



AIP EFFECTS IN AIRBORNE EM FIXED WING SYSTEMS: A SPECTREM THEORETICAL STUDY.

Andrea Viezzoli
Aarhus Geophysics srl
Cascina, Pisa, Italy
av@aarhusgeo.com

Francesco Dauti
Aarhus Geophysics srl
Cascina, Pisa, Italy
fd@aarhusgeo.com

Nirocca Devkurran
Spectrem Air
Johannesburg, South Africa
nirocca@spectrem.co.za

Brad Pitts
Spectrem Air
Johannesburg, South Africa
brad@spectrem.co.za

SUMMARY

IP effects can distort airborne EM data, usually producing faster decays and, under certain conditions, changes in signal polarity. These effects, if not recognized and treated with a dispersive resistivity model, often lead to artefacts in the resistivities recovered. Historically, the IP effects in fixed-wing AEM systems have been put in the “too hard basket”. This was mainly due to their geometric configuration (and its monitoring) that prevented an unambiguous relation between negative voltages and IP effects. Another deterrent was the high ground clearance, expected to make possible IP effects insignificant. The rapidly accumulating experience on IP effects in helicopter EM systems, however, warrants further research on fixed wing EM and IP. With this work we therefore investigated the fixed wing EM systems sensitivity to Induced Polarization effects, presenting numerical experiments on the SPECTREM^{PLUS} system. We carried out a great number of forward responses, associated with different combinations of Cole & Cole parameters in both homogeneous halfspaces and two - and three - layered models. The analysis showed the SPECTREM^{PLUS} system to be sensitive to the presence of chargeable material, in several Cole & Cole parameters domains. These effects vary non monotonically with resistivity, and become more marked with variations in the layering, i.e., adding a purely resistive basement under a shallower chargeable layer. Deep conductors’ responses can also be widely affected by shallow chargeable strata. The result demonstrate that IP effects are, at times, detectable by the fixed wing EM systems. As is the case for the helicopter EM systems, taking IP into consideration during processing and modelling may increase the accuracy of both data and derived resistivities.

Key words: AEM, AIP, SPECTREM, Fixed-Wing Systems

INTRODUCTION

The interest in the possibility of recovering induced polarization (IP) parameters from airborne time-domain electromagnetic (TDEM) data has recently increased from the mineral exploration industry, academy and AEM data providers (Viezzoli et al., 2013). These effects, often present to some extent in AEM data and referred to as Airborne IP (AIP), are related to the electrically dispersive materials present in the subsurface. These materials can complete a charge and discharge cycle over a finite period of time producing a polarization current which is added, under the quasi-static

assumption, to the induced electromagnetic vortex current. As result, the currents interaction may manifest itself as a strong distortion of the recorded electromagnetic signal which often culminates in the change of sign. Under these conditions, the standard EM inversion approaches based on the general relationships between the measured voltages versus time and depth (from which one can derive the correlation between the conductance and the data sensitivity) can significantly be altered and, in common cases, ceases to be valid (Viezzoli, 2017). As a consequence, failing to recognize and properly model IP effects lead to difficulties in accurate fitting of the data or, worse, recover false structures with incorrect conductivity-thickness parameters. Virtually all the work on IP effects in AEM carried out so far lies in the helicopter TDEM domain. Historically, the IP effects in fixed-wing AEM systems have been put in the “too hard basket”. This was mainly due to their geometric configuration (and its monitoring) that prevented the unambiguous relation between negative voltages and IP effects. However, the severity of the potential implications to EM modelling warrants more research on the potential impact of IP on fixed wing EM system’s data. We turn to the Spectrem system (Leggatt et al., 2000) with a large and systematic dataspace analysis.

METHOD AND RESULTS

In order to define how and if the Induced Polarization effects affect the SPECTREM fixed-wing system AEM response, we use an approach that points to a large and consistent dataspace inspection, relative to a great number of capacitive models. For doing this, we perform a forward responses analysis relative to different synthetic models parametrized by the Cole & Cole parameters. Applying several small variations to each parameter we aspect a suite of continuously changing responses in the data space, with the AIP signature that manifest themselves with negative gates or with transient distortions without giving a change in sign. In order to obtain a satisfactory geological-applicative description of the model-space, we consider three different halfspace layering configurations (homogeneous, two-layers and three-layers) that approximate, varying their layer parametrisation in each experiment iteration, a great geological assets variety. For each Cole & Cole characterized capacitive model, an equivalent purely resistive model with the same layering and electrical stratigraphy was calculated. This approach allows one to compare the forward responses relative to two equivalent halfspaces, that differs only by their dissipative behaviour, and to uniquely relate the measured signal distortions to the Induced Polarization effects. To quantify these distortions, a vectorial metric called “*IP Ratio*” is used. This metric is defined as the ratio, gate per gate, between each pair of equivalent models forward responses (equation 1).

$$IP_Ratio_i = \frac{voltage_IP_i}{voltage_NOIP_j} \quad (Eq. 1)$$

The elements of the resulting vector quantify the magnitude, as a pure number, of the IP distortions. These are calculated only above the additive and multiplicative noise level to quantify the measurable and detectable capacitive effects only. An example of IP Ratio, relative to a pair of synthetic forward responses, is represented in figure 1 as red dots.

