Propagation of Uncertainty Associated with Towed Streamer EM System Data Acquired 2012 into a 3D-inversion model

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Summary

This paper considers data acquired with the newly developed Towed Streamer EM System over The Troll West Oil Province in October 2012. We study how the uncertainties within the data propagate into the estimated 3D resistivity model obtained from inversion. This provides us with associated statistics that is useful in the evaluation of the reliability of the resistivity model. This approach also provides us with the possibility for further improvements of the 3D inversion result and the complete workflow.

Introduction

In October 2012, several previously known oil and gas fields, in the North Sea, were surveyed with a newly developed Towed Streamer EM System. This paper discusses a first result on propagation of the uncertainties within the frequency responses into the 3D-inversion result. The inversions are based on a subset, see Figure 4, of the data acquired over Troll West Oil Province (TWOP).

The Troll West Oil Province field is located in the Norwegian sector of the northern part of the North Sea. The water depths over the area range from 310 m to 350 m. The reservoir at a burial depth of 1150 m below the mud-line has a 22 m – 26 m oil column under a small gas column. The horizontal extent is roughly 3 × 8 km and the over and under burden are relatively homogeneous and consist of shale. The vertical resistivity is about 3 Ωm and horizontal resistivity about 1.5 Ωm.

Towed Streamer EM System

The Towed Streamer EM system consisted of a surface towed source 10 m below the surface, with a source strength of 1.2 MAm. From the same vessel an 8700 m long EM streamer was towed at a depth of 100 m. In Figure 2 the corresponding configuration is illustrated. The injected electric current from the source was transmitted as an Optimized Repeated Sequences (ORS), where each sequence consisted of a 100 s long active part (source on) followed by a 20 s silent period. The resulting electric field was measured along the streamer at effectively 23 offsets ranging from 500 m to 7500 m at a towing speed of 4 kn. The silent periods are used for noise estimation and noise reduction processing. The source sequence was designed to obtain as high energy as possible in a discrete set of frequencies where the electric field response is sensitive to the resistive reservoir anomaly. See Mattsson et al. (2012) for a presentation of the deconvolution and current noise reduction methodology for the Towed Streamer EM System.

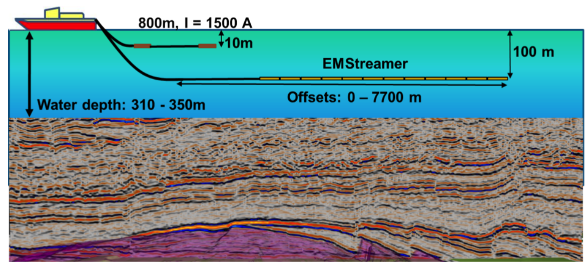

Figure 1. The Towed Streamer EM System configuration.

Total uncertainty

Estimating the uncertainty in the frequency response data as a function of frequency and offset is an important aspect of the processing and analysis of the acquired data. The signal needs to exceed the noise level to be recognized as signal with confidence. The uncertainty originates in the measurement system, navigation and the electric field noise in the measurement. In this case, the total uncertainty in the frequency response data was calculated as seen in figures 2 and 3 for data acquired at the TWOP oil & gas field in the North Sea. The maximum relative amplitude uncertainty is seen to be about 5% and below 3% for the phase. The dominant part of the uncertainty is coming from the electric field noise for the low frequencies and long offsets. The measurement and navigation uncertainties are together below 1% and influence the total uncertainty only where it is very low, i.e., in the higher frequencies and shorter offsets.

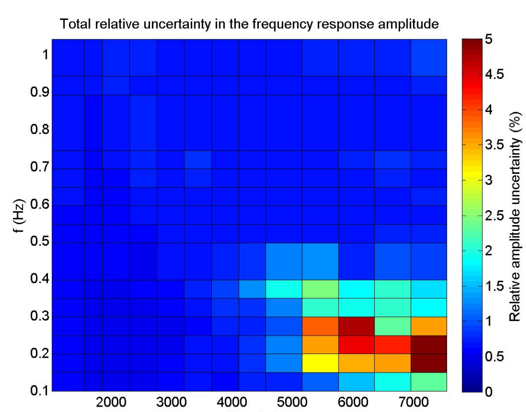

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Figure 2. The total relative uncertainty in the frequency response amplitude for one of the survey lines at the TWOP field.

