Effect of receiver density and azimuth data in grid modelling of Seabed Logging

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Summary

Fast Finite-Difference Time Domain Modelling (FDTM) of seabed logging (SBL) is used to study the effect of the spacing between receivers positioned in a regular grid on the seabed. A relatively simple model is used as an example to demonstrate the effect of receiver grid spacing on detectability of high resistive subsurface anomalies. We also show that the results can be refined by extracting azimuth data for large source-receivers distances.

Introduction

SBL exploration data, introduced by Eidesmo et al. (2002) and Ellingsrud et al. (2002), are usually collected along lines of receivers typically positioned 1 km apart. The electromagnetic (EM) source is towed along the line and subsurface resistive anomalies can be detected by studying the EM response of each receiver relative to a reference. The survey lines are carefully chosen based on geological data previously acquired in the area of interest. However, in case little is known about an area, one could study an area of interest by positioning the receivers in a grid covering a larger area. In order to keep the cost of such surveys low, the receivers must be positioned further apart to save deployment and acquisition time. Another time saving factor is to tow the source only along one direction of the receiver grid, in parallel lines.

Method

The synthetic data are prepared using the in-house FDTM software prepared by Maaø (2007). The 3 main layers in the conductivity model are: air, sea water and subsurface. The seabed has a realistic bathymetry profile. The sea water depth varies from 1,400-2,000 meters and has constant conductivity. The deep water allows us to avoid correction of the effect of the direct air-wave. The subsurface is a 1 Ωm halfspace that has three 50 Ωm (high resistive) anomalies at depths of 500, 1,000 and 1,200 meters below the seabed. The oval shaped anomalies are 50m thick. See Figure 1.

The electromagnetic (EM) response is modeled for receivers positioned in a 1x1km grid. The source is positioned in a 20x20km grid around each receiver at two main orientations: north and east. Data along arbitrary lines and receiver positions are then extracted using linear combination of the source components and interpolation. This allows fast extraction of data without rerunning the entire numerical model. The data coverage of the synthetic model is much larger than in real surveys, but we extract only data similar to what one can expect from a real survey. The frequencies chosen for this study is 0.3 and 0.7 Hz.

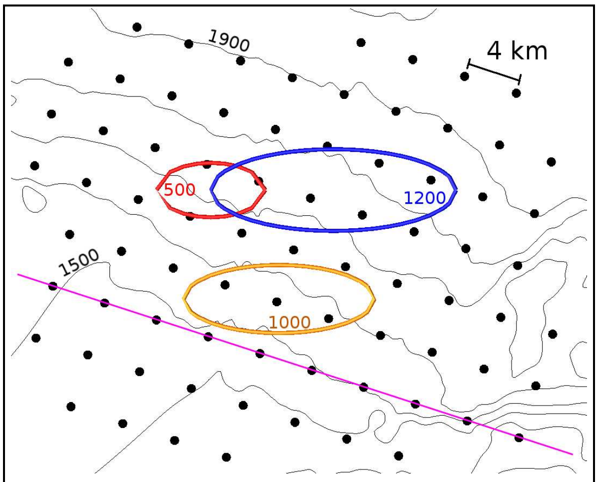

Figure 1: The contour lines show the bathymetry, the black dots are the receiver positions in the 4x4 km grid and the coloured outlines show the high resistive anomalies in the subsurface with depth below seabed in meters indicated by the coloured numbers. The pink line shows the direction of the parallel tow lines, which are roughly acquired at constant depth.

A reference receiver is chosen in a representative area (in this case at medium depth and far from the known anomalies) and the EM data for each receiver is normalized relative to the reference. From these data it is common to extract the magnitude and phase and plot as a function of offset: Normalised Magnitude versus Offset (NMVO) and Phase Difference versus Offset (PDVO) plots are then produced. When the normalized magnitude of the electric and magnetic fields are larger than unity for a given offset, this indicates the presence of a high resistive anomaly in the subsurface somewhere between the receiver and the source. Similarly, a negative phase response indicates higher velocities and thus higher resistivity. In this article we only present the NMVO plots.

The common midpoint between the source and receiver is often used to indicate the location of the part of the subsurface mainly responsible for the response at a given source-receiver offset. This simplified representation works fairly well for synthetic data with a homogeneous half space as background. In a grid of receivers it then makes sense to display the data as a map for a given offset and frequency. This gives a grid of data points as shown in Figure 2. The regularity of the grid will depend on the chosen offset and receiver spacing.

