Exploring magnetotelluric model space

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SUMMARY

Magnetotelluric (MT) inversions are inherently non-unique. Due to the large computational requirement of 3D MT inversion, there is always a trade-off between exploring model space and the amount of time invested in the inversion process. A standard approach is a two-stage inversion, where coarse features are resolved first, and the outputs from the coarse model are used as the starting model for a finely discretized inversion. Inversion may be followed by a combination of sensitivity analysis and forward modelling to test the robustness of features. This approach quickly leads to a low RMS model but has a limited capacity to explore the potential range of acceptable models.

In this paper, we propose a revised two-stage process which enables fast comparison of inversion results from a series of inversion parameters. Three inversions were run using a starting half space with only the input data varied: one inversion using un-rotated full tensor and tipper data; one inversion using only tipper data; and the third inversion using rotated tensor and tipper data. In addition to these half-space models, an inversion was run using starting models based on geological constraints. It used three domain boundaries with roughness penalties turned off between units. The modified two stage inversion process suggested in this paper offers a balance between arriving at final inversion within a reasonable time frame while still allowing the user to explore a larger range of possible models than the original methodology.

Key words: magnetotelluric inversion

INTRODUCTION

The non-unique nature of geophysical inversion is a well-known issue (Parker, 1994). While some approaches exist for exploring model space for gravity and magnetic inversion (Jessell et al., 2010; Lindsay et al., 2014; Wellmann et al., 2010), and to some extent airborne EM inversion (Brodie and Sambridge, 2012) and 2D magnetotelluric (MT) (Schnaidt and Heinson, 2015), no such feasible method exists for 3D inversion of MT data. This is primarily due to the significant computing requirement for 3D MT inversion. A standard approach to minimise computing resource usage is a two-stage inversion, with the coarse features resolved in the first inversion. The outputs from the coarse inversion are then used as the starting model for a finely discretised final inversion (Lindsey and Newman, 2015). While this approach allows the user to arrive at a reasonable inversion solution quickly, it does not explore the range of possible models which may account for the data.

In 2014-2015 809 broadband MT stations were collected in south west Queensland by the Geological Survey of Queensland. Sites were collected on a 2 km x 5 km grid with a frequency band of 300 Hz to 2000 s. This dataset provides a useful test data set to look at how model space can be better explored during 3D inversion by exploiting sub-setting and sequential inversion. We propose a modification of the Lindsey and Newman (2015) methodology to explore MT model space better (figure 1).

METHOD AND RESULTS

To facilitate a wider exploration of MT model space, it was necessary to subset the original data set. The dataset was reduced to a 10 km x 10 km grid with a total of 89 stations. Additionally, the high-frequency component of the data was removed resulting in data with a frequency band of 1 s - 2000 s. Error floors of 5% for impedance and 2% for tipper were used for all inversions. This combined reduction of resolution enabled four "coarse" models to be run without requiring excessive computing resources. Inversions were conducted with the ModEM inversion code (Kelbert et al., 2014) and average time per iteration for the "coarse" models was 90 minutes. The focus of the “coarse” modelling was to explore possible resistivity structures of the mid to lower crust. Four inversions with different starting conditions were run:

1. Standard unconstrained half space model
2. Rotated data unconstrained half space model
3. Tipper first unconstrained half space model
4. Fault blocks starting model

The same inversion mesh was used for each of these inversions with mesh parameters created using guidance from Meqbel et al. (2014) and Tietze and Ritter (2013).

“Coarse” Model

The standard unconstrained model was started from a 100 Ω·m half space. The inversion ran to an RMS of 1.8, model fits deteriorate at long periods. The initial inversion had a significant number of conductive features at the extremities of the model which are unconstrained by the site observations. Such structures were removed, and the inversion restarted. The inversion reached an RMS of 1.7 without the edge features, indicating they were an artefact rather than real features.

The rotated data model was also started from a 100 Ω·m half space with data rotated to the dominant strike of N165°E and achieved an RMS of 1.9.

