Comparison of the DC-IP instruments Syscal and Terrameter LS

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1. INTRODUCTION AND SETTINGS

1.1 Motivation

The present study aims at comparing two different instruments for the acquisition of IP/DC data, namely the Terrameter LS (Abem instrument) newly acquired by the HydroGeophysics Group and the Syscal-Pro (Iris instrument). The Syscal-Pro instrument has been used for many years within the group in IP/DC, mainly for the characterization and identification of buried landfills. Several studies comparing the collected data with the Syscal and data from boreholes (see Gazoty et al. 2012a, 2012b) showed a very good agreement and consistency between both and proved the reliability of the instrument, also in terms of repeatability. The Terrameter LS is pretty new on the market, and offers many more possibilities than the Syscal, among which are: more channels for acquiring data simultaneously (12), the record of the full waveform data, a better system storage with the possibility of creating a project within which several profiles from the same campaign can be stored, and a better management system for large amounts of data due to a database.

Before using the Terrameter intensively for further projects, we have carried out a background study, collecting data with the two instruments, under identical conditions (same electrodes, same cables, same location, identical ground resistance, etc.), and compare the raw data in DC/IP between the two.

This study will present an overview of the main results from this comparison in terms of injection settings, data reproducibility, and quality in resistivity and IP.

1.2 Quick overview on the TDIP method and its terminology

Time Domain IP (TDIP or IP) consists of measuring a voltage decay resulting from an exciting current pulse. Figure 1 summarizes the basic principles of TDIP signal acquisition, and all the following denotations refer to this figure. Immediately after the current is turned on, a potential rises across the potential electrodes. After a charge-up effect built along Vdly, the primary voltage is measured for the computation of the direct current resistivity just before the current is turned off. When the current is turned off, the voltage drops to a secondary level and then decays with time during the relaxation period. This decay curve is characteristic of the medium (in terms of initial magnitude, slope and relaxation time), and represents the target of TDIP.

Because of inductive coupling occurring after the current shut-off, a time gap or delay is applied before performing the measurements. The signal decay is usually integrated over *n* time windows or gates for the computation of the chargeability M. The integral chargeability [mV/V] is defined as following (Schön 1996, Slater and Lesmes 2002):

$$Ma_i = \frac{1}{V_{DC}.[t_{i+1} - t_i]} \int_{t_i}^{t_{i+1}} V_{ip}\, dt \qquad (1)$$

where V_{ip} is the intrinsic or secondary potential [mV] that can be seen as the transient response resulting from the ground polarization after the current is shut off. t_i and t_{i+1} are the opening and closing times [s] for the gate over which the signal is integrated.

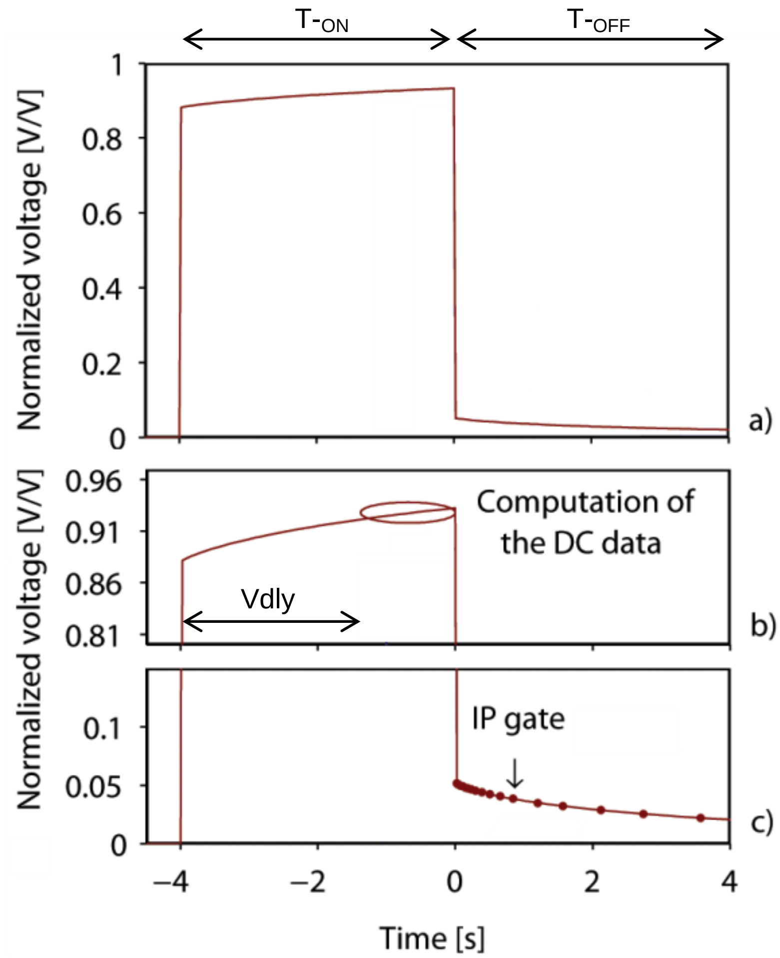

Figure 1. Basic principle of TDIP acquisition and terminology.

There are different ways of defining the gate length. With log-gating, which is usually carried out for transient electromagnetic measurements, the secondary potential is integrated over time intervals, the length of which increase logarithmically with time (Effersø *et al.* 1999, Christiansen *et al.* 2006). This way of integrating the IP signal yields a significant increase of the signal-to-noise ratio by decreasing the standard deviation of the noise with time by a factor of the square root of the gate length (Munkholm and Auken 1996). If linearly distributed gates are used, the signal-to-noise ratio will decrease significantly for later times.

1.3 Acquisition settings and survey

A geophysical survey was conducted in November 2012, where data could be collected along a single profile setup in the Eskelund landfill (Aarhus, Denmark), only by switching the instruments, and re-using the same devices (cables, electrodes, connectors). This profile ranged 400 m long, using 81 stainless steel electrodes 5 m spaced (see Figure 2). The survey was performed using the gradient array (Dahlin and Zhou 2006) with the so-called 'long+short' protocol, already implemented on the Syscal-Pro instrument, and identically implemented on the Terrameter LS for this study. By using this procedure, high near surface resolution towards the center of the measured section is achieved, whereas long spacings between electrodes enable the instrument to collect data at depth all through the profile. The protocol used 10 channels for the data collection, which is the maximum capability of the Syscal-Pro (against 12 channels for the Terrameter LS). The maximum distance set between the current electrodes was 360 m.

The on- and off-time lengths for the time decay measurements were set to 4 s (also called 50% duty cycle) and the data were acquired using logarithmic spaced gates with a total of 12 gates (maximum number of gates imposed by the Terrameter).

As far as possible, the same settings have been used with both instruments, in order to minimize bias induced by the settings (number of stacks, Vdly, etc.), so that the observed differences in the data reflect the intrinsic difference in the data quality provided by the two instruments.

With both Syscal and Terrameter it is possible to use a maximum power of 250 W. However, the Syscal-Pro sets a constant maximum voltage (V_{AB} maximum) and adapts the injected current according to the maximum power selected, whereas the Terrameter sets output current and power, and defines the voltage accordingly. This is the main difference in the settings between the two instruments.

Of course, both instruments have different kinds of flexibility in the way the settings can be defined. For instance, the Syscal can handle a maximum number of gates for the measurement of IP data of 20, whereas the Terrameter, in the version used for the tests, could handle a maximum of 12. This is why the limitations of one instrument were used to constrain and define the acquisition settings of the survey, so that the injection parameters were set very closely between both instruments. The main parameters used in this study are summarized in table 1.

