Review of three airborne EM systems

Shane Mulè
Fugro Airborne Surveys, Australia
3/435 Scarborough Beach Road, WA
smule@fugroairborne.com.au

Roger Miller
Fugro Airborne Surveys, Australia
3/435 Scarborough Beach Road, WA
rmiller@fugroairborne.com.au

Heather Carey
Fugro Airborne Surveys, Australia
3/435 Scarborough Beach Road, WA
hcarey@fugroairborne.com.au

Ray Lockwood
Fugro Airborne Surveys, Australia
3/435 Scarborough Beach Road, WA
rlockwood@fugroairborne.com.au

SUMMARY

Time Domain Airborne Electromagnetic (TDEM) systems are defined by a set of technical specifications, which include dipole moment, bandwidth, transmitter waveform and transmitter-receiver geometry.

Comprehensive analysis of these specifications is fundamental in understanding how they define the target response. For example, a system optimised for mapping deep, discrete ore bodies is not necessarily the ideal solution for mapping regolith where good vertical resolution may be required.

Data acquired by three TDEM systems developed by Fugro Airborne Surveys are used to demonstrate the effects that different system specifications have on the response of an exploration target.

Key words: airborne electromagnetics, time domain electromagnetics, TEMPEST, GEOTEM, HELITEM

INTRODUCTION

This paper will review three airborne electromagnetic systems. The specific applications of TEMPEST, GEOTEM and HELITEM will be explored and used to highlight the importance of selecting an airborne electromagnetic system based on its design principles. All three airborne systems operate three-axes receivers which measure the X, Y and Z components of the dB/dt response vector. Each system measures during the on-time to aid in the calculation of the B-field response and to improve sensitivity to strong or shallow conductors. A complete list of technical specifications for each system is outlined in Table 1.

Apart from technical specifications, the type of operating aircraft plays an important role in the selection of an airborne electromagnetic system.

Advantages of fixed wing systems:

- larger payloads provide clients with the option of combining the electromagnetic system with gravity and/or radiometric acquisition
- larger fuel capacities allow for larger ferries and increased endurance
- more cost effective for large scale regional surveys

Advantages of helicopter systems:

- lower survey airspeed provides better spatial resolution
- lower flying height provides improved resolution
- ability to operate without airstrip access

TEMPEST

The TEMPEST system was developed by Fugro Airborne Surveys in the 1990's for shallow to deep geological mapping applications. It has been used for a range of exploration targets including; uranium, groundwater, base minerals and geological mapping. The system operates with a 50% duty cycle square wave of 40 ms period. During processing the 50% duty cycle square wave is deconvolved to a 100% duty cycle square wave and the 20 ms half-cycle is binned into 15 windows (Lane et al., 2000). It typically operates with a 25 Hz base frequency. The receiver bird has recently been fitted with a GPS receiver allowing its position to be accurately known during flight. The position of the receiver is critical in understanding the target response and is particularly useful when undertaking Layered Earth Inversions (LEI) of TEMPEST data. (Brodie, 2010; Lane et al., 2004).

The standard system configuration of the TEMPEST system is presented in Figure 1. Although traditionally flown at a transmitter height of 120 m, in recent years it has been successfully flown with the transmitter at 100 m. This results in the receiver being at a nominal height of just 60 m above the ground. Since its release TEMPEST has been in a state of continual development. Recent improvements include, reductions in system noise and enhancement to the receiver bird and receiver coil stability during flight. These improvements have come principally through advances in the receiver and acquisition systems.

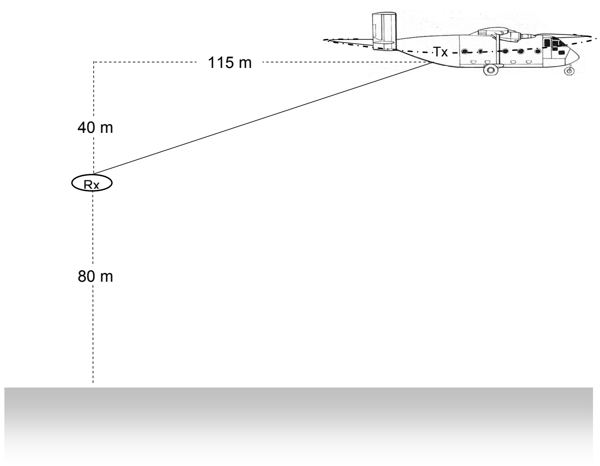

Figure 1. System configuration of TEMPEST and GEOTEM

TEMPEST airborne electromagnetic (AEM) and magnetic data, were acquired over the Yule River borefield to provide assistance for a groundwater drilling program and to provide data for a groundwater model. Additional aims of the survey were to define major hydrogeological units, including palaeochannels, mapping of the bedrock surface, and developing an understanding of how the basement geology influences the shallow hydrogeology.

