Lessons learned from a decade of AIP modelling

Andrea Viezzoli
Emergo s.r.l.
Pisa (IT)
andrea.viezzoli@em-ergo.it

SUMMARY

Work carried out from AEM 13 till now shows that IP effects in AEM data need to be modelled. Doings so augments the overall impact of an AEM survey on a variety of levels, whether the physical proxy for the mapping is conductivity or chargeability. Modelling IP effects in AEM data will soon become the industry standard.

Key words: airborne EM, IP, AIP, exploration, modelling, inversion.

INTRODUCTION

At AEM 2013, Viezzoli et al. (2013) discussed on the possibility of modelling IP effects in AEM data, extending beyond the seminal research of the late eighties (Smith and West, 1988). Although based on reasonable theoretical background, the AEM 2013 work was at its very early stages, and lacked significant statistics in real life applications. The last 10 years saw a continuous growth in AIP research and applications by several groups (e.g., Oldenburg and Kang, 2015, Macnae, 2016). I now summarize herein the main take home messages from the work that I, together with several colleagues, have been personally involved in during the past decade.

METHOD

The fundamental concept around AIP is that AEM too captures the dispersive nature of resistivity, a phenomenon not limited to galvanic methods. Is it only using a dispersive resistivity model that negatives in concentric loops can be explained.

The vast majority of the work we carried out is based on what is perhaps the most common of the induce polarization models, the one by Cole and Cole, in the notation given by Pelton et al. (1978). Ever present in galvanic methods, it was found to be suitable also for inductive methods.

Alternative models tested include the MPA (Fiandaca et al., 2018). These were the basis for forward models. As for inversions, the workhorse was the Spatially Constrained Inversion. Variations on the SCI included hybrid, multimesh approaches (Fiandaca) that explored more thoroughly the balance of information across the model parameters. The added value of joint inversions of ground galvanic and ground/airborne inductive data was also assessed.

Starting from the easier concentric loop AEM systems, where the presence of negatives is unmistakably associated with IP effects, we moved onto offset systems, B field (including *squids*) receivers. All the modelling, both synthetic and on real data, was carried out using Aarhus Inv (Auken et al., 2015) and, more recently, EEMverter (Fiandaca et al., 2023).

RESULTS

This sections recaps a list of the main findings of hundreds of case AIP studies, numerical experiments, discussions with clients and colleagues. Most of the work is ongoing. Space limitations allow including herein supporting evidence only for a few of them. Some were already included in the different publications on this topic (cfr Viezzoli et al., 2017; Kaminski and Viezzoli, 2017; Viezzoli and Manca, 2020; Viezzoli, et al 2020, Viezzoli and Manca, 2020; Viezzoli et al., 2021a; Viezzoli et al., 2021b; Fiandaca and Viezzoli, 2021)

1. **How does AIP manifest itself**: there is more than negatives to AIP; they usually affect entire transients, from early to late times (cfr Figure 1). The interplay between standard EM eddy currents and IP currents can alter significantly the *time/depth* relationship in TEM soundings.
2. **Relevance towards recovering correct resistivities**: Failing to model IP effects, when present in the EM data, results in erroneous resistivity models. Typical artefacts are overestimation of bedrock resistivity, underestimation of cover thickness and resistivity, geological conductors appearing as isolated bedrock conductors, but also legit bedrock conductors disappearing. On the other hand, modelling IP can (it does not always) return the correct resistivity, at all depths.
3. **How much sensitivity does AEM have on IP**: AEM's sensitivity to chargeability is limited by a number of factors (base frequency, S/N, the fact that pure induction currents and IP currents are present at once). As a consequence, the most common source of measurable AIP effects originates from shallow chargeable layers over resistive basement. It is possible to track chargeable layers to depths of hundreds of m, if buried below resistive cover. Customized regularization and model updates of the different parameters is crucial to obtain more robust results.
4. **How does AIP compare with galvanic IP**: Direct comparison on real data is hindered by the fact that they usually use different frequencies (lower for ground IP, which charges up bigger particles), and are inverted with different models (e.g., solving for m versus M). In these cases the comparison shows positive correlations only at times, and over certain subdomains. Using more similar approaches increases the correlation (cfr Figure 2). AIP will/should not replace ground IP, but rather complement it. There is room to increase further the interaction, with associated mutual benefits, between AIP and ground IP. Joint inversion of inductive and galvanic IP data is possible and can improve mapping capabilities.
5. **What does AIP-derived chargeability tell us**: This is one of the points that calls for much more work. To date, evidence has shown that chargeability recovered from standard AEM systems is more frequently associated to fine grained material such as regolith, certain types of

alterations, permafrost, lake sediments, etc. In fewer occurrences it was due to disseminated mineralization.

