Cole-Cole Inversion of Telluric Cancelled IP Data.

Peter Rowston — *MIM Exploration Pty.Ltd., Australia* — *parowsto@mim.com.au*
Stephen Busuttil — *MIM Exploration Pty.Ltd., Australia* — *sxbusutt@mim.com.au*
Gerard McNeill — *GPX Geophysical Services, Australia* — *gerard@gpx.com.au*

SUMMARY

Induced Polarisation, like all geophysical methods, suffers from the presence of noise. Of the many sources of noise, tellurics can often be one of the most problematic to remove.

An effective method of removing telluric noise has been trialed on dipole-dipole data acquired by MIM Exploration's proprietary MIMDAS system, during routine surveying in NE South Australia. The method utilises impedances determined from previously acquired MT data to estimate the natural field component of the measured signal.

This paper presents results obtained thus far, displaying significant improvement in data quality when compared to the uncorrected data. The benefits of increased signal to noise and higher confidence in Cole-Cole parameter estimation are outlined.

Keywords: MIMDAS, Induced Polarisation, Magnetotellurics, Telluric Cancellation.

INTRODUCTION

In recent times there have been many advances made in the acquisition and processing of Induced Polarisation (IP) data. One of the most important of these, full wave-form continuous sampling acquisition, has facilitated the use of advanced signal processing techniques to increase signal to noise ratios and in turn, increase the depth of penetration of the technique.

Sophisticated stacking routines are very successful in removing semi – random noise e.g. sferic activity. Periodic noise, such as 50 Hz power line noise can also be easily rejected with optimal sampling, stacking and standard frequency domain filtering. However, the predominantly longer period telluric noise is more difficult to remove, particularly if it contains significant frequencies approaching that of the transmitted signal.

The level of telluric noise is often the limiting factor in the attempt to get measurable IP signal at low signal levels. At its worst, telluric noise can often bring acquisition to a stand still.

Also, reliable estimation of Cole-Cole parameters can be highly dependant on the level of telluric activity and our ability to remove its contribution from the IP signal. The estimation of spectral parameters is important as the commonly used 2D inversion codes use an IP parameter more akin to intrinsic chargeability than an observed integrated chargeability.

Using the MIMDAS system a method of telluric cancellation has been implemented by MIM Exploration (MIMEX) and trialed on a routine survey in northeastern South Australia. The process employed utilises impedances determined from previously acquired MT data to estimate the natural field component of the measured signal.

The result of this trial has shown that a significant improvement in signal to noise ratios and in turn an improved capacity to estimate Cole-Cole parameters is achieved. This paper presents the method used and the results of this work

METHOD

Telluric cancellation is undertaken via the calculation of an "inferred natural field", denoted herein as E_{nfx}, for each receiver dipole in the IP array. E_{nfx} is calculated using certain components of the impedance tensor derived from previously acquired MT data and the horizontal magnetic field components acquired at a site remote from the survey area. The applied correction is simply E_{nfx} subtracted from the measured signal for each receiving dipole.

This method is reliant on the collection of MT data prior to IP acquisition. Due to the MIMDAS mode of operation (The reader is referred to Sheard (1998) for a general description of the MIMDAS system and generic survey layout), the collection of MT data in "EMAP" mode (Torres-Verdin and Bostick 1992) is routine and is carried out with little additional overhead. In practice this requires (minimally) the addition of only one set of orthogonal magnetometers and an orthogonal electric dipole to the normal IP survey layout and generally takes less than one hour to collect. The cancellation method is described as follows,

For every IP dipole, impedances Z_{xx} and Z_{xy} are calculated.

For a given frequency ω, the relationship between the electric field $E(\omega)$ and the horizontal components (as measured in traditional MT practice) of the magnetic field $H(\omega)$ can be expressed as the tensor equation,

$$E(\omega) = Z(\omega)H(\omega) \qquad (1)$$

Where Z is the impedance tensor. In the Cartesian coordinate system this can be expressed by the matrix equation,

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix} \begin{bmatrix} H_x \\ H_y \end{bmatrix} \qquad (2)$$

For the cross-strike in-line receiver dipoles we are generally interested in, E_x which from (2) is

$$E_x = Z_{xx}H_x + Z_{xy}H_y \qquad (3)$$

For uniform 1D and 2D earths, the off-diagonal components will be zero and equation (3) becomes

$$E_x = Z_{xy}H_y \qquad (4)$$

Equation (4) is often sufficient to recover the inferred natural field where $E_{nfx} = E_x$ and H_y is the transformed magnetic data measured synchronously at the remote site in the y direction and Z_{xy} is the previously measured impedance data.

