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Comparing performance of instrumental drift correction by linear and quadratic adjusting in inductive electromagnetic data

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ABSTRACT

Electromagnetic induction (EMI) method results are shown for vertical magnetic dipole (VMD) configuration by using the EM38 equipment. Performance in the location of metallic pipes and electrical cables is compared as a function of instrumental drift correction by linear and quadratic adjusting under controlled conditions. Metallic pipes and electrical cables are buried at the IAG/USP shallow geophysical test site in São Paulo City, Brazil. Results show that apparent electrical conductivity and magnetic susceptibility data were affected by ambient temperature variation. In order to obtain better contrast between background and metallic targets it was necessary to correct the drift. This correction was accomplished by using linear and quadratic relation between conductivity/susceptibility and temperature intending comparative studies. The correction of temperature drift by using a quadratic relation was effective, showing that all metallic targets were located as well deeper targets were also improved.

1. Introduction

Cities are quickly and irregularly increasing as a result of unplanned land occupation. Due to that it is necessary to improve infrastructure all through geotechnical subsurface works, for example, subway enlargement lines, the installation of electrical and telephone cables, gas and water pipelines, galleries of pluvial water canalization, and sewerage system.

Due to underground constructions it is evident that the occurrence of accidents related to the disruption of pre-existing cables and pipes, leading to financial disorders, hard traffic, and putting people's lives at risk. Applied geophysics can minimize incident occurrence by using nondestructive methods to characterize subsurface in order to locate underground interference or environmental studies.

According to Reynolds (1997) the main advantages of geophysical methods are low cost and quickness in field surveys. Conversely, the use of geophysical methods in urban areas has several limitations caused by: (1) large amount of electromagnetic noise, (2) cultural factors may compromise data quality, and (3) ambiguity found in result interpretation. For those reasons, it becomes a great challenge to employ shallow geophysical methods in urban environment. A line of research with geophysical surveys in urban areas performs studies under controlled conditions, with the objective of better understanding of normal response patterns caused by different targets in subsurface. Several researchers have completed studies in areas with these characteristics, such as Radzevicius and Daniels, 2000; Gerber et al., 2004; Paniagua et al., 2004; Porsani & Sauck, 2007; Naser & Junge, 2008; Porsani et al., 2010, among others.

In that context, the present paper aims at comparing correction of instrumental drift provoked by data obtained with the EM38 equipment using linear and quadratic adjusting in order to improve the image quality of underground targets, such as metallic pipes, and electrical cables buried in urban subsoil usually occurring in worldwide largest cities.

Data were acquired from the Institute of Astronomy, Geophysics and Atmospheric Science (IAG) at the University of São Paulo (USP) test site located in São Paulo City, Brazil. This test site objectifies to simulate geotechnical problems as well as environmental and archaeological studies in which different materials were buried along seven study lines, such as archaeology (line 1), PVC pipes (line 2), concrete tubes (line 3), metallic drums (line 4), plastic drums (line 5), metallic pipes (line 6), electrical cables, metallic pipes, and PVC conduits (line 7). Detailed information about the IAG/USP test site installation as well some geophysical results are found in literature (Porsani et al., 2006; Rodrigues and Porsani, 2006; Porsani and Sauck, 2007; Borges, 2007; Santos, 2009; Porsani et al., 2010).

Although there are some authors who approach inductive electromagnetic method results by using linear adjusting to correct instrumental drift provoked by environmental temperature in apparent conductivity measure, for instance, Sudduth et al. (2001), here the objective is to investigate a better way to correct that instrumental drift. Electromagnetic induction (EMI) method results

