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Improved interpolation scheme at receiver positions for 2.5D frequency-domain marine CSEM forward modelling

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Introduction

We present an improved interpolation scheme for 2.5D marine controlled-source electromagnetic (CSEM) forward modelling problem. As the resistivity contrast between the seawater and seafloor sediment layers is significant, it is usually difficult to compute the EM fields accurately at receivers which are usually located at the seafloor. In this study, a new interpolation scheme at receivers is proposed, in which the interpolation of EM fields at the cell nodes for the whole computational domain to arbitrary receiver locations is discussed in detail. Numerical tests indicate that, our improved interpolation is more accurate for simulating the EM responses at receivers located on the seafloor, compared with the linear or rigorous interpolation.

Theory

Forward modelling

The Maxwell's equations for 2.5D frequency-domain CSEM forward modelling are given by:

$$\tilde{\nabla}\times\tilde{\nabla}\times\tilde{\mathbf{E}}^{S}-\mathrm{i}\omega\mu_0\sigma^{*}\tilde{\mathbf{E}}^{S}=\mathrm{i}\omega\mu_0\left(\sigma^{*}-\sigma^{P*}\right)\tilde{\mathbf{E}}^{P},$$

where the nabla operator has been transformed into spatial-Fourier domain as $\tilde{\nabla}=\left(\mathrm{i}k_x,\partial_y,\partial_z\right)$.

For avoiding source-point singularities, the electric or magnetic field can be split into a primary part (donated by "*P*") and a secondary (or scattered) part (donated by "*S*") . The primary fields excited by the physical sources embedded into the 1D layered background is computed quasi-analytically following Li and Li (2016). The staggered-finite difference (SFD) approach is used for computing the secondary fields (Yee 1966, see Fig. 1 for details).

