Tu LHR1 07

MT Noise Suppression for Marine CSEM Data

K.R. Hansen* (EMGS ASA), V. Markhus (EMGS ASA) & R. Mittet (EMGS ASA)

SUMMARY

We present a simple and effective method for suppression of MT noise in marine CSEM data. The method can be applied to any CSEM data set where both electric and magnetic fields are measured, and does not require deployment of reference receivers. By applying the method to field data from the Barents Sea, we obtained a significant reduction of MT noise.

Introduction

Data from marine controlled-source electromagnetic (CSEM) acquisition is used in hydrocarbon exploration to evaluate the resistivity of reservoir prospects in a more conductive subsurface. A deep and/or small reservoir may require very good CSEM data quality to be detectable. Environmental noise from magnetotelluric (MT) signals may degrade the CSEM data quality to a level where the target is no longer detectable, and may therefore require reacquisition of the CSEM data to avoid the MT contamination. Processing of the CSEM data that can significantly reduce the impact of the MT noise is therefore highly valuable. Earlier attempts to remove MT noise from CSEM data have relied on a reference receiver assumed to be outside the range of the CSEM source (Ryhove and Maaø, 2008). However, in shallow water where MT is strongest, the airwave can extend to source-receiver offsets in excess of 50 kilometres, making this approach operationally inefficient, since the survey vessel needs time to place the reference receiver a safe distance from the CSEM survey. Another drawback with this method is that uncorrelated noise from the reference station will affect the receivers of the CSEM survey in the processing.

In this paper we present a simple and effective MT noise suppression technique, which does not require a reference receiver. Our technique is very similar to up-down decomposition (Amundsen et al., 2006), which is used for mitigating the effect of the airwave in shallow water. While the primary purpose of our proposed processing is MT noise suppression, we find that it is also able to partially remove the airwave at high CSEM frequencies. We also show how to properly estimate the noise in the processed CSEM data by estimating the covariance between the electric and magnetic channels in the frequency domain stacking process. Finally, we apply the processing to field data from the Barents Sea to demonstrate the effectiveness of the method.

Theory

The measured horizontal electric and magnetic field components E_x and H_y can be considered as a sum of a CSEM contribution and an MT contribution

$$E_x = E_x^{CSEM} + E_x^{MT}, \quad H_y = H_y^{CSEM} + H_y^{MT}, \tag{1}$$

where the MT electric and magnetic fields are related by $E_x^{MT} = Z_{xy}^{MT} H_y^{MT}$. If MT noise is present on the CSEM frequencies of interest, we will normally be able to robustly estimate the frequency-dependent MT impedance Z_{xy}^{MT} from logged receiver data acquired when the source is not active (Markhus et al., 2015). In order to remove the MT contribution, we form the following linear combination of the horizontal field components

$$E_x^c(f) = \frac{1}{2}\left[E_x(f) - Z_{xy}^{MT}(f) H_y(f)\right], \tag{2}$$

where f is the frequency of the CSEM signal. Inserting equation (1) into equation (2), we see that the MT contribution to the cleaned electric field E_x^c should cancel, provided that our estimated MT impedance is accurate.

Our proposed processing is very similar to the up-down decomposition described in Amundsen et al. (2006), where the impedance is the plane wave impedance Z_f of the top formation below the receiver. In fact, equation (2) was suggested by Chen and Alumbaugh (2011) as a means to remove the airwave from the CSEM data, where Z_f was estimated by the high-frequency limit of Z_{xy}^{MT}. Since our primary focus is MT noise reduction, our decomposition given in equation (2) uses the MT impedance at the relevant CSEM frequency, rather than the high-frequency limit suggested in Chen and Alumbaugh (2011). However, for high frequencies $Z_{xy}^{MT} \to Z_f$, and we therefore expect that our processing should be able to at least partly remove the airwave at high frequencies where the airwave effect is strongest. Since our proposed processing only involves a linear combination of electric and magnetic data, it is a simple matter to use the processed data in any inversion scheme, as shown by Mittet and Gabrielsen (2013).

In order to estimate the noise $\sigma_{E_x^c}$ for the cleaned electric field, it is imperative to take the correlation between the electric and magnetic channels into account, since this correlation will be high when the noise is dominated by MT. It is easy to show that the noise for the cleaned electric field in terms of the noise of the measured electric (σ_{E_x}) and magnetic (σ_{H_y}) fields, as well as their covariance $c(E_x,H_y)$, is given by

$$\sigma_{E_x^c} = \frac{1}{2}\sqrt{\sigma_{E_x}^2 + \left|Z_{xy}^{MT}\right|^2 \sigma_{H_y}^2 - 2Re\left[Z_{xy}^{MT*} c(E_x,H_y)\right]}. \tag{3}$$

When MT dominates the ambient noise, the covariance $c(E_x,H_y)$ will be large, leading to a reduction in the noise estimate $\sigma_{E_x^c}$ for the cleaned electric field.