In practice, Z_{xy} in equation (4) can introduce noise related to inexact amplitudes and phases. The 1D inversion results from the program "RhoPlus" (Parker and Booker, 1996) can be used in the scalar approach to correct poorly measured amplitudes and phases and to provide a physically realisable set of observations. The RhoPlus inversion fits are presented in Figure 1 as a line plot.

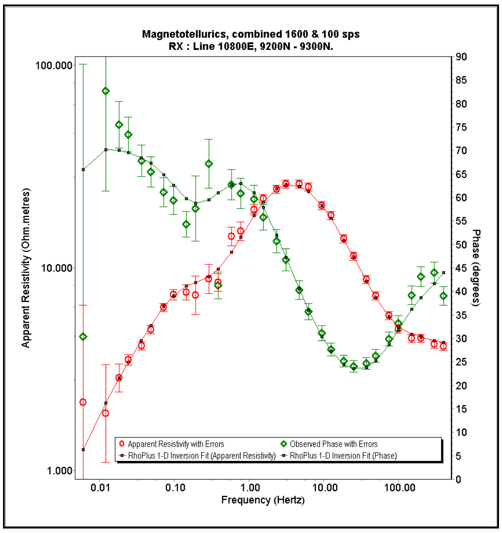

Figure 1. "TM" Apparent Resistivity and Phase with "RhoPlus" Inversion fit. The RhoPlus model fits (lines) are used instead of the measured MT (symbols) to calm the outlier amplitudes and phases

An example of the correction using this method is illustrated in Figure 2 (a). Here a subset of a raw time series (in red) is presented with the calculated telluric in green and the difference in blue. Intuitively, a better stack should result from the processing of the "telluric cancelled" data. Figure 2 (b), a small 3 second sample from the time series in Figure 2(a) is also shown. This is a typical example of the point for point tracking of low signal data and inferred natural field data.

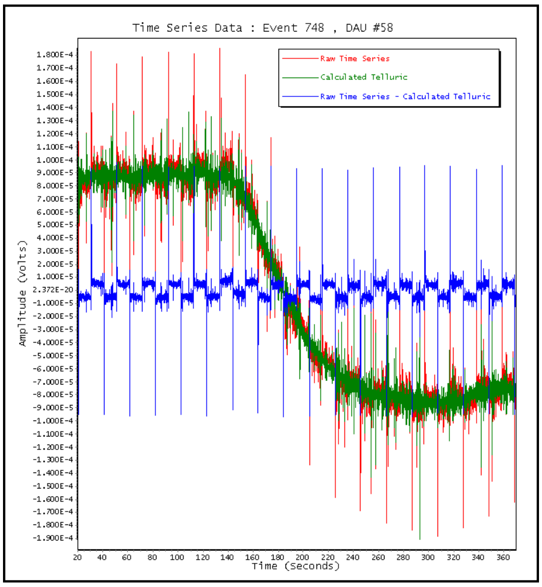

Figure 2(a). Raw Time Series (red), Inferred Natural Field (green), Raw Time Series - Inferred Natural Field (blue).

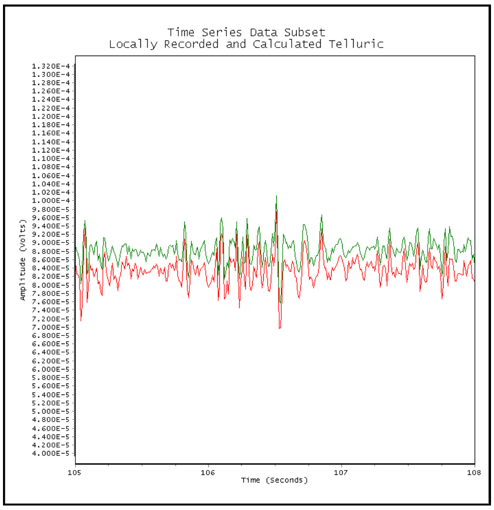

Figure 2b. Subset of Figure 2a from 105 secs to 108 secs. Raw Time Series (red) and Inferred Natural Field (green) .

Synchronisation between the remote site and the survey area is achieved via GPS clocks. The remote site and survey area are networked via a radio or satellite link. This allows real time transfer of H data from the remote base to the survey area providing the operator with the ability to inspect the “corrected data” at the time of acquisition. The correction is usually applied in the time domain to allow for more intuitive QC of the supplied correction.