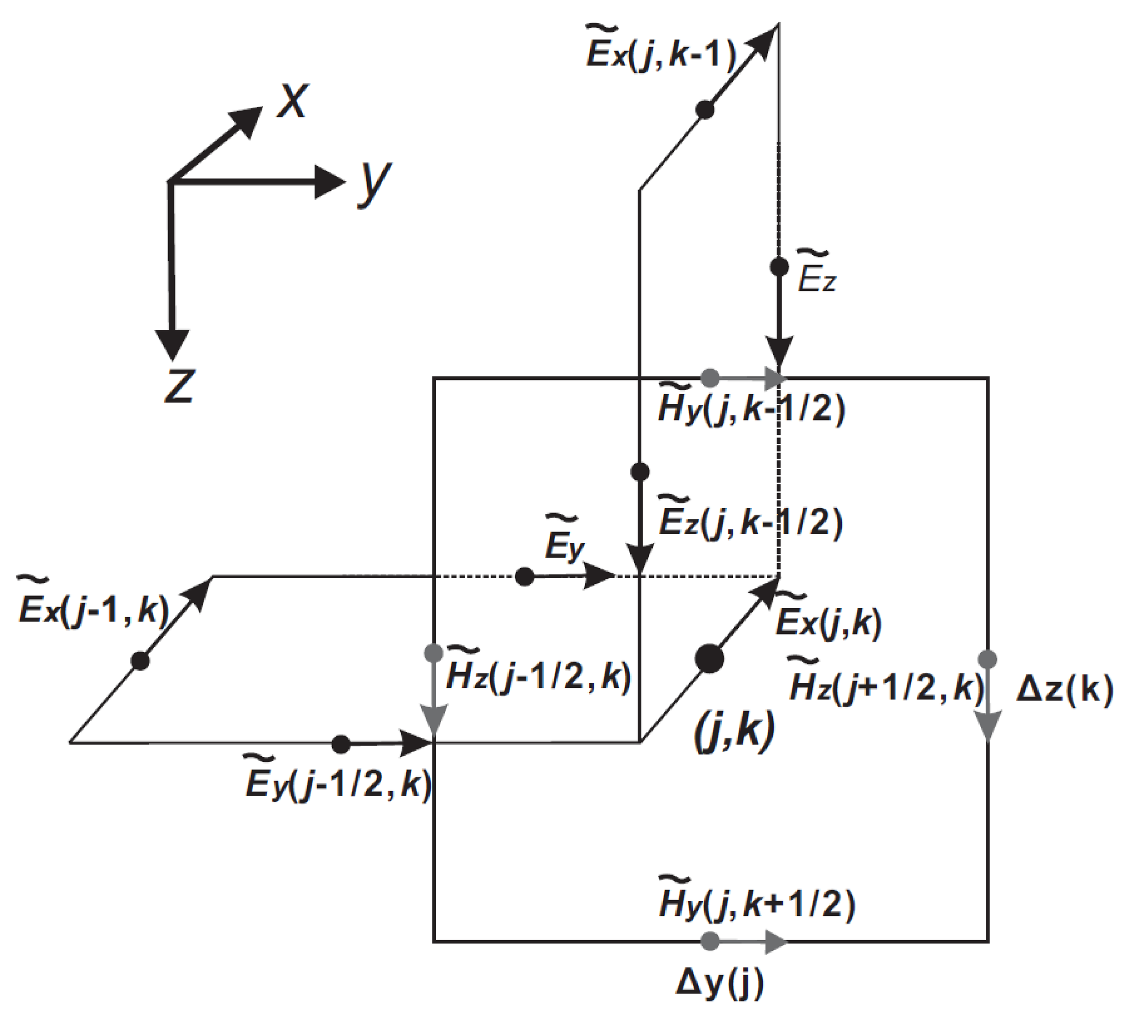

Fig.1 The 2D staggered-grid for cell (j,k) modified after Li and Han (2017), where △y and △z are the horizontal size and vertical size, respectively.

Interpolation scheme at receivers

One of challenges for the SFD modelling of EM fields are computing the EM fields recorded by receivers located at the seafloor with resistivity contrast.

The EM fields at the grid nodes may be required to be interpolated to the recording receiver positions as receivers are usually not confirmed with grid nodes. The interpolating errors could not be neglected as the discontinuities caused by the resistivity contrast at the seafloor surface will lead to large interpolating errors (Wirianto et al., 2011; Li et al., 2020). As the primary fields at receivers can be calculated quasi-analytically, here we only discuss the interpolation of secondary fields for receivers located on the seafloor (Fig. 1). For simplicity, we discard the donation of "*S*" when citing the secondary electric ($\tilde{\mathbf{E}}^{S}$) and magnetic field ($\tilde{\mathbf{E}}^{S}$).

In this study, we present a new interpolation scheme for computing EM fields at seafloor receivers. As the sampling points are staggered (Fig. 1), $\tilde{E}_z$, $\tilde{H}_x$ and $\tilde{H}_y$ are sampled at the seafloor surface at the depth of $z_{k_0-1/2}$, while $\tilde{E}_x$, $\tilde{E}_y$ and $\tilde{H}_z$ are sampled below the seafloor surface at z_{k_0} (Fig. 2). Here (*j*, *k₀*) is for the first layer below the seafloor surface.

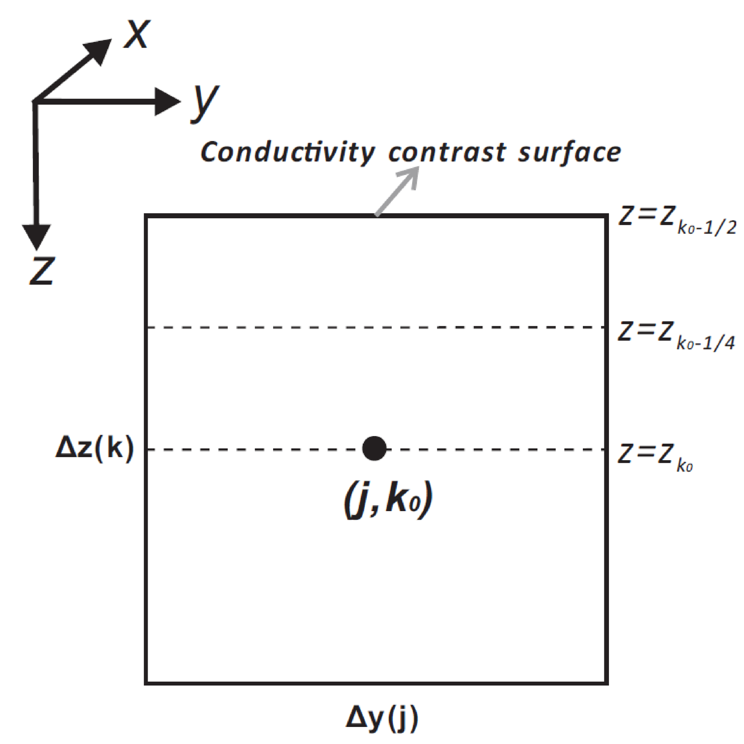

Fig.2 The schematic map of sampling points across the seafloor surface.

The proposed interpolation can be summarized into two steps. Firstly, $\tilde{E}_x$, $\tilde{E}_y$ and $\tilde{H}_z$ are interpolated linearly to the seafloor surface. Then, along the seafloor surface, the electric and magnetic fields can be linearly interpolated to wherever needed. The readers are referred to Li et al. (2020) for details of the interpolation scheme.