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Receiver density

We will first look at the effect of the grid spacing. We expect to see more details with a denser grid of receivers and we start with the 1x1km (see Figure 2). There is a very good correlation between the NMVO plotted at the common midpoint and the outlines of the high resistive anomalies.
In the 2x2km grid (see Figure 3), the outline of the smaller shallow anomaly is still visible, but as in the 1x1 km grid, it is not clearly distinguishable from the larger and deeper one. In order to separate the two anomalies, one has to study the response at several offsets and frequencies.

Effect of the frequency and offset

Figure 4 shows the NMVO for an offset of 7 km. The shallow anomaly is nearly gone, only the larger and deeper ones are visible. Figure 5 shows that the smaller shallow anomaly is visible at short offsets and higher frequencies, in this case 0.7 Hz and 3 km offset.

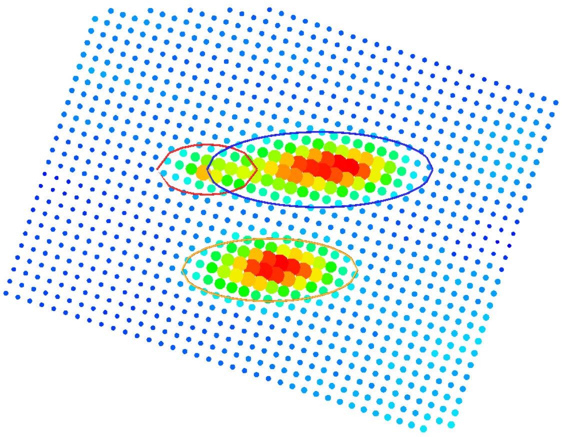

Figure 2: Inline NMVO plotted at common midpoints for an offset of 5 km at a frequency of 0.3Hz. Receiver spacing is 1 km. The small blue dots indicate values equal to 1 and the large red dots indicate values equal to 3.

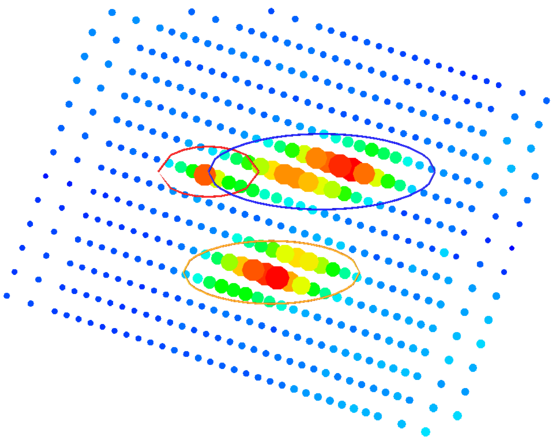

Figure 3: Inline NMVO plotted at common midpoints for an offset of 5 km at a frequency of 0.3Hz. Receiver spacing is 2 km.

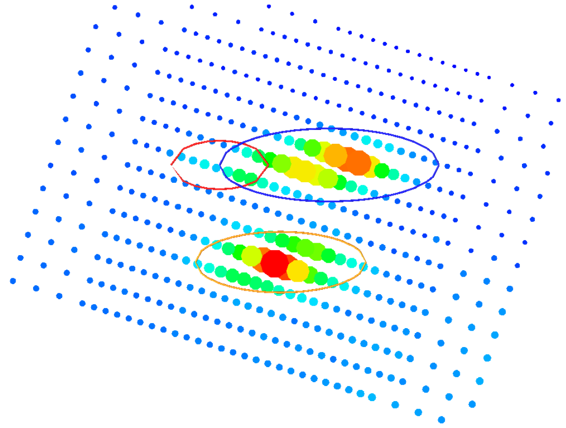

Figure 4: Inline NMVO plotted at common midpoints for an offset of 7 km at a frequency of 0.3Hz. Receiver spacing is 2 km.

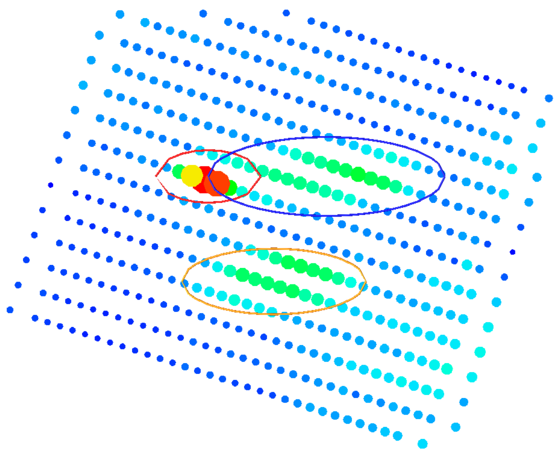

Figure 5: Inline NMVO plotted at common midpoints for an offset of 3 km at a frequency of 0.7 Hz. Receiver spacing is 2 km.