RESULTS

A trial of the method was undertaken on a routine survey conducted in northeast South Australia. The survey used a standard dipole-dipole configuration with 100m dipoles. As is evident in the plot provided in figure 2(a), MIMDAS surveys are generally acquired with a 100% duty cycle waveform. Unlike most other commercially available IP systems, the current waveform, in addition to the received voltage waveforms, is digitally recorded. This allows any user specified current waveform to be convolved with the system response to produce theoretical decays. We typically choose a 50% duty cycle idealised waveform and derive a chargeability (in mV/V) based upon the MIM chargeability standard[1]. Figure 3 presents calculated waveforms for both telluric corrected and non-telluric corrected data for dipoles at a separation of n = 16.5. Predictably the telluric cancelled

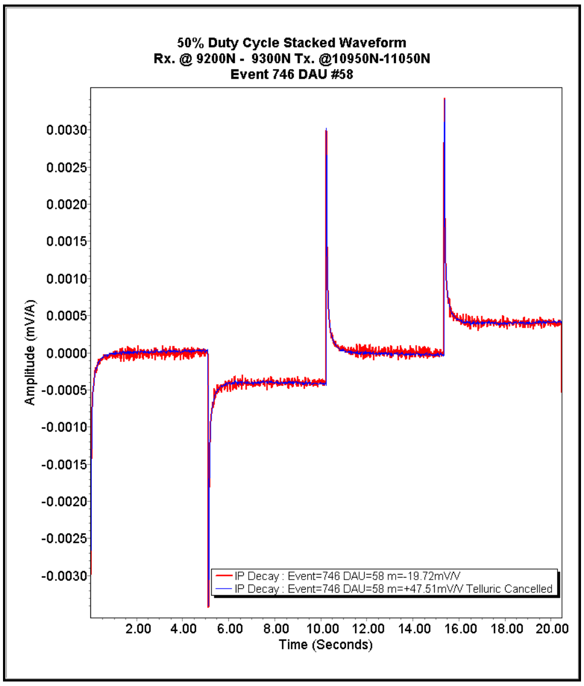

Figure 3 The 50% duty cycle stacked waveforms for the non-cancelled (red) and telluric cancelled (blue) event/dipole pair from figure 2.

response results in a cleaner trace. It is important to note the low signal levels i.e. a normalised Vp in the order of 0.5 uV and also the large difference in chargeability between the telluric corrected (chargeability = 47 mV/V) and the non telluric corrected data (chargeability = -19 mV/V).

COLE-COLE ESTIMATION

Spectral IP parameters are estimated by time domain least squares inversion of the well known Cole-Cole model,

$$\rho(\omega) = R_0 \left\{ 1 - \mathrm{m} \left[1 - \frac{1}{(1 + i\omega\tau)^c} \right] \right\}$$

where R_0 is the DC resistivity, τ is the time constant, c is the frequency dependence and m is the intrinsic chargeability.

The default seed model for the Cole-Cole inversion is based upon measured Vp and measured observed chargeability and assumed average spectral properties of the ground. Any parameter may be held fixed and it is common practice to fix the frequency dependence, c. A Non-linear least squares inversion is carried out on the chosen off-time data points and complementary on-time window. The inversion halts when desired fits are achieved or when a maximum number of iterations is reached.

Figure 4 provides an example of a Cole-Cole model estimate

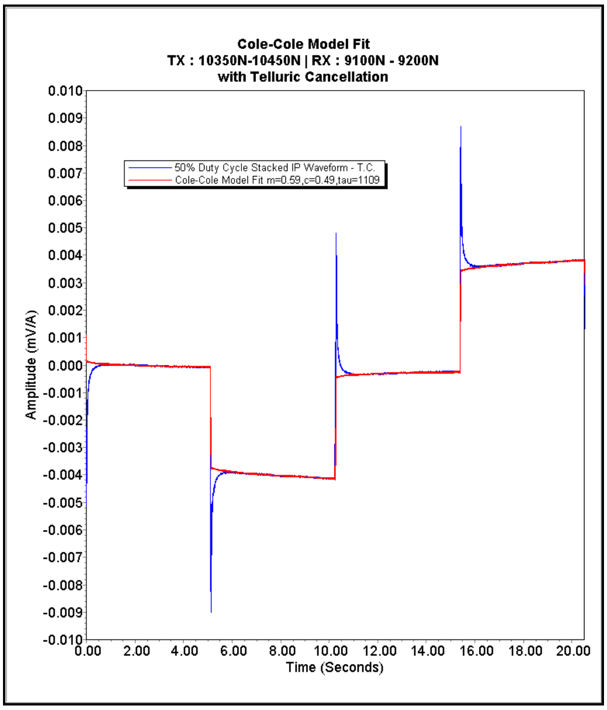

Figure 4. 50% Duty Cycle waveform with fitted Cole-Cole Model with telluric cancellation.

(red) from telluric corrected 50% duty cycle waveform (blue). The waveform presented is the calculated waveform for a potential dipole at a separation of n = 11.5. Primary signal levels are low i.e. normalised Vp here is in the order of 4 uV and yet by virtue of the application of telluric cancellation a reasonable Cole-Cole model estimate can be made.

