A new technique of model appraisal in 2D MT inversion

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Introduction

In usual MT inversions, resistivity models are obtained by minimising a functional which includes a part that penalises data misfit and a regularisation function, which takes into account some sort of model norm. Thus, the resulting "best" model from the point of view of data fitting and model norm are usually smoothed images of the geoelectrical structures which may have little geological significance. To be able to interpret the geoelectrical models in geological terms, usually sensitivity studies are performed in order to establish some limits for the information given by the inversion. Most sensitivity studies are resistivity based, meaning that while we can obtain information on the actual value of the resistivity of the resistive and conductive bodies, we have no other clues about its geometry. This is not a problem in case of conductive bodies due to the presence of fluids or partial melting, in which we are interested in the actual value of the resistivity to interpret it as porosity of rocks or amount of partial melting. But in other cases, such as with conductors associated with mineralisations, we are more interested in the location and extension of such bodies rather than in its exact resitivity value. The only way to test which features are really required by the data and to which extent is manually modifying the model and performing a forward modelling.

In this work we present a method that allows changing the geometry of the resistive and conductive bodies while keeping the fit to data. Random models are generated by "moving" the boundaries of the resistivity features and then the changes introduced are projected to the nullspace of the original model so, in the lineal approximation, the fit is kept. This method avoids the manual edition of the models and is much faster than the forward modelling, as the projector has to be calculated only once and can be used for the different models instead of calculating the response for each one.

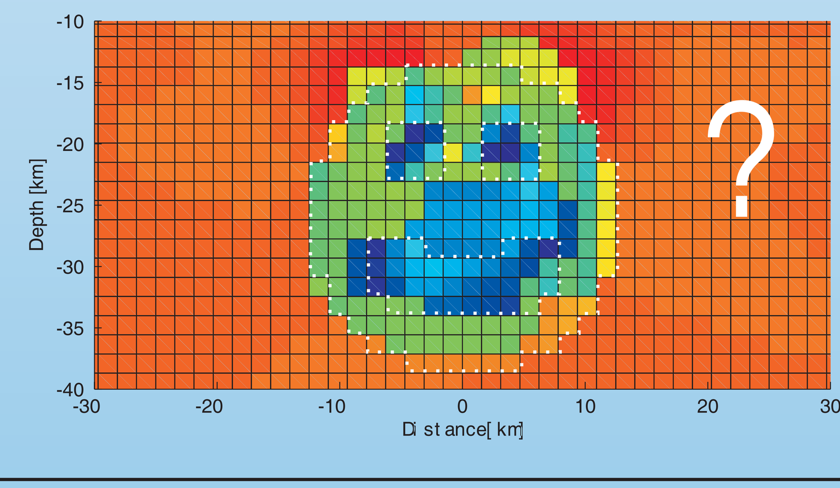
Overview

Data → Sensitivity matrix

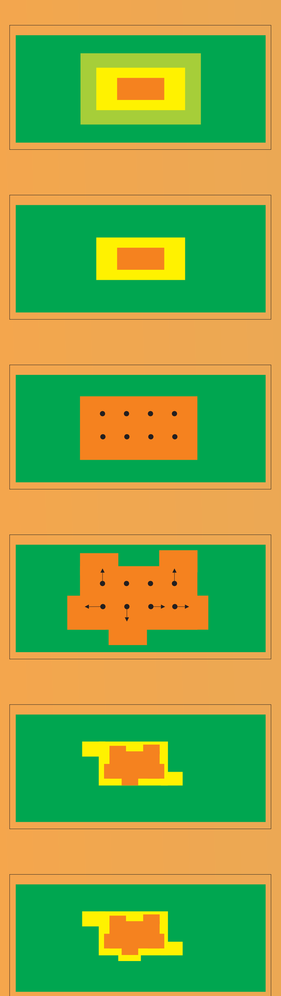
Initial model m_0 → Sensitivity matrix; Initial model m_0 → Modified model m → Model change $\delta m = m - m_0$

Sensitivity matrix → Nullspace projector

Model change + Nullspace projector → Projected model change δm_{null} → Conservative model $m_c = m_0 + \delta m_{null}$



Geometry Change Algorithm



Model; Resistivity set (ex: 1 10 100; Background)

