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Calculation of the Influence of Conductors Using Current Density Maps in 3D MCSEM Data

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Abstract Summary

The Marine Controlled Source Electromagnetic (MCSEM) method is used in industry to locate resistive targets associated with hydrocarbon reservoirs. In this study, we simulated MCSEM in the presence of a well and an HC reservoir, analyzing the current density vector. The tests were performed using software based on the 3D finite element mesh method. The results show that it was an effective tool in evaluating the effect of conductive production structures on MCSEM data.

Introduction

The Marine Controlled Source Electromagnetic (MCSEM) method is effective in detecting hydrocarbon reservoirs in deep waters (Constable and Srnka, 2007). However, metallic structures such as steel-cased production wells can influence the acquired data, distorting or amplifying electromagnetic fields depending on their geometry and/or position. Studies such as those by Patzer et al. (2017) and Castillo-Reyes et al. (2022) show that production wells can be efficiently modeled and even used to enhance the method's sensitivity. Meanwhile, Li et al. (2022) indicates that horizontal metallic casings can act as conductive guides, extending detection range. Nevertheless, the presence of steel remains a challenge for electromagnetic simulations due to the high conductivity contrast between metal and rocks, which complicates the accurate application of traditional numerical techniques such as finite differences and finite elements. The objective of this work is to evaluate the effect of metallic conductors on MCSEM data by analyzing the current density vector distribution. The results were obtained through 3D MCSEM modeling using the finite element method.

Method and Theory

The MCSEM uses artificial sources to transmit electromagnetic signals into the ocean, measuring electric or magnetic fields at receivers placed on the seabed, enabling the characterization of the subsurface resistivity distribution. This technique is particularly effective in identifying hydrocarbon reservoirs, whose resistive properties generate distinct electromagnetic responses (Silva (2018)). The system employs a horizontal electric dipole (HED) towed 30–50 m above the seabed, operating in the frequency range of 0.1 Hz to 10 Hz. During data acquisition, we adopt an inline configuration, discretizing the domain using a tetrahedral mesh, where the solution is obtained along the edges of the elements. For numerical modeling, we use the Vector Finite Element Method, which solves the electric or magnetic field components directly on the mesh edges (Piedade et al. (2021)). This approach is ideal for anisotropic media, allowing accurate representation of resistivity variations in all directions. The total field is obtained by superimposing the primary field (known from the source) with the numerically computed secondary field.

Results

The 3D model includes a metallic well with 25 cm radius and 1 km height located at position x = 1925 m, and a HC reservoir represented as a flattened hexahedron measuring 4 km x 3 km x 100 m in the directions x, y and z, respectively. The water depth is 1.5 km with the reservoir located 1 km below the seafloor. The finite element mesh was generated by Tetgen software and in this work we are using the frequencies 0.75 and 1.0 Hz. The assigned resistivities to the mesh regions were $10^{12}\,\Omega$m (air), 0.3 Ωm (sea), 1.0 Ωm (sediment), 100 Ωm (reservoir) and $10^{-6}\,\Omega$m (well).

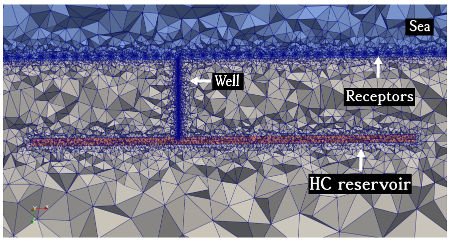

Figure 1: Mesh of finite element for 3D CSEM model with the well and the HC reservoir.

When generating current density maps on the finite element mesh, we initially used a grid with 150 m spacing in both x and z directions, spanning from the seafloor to the sediments below the reservoir, as shown in Figures 2a and b. These figures display the real and imaginary components of the vector at frequencies of 0.75 Hz and 1.0 Hz for two simulation scenarios: one including both the hydrocarbon reservoir and the well, and another with only the reservoir. The figures reveal anomalous current distributions at both the seafloor-sediment interface and the hydrocarbon interface, but the well's presence remains undetectable due to its small radial dimension.

To address this, we created a more refined grid focused around the well. First, in the XY plane at a depth of 1500 m, with 20 m spacing in both directions. The results, presented in Figure 3, compare current densities with and without the well, demonstrating that its influence is highly localized: beyond approximately 100 m, the effect becomes negligible. However, we observed that this effect is more pronounced in the real component of the current density and at a frequency of 1.0 Hz.

A second grid was constructed in the XZ plane with 25 m spacing in both directions, covering depths from the seafloor to a region below the reservoir, as illustrated in Figure 4. Here, we analyzed the real and imaginary components of the vector at 1.0 Hz, which proved to be the most significant frequency. The response without the well was also included for comparison. By computing the difference between the two scenarios, we found that the well's influence is stronger in the real component and in shallower sections. Additionally, a noticeable deflection in current flow direction occurs near the well (x = 1925 m). The amplitude difference map further confirms that the well's effect extends no more than 100 m from its location. This refined analysis highlights the localized electromagnetic perturbation caused by metallic wells in MCSEM surveys, emphasizing the need for high-resolution modeling near such structures.