6. **Are fixed wing EM systems affected by IP:** there is no fundamental reason they should not. On the other hand, spotting AIP in them is harder due to a number of factors. Beside the most obvious (negatives can have a geometrical reason), these factors include the extra degrees of freedom introduced by the poorly monitored varying Tx-Rx distance and varying Rx attitude, the relatively heavy postprocessing carried often out by some of the contractors that introduce other unknowns.
7. **How pervasive/frequent are AIP effects:** experience shows that measurable IP effects can be/are present in all the instances there is both a chargeable cover and the cover itself has a conductance < 100 S. Such scenarios are very common across all latitudes. This finding agrees with theoretical results shown in Figure 3. The latter displays the measurable (i.e., above noise) distortions due to extremely strong chargeability over each one (j) of the gates of a nominal HTEM system, calculated as below: Only transients associated with conductance above 100 S can be considered safely free from measurable IP artefacts also in presence of the strongest chargeabilties. For example, a sequence of alluvium layers, with thick (> 200m), fine grained strata provide a typical examples of scenario where IP will never affect AEM data (down to frequencies presently considered realistic for these systems; ground EM can be affected further). This is because the EM currents in such layer are strong and take a long time to pass through it, therefore masking the contribution of the IP currents.

$$Distortion_j = log10\left\| 100\,\frac{fwr_{NOIP_j} - fwr_{IP_j}}{fwr_{NOIP_j}} \right\|$$

8. **AIP relevance towards mapping:** the goal of an AEM campaign is to investigate the electrical properties of subsurface; unattended AIP will result, in many instances, in artefacts in the recovered properties. This applies both to mineral exploration and (hydro)geological mapping.
9. **AIP in old and new data:** Virtually all "modern" data, that is acquired past 2000, can be re-modelled taking IP into account. This may unlock new value from these datasets. As for new data, the ever-increasing dipole moment, the lowering base frequencies and the greater attention contractors are devoting to IP effects, they all concur towards affirming AIP modelling as the new norm in AEM.

CONCLUSIONS

Modelling IP effects in AEM data has proven its relevance and worth over a variety of cases and applications, and is bound to become the industry standard.

AKNOWLEDGMENTS

I would like to acknowledge all the colleagues and co-authors that worked with me on this topic, together with clients that shared their feedback and allowed publishing results. They are too many to mention each of them. I do however owe a mention to Yusen Ley Cooper, Gianluca Fiandaca, Francesco Dauti, Antonio Menghini, Regis Neroni, Chris Wijns, Tim Munday, Vlad Kaminski. Part of this work was funded by the H2020 European projects "Semacret" and "Infact".

REFERENCES

Auken, E., A. V. Christiansen, G. Fiandaca, C. Schamper, A. A. Behroozmand, A. Binley, E. Nielsen, F. Effersø, N. B. Christensen, K. I. Sørensen, N. Foged, and G. Vignoli, 2015, An overview of a highly versatile forward and stable inverse algorithm for airborne, ground-based and borehole electromagnetic and electric data: Exploration Geophysics, 2015, 223-235.

Fiandaca, G., Viezzoli, A. (2021) Inversion of Airborne IP data with a multi-mesh approach for parameter definition. AEGC expanded abstracts.

Fiandaca, G., Zhang, B., Chen, J., Signora, A., Dauti, F., Galli, S., Sullivan, N.A.L., Viezzoli, A. (2023). Closing the gap between galvanic and inductive methods: EEMverter, a new 1D/2D/3D inversion tool for Electric and Electromagnetic data with focus on Induced Polarization AEM2023 - 8th International Airborne Electromagnetics Workshop, 3-7 September 2023, Fitzroy Island, QLD, Australia.

Fiandaca, G., Madsen, L.M. and Maurya, P.K. (2018), Re-parameterisations of the Cole–Cole model for improved spectral inversion of induced polarization data. Near Surface Geophysics, 16: 385-399.

Kaminski V., and Viezzoli A., 2017. Modeling induced polarization effects in helicopter time-domain electromagnetic data: Field case studies. B49-B61 (82-2), Geophysics.

Macnae, J. 2016, 'Quantitative estimation of intrinsic polarization and superparamagnetic parameters from airborne electromagnetic data', Geophysics 81(6), E433-E446.

Oldenburg, D. W. and Kang, S. 2015, 'Recovering IP information in airborne-time domain electromagnetic data', 24th ASEG-PESA meeting - Perth, Extended Abstract.

