Journal of Archaeological Science 36 (2009) 2089–2095

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Review

Reduction of topography effect in inductive electromagnetic profiles: application on coastal *sambaqui* (shell mound) archaeological site in Santa Catarina state, Brazil

Vinícius R.N. Santos [a], Jorge L. Porsani [a,*], Carlos A. Mendonça [a], Selma I. Rodrigues [a], Paulo D. DeBlasis [b]

[a] Universidade de São Paulo (USP), Instituto de Astronomia, Geofísica e Ciências Atmosféricas (IAG), Departamento de Geofísica, São Paulo 05508090, Brazil
[b] Universidade de São Paulo (USP), Museu de Arqueologia e Etnologia (MAE), São Paulo, Brazil

ARTICLE INFO

Article history:
Received 19 May 2008
Received in revised form
17 April 2009
Accepted 19 May 2009

Keywords:
Inductive electromagnetic method
Topographic correction
Archaeological *sambaqui* site
Santa Catarina State
Brazil

ABSTRACT

We present results of electrical conductivity profiles obtained with inductive electromagnetic geophysical method in Santa Marta archaeological site, Santa Catarina State, southern Brazil. This site is a *sambaqui* (shell mound), in which several human occupation remains are found during pre-colonial period such as buried lithic and bone artifacts, fire-place, etc. Most of these mounds include as well many human burials, which, in many cases, point to funerary ritual as a main agency for mound building. A set of profiles of apparent electrical conductivity and magnetic susceptibility was acquired in two sites aiming the identification of geophysical anomalies with potential interest for excavation. To enhance conductivity data, we applied an effective procedure to remove topographical effects in the apparent conductivity measurements, which are rather conditioned by the presence of a variable water table depth or conductive sediment layer. A linear dependence among conductivity values and the site elevation provided a simple linear model to remove the influence of topography. Corrected electric conductivity maps substantially improved the definition of anomalies, many of them rather subtle in raw data images. Corrected maps also show a better adherence with magnetic susceptibility maps, both of them identifying archaeological structures of interest: a well-structured fire-place and a concentration of ceramic fragments.

1. Introduction

Technological advance in the last decades has propitiated a realizable increase of applied geophysical works to archaeological studies. The use of shallow geophysics has effectively contributed with no destructive actions in modern archaeological studies, by identifying favorable places for excavation in reduced time and costs (Conyers and Goodman, 1997). Among geophysical methods with applications in archaeology, inductive electromagnetic and GPR methods are highlighted due to their robustness and functionality in data acquisition and interpretation (Conyers, 2004; Reynolds, 1997).

Inductive electromagnetic methods have found many applications such as, archaeology (Tabbagh, 1986; Bevan, 1991; Dalan, 1991; Clay, 2001; Gomes, 2003; Venter et al., 2006; Rodrigues et al., inpress), precise agriculture (Corwin and Lesch, 2003; Oliveira et al., 2005), mapping of metallic piping (Borges and Porsani, 2003; Carpenter and Deignan, 1993; Cisar et al., 1993; Maclean et al., 1991; McNeill, 1980), and soil salinity (Bennett and George, 1995; Triantafilis et al., 2000), among others. Theoretical basis to this method can be found in (Keller and Frischknecht, 1966; McNeill, 1980; Telford et al., 1990).

There are various geophysical equipments that by using inductive electromagnetic method principles, such as EM31, EM34, EM38, EM61 (Geonics, Instruments), among other instruments. In this work, EM38 equipment was used (Geonics, 1998). The mapping by using EM38 equipment provides the spatial variation of the soil electrical conductivity, and magnetic susceptibility. The equipment possesses two coils spaced of 1 m, working with 14.6 kHz of frequency, and it could be employed through two acquisition ways: Vertical Magnetic Dipole – VMD – that allows investigating up to 1.5 m of depth, and Horizontal Magnetic Dipole – HMD – that allows investigating up to 0.75 m of depth (McNeill, 1980). As electrical conductivity as magnetic susceptibility derive of a relation between primary and secondary electromagnetic fields, seeing that electrical conductivity correspond to a quadrature component

* Corresponding author. Tel.: +55 11 30914734; fax: +55 11 30915034.
E-mail address: porsani@iag.usp.br (J.L. Porsani).