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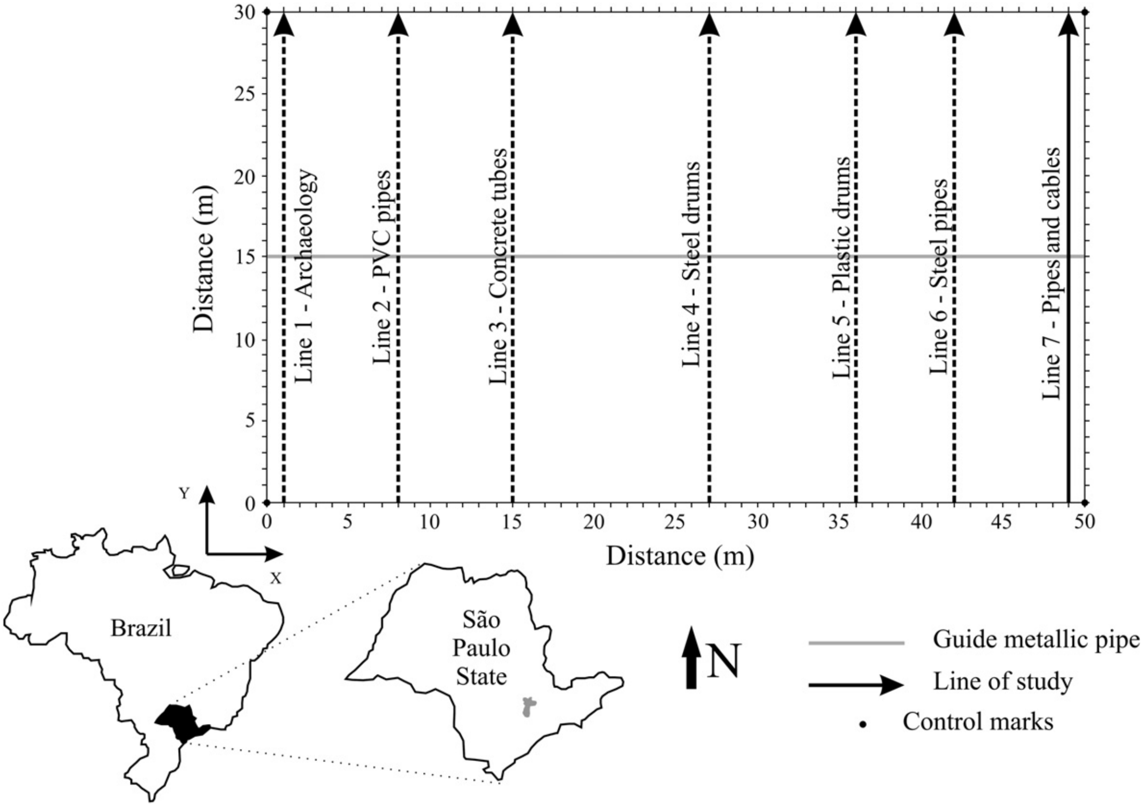

Fig. 1. IAG/USP test site location showing seven study lines and metallic pipe guide (addapted from Porsani et al., 2010).

over metallic pipes and electrical cables (line 7) from the IAG/USP test site are presented in this paper. Data revealed quadratic variation between apparent conductivity/magnetic susceptibility and environmental temperature. As a result, in this paper we present an effective correction of temperature drift through quadratic adjusting in which the location of metallic deeper targets were clearer, improving the picture quality of subsurface targets.

2. Study area: IAG/USP test site

Geologically, the study area is characterized by sand-clayey sediments of Resende and São Paulo formations underlined local area, overlapping onto granite-gneissic basement (Porsani et al., 2004).

The IAG/USP test site is located inside USP campus, in São Paulo City, Brazil, and it is characterized by seven study lines, with a total area of 1500 m^2 (30 m in NS direction × 50 m in EW direction). Fig. 1 shows the IAG/USP test site location, seven study lines, and metallic pipe guide. The depths of target tops vary from 0.5 to 2 m, and in 15 m position (NS direction) a metallic pipe with a 3.8 cm diameter and 51 m length (EW direction) was perpendicularly buried in survey lines. It accomplishes a role as reference guide for geophysical surveys.

In this paper, EMI results are present for targets buried at line 7 (Fig. 2). This line is characterized by metallic pipes with a 16 cm