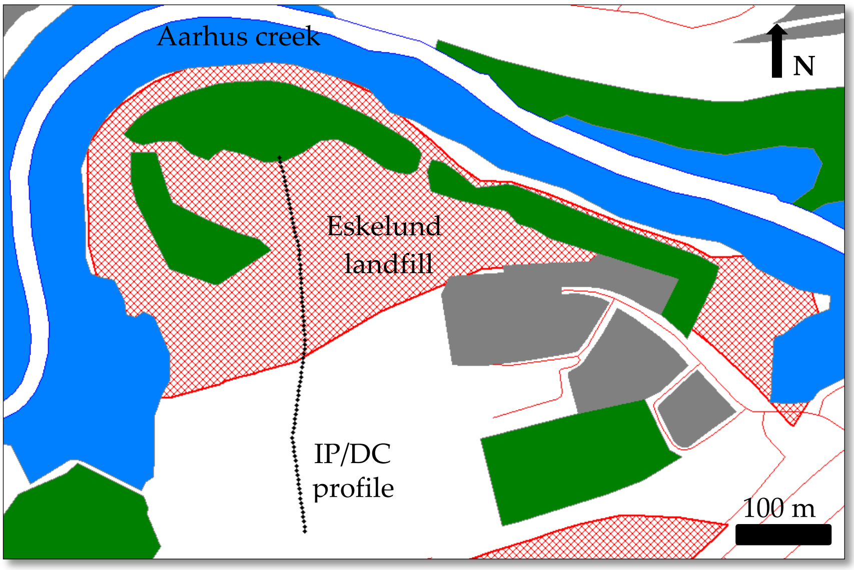

Figure 2. Map of the survey. The Eskelund landfill covers the red area, and the IP/DC section lays from North to South (black dots).

Protocol	Gradient "Long + Short"	
Number of electrodes	81 (overlaps)	
Miimumn spacing (m)	5	
Delay before measuring IP data (ms)	20	
Number of gates*	12	
Gate length (ms) **	20 40 60 80 100 140 180 260 400 600 880 1200	
Vdly (ms)***	2600 (Terrameter)-2620 (Syscal)	
Integration Time for DC data (ms) ***	1400	
Minimim number of stacks	3	
Maximum number of stacks	3	
Maximum power	250 W	
Injection settings	Syscal: Vab maximum 800 V	Terrameter: Maximum 1 A

* Maximum number of gates imposed by the Terrameter LS
** Multiple of 0.02 (50 Hz), recommended for the use of Terrameter LS
*** Values imposed by the Syscal, non-modifiable on the Syscal instrument.

Table 1. Summary of the main injection settings used in this study. The terminology refers to the settings presented in Figure 1.

2. DATA COMPARISON

DC and TDIP data were acquired with the same sequence and acquisition settings as described in the previous section. In the following, we try to estimate and quantify the differences in the raw data between both instruments.

2.1 Estimation of data difference in resistivity

In Figure 3 pseudo-sections of apparent resistivities are measured with the two instruments. Note that the Terrameter presents a few more data at the very near surface, due to a slight difference between the implemented protocols.

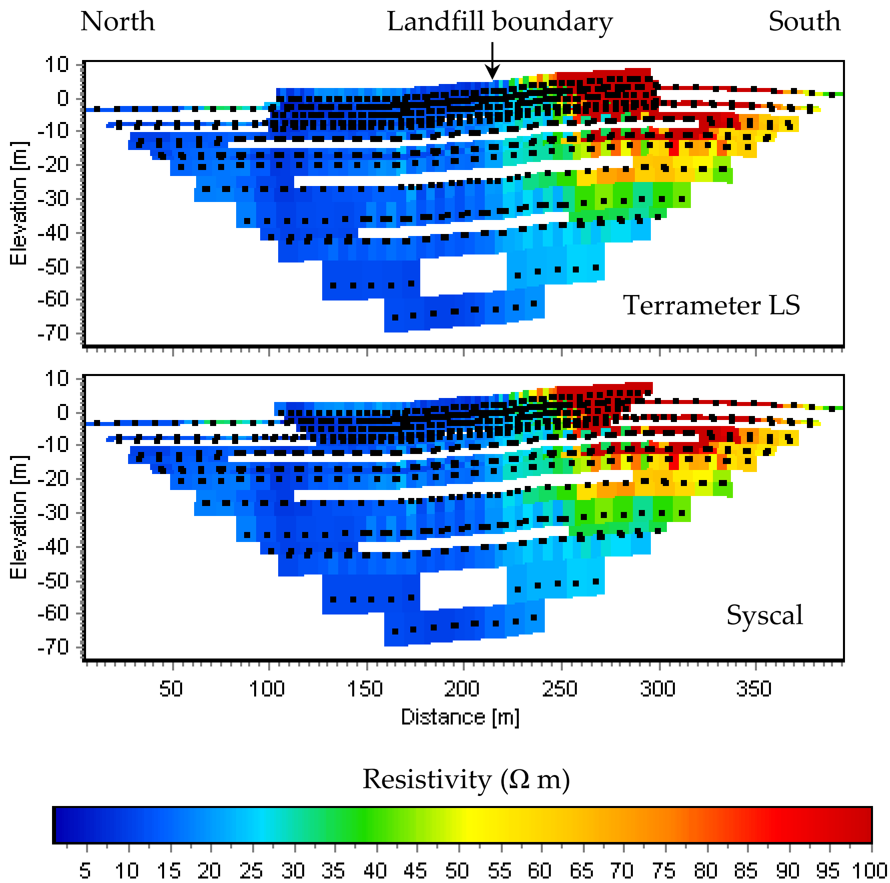

Figure 3. Comparison of raw data in resistivity.

The comparison of the two pseudo-sections reveals a very good agreement between the raw data, with identical features present at similar depth, with the same lateral boundaries. In particular, the sharp edge of the landfill, present at 215 m from the north, is identically defined by both instruments and the glacial deposits beyond, towards the south, are identically characterized.

In order to quantify the differences, the percentage of difference has been computed following expression (2) for each data point. Results are shown in Figure 4.

$$\Delta\rho = \left|\frac{\rho_{abem} - \rho_{syscal}}{\rho_{abem}}\right| * 100 \qquad (2)$$

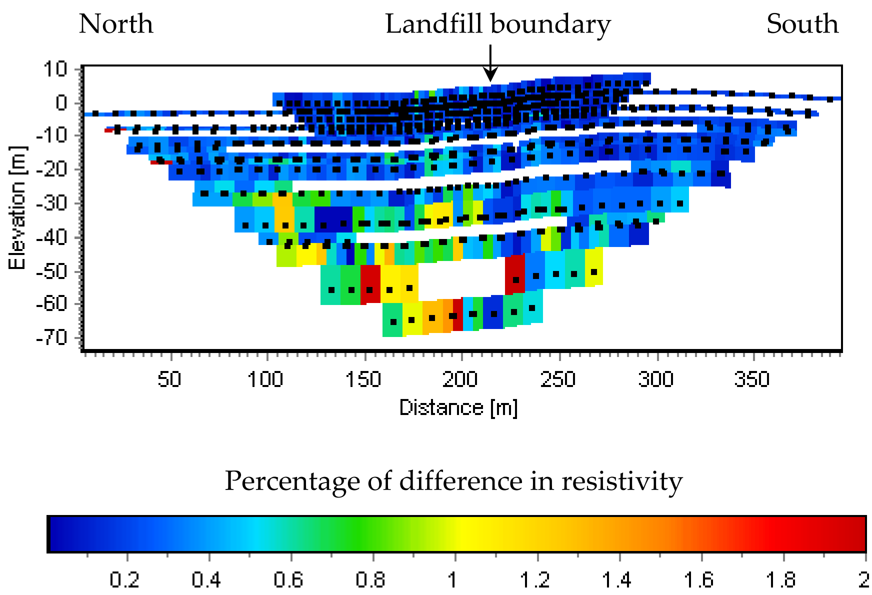

Figure 4. Pseudo-section showing the distribution of the percentage of difference in resistivity.

