# Leveraging the true value of historic AEM data sets with quantitative inversion


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## SUMMARY

Large holdings of airborne electromagnetic data exist in public archives of government agencies that have never been fully utilised. Many of these surveys would have only been interpreted as profile data to identify discrete conductor anomalies, which may in turn have been subjected to parametric plate-modelling techniques. Most datasets from prior to the turn of the century will not have been interpreted with the stitched 1D inversion algorithms that are now used as a routine practice.

Since historic datasets were not routinely quantitatively inverted at the time, there was no driver for survey clients to demand accurate system specifications or calibrations. Added to this is the difficulty of dealing with data that are presented in units of parts-per-million, as well as the lack of measurement of the transmitter-receiver separations and orientations. Despite these impediments, we have been motivated to ascertain if further value can be extracted from historic data sets through quantitative inversion techniques.

We have investigated various techniques in an attempt to overcome these impediments. This includes using inversion parameter-sweeps on selected subsets of a data set to derive calibration parameters that best represent the known unknowns in the data. Examples of which are the waveform pulse-width and the high-altitude reference geometries by which data are provided in the case of parts-per-million normalised systems. A new bunch-by-bunch inversion algorithm, which allows along-line system geometry constraints to be applied, is also used in the procedure. The methodology shows promise of remedying the issues for some data sets, but good results are not always achievable.



**Key words:** airborne electromagnetics, AEM, historical data, GALEISBSTDEM


## INTRODUCTION

Australia is covered with a significant number of airborne electromagnetic (AEM) surveys. The majority of these surveys were acquired in the 1990s and early 2000s by private industry and flown primarily for detection of anomalous conductive features at depth. As these data were traditionally analysed using channel data (Smith et al., 1996) or conductivity transforms (Macnae et al., 1998) incorporating them into modern projects requires reanalysis and inversion to extract a model of the variation of conductivity with depth (Brodie and Sambridge, 2009b; Christiansen et al., 2011).

Unfortunately, the potential value of these historical data sets is not easily realised because they were not robustly modelled at the time of acquisition and lack critical metadata and system information to allow inversion using modern software (Auken et al., 2005; Brodie and Sambridge, 2009a). A typical approach used to deal with this is to adopt “nominal values” for system parameters extracted from available published reports or within inversion code examples. Due to the non-unique nature of AEM, without other comparison data or ground truth it is often difficult or impossible to determine the impact of the chosen system parameters on inversions derived from this approach. Some deal with this by running a variety of input models to determine those which are “optimal” (Sattel et al., 2004). Although this adds confidence to the chosen model parameters it does not account for the along-line variability of the system geometry. Some software provide an ability to invert for the system geometry (Auken et al., 2009; Brodie, 2016). When done in a sample-by-sample approach this method yields sporadic (and often unrealistic) geometries along-line, and available laterally constrained approaches lack constraints to model the expected or assumed along-line variability.

Here we present an approach for modelling and inverting AEM data using new inversion approaches recently implemented in GALEISBSTDEM (Brodie and Mulè, 2023). We have applied the new combined XZ-amplitude and bunch-by-bunch constrained geometry approach to a high resolution historical AEM survey acquired by Geotem in the 1990s. We show that by using an optimised system geometry and the constrained bunch-by-bunch geometry inversion approach we can achieve a more coherent inversion result.

## INVERSION METHODOLOGY

Following work initially investigated in Mulè and Munday (2021) it was highlighted that although manual methods could be used to account for unknown or uncertain system parameters, a more robust and automated method would be preferred. To this end, a collaboration was initiated between CSIRO and GA to review existing methods and develop additional functionality into GALEISBSTDEM particularly for handling unknown and uncertain system geometries (Brodie and Mulè, 2023).

In an attempt to simplify the inversion problem when dealing with uncertain system geometries a combined data vector amplitude inversion was implemented. This approach inverts the XZ-amplitude, the combined response in the XZ-plane, rather than the conventional approach of inverting the X- and Z- vector components of the response, either jointly, or separately. Since the modelled XZ-amplitude data are not impacted by the receiver pitch, it is generally easier to fit the data and it is not necessary to include receiver pitch as an inversion parameter. This has been shown to provide improved along-line coherency (Ley-Cooper et al., 2019), however we suspect it reduces sensitivity to some subsurface features.

