3D numerical modelling and 1D inversion and resolution analysis of time-domain marine controlled source electromagnetic data

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1 Introduction

The marine Controlled Source Electromagnetic (CSEM) method has been increasingly used for gas hydrate explorations and investigation of the marine subsurface. This technique is based on the diffusive propagation of electromagnetic (EM) signals emitted from a source dipole (Tx) on or close to the seafloor. The EM signal travels away from the source dipole through the conductive seawater where it is attenuated quickly, and through the more resistive seafloor sediments. It is recorded by one or more receivers located on the seafloor at some distance away from the Tx. The part of the signal passing through the seafloor arrives at the receivers first. The marine controlled source electromagnetic group at Federal Institute for Geosciences and Natural Resources (BGR) has developed a new, bottom-towed, time domain, multi-dipole CSEM system (Figure 1). The system consists of a bipolar electrical transmitting dipole located on the seafloor and electrical receiving dipoles at offsets between 100 m and 1000 m settled in-line with the source dipole. The system measures the horizontal component of the electric field (E_x).

The possibility to estimate accurately the seafloor properties from CSEM data is obstructed by the appropriateness of the inverse modeling technique to derive marine subsurface structures. Successful inversion is challenging, since the inverse problem should satisfy elemental well-posedness conditions. In the context of marine CSEM studies, several inversion scenarios are taken into account. OCCAM inversion assumes a smooth model and can be employed to have an initial estimation about the number of sub-seafloor layers. Marquardt inversion can also be used for marine CSEM applications. This method is more appropriate to resolve sharp boundaries. Nevertheless, the results are strongly dependent on the starting model, i.e. several initial models can produce different inversion outcomes.

Bathymetry effects on the marine CSEM response have been rarely reported in the geophysical literature. These effects can be simulated by numerical methods. Motivated by CSEM data collected in deep water offshore New Zealand and in shallow water in the

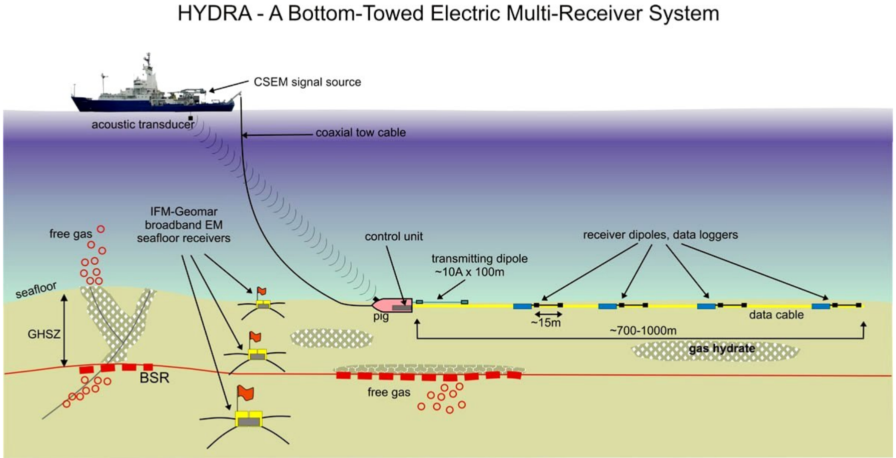

Figure 1: Set-up of the inline electric dipole-dipole system.

German North Sea, we study the effect of seafloor topography and sub-seafloor structure for both shallow and deep water environments. This study was carried out through systematic 3D forward modeling demonstrating to which extent topography is relevant, and should be included in the modeling process. These data sets were analyzed by 1D OCCAM- and Marquardt- type inversion strategies using the code by C. Scholl. Moreover, we compared the results of the OCCAM and Marquardt inversions with global-local optimization approaches to obtain sub-seafloor layering through numerical simulations. The global-local approaches correspond to the global multilevel coordinate search (MCS) algorithm (Huyer & Neumaier, 1999) combined sequentially with the classical Nelder-Mead simplex algorithm (NMS) (Lagarias et al., 1998).

2 Effect of topography

The sea floor topography can have great influences on the measured CSEM data. As a result, information about the extent of such influences can assist us for an accurate interpretation of the data. We simulated the sea floor topography using a 3D EM forward code of Zonghou Xiong. We considered four different scenarios including 1) a model without sea floor topography and sub-seafloor 3D structure, 2) a model without sea floor topography and with sub-seafloor 3D structure, 3) a model with sea floor topography and without sub-seafloor 3D structure, 4) a model with both sea floor topography and sub-seafloor 3D structure. The 3D structure was simulated considering a 3D block with $\rho = 50\ \Omega \times m$ in the sub-seafloor with background resistivity of $\rho = 1\ \Omega \times m$. The seafloor topography was simulated using a 3D block with 20 m height and resistivity of $\rho = 1\ \Omega \times m$. The numerical simulation was carried out considering both shallow (100 m) and deep (5000 m) water ($\rho = 0.3\ \Omega \times m$). The RMS error between the first scenario (E_x^1) and other scenarios (E_x^m) was calculated as follows:

$$RMSE_{1m} = 100 \times \sqrt{\frac{\sum(E_x^1 - E_x^m)^2}{\sum(E_x^1)^2}} \tag{1}$$