The variance and covariance estimates used in equation (3) can be estimated from the measured data as part of the transformation of the recorded time domain data to the frequency domain. First, the relevant section of the recorded time series is divided into M short taper window segments denoted $e_{x,m}$, where m is an index for the segment. Each segment is Fourier transformed to the frequency domain representation $E_{x,m}$, and then stacked to produce a single CSEM datum (Myer et al., 2011). Obvious outliers in the time domain signal, caused by e.g. amplifier gain switching, can severely degrade the signal quality, and segments containing such outliers are therefore excluded in the stacking. The post-stack datum is thus given by

$$E_x = \frac{1}{\sum_{m=1}^{M} l_{E_x,m}} \sum_{m=1}^{M} l_{E_x,m} E_{x,m}, \tag{4}$$

where $l_{E_x,m} = 0$ if the window contains outliers, and $l_{E_x,m} = 1$ otherwise. An estimate of the variance of E_x and H_y is calculated by first removing any linear trend present in the set of transformed segments due to the moving source, and then computing the variance of the post-stack datum given in equation (4). In the estimate of the covariance $c(E_x,H_y)$ we face the added complication that outliers may be present in different segments of the time series for E_x and H_y. One possible way to handle this problem is to simply exclude a given segment from both E_x and H_y if just one of the two segments contains an outlier. While this method produces consistent estimates of variances and covariance, it has the disadvantage of discarding usable data from the stacking. Instead, we compute the datum and associated variances using all segments not marked as an outlier. The covariance is estimated as

$$c(E_x,H_y) = \frac{1}{M'(M'-1)} \sum_{m=1}^{M'} l_{E_x,m} l_{H_y,m} \left(E_{x,m} - E_x\right) \left(H_{y,m} - H_y\right)^*, \tag{5}$$

where M' is the number of segments where at most one of E_x and H_y contains an outlier, and $l_{H_y,m}$ is a masking function for the magnetic channel analogous to $l_{E_x,m}$. Note that if a time segment contains an outlier in either E_x or H_y, this segment contributes the value 0 to the covariance $c(E_x,H_y)$. In this way, we get a conservative estimate of the covariance that is also consistent with our estimates of the variances.

Results

During the summer of 2015, EMGS acquired multi-client CSEM data in the Hammerfest Basin in the Norwegian part of the Barents Sea. In this area the water depth is around 300 m which, in combination with the high latitude, results in a high risk of MT noise contamination. The CSEM source first harmonic was 0.2 Hz, and a number of higher harmonics also had a significant source amplitude. Figure 1 shows the inline horizontal electric field at 0.4 Hz as a function of source-receiver offset along with the noise estimate. The data is clearly contaminated by MT noise on both intowing and outtowing, resulting in poor data quality on offsets exceeding 10 km. From processing of the MT data acquired while the source was not active, we obtained an estimate of the apparent resistivity $\rho_{xy} = 2.83$ Ωm and phase $\phi_{xy} = 46.9°$ at 0.4 Hz. By applying our proposed MT suppression processing, we obtained the cleaned electric field E_x^c also shown in Figure 1. It is clear that the MT noise is dramatically reduced by up to a factor of 30, giving good data quality at offsets out to 20 km.

Due to the high latitude of the survey, we found that MT was also present at higher CSEM frequencies. From our MT processing we found an apparent resistivity $\rho_{xy} = 2.97$ Ωm and phase $\phi_{xy} = 45.5°$ at 1.2 Hz. We note that the MT phase is very close to 45 degrees and that the apparent resistivity is close to