An alternate approach was to include additional constraint into the existing geometry inversion in GALEISBSTDEM using a bunch-by-bunch approach. This method utilises stations or fiducials along the survey line with a specified sample spacing and applies an across-bunch variability or consistency constraint in addition to the conductivity and vertical and horizontal regularisation constraints. We would expect that this improves the inversions' ability to derive appropriate and consistent system geometry parameters along-line.

For further details of these methods refer to Brodie and Mulè (2023).

## CASE STUDY

A large and high resolution Geotem III survey acquired near Cloncurry, QLD in 1995 (Geological Survey of Queensland, 1995) was interrogated to investigate the potential to extract greater value through inversion (Figure 1). The survey is over 10,000 km with a line spacing of 300 m. The Geotem III system utilised a 25 Hz base frequency, a 4 ms half sine pulse, acquired both X- and Z- component data with a nominal receiver position of 120 m behind and 45 m below the transmitter. Transmitter and receiver orientation were assumed to be zero.

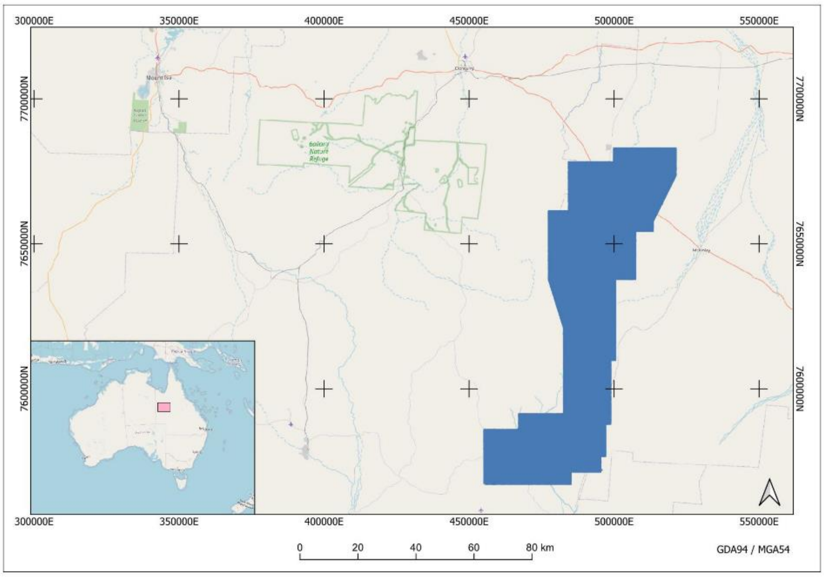


**Figure 1. Location of the Geotem III EM823 survey.**

### High altitude geometry

The Geotem III system employed a PPM normalisation whereby the collected survey EM data was divided by the EM data acquired at high altitude to provide data which was reduced to parts per million of the primary field in the receiver at high altitude. This is often referred to as compensation and normalisation in survey reports (Brodie, 2010; Geological Survey of Queensland, 1995). Although this was intended to assist with accounting for unknown system scaling and geometry, it introduces difficulties for the system forward modelling, a key part of the inversion. Since the data have been normalised to the high altitude EM response, it is critical that the high altitude system geometry is known to undertake modelling. The transmitter-receiver location provided for Geotem data was nominal in nature and not monitored or calculated, likely derived via forward modelling of high altitude data, theoretical modelling and/or photography (Smith, 2001). To ensure accurate inversion of PPM data it is important that a representative high altitude transmitter-receiver geometry and orientation is used.

In an attempt to determine this, an array of parameter-sweeps were undertaken. We ran inversions for locations across the survey varying the high altitude transmitter pitch, receiver pitch and transmitter-receiver location. From this we extracted an average relative misfit for each input geometry and selected a geometry which coincided with a minimum misfit for the majority of inverted stations. This process provided a transmitter-receiver location of 124 m behind and 42 m below and a transmitter pitch of 4 degrees. These optimised geometry parameters were then used as the input geometry for subsequent inversions.

