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Low induction number approximation revisited

Welcome readers to this issue's column on geophysics applied to the environment. Back in the December 2017 issue I diatribed about the use and misuse of the Low Induction Number (LIN) approximation in Terrain Conductivity Meters (TCM) like the Geonics EM31 and various other instruments like the GF Instruments CMD devices. I mentioned that there was some code that James Reid had written that corrected the LIN approximation when data were collected under conductive conditions. I then mentioned that I have been working with inverting the data, as an alternative to LIN correcting it, and that I liked the results. Well I have been working on some data provided by Andrew Telfer from Australian Water Environments (AWE), to evaluate the use of a TCM for work with the Murray Darling Basin Authority and the results of this inversion are not as good as hoped. So, in this article, I am going to present the results that bothered me, and I am hoping that someone out there has some insight as to why this isn't working as well as it seems it should.

It all started with some shallow TEM (not TCM) data that I collected in 2005 with AWE on a small section of Murray River floodplain as part of a larger project to look at strategies to rejuvenate some of the drought affected floodplains on the river. The data set was interesting as it clearly showed a conductive (salt affected) floodplain and a nice wedge of relatively resistive river water on the river bank (Figure 1 shows data collected at the same site in 2011). These data were collected using a 'standard' Zonge Engineering NanoTEM system, utilising 20 m × 20 m transmitting loops and a 5 m × 5 m centred receiving loop; data were collected at 20 m intervals along the transect. We have collected data in this area a number of times over the years.

In 2016 AWE collected data roughly along the same traverse using a GF Instruments CMD Explorer, and then collected soil and groundwater conductivity data from shallow bores at set intervals along this traverse to provide 'ground truth'. Remember that with the CMD Explorer run in the high moment mode, data are collected using vertical coaxial transmitter and receiver coils at three 'dipole' lengths to get information from approximately 2 m depth to about 7 m depth. I inverted the data using the *Aarhusinv* program (Auken et al., 2015; http://hgg.au.dk/software/aarhusinv/); in fact all of the data shown in this article were inverted using *Aarhusinv*. This program is available for academic projects, but is also the engine that drives AarhusGeoSoftware's Workbench inversion platform and is commercially available from AarhusGeoSoftware. *Aarhusinv* is very flexible, allowing, for example, the data to be inverted to produce both blocky, discrete layered inversions, as well as smooth-model inversions. Smooth model results are shown here, but I generally test both inversion styles when inverting EM data.

For the CMD data, to get as much depth information as possible, I inverted data collected from all three of the transmitter/receiver separations available. I tested inverting just the quadrature data (derived from the recorded conductivities), as well as both the quadrature and the in-phase data together. Figure 2*a* shows the results when only the quadrature data were inverted (the approach that I suspect is most often used) and Figure 2*b* shows the result when the quadrature and in-phase data were inverted together. Figure 3 shows the NanoTEM inversion for the data collected in 2011; this is the same data set as shown in Figure 1 – only the top 10 m are shown here so as to make comparison with the CMD data easier. The depth of investigation (DOI) as reported by *Aarhusinv* for the CMD data ranged from about 3.5 to 5 m for the quadrature-only results shown in Figure 2*a*, with inversion residuals that ranged from about 0.1 to 1.1 (higher values over the more complicated structure at the west end of the line). For the inversion of the in-phase and quadrature CMD data shown in Figure 2*b* the DOI's ranged from 6 to 9 m, while the inversion residuals ranged from 0.8 to 5 (again the

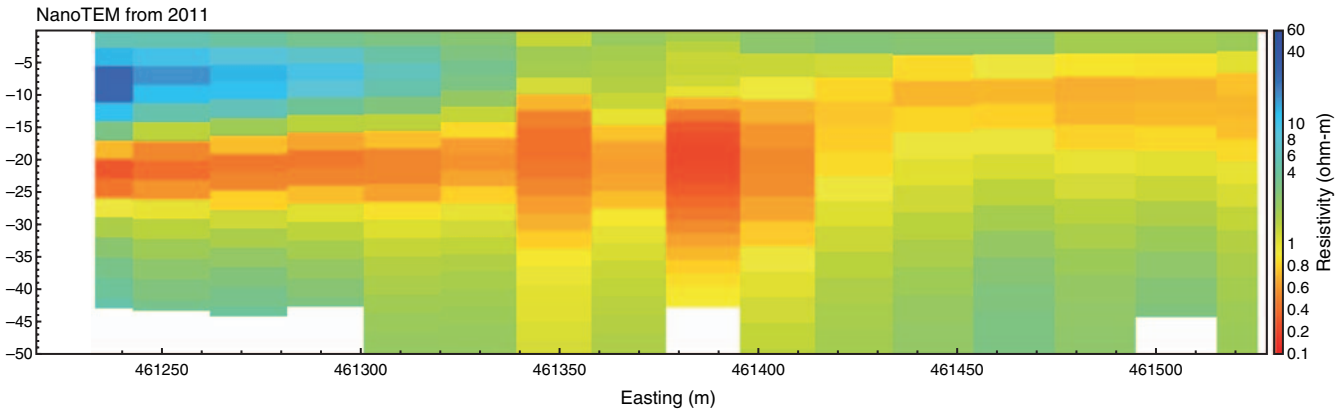

Figure 1. *Resistivity-depth section of NanoTEM data collected in 2011. These data were inverted using Aarhusinv and the whole depth range of the inversion is shown. The river (for all of these sections) is only 10 or 20 m from the left end of the plot. There is an obvious wedge of resistive fresh groundwater sitting over the more conductive, saline groundwater at that left edge of the section.*

higher residuals were observed at the river end of the line where the structure is more complicated). For the NanoTEM data, the DOIs were on the order of 25 m, and the inversion residuals ranged from 0.55 to 1.5.

Figure 4 graphically compares the results from the CMD and NanoTEM data sets at one of the sample locations near the river; the CMD and NanoTEM data are shown in units of mS/m (everywhere else the inversion results are shown in ohm-m) while the soil conductivity and groundwater data are shown as TDS (in mg/litre); this comparison of conductivity and TDS explains some of the obvious difference between the two sets of results. The explanation for differences are undoubtedly more involved than just the difference in units – Archie's Law type factors must also be in play. Interestingly, it appears that the response from the CMD is just too shallow (and looks that way when Figures 2*b* and 3 are compared as well), and assuming that the two sets of units scaled properly, the shallow TEM response appears to at least track the ground variation better. Obviously this isn't a perfect comparison as the TEM data were collected in 2011, while the CMD and ground data were collected in 2016. Nevertheless, the two data sets collected at the same time (the CMD and ground data) just don't match very well. Or am I expecting too much?

Thinking a little more about the results, part of me wants to 'like' the results when the in-phase data are included, as there appears to be more information, but I am just not sure about that, and need to keep testing that at more locations (and in different conductivity scenarios). Maybe I'm just trying to get too much out of these simple data sets and should be satisfied with the results from the quadrature- only inversions. Nevertheless, it seems to me that the quadrature-only inversion does not match the ground data

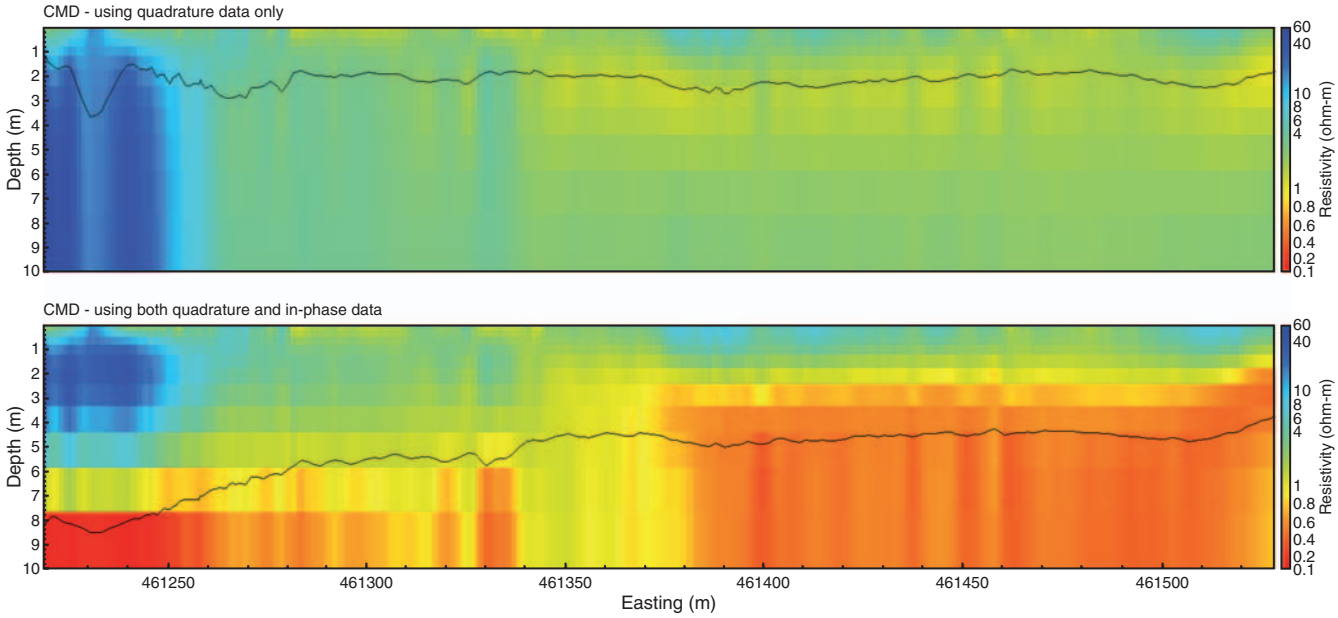

Figure 2. *Resistivity-depth sections of inverted CMD data comparing results using only quadrature data in Figure 2a, while both in-phase and quadrature data were inverted together for the results shown in Figure 2b. Note that the approximate DOI is indicated with the thin black line. The approximate location of the test bore shown in Figure 4 is indicated with the vertical black line.*

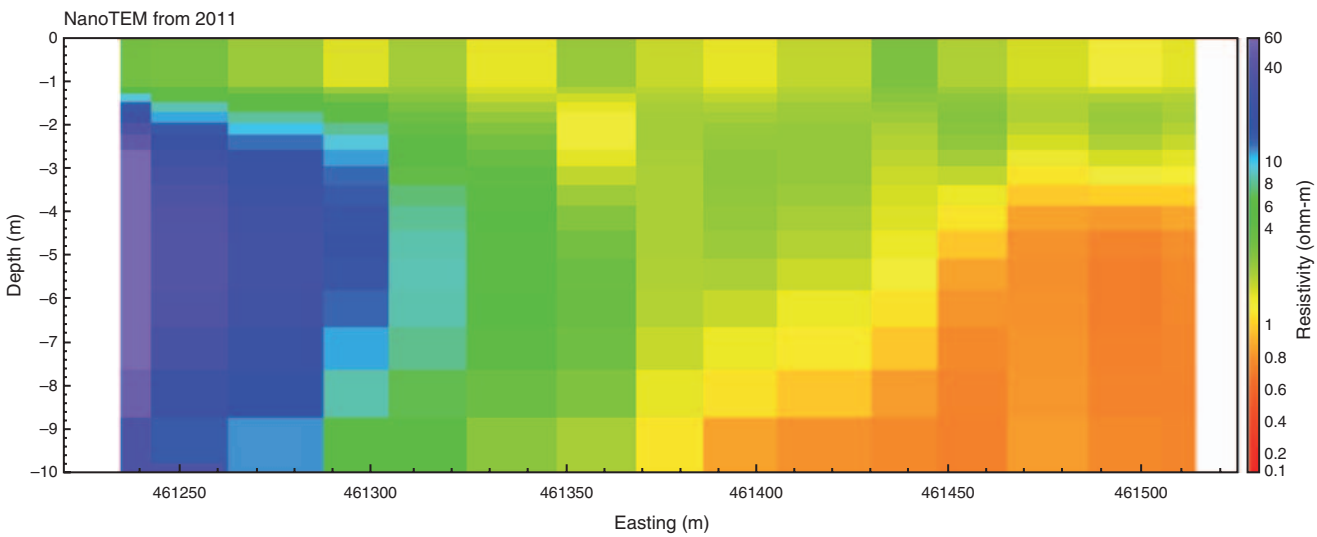

Figure 3. *This figure shows just the top 10 m of NanoTEM inversion shown in Figure 1. Note that DOI is deeper than 10 m for all stations. The approximate location of the test bore data shown in Figure 4 is indicated with the vertical black line.*

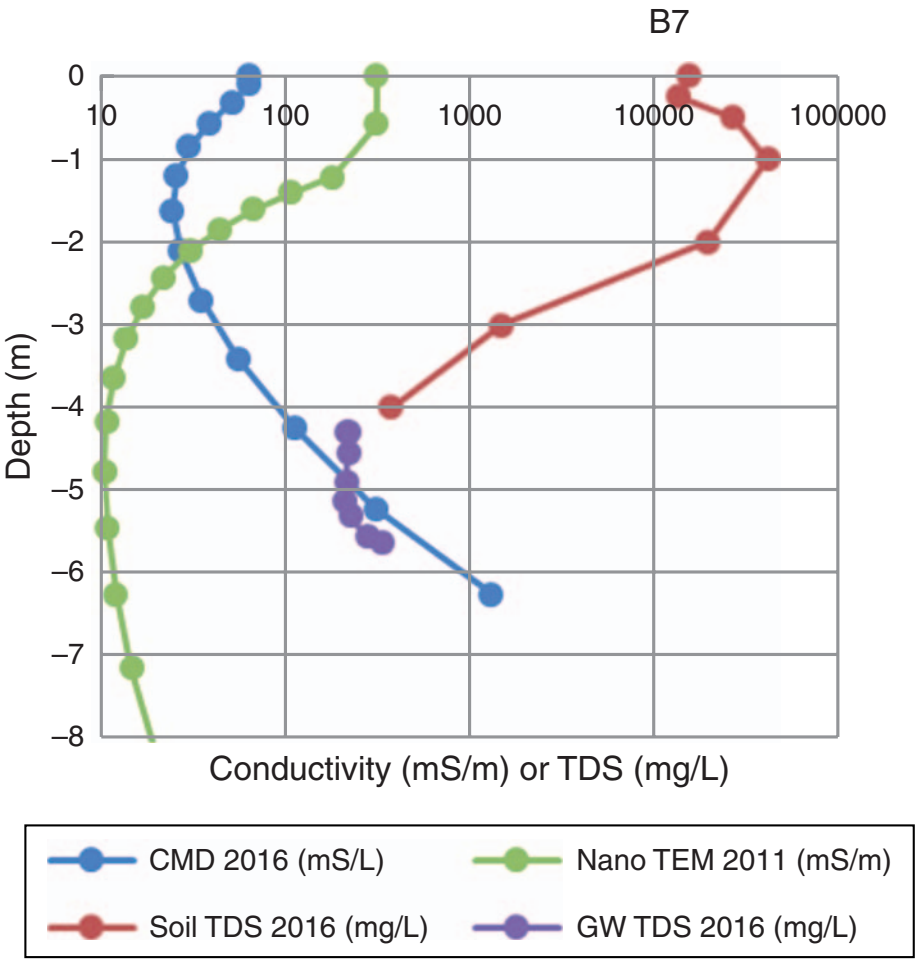

Figure 4. *Comparison between soil and groundwater TDS data against the inverted NanoTEM and CMD data at the test bore indicated with black line in Figures 2 and 3. The pattern of response between TDS and NanoTEM are quite similar, while the CMD response appears to be too shallow.*

any better, and the results just don't look as 'good'.

Has anyone else experimented with other inversions and had better (or worse) results? Overall, I am not satisfied when I see data from these TCMs that purport to provide information at a number of depths and then the data are plotted in Excel (or contoured onto a plan view), with only 'arm waving' depth information. We should be able to do better than that!

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Reference

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