0305-4403/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jas.2009.05.014

(imaginary part) and magnetic susceptibility correspond to a phase (real part) of these fields.

According to McNeill (1980), the ratio between secondary magnetic (H_S) and primary magnetic (H_P) field is linearly proportional to electric conductivity (σ) of mean, being expressed by:

$$\sigma = \frac{4}{\omega\mu_0 s^2}\left[\frac{H_S}{H_P}\right]_q \quad (1)$$

where "ω" is angular frequency ($\omega = 2\pi f$), "μ_0" is magnetic permeability of vacuum, "s" is the space between sensors (transmiter-Tx and receiver-Rx), and "q" denote a part in quadrature of these field. On the other hand, magnetic susceptibility (χ_m) values are obtained with equipment in vertical magnetic dipole – VMD – mode by the means of conductivity measurements accomplished in soil surface (σ_0^{VMD}), and in 1.5 m of height ($\sigma_{1,5}^{\mathrm{VMD}}$), whose measurement difference is given by:

$$\Delta\sigma = \sigma_0^{VMD} - \sigma_{1,5}^{VMD} \quad (2)$$

Thus, magnetic susceptibility (χ_m) value could be obtained by expression:

$$\chi_m = 58 \times 10^{-6}\Delta\sigma \quad (3)$$

In this work we show that irregularities in terrain surface meaningfully distort the conductivity maps, even hiding anomalies with archaeological structures. Topography disturbance, however, seems to be cast in a very predicable way: higher the elevation, lower its apparent conductivity. At least for the studied sites, this simple behavior can be associated to the distance of sensor regarding a shallow water table. Since EM38 signal is focused to about 0.5 m depth (VMD mode) (McNeill, 1980), its signal response in depressions is to a large extent conditioned by conductive saturated zone. Otherwise, in elevations, its response reflects the low conductivity values usually found in vadose zone. In the middle of such limiting heights, a smooth variation in apparent conductivity is observed, and conductivity maps exhibit a regional pattern, higher correlated with site relief.

In the study of contaminated sites, a practical procedure was proposed to remove such regional effect from EM31 and EM34 data (Monier-Williams et al., 1990). This article shows that the dependence among electric conductivity values and site elevation provided a linear model to remove the topography influence. This procedure is applied here intending to enhance the response from archaeological targets that in some cases were note clearly distinguished. Despite good results in contaminated areas, there are no records in scientific literature about removal of topographic effects in measures of electrical conductivity carried out with inductive electromagnetic method applied in study of archaeological sites up to now.

This simple predicable variation are associated to underground conductivity, for example conductive sediment layers, and the variation in water table depth that usually follow the topography, seems to be a main factor conditioning the electromagnetic induction response, with capacity for even hiding small variations produced by archaeological targets. In this article it is presented an effective methodology that removes the influence of topography in electrical conductivity data obtained by inductive electromagnetic methods, and it shows two examples of application in archaeological site studies.

2. Santa Marta archaeological site

Santa Marta *sambaqui* archaeological site is located at Jaguaruna region, in Santa Catarina State, southern Brazil (Fig. 1). *Sambaqui* is a *guarani* (Brazilian native language) word meaning: *Tambá* – shells and *Qui* – conic mound, or shell mound. These *sambaquis* are constituted by a high variation in volume and morphology, presenting a distribution and concentration pattern defined by sediments. According to DeBlasis et al. (1998), these structures were built by inhabitants that lived in south of Brazil during pre-colonial period, about 6000 years before present.

Sambaquis (as already said, it is an original word from native Tupi language, literally meaning "shell mounds" or *concheiros*) are archaeological mounded sites distributed all over Brazilian coast, mainly at ecologically patchy areas involving brackish waters, mangrove and forests such as lagoon, bay and coastal island areas. These sites present different sizes, achieving impressive dimensions especially at southern coast of Santa Catarina, where they may reach up to 70 m height and 500 m width. In general, they exhibit heterogeneous stratigraphic sequences differently composed, mostly thicker shell layers irregularly intercalated with smaller dark strata richly composed of organic materials, including abundant funerary structures in specific areas. In fact, several burials are reported in most *sambaqui* descriptions, disposed ritually in specially prepared places, frequently accompanied of artifacts, food offerings and fire-place (DeBlasis et al., 2007; Gaspar et al., 2008).

