3D Effects on 2D Resistivity Imaging – Modelling and Field Surveying Results

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SUMMARY

Today resistivity surveying plays an important role in many large-scale area investigations. The existence of 2D effects on 1D resistivity modelling is a well known problem; however, former studies show that 3D effects in 2D surveying are less evident. The results presented here show that, nevertheless, there is an advantage in performing 3D inversion. A comparison between 2D inversion and 3D inversion has been made with analysis of data from two different synthetic models and three field datasets. From the synthetic study it is clear that 3D inversion give higher contrast, less inversion artefacts and better model recognition than 2D inversion. From the field studies it is also evident that 3D inversion gives models with higher contrast. With only limited ground truth data it is not always possible to determine which model is closest to the true one; however, where ground truth data is available it is clear that the 3D inversion gives a better result. In addition we show that the choice of array configuration have a significant influence on the result, with gradient array generally giving better results than the other options.

Introduction

Today resistivity surveying plays an important role in many large-scale area investigations. DC resistivity imaging is applied broadly in the fields of engineering and environmental surveying. 2D resistivity imaging is in many cases sufficient, even to recover 3D structures reasonably well. The existence of 2D effects on 1D resistivity modelling is a well known problem (e.g. Dahlin and Loke, 1998); however, former studies (Dahlin and Loke, 1997) show that 3D effects in 2D surveying are less evident. The results presented here show that, nevertheless, there is an advantage in performing 3D inversion compared to 2D inversion.

Previously, one of the most important short-comings for 3D inversion is that it is time-consuming and computer exhaustive. With the on-going development of computers and software this becomes gradually less important. Another major limitation is that 3D inversion requires a dense data coverage to be meaningful, which increases the field data acquisition cost; however, multi channel data acquisition systems and efficient field strategies can reduce this cost significantly.

For the results presented here numerical simulation has been made for several resistivity models. Results from one of these models, that are representative for the entire study, are presented here. Also, three field examples that show the behaviour and possible advantage of 3D inversion are presented.

Method

Resistivity surveying was simulated and performed as a set of parallel 2D surveys, i.e. measurements are only made in one direction over the target area. The distance between the lines for the numerical simulation study was equal to the in-line electrode distance, but in the field tests twice that of the in-line electrode distance. Compared with 3D surveys where measurements are made in more than one direction (e.g. Loke and Barker 1996; Dahlin et al., 2002) this approach is fast and logistically simple.

In this study we tested six different array configurations. The pole-pole (PP), dipole-dipole (DD), pole-dipole (PD), Wenner (WN) and Schlumberger (SC) configurations are well known and described in any standard geophysical textbook (e.g. Sharma, 1997). The application of the multiple gradient (GD) array for multi-channel measurement systems was described by Dahlin and Zhou (2004; 2006). They show that this array has a high signal to noise ratio and at the same time a good distribution of the sensitivity.

The numerical simulations were carried out in order to better understand the differences between 2D and 3D inversion. One model is presented here together with the subsequent inversion results. Synthetic data for all six different array configurations that were described earlier have been inverted using 2D inversion with L_1- and L_2-norm and 3D inversion with L_1-norm. The 3D forward modelling was done using the 3D finite-difference modelling software, Res3dmod (Loke, 2005). From the forward modelling result a dataset of 21 profiles was extracted. In the synthetic examples the profile distance is equal to the electrode distance. For 2D inversion the 21 separate profiles were inverted separately. They are, however, presented as depth slices in the same way as the 3D models. For 3D inversion the 21 datasets were combined to one dataset. Care was taken to assure that the same inversion parameters were used for the 3D inversion as for the 2D inversion (e.g. layer thicknesses, damping factors etc.).

In the field examples, resistivity data was collected as CVES data with different versions of the ABEM Lund Imaging System. The data acquisition was done as multi-channel measurements which makes it possible to collect datasets with very high data density using e.g. multiple gradient or dipole-dipole measurement array configurations in a time and cost efficient manner.

Numerical Model Study

A number of synthetic 3D resistivity models were created to evaluate the difference between 2D inversion and 3D inversion. One of these models is shown as example in this paper

(Figure 1). The synthetic models are constructed in 6 layer slices, with a 41 by 21 electrode grid as shown in Figure 1. The layer depths are 0.3, 0.7, 1.5, 2.4, 3.5 and 4.7 m respectively. As mentioned in the chapter on forward modelling, 21 separate synthetic datasets, each with 41 electrodes, are created.