The geology of the Lower Yule River consists of: Tertiary and Quaternary alluvium (sand, gravel, silt and clay) unconformably overlying the Wacke and Constatine sandstone (De Grey Group), Archaean greenstones (ultramafics) and granites (Portree Granitoid Complex) of the Pilbara Craton, and a series of east-west trending mafic dykes (Haig, 2009). Throughout the area there is a weathered profile at the top of the Archaean basement with occasional occurrences of calcrete (Haig, 2009).

The integrated interpretation results included:

1) Updated interpretation of the basement geology, focussing on structures that control hydrogeology in regolith aquifers;
2) Interpreted relative porosity map showing the vertical and horizontal extent of various units identified from changes in conductivity;
3) Basement surfaces, both weathered and competent, that mark the base of the regolith groundwater system in areas where there were no borehole logs;
4) Palaeochannel extents within the Yule River drainage; and
5) Targets for possible groundwater extraction.

Figure 2 presents schematic cross-sections along Flight Line 1005601 and Tie Line 1900901 (Locations of the lines are shown in Figure 3). Drainage channels have been identified in both sections based on the interpretation of shallow resistive zones as being indicative of the presence of fresh water (eg. Yule River main channel, Flight Line 1005601) or partially saturated gravels and/or sands (eg. current floodplain/possible main palaeochannel, both lines). The basement contact and upper aquifer basal contact were determined based on correlation with borehole log data.

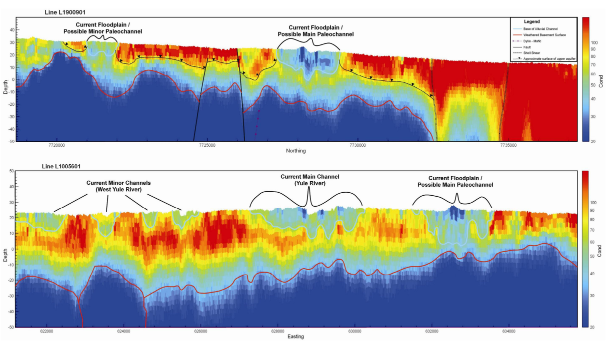

Figure 2. Schematic cross-sections along conductivity depth profile for Tie Line 1900901 and Flight Line 1005601 as indicated in Figure 3 (from Miller and Finn, 2009).

Examination of the EM conductivity-elevation grids showed that as well as identifying current drainage channels it has been possible to identify a number of possible buried palaeodrainage channels (Figure 3). The main trend of the floodplain/shallow extent drainage, only identifiable in the 20m and 10m elevation (AHD) grids, is sub-parallel to the main channel/deep extent drainage. However, it is noticeable that the floodplain/moderate extent drainage patterns display a cross-cutting trend that has been truncated by the present day drainage patterns.

Of the two main cross-cutting, floodplain/moderate extent palaeodrainage bodies identified, the easternmost feature, corresponding to the deep channel in the centre of Tie Line 1900901 presented in Figure 2, has a conductivity response indicative of the possible presence of fresh water and appears to be interconnected with the main channel of the Yule River at its southern extent (Figure 3). This is significant as it provides a possible means of groundwater recharge making this body a target for groundwater extraction. The second, westernmost body has an elevated conductivity response, possibly suggesting the presence of saturated clays which offer reduced prospectivity for groundwater extraction.