The application of geophysical surveying methods to these mounds aims a quicker, larger, and non-destructive understanding of underlying structures as well as the identification of punctual features such as fire-place and burials without intensive digging, consequently contributing to preservation of prehistoric Brazilian heritage. It is expected such structures generate resistive anomalies

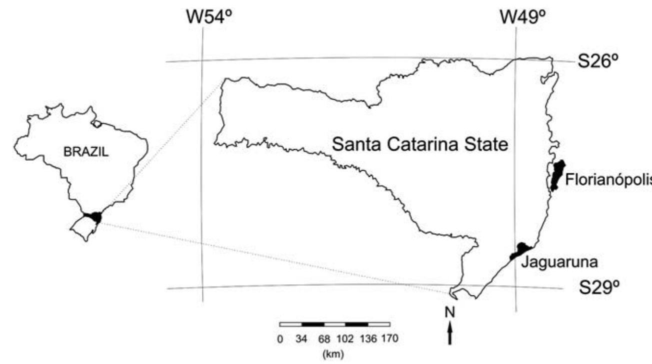

Fig. 1. Study area localization in Jaguaruna region, Santa Catarina state, Brazil.

Fig. 2. Acquisition of electric conductivity profiles with EM38 equipment.

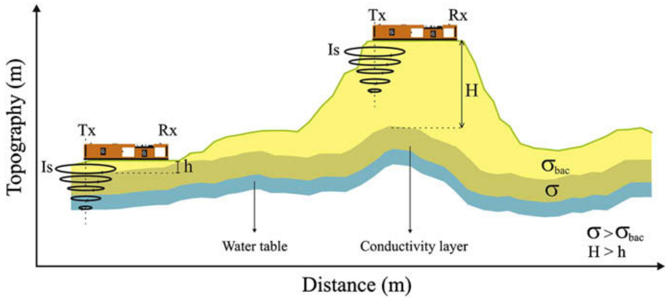

Fig. 3. Schematic of topographic variation influence in measurements of electric conductivity with inductive electromagnetic method.

and of low magnetic susceptibility values, once there were not relates of metallic artifacts to this civilization. However, some structures could provoke anomalies values of high electrical conductivity, and magnetic susceptibility as paleo-fires that present remaining magnetization. This magnetization can be caused by freezing of Earth magnetic field in ferromagnetic minerals present in rock fragments during the burnt processes.

3. Data acquisition and treatment

Two areas of Santa Marta archaeological site – grid-1 (25 m $\times$ 10 m), and grid-2 (20 m $\times$ 5 m) – have been investigated. In grid-1, measurements were done along 11 parallel inductive electromagnetic profiles, and in grid-2, along 6 lines. In both areas the lines were orientated from south to north direction. Lines were regularly separate of 1 m, and measurements were done along line in 0.5 m of interval.

Measurements were carried out with EM38 equipment in VMD mode (Fig. 2) for a deeper investigation depth. During data acquisition, a base point was set for further drift correction. This procedure is necessary to guarantee a good data quality, by avoiding conductivity variations caused by changes in the equipment temperature (Sudduth et al., 2001).