The presented model (Figure 1) has a high-resistive T-shape anomaly (500 Ωm) in the upper two layers (4 unit electrode spacing grid width) surrounded by a low-resistive medium (10 Ωm) The deeper layers are homogeneous with a resistivity of 100 Ωm. The inversion results for data from the T-shaped model are presented. The 2D inversion results in large disturbances in the resistivity of the lower parts of the model, especially in the L_2-norm inversion result. These effects are almost completely absent in the 3D inversion model, where only weak shadow effects from the structure in the top layer is visible.

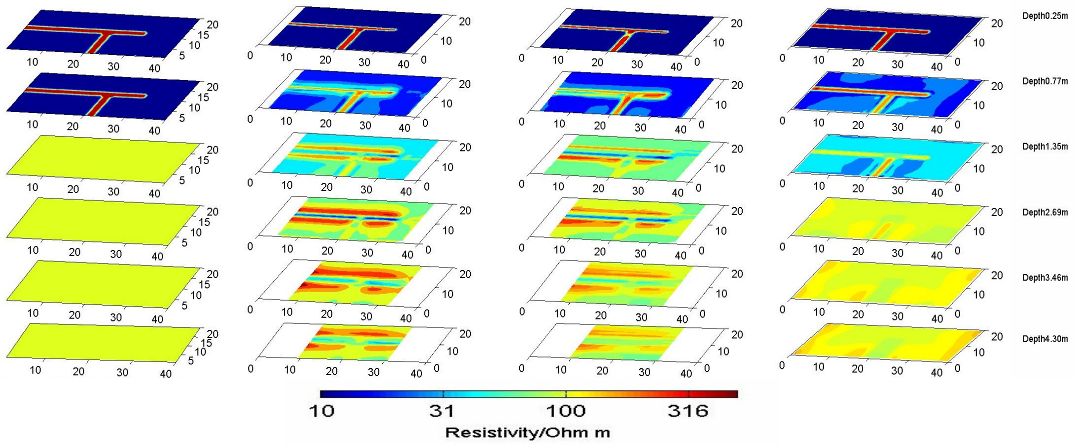

Figure 1. (a) True model, (b) 2D inversion (L_2-norm), (c) 2D inversion (L_1-norm), (d) 3D inversion (L_1-norm)

Field Example: Mörrum, Sweden

The data in this case study was collected for bedrock detection prior to design of a sludge deposit dam for a paper pulp industry in southern Sweden. The geological environment is a crystalline gneissic bedrock valley where the bedrock is overlain by Quaternary deposits. The Quaternary deposits consist of till overlain by silt and clay. At one side of the area (between x=60 to 100 m and y=0 to 30 m, (Figure 2) an outcrop of bedrock is present in the middle of the valley. On both sides of the area, in the x-direction, the valley sides are present in the topography and bedrock is outcropping, the soil thickness should therefore decrease in these directions. The valley continues towards increasing y-coordinate.

The dataset consist of 7 parallel profiles of 160 m length with 10 m distance and 5 m in-line electrode separation. Multiple gradient array was used and Figure 2 shows the 2D and 3D inversion results. The height of the outcrop is maximum 2 m in an otherwise fairly flat area.

One feature with very high resistivities (>10000 Ωm) is evident in the upper and middle part of the models in one of the sides. Except for this feature the resistivity down to about 13 m is low (<100 Ωm). In the lower part of the model the resistivities are higher (up to above 2000 Ωm), although not as high as for the outcrop. There are very obvious differences between the 2D and 3D inversion results, most notably the low resistive zones that are present at lower depths around the high resistive outcrop. These are not present in the 3D inversion model, and it can hence be concluded that these are artefacts due to the use of a 2D approach in a 3D environment. There is also a regular pattern in the surface layer of the 2D model that must be regarded as an artefact from the inversion.