Pelton W.H., Ward S.H., Hallof P.G., Sill W.R. and Nelson P.H. 1978. Mineral discrimination and removal of inductive coupling with multifrequency IP, Geophysics, vol. 43.

Smith R. and West G., 1988, TEM Coincident Loop Negatives and the Loop Effect: Exploration Geophysics, 19, 354 - 357

Viezzoli, A., V. Kaminski, and G. Fiandaca, 2017, Modeling induced polarization effects in helicopter time domain electromagnetic data: Synthetic case studies: Geophysics, 82, no. 2, E31–E50.

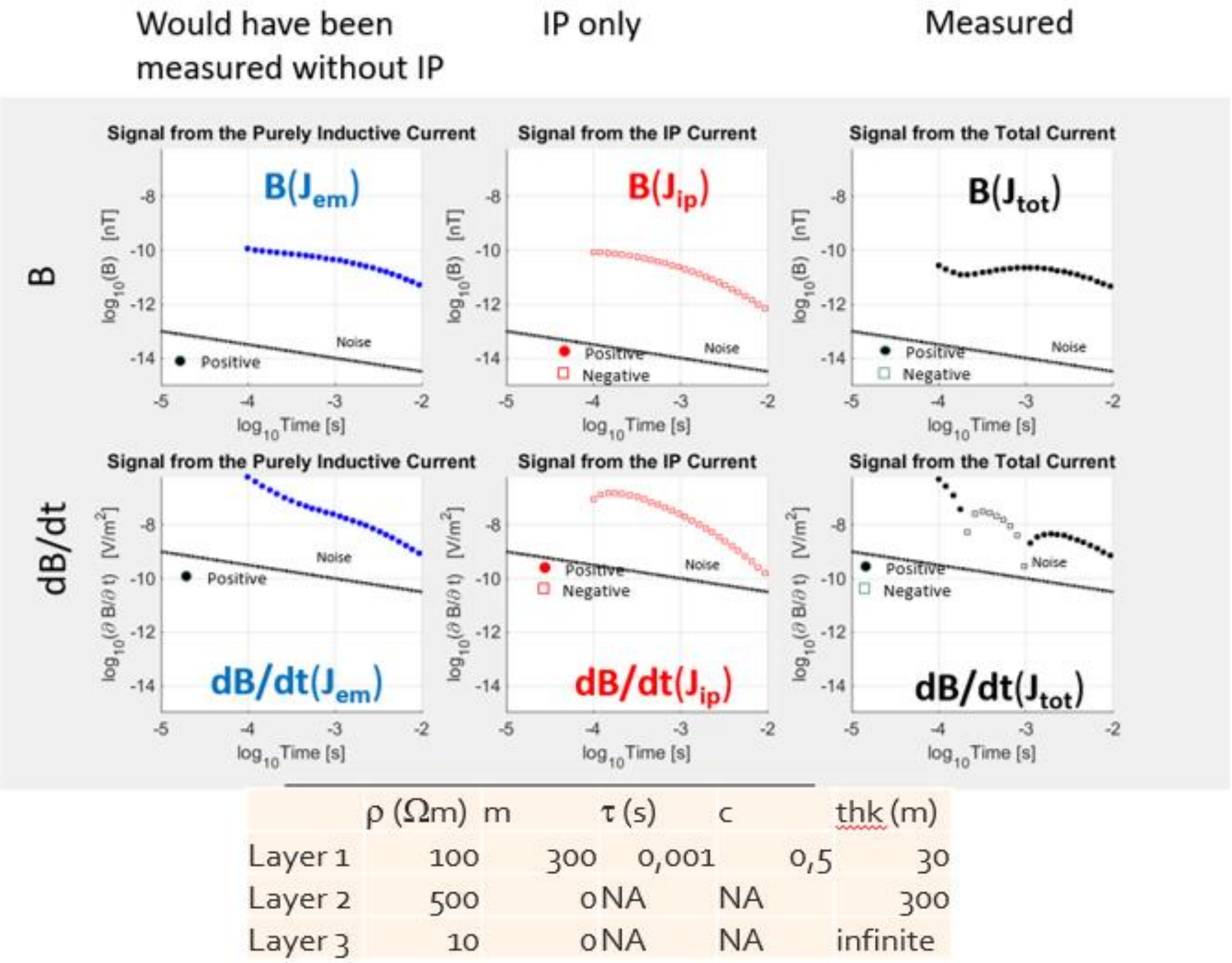
Viezzoli, A., Dauti, F., Devkurran, N., Pitts, B., 2021a. AIP effects in airborne em fixed wing systems: a spectrem theoretical study. AEGC expanded abstracts.