Figure 4 shows that the differences in resistivity for the majority of the section are below 0.5 %, except for few data at depth where the differences reach 2%. These differences are extremely small, quasi negligible, and most likely not significant for the mapping of the geological features.

2.2 Estimation of data difference in TDIP

In order to visualize the differences in chargeability Figures 5 to 8 show some comparisons between the two instruments for four selected gates. Indeed, considering that the chargeability values decrease considerably along the IP decays, we select gate 3 (gate center time: 110 ms), gate 5 (gate center time: 270 ms), gate 8 (gate center time: 770 ms), and gate 10 (gate center time: 1.6 s) as representative of the entire time range.

Because the Syscal-Pro instrument encompasses a 10 Hz low-pass filter, we chose to start the chargeability analysis after the end of the filter (e.g. after 100 ms), which is why the comparison is made from gate 3.

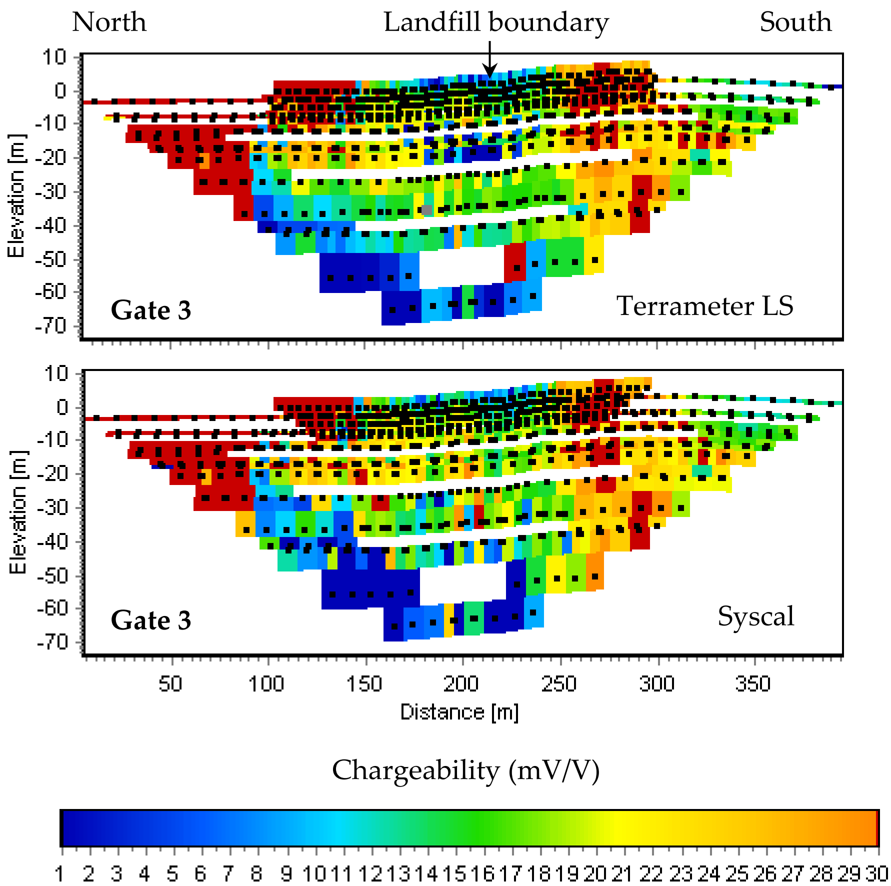

Figure 5. Comparison of raw data in IP, gate 3.

Figures 5 to 8 show high similarities on the central top layer where short spacings between electrodes have been used. Also, both edges, roughly from 0 to 100 m and from 250 to 400 m, laterally, are well reproduced, for the four selected gates.

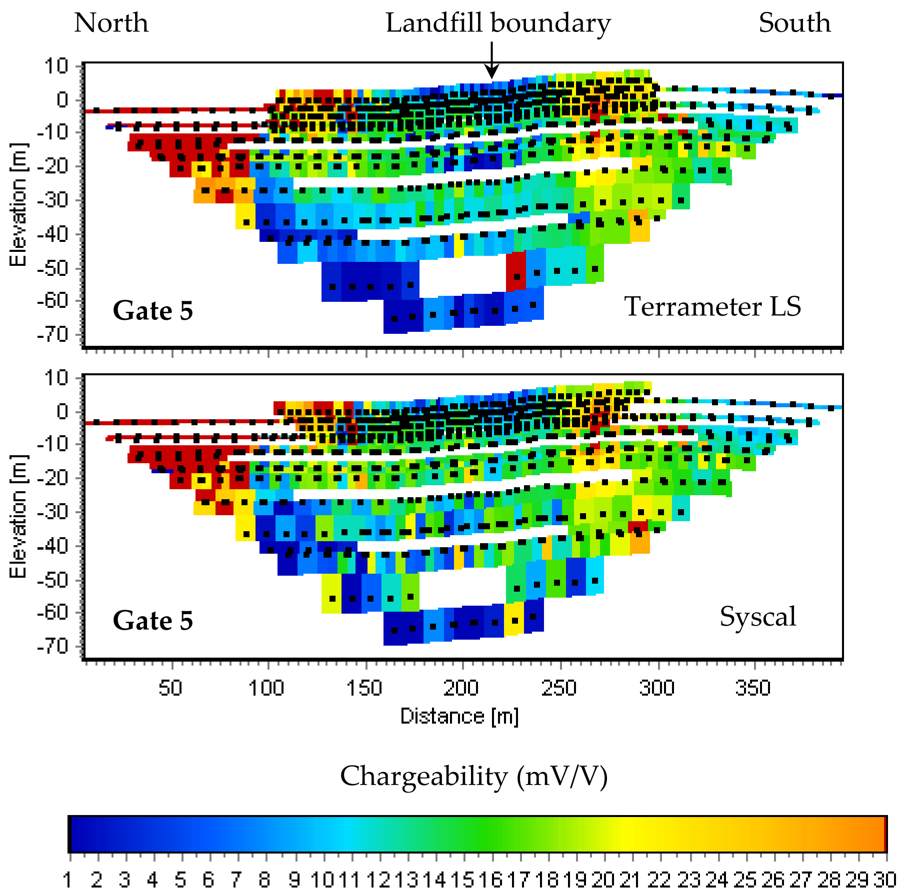

Figure 6. Comparison of raw data in IP, gate 5.

From Figure 5 in particular, it seems that shallow areas and/or areas with a high signal display more resemblance.

In order to quantify the differences in the raw data in TDIP, the percentage of difference has been computed for the different gates above mentioned, as following:

$$\Delta M^{gate\ X} = \left| \frac{M_{abem}^{gate\ X} - M_{syscal}^{gate\ X}}{M_{abem}^{gate\ X}} \right| * 100 \qquad (3)$$

The results are shown in Figure 9 for gates 3, 5, 8, and 10.

As previously seen on the different pseudo-sections, there is a top area (see the white line defining the boundary in Figure 9) where a similarity between the two instruments is very high, with a percentage of difference in the raw data close to 2%. Below this area another distinct area, spreading from the center of the pseudo-section to the bottom, gathers almost all the very poor likenesses between the two instruments, with differences reaching 50 %.

