Characterising cover and exploring under cover with AEM

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SUMMARY

Characterisation of cover is an important aspect of understanding many geological systems. Through a better understanding of cover and improved sensitivity to deeper structures the footprint of mineral systems can be extracted. This is important in providing greater confidence to mineral explorers and will assist with further exploration success at depth. UNCOVER is a government initiative, focussed on improving the mineral prospects of Australia through better exploration of the subsurface under cover. AEM is well placed in supporting this initiative, by providing a rapid and efficient way to undertake near surface geophysical exploration. To accurately characterise the subsurface, AEM systems must have both accuracy and precision which are achieved through robust calibration and low noise levels. Tempest has a long history of exploring cover and under cover. The characteristics of the system are tuned to provide a broad bandwidth which maximises its sensitivity and applicability. Years of development has led to significant improvements in signal-to-noise along with deployment of system variants and platform diversity, including High Moment Tempest which provides increased transmitter moment along with reduced noise levels leading to greater depth of penetration and sensitivity to low conductivity contrasts.

Key words: Tempest, Airborne EM (AEM), UNCOVER, cover, FTEM

INTRODUCTION

Global exploration has been stunted in recent years suffering from low levels of economically viable discoveries. UNCOVER, an initiative developed by the Australian government, is designed to provide a forum for government and industry to discuss, focus and progress exploration under cover throughout Australia, with the aim of increasing the mineral prospects of the country (Australian Academy of Science, 2012). One of the key focus areas of UNCOVER is to improve exploration success through better understanding and characterisation of the subsurface. Airborne electromagnetic (AEM) technology is well placed in assisting with this goal by providing a rapid and economical way to characterise and explore through cover to better understand the underlying geology. To achieve this, an AEM system must be sensitive to both the near surface as well as the deeper conductivity distribution, since understanding both will provide the greatest potential for characterising mineral systems and associated alteration. This requires a system to be accurate and repeatable, achieved through calibration, and precise and resolvable, achieved through low noise. Repeatability ensures that the system can be compared to existing or future datasets, and used for integration into broader geological models to reveal and confirm the distal footprint of mineral systems. Precision ensures a sensitivity to subtle variations within the subsurface that aids in understanding cover and exploring at depth under cover.

Given the sensitivity and resolution of time domain airborne EM (TDEM) systems, they have been employed to help interpreters characterise cover and better understand the distribution of conductivity under cover. They have been used for a wide variety of applications, and in a wide variety of geological settings. Applications range in scale from mine scale to large regional scale surveys, and have targeted cover, the underlying basement, or both.

Many AEM projects have been undertaken to target: depth of cover (Worrall, et al., 2001); groundwater systems within the cover (Fugro Airborne Surveys, 2009); underlying geology characterised by the cover type (Lane, et al., 1999); and basement topography (Kovac, et al., 2013). Numerous surveys mapped palaeochannel systems and basement topography for uranium exploration (Sørensen, et al., 2015; Fitzpatrick, 2013). Large regional surveys for mapping groundwater and salinity have been undertaken throughout Australia, including in the Lower Macquarie River Valley (Macaulay & Kellett, 2009). Other projects have targeted basement and other geology under cover; subtle alteration associated with gold and uranium mineralisation (Beckitt & Bisset, 2003); direct detection of base metal deposits (Burrows, et al., 2013); and geological mapping for a multitude of exploration targets.

Many surveys targeting information from both the cover, and under cover have been flown, including many by government bodies worldwide. Numerous surveys for Australian government groups have mapped large areas of the country with Tempest® under various initiatives including the Onshore Energy Security Initiative and UNCOVER. The Onshore Energy Security Initiative undertaken for Geoscience Australia (GA) encompassed three surveys which mapped cover and basement on a regional scale. This included the Paterson project in the Yeneena Basin (Roach, et al., 2010), the Pine Creek project in the Kombolgie Subgroup (Craig, et al., 2011) and the Frome Embayment project (Roach, et al., 2012). A survey of the Capricorn Oregon undertaken for the Geological Survey of Western Australia (GSWA) as part of the UNCOVER Australia project was successful in mapping the variability and complexity of the conductive cover in the region (Ley-Cooper, et al., 2015).