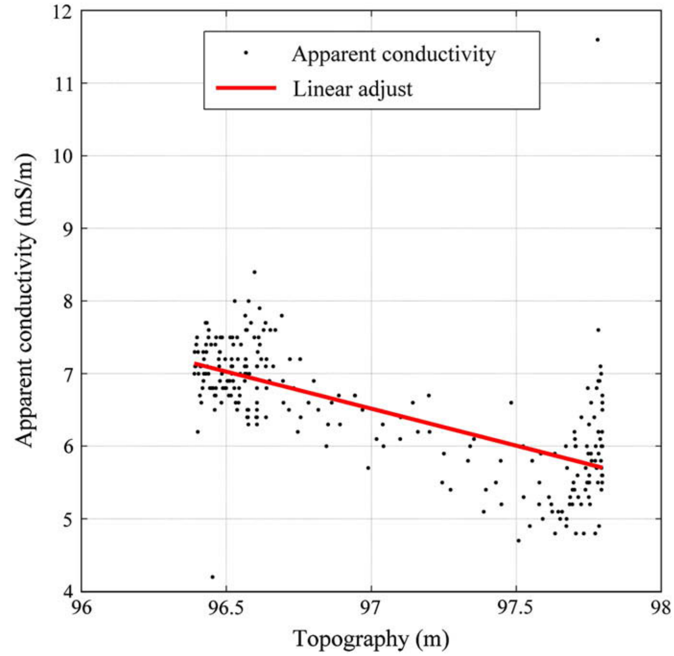

Fig. 5. Relation between apparent electric conductivity in terms of topographic variation to grid-2.

Terrain elevation was measured with a Leica TCR305 infra-red total station, by taking random measurements along lines. Approximately one measurement per square meter was taken. Elevation model errors were below some few millimeters.

Topographic variation effect in the apparent electric conductivity measurement by using inductive electromagnetic method is illustrated in Fig. 3. According to this conceptual model when sensors (Tx and Rx) are put at a topographic lower part (h) they are close to conductive sediments or water table (conductors), so electric conductivity measurement values are higher. This fact

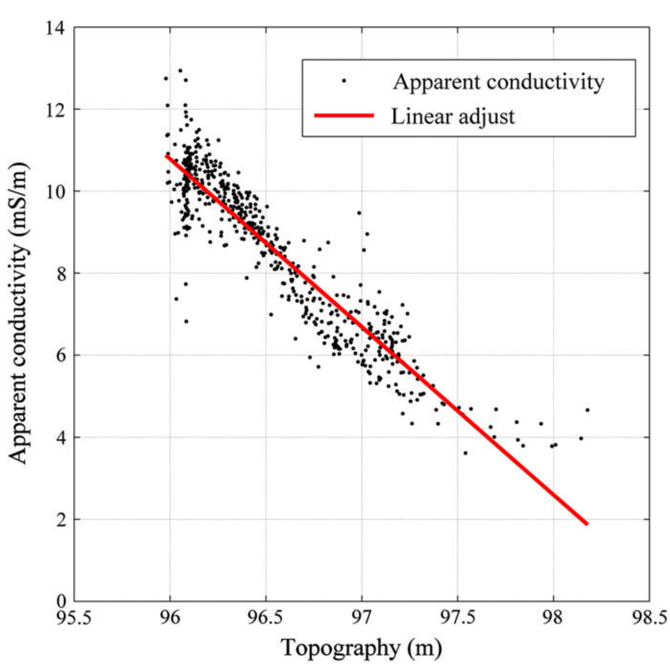

Fig. 4. Relation between apparent electric conductivity in terms of topographic variation to grid-1.

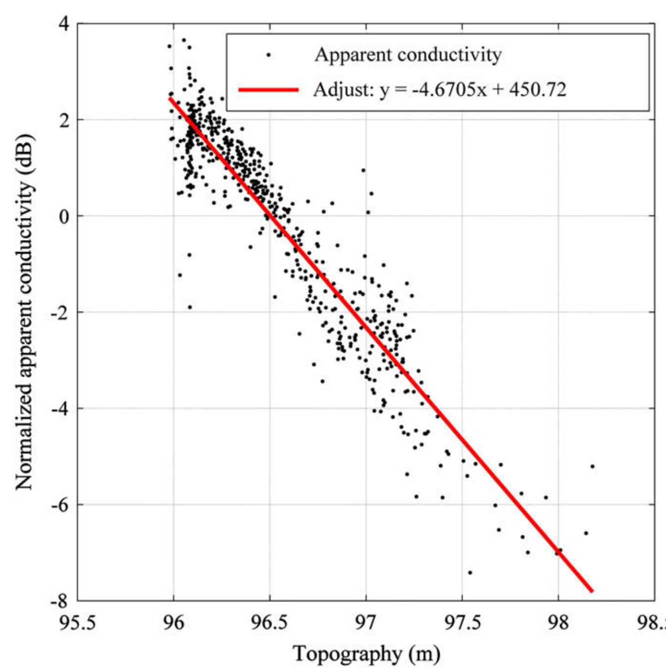

Fig. 6. Normalized apparent conductivity measurements in terms of topographic variation to grid-1. Red line correspond to the best adjust for data.