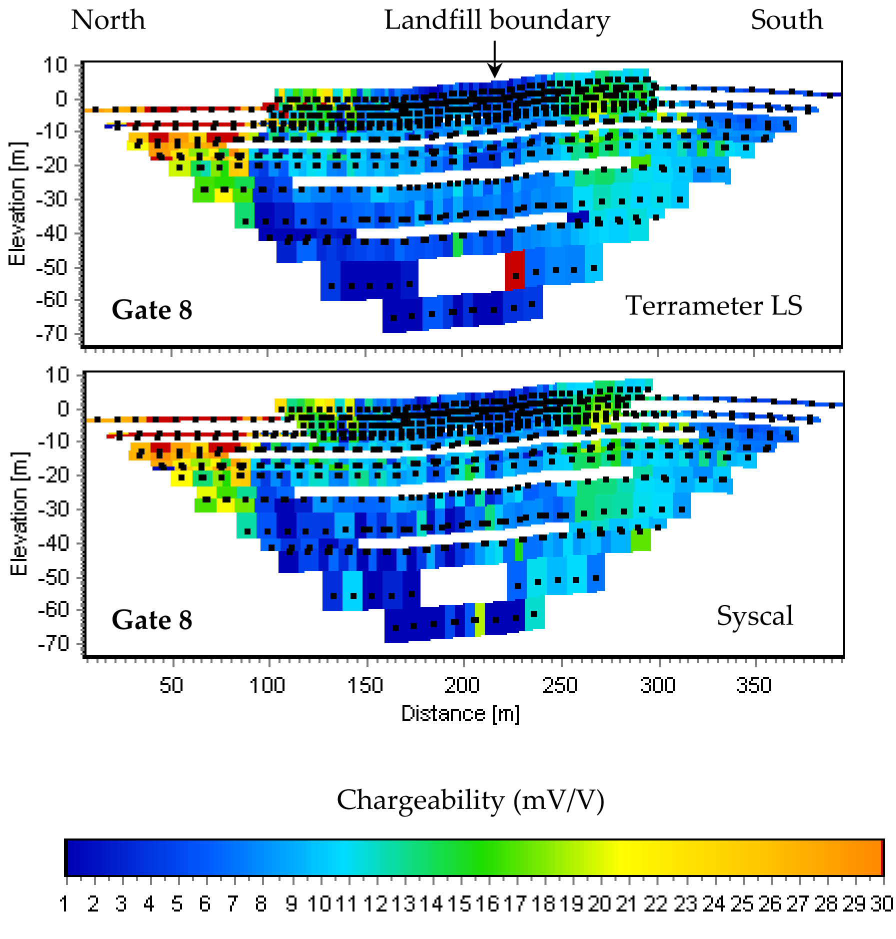

Figure 7. Comparison of raw data in IP, gate 8

From Figure 9 the spatial boundary between high and poor similarities remains the same for all gates. However, the percentage of difference within the bottom layer increases significantly towards the late times, with some differences going from 18 % (gate 3) to 50 % and above at gate 10. The top area, however, keeps a very high ratio of similarity, which is roughly the same between all gates.

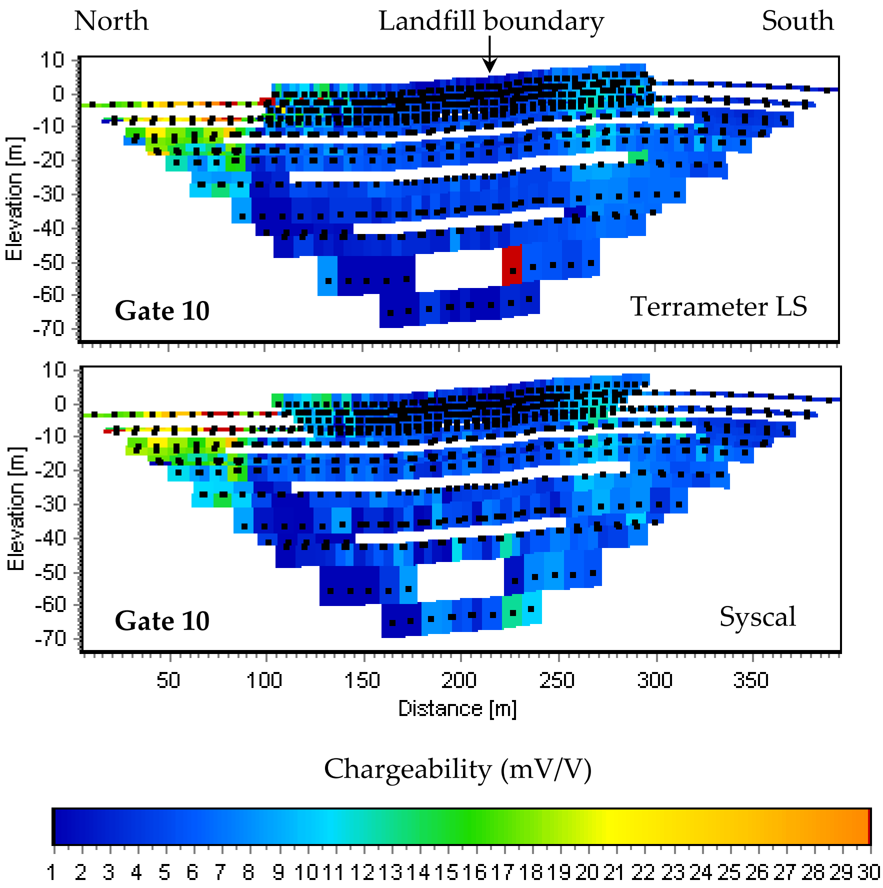

Figure 8. Comparison of raw data in IP, gate 10.

The percentage of differences has been plotted against AB (current electrodes) and MN (potential electrodes) spacings (not shown here), but no clear correlation appeared between high differences and big electrode spacings.

In Figure 10, the percentage differences for four gates are plotted on four different histograms. For gates 3 and 5, most of the data display a ratio of similarity between 0-3 %. This is also the case for gates 8 and 10, but the shape is less narrow, as it was for early times, and it spreads a bit more towards the high differences. Despite this, there is no clear shift towards the high differences for late times as could be expected. The stretched shape of the histogram towards higher differences, for gate 10 for instance, probably reflects the increase of differences within the lower area described earlier.

Figure 11 is the same as Figure 10, but shows the full range of differences without taking the absolute value. It confirms that there is no obvious bias in the difference values to the negative or positive side.