Numerical test

The example used for testing the presented interpolation scheme is a 2D model with an upward slope modified after Li and Constable (2007), (Fig. 3). The transmitter is located at (0,0,950) m. Thirty-six receivers are located at the seafloor along *y* = −8000 to 8000 m with an equal interval of 400 m. The receivers with receiver–transmitter offset less than 1 km are not used. The adaptive finite-element (adaptive FEM) code MARE2DEM is used for benchmarking the results of the 2.5D SFD modelling using our improved interpolation (Key, 2016). For the adaptive FEM modelling, 26 refinement iterations are required for reaching the target reference error 0.6 %. Grids near the transmitter and receiver locations are finer for both the inline and broadside transmitter–receiver geometry.

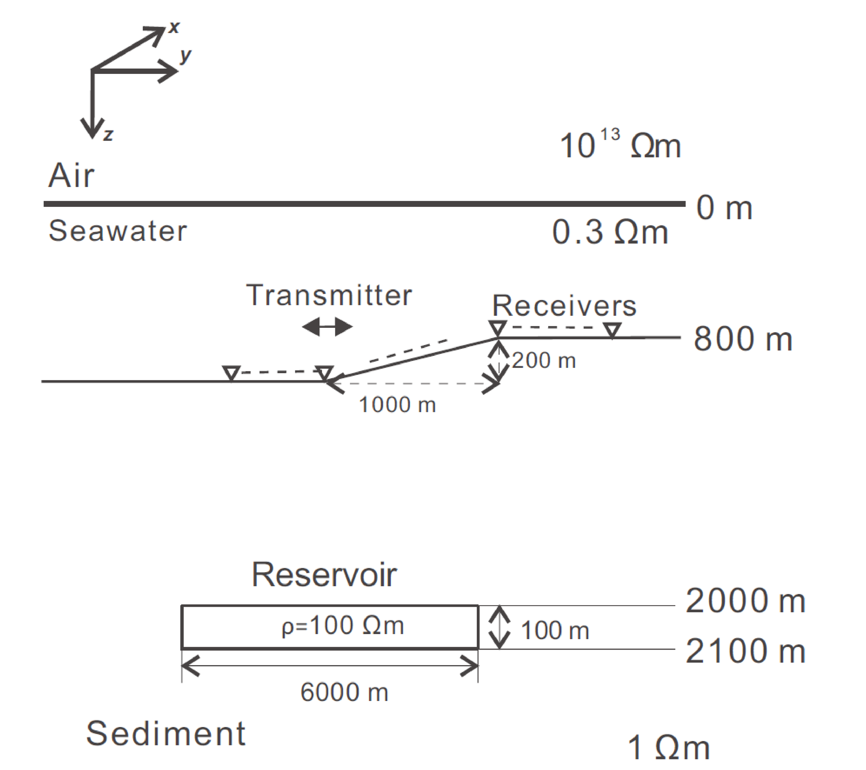

Fig.3 The 1D reservoir model modified after Constable and Weiss (2006) .

The 2.5D SFD results using the improved interpolation for receivers agree well with the adaptive FEM results for both inline and broadside responses (Fig. 4). The relative error for amplitudes and absolute error for phases are no more than 1.5% and 1.5◦, respectively (Fig. 5).