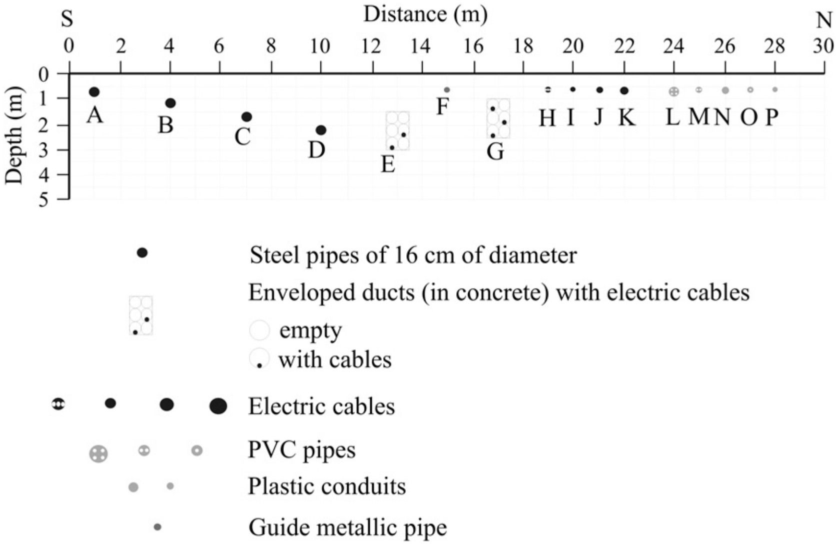

Fig. 2. Layout of targets buried at line 7 at the IAG/USP test site.

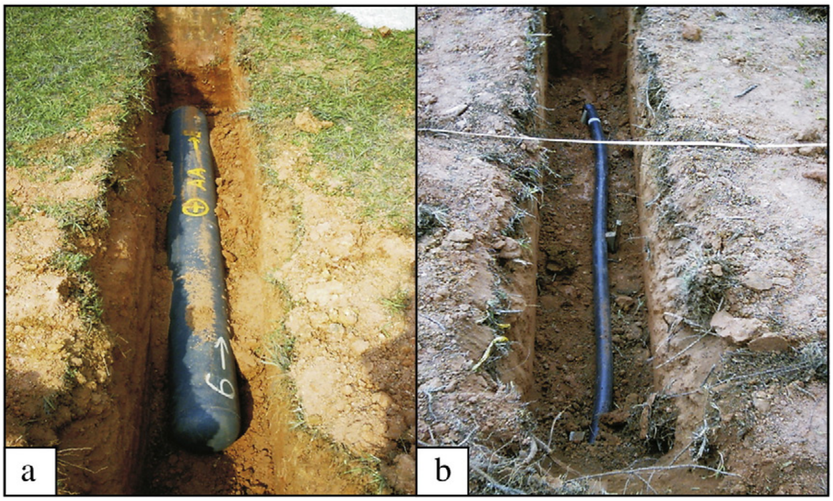

Fig. 3. a) Metallic pipe with a 16 cm diameter. b) Electrical cable with a 2 in diameter.

diameter and 2 m length (Fig. 3a), electrical cables not energized (Fig. 3b), PVC conduits for optical fiber passage, and PVC pipes with electrical cables inside concrete box. In the largest cities, these materials are usually used for electricity, telephone, water, and gas transport.

3. Acquisition and data treatment

The electromagnetic induction (EMI) method for low induction number has the ability to directly measure apparent electrical conductivity and magnetic susceptibility of soil and subsurface targets. The EM38 equipment known as portable soil conductivity has a coil spacing of 1 m and an operating frequency of 14.6 kHz (Geonics, 1998). According to McNeill (1980), it enables users to obtain electrical conductivity and magnetic susceptibility in theoretical depths of 0.75 m in HMD (horizontal magnetic dipole) and 1.5 m in VMD (vertical magnetic dipole). Its main applications are: (1) study of precision agriculture, (2) soil salinity mapping, (3) archaeology, and (4) mapping of metal pipes, among others.

Usually, EMI data present some type of drift due to topographic variation and temperature. Corrections are necessary in order to improve contrast between physical properties of background and subsurface targets. A good discussion about topographic drift correction can be found in Santos et al. (2009). On the other hand, Sudduth et al. (2001) showed that there is an increase in values of apparent ground conductivity with decreasing temperature, and vice versa. In the same research line, Robinson et al. (2004), after laboratory and field tests, found instability in apparent conductivity measures obtained with the EM38 equipment, once there is a differential heating with control panel being warmer than coils. Through product wrapped in an electric blanket (simulating warming attributable to solar radiation), there was an increase in values of apparent conductivity at the time equipment reaches a temperature of 40°–46 °C. However, when it reaches 53 °C, values tend to decrease. Subsequently to decreasing equipment temperature, it was observed there was a discrepancy in values of apparent conductivity.

From EMI data (EM38 equipment) obtained at the IAG/USP test site, it was observed that conductivity decreases as temperature increases and with time measurement acquisition. In the morning, the moment when much data were collected, temperature increases, affirming that conductivity decreases with time.

