Modelling of Terrain Effect from the Magnetotelluric (MT) Field Data

Deepak Kr. Tyagi, Rajeev Sehrawat, Rashmi Mittal, Millan Kr. Bera, Anil Kr. Sharma

ABSTRACT*: *Magnetotelluric (MT) data were recorded over highly undulating terrain in Himalayan region from Roorkee to Gangotri section in period 0.001-1000 second. In the presence of topographic distortion the interpretation may become misleading. A simple scheme based on finite difference method for the simulation of the topographic distortion in magnetotelluric response is presented. The finite difference based, forward response computation algorithm, has been extended for undulating topography. The distortion coefficients, representing the topographic effect, are designed for correcting the observed distorted impedance tensor recorded in the vicinity of topographic features. The accuracy of the scheme is checked by comparing the computed responses with the finite element, Rayleigh scattering and transmission surface results for transverse electric (TE-mode) and transverse magnetic (TM-mode) responses. The modified algorithm is used to model the terrain effect on MT data recorded from Himalayan terrain.

Keywords*: *finite difference method, Magnetotellurics (MT), Topographic distortion, 2D Terrain model and correction, TE- and TM – mode.

I. INTRODUCTION

Magnetoelluric is an electromagnetic exploration technique to delineate the subsurface earth resistivity structure. Magnetotelluric response is distorted in the presence of topographic irregularities. The amplitude of these distortions varies with topographic relief and resistivity structure underneath the measuring sites. Several attempts have been made in literature for the numerical simulation of transverse electric (E-polarization) and transverse magnetic (H-polarization) responses. Finite element method have been used to simulate the two dimensional topographic response in MT data and compared the accuracy of his results with the other numerical techniques [1].

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The finite element code has been used to compute the correction coefficients to reduce the topographic effects [2]. The relevance of topographic correction on magnetotelluric responses data have been studied [3]. The topographic effect is responsible for a large part of the spectral variation of the land cover in rugged terrain [4], [5]. A method has been proposed for correcting topographic error in EM data by using a small DC configuration to obtain the surface resistivity [6]. They have discussed the possibility of geometrical distortion of real subsurface structure resulted from the topographic correction. In the present paper we have employed the finite difference forward modeling code to compute correction coefficients. The results over some relevant topographic models are compared with the results obtained by finite element and Rayleigh scattering methods.

Finite difference method (FDM) was initially used [7] to model 2D geoelectromagnetic perturbation due to inhomogeneity. The method was subsequently extended for 3D models [8]. Since then several features were added to the finite difference modeling methods in order to make it more versatile. The use of Conjugate Gradient Method (CGM), asymptotic and integral boundary conditions to optimize the domain of modeling have increased its efficiency and versatility in electromagnetic field computations. A detailed discussion on electromagnetic field computation using finite difference method is given by [9], [10] further developed the finite difference method for the 2D inversion of geoelectromagnetic data recorded over a flat earth, and the relevant code is referred to as EM2INV.

In the present paper, the extended 2D forward modeling code of EM2INV for the irregular topography is employed [13]. The correction coefficients have been estimated to reduce the topographic effect. The scheme is demonstrated over a few standard topographic models and computed responses are compared with the results obtained by other numerical techniques.

II. METHODOLOGY

The finite difference method is based on the discretizatioin of the domain of study in rectangular grid. The differential operator equation is reducing to matrix operator equation through difference approximation. The mathematics of FDM is much simpler and easier to implement in comparison to the finite element and other numerical techniques. The details of implementation of finite difference scheme for the electromagnetic field computations for transverse electric (TE-mode) and transverse magnetic (TM-mode) cases over a flat-ground surface has been discussed [10].

The 2D forward modeling computational algorithm has been extended for the irregular topography. Chouteau and Bouchard [2] procedure have been used to compute the distortion tensor for topographic effect. The computation of distortion tensor is based on the assumption that the topographically distorted subsurface field can be estimated by multiplying the distortion tensor with by the flat earth subsurface field given by:

$$\tilde{E}_D = \tilde{D}\tilde{E}_N \qquad (1)$$

Where $\tilde{E}_D$ and $\tilde{E}_N$ are the distorted and normal electric field matrices with elements $E(f,r)_D$ and $E(f,r)_N$ respectively; $\tilde{D}$ is the distortion tensor with elements $D(f,r)$, where f is the frequency and r is the measuring site position.