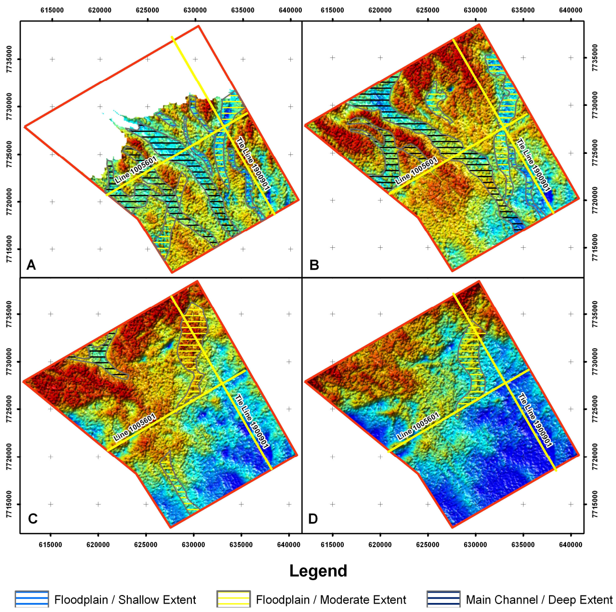

Figure 3. Conductivity-elevation grids with zones indicating the current drainage channels and possible palaeodrainage channels. Elevation (AHD) grids of A) 20m, B) 10m, C) 0m, D) -10m with cross-section profile lines (from Miller and Finn, 2009). Note:grid=5 kilometres.

GEOTEM

The GEOTEM system was developed by Fugro Airborne Surveys in the 1980's for detection of discrete conductive mineral targets. The system operates with a 4 ms half sine wave. It typically operates with a 25 Hz base frequency, however has in the past been used at a range of frequencies from 6.25 Hz to 125 Hz. The standard system configuration of the GEOTEM system is presented in Figure 1.

GEOTEM and HELITEM, airborne electromagnetic surveys were completed over the Nepean EM test area, approximately 25 km southeast of Coolgardie, Western Australia. The area contains a range of known anomalous features associated with nickel sulphide mineralisation within the deformed Norseman-Wiluna greenstone belt. (Combrinck et al., 2008)

The Nepean ore body comprises two nickel sulphide lodes hosted in thrust-stacked serpentinite altered ultramafic units and horizontal pegmatite sills (Abeysinghe and Flint, 2007; Scherbarth, 2008). Based on drilling results, the depth of weathering in the Nepean region ranges from between 7 and 16 metres, and generally increases to the south along the western margin of the survey area (Scherbarth, 2008).

Two known conductive targets exist within the Nepean EM test area. NC1 is a shallow relatively small massive barren pyrrhotite body with a dip of approximately 75 degrees to the west. NC2 is a relatively large carbonaceous shale, approximately 80 meters deep and with a dip of approximately 75 degrees to the west. The X and Z component profile data for NC2 is presented in Figure 4. The double Z component and single X component peak is a typical GEOTEM response for a steeply dipping conductor (Smith and Keating, 1996). The larger Z component western peak suggests that the plate is dipping to the west. Initial modelling analysis suggests that the GEOTEM response agrees well with known target parameters and historical ground survey results.

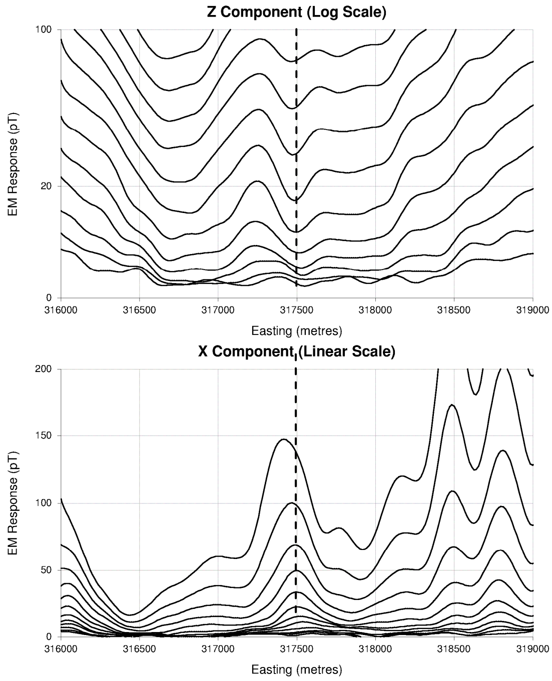

Figure 4. GEOTEM Z and X component B-Field profile data over NC2. Note: the dotted line represents the position of the conductor.

HELITEM

The HELITEM system was developed by Fugro Airborne Surveys in the mid 2000's for detection of deep discrete conductive mineral targets. The system typically operates with a 4 ms half sine wave at a base frequency of 25 Hz, however it can also be operated at other frequencies. The standard system configuration of the HELITEM system is presented in Figure 5.

