Forward modeling for CSEM excited by the cable current with finite length

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SUMMARY

In this paper, we developed a new modelling code for the controlled source electromagnetic (CSEM) method, in which the current source of a line element with finite length is implemented. We choose an approach by the integral equation method and the 2-D FFT for horizontal plane and variable separation for both vertical components of the locations at the source and the receiver are adapted to reduce both computational memory and time. To evaluate the electromagnetic (EM) fields excited by a line source with finite length, the source term in wavelength domain for the horizontal plane is input analytically in the code. To accelerate the convergence of numerical solution of integral equation, modified IDM is adapted as a pre-conditioner to solve a huge linear equation. By numerical test, the results by our code with a line source with a unit length show good coincidence with the results by other codes with a dipole source, and the accuracy of our codes are confirmed. Further, in our code, not only single line element but also several line elements can be input. Thus by superposing the several short line elements, the EM fields can be calculated, excited by a cable source with arbitrary shape. Further, a vertical line sources can be also input in our code.

Keywords: forward modeling, modified IDM, CSEM method, line element with finite length

INTRODUCTION

The EM sounding method is one of the important methods for geophysical surveys as well as seismological method. Recently, however, industrial powers became strong noises for EM survey so that magnetotelluric method with natural sources cannot be adapted.

Instead of it, the CSEM method is a useful and effective tool to elucidate the electrical conductivity structure of subsurface. But the modelling of the CSEM method is commonly performed by using a dipole source instead of a line source of the cable, and so the evaluation must be wrong more or less if the observation site is as close to the source as the length of the cable.

In this paper, we developed a new modelling code, in which the current source of a finite line element is implemented.

FORWARD MODELING

In usual, the 3-D forward modeling is performed by finite difference method, finite element method or integral equation method, as reviewed in Avdeev (2005). In this paper, we choose an approach by the integral equation method. In the integral equation method, the EM fields, E(r) and H(r), in the 3-D anomalous conductivity structure σ (r) excited by the current source j(r) are expressed as convolution of a previously known Green's tensor, G_E(r;r') and G_H(r;r'), for an arbitrary conductivity structure σ_0(r) and a reconstructed source term.

$$\mathbf{E}(\mathbf{r}) = \int d\boldsymbol{r}' G_E(\boldsymbol{r};\boldsymbol{r}')\{\left(\sigma(\boldsymbol{r}') - \sigma_0(\boldsymbol{r}')\right)\boldsymbol{E}(\boldsymbol{r}') + \boldsymbol{j}(\boldsymbol{r}')\} \quad (1),$$

$$\mathbf{H}(\mathbf{r}) = \int d\boldsymbol{r}' G_H(\boldsymbol{r};\boldsymbol{r}')\{\left(\sigma(\boldsymbol{r}') - \sigma_0(\boldsymbol{r}')\right)\boldsymbol{E}(\boldsymbol{r}') + \boldsymbol{j}(\boldsymbol{r}')\} \quad (2).$$

A 1-D vertically stratified structure is commonly used as σ_0(r). Here G_E(r;r') has 6 components which are r=(x,y,z) and r'=(x', y', z'), and so they require huge computational memory and execution time. To reduce them, Avdeev et al (1997) adapt the 2-D FFT for horizontal plane to Green's tensors. By using them, computational memory and time are reduced to O($NxNyNz^2$) and O(NxNyNz(log(NxNy)+Nz)), respectively. To implement the line element with finite length as source field, the source field in the space domain is analytically converted to in the wavelength domain for the horizontal plane, and so the source field can be input with highly accuracy.

Koyama et al. (2008) and Avdeev and Kniznik (2009) reduced them further to O(NxNyNz) and O(NxNyNzlog(NxNy)) by using the variable separation of z and z' in Green's tensor. Note that O(log(NxNy)) is negligible in huge problems in comparison with O(Nx), O(Ny), and O(Nz).

To accelerate the convergence of numerical solution of integral equation (1), modified IDM was adapted in our code (Singer, 1995; Pankratov et al., 1995; Avdeev et al., 1997; Kuvshinov et al, 1999).

NUMERICAL EXAMPLE

By using a new code, numerical calculation has been done. Figure 1 shows a plan map of vertical component of magnetic field, Hz, excited by a line source. Note that a line source is not along a horizontal grid boundary.

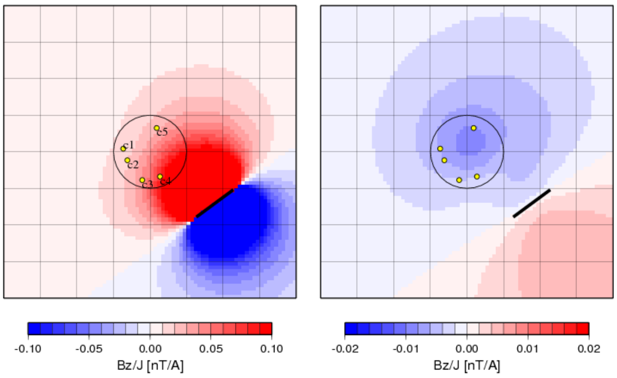

Figure 1. A plan view of numerical result of vertical magnetic field, Hz, excited by a line source, a bold line. A columnar anomalous conductor is put in the center, a circle. Left and right figures are real part and imaginary part respectively.

This result which looks like a separated-dipole field indicates that the numerical calculation is accurately performed.
Indeed, we confirm that the calculation by our code with a unit length source field is just the same as the published results of other codes in which a dipole field is used (Avdeev et al., 1997).
In our code, by superposing a several short line elements, a current source with cable of arbitrary shape can be implemented. Vertical line sources also can be input in our code.

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