Around line 7, nine VMD profiles with a sensor with a 0.1 m height were acquired. Profiles were spaced by 0.5 m, the measured interval was 0.5 m, and 5 stacking measures were used. Fig. 4 shows the position of survey lines over and around buried targets at line 7.

According to Sudduth et al. (2001), the effect caused by the variation of environmental temperature can be corrected by linear adjusting. To correct this variation, initially a base line at 21 m EW-position was defined, because in this position we don't have any buried target. Therefore, data were collected along the base line at 21 m position before and after EMI data were acquired around line 7. The observed difference is due to variation in electric conductivity and susceptibility magnetic values caused by temperature. In such a way, the difference is distributed in whole data.

Subsequently, the equipment in VMD configuration was left for 20 min in a local where there are no metallic targets at the IAG/USP test site, acquiring a total of 2400 measures in 0.5 sec intervals. This procedure was necessary to verify the influence of environment temperature in measurement of electrical conductivity and magnetic susceptibility. To validate this procedure, an experiment was done in seven different locations at the test site, and each and every one had the same feature. Temperature variation was less than 1 °C.

4. Discussion of results

Fig. 5 shows inductive electromagnetic method (EMI) result obtained around line 7 without any drift correction. This figure objective shows that targets buried in subsoil are not clearly determined, and only targets located at the 1 m position presented good location. Observe in the figure that values of apparent conductivity (Fig. 5a) and magnetic susceptibility (Fig. 5b) are very high. Therefore, in order to improve the contrast between the physical properties of subsurface targets and background it is necessary to apply some data correction.

Fig. 6 shows EMI data obtained around line 7 with linear correction according to Sudduth et al. (2001). As expected, several metallic anomalies were observed. Apparent conductivity values ranged between −8.5 and 56.5 mS/m, and magnetic susceptibility between

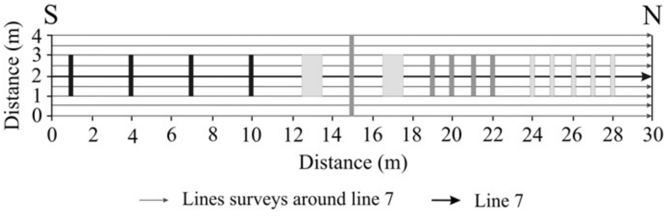

Fig. 4. Scheme of survey lines around targets buried at line 7 at the IAG/USP test site.

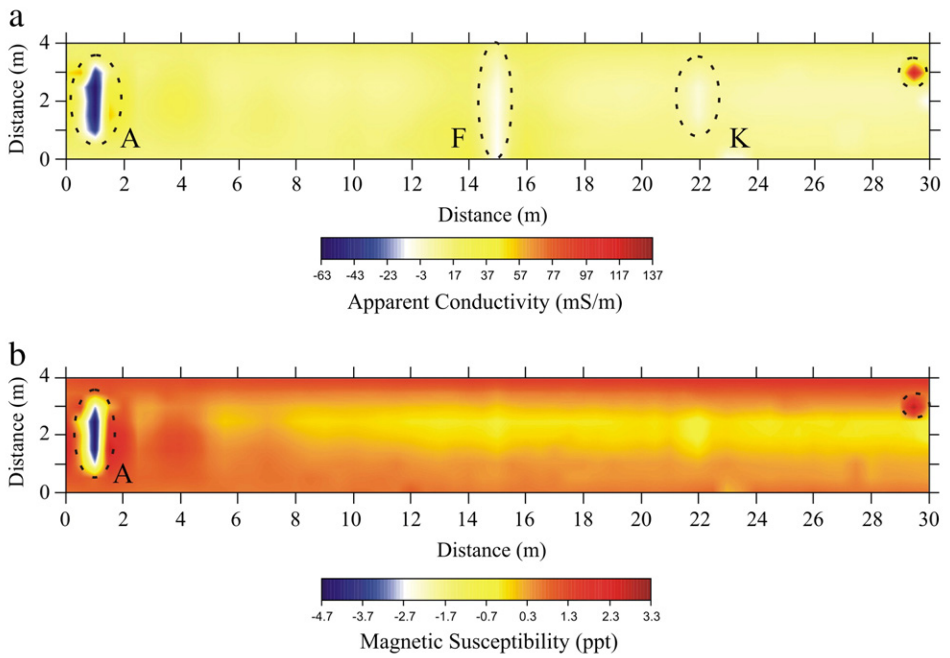

Fig. 5. EM38 result around line 7 without any correction. a) Apparent conductivity. b) Magnetic susceptibility.