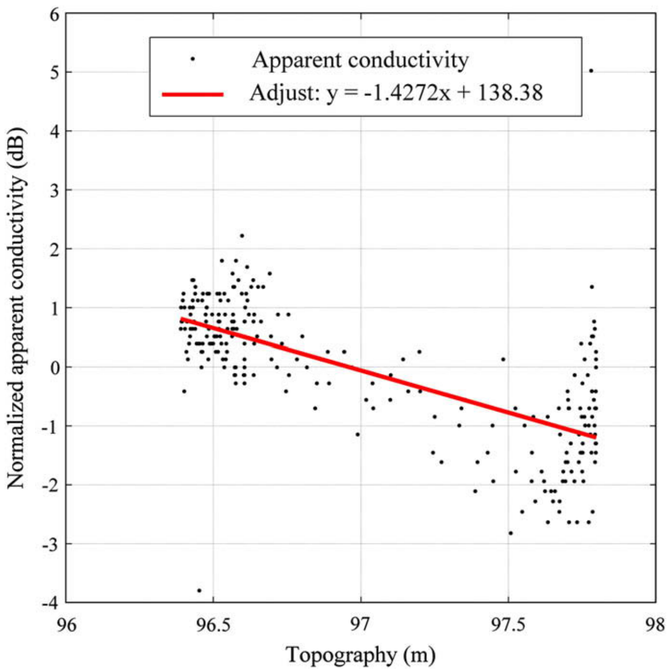

Fig. 7. Normalized apparent conductivity measurements in terms of topographic variation to grid-2. Red line correspond to the best adjust for data.

happens due to higher sensor proximity with saturated sediments that are more conductive than background one, provoking an increasing in induction of electrical current (Is) in the conductor, increasing measured electrical conductivity values measured by equipment. On the other hand, where topography is higher (H), conductive sediments or the water level is kept distant of sensors so the conductivity reading by equipment is lower. In other words, more distant sensors are from saturated sediments in subsurfaces, lower electrical current induction in the conductor will be, it means, electrical conductivity influence in conductor will be lower; so electrical magnetic field intensity is attenuated by mean, decreasing electrical conductivity values measured by equipment (McNeill, 1980).

The relation between topographical variation and apparent conductivity measurements in grid-1 and grid-2 are presented in Figs. 4 and 5, respectively. Fig. 4 was elaborated starting from a set of 561 points of apparent conductivity to grid-1 area, and Fig. 5 was elaborated starting from a set of 246 conductivity values to grid-2. Note there is a well defined linear data trend for both areas. This fact clearly indicates data suffer influence of topographical variation. Thus, they can be corrected. On the other hand, magnetic susceptibility (equation 3) does not possess any relation with topographical variation, it means, with proximity of saturated sediments, because it only depends on the amount of magnetic minerals presented in material, so it does not need correction.

To analyze the dependence of conductivity values with elevation, electromagnetic induction and topographic data were interpolated on a regular same size mesh. This task was necessary because both data sets have no coincident reading points. Conductivity and magnetic susceptibility data were acquired along regular S-N profiles but elevation heights were randomly acquired, only guaranteeing a suitable data density. That occasion, data were adjusted for regular mesh with coincident points, and maps were elaborated. With data adjustment in regular grids, effect of temperature drift was reduced by the means of procedure described by Sudduth et al. (2001). Subsequently, apparent conductivity and magnetic susceptibility maps were elaborated. It is important to note these procedures are usually applied in processing grid data and they are not effective in removing elevation influence. Following procedures to remove topographical effect in conductivity data are shown.