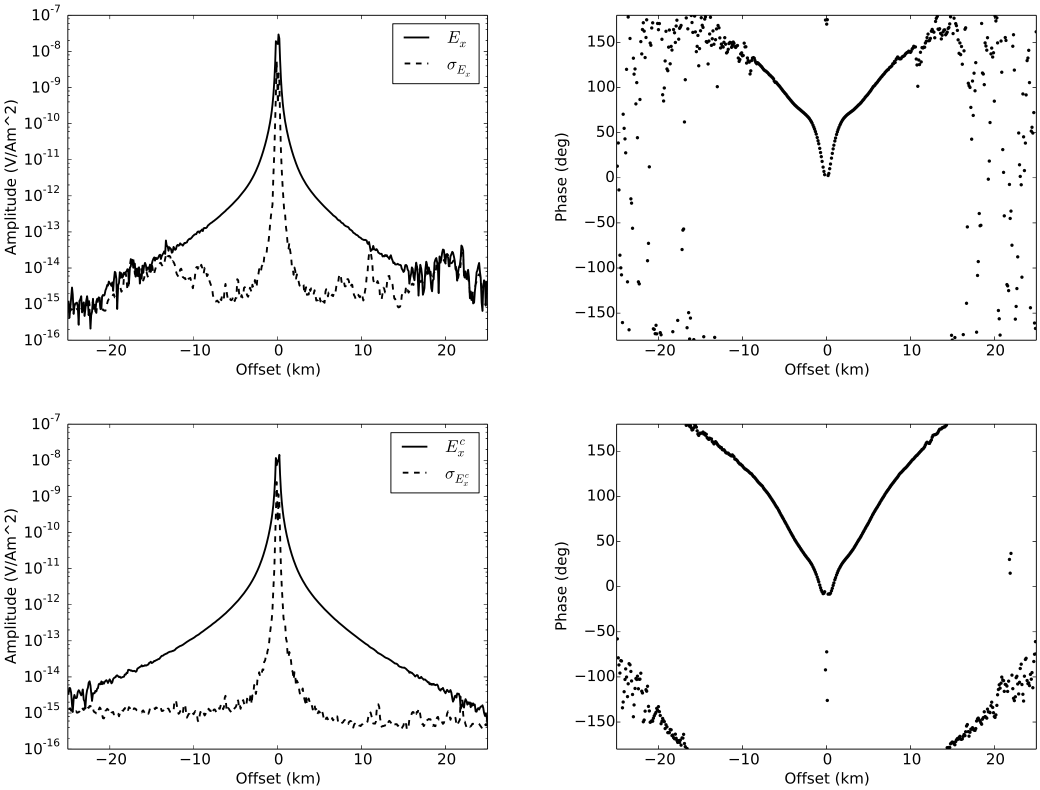

Figure 1 *Amplitude (top left) and phase (top right) for E_x at 0.4 Hz and associated noise estimate σ_{E_x} (dashed curve). Amplitude (bottom left) and phase (bottom right) for E_x^c at 0.4 Hz and associated noise estimate $\sigma_{E_x^c}$. The MT noise contaminating the long-offset data is clearly reduced.*

constant for frequencies exceeding 1 Hz, and we therefore expect that the apparent resistivity at 1.2 Hz is quite close to the resistivity of the top formation ρ_f. In this case, our MT suppression processing should therefore be able to partly remove the airwave while at the same time suppressing the MT noise. Figure 2 shows the inline electric field E_x at 1.2 Hz. Even at this relatively high frequency, the noise is increased due to MT, in particular on the outtowing (positive offset) part of the CSEM data. The MT noise at 1.2 Hz mostly consists of short bursts, which appear as spikes in the noise estimates. From the noise estimate for the cleaned electric field E_x^c we see that these spikes are reduced, although the average noise is slightly higher compared to the normal electric field. We note, however, that E_x^c at offsets shorter than approximately 15 km has a higher amplitude than E_x, and the signal to noise ratio for E_x^c is therefore similar to that for E_x. It may seem counterintuitive that E_x^c has a larger amplitude than E_x at offsets shorter than 15 km, since our processing should at least partly remove the strong airwave. This may be due to destructive interference between the upgoing and downgoing field components, and may also be due to a slight difference between the plane wave impendance of the top formation Z_f and the MT impedance at 1.2 Hz. In any case, our processing can be thought of merely as a linear combination of the horizontal electric and magnetic fields, and this linear combination may produce a signal with a larger amplitude than E_x. In the phase data of the inline electric field, we note a phase roll-over at an offset of 8 km, which is due to the influence of the airwave in the relatively shallow water. This roll-over is seen to be reduced and moved to longer offset for the cleaned field, indicating that the airwave is at least partially removed.