−0.9 and 2.3 ppt. Fig. 6a shows conductivity data in which five anomalies can be observed: metallic pipes at positions 1 m ("target A"), 4 m ("target B"), and 7 m ("target C"), metallic guide pipe at 15 m ("target F"), and position of 22 m has the presence of an electrical cable ("target K"). Fig. 6b shows susceptibility data, whose "target A," "target B" and "target C" anomalies related to metallic pipe can only be observed. In both figures, an anomaly located at 29.5 m is clearly observed. It is related to concrete structure with metallic bars installed in boundary corners at the IAG/USP test site.

As observed in Fig. 6, apparent conductivity and magnetic susceptibility results showed negative values. These values have no physical significance to previously said properties, but as they are related to shallow metallic targets buried at 0.5 m depth, the limit of low induction number was broken. So, this is a characteristic of inductive electromagnetic method, and it is used just as a good indicator of shallow metallic targets.

In order to find the best equation to correct EMI data affected by environment temperature, graphics of apparent conductivity × time, and magnetic susceptibility × time were analyzed. Fig. 7 shows corresponding graphs for the points located at the X = 21 m and Y = 21 m positions. Observe that the relation between time (or temperature) and electric conductivity and magnetic susceptibility were best represented by a quadratic function.

These graphics show values of electric conductivity (σ_a) and magnetic susceptibility (χ) without temperature influence. Accordingly, the first minute of measurement was chosen as reference value.

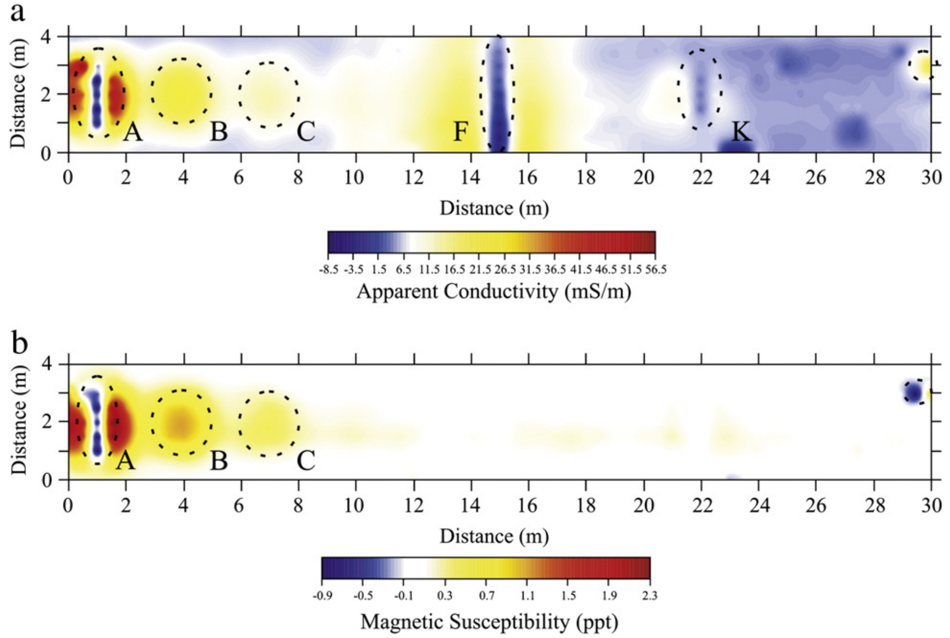

Fig. 6. EM38 result around line 7 by using linear correction. a) Apparent conductivity. b) Magnetic susceptibility.

