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Source depth estimation of self-potential anomalies by spectral methods

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ABSTRACT

Spectral analysis of the self-potential (SP) field for geometrically simple anomalous bodies is studied. In particular, three spectral techniques, i.e. Periodogram (PM), Multi Taper (MTM) and Maximum Entropy (MEM) methods, are proposed to derive the depth of the anomalous bodies. An extensive numerical analysis at varying the source parameters outlines that MEM is successful in determining the source depth with a percent error less than 5%. The application of the proposed spectral approach to the interpretation of field datasets has provided depth estimations of the SP anomaly sources in very good agreement with those obtained by other numerical methods.

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1. Introduction

During last few decades, various spectral methods have been successfully applied for depth estimation of potential field sources, like gravity and magnetic anomaly sources (Spector and Grant, 1970; Negi et al., 1986; Maus and Dimri, 1995; Bansal et al., 2006; Bansal and Dimri, 2010). As concerns self-potential (SP) anomaly interpretation, spectral analysis approach has been first proposed by employing the Fourier transform. In particular, the Fourier amplitude and phase spectra have been analyzed to find the parameters of sheet-like sources (Atchuta Rao et al., 1982; Rao and Mohan, 1984) and polarized spherical and cylindrical bodies (Skianis et al., 1991; Asfahani et al., 2001). More recently, the energy spectrum method has been used to SP data analysis (Das and Agarwal, 2012). In this case, energy spectrum (power spectrum) is taken as the square of the Fourier amplitude spectrum and the SP source depth is estimated as half of the slope of the straight line of the spectrum. Lately, high-resolution spectral methods (HRSMs) of power spectrum estimation, such as multi-taper method (MTM) and maximum entropy method (MEM), have been applied by the authors for depth estimation of SP anomaly generated by some simple geometrical bodies (Rani et al., 2015). In particular, in the present work, an extended comparative study has been carried out among the three different spectral methods: Periodogram Method (PM), MTM and MEM to estimate the depth of sources of SP anomalous signals. Once power spectrum is computed, the depth of the anomalous body is estimated as half of the slope of straight line fitted to the log of power spectrum, $P(k)$, versus the wavenumber, k, by following the approach of Spector and Grant (1970). In the following, after a brief theoretical introduction, the proposed methods are applied to synthetic SP data generated by geometrically simple anomalous bodies, such as sphere, horizontal and vertical cylinder, and inclined sheet. Then, the application of the three spectral methods to different SP field datasets is presented. In particular, the effectiveness of the proposed HRSMs has been confirmed by the good agreement with the source depth values estimated by other numerical approaches. Furthermore, the reliability of the obtained results has suggested the integration of the proposed spectral approach with other inversion methods for a full characterization of the SP anomaly source parameters (Di Maio et al., 2016a; Di Maio et al., 2016b).

2. Spectral analysis approach

The spectral approach is based on selection of an appropriate method for power spectrum estimation. There are different methods for power spectrum evaluation, which can be categorized in parametric and nonparametric methods (Stoica and Moses, 2005).

The nonparametric methods apply a band pass filter with a narrow bandwidth to a data sequence and use the filter output power divided by the filter bandwidth as a measure of the spectral content of the input data. The parametric methods select a model, estimate the model parameters for the given data and, then, compute the power spectrum by using the estimated parameters.

The most accurate estimates of the power spectrum can be obtained by using parametric or nonparametric methods depending on if the data indeed satisfy or not the model assumed by the parametric methods (Stoica and Moses, 2005).

In the present study, the power spectrum of SP data is computed by using the nonparametric methods PM and MTM and the parametric method MEM, which are shortly described in this section.

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2.1. PM

PM is a fast and conventional method to compute the power spectrum of discrete data. It estimates the power spectrum by computing the Discrete Fourier Transform (DFT) and appropriately scaling the magnitude squared of the result. The DFT is evaluated with a Fast Fourier Transform algorithm. In particular, the so called radix-2 FFT procedure is generally used, which is easy to encode and quite computationally efficient (Cooley and Tukey, 1965). The PM method provides reasonably high resolution for sufficiently large number of data, but is a poor spectral estimator because its variance is high and does not decrease with increasing data length. However, PM is considered a relevant basic spectral estimator as many other nonparametric estimators derive from it (Stoica and Moses, 2005).

