Three-dimensional vector finite element forward modeling and inversion for airborne electromagnetic data considering induced polarization effect

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Workshop session: From field data acquisition and processing to inversion

Modelling Induced polarization effects in airborne electromagnetic (AEM) data is becoming a standard tool in mineral exploration, but the industry standard is still based on one-dimensional (1D) forward and Jacobian modelling. We are developing a three-dimensional (3D) finite element electromagnetic forward and inversion method considering IP effects within the EEMverter modelling platform (Fiandaca et al., 2024). The computations are carried out in frequency domain, and then time-transformed in time domain through an Hankel transform. This allows to model any parameterization of the IP phenomenon, from the simple constant phase angle model to a full debye decomposition. Furthermore, 3D forward modeling mesh and inversion mesh are constructed separately: an Octree mesh is designed for efficient spatial segmentation for each sounding, while the inversion parameters are defined on a structured model mesh linked to the forward meshes through interpolation.

Each forward mesh only needs to be locally refined in the underground sensitive areas covered by the transmitter and receiver. This structure has good geometric flexibility, can easily simulate complex terrain, and greatly reduces the mesh size required to solve forward modeling problems. By separating the primary field $\mathbf{E}^{\boldsymbol{p}}$ and the secondary field $\mathbf{E}^{\boldsymbol{s}}$, the background conductivity $\boldsymbol{\sigma}^{\boldsymbol{p}}$ and the abnormal conductivity $\boldsymbol{\sigma}^{\boldsymbol{s}}$, and applying Dirichlet boundary conditions, the frequency domain electromagnetic double-curl partial differential equation is solved based on the vector finite element idea (Zhang et al. 2021):

$$\int_{\Omega}(\nabla \times \mathbf{N} \cdot \nabla \times \mathbf{E}^{s} - i\omega\mu(\sigma^{s} + \sigma^{p})\mathbf{N} \cdot \mathbf{E}^{s})dV = \int_{\Omega}(i\omega\mu\sigma^{s}\mathbf{N} \cdot \mathbf{E}^{p})dV\,, \quad \boldsymbol{E}_{s}|_{\Omega} = 0. \tag{1}$$

Figure 1 and Figure 2 present the accuracy of forward and Jacobian computations as a function of frequency and resistivity.

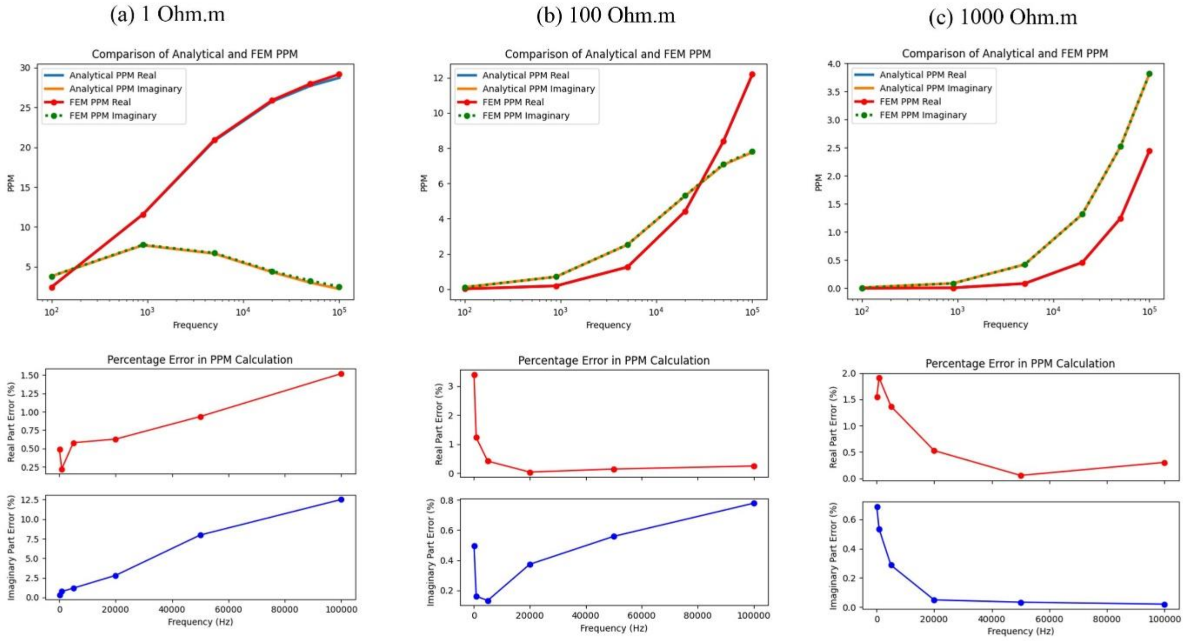

Figure 1: Comparison of calculation accuracy of three-dimensional finite element frequency domain electromagnetic forward modeling based on Octree mesh. The first row of graphs shows the comparison of PPM response values, and the second row shows the relative percentage error. (a) Half-space resistivity is 1 Ohmm; (b) Half-space resistivity is 100 Ohmm; (c) Half-space resistivity is 1000 Ohmm.

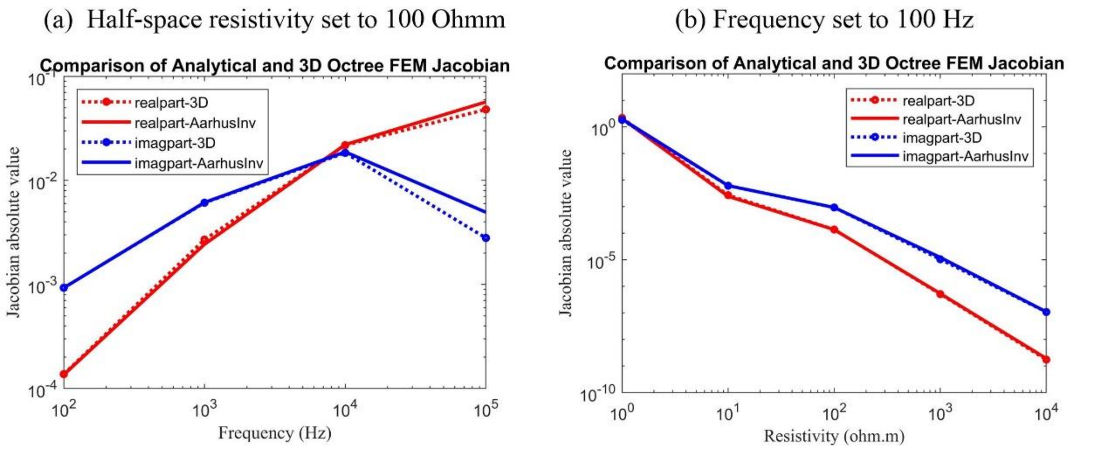

Figure 2: Comparison of calculation accuracy of the Jacobian. (a) Comparison of Jacobian values at different frequencies; (b) Comparison of Jacobian values at different resistivities.

References

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