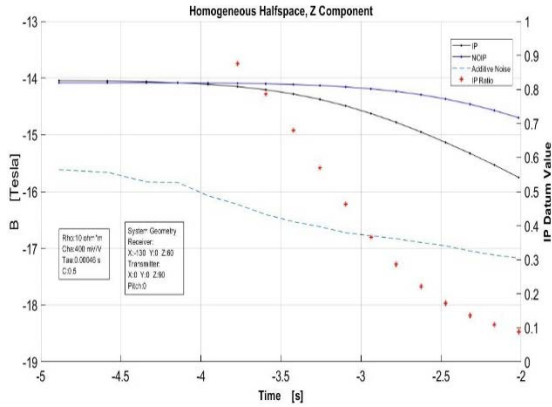


FIG 1: Comparison between a couple of equivalent forward responses relative to a capacitive (black) and a purely resistive homogeneous halfspace (blue). The halfspace parameters and the system's specifications are indicated in the box in figure. The red dots represent the relative IP Ratio vector for the two signals.

To better resume and visualize this huge quantity of vectorial information, the IP Ratio metric is summarized into a scalar metric called the “IP Datum”. This is defined as the number of time windows (IP Ratio vector elements) that present a distortion. Given the experiment's configuration, the distortion quantified by the IP Datum are attributable only to IP effects. With this approach, we inspect and visualize the forward responses relative to 10^4 capacitive models for the homogeneous halfspace, $5 \cdot 10^4$ forwards for the two-layers model and 100 forwards for a selected parameters suite for the three-layers model.

The IP Datum thus calculated is displayed in a multi-dimensional plot in order to map the capacitive effect distortion magnitudes in function of the Cole & Cole parameters from which they were calculated. An example of the result's representation for a homogenous halfspace is represented in figure 2.

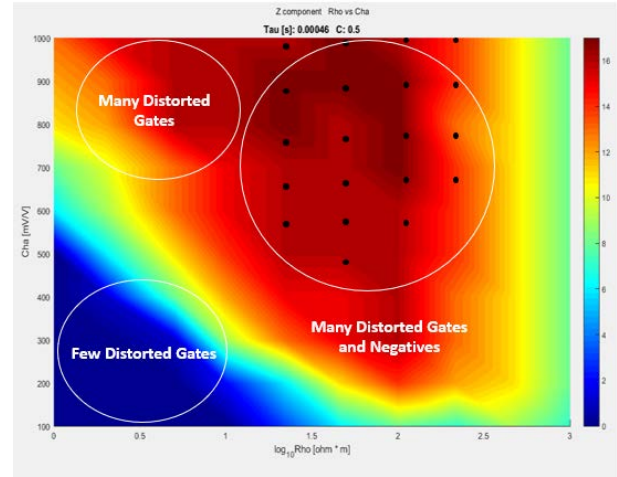


FIG 2: Representation of the IP Datum magnitudes for a homogeneous halfspace. The Tau and C parameters are kept fixed in the title, while the $\log_{10}(\text{Resistivity})$ and Chargeability vary in the axis. The colour scale represents the number of distorted gates quantified by the IP Datum, and the black dots where at least one negative gate is measured.

With this visualisation, the displayed point represents the Datum magnitude value, and, its coordinates, the model parameters from which it is calculated. The black dots represent where at least one negative value was measured in the corresponding forward response.

With this approach it is possible to define for which parameter domains the Induced Polarization effects produce visible distortions.

For a selected set of parameters, the results are represented in tables like figure 3 to compare consistently the effect of the Cole & Cole parameters on the measured data.

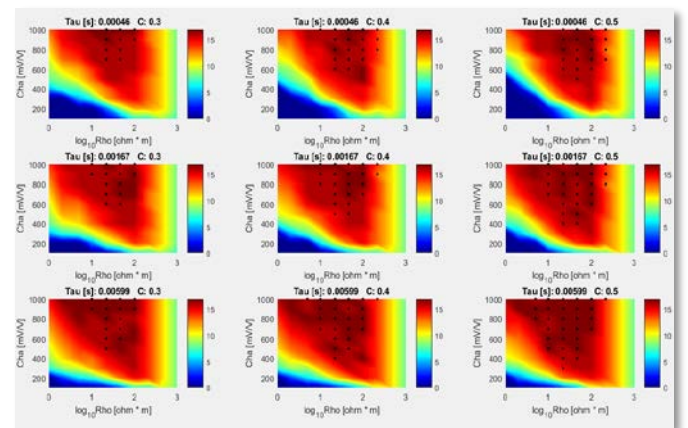


FIG 3: Table of results for a homogeneous halfspace varying also the Tau and C parameters on the titles.