The Tempest system was developed in the 1990's and launched commercially in 2000. The system operates with a 50% duty cycle square wave. During processing the 50% duty cycle square wave is deconvolved to a 100% duty cycle square wave which standardises and thereby increases the usability of the output data (Lane, et al., 2000). The system's versatility can be credited to its broad operational bandwidth, multifaceted software approach and distinctive calibration technique that ensures the system is able to capture and process early and late time ground responses.

CALIBRATION

Calibration of an AEM system is broadly understood as a procedure used to monitor the variations of the system which can be applied, either in processing or inversion, to improve the accuracy of the recorded data. AEM systems can be calibrated by comparison of known and observed geological data (lithologies, contacts), geophysical data (drill hole, ground EM), or man-made tests (grounded EM loops, buried EM targets). System calibration may also take the form of monitoring and compensation of the variable parameters of the system (transmitter current/area, height, orientation; receiver area, position, orientation). Calibration of an AEM system is vital in standardising data such that it can be used to accurately image the structure and geometry of the subsurface. Poor calibration can lead to an inaccurate understanding of the geometry and orientation of the geology.

The large receiver and transmitter offset employed on fixed-wing AEM systems requires that the position and orientation of both transmitter and receiver are well known. The standard calibration procedure used by the Tempest system requires multiple pre- and post-flight calibrations to be undertaken at high altitude on each survey flight. Survey altitude repeat lines are also regularly captured to aid in measurement and verification of repeatability. The calibrations ensure that system variations, which may occur between flights, are monitored, captured and corrected as required. Smiarowski & Sattel (2015) showed how errors in transmitter pitch and receiver position can result in scaling and depth estimate errors on calculated inversion results. The inclusion of a GPS receiver on the EM receiver platform (Mulè & Lockwood, 2013) has provided an accurate and precise measure of the transmitter and receiver offset, which due to its variable nature on fixed-wing platforms is significant for calibration.

Sørensen, et al. (2015) compared and explored calibration of ground and airborne EM data. The comparison showed that conductivity models resultant from ground EM and Tempest data acquired in the Frome Embayment were comparable; and provided the basis for using Tempest data to calibrate data from a helicopter TDEM system acquired in the same area. This raises the possibility that well calibrated AEM systems can be used to calibrate data acquired by ground and other airborne systems that lack robust calibration. In fact Sørensen, et al. (2015) stated that "in principle the Tempest data could be used as a basis for evaluating and standardising the ground-based data and/or airborne EM data". This approach is useful in extracting further detail out of historical AEM datasets and can be particularly beneficial when combining new and existing datasets with various resolutions. The review and combination of historical datasets is a typical approach of broad interpretation studies and will form a key component of the initial implementation stages of UNCOVER.

Repeat line data is typically used by government and commercial clients to monitor the performance of AEM systems. Fitzpatrick (2013) utilised thirty-six Tempest surveys, collected over a decade, to build a basin-wide conductivity model for uranium exploration. The data contained multiple repeat lines collected over nine years and many surveys. These repeat line data were inverted and provided comparable conductivity distributions, even though the data were collected on different aircraft platforms, at different times of the year and through different iterations of the system's development lifecycle. This example illustrates the importance of calibration in providing data that is independent of the survey platform or conditions. EMFlow (Macnae, et al., 1998) CDI results of six repeat lines from the Capricorn GSWA survey flown in 2013 as part of UNCOVER are presented in Figure 1 to a depth of 1 km. The CDI results show significant correlation in the top 500 metres with some variation present at greater depths where the system noise level becomes more dominant. Repeatability is important when undertaking regional surveys which are likely to be flown over multiple years, with different systems and in different conditions. It also ensures that survey infill undertaken to provide better local coverage can be fit within a broader regional context. The regional survey approach will continue to be a significant component of government funding of UNCOVER and other exploration initiatives into the future.