Viezzoli, A., Dauti, F., Wijns, C., 2021b, Robust scanning of AEM data for IP effects, Exploration Geophysics, 52 (5).

Viezzoli A., and Manca, G., 2020. On airborne IP effects in standard AEM systems: tightening model space with data space, Exploration Geophysics, 51:1, 155-169.

Viezzoli, A., Manca, G., Wijns, C., 2020, Causes and effects of the AIP trap in AEM data, Journal of Applied Geophsyics, 175.

Viezzoli A., Fiandaca, G., Sergio, S. 2013, Study on the potential of recovering IP parameters from Airborne TEM data in layered geology, Expanded abstract, 6th International AEM Conference & Exhibition.



	ρ (Ωm)	m	τ (s)	c	thk (m)
Layer 1	100	300	0,001	0,5	30
Layer 2	500	0	NA	NA	300
Layer 3	10	0	NA	NA	infinite

Figure 1. The effect of IP currents on measured transients of a nominal HTEM system, for the three-layer model described in the panel. The first layer is the only chargeable, the last represents a bedrock conductor

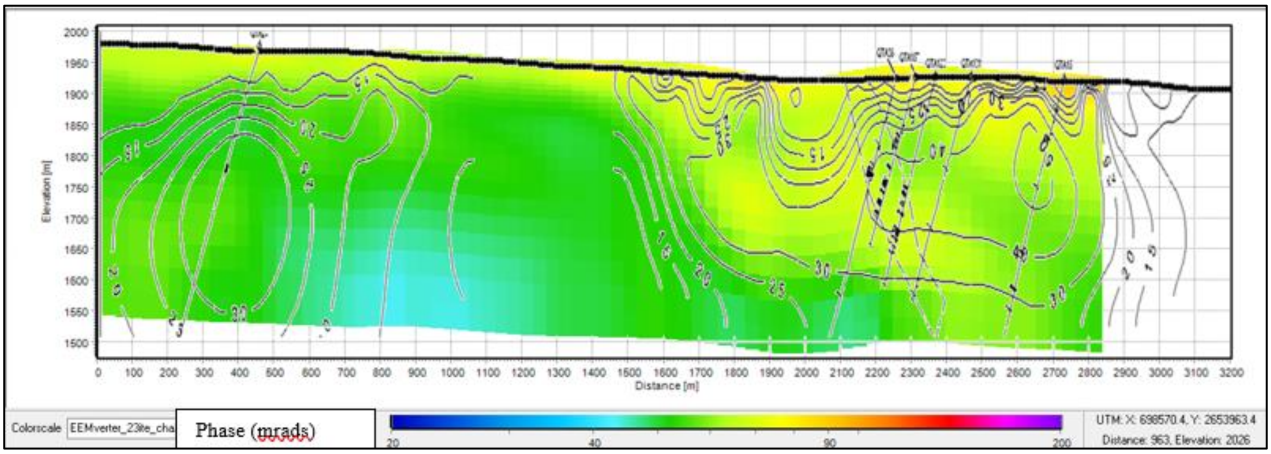


Figure 2. Phase (IP) derived fromn Galvanic (isolines) and AEM (bottom background colour) data, over coincident lines (edited from Fiandaca and Viezzoli, 2021)

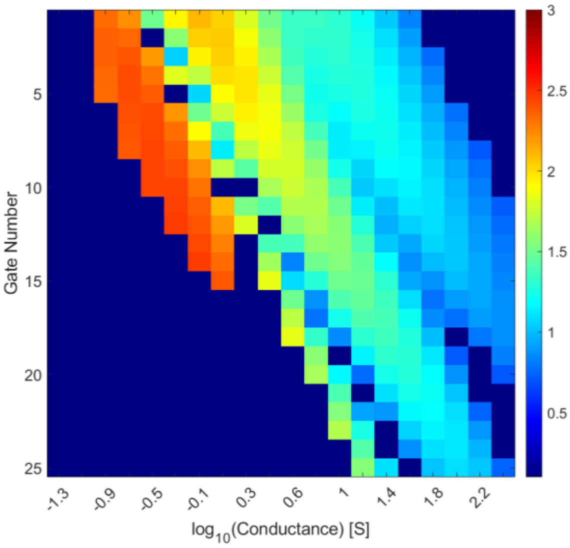


Figure 3. Distortions (cfr text for details) due to IP effects over individual gates of nominal HTEM system, as a function of cover's conductance.