The results of simulations for shallow and deep water considering 1100 m offset are shown

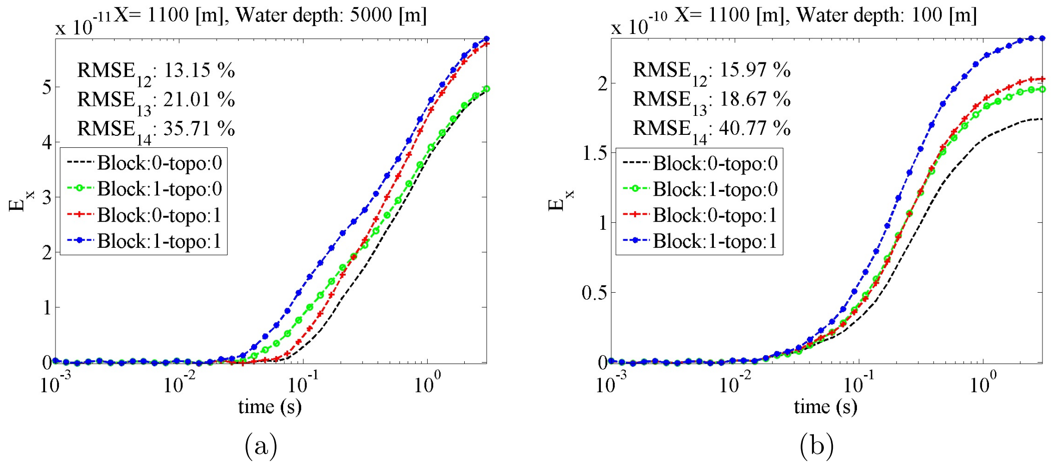

Figure 2: The results of simulations for shallow and deep water considering 1100 m offset.

in Figure 2. As can be seen, for shallow water, the air wave interferes to the results causing to obtain smoother data, i.e., the bumps originated from the sub-seafloor structure are not observed for data related to shallow water. Moreover, the RMS error between the first scenario and the second one (no topography) is lower than those between first and the other scenarios (see Fig. 2). Similar results (not shown here) were obtained for other offsets. Consequently, for interpretation of the marine CSEM data, the effect of topography should be taken into account.

3 Inversion scenarios

In order to investigate the robustness of several inversion algorithms to derive sub-seafloor structures, we performed 1D inversion using OCCAM, Marquardt and global-local approaches. In this respect, synthetic data were generated using a shallow water model with 200 m water depth ($\rho = 0.3\ \Omega \times m$) and a three layer sub-seafloor. In this example, the sub-seafloor layered medium consists of the two first layers with 100 m and 50 m thickness located over a homogenous half-spaces. The resistivity of the layers are 1 $\Omega \times m$, 20 $\Omega \times m$ and 1 $\Omega \times m$, respectively. In order to have simulations close to real case scenarios, we added Gaussian random noise of 2 percent to the electric field. The RMSE between measured (E_x^{meas}) and modeled (E_x^{mod}) data are calculated by

$$RMSE = \sqrt{\frac{1}{N}\sum\left(\frac{E_x^{meas} - E_x^{mod}}{\delta}\right)^2} \qquad (2)$$

where ($\delta = \delta^{meas} \times E_x^{meas}$)/100 and δ^{meas} (%) is the measurement error. Figure 3 presents the synthetic data versus modeled values obtained using different inversion scenarios. For all offsets, the synthetic and modeled values presents very well agreements for both OCCAM and MCS-NMS inversion scenarios. In the case of Marquardt inversion, some discrepancies can be observed, in particular for larger offsets.

The final inversion results are illustrated in Figure 4. As expected, the OCCAM inversion suggests a three layer smoothed model. The global-local approach allows for accurate