For 2-D problem in the H-polarization mode, with x-axis is the direction of strike, equation (1) can be written as

$$E_{YD}(f,y) = D_{YY}(f,y)E_{YN}(f,y) \qquad (2)$$

Impedance tensor can be written by dividing equation (2) with Hx, as follows.

$$Z_D(f,y) = D(f,y)Z_N(f,y) \qquad (3)$$

Where $Z_N(f,y)$ and $Z_D(f,y)$ are, respectively, the normal (flat earth) and distorted impedances. The observed impedance ($Z_D(f,y)$) is measured in the vicinity of irregular topography. The complex coefficients $D(f,y)$ are distortion coefficients which reflect topography effects. The distortion coefficients are computed by by normalizing the impedance computed over topographic model above a homogeneous medium with the half space impedance. The corrected impedance over a flat-earth can thus be obtained by taking the ratio of the observed impedances, $Z_D(f,y)$, over irregular terrain, to the distortion coefficients, $D(f,y)$ as:

$$Z_C(f,y) = Z_D(f,y)/D(f,y) \qquad (4)$$

where $Z_C(f,y)$ is terrain corrected impedance. The corrected impedance can be used to compute apparent resistivity and phase responses [2].

III. VALIDATION OVER THEORETICAL MODEL

To check the accuracy of numerical computation we have selected a few terrain models which have been used in literature and responses are computed using different numerical and analytical methods. Fig. 1 shows the results over a gentle co-sinusoidal hill model used by [1]. The hill is 100 m high, 2400 m wide at the base, and the earth has 100 Ω-m resistivity. The apparent resistivity and phase responses computed using the present technique are compared with the Rayleigh scattering and finite element methods. Transverse electric (TE-mode) and transverse magnetic (TM-mode) responses are computed at 10 Hz frequency of excitation. The shape of the anomaly is similar in all cases. The small differences are due to the discretization in finite element and periodic nature of Rayleigh model.

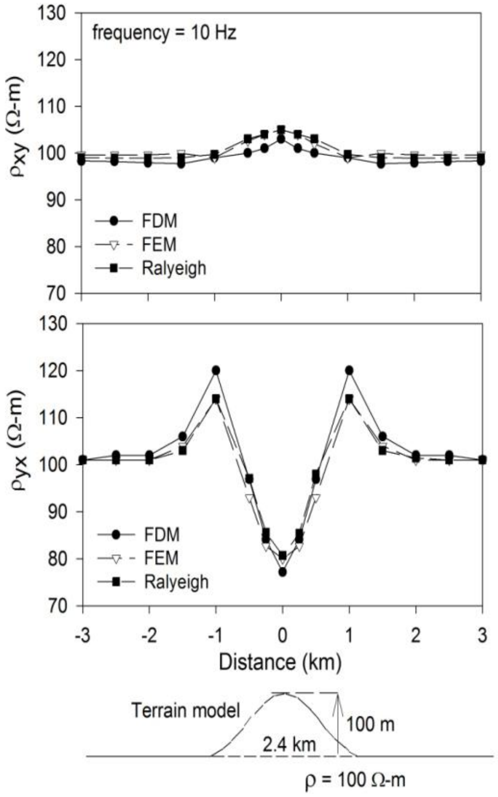

Fig. 1: Finite difference response compared with the finite element and Rayleigh scattering responses for TE and TM modes.

A trapezoidal hill model is used for finite difference response computation of TE and TM mode. The response is compared with the finite element program [2]. Fig. 2 compare the TE and TM modes apparent resistivity responses at 2 Hz computed using finite element [2] and finite difference based modified algorithm. The finite element apparent resistivity shows very low value at the top corner of the model whereas this feature is smoothed in the finite difference case. The two responses are matching in almost entire zone. The results from model 1 & 2 demonstrate that only TM mode apparent resistivity response is distorted significantly due to irregular terrain features in the vicinity. Therefore, we shall limit our subsequent discussion only on distortion of TM – mode response.

