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## CSEM Interferometry Using a Synthetic Aperture Source

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### SUMMARY

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With interferometry by multidimensional deconvolution for Controlled Source Electromagnetics, the medium above the receivers is replaced with a homogeneous halfspace and the source is redatumed to the receiver level. The resulting retrieved reflection response is completely free of any airwave effect. Since the source is redatumed, the original source position becomes irrelevant, which is a useful property for time-lapse surveys. So far, interferometry by multidimensional deconvolution required a densely spaced receiver array. We show that this restrictive sampling requirement can be overcome by combining a lot of source positions to one very long source. By creating such a synthetic aperture source, we were able to apply interferometry for a receiver spacing as large as 1280 m.

## Introduction

Marine Controlled Source Electromagnetics (CSEM) for exploration purposes uses diffusive electromagnetic fields to detect resistors, e.g. oil reservoirs, in the subsurface. An electric source is towed by a boat close to the ocean bottom and emits a monochromatic signal. The resulting electromagnetic field diffuses through the water and the subsurface and is eventually recorded by receiver stations at the ocean bottom as a function of offset from the source position. A more detailed description of the method and its history is given by Constable (2010).

Unfortunately, besides the subsurface response an unwanted signal from the air-water interface is recorded. This so-called airwave is especially problematic in shallow water. We apply interferometry by multidimensional deconvolution (MDD) to replace the medium above the receivers with a homogeneous half-space with the same medium parameters as the sediment below the receivers. In this way, the airwave, including possible multiples, is removed. Furthermore, the source is redatumed to the receiver position. Consequently, it does not matter anymore, where the source is located. Therefore, interferometry by MDD has potential for time-lapse surveys.

Interferometry by MDD consists of two steps: First, the electromagnetic fields are decomposed into upward and downward decaying components (Amundsen et al., 2006; Slob, 2009). In the second step, an upward decaying component is deconvolved with a downward decaying component in order to retrieve the subsurface reflection response, i.e., the scattered Green's function of the subsurface (Wapenaar et al., 2008b). The deconvolution is computed using a stabilized least-squares algorithm. In order to decompose the fields, multicomponent receivers are necessary. Furthermore, the field needs to be properly sampled over all offsets, which means that the sampling distance is required to be smaller than either the length of the source or the vertical distance between the source and the receivers (Hunziker et al., 2010). Consequently, in order to use a reasonable receiver location separation, the data acquisition needs to change, i.e. either the source needs to be towed vertically farther away from the receivers or a very long source antenna has to be used.

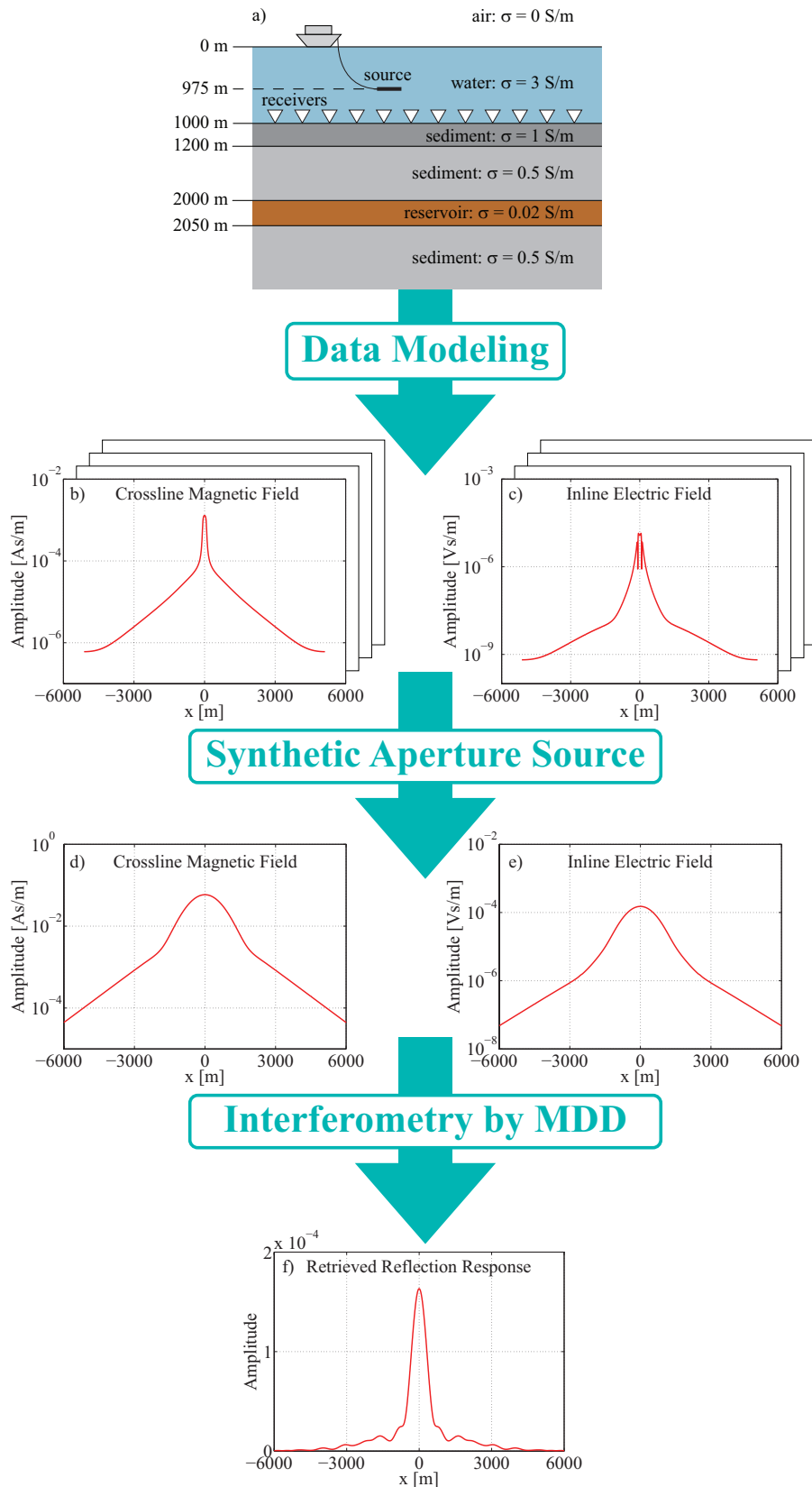
In this paper, we present a method of applying interferometry by MDD to standard CSEM data using large receiver sampling distances. The basic idea is to create a synthetically long source antenna during processing instead of a actually using a physically long antenna. The concept of this synthetic aperture sources for CSEM was introduced by Fan et al. (2010).