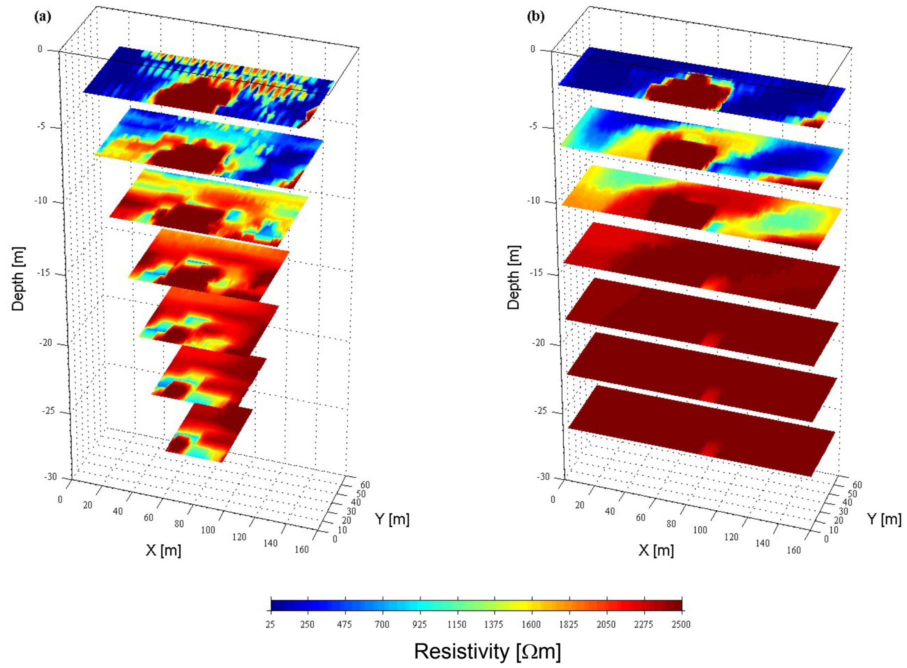

Figure 2. Inverted models from Mörrum test site; (a) 2D inversion (L_1-norm), (b) 3D inversion (L_1-norm)

The geological interpretation is that the high-resistive feature at surface corresponds to the rock outcrop, and the reason for the very high resistivities is that the outcrop contains hardly any water. The low resistivity in the shallow layer surrounding the outcrop is due to fine grained sediments. The high resistivites in the bottom of the model correspond to crystalline bedrock, although the resistivities are not quite as high as in the outcrop which may be due to water saturated fractures. The low resistive artefacts at depth around the outcrop in the 2D inversion model would be very difficult to explain as being related to geological features.

Discussion and Conclusions

A comparison between 2D inversion and 3D inversion has been made with analysis of data from two different synthetic models and three field datasets. We show that in environments with evident 3D variation in resistivity, the approach consisting of 3D inversion of combined 2D surveys can give increased detail and accuracy of the resulting resistivity model compared to that given by 2D inversion.

The field data acquisition strategy of combining a number of perpendicular 2D sections can be regarded as a roll-along procedure for 3D surveying. We expect this approach to become a standard procedure for routine application, since it is in practice hardly an option to cover a survey area with enough electrodes to give meaningful area cover and resolution. On the other hand, a standard data acquisition system for 2D resistivity surveying can be used to measure very large grids using the roll-along procedure. It is efficient from a field logistical point of view, as the next the line can be established while measurements are in progress on one line. In cases with severely complex environments and high demands on resolution the roll-along procedure could be repeated in the perpendicular direction, if considered necessary after preliminary inversion of the data from the parallel lines.

Even though 3D effects on 2D data is much smaller than 2D effects on 1D data there is a benefit of performing 3D inverse modelling. In addition we show that the choice of array configuration has a significant influence on the result, with gradient array generally giving better results than the other options. For the results presented here the L_1-norm solution has been used for most inversion. It has been evident throughout this study, and from earlier work, that it is generally producing better results than L_2-norm solution. It should be mentioned that the 3D inversion requires an extended model containing more cells per data than what was the case for the 2D models here. This might result in that 2D inversion gives better result in some cases, e.g. where a 2D approximation of the environment can be justified and the dataset contains a relatively small amount of data.

From the synthetic study it is clear that 3D inversion give higher contrast, less inversion artefacts and better model recognition than 2D inversion. Even though all arrays give reasonable results in some circumstances the multiple gradient array always is among the ones that produce the best results. Another observation made is that the dipole-dipole arrays gave much too low resistivity in the lower parts of the inverted models based on synthetic data, which is not seen for the other electrode arrays, and similar behaviour is seen for the models based on some of the field data (not presented in this paper).

From the field studies it is also evident that 3D inversion gives models with higher contrast. With only limited ground truth data it is not always possible to determine which model is closest to the true one; however, where ground truth data is available it is clear that the 3D inversion gives a better result. In the Mörrum site the 3D inversion give significant improvement of the model.

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