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Effect of Shallow Resistive Bodies on 3D MCSEM Data

Jadiane Carmo (Universidade Federal do Pará), Marcos Silva (Universidade Federal do Pará), Jéssica Itó (Universidade Federal do Pará)

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Abstract Summary

Gas hydrates are crystalline structures formed by methane and water, common in marine environments under high pressure and low temperature. This work analyzes the application of the marine controlled source electromagnetic (MCSEM) method to detect these shallow resistive bodies, using 3D numerical modeling with the Vector Finite Element Method (VEFM). Two acquisition configurations (inline and broadside) were simulated, evaluating the Ex and Ey components at frequencies of 1.0 Hz, 7.0 Hz, and 10.0 Hz. The results show how geometry and frequency affect the electromagnetic response, aiding in the efficient detection of gas hydrates.

Introduction

Gas hydrates are crystalline structures formed by water and methane, common in marine sediments and polar regions under conditions of low temperature and high pressure (Li et al., 2023). Considered a promising source of natural gas, these deposits could reduce dependence on conventional fossil fuels (Milkov, 2004). However, their exploitation involves significant technical and environmental challenges.

The Marine Controlled-Source Electromagnetic (MCSEM) method has stood out in the detection of resistive gas hydrate bodies due to the high resistivity of these formations. This technique allows mapping the distribution of resistive bodies in the marine subsoil and estimating their volume and saturation (Jana et al., 2017; Milkov, 2004). Studies such as those by Li et al. (2023), Weitemeyer et al. (2011), and Wang et al. (2017) demonstrate its effectiveness in different regions and contribute to the improvement of acquisition systems, especially in deep waters. Thus, MCSEM represents an essential tool in the safe and efficient exploration of gas hydrates as an energy alternative.

Therefore, this work aims to analyze the MCSEM 3D data in the presence of shallow resistive bodies, such as gas hydrates, through numerical modeling in marine anisotropic environments. To this end, the Vector Finite Element Method (VEFM) will be used, considering the inline and broadside geometric acquisition configurations.

Methodology

The Marine Controlled Source Electromagnetic (MCSEM) method is widely used in geophysics to investigate subsea geological structures, such as hydrocarbons, gas hydrates, and gas, due to its sensitivity to resistive materials with large lateral extent beneath the seafloor (Duan et al., 2021). The technique involves the use of a horizontal electric dipole (HED) transmitter, usually towed at a depth of 30 to 50 meters, which emits an alternating electromagnetic field through an antenna 50 to 200 meters long (Constable and Srnka, 2007). Receivers positioned on the ocean floor record the electromagnetic responses generated, which are then analyzed to characterize the properties of the submarine sediments and enable the interpretation of the geological structures.

Results

To represent shallow resistive structures, we will analyze in this study the effect of gas hydrates using the Controlled Source Electromagnetic Method (MCSEM), considering two geometries for the transmitter-receiver arrangement: inline and broadside. In the inline configuration, calculated in profile 1 for y = 0 m, only the Ex component was used, while in the broadside configuration, calculated in profile 2 with y = 500 m, the Ex and Ey components were considered. The source was positioned 30 meters above the ocean floor, and simulations were performed for frequencies of 1.0 Hz, 7.0 Hz, and 10.0 Hz, with each body inserted at positions -1000 m, -500 m, 0 m, and 500 m, obtaining amplitude and phase curves. The results presented here refer to the model illustrated in Figure 1, and a section of the finite element mesh used is shown in Figure 2.

With the transmitter located at position -1.0 km, Figure 3 shows the amplitude of the total and primary electric field Ex for frequencies of 1.0, 7.0, and 10.0 Hz. Here we can see the effect of the resistor by the displacement of the total field curves in relation to the primary curves. The effect is symmetrical for the resistor located below the source and occurs in the forward wave region of the curve.

For the broadside line, we collected profile 2 with the transmitter located at position -1.0 km and we see in Figures 4 and the amplitude of the total and primary electric fields Ex and Ey for frequencies of 1.0, 7.0, and 10.0 Hz. In these figures, we also observe the effect of the resistor by the displacement of the total field curves in relation to the primary ones. The effect is more pronounced at higher frequencies and is also symmetrical for the resistor located below the source and occurs in the region of the direct wave of the curve.