**Inversion**

Multiple inversions were undertaken to assess the impact of the new optimised geometry and new inversion approaches. Results from these inversions for a survey line are presented in Figure 2. The first inversions (Figure 3a) were completed using joint X- and Z- component data, the provided nominal geometry at high altitude and no solving for geometry during inversion. These inversion results show conductive banding in the near surface and inconsistent recovered conductivity structure along-line and at depth. The second inversions (Figure 3b) were completed using combined XZ-amplitude data, the provided nominal geometry at high altitude and no solving for geometry during inversion. These inversion results are much more consistent along-line and at depth, with a reduced overall conductivity. The third inversions (Figure 3c) were completed using joint X- and Z- component data, the new optimised geometry at high altitude and solving for transmitter-receiver and receiver pitch at survey altitude using the bunch-by-bunch inversion with an imposed similarity constraint. These inversion results have similar consistency to the second inversion but retain some high frequency near surface variation. The second and third inversion results are both significantly improved over the result using the provided input system parameters.

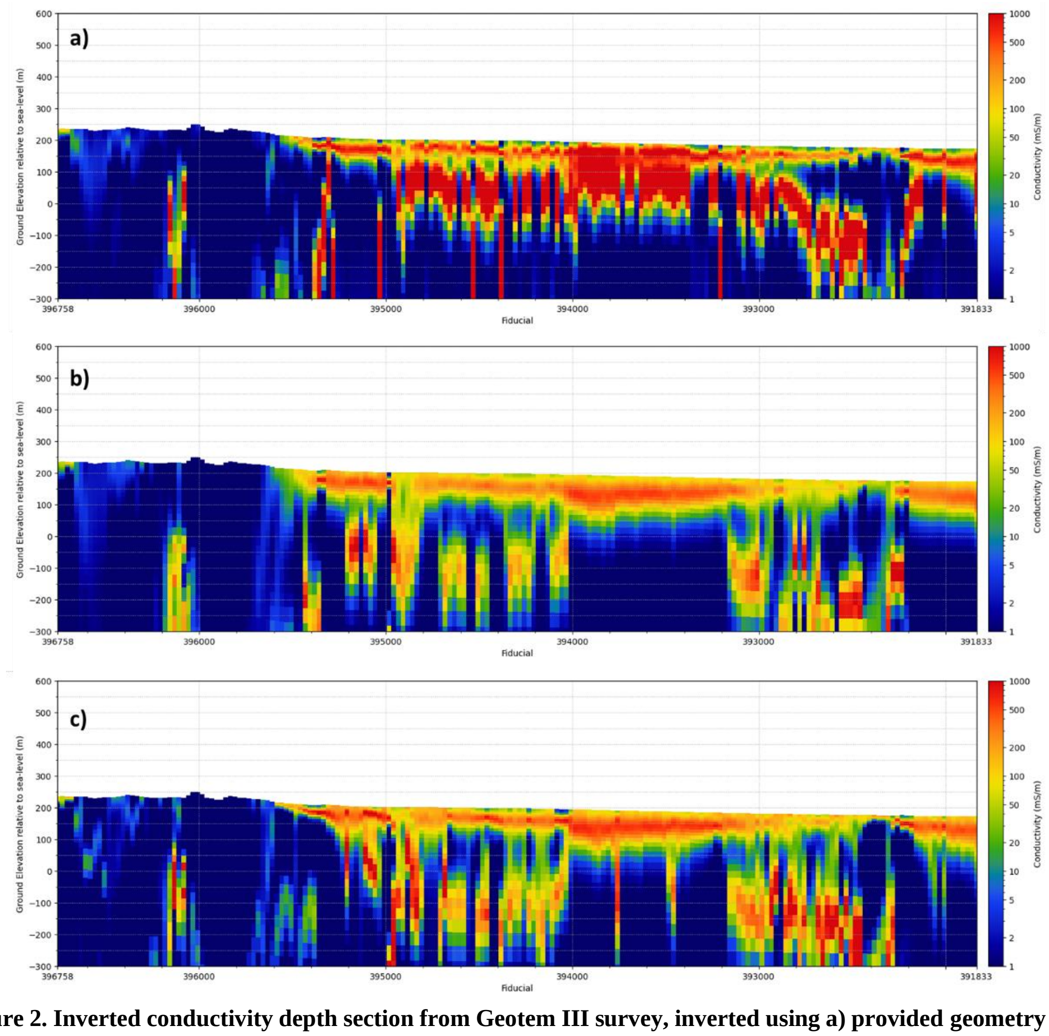


**Figure 2. Inverted conductivity depth section from Geotem III survey, inverted using a) provided geometry and joint X- and Z- component, b) provided geometry and combined XZ-amplitude, c) optimised geometry and joint X- and Z- component using bunch-by-bunch to solve for along-line geometry.**

The inverted results for a depth slice over the survey area is presented in Figure 3. As in the depth section comparison, the inversions using the optimised geometry provide a result similar to that achieved using the combined amplitude inversion, but with more high frequency features. Since the combined XZ-amplitude approach is insensitive to receiver pitch variation it can be used to assess the validity of the joint X- and Z-component inversion results. Using this metric, it is reasonable to conclude that the use of an optimised geometry and the bunch-by-bunch geometry constraining have provided an improved and acceptable inversion result.