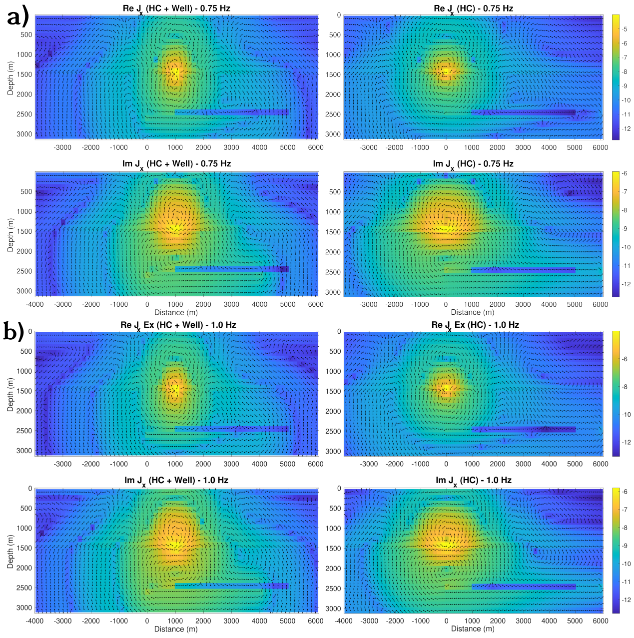

Figure 2: Sections of the current density vector: a) Top: Real component of Jx for the frequency of 0.75 Hz with the reservoir and the well (left) and only the reservoir (right); Bottom: Imaginary component of Jx for the frequency of 0.75 Hz with the reservoir and the well (left) and only the reservoir (right); b) Top: Real component of Jx for the frequency of 1.0 Hz with the reservoir and the well (left) and only the reservoir (right); Bottom: Imaginary component of Jx for the frequency of 0.75 Hz with the reservoir and the well (left) and only the reservoir (right).

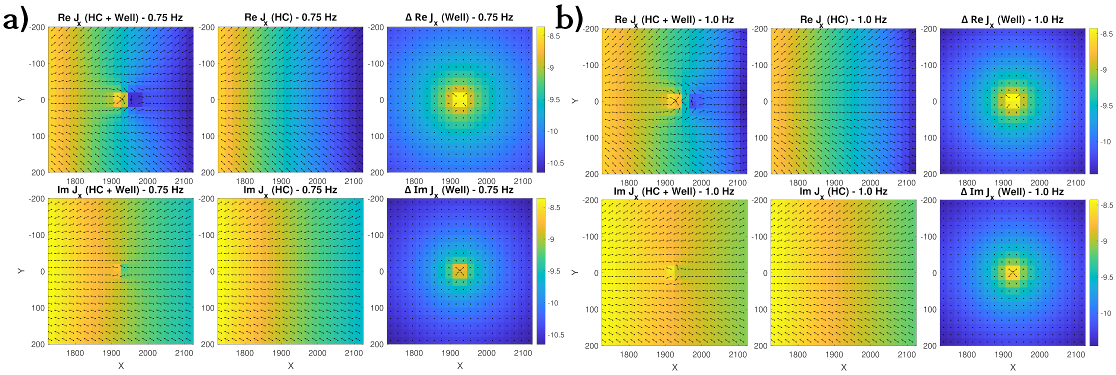

Figure 3: Current density vector map at a depth of 1500 m: a)Top: Real component of Jx at 0.75 Hz with reservoir and well (left), reservoir only (center), and their difference (right). Bottom: Imaginary component of Jx at 0.75 Hz with reservoir and well (left), reservoir only (center), and their difference (right); b)Top: Real component of Jx at 1.0 Hz with reservoir and well (left), reservoir only (center), and their difference (right). Bottom: Imaginary component of Jx at 0.75 Hz with reservoir and well (left), reservoir only (center), and their difference (right).

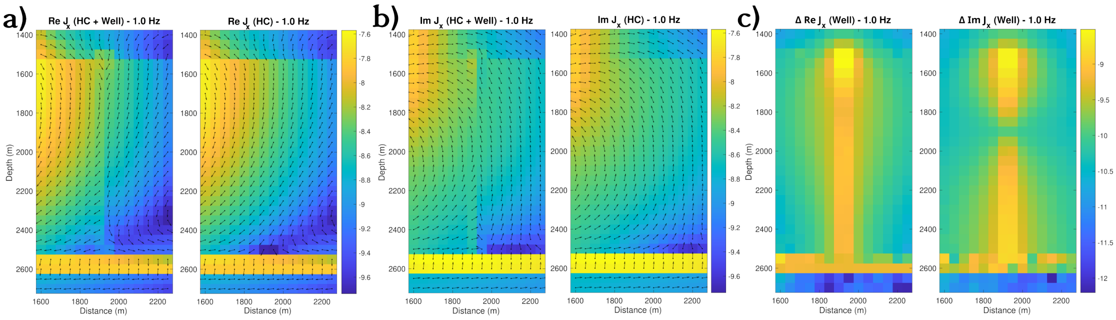

Figure 4: Vertical section of the current density vector around the well: a) Real component of Jx at 1.0 Hz with reservoir and well (left) and reservoir only (right); b) Imaginary component of Jx at 1.0 Hz with reservoir and well (left) and reservoir only (right); c) Current density amplitude difference between responses with and without the well: real part at 1.0 Hz (left) and imaginary part at 1.0 Hz (right).

Conclusions

The 3D MCSEM current density modeling has proven to be an effective tool for assessing the effect of conductive production structures on MCSEM data. For the vertical wells presented here, their influence extends only a few hundred meters and is most noticeable in the real component of the electric current density.

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