## Method

The method is illustrated with the numerical example of Figure 1. First, we model the crossline magnetic and the inline electric field components for the conductivity distribution shown in Figure 1a in 2D. Next the electromagnetic fields (Figures 1b, c) from individual source locations are weighted and summed over the source positions in order to get the electromagnetic fields due to a synthetically elongated source of 5 km (Figures 1d, e). Since the source is towed over the receivers, there is an almost continuous record of source positions. We use a Gaussian distribution function  $f(x)$  for the weights:

$$f(x) = \frac{1}{\sqrt{2\pi}\gamma} \exp\left(-\frac{(x-x_0)^2}{2\gamma^2}\right), \quad (1)$$

where  $x_0$  is the center of the synthetic aperture source, to ensure that the center source position gets maximum weight. The width  $\gamma$  is chosen to be one eighth of the length of the synthetic aperture source. The parameter  $x$  represents the source location in inline direction. Eventually, interferometry by MDD is applied to retrieve the unitless reflection response (Figure 1f). Due to the layered Earth model, the deconvolution was implemented in the wavenumber domain.



**Figure 1** Overview over the method: a) Geometry and conductivity values  $\sigma$  of the model (not to scale); b) and c) the modeled magnetic and electric fields, respectively; d) and e) the magnetic and electric field for a synthetic aperture source; f) the retrieved reflection response after applying interferometry by MDD.

## Results

In our simulation the antenna is pulled over the receivers at a height of 25 m and has a length of 160 m. Following Hunziker et al. (2010), it is not possible to have a receiver spacing larger than 160 m. We show in this section that by creating a synthetic aperture source, significantly larger receiver spacing distances can be achieved.

We create a synthetic aperture source with a length of 5000 m and retrieve the reflection response for various receiver spacings. Figure 2a) and b) show in red the retrieved reflection response for a spacing of 20 m in the wavenumber domain and in the space domain, respectively. The black curve shows the directly modeled reflection response, i.e. the correct solution, which was modeled by actually replacing the overburden with a homogeneous halfspace and by positioning the source at a receiver position. In the wavenumber domain we see a perfect match between the red and the black curve in the range of  $-10^{-3}$  and  $10^{-3} \text{ m}^{-1}$ . Due to the synthetically elongated source, signal at large wavenumbers is damped, but not eliminated. In the deconvolution step of interferometry by MDD, this part of the signal can be recovered again if it is above the noise level. Unfortunately, this can also lead to instabilities. Therefore, in the space domain the reflection response is well retrieved, apart from some oscillation around an offset of 1500 m. A larger stabilization parameter in the least-squares algorithm, which is used to carry out the deconvolution, flattens these oscillations, but it would also underestimate the amplitude at zero offset more significantly.