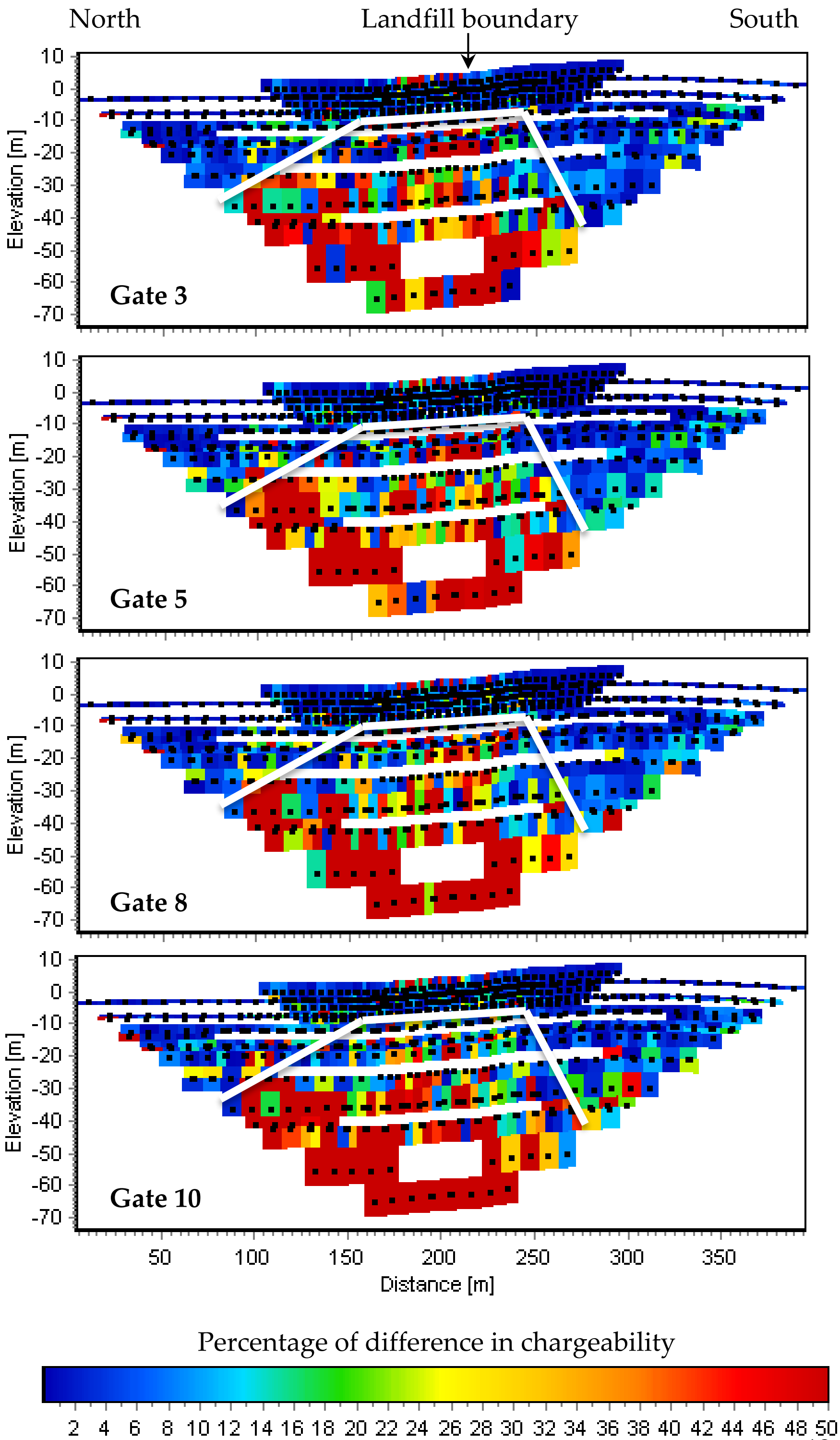

Figure 9. Distribution of the percentage of difference for each gate. The white line defines the upper and lower areas of high and poor similarities between instruments, respectively.

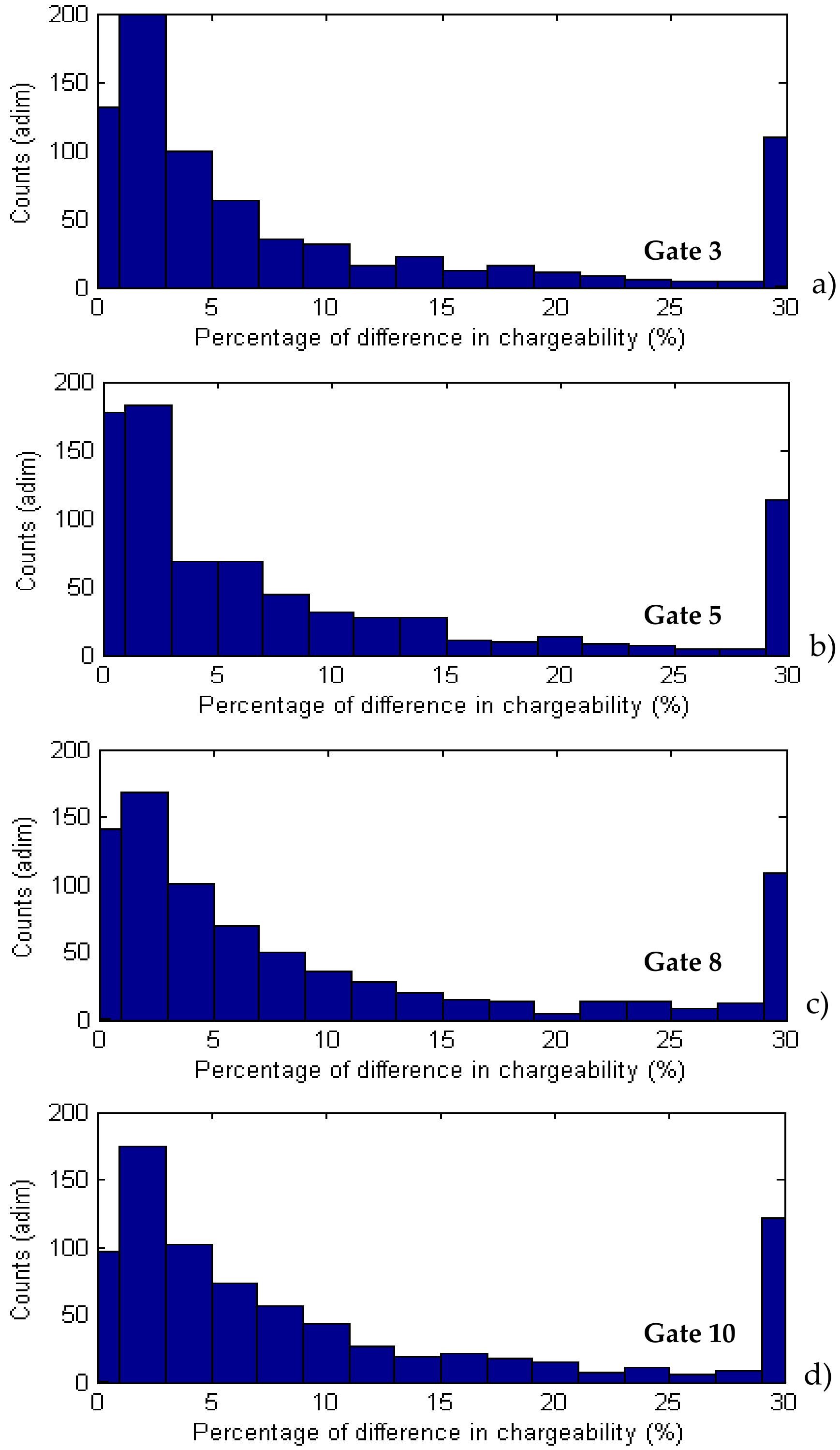

Figure 10. Histogram showing the absolute percentage difference in chargeability. Note that the 30 % bins include anything larger than 30 %.