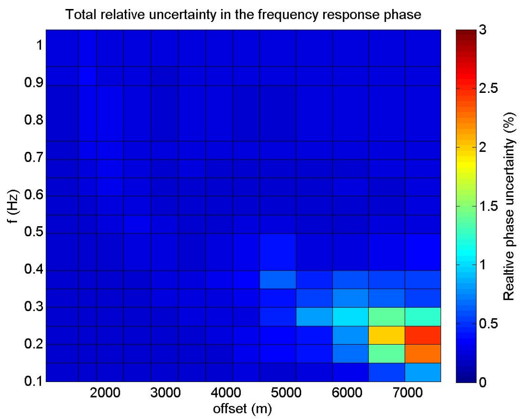

Figure 3. The total relative uncertainty in the frequency response phase for one of the survey lines at the TWOP field.

The inversion

A background 1D resistivity model for the TWOP is estimated by 1D multi-trace anisotropic inversion. The inversion is formulated as a minimization problem using a trust-region-reflective algorithm based on the interior-reflective Newton method described by Coleman and Li (1994, 1996).

The estimated 1D models are used in the 3D integral equation inversion of this data set. A so-called four-layer model has been estimated. This means that the model consists of one seawater layer where the resistivity value is taken from a CTD measurement. The water depth is inverted for as well as the vertical and horizontal resistivities in the in the first sediment layer. Inversion is also done for the remaining two sediment layers with respect to both the layer depths and the resistivity values. Hence, in total nine parameters are estimated through this 1D inversion. The selection of frequencies and offsets for the inversion is given in Table 1.

Frequencies (Hz)	0.148, 0.248, 0.347,0.496, 0.595, 0.694
Offsets (m)	1559, 1858, 2308, 2757, 3206, 3655, 4104, 4554, 5152, 5751, 6350, 6949, 7548

Table 1. Selection of data for the 1D-inversion

A straightforward approach to obtain the parameter value uncertainties is to create a sufficient number of frequency response data realization sets from random selections in a normal distribution with the total frequency response values and uncertainties as average values and standard deviations, respectively. The inversion algorithm is then run for each realization. This results in a set of resistivity values from which average and standard deviation values are calculated.

The average four-layer 1D resistivity model is estimated given a fixed seawater resistivity of 0.27 Ωm. The remaining nine parameters in the model with corresponding standard deviations are estimated from a total of 100 normally distributed resistivity profile realizations obtained by anisotropic multi trace 1D inversion. The result is shown in Table 2 where the columns from left are the layer depth, its standard deviation, the vertical resistivity, its standard deviation, the horizontal resistivity and its standard deviation, respectively. For comparison, the depth in parenthesis is the measured water depth. The initial model for all inversions is effectively an isotropic half-space of 1.0 Ωm.

d	$\sigma(d)$	ρ_v	$\sigma(\rho_v)$	ρ_h	$\sigma(\rho_h)$
308 (312)	5.3	2.30	0.13	1.55	0.09
808	4.8	3.74	010	1.32	0.05
1408	5.3	3.54	0.13	1.48	0.12

Table 2. The resulting estimated values associated with the 1D inversion.

We will now discuss the general framework for the 3D inversions. As a forward modeler, for the electromagnetic fields, we use a code based on a volume integral formulation. The inversion is formulated as the problem of locating minima of a specific cost function with respect to a physical reasonable set. The cost function, acting on a specific feasible model, is defined as the sum of one norm measuring the data misfit with respect to the measured field associated with the model and one for measuring the deviation between the background and the model. We scaled the last term to get a balance between the two terms. The cost function and the set were kept fixed in all of the inversions. The algorithm used for the minimization is Gauss-Newton based. We refer to Enstedt et al. (2013) and Skogman et al. (2013) for a more detailed discussion.