2.2. MTM

MTM is a nonparametric method (Thomson, 1982; Percival and Walden, 1993) that reduces the variance of spectral estimates by using a small set of tapers rather than a single taper (or spectral window), like conventional PM does. The data are multiplied by orthogonal tapers and the power spectrum is obtained by averaging over the set of independent computed power spectra. The orthogonal tapers are constructed to minimize the leakage outside of a frequency band with bandwidth equals to $2pf$, where $f = 1 / (N\Delta)$ is the Rayleigh frequency, N is the number of data points, Δ is the sampling interval and p is a suitably chosen integer related to the number of tapers J. Actually, since only the first 2p-1 tapers provide usefully small spectral leakage (Slepian, 1978; Thomson, 1982; Park et al., 1987), J should be <2p-1.

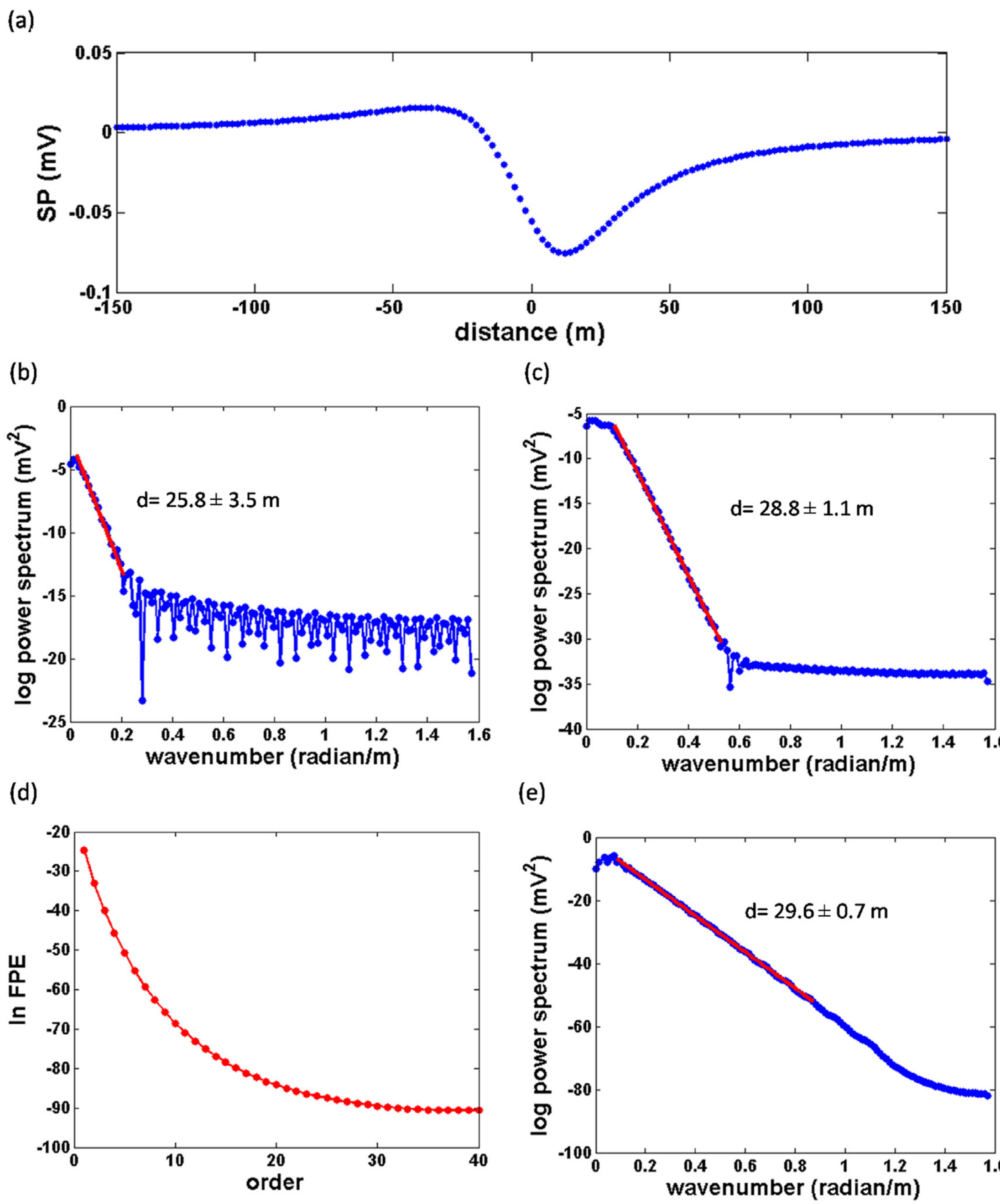

Fig. 1. (a) SP anomaly due to a sphere characterized by the parameters indicated in Table 1; (b) power spectrum estimated by PM; (c) power spectrum estimated by MTM; (d) order selection for AR process and (e) power spectrum estimated by MEM. The estimated order of the AR process is 35.

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