HELITEM has been in continuous development for a number of years, utilising improvements to system configurations, electronics and post flight processing. Major developments include; increased peak moment, the implementation of a stable receiver platform, improved B-field calculation and enhanced primary field compensation methods. These developments have led to large reductions in system noise and an increased effectiveness in handling rough weather environments and extreme terrain.

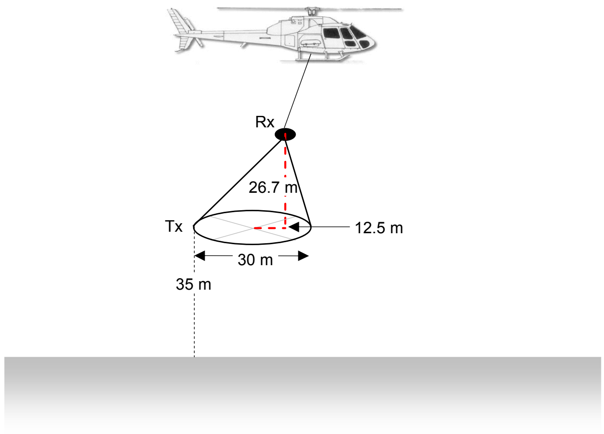

Figure 5. System configuration of HELITEM

The X and Z component profile data for the Nepean conductor, NC2 is presented in Figure 6. The double Z component peak and X component cross over is a typical HELITEM response for a steeply dipping conductor. The larger Z and X component western peaks suggest that the plate is dipping to the west. The X and Z component grids of the Nepean area, 5.19ms after the end of the pulse is presented in Figure 7. The amplitude peak in the Fraser filtered X-component grid (Djeddi et al., 1998) and the skewed double peak in the Z-component grid suggests that the targets are steeply dipping which complement the profile data conclusions. Initial modelling analysis suggests that the HELITEM response agrees well with known target parameters and historical ground survey results.

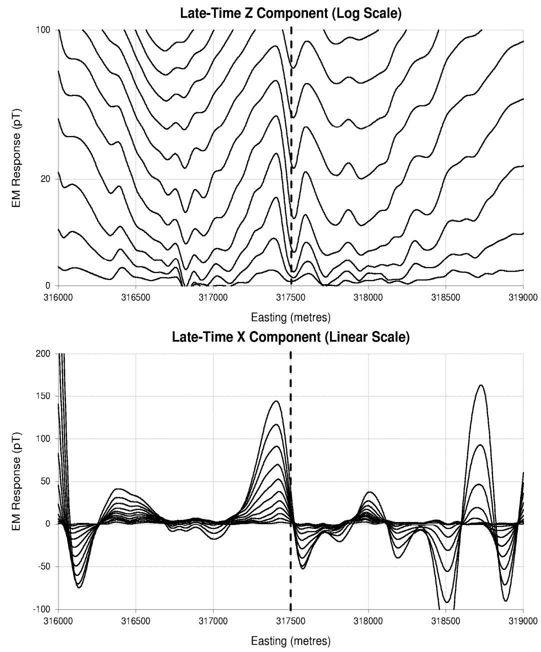

Figure 6. HELITEM Z and X component B-Field profile data over NC2. Note: the dotted line represents the position of the conductor.

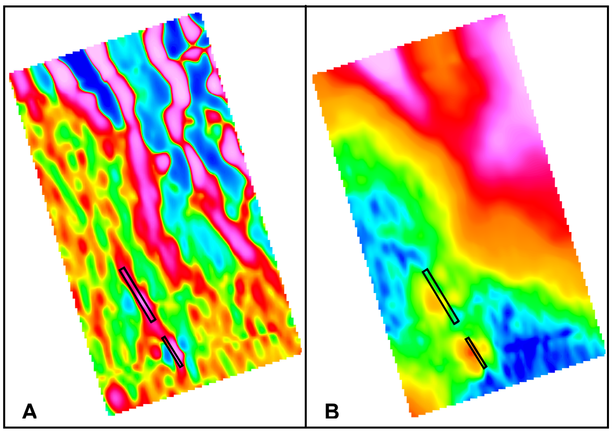

Figure 7. Gridded HELITEM EM B-field 5.19 ms after pulse A) Fraser-Filtered X-Component, B) Z-Component. Note: the black outlines are the positions of the NC1 (south) and NC2 (north) conductor.