Next, we have taken a mountainous model applicable in Himalayan terrain. The model consists of a resistive 10 000 Ω-m block, about 1 km thick, embedded in a 500 $\Omega - m$ conductive media. The Conductive 500 Ω-m half-space is a high relief surface. Slope inclination varies between 10 and 30 degree. The model is used for the computation of terrain effect and subsequently correcting the MT response [2]. Fig. 3(a) shows the terrain model (bottom) along with the TM-mode apparent resistivity and phase response computed using the present scheme and its comparison with the finite element response. Fig. 3(b) shows the terrain corrected response using the present scheme and its comparison with finite element and the actual response computed over a flat earth model. The corresponding flat earth model is also shown in bottom.

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The two responses are in good agreement. The example demonstrates the applicability of the scheme in mountainous terrain.

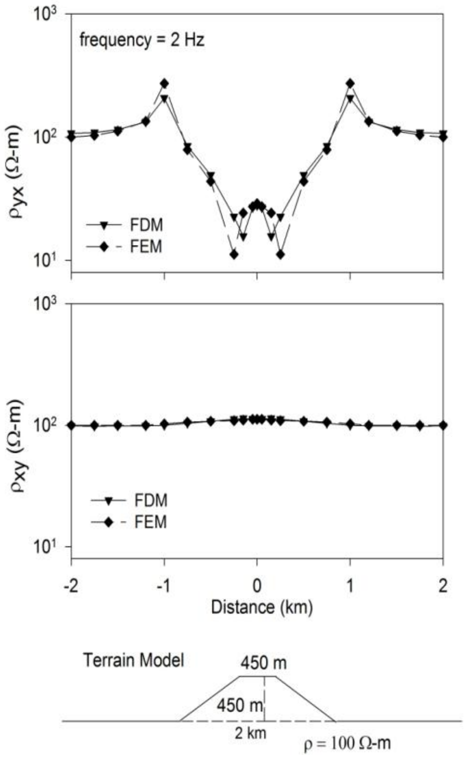

Fig. 2: Comparison between TE & TM mode response with finite difference and finite element over a trapezoidal model.

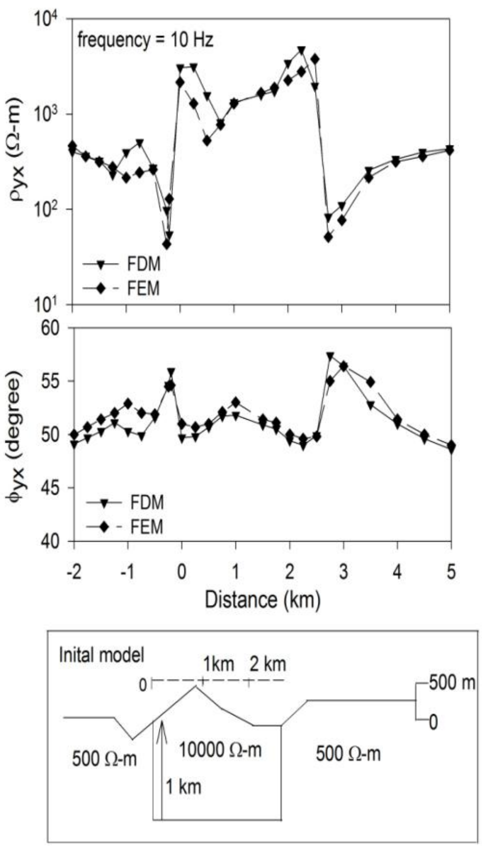

Fig. 3 (a): Comparison of finite difference TM-mode response of a mountainous model with finite element responses.

