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Three Step Depth Focussed Inversion as a Tool to Resolve Small Resistivity Contrasts by ERT

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SUMMARY

In more recent times Electrical Resistivity Tomography (ERT) has become a valuable tool for many environmental research themes. Within these topics the resistivity contrasts of the different layers and zones are of importance, i.e. sand, clay, water salinity and preferential infiltration pathways are quite small. Inclusions with such small resistivity contrasts to the surrounding are difficult to resolve by ERT inversion and typically the following problems occur: 1.) the true resistivity contrasts are underestimated 2.) the size of the anomalous zone is overestimated 4.) fake anomalies arise beside and between the true anomalous zones. 4.) surface heterogeneities infer fake anomalies into the subsurface.

A two step inversion method is suggested to overcome these problems at least partly. Firstly the near surface heterogeneities are reconstructed by inversion. A forward model comprising the near surface structures only is extracted and used to remove their effect from the data by the application of a reference inversion method. Forward modelling is used to estimate the true sizes and the true resistivity contrasts of the inclusions. These methods are applied to array electrical resistivity tomography measurements at a sandy site with distinct heterogeneities at a depth of 30 - 60cm and show improved resolution capabilities.
The problem

The pseudo-section of ERT measurements on a heterogeneous surface with slight resistivity contrasts at depth inevitably appears quite messy. A direct inversion of such a data set will hardly resolve the subsurface structures properly because the subsurface resistivity contrasts are low (often ratios between 0.2 – 8), the structures small (some 10’s cm) and the surface heterogeneities are much higher in amplitude than the structures to be resolved.

Surface heterogeneities frequently occur due to inter alia changes in vegetation, clay content, etc. resulting in high resistivity contrasts at a dry surface owing to the fact that at low water content the resistivity increases rapidly with decreasing water content (Sen (1988), Kennedy (2007), Pozdnyakova (1999)).

The model

The two step inversion method is demonstrated for a 2D example but later used for 3D measurements accordingly. The model comprises a heterogeneous surface layer with a thickness of 30 cm. In the subsurface two inclusions are embedded (Figure 1). By forward calculation theoretical apparent resistivity “measurements” are created and noise is added to the data (Figure 2). A dipole-dipole configuration with increasing dipole length at depth is used because it combines the advantages of good resolution of near surface structures with the possibility to fully exploit the multi-channel measurement technique as implemented in modern resistivity equipment thus enabling fast array measurements. The theoretical calculations and inversions are executed with DC2DinvRes by Günther (2004).

Figure 1: Model with heterogeneous surface and two inclusions at depth (100 Ωm surrounding, 300 Ωm inclusions, RMS of surface layer 107 Ωm (Maximum: 690 Ωm, Minimum 120 Ωm)).
The first step

The first step of the iterative inversion procedure comprises the “normal” inversion of the data. It is recommended to use for this step a small regularisation parameter and no smoothness constraint, in order to better reconstruct the surface heterogeneities. As shown in Figure 3 the inversion programme reconstructs the surface heterogeneities quite sufficiently but the subsurface structures are a “weak shadow”.

Even beneath a homogeneous surface the inversion will underestimate the true resistivity contrasts of subsurface inclusions and overestimate the sizes, but with increasing surface heterogeneities the subsurface structures get increasingly obscured (Figure 3).

Specifically the lower edges of the inclusions can hardly be resolved. In addition, unfortunately, negative anomalies are calculated by the inversion procedure. These are typically in between and beside the positive anomalies (vice versa if the resistivities of the inclusions are lower than the surrounding).

The second and third step (“pseudo time lapse inversion”)

In the second step the reconstructed model (Figure 3) is now taken and the lower layers are associated a mean value. With this model (upper layers as reconstructed by inversion, lower layers constant) a forward calculation is performed (second step). Then the ratio is calculated between the original data and this forward model and this data set is inverted (third step). This is principally the same procedure as used in time lapse interpretation approaches, when only the ratio between the second and the first time step is looked upon (either with reference technique or as a ratio inversion). Therefore this approach is tentatively called “pseudo time lapse inversion”.

Figure 2: Pseudo-section of the model (Figure 1), dipole-dipole configuration, electrode distances 20cm.

Figure 3: Inversion results for the data set in Figure 2 (model Figure 1).
By using this method the resolution of small resistivity contrasts in the subsurface is improved (Figure 4). However, the problem of overestimated sizes and underestimated resistivity contrasts prevails. These deviations can only be corrected for by subsequent modelling studies.

**Modelling studies to estimate size and resistivity contrast of the inclusions**

The smaller and deeper the inclusions are the more they get overestimated in size. The extent of the “overestimation” depends critically on the applied inversion parameters. For the parameter settings used in this study this overestimation was quantitatively calculated by systematic forward modelling and inversion of different inclusion parameters. In principal this can be done for all inversion algorithms and inversion parameter settings.

The smaller and deeper the inclusions are the more the resistivity contrasts get underestimated. For a given size and location of an inclusion the ratio between real and reconstructed (by inversion) resistivity can be analysed. A function can be constructed which enables the calculation of the “true” resistivity contrast from the inversion result for every single inclusion.

Therefore, consecutively, firstly improved sizes and secondly improved resistivity contrasts for the inclusions in the subsurface can be constructed.

Still, the problem of the “fake” anomalies prevails. If the inclusions are relatively close to the surface (still below the heterogeneous surface layers) in most cases (exceptions are very low (<2/ >0.5) or very high (>8 / <0.1) resistivity contrasts) the amplitudes of the fake anomalies are smaller than of the real anomalies. This criterion increasingly fails if looked into the deeper layers. However, as a rule of thump negative (positive) anomalies neighbouring positive (negative) anomalies should be looked upon with suspicion.

**The test**

The two step inversion approach is tested for an ERT array measurement at a sandy site near Hannover. At this site an infiltration experiment was conducted and the site was subsequently excavated. The TDR measurements at different depths levels revealed distinct contrasts in water content. The surface layers were heterogeneous in terms of resistivity and the structures at a depth of 30 – 60 cm were small, some 30cm in diameter. The two step inversion procedure is applied for the first initial state measurement before the infiltration. Classical inversion approaches could only resolve the subsurface structures insufficiently. The
developed two step inversion method showed improved resolution capabilities, however, there are still open questions.

**References**