In order to correct elevation effect, we applied the following equation (Monier-Williams et al., 1990):

$$C(x,y) = 20\cdot\log_{10}\left[\frac{\sigma_{ap(x,y)}}{\sigma_{ap(bac)}}\right] \tag{4}$$

where C (x,y) is electrical conductivity value normalized in decibel (dB) at position (x,y), $\sigma_{ap(x,y)}$ is apparent conductivity, and $\sigma_{ap(bac)}$ is background electrical conductivity. In this work, the reduction of topographic effect in apparent conductivity measure was done through its normalization by apparent mean background conductivity value obtained from all data set measurement for grid-1 and grid-2. The mean conductivity value of background obtained for

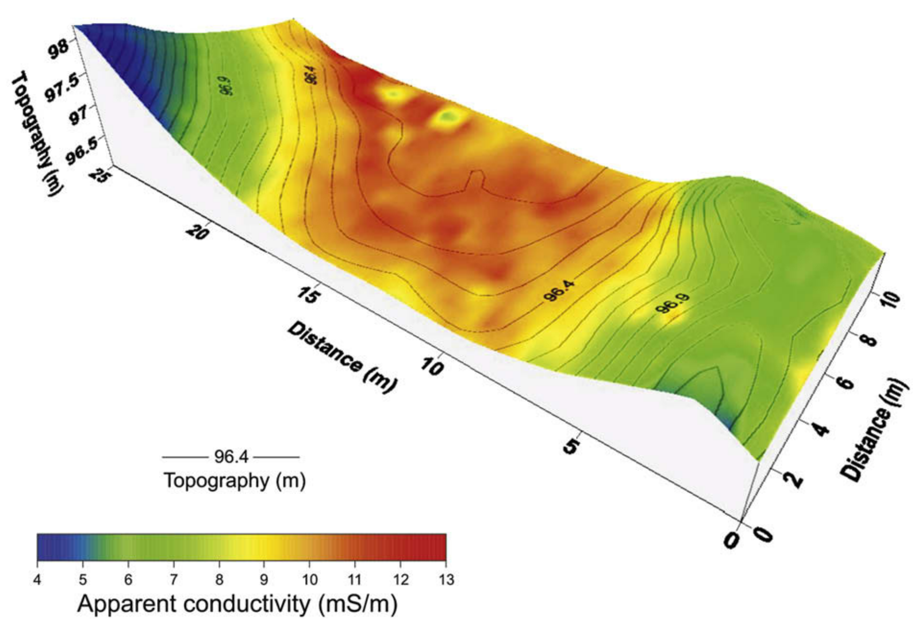

Fig. 8. Map of apparent electric conductivity (raw data) overlapped to topographic variation to grid-1.