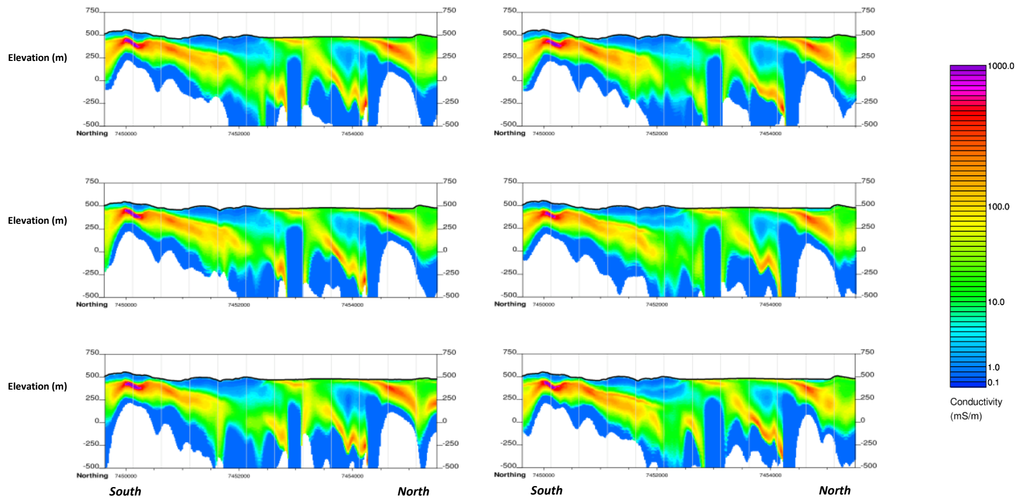

Figure 1 EMFlow CDI of EMZ repeat line data from Capricorn GSWA survey flown in 2013.

NOISE

AEM system noise fundamentally limits what can be extracted from collected data. A traditional approach used to define the noise of an electronic system requires noise measures for each component of the system and an understanding of how each component contributes to overall system noise. Due to the complexity of AEM systems this approach is difficult to undertake and therefore noise is typically approximated by analysing observed data from multiple flights (Brodie & Fisher, 2008; Christensen & Lawrie, 2012; Green & Lane, 2003). Using this method the additive noise term is identified as the clearest indicator of system noise and resolvability. The additive noise is a measure of the variability of the high frequency component. In AEM it is determined using the standard deviation from the mean of the high altitude background line. Main factors contributing to additive noise include: equipment noise, processing (e.g. filtering, stacking) and external sources (e.g. VLF, sferics). Since additive noise includes environmental and cultural noise sources, calculation of the additive term requires the removal of statistical outliers and the use of a statistically valid sample size to ensure system related variations are emphasised. The nature of additive noise is such that it usually remains as the dominant factor in defining what can be extracted from AEM data. This is especially true for gates at later delay times which generally represent responses from greater depths.

Since its launch in the late 1990's the Tempest system has been deployed globally and is now available on a range of aircraft platforms, and in several variants. Throughout this period the system has undergone a range of software and hardware developments aimed at improving signal-to-noise. These developments include monitoring of transmitter and receiver motion; vibration isolation; expanded processing compensation techniques; reduced equipment noise; improved waveform stability and monitoring; increased dipole moment; installation on more modern and economical aircraft platforms and broader range of transmitter base frequencies (12.5 to 270 Hz). (Mulè & Lockwood, 2013; Mulè & Smiarowski, 2013)

In 2015 a new Tempest variant was deployed that provides significantly improved signal-to-noise, leading to an increased depth of penetration and better characterisation of features under cover. The High Moment Tempest system operates with the latest transmitter and receiver technology with a more powerful 1200 A transmitter current providing a maximum dipole moment of 300,000 Am^2. The increase of dipole moment is significant because it is coupled with minimal increase in system noise therefore providing a signal-to-noise many times higher than the standard configuration.

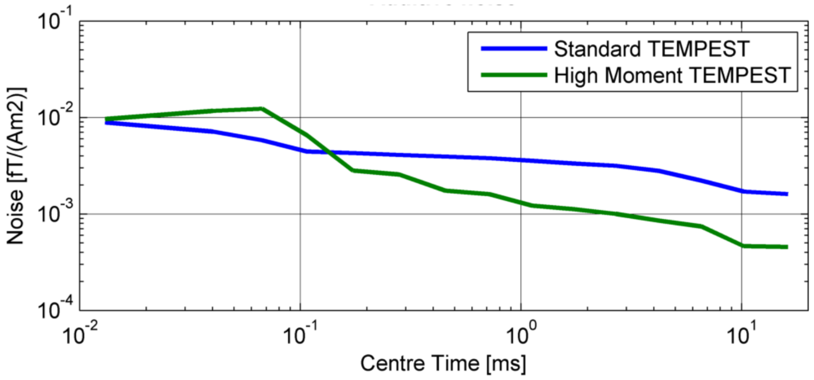

Figure 2 Additive noise (standard deviation of signal at high altitude) for standard (blue) and High Moment Tempest (green).