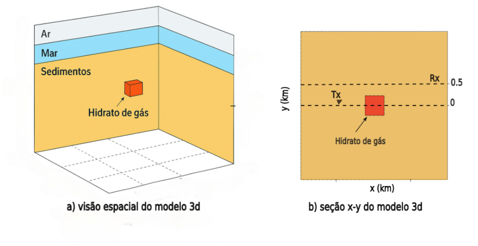

Figure 1: 3D geophysical model: air (resistivity of 10^6 Ohm.m), sea (resistivity of 0.3 Ohm and depth of 1,200 meters), encasing sedimentary rock (vertical resistivity of 2 Ohm.m and horizontal resistivity of 1.2 Ohm.m) and gas hydrate with 6.0 Ohm.m.

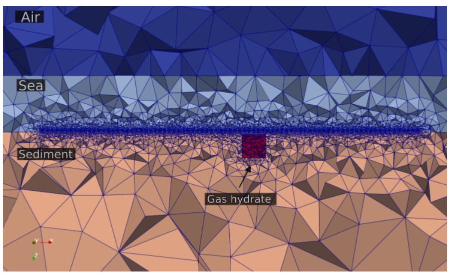

Figure 2: 3D geophysical model in the finite element mesh with the regions of air, sea, sediments, and gas hydrate. The densest region of points represents the measurement positions.

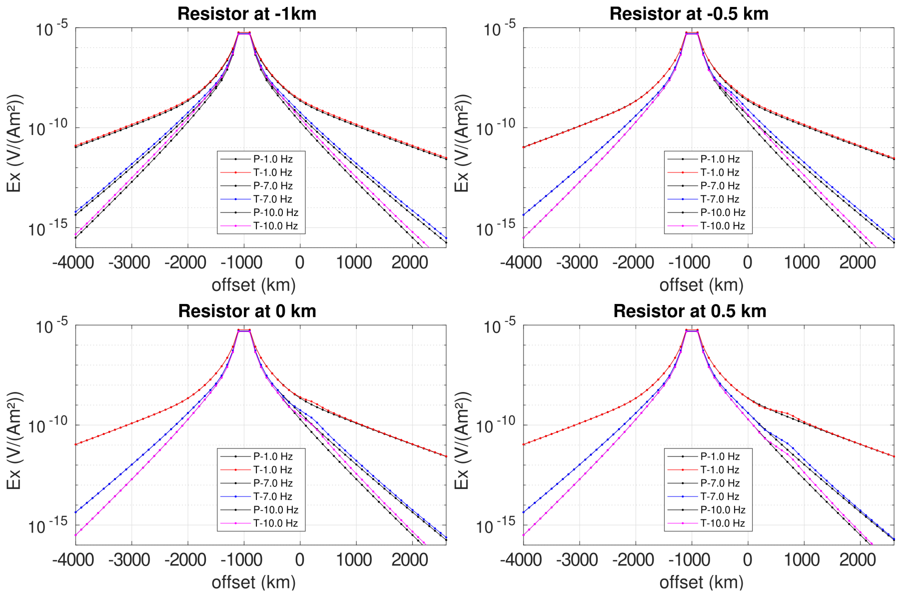

Figure 3: Electric field amplitude in the inline configuration for frequencies of 1.0, 7.0, and 10.0 Hz and different locations of the shallow resistor.

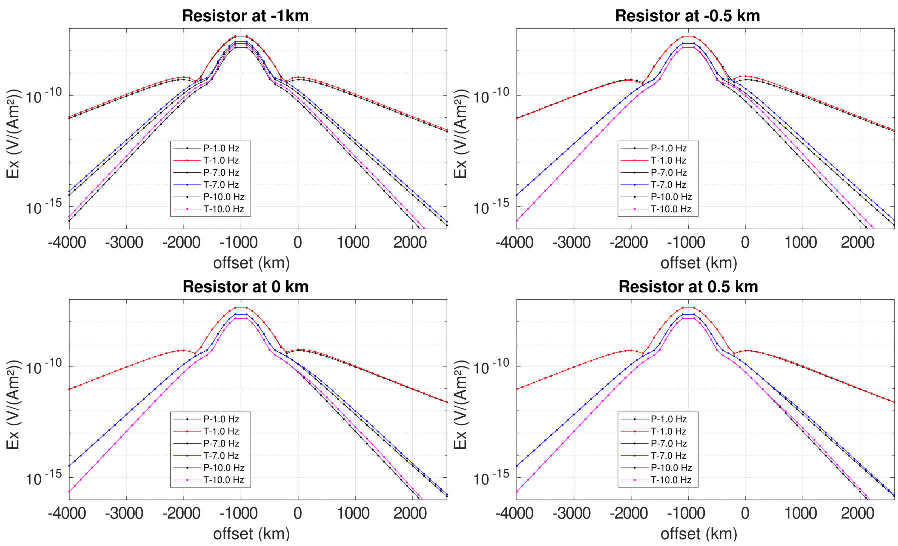

Figure 4: Amplitude of the electric field Ex in the broadside configuration (profile 2) for frequencies of 1.0, 7.0, and 10.0 Hz and different locations of the shallow resistor.