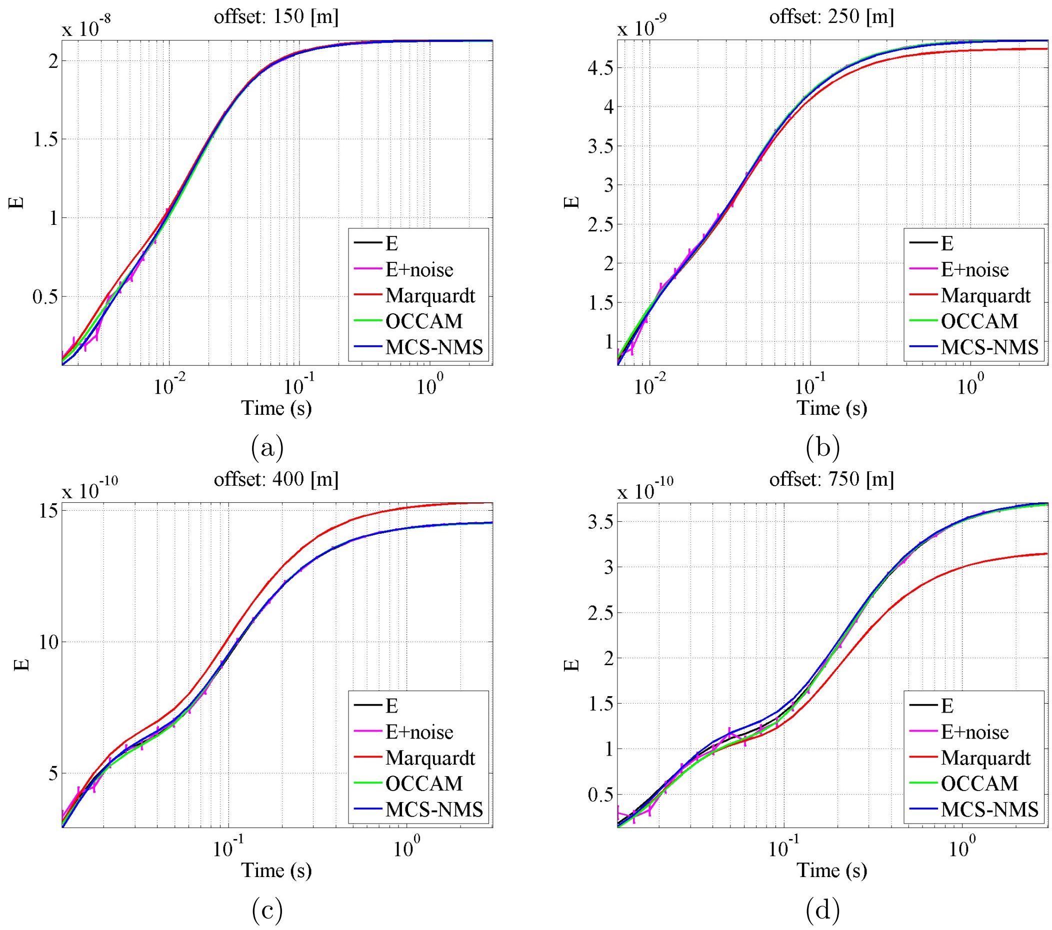

Figure 3: Synthetic and modeled marine CSEM data considering several inversion schemes.

retrieval of the sub-seafloor layering. Less satisfactory results obtained by Marquardt inversion which originates from the sensitivity of this approach to the starting model. Furthermore, the RMSE between synthetic and modeled data is also lower for MCS-NMS than those from Marquardt inversion.

4 Conclusions

We studied the effect of seafloor topography and sub-seafloor structure on marine CSEM data for both shallow and deep water environments. According to the results, the sea floor topography presents significant impact on the marine CSEM data. In addition, we compared the results of the OCCAM and Marquardt inversions with global-local optimization approaches to obtain sub-seafloor layering through numerical simulations. The results show that the MCS-NMS inversion appears to be promising to resolve sub-seafloor structures. The results are valid for 1D structures and for 2D or 3D cases a more complex inversion approach is required. Future work will focus on the inversion of marine CSEM data using MCS and Marquardt approaches in a sequential inversion scheme.

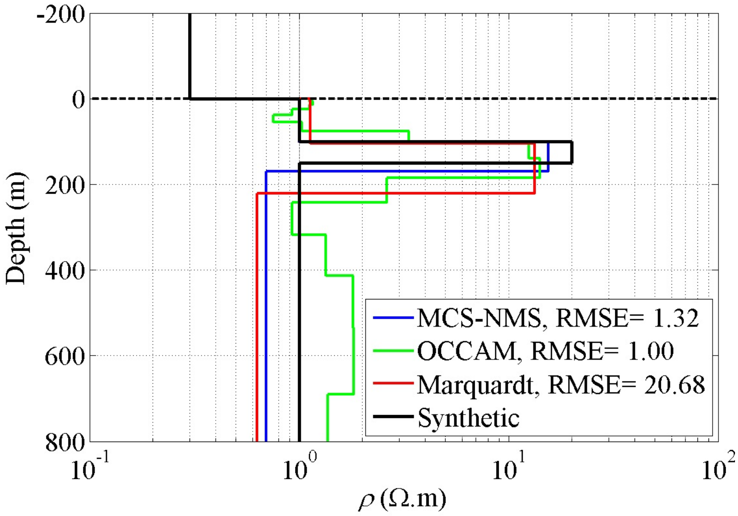

Figure 4: Inversely estimated sub-seafloor layers versus true values.

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