The primary normalised additive noise for the standard and High Moment Tempest variants are presented in Figure 2. The data shows the improved noise levels of the High Moment system, especially at later gate times. This is a result of the increased transmitter moment with minimal change to un-normalised noise levels, resulting in normalised noise levels many times lower. The early time gates do present some increased base levels as a result of the multiple transmitter turn approach employed, however due to the typically large signal amplitudes present in these gates this will only minimally impact near surface resolvability.

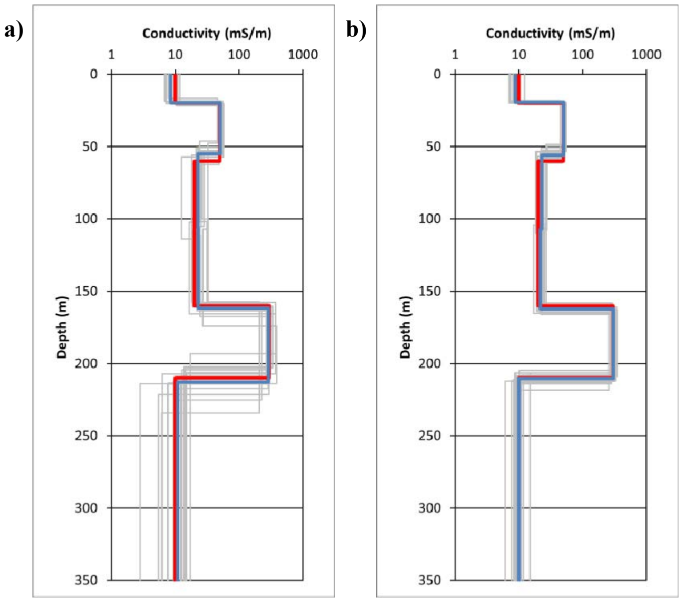

Figure 3 Forward model (red), each noise perturbed inverted model (grey), and average inverted model (blue); using a) standard Tempest noise model, b) High Moment Tempest noise model.

Synthetic modelling was undertaken to analyse the importance of system noise for the determination of layer depth and conductivity. AIRBEO from the AMIRA P223 project was used to undertake forward and inverse modelling of synthetic AEM data (Chen & Raiche, 1998; Raiche, 1998). The subsurface model used in the modelling study used layer thicknesses and conductivities broadly based on the conductivity distribution present in the Capricorn Orogen. The model contains a thin resistive top layer, followed in depth by a moderately conductive near surface layer, a thicker resistive layer and then a relatively conductive layer at depth. The modelling procedure involved forward modelling of the response to the subsurface model followed by calculation of a set of Gaussian distributed noise perturbations of 1 standard deviation of additive noise (Figure 2) for each noise model. Each noise perturbed result was inverted for layer conductivity and thickness using a 6 layer, 10 mS/m half space starting model with power-law layer thickness expansion. The forward and inverted model results are presented in Figure 3. The noise perturbed inverted models represent the precision of the system as a function of the variation in the high altitude noise of the system. The results show that although both systems on average will resolve the input subsurface model, the reduced amplitude of normalised additive noise observed on High Moment Tempest improves the resolvability of layer conductivity and thickness, especially at depth.

The standard and High Moment Tempest system variants were also flown over a test line located near Gingin, north of Perth. The line runs from the coast to approximately 35 km inland, due east. The geology of the region is comprised of sedimentary formations to the west of the Darling Fault. The data from each variant was run through EMFlow and the results presented in Figure 4. Both system variants are able to well define the salt water intrusion (western end), and shallow discrete conductive features. The High Moment variant contains fewer isolated anomalies (typically associated with noise) and suggests the presence of a deeper conductive dipping layer (eastern end). The geometry of this layer is consistent with layering observed on geology and seismic data from the area (van Buren, et al., 2015). The ability to image the subsurface at greater depths with confidence is key in addressing the UNCOVER objective of improved exploration under cover.