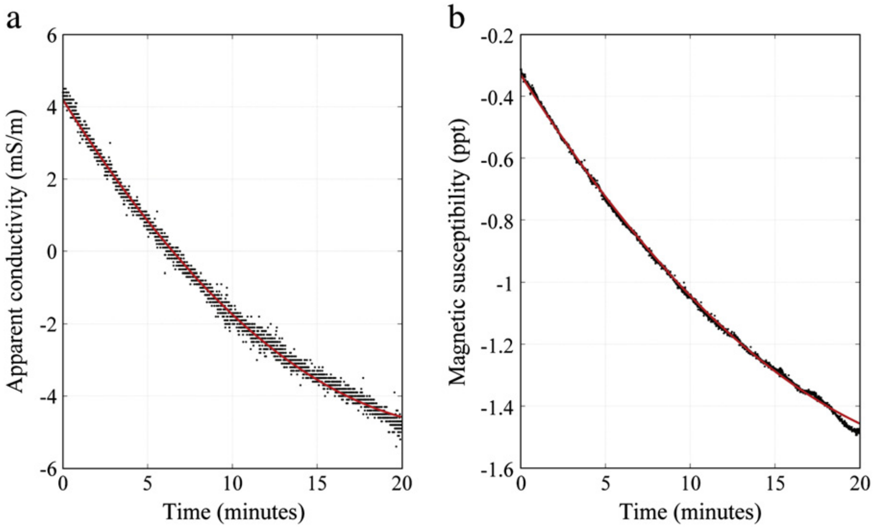

Fig. 7. Influence of environment temperature *versus* time at the X = 21 m and Y = 21 m positions at the base line. a) Apparent conductivity. b) Magnetic susceptibility.

Average data of 120 measurements for conductivity ($\bar{\sigma}_a = 4.12 \pm 0.20$) and susceptibility ($\bar{\chi}_m = -0.35 \pm 0.02$) were used as reference values representing values with no influence of temperature variation.

With these values in hand subtract them from each data, electric conductivity and magnetic susceptibility in order to get a residue of an entire data set, and confirming that the relation between σ_a/χ_m and temperature is quadratic, graphics can adjust the curve to find the relation between variables. Fig. 8 shows a residue of apparent conductivity and a residue of magnetic susceptibility. This adjustment is necessary to correct or remove the temperature effects of (1) electric conductivity and (2) magnetic susceptibility from EMI data. Its mathematics relation is given by

$$\sigma_a = -0.0155\,t^2 + 0.749\,t - 0.0016 \tag{1}$$

$$\chi_m = -0.0015\,t^2 + 0.0863\,t + 0.67. \tag{2}$$

Thus, after relations were determined, noted in schedule time interval between the start and the end of surveys, the interval is distributed to data according to the above-mentioned mathematics relations correcting temperature drift. Therefore, this procedure allows us to reduce fieldwork time because it is not necessary to acquire data at the base line, and it becomes quick.

Fig. 9a and b shows electric conductivity and magnetic susceptibility results around line 7 after removing instrumental drift with a quadratic function. Observe that deeper targets were highlighted and the shallower targets were better defined. Results of conductivity (Fig. 9a) allow us to locate five anomalies, such as metallic pipes “target A,” “target B,” “target C,” and “target D,” metallic pipe guide “target F,” and electrical cable “target K.” For magnetic susceptibility (Fig. 9b), targets “A,” “B” and “C” were clearly located. These anomalies were enhanced due to higher contrast in physical properties related to the background.

Fig. 10 shows differences obtained with the correction of instrumental drift by using linear and quadratic adjusting for line 7 at the IAG/USP test site. Note the difference in amplitude between two corrections to apparent conductivity and magnetic susceptibility whose quadratic correction amplitude is greater.

5. Conclusions

The correction of temperature drift in apparent electric conductivity and magnetic susceptibility from inductive electromagnetic

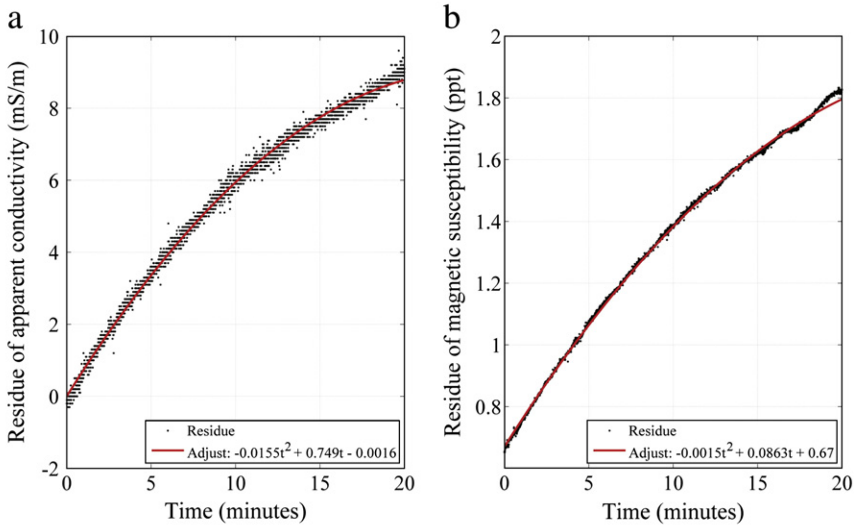

Fig. 8. Residue of adjusting responsible for quadratic correction at the X = 21 m and Y = 21 m positions at the base line. a) Apparent conductivity. b) Magnetic susceptibility.