We have introduced lower and upper bounds for the feasible resistivity values in each cell used in the inversion grid. These extreme values are defined as 0.5 Ωm as the lower value and 20 Ωm as the upper value. Each time an inversion provide a result that contains a value which

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equals the upper value or the lower value it is removed since the limits represent physically acceptable levels.

Frequencies (Hz]	0.148, 0.248, 0.347
Offsets (m)	4554, 5152, 5751, 6350, 6949, 7548

Table 3. Data used for the 3D TWOP-inversion.

Data are collected over 12 lines. For the inversion we select a subset of data according to Table 3. The TWOP anomaly is mostly sensitive to the frequency 0.248 Hz at mainly longer offsets. The other frequencies were chosen to support the sensitivity. The common midpoints shown in Figure 4 are chosen as a sufficient data set with coverage over TWOP, which was the area we were interested in.

Results and Conclusions

The mean value over all of the accepted inversions can be found in Figure 5. The mean anomaly depth, from the sea surface, was estimated to 1450 m and the anomaly thickness to approximately 30 m. We have used a-priori information on the possible location of the anomaly and chosen an isolated part to do inversion on. The main reason for this choice is that we were interested in a short run time for our inversion.

The value of resistivity is slightly lower compared to other results over TWOP. This is reasonable considering the amount of inversions, over a fixed problem, and with a background where the lower sediments have higher uncertainties. On the other hand the location where the resistivity is significantly increased agree very well with previous results. The standard deviation is small over both the cells with high resistivity and the once with lower resistivity. The final two plots in Figure 5, represents a cell with high resistivity (left) and one with low resistivity (right), and show the distribution of accepted samples.

On the left-hand side, in the mean resistivity plot, we have certain areas were the mean resistivity is increased and also a higher standard deviation. The author's explanation of this is the fact that we have some rather significant bathymetry changes, which agree well with the fact that we have a rather high uncertainty in these areas. On the right-hand side in the same plot we have an even larger mean values for the resistivity. The standard deviation is also rather high. The authors believe that the most probable explanation is the impact from the gas province to the east of TWOP. This also highlights the problem of selection data that is mainly associated with the grid area.

We note that the location of the parts with higher resistivity agrees well with previous results over TWOP. It is also interesting to note that the standard deviation is much higher within the area outlined by the seismic. The uncertainties follow this area quite well. The 3D model is also reasonable from a geological point of view.

We have studied how the uncertainty in the data propagates into our model. The method used provides us with a model that in some sense take into account the uncertainty in the data. The result agrees rather well with known results in the area. The background was the assumed a-priori resistivity model. Based on this, the 3D inversions created a new model. This new model can be used for example in combination with the most probable background model to improve the result further. In addition, it is possible to incorporate more geological information and study how this impacts the result.

One of the problems when performing inversion is how to provide the inversion with an appropriate amount of information. This method incorporates different inversion results and will be more objective than just relying on one result. In total the inversions required approximately 12 h on our computational cluster.

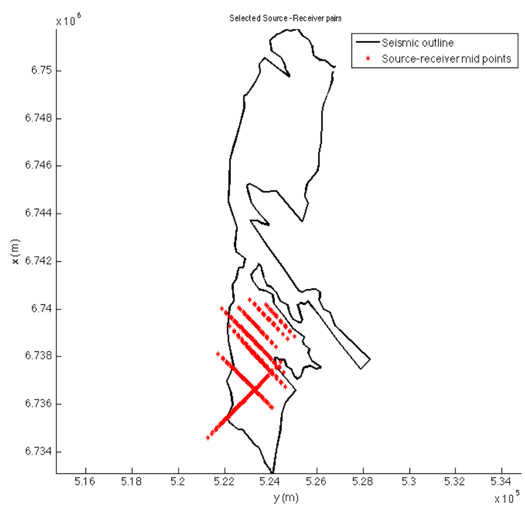

Figure 4. Selected source-receiver pairs.