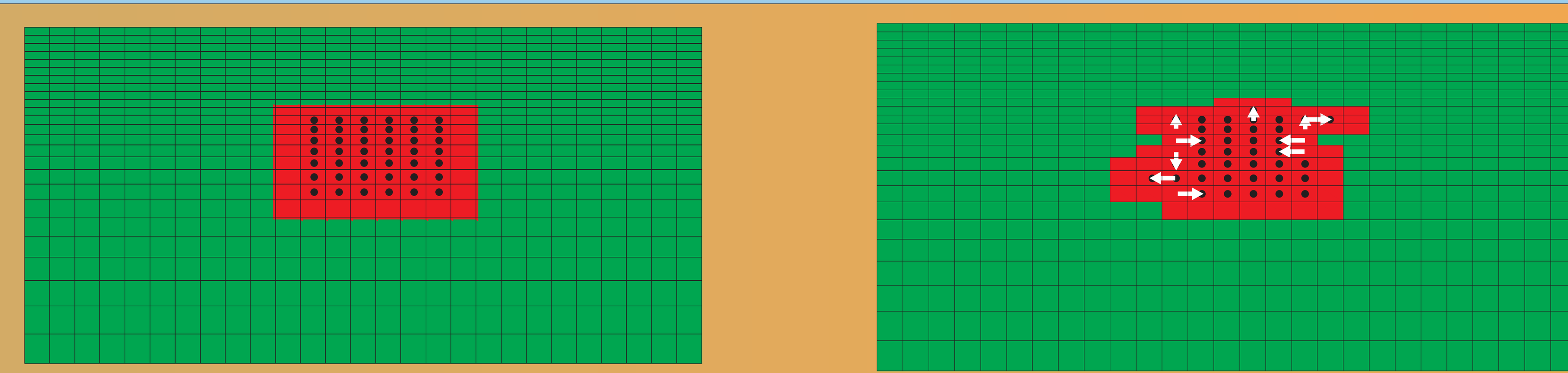
→ Segmentation

→ Identify "generating cells"

→ Move "generating cells" (Repeat process)

→ Check inconsistencies (Iteration on resistivities)

→ Final Model



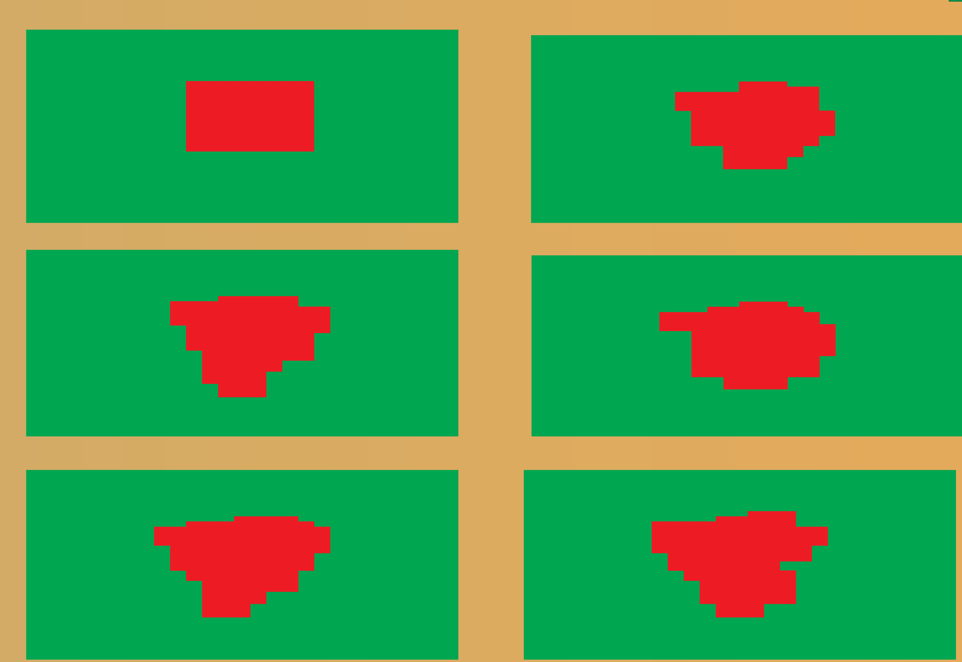


Figure 1

The upper panel shows the "generating cells" before and after the first iteration (black dots) and the displacement performed by the algorithm (white arrows). The cells without arrow either didn't move or moved to a position already occupied by a generator.

