Electromagnetic Interferometry by multi-dimensional deconvolution applied to diffusive controlled-source exploration

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Introduction

Controlled Source Electromagnetics (CSEM) can be used to identify potential oil or gas reservoirs previously mapped with seismics. In the marine application of CSEM, a boat tows a source in the ocean over an array of receivers situated at the ocean bottom. The source emits an electromagnetic field in the low frequency range. In our synthetic example the frequency is 0.5 Hz. The receivers record horizontal components of the resulting diffusive electromagnetic (EM) field as a function of offset from the source position. A reservoir forms a high resistivity zone which leaves an imprint on the recorded response. Besides the measurements above an expected reservoir, a reference measurement is taken in a region where no reservoir is expected. A difference between the two measurements at intermediate offsets indicates the presence of a reservoir. Figure 1 shows synthetically modeled data of a typical CSEM measurement above a layered earth structure. This technique is often also referred to as Sea Bed Logging (SBL).

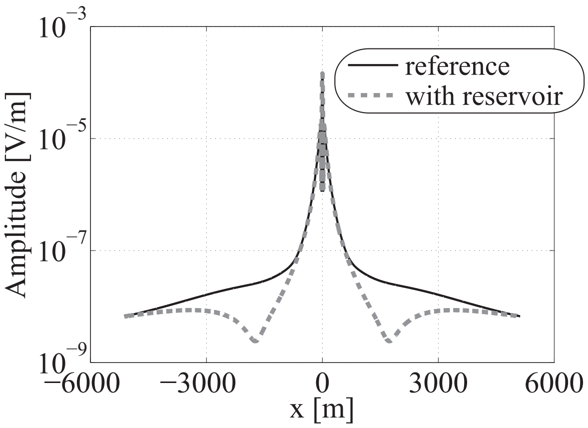

Figure 1: Synthetically modeled 2D electric field with a reservoir present in the subsurface (dashed grey line) and the reference response without a reservoir (solid black line).

The recorded EM fields are strongly affected by the water layer thickness and the position of the source in the water as can be seen in Figure 2, where the EM fields are shown for a water layer thickness of 200 m (shallow sea) and 1000 m (deep sea). The source is in both cases 175 m below the water surface. This dependence of the water layer thickness makes a quantitative interpretation of the data with respect to subsurface structures difficult.

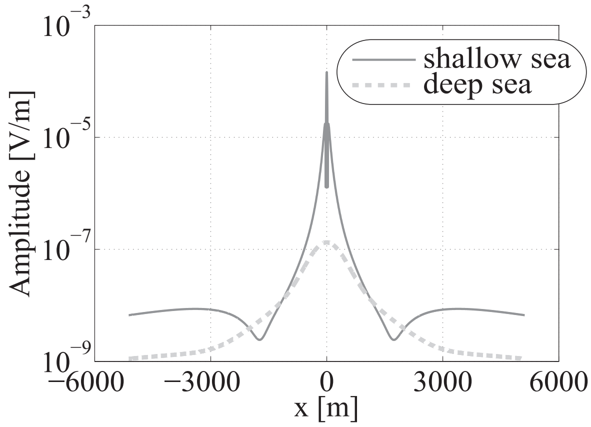

Figure 2: Synthetically modeled 2D electric field for a shallow sea situation (dark grey line) and a deep sea situation (dashed light grey line).

Interferometry by multidimensional deconvolution (MDD) can overcome this issue, because it allows to retrieve a reflection response which contains only information from the subsurface. By applying interferometry by MDD the structure above the receivers is replaced with a homogeneous halfspace consisting of the same material parameters as the first layer below the receivers. In other words, all reflections from above the receivers are eliminated. Furthermore the direct field is erased too and the sources are redatumed to the receiver positions.

Theory of Interferometry by MDD

Interferometry by MDD consists of two steps. First the recorded fields need to be decomposed in upwards and downwards decaying fields. This was first done by Amundsen *et al.* (2006)

in CSEM. Here an algorithm provided by Slob (2009) is used. This decomposition requires in 3D recordings of all four horizontal EM field components. The decomposed fields can be related to each other through a reflection response $\hat{\mathbf{R}}_0^+$:

$$\hat{\mathbf{P}}^- = \hat{\mathbf{R}}_0^+ \hat{\mathbf{P}}^+. \qquad (1)$$

Equation 1 uses matrix notation introduced by Berkhout (1982). Each column of the matrices $\hat{\mathbf{P}}^-$ and $\hat{\mathbf{P}}^+$, containing the upwards and downwards decaying fields, consists of various receiver positions but a fixed source position and vice versa for the rows. The circumflex denotes space-frequency domain and the superscripts $^-$ and $^+$ indicate upwards and downwards direction respectively. The subscript $_0$ stands for the absence of any reflections from above the receiver level in the reflection response.
In the second step, the reflection response $\hat{\mathbf{R}}_0^+$ is retrieved with a least-squares inversion of equation 1:

$$\hat{\mathbf{R}}_{\mathbf{0}}^+ = \hat{\mathbf{P}}^- \left(\hat{\mathbf{P}}^+\right)^\dagger \left[\hat{\mathbf{P}}^+ \left(\hat{\mathbf{P}}^+\right)^\dagger + \varepsilon^2 \mathbf{I}\right]^{-1}. \qquad (2)$$

The superscript † denotes complex-conjugation and transposition and $\mathbf{I}$ is the identity matrix. The stabilization parameter ε prevents the inversion from getting unstable. Compared to classical interferometry carried out by Cross-Correlation (CC), interferometry by MDD is not a trace to trace process, but requires an array of receivers. The advantages of MDD include elimination of the source signature, improved radiation characteristics of the retrieved source and relaxation of the assumption of a lossless medium. On the other hand, MDD is more expensive and the matrix inversion involved may be unstable. A general overview of interferometry by MDD can be found in Wapenaar *et al.* (2008).

Results and Conclusion

The retrieved reflection response for the shallow sea and the deep sea situation are plotted in Figure 3. Since the only difference between the two models is the thickness of the water layer, the two retrieved reflection responses have an identical shape. Consequently it can be said, that interferometry by MDD successfully removed the effects of the water layer.

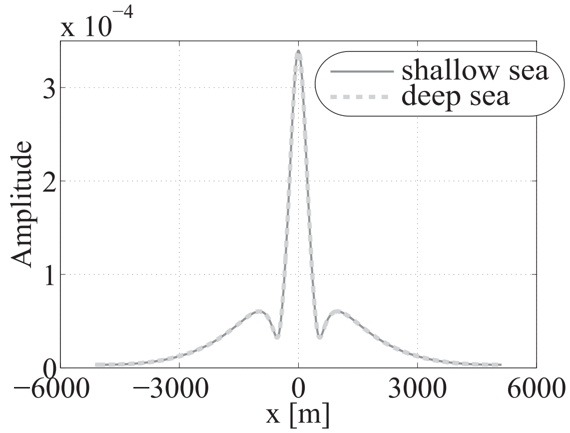

Figure 3: Retrieved reflection response for a shallow sea situation (dark grey line) and a deep sea situation (dashed light grey line).

Acknowledgments

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