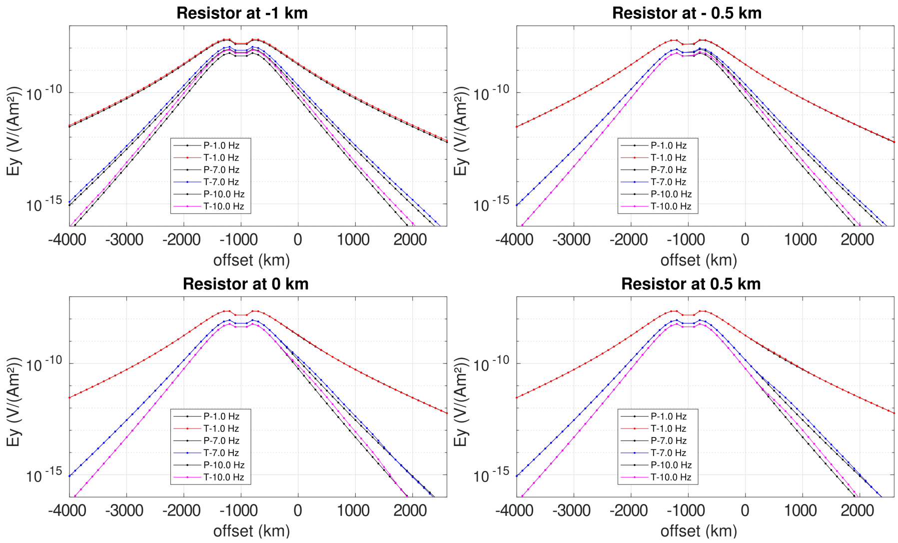

Figure 5: Electric field amplitude Ey in the broadside configuration (profile 2) for frequencies of 1.0, 7.0, and 10.0 Hz and different locations of the shallow resistor.

Conclusion

MCSEM has proven effective for detecting shallow resistive structures and should be used at higher frequencies, which results in a lower interpretation offset for anomalies. When the resistive body is very close to the source, there is a shift in the entire amplitude curve, even for the direct wave region.

References

Constable, S., and L. J. Srnka, 2007, An introduction to marine controlled-source electromagnetic methods for hydrocarbon exploration: Geophysics, **72**, WA3–WA12.

Duan, S., S. Hölz, A. Dannowski, K. Schwalenberg, and M. Jegen, 2021, Study on gas hydrate targets in the danube paleo-delta with a dual polarization controlled-source electromagnetic system: Marine and Petroleum Geology, **134**, 105330.

Jana, S., M. Ojha, K. Sain, and S. Srivastava, 2017, An approach to estimate gas hydrate saturation from 3-d heterogeneous resistivity model: A study from krishna-godavari basin, eastern indian offshore: Marine and Petroleum Geology, **79**, 99–107.

Li, Y., E. Slob, D. Werthmüller, L. Wang, and H. Lu, 2023, An introduction to the application of marine controlled-source electromagnetic methods for natural gas hydrate exploration: Journal of Marine Science and Engineering, **11**.

Milkov, A. V., 2004, Global estimates of hydrate-bound gas in marine sediments: how much is really out there?: Earth-science reviews, **66**, 183–197.

Wang, M., M. Deng, Z. Wu, X. Luo, J. Jing, and K. Chen, 2017, The deep-tow marine controlled-source electromagnetic transmitter system for gas hydrate exploration: Journal of Applied Geophysics, **137**, 138–144.

Weitemeyer, K. A., S. Constable, and A. M. Tréhu, 2011, A marine electromagnetic survey to detect gas hydrate at hydrate ridge, oregon: Geophysical Journal International, **187**, 45–62. (Accepted June 6, 2011. Received May 27, 2011; in original form April 8, 2010).