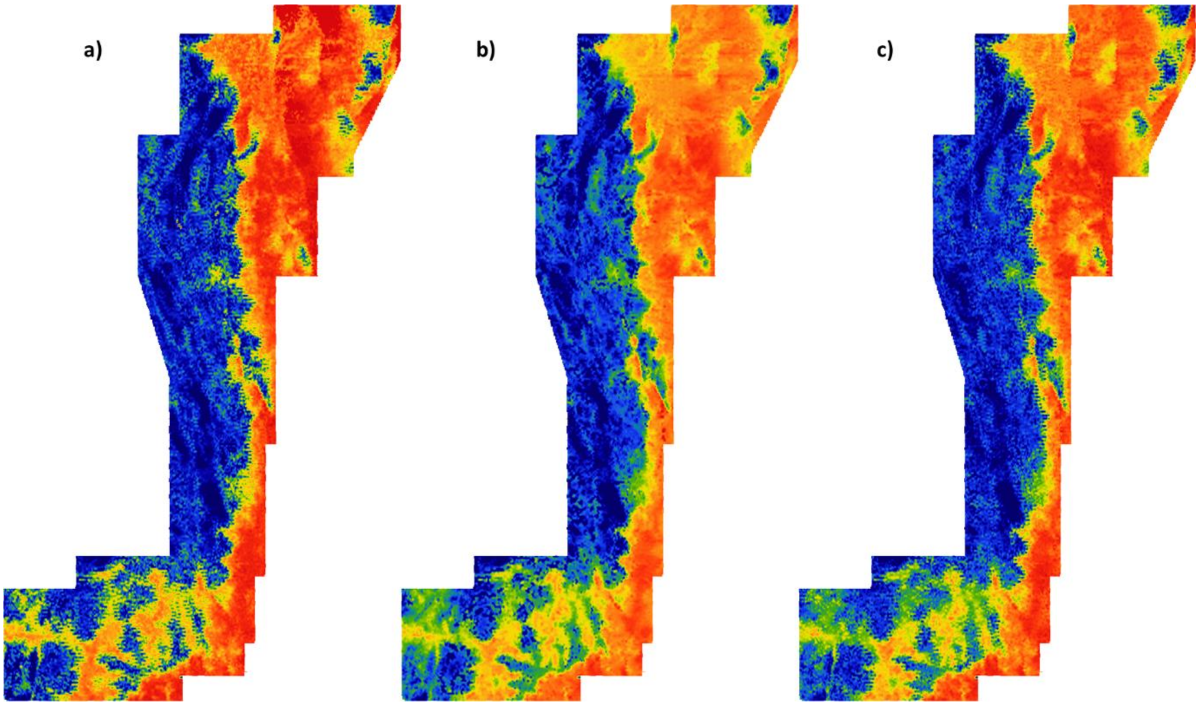


**Figure 3. Inverted conductivity depth slices for 25-50 m depth slice, a) provided geometry and joint X- and Z-component, b) provided geometry and combined XZ-amplitude, c) optimised geometry and joint X- and Z-component using bunch-by-bunch to solve for along-line geometry and orientation.**

## CONCLUSION

Although inverting historical AEM data is problematic and underdetermined, improved inversion methods can be used to extract useful results. The combined amplitude and bunch-by-bunch inversion approaches recently implemented in GALEISBSTDEM have been shown to improve conductivity-depth models extracted through inversion for a historical Geotem III survey. Using an optimised geometry and along-line geometry constraints, an improved inversion result was achievable using both X- and Z- component data, comparable to that achieved using receiver pitch independent combined XZ-amplitude inversion. This initial work shows the type of results that can be extracted from historical AEM data. Work is ongoing to improve methods for handling these types of data sets in inversion.

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