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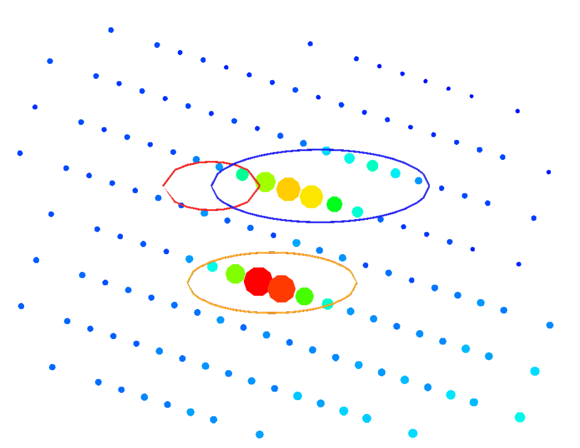

Figure 6: NMVO plotted at common midpoints for an offset of 6 km at a frequency of 0.3Hz. The receivers are 4 km apart.

The 4x4 km grid (see Figure 6) still shows the two larger anomalies clearly, but the smaller one is entirely gone. To produce a color map we interpolate using a surface B-spline algorithm. This produces a visual effect of continuity in the data as shown in Figure 7. The fit is good, but the shape is influenced by the tow line direction.

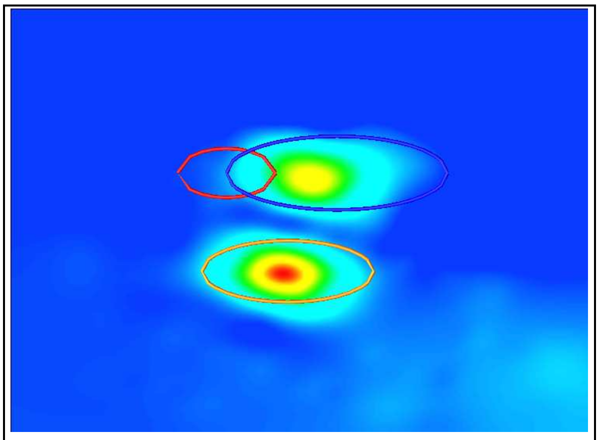

Figure 7: Interpolated colour map of data shown in Figure 6 above.

Azimuth data

We will now look at the azimuth data in the 4x4km grid. We assume in this study that all receivers are collecting data at all times. This means that one can extract azimuth data from a receiver when the source is towed along neighboring lines. The decomposition of the EM response from an azimuth source assumes a plane layer model and it has been shown by Maaø (EAGE 2007) that this assumption is only valid when the angle between main axis of the dipole source and the azimuth receiver is larger than 45 degrees. In this study we therefore mute the data for angles larger than 45 degrees. A consequence is that azimuth data is only available at offsets larger than $d \cdot \sqrt{2}$, where d is the line spacing. This results in a blind zone as shown in Figure 8. The azimuth response will often attenuate to the noise level faster than inline data. The useful data window is therefore restricted for azimuth source-receiver configurations.

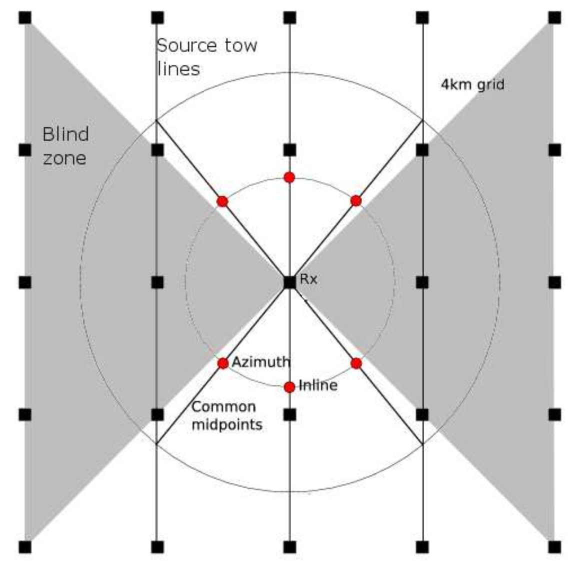

Figure 8: Scanning survey geometry: sources are towed along the lines, over the receivers (squares). For a given source to receiver offset (about 6km in this example), the normalised magnitude of the inline and azimuth source positions are plotted at the common midpoint (red dots). The figure also shows the blind zone of the azimuth data in the grey areas.