The left panel shows the effect of five iterations of the algorithm.

In all these models only two resistivities are used: a background of 100 Ωm and an anomaly of 1 Ωm.

Due to the random nature of the moving algorithm, there is a natural tendency to increase the size of the anomalies at each iteration. In order to avoid this, size control can be enabled. This feature checks the size of the anomaly (in number of cells) at each iteration. If it has increased more than a pre-set value, the iteration is rejected and the movement process is repeated.

Nullspace projection Algorithm

$A = \dfrac{\partial F}{\partial m}$ — Sensitivity matrix

→ $A^T A$

$A = U \Lambda V^T$ — SVD decomposition

$V = (V_p \mid V_{null})$ — Construct nullspace

$\delta m_{null} = V_{null} \cdot V_{null}^T \delta m$ — Construct projector; Moved Model

$m_c = m_0 + \delta m_{null}$ — Conservative Model

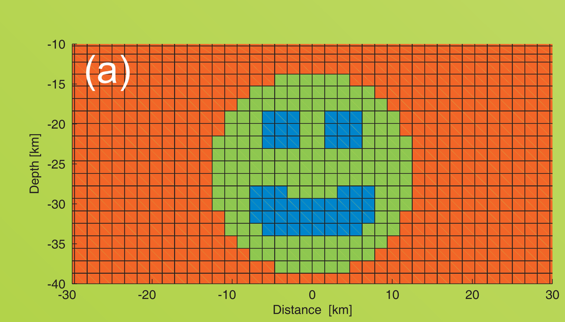
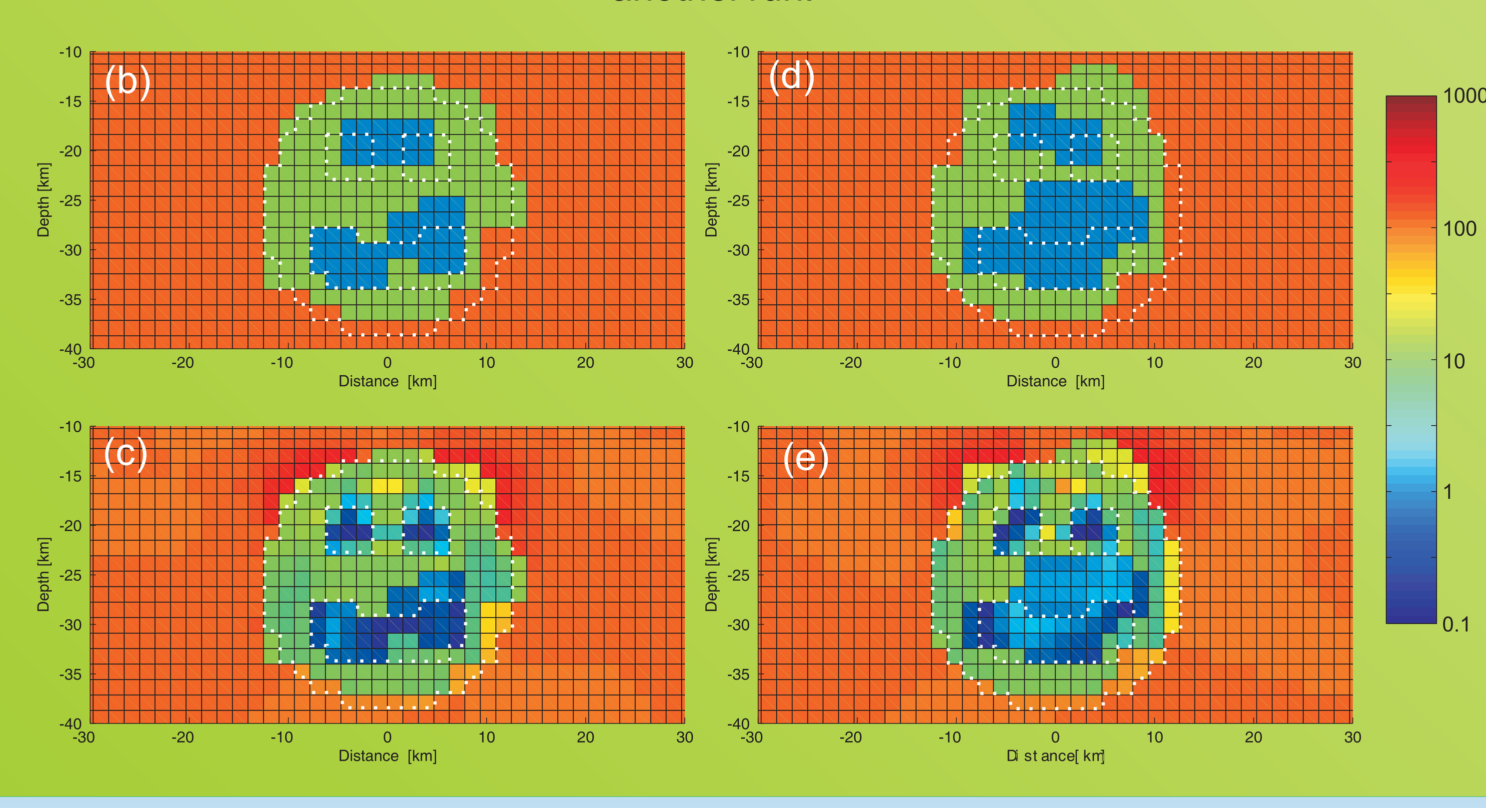