Figure 5 presents pseudosections of Apparent Resistivity, normalised Vp, Measured Chargeability and the Cole-Cole parameters m and tau, for the non-telluric corrected data (b) and telluric corrected data (c). The primary voltages are provided as an indication of the overall signal levels and again it's pertinent to note that much of the data in the pseudosection (below n= 10.5) has a Vp less than 0.1 mV.

[1] MIM chargeability is defined as an estimate of the average decay voltage in a chosen off-time window multiplied by 1000 and divided by the average charge voltage for a half-duty square wave response over the complementary on-time window.

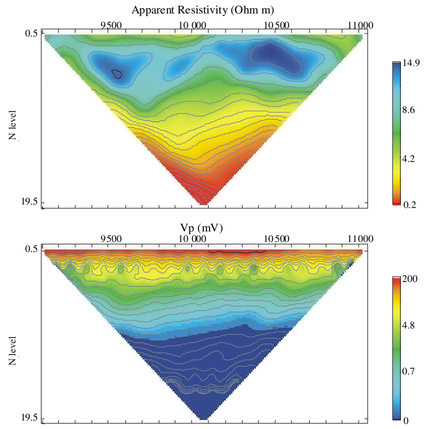

Figure 5(a) Pseudosections of Apparent Resistivity and Vp

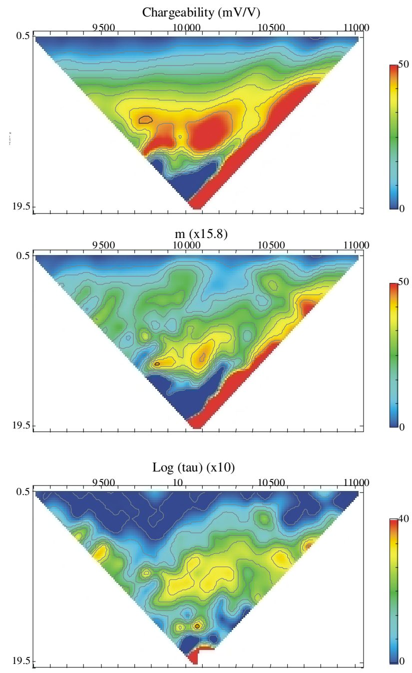

Figure 5(b). Pseudosections of Chargeability and Cole-Cole parameters m and tau for uncorrected data

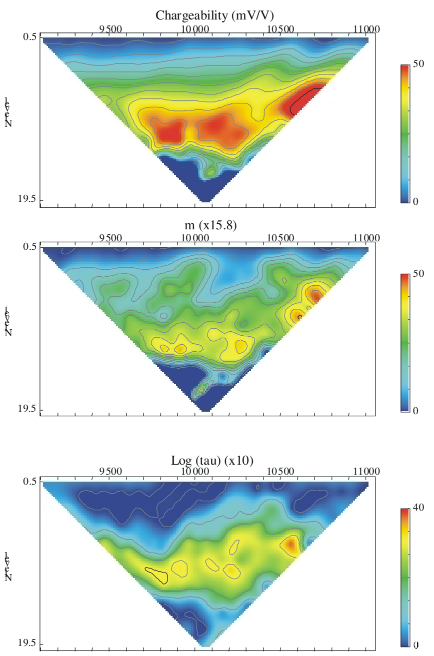

Figure 5(c). same as (b) with telluric cancelled data

The overall improvement in data quality, between the telluric corrected data in figure 5 (c) and non- telluric corrected data Figure 5 (b) for all calculated parameters is clearly evident. The telluric cancellation has also removed the large stripe on the right hand side of the measured and intrinsic chargeability.

CONCLUSIONS

The application of telluric cancellation procedures results in more reliable IP parameter estimates, particularly where natural field noise is of sufficient amplitude and/or at frequencies which envelope the fundamental frequency of transmission. Even in cases where natural field noise is not of major concern, the reliable estimate of spectral parameters is enhanced by its application.

ACKNOWLEDGEMENTS

The authors would like to thank MIM Exploration Pty. Ltd. for permission to show the data used in this paper. Appreciation is also extended to Terry Ritchie for his contributions to the implementation of this method.

REFERENCES

Parker R.L. and Booker J.R. , 1996, Optimal One-Dimensional Inversion and Bounding of Magnetotelluric Apparent Resistivity and Phase Measurem,ents: Phys. Earth Planet. Int, 98,269-282.

Sheard, S.N., (1998). 'MIMDAS - A new Direction in Geophysics'. 13th Bi-annual Conf., Australian Society of Exploration Geophysicists. Abstracts, Preview, 76, 104.

Torres-Verdin, C. and Bostick, F., 1992, Principles of spatial surface electric field filtering in magnetotellurics: Electromagnetic array profiling (EMAP): Geophysics 57, 603-622.