The tipper first inversion also has a 100 Ω·m half space starting model and involves two-stages. Initially, the inversion was run with only the tipper data and achieved an RMS of 1.3. Subsequently, the impedance data were added, producing a final RMS of 1.6.

The fourth coarse inversion run was started with a fault block model. The model was created using the GSQ (2011) solid geological interpretation. The model was split into three crustal blocks – the Ardmore-May Downs, Leichhardt River and Kalkadoon- Leichhardt Domains. Each block was assigned a different starting resistivity based on the outcomes of the unconstrained inversion, and roughness penalties were turned off between domains. A fourth domain was created containing the area below the currently interpreted Moho, with roughness penalties turned off between the three crustal domains and the mantle domain. The final RMS for this model was 2.

Models achieved a comparable fit for periods between 5 s and 100 s. Overall the tipper first and unconstrained models had the best fit while the rotated data and geological domains models achieved poorer fits. The rotated data model produced features very similar to the unconstrained inversion. The tipper first and geological domains models produced significantly different models while achieving similar misfits.

The tipper first inversion was chosen as the preferred model due to the overall simplicity of inverted features.

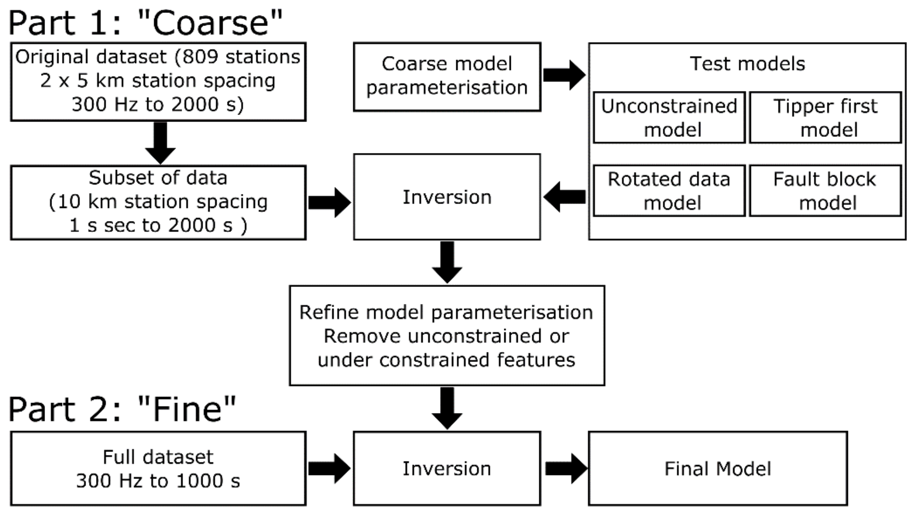

Figure 1: Revised sequenced workflow diagram (modified after Lindsey and Newman, 2015)

“Fine” Model

The result of the tipper first inversion was used to generate a more finely discretized starting model for the "fine” inversion. Some unconstrained or under constrained features were evident around the edges of the dataset and in the shallow layers of the coarse model. Shallow features are considered to be any features within one skin depth of the surface for the highest frequency data inverted for the “coarse” models. Shallow or edge features which do not appear in all "coarse" models are viewed as suspicious.

The shallow and edge features were determined to be problematic for the "fine" inversion and were removed (in the case of the erroneous edge features) or replaced with a realistic basin model (for the shallow features). This was necessary for the fine model to converge in a reasonable time frame. Where a realistic basin/shallow model is not available, under constrained shallow features should still be removed.

CONCLUSIONS

This paper proposes an expansion of the methodology proposed in Lindsey and Newman (2015) where additional coarse models are run to explore better the range of possible models which fit a given data set. Running different starting models during the “coarse” stage of the process enables more models to be tested quickly. The preferred coarse model is then used as the starting model for the “fine” inversion step. It is important to determine which features are required by the data and which are model artefacts before initiating the “fine” inversion. Where appropriate, these should be removed as they may prevent the fine inversion converging appropriately.

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