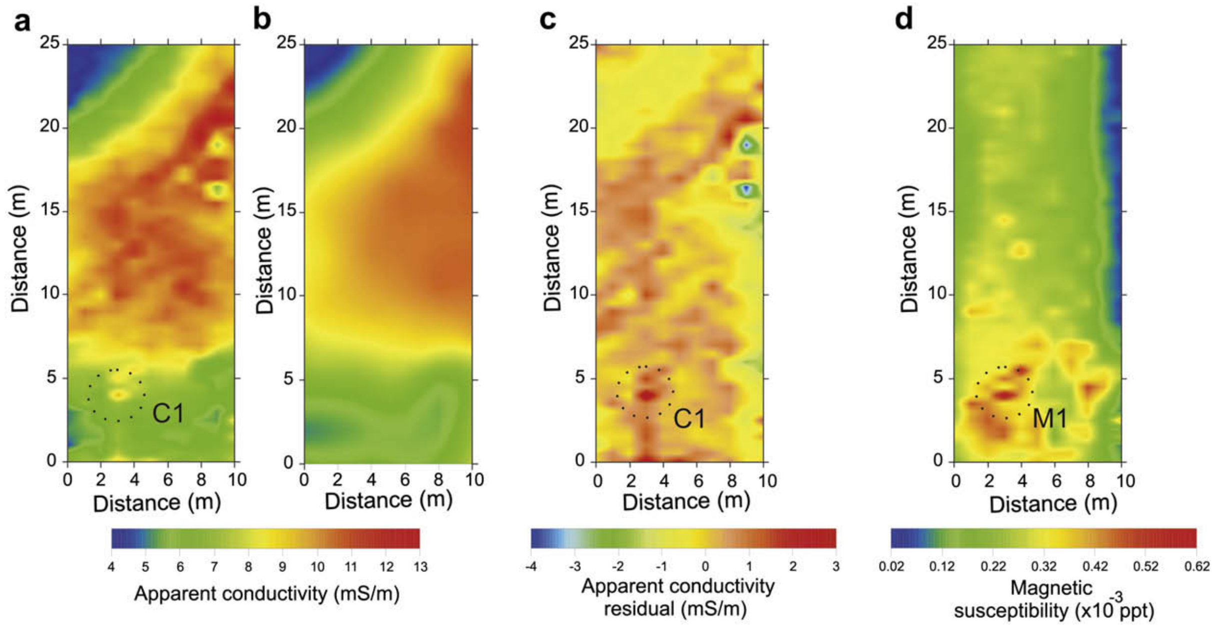

Fig. 9. Results to grid-1. a) Map of "raw" apparent electric conductivity. b) Map of "regional" apparent electric conductivity. c) Map of "residual" apparent electric conductivity. d) Map of magnetic susceptibility.

grid-1 was 15.04 mS/m, and for grid-2 was 6.83 mS/m. Mean conductivity of background used in this work is due to this measure be statistical robust (Barbetta, 2002).

Since there are relation linear trend between electric conductivity and topographic variation, and electric conductivity values of background, also called "regional conductivity" can be determined, so topography influence can be corrected. Figs. 6 and 7 shows normalized apparent conductivity measurements in terms of topographic variation to grid-1 and grid-2, respectively. Note to grid-1 straight line equation of better adjust is done by ($y = -4.6705x + 450.72$), and to grid-2 straight line equation is done by ($y = -1.4272x + 138.38$). In such a way, final apparent conductivity "y", without topographical influence, was calculated by these equations whose topographical values are replaced in "x". This correction allows enhancing the obtained apparent conductivity anomalies with inductive electromagnetic method before masked for topographical variation influence.

4. Analysis of results

4.1. Grid-1

Fig. 8 shows apparent electric conductivity data overlapped to the topographical variation for grid-1. As it can be observed in the figure, topography influence in conductivity values is clear. This effect is enough evident, it means, the place where a low topographical exists apparent electric conductivity value is raised; on the other hand, in places topographically higher, electric conductivity values are low.

Fig. 9 shows raw data apparent conductivity map (a), background conductivity map (b), residual conductivity map (c), as well as the magnetic susceptibility map (d). Residual conductivity map corresponds to apparent conductivity map corrected for topographical effect obtained from subtraction of measured conductivity map by apparent background map. Residual map shows as negative as positive conductivity values. Negative values indicate it is less than regional conductivity, and positive more. Although negative conductivity values do not have physical meaning, these values were included by bearing in they are referenced to a particular background value. In this sense, conductivity anomaly is distinguished, and not true physical property value. With magnetic susceptibility data integration we have elements to better understand these residual anomalies; therefore we prove the presence of this anomaly for apparent conductivity residues and magnetic susceptibility.

Apparent corrected conductivity clearly evidences a conductivity anomaly (C1) that before topographic correction was not clearly observed. Note that information about magnetic susceptibility allowed defining a significant magnetic anomaly (M1), which matches with observed conductivity anomaly positioning. The other two conductivity anomalies observed in Fig. 9c (position $x = 9$ m, $y = 16$ m, and 19 m) are less relevant because there are not correspondence with magnetic susceptibility data. As a consequence, they were not indicated as potential archeological targets.

Archaeologists' team from *Universidade de São Paulo*, leaded by DeBlasis, has accomplished archeological excavation in study areas, taking as base results obtained in this research. As excavation result

Fig. 10. Paleo