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Linear and non-linear approximations based integral equation method in marine EM field modeling

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Extended Abstract

Summary

Electromagnetic induction (EMI) methods have an important role in modeling hydrocarbon reservoirs embedded in marine sediments. One of these methods is marine control source electromagnetic (MCSEM) technique. In comparison with other geophysical techniques like seismic methods, which model hydrocarbon reservoir with high accuracy, The MCSEM technique is comparatively less accurate but due to much less costs, this method may be recommended for modeling hydrocarbon reservoirs embedded in marine sediments. In addition, the sea water reduces the voltage resulting from magnetotelluric (MT) currents, thus the MT method is not efficient, and is not suitable for imaging marine hydrocarbon reservoirs. Hence, the MCSEM method is used for these reservoirs. In this research, for three-dimensional (3D) forward modeling of a hydrocarbon reservoir with regular and irregular geometrical shape, and also, for four-dimensional (4D) forward modeling of a regular geometrical reservoir, integral equation (IE) method is used. The aim of the present study is to develop and apply several approximations to simulate the electromagnetic problems and to solve integral equation for 3D MCSEM synthetic data in order to avoid solving full integral equations, and also, to decrease the computational costs. In order to monitor small changes in electrical conductivity among increasing pressure inside the reservoir, the capability of time-lapse CSEM data has been discussed. It has been found that this method can detect the changes in the reservoir due to the fluid injection. In this study, T-matrix approximation (TMA), born approximation (BA) and extended born approximation (EBA) are applied to approximate 3-4D integral equations in the MCSEM method at low frequencies.

Introduction

The MCSEM method uses an electric current dipole to construct a source field that is measured at receivers positioned on the sea floor. Over the past decade, the use of the MCSEM method for hydrocarbon exploration because of its sensitivity to thin resistive layers has been increased. However, its resolution is not as well as the seismic wave propagation method. The MCSEM surveying is more detailed and less cost than potential field methods like gravity. For forward modeling of a 3D hydrocarbon reservoir having regular or irregular geometrical shape, integral equation methods are used. In order to avoid solving full integral equations, several linear and non-linear approximations such as TMA, EBA and BA are developed to approximate 3D integral equations in the MCSEM method at low frequencies. At the end, these three approximations in term of accuracy and relative error are compared, and as a result, we find that the TMA scheme has better accuracy and a wider electrical conductivity application range than the BA and EBA approaches.

Methodology and Approaches

In order to derive the integral equation, the Green's function technique is usually used. In this research Fredholm integral equation of the second kind is used. The BA, EBA and TMA approaches are used to avoid solving the super-large system of linear and non-linear equations in the full integral equation algorithm. The BA scheme considers the total electric field in the integral terms being approximated by the background field, and neglects multiple scattering within the scattered field, and works well for small conductivity contrasts and low frequencies. The EBA scheme is applied to improve the BA results. The EBA strategy replaces the total field in the integral equation not by the background field, like the BA scheme, but considering its projection onto the depolarization tensor. The TMA scheme includes all effects of multiple scattering and is completely independent of source-receiver configuration, but only needs knowledge about the scattering potential and the background Green's function. Unlike the BA scheme, the contrasts need not inevitably be small in the TMA scheme. These approximation approaches are numerically implemented for 3D MCSEM forward modeling in MATLAB.

Results and Conclusions

In this paper, we applied three scattering approximations (i.e., BA, EBA, and TMA) in the integral equation method for 3D MCSEM synthetic data modeling. Based on the numerical experiments using two simulated models and the ability of time-lapes CSEM data, it is demonstrated that the TMA has better accuracy and a wider electrical conductivity application range. The TMA scheme approximates roughly full integral equation solution for electromagnetic field, while the EBA scheme in comparison with the BA scheme is expected to improve approaches of EM field over large conductivity contrasts between the reservoir and background model. The TMA and EBA approaches are valid for high contrasts, thus to improve the accuracy of these approximations, number of grid blocks need to be increased by considering computational costs.