DISCUSSION

The ability for a TDEM system to map regolith relies principally on a broad bandwidth and well controlled waveform, while the mapping of deep, conductive targets will benefit from a high transmitter moment and low base frequency. In addition to the broad bandwidth, the mapping of narrow near surface targets requires high spatial resolution which is improved with low system height and close transmitter - receiver separation.

To map the more subtle resistivity contrasts and thinner layers that are utilised in regolith and water resource mapping requires high-frequency content to be generated by the transmitter and fully recorded by the receiver electronics. Despite having a moment of 10 times less than GEOTEM and 50 times less than HELITEM; TEMPEST generates more signal than GEOTEM above 1 kHz and HELITEM above 4 kHz due its rapid turn-off square-wave pulse. The 40 KHz transmitter bandwidth is matched with 50 kHz coils and a 75 kHz acquisition system. The controlled turn-off of a square wave pulse allows the placement of narrow gates close to the transmitter turn-off to capture this high-frequency content.

Both GEOTEM and HELITEM use half sinusoid waveforms with a duty cycle of 20% at a base frequency of 25 Hz. The power drawn from an aircraft generator, or external generators in the case of HELITEM, are used to power the transmitter during the on-time. This is augmented with power from capacitors that have been charged during the off-time allowing for significantly larger moments than could be achieved with higher percentage duty cycles. The dB/dt for a 4 ms half sinusoid waveform is three times higher than for a similar amplitude 10 ms pulse. These very high moments are generated by pulsing half-sinusoidal currents into multi-turn loops and are ideal for energising deep conductors or conductors under conductive overburden. (Liu, 1998).

CONCLUSIONS

The selection of a geophysical system must be determined by the type of exploration target and the required survey specifications. The TEMPEST system is equipped with a large bandwidth that is able to detect subtle conductivity contrasts throughout a broad range of conductivities. This feature of the system is well suited to geological mapping applications and for the detection of unconformity layers. The sinusoidal waveform of the GEOTEM and HELITEM systems is well suited to the detection of discrete conductors due to its ability to achieve much higher peak moments than the TEMPEST square wave system. The significantly higher peak moment of the HELITEM system provides an increased ability to penetrate thicker conductive overburden which is of specific relevance to Australian conditions. In most cases a fixed wing system will have financial advantages over a more costly helicopter system. The lower flying height and slower flying speed of the helicopter system will however, provide for improved spatial and vertical data resolution.

There is no single airborne EM system that provides solutions to all geological scenarios. Each system has strengths suited to a different set of technical, geological and financial factors which are balanced by the client when planning an airborne electromagnetic survey.

ACKNOWLEDGMENTS

We thank Andrew Jones of Water Corporation the Department of Water, Government of Western Australian for permission to use the DeGrey River dataset. We also thank Peter Wolfgram and Denis Cowey for providing technical input in preparation of this paper.

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	TEMPEST	GEOTEM	HELITEM
Base frequency (Hz)	25	25	25
Transmitter area (m^2)	244	231	708
Transmitter turns	1	6	2
Waveform	Square 100% duty cycle	Half-sine	Half-sine
Transmitter pulse width (ms)	10	4	4
Transmitter off-time (ms)	10	16	16
Peak current (A)	300	650	1415
Peak moment (Am^2)	73,200	600,600	2,000,000
Sample rate (kHz)	75	76.8	102.4
Sample interval (μs)	13	52	9.77
Samples per half-cycle	1500	384	2048
Nominal flying height (m)	100-120	120	83
Nominal survey airspeed (m/s)	65	65	25
Transmitter/Receiver separation (m) wrt transmitter X/Y/Z (m)	120/0/40	120/0/40	-12.5/0/26.7
Number of windows (on-time/off-time)	0/15	4/16	4/26
Window centre times	13 μs to 16.2 ms	0.39 to 18.59 ms	0.15 to 18.27 ms
Receiver components	X,Y,Z	X,Y,Z	X,Y,Z
B-field processing	Yes	Yes	Yes
Standard dB/dt units	$pT/s.A.m^2$	nT/s	nT/s
Standard B-field units	$fT/A.m^2$	pT	pT

Table 1. Technical specifications of the TEMPEST, GEOTEM and HELITEM systems