Figure 9 shows the NMVO at common midpoints including the azimuth data. Plotted at the common midpoints, the azimuth data traces lines in between the inline data. The corresponding colour map is shown in Figure 10. The smaller shallow anomaly is still not visible. This is due to the combination of the chosen survey line geometry, the small size and the fact that one cannot extract azimuth data for large angles. On the other hand, the azimuth data improves the definition of the outlines of the larger anomalies. The B-spline surface interpolation gives an impression of a nice fit to the outlines in both cases, but the azimuth data gives much better confidence to the data as there are nearly twice as many data points used for mapping.

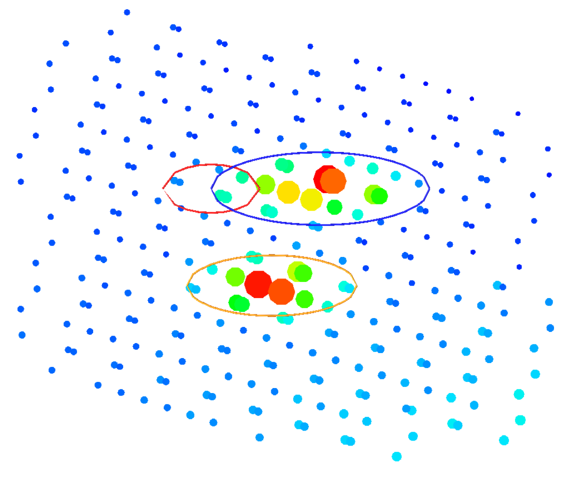

Figure 9: NMVO plotted at common midpoints for an offset of 6 km at a frequency of 0.3Hz for 4x4 km receiver spacing. Azimuth data are included.

As seen in Figure 5, the shallow target is only visible at short offsets and higher frequency. This also applies to the azimuth data which do not show any response for the small and shallow anomaly when the grid spacing is 4 km. As explained above, azimuth data is only available for offsets larger than 5.6 km, for which the response from the shallow target is weak. For grid spacing larger than 5 km, it will be hard to get azimuth data as the offsets for which azimuth data can be extracted is 7 km and above. Smaller grid spacing or staggered layout can improve the quality of the data acquisition

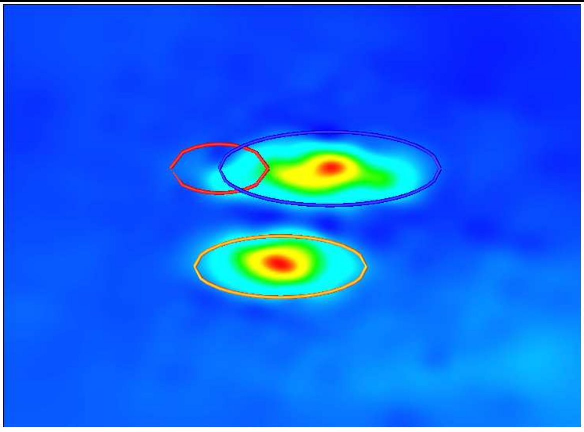

Figure 10: Interpolated colour map of data shown in Figure 9 above.

Conclusions

We have seen that the grid density of a scanning survey strongly influences the ability to detect high resistive bodies in the subsurface. Plotting the NMVO at the common midpoints of the source and receiver is shown to outline the anomalies accurately. Anomalies are, as expected, outlined in more detail with smaller grid spacing. For scarce grids, azimuth data can be extracted to improve data confidence, but only at larger offsets. For every kilometer increase in line spacing, 1.4 km worth of azimuth data is lost. Smaller targets can remain undetected if source and receivers are positioned such that neither inline nor azimuth response is detectable. Azimuth data are therefore in particular valuable at lower frequencies and relatively deep and large targets. A compromise between survey cost, need for azimuth data and data quality must therefore be found when the grid density of a scanning survey is to be decided.

It is also shown that a source with multiple frequencies and variable source-receiver offsets are needed to separate the responses from targets located at different depths.