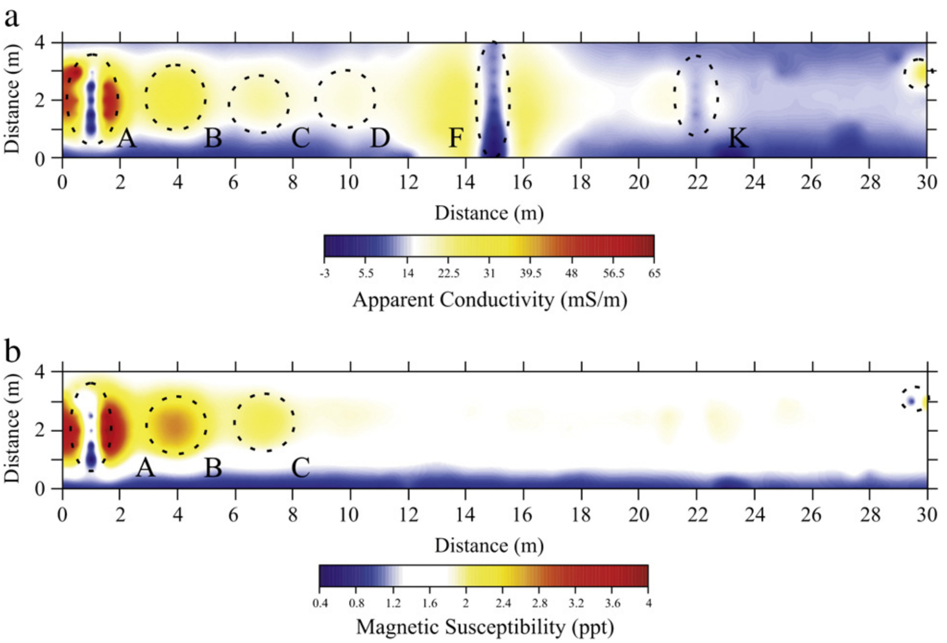

Fig. 9. EM38 result around line 7 by using quadratic correction. a) Apparent conductivity. b) Magnetic susceptibility.

data (EM38 equipment) by using quadratic function adjust was effective for the location of metallic pipes and electrical cables buried at line 7 at the IAG/USP test site (São Paulo, Brazil). Electric conductivity and magnetic susceptibility anomalies were enhanced, improving lateral pipes positioning and deeper targets. This procedure can be used to enhance masked anomalies by the influence of temperature variation. Besides, data acquisition and treatment become faster because it is not necessary to survey and re-occupation a base line.

Quadratic relation found in this work is valid for geological conditions at our study area. For other areas it is necessary to perform procedures to find better relation between apparent electric conductivity/magnetic susceptibility and time (or temperature). In this manner it is possible to calculate correct data relation.

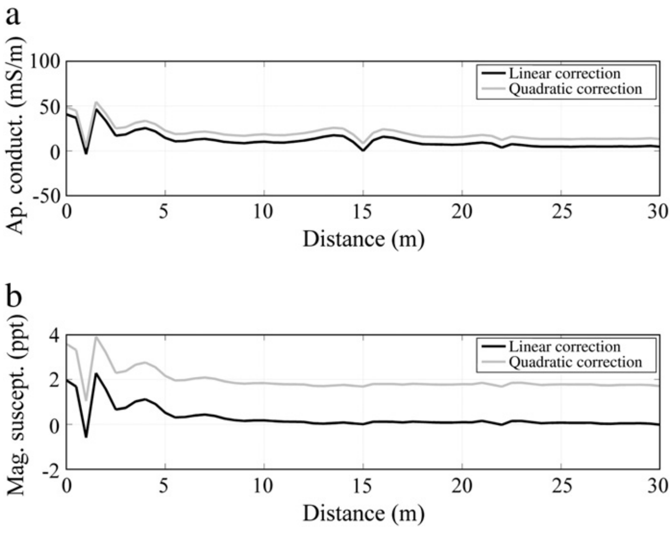

Fig. 10. EM38 result over line 7 by using linear and quadratic correction. a) Apparent conductivity. b) Magnetic susceptibility.