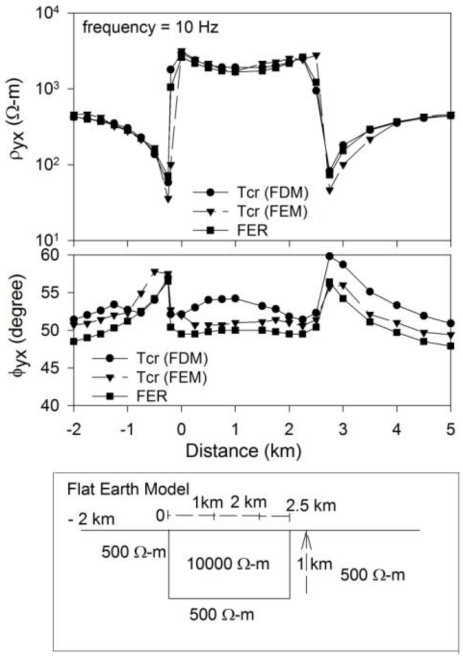

Fig. 3 (b): Comparison of terrain corrected finite difference response with corresponding finite element and flat-earth response.

IV. TERRAIN CORRECTION ON FIELD DATA

The Roorkee to Gangotri profile (hill, valley and ramp type) in Garhwal Himalaya has approximately 2.7 km elevation. The Roorkee to Gangotri profile elevation model is given below in Fig. 4. The modified EM2INV algorithm is used to study the terrain effect on the observed data in Garhwal Himalaya corridor [11]. The surface topography was approximated by the rectangular cells of finite difference. In our case, we have the observed data (impedance) at different elevation points in the profile region. The terrain effect is analyzed for TM-mode data only. The complex distortion coefficient $D(f, y)$ is calculated over the 100 Ωm homogenous half spaces. Therefore, the division of the measured impedance Z_D (field data) by $D(f, y)$ (distortion coefficient) gives terrain corrected responses Z_C. The terrain corrected apparent resistivity and phase are shown in Figure 4 at two frequencies 98.04 Hz and 9.40 Hz. Not much effect is visible seen between the observed and terrain corrected MT data. The spatial and frequency distortion due to the slope have been discussed in detail and shows the distortion effect due to the topography is depend on the slope [12]. In our case (Roorkee-Gangotri profile) the slope angle is $\leq 1^{0}$ over an approximately 160 km long profile with 2.7 km elevation. Therefore, not much effect was observed in apparent resistivity and phase curves due to the topography [11], [13]. There is no need to apply terrain correction before the 2D inversion of the MT data along the profile.

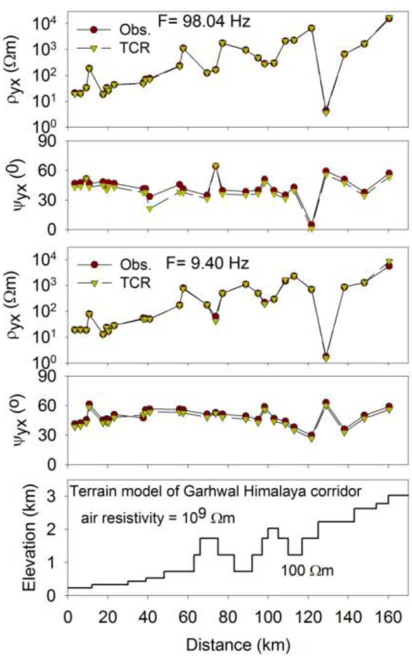

Fig. 4: Comparisons of observed data in Roorkee-Gangotri profile with the terrain corrected data for TM-mode.

V. CONCLUSION

MT responses are computed over irregular topography. This has been done by extending finite difference based 2D forward response computational algorithm for irregular topographic aspect. This assist in computation of MT responses over a flat earth surface from the response observed in the vicinity of irregular terrain. The accuracy of the modified algorithm is demonstrated over a few terrain models taken from literature. The computed responses are well compared with the responses computed by other numerical techniques. The distortion effects in field data due to the undulating topography are analyzed and are very small on Roorkee-Gangotri profile. It is concluded that there is no need to apply terrain correction on the data before 2D inversion of field responses.

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