Figure 2 also features receiver sampling distances of 320 m, 640 m and 1280 m. With increasing receiver sampling distance, the correctly retrieved wavenumber content of the reflection response becomes narrower. In other words, the band of wavenumbers where the red and the black curve are identical, decreases with increasing receiver sampling distance. In order to achieve a fair comparison in the space domain, the directly modeled reflection response has been filtered to fit the wavenumber content that is well retrieved. It can be seen, that even for a spacing of 1280 m, the reflection response is retrieved more or less well in the according bandwidth. In Figures 2d),f) and h) the location of the datapoints is indicated with a red point. One datapoint at the kink of the reflection response, which lies in the same area as the oscillations were observed for a receiver spacing of 20 m, can not be retrieved properly. All the other datapoints are retrieved well.

## Conclusions

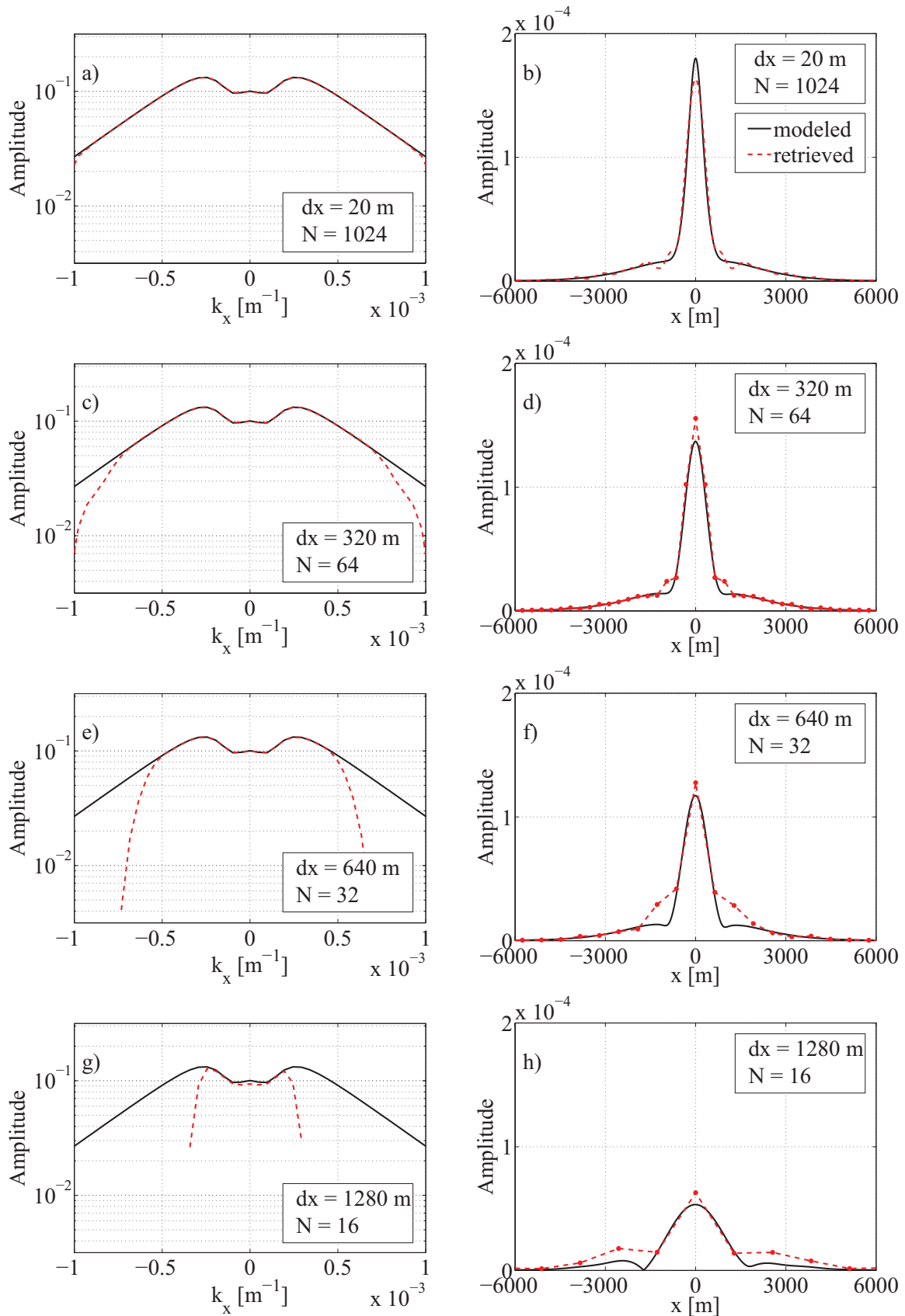
We have shown that the sampling problem in CSEM interferometry can be overcome by using synthetic aperture sources. This technique allows to apply interferometry by MDD to conventional recorded CSEM datasets without a change in acquisition.

## Acknowledgements

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**Figure 2** Retrieved reflection responses in the wavenumber domain (left column) and in the space domain (right column) for different receiver spacings: a)b) 20 m, c)d) 320 m, e)f) 640 m and g)h) 1280 m. The value  $N$  specifies the amount of receivers used.