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References

Borges, W.R., 2007. Caracterização geofísica de alvos rasos com aplicações no planejamento urbano e meio ambiente: Estudo sobre o Sítio Controlado do IAG/USP. D.Sc. Thesis, Instituto de Astronomia, Geofísica e Ciências Atmosféricas, USP, São Paulo, Brazil.

Geonics, 1998. EM-38 Ground Conductivity Meter Operating Manual. Geonics Ltd, Mississauga, Ontario, Canada. 27 pp.

Gerber, R., Felix-Henningsen, P., Salat, C., Junge, A., 2004. Investigation of the GPR reflection pattern for shallow depths on a test site. Proceedings of the Tenth International Conference on Ground Penetrating Radar (GPR'2004), Delft, Netherland, pp. 275–278.

McNeill, J.D., 1980. Electromagnetic terrain conductivity measurement at low induction numbers. Geonics Ltd, Mississauga, Ontario, Canada. Tech. Note TN-6. 13 pp.

Naser, M., Junge, A., 2008. The Frankfurt test site for utility detection: Construction and first GPR tests. 12th International Conference on Ground Penetrating Radar (GPR'2008), Birmingham, United Kingdom. CD-Rom.

Paniagua, J., Del Rio, M., Rufo, M., 2004. Test site for the analysis of subsoil GPR signal propagation. Proceedings of the 10th International Conference on Ground Penetrating Radar (GPR'2004), Delft, Netherland, pp. 751–754.

Porsani, J.L., Borges, W.R., Elis, V.R., Diogo, L.A., Hiodo, F.Y., Marrano, A., Birelli, C.A., 2004. Investigações geofísicas de superfície e de poço no sítio controlado de geofísica rasa do IAG-USP. Revista Brasileira de Geofísica 22, 245–258.

Porsani, J.L., Borges, W.R., Rodrigues, S.I., Hiodo, F.Y., 2006. O sítio controlado de geofísica rasa do IAG/USP: Instalação e resultados GPR 2D-3D. Revista Brasileira de Geofísica 24, 49–61.

Porsani, J.L., Sauck, W.A., 2007. Ground-penetrating radar profiles over multiple steel tanks: Artifact removal through effective data processing. Geophysics 72, J77–J83.

Porsani, J.L., Slob, E., Lima, R.S., Leite, D.N., 2010. Comparing detection and location performance of perpendicular and parallel broadside GPR antenna orientations. Journal of Applied Geophysics 70, 1–8.

Radzevicius, S.J., Daniels, J.J., 2000. Ground penetrating radar polarization and scattering from cylinders. Journal of Applied Geophysics 45, 111–125.

Reynolds, J.M., 1997. An introduction to applied and environmental geophysics. John Wiley & Sons, Chinchester.

Robinson, D.A., Lebron, I., Lesch, S., Shouse, P., 2004. Minimizing Drift in Electrical Conductivity Measurements in High Temperature Environments using the EM-38. Soil Science Society of America Journal 68, 339–345.

Rodrigues, S.I., Porsani, J.L., 2006. Utilização do GPR para caracterizar tambores plásticos enterrados no sítio controlado de geofísica rasa do IAG/USP. Revista Brasileira de Geofísica 24, 157–168.

Santos, V.R.N., 2009. Emprego dos métodos eletromagnético indutivo e GPR no mapeamento de redes de interferências instaladas no Sítio Controlado de Geofísica Rasa do IAG/USP. M.Sc. Thesis, Instituto de Astronomia, Geofísica e Ciências Atmosféricas, USP, São Paulo, Brazil.

Santos, V.R.N., Porsani, J.L., Mendonça, C.A., Rodrigues, S.I., De Blasis, P.A.D., 2009. Reduction of topography effect in inductive electromagnetic profiles: application on coastal *sambaqui* (shell mound) archaeological site in Santa Catarina State, Brazil. Journal of Archaeological Science 36, 2089–2095.

Sudduth, K.A., Drummond, S.T., Kitchen, N.R., 2001. Accuracy issues in electromagnetic induction sensing of soil electrical conductivity for precision agriculture. Computers and Electronics in Agriculture, 31. Elsevier, pp. 239–264.