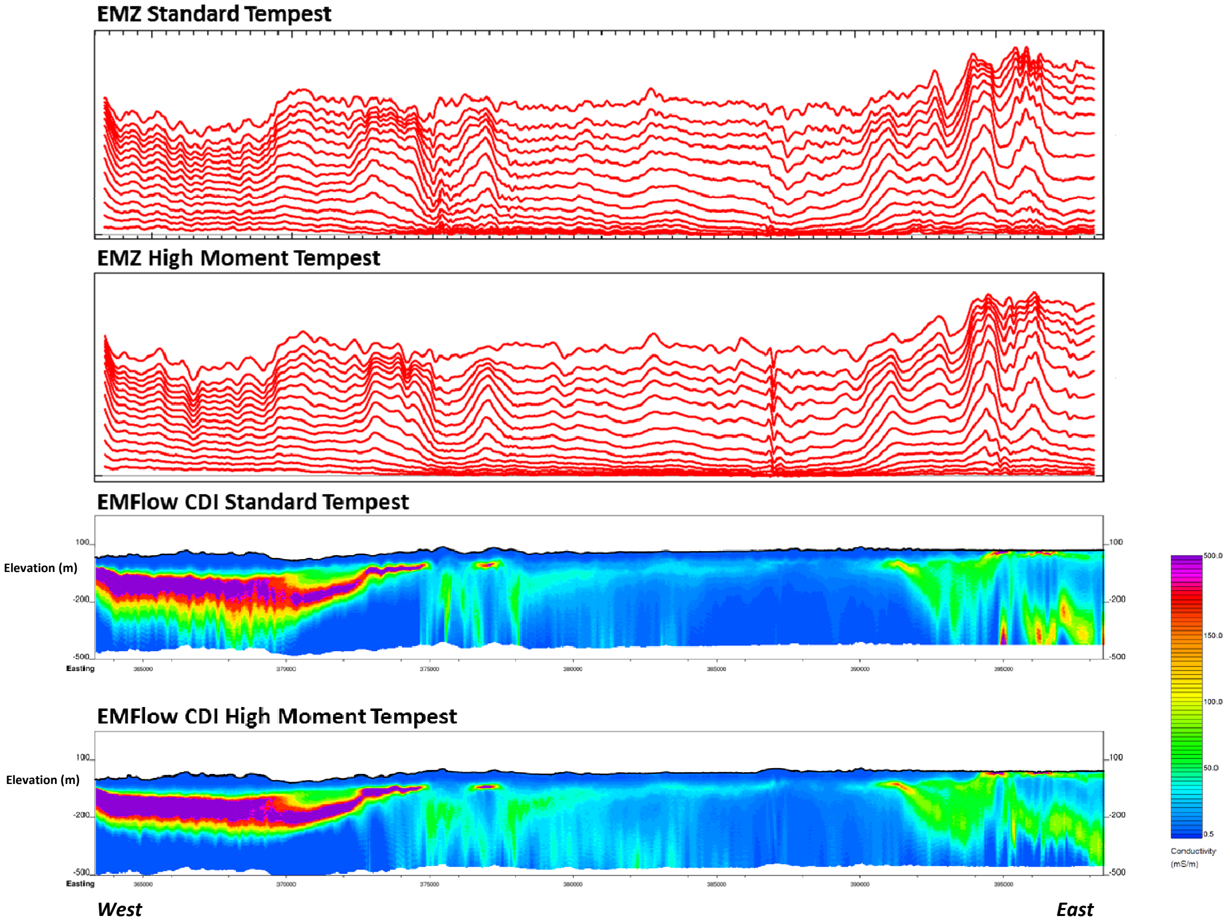

Figure 4 EMZ data and EMFlow CDI for a test line located near Gingin, WA, flown with standard and High Moment Tempest.

CONCLUSION

Airborne EM has been successfully deployed for a wide range of targets including groundwater, uranium, gold and base metals exploration as well as for geological and basement mapping. To address the goals of UNCOVER an AEM system must be well versed in accurately characterising cover and exploring under cover by providing both repeatable and precise data. The repeatability of a system, presented through calibration and comparison to known datasets, provides the ability for interpreters to assess acquired data in both a local and global context and compare results across a range of geophysical phenomena. The precision of a system, principally attained through low noise, improves the depth of exploration of a system and provides greater sensitivity to low conductivity contrasts. The Tempest system is shown to provide both of these traits and is therefore well placed to address the broad near surface exploration goals of the UNCOVER project and improve our understanding of cover throughout the Australian continent. Improved noise levels as well as updates to system processes and configurations are shown to enhance the Tempest system's ability to characterise the depth and composition of the cover and map bedrock geology.

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