Figure 2

The figure presents the effect of the projection on two modified models. The dotted white line shows the original model for comparison purposes. This original model is shown also in the upper left corner **(a)**. Model **(b)** is the result of 5 moving steps and model **(d)** was produced by 3 steps on another run.



In panel **(b)**, we can see that in the unprojected model, the "eyes" have joined and the bottom of the anomaly is cut. The projection **(c)** shows how the position of the "eyes" is recovered, thus indicating that they can be resolved. The "smile" remains distorted. The bottom appears reduced in depth like in the unprojected model, indicating that the bottom position is not well resolved.

In panel **(d)** we see similar features: the projection recovers the true position of the "eyes" and leaves the bottom depth reduced. In addition, we can see that the rightmost column of the anomaly (which is not present in the unprojected model) is reset by the projection **(e)**. So, we can see that the horizontal position of the anomaly can be well determined by the data.

The data consist of TE and TM phases and apparent resistivities at 13 periods (10^{-1} s to 10^{5} s) and 5 sites.

Discussion and conclusions

The present technique consists of two building blocks: (1) a simple algorithm of model modification, and (2) the null-space projection as a fast and reliable method to keep the fit to data, assuming a linear approximation.
Many different models with the same fit to data can be obtained. Though the null-space projection represents a constraint in data space, we still need some additional criterion in order to establish which models can be accepted. There are several possibilities:

- We can use some regularization functional (like in traditional geophysical inversion) and establish a threshold in the value of this functional. For instance, we can use the traditional least-squares functional. Using this functional, we will obtain smooth images, which sometimes may have little geological sense. As we are often more interested in the geometry of the anomaly, we propose to use a minimum gradient suport (MGS) functional. This functional minimizes the area where strong model changes occur, thus providing focused images. At present we are working on introducing this feature in the present algorithm.
- In order to guide the movement algorithm, the probabilities of displacement can be different for each direction. For example, the models shown in figure 2 were generated with the probability of upward displacement increased by a factor of 2. This way we can enforce the reduction of the depth to the bottom of the anomaly. Of course it is possible to outweight any other direction, for example any horizontal direction to check the resolution of the horizontal position of the anomaly.
- Apart from the special model modification scheme presented here, we can use the null-space projection approach for testing of hypotheses. In particular, we can introduce our favourite model or geometry from a priori information from other geophysical methods or geological theory.

Even if the present technique is at a very early stage of development, it is a useful tool to appraise 2D MT models, specially to check the position and geometry of the anomalies found in the inversions. The use of this technique may help to reduce artifacts introduced by special inversion techniques, and that may have little or no geological significance.

References

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