Conclusions

We have proposed a simple processing method to reduce MT noise affecting CSEM data by modifying the up-down decomposition method previously proposed for airwave mitigation. The method does not require deployment of reference receivers, and can be applied to any CSEM data set for which both

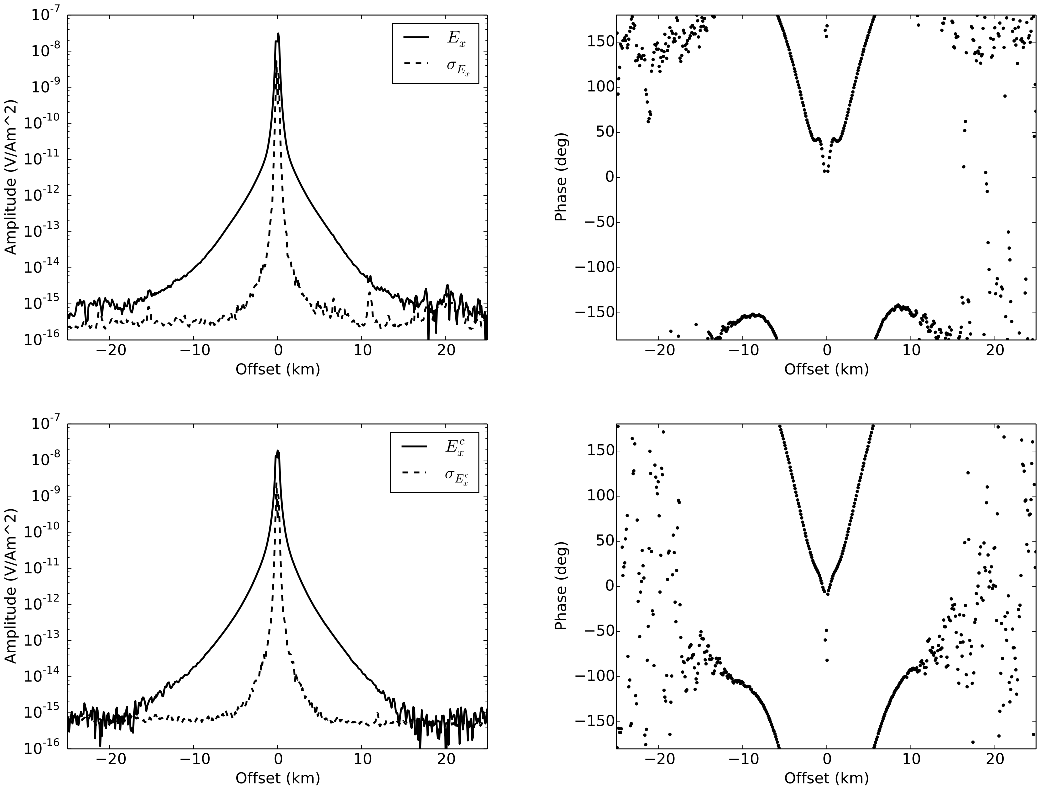

Figure 2 *Amplitude (top left) and phase (top right) for E_x at 1.2 Hz and associated noise estimate σ_{E_x} (dashed curve). Amplitude (bottom left) and phase (bottom right) for E_x^c at 1.2 Hz and associated noise estimate $\sigma_{E_x^c}$. The airwave is suppressed in addition to the MT noise.*

electric and magnetic data is acquired. Applying the method to field data from the Barents Sea resulted in a significant reduction of MT noise. At higher frequencies, we observed that the characteristic phase roll-over due to the airwave is reduced, indicating that our processing is also reducing the impact of the airwave. Since our proposed processing only involves a linear combination of the horizontal electric and magnetic fields, it can easily be integrated into any inversion scheme.

Acknowledgements

The authors wish to thank EMGS for permission to publish the results.

References

Amundsen, L., Løseth, L., Mittet, R., Ellingsrud, S. and Ursin, B. [2006] Decomposition of electromagnetic fields into upgoing and downgoing components. *Geophysics*, **71**, G211–G223.

Chen, J. and Alumbaugh, D. L. [2011] Three methods for mitigating airwaves in shallow water marine controlled-source electromagnetic data. *Geophysics*, **76**, F89–F99.

Markhus, V., Calvert, M., Uri, L. and Twarz, C. [2015] Robust and Fast Data-Driven MT processing. *77th EAGE Conference & Exhibition*, Extended Abstracts, N105 04.

Mittet, R. and Gabrielsen, P. T. [2013] Decomposition in upgoing and downgoing fields and inversion of marine CSEM data. *Geophysics*, **78**, E1–E17.

Myer, D., Constable, S. and Key, K. [2011] Broad-band waveforms and robust processing for marine CSEM surveys, *Geophysical Journal International*, **184**, 689–698.

Ryhove, S. K. R. and Maaø, F. [2008] On the removal of MT signal from SBL data. *70th EAGE Conference & Exhibition*, Extended Abstracts, H047.