Acknowledgement

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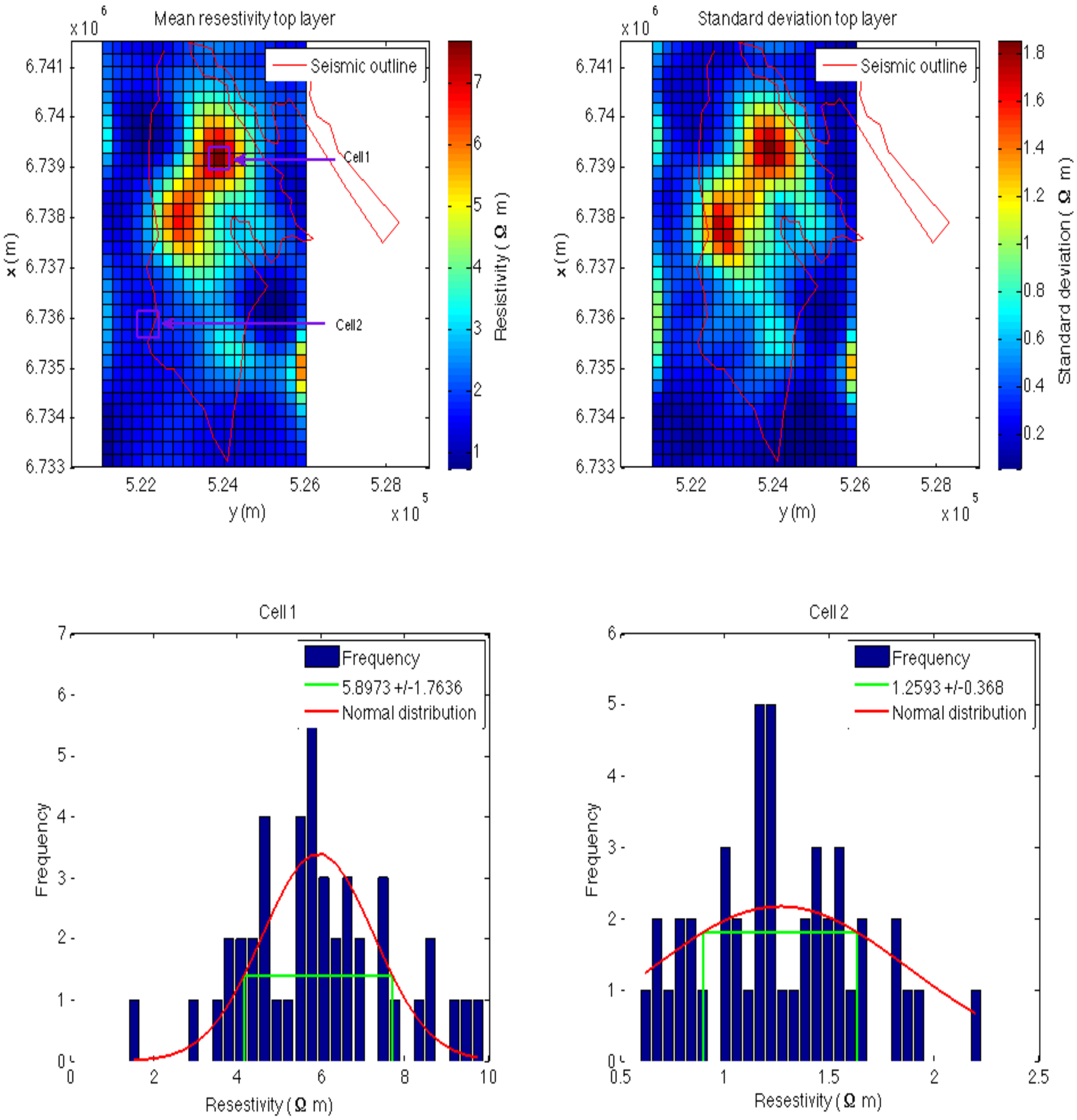

Figure 5. Statistics associated inversions.

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EDITED REFERENCES

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