The table represented in figure 3 shows the results for a homogeneous halfspace. It is visible, in first instance, how the recorded signals are diffusely affected and distorted by the induced polarization effects. The progression in the intensity of IP distortion follows the resistivity increasing and culminate, for a central resistivity range, in the voltages change of sign.

For lower resistivities, the dominant conductive domain does not favour the development of negative gates, given a stronger conductive current over the polarizing one. As resistivity grows, the induced current decays faster and is superceded, in intensity, by the polarizing current. For this parameter's configuration, the polarization current dominates until the resistivity becomes too high and the signal is affected by noise at early times.

Differently, for a two layer (figure 4) model with an equivalent model parameters configuration, the negative gates became more pervasive and the signal rapidly decays into noise. This behaviour is given by the presence of a deep resistive basement located below the capacitive parameter-varying first layer. For this configuration, the vortex current moving in depth meets a highly resistive layer in which it will propagate and decays faster than in the previous one. This leads to a dominance of the polarization current mode at opposite toward on the conductive current in the shallower layer, also for conductive domains.

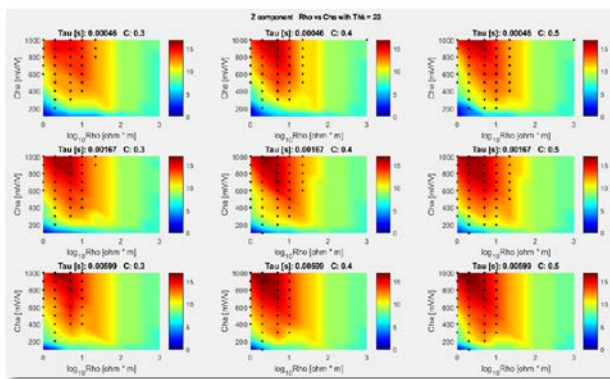


FIG 4: Table of results for a two layers model. The parameters indicated on the axis and in titles are referred to the first shallower layer. The first layer thickness is of 25m for all the combinations and overlays a deep purely resistive basement

For a 3 Layer model (figure 5), where the IP Datum is expressed as a function of the first layer resistivity (abscissae) and of the second layer thickness (ordinate). The Datum anomaly appear only after about 100m of thickness of the second layer. It is thus legitimate to assume that if the conductive layer is close enough the first layer, no difference in the IP Datum are visible, due to the strong inductive currents that. Only by increasing the second resistive layer thickness is it possible to observe the IP effects and, thus, the Datum anomalies. This indicates how the deep conductive layer contributes to the propagation of the inductive currents in the halfspace; when it is placed at shallow depths, the polarization currents do not develop with sufficient intensity to dominate the strong induction currents that are generated in the underlying conductive layer.

Wherever one of these conditions yield measurable distortions of the Spectrem responses due to IP, failure to take IP into account will result in inaccurate modelling of the EM data.

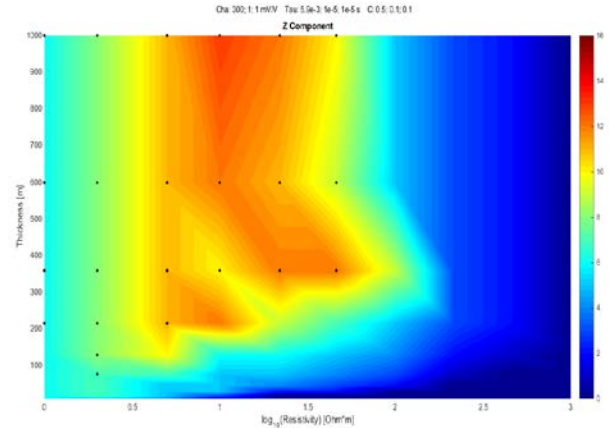


FIG 5: IP Datum response for a three layers model with parameters reported in title and axis.

CONCLUSIONS

The results presented herein offer a solid base for a better understanding and recognition of the range of AEM fixed wing data affected by IP.

Summarizing the results, we conclude that:

- 1) in a homogeneous and chargeable halfspace, AIP effects are present in limited subdomains of the model space. They never decrease with increasing resistivity and chargeability, but there are large domains where they are unaffected by their change.
- 2) In general, the AIP effects are predominantly affected by layering, and Spectrem is no exception. The presence of resistive hosts increases the IP effects by orders of magnitude.
- 3) Under some circumstances, failure to take IP effects into account may provide significant artefacts in the modelling of the Spectrem data.

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