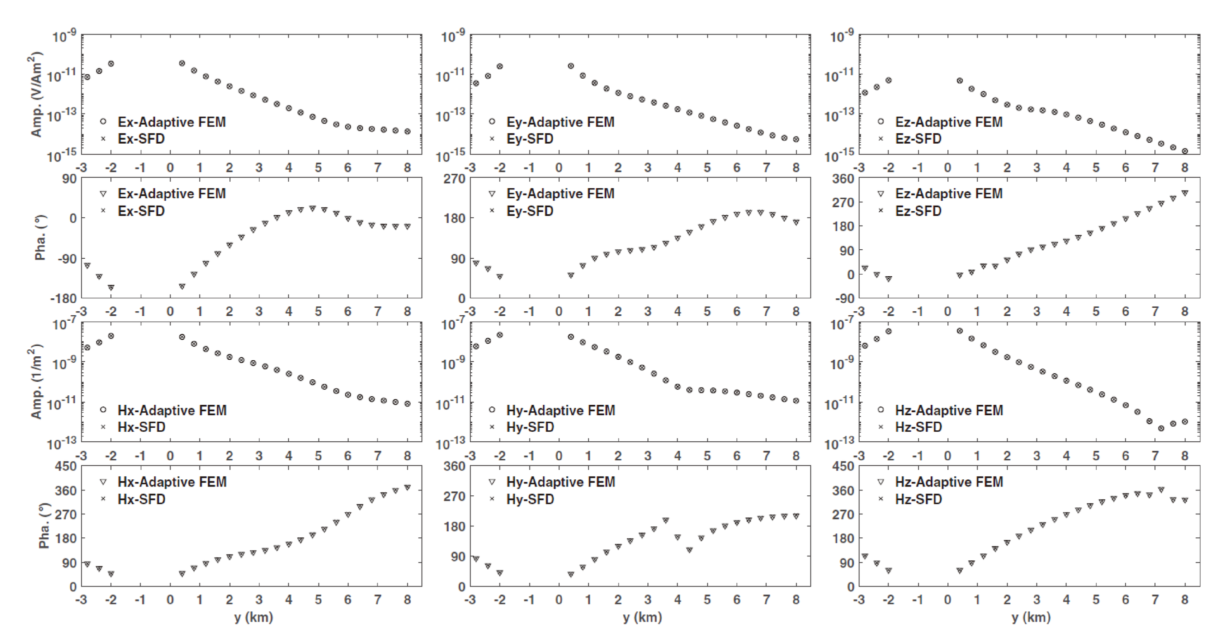

Fig.4 Comparison of the 2.5D numerical results of the total fields for the 2D marine slope model shown in Fig. 3. The adaptive FEM results (denoted by circles for the electric components and triangles for the magnetic components, respectively) computed by MARE2DEM following Key (2016) are used for benchmarking the SFD results (denoted by crosses).

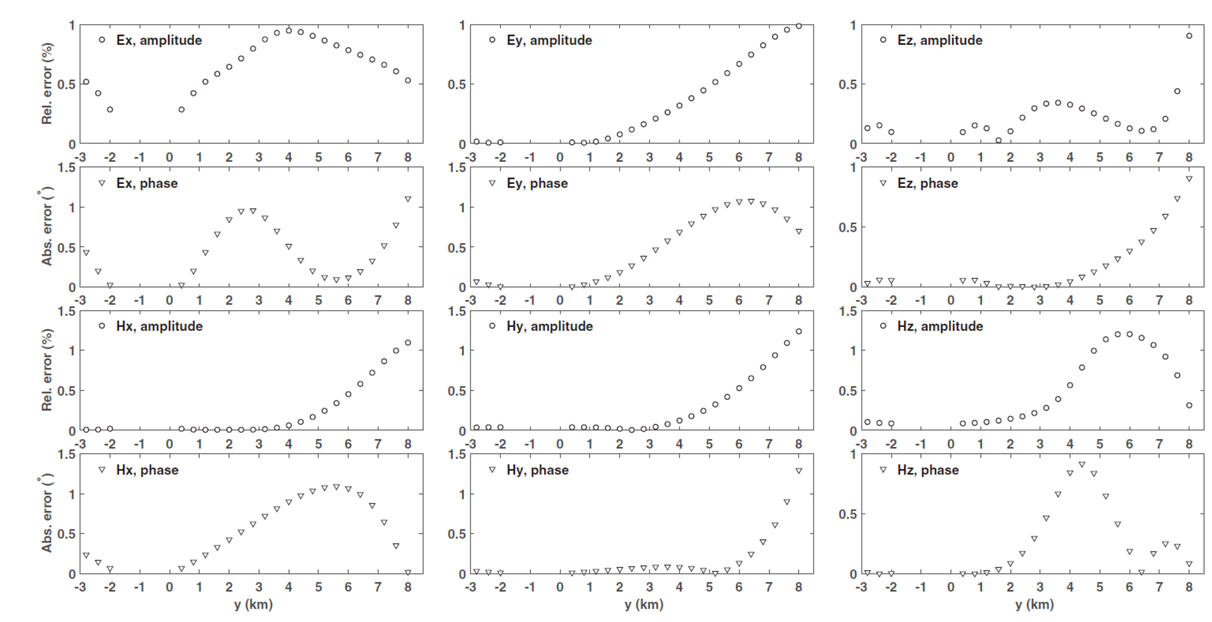

Fig.5 The relative error of amplitudes (Rel. error, denoted by the circles) and the absolute error of phases (Abs. error, denoted by the triangles) for the 2.5D total field results benchmarked by the adaptive FEM results for the 2D marine slope model shown in Fig. 3.

Conclusions

In this study, an improved interpolation scheme for receivers is presented for the 2.5D marine controlled-source EM forward modelling, which can be used for accurately computing the EM fields at receivers located at the resistivity–contrast interface.

Numerical test shows that the improved interpolation developed in this study, which only uses the cell nodes below the resistivity–contrast interface where seafloor receivers locate, is proven to be accurate.

Main references

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