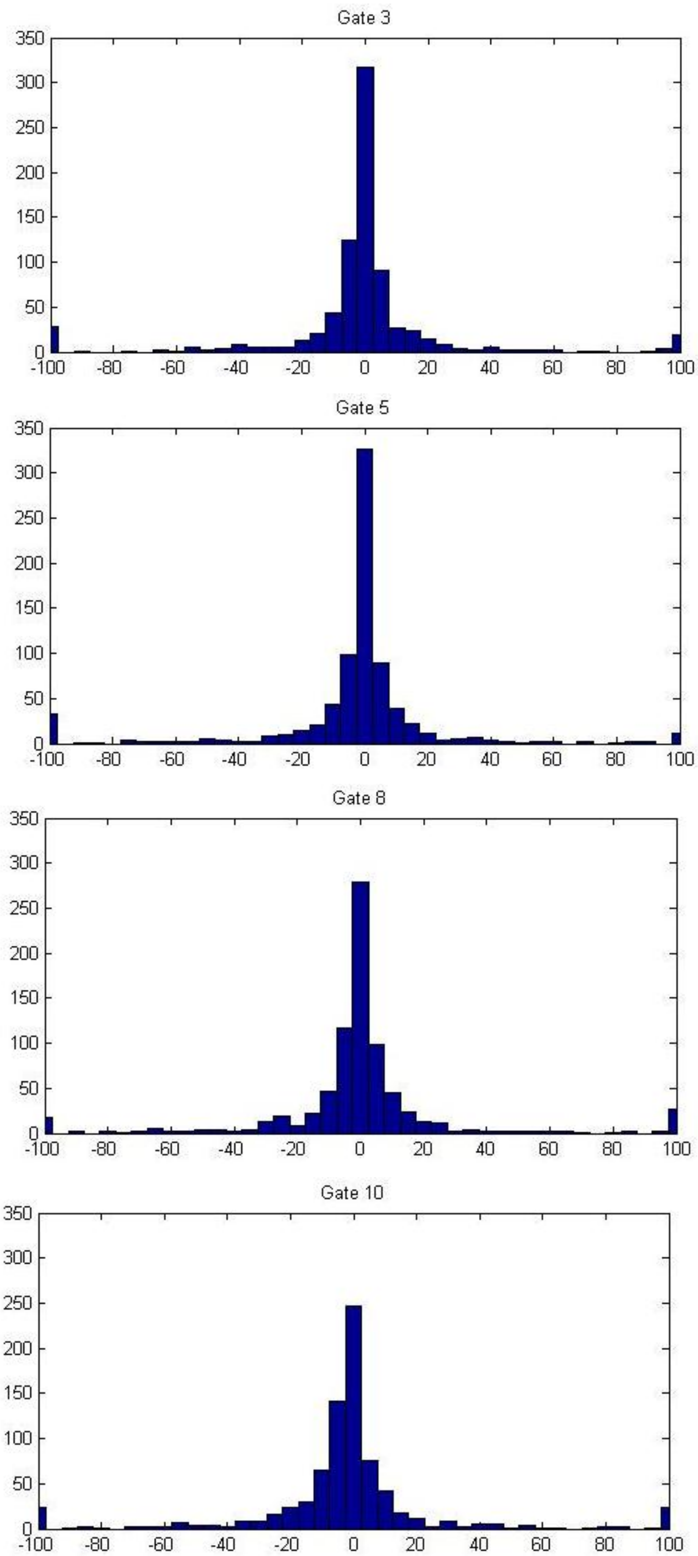

Figure 11. Same as Figure 10, but showing the full range of values. Note that the 100 % bins include anything larger than 100 %.

3. INJECTION PARAMETERS

The efficiency of performing an IP survey depends very much on the choice of the instrumentation set-up (array, acquisition parameters such as the pulse length (T-On, T-Off), stack size, injected current, etc.). In order to increase the signal level, it is necessary to increase the injected current and/or to decrease the geometrical factor (see expression 4), the soil parameters being independent on the survey design:

$$V_{IP\ (t=t0)} = \frac{\rho * M_0 * I}{k} \qquad (4)$$

Our experience suggests the use of the maximum power selectable with auto-switching instruments for the current injection (typically 250 W), even if it implies some complications in the power supply management in the field.

In the following part, we are going to show a comparison between the two instruments in terms of injection parameters, including the injected current, the output voltage, and the generated power. Such a comparison is made possible because in both cases the maximum power has been selected (250 W), and ground conditions were identical, as the two acquisitions were performed on the same day, with a lag of few hours only. Results are shown in Figures 12 to 14. In Figure 12, the distribution of the injected current is presented on a pseudo-section, for both instruments. In Figure 13, the distribution of the output voltage is presented on a pseudo-section for both as well. For more clarity, the generated power has been computed and showed in Figure 14.

From Figure 12, it seems that the two instruments could inject an equivalent amount of current. Inside the landfill, and within the interval of 0-20 m depth, up to 900 mA to 1 A could be injected. The top area outside the landfill (containing glacial deposits) was acquired with 400 mA, whereas 550-650 mA could be injected in the bottom the bottom layer, in both cases.

Figure 13 displays some similar areas of distribution for the output voltage (in terms of boundaries), with a clear discontinuity at the edge of the landfill.

Since the maximum output power is also an injection setting that has to be defined in both instruments, it is relevant, for comparison, to evaluate its distribution (see Figure 14).

It is very clear by looking at the overall distribution of power that the Terrameter can transmit a bit more than the Syscal, with a 250 W spread almost everywhere in the pseudo-section. If the transmitted power is in the same range between the two instruments, the Syscal displays a more heterogeneous distribution of power than the Terrameter, which is roughly 10 % below (230 W).

Such a difference is very small, and for this survey, where the ground conditions were excellent for transmitting power (contact resistance lower than 1 kΩ) both could transmit equally well.

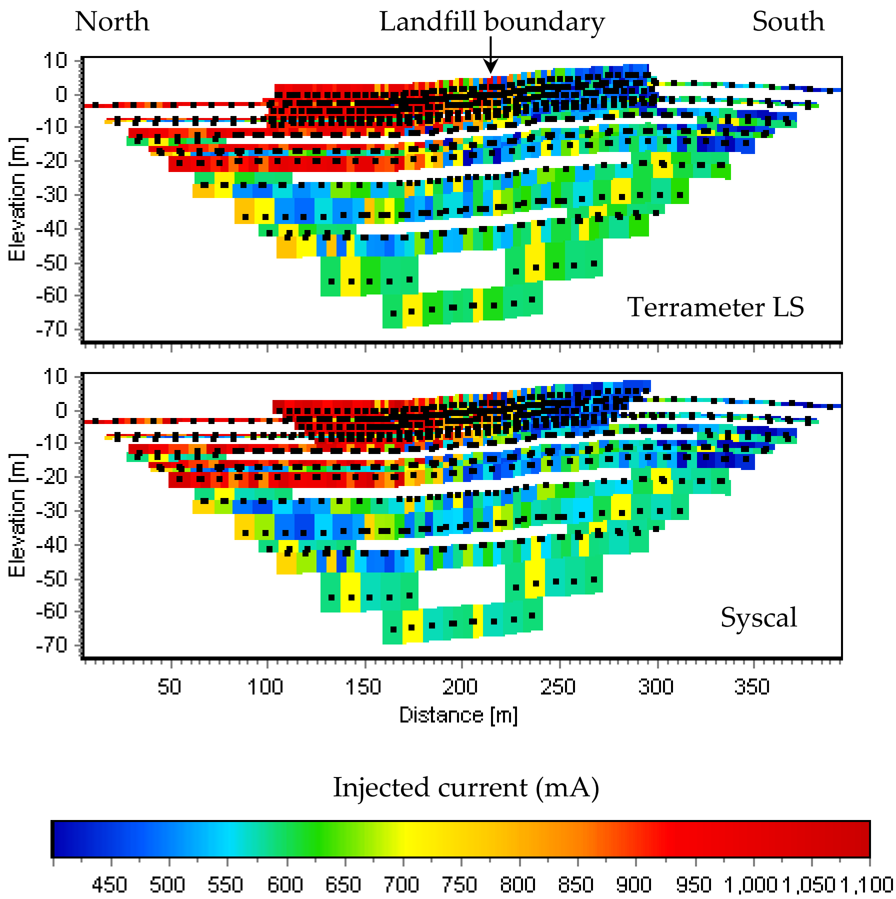

Figure 12. Injected current for both instruments.

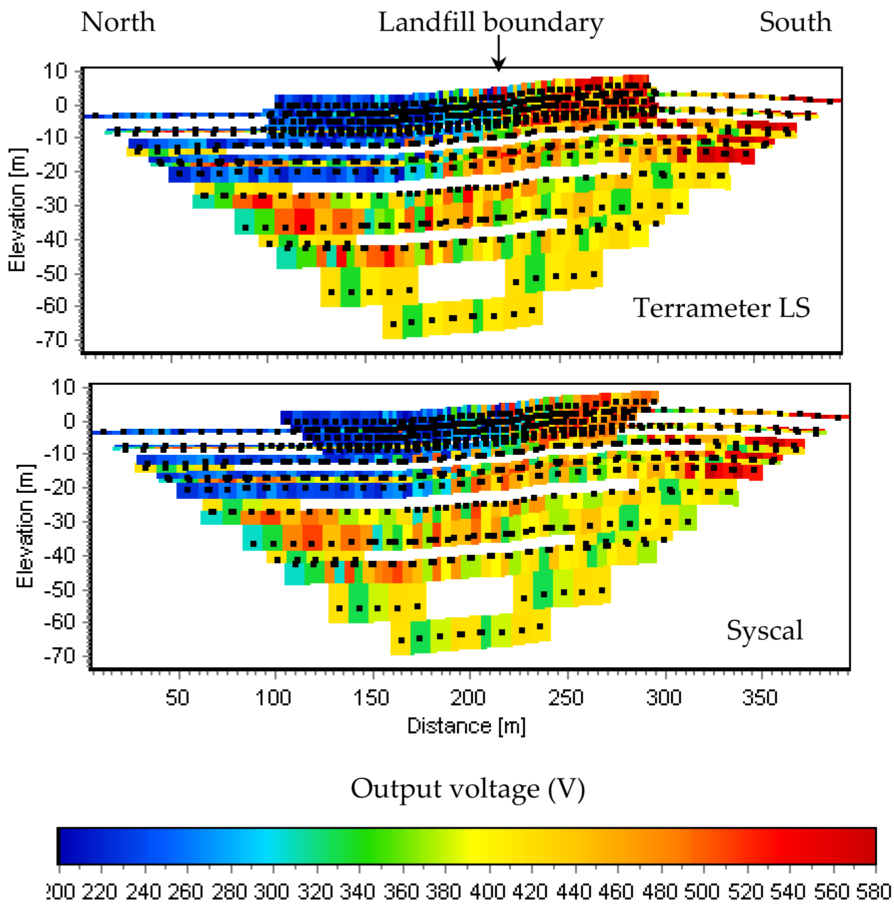

Figure 13. Output voltage for both instruments.

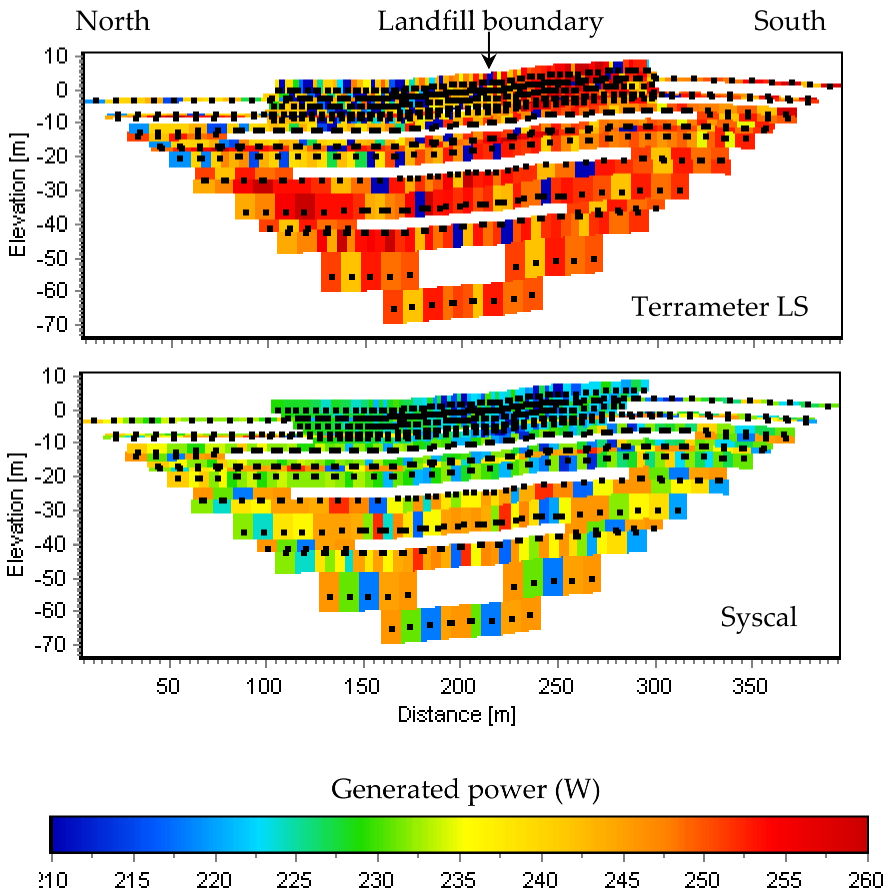

Figure 14. Generated power for both instruments.

4. DATA QUALITY

Now we have analyzed and quantified the similarity between the raw data and the injection parameters, it is important to compare and evaluate the data in terms of quality. In Time Domain IP, the most common criterion is to observe and estimate the quality of the decay curves regarding their smoothness. In this part, we will focus on the decays and try to determine if a general trend in terms of quality can be inferred from the different observations.

4.1 Overview

All the decay curves from both instruments have been plotted on top of each other through the entire pseudo-section. Overall, there is a very good concordance between the decays. Gates 1 and 2 differ from each other between the two instruments because of the presence of the low-pass filter in the Syscal, which enhances the signal magnitude at early times. Figure 15 shows an example of typical decays observed in this study, with matching data from gate 3.

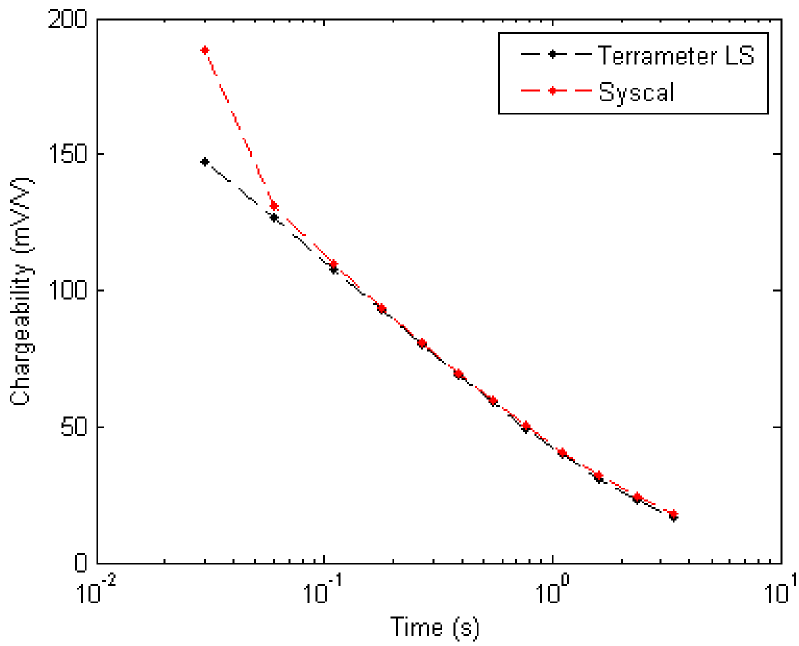

Figure 15. Example of typical decay curves observed from the TDIP data. The difference in magnitude at early times (2 first gates mainly) can be explained by the low-pass filter contained in the Syscal.

4.2 Further comparison

It has been shown in the previous paragraph that the decay curves from both instruments are consistent, as they overlap pretty well in general. However, we saw in Figure 9 that some significant differences are present at depth. In this paragraph, we show different examples of decays taken from different locations in the pseudo-section showed in Figure 16. Because the distribution of the percentage of difference is very different from one location to another, and the geological background varies significantly laterally because of the landfill, we choose four representative locations, inside and outside the landfill, with high and poor repeatability (see Figure 16). For these four locations, the resulting decay curves are shown in Figure 17.

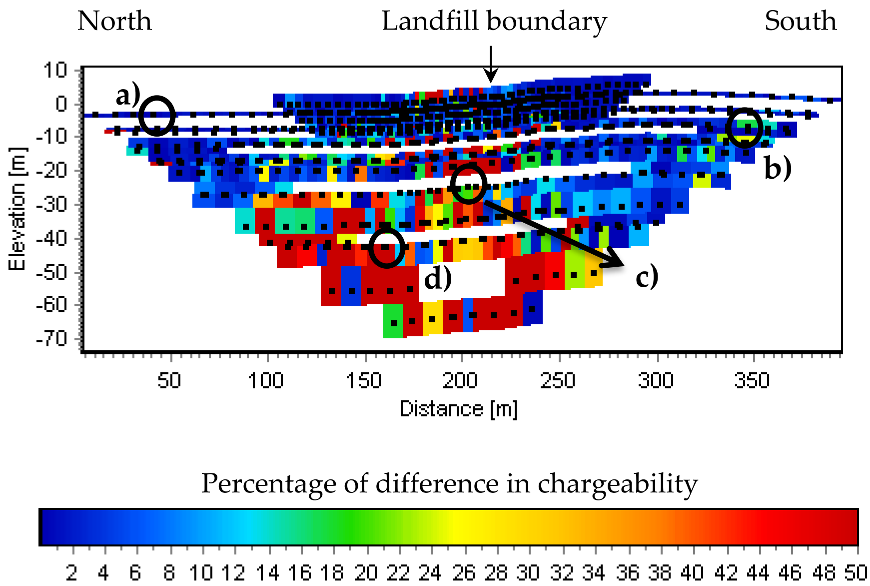

Figure 16. Pseudo-section showing the distribution of the percentage of difference in IP, gate 3. The four black dots refer to the location where the decays in Figure 17 have been extracted.

Figure 17 a) and b) show decays taken from areas where high similarities have been found. 17 a) is located within the landfill, and 17 b) outside. Both show a very good agreement between the curves (slightly better in 17a)), in areas where signal levels are very different from each other.

Figures 17 c) and d) are from areas with poor similarities on Figure 16. In both, the decays from the Terrameter are smoother, as they are very oscillating for the Syscal. The complete observation of the full pseudo-section confirms this trend, with comparable decays in most cases, but smoother and better quality from the Terrameter LS.

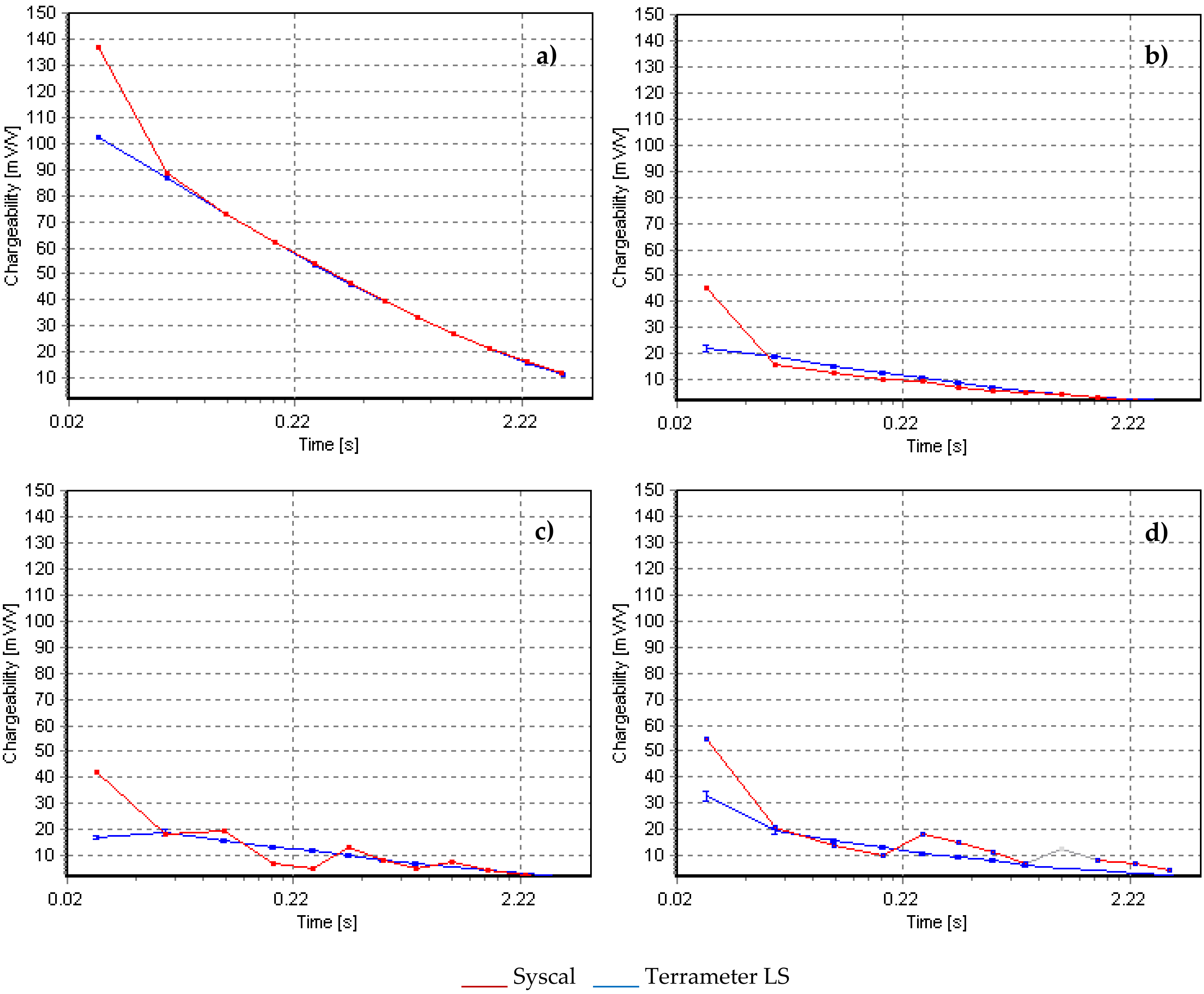

Figure 17. Example of decay curves extracted in locations mentioned in Figure 15.

5. CONCLUSION

In this study we have presented a comparison between the Syscal-Pro instrument and the Terrameter LS. Raw data in DC resistivity, chargeability for different gates, and injection parameters have been confronted.

The comparison of the raw data in the DC resistivity showed an excellent agreement between the two instruments, with differences in a range of 0.5 % all over the pseudo-section. In IP the results are more contrasted, because the degree of similarity varies a lot in the pseudo-section (2 to 50%), and highly depends on the spatial location.

The analysis of the injection parameters showed that comparable injections were provided by both instruments, with an injected current close to 1 A within the landfill, for both. The computation of generated power showed a slightly higher power for the Terrameter, around 8 % above the Syscal.

Finally, the observations of the decays for IP all through the section revealed a good match between the instruments for the majority of the decay curves. However, the decays from the Terrameter were of a globally higher quality and smoother than seen from the Syscal.

Also, the Syscal instrument includes a low-pass-filter which clearly affects the first couple of gates, which have therefore been excluded from the comparison. The low-pass filter will inevitably reduce the amount of spectral information that can be retrieved from the IP data.

6. REFERENCES

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APPENDIX I: FOLDER CONTENTS

- All data and folders are contained in

U:\FieldTests\2012_IPDC_testEskelund

- The specific data used for the present study are stored in

U:\FieldTests\2012_IPDC_testEskelund\nov2012\eskelund\20121126

Abem data:

Abem_20121126.usf

Abem_20121126.txt

Abem_20121126.dat

The use of the .txt file is recommended because contains all data and information including acquisition settings.

Iris data:

Syscal_20121126.bin

Syscal_20121126.txt

Syscal_20121126.dat

The binary file contains all kind of information including acquisition parameters, and can be exported through Prosys (on Rebus).

- The information regarding the waveform (Terrameter LS) can be found in:

U:\FieldTests\2012_IPDC_testEskelund\nov2012\COMPARISON_LS 211110120_2012-09-06_12-24-19

This database contains data from September/October/November 2012; it can be read with specific Terrameter utilities available on the ABEM website.

- The workspace containing raw data in IP/DC (September/October/November 2012), but also all data regarding injection parameters, differences between data is located in:

U:\FieldTests\2012_IPDC_testEskelund\workbench

With corresponding files in:

U:\FieldTests\2012_IPDC_testEskelund\nov2012\eskelund\20121126

- The sequences implemented on the instruments are stored in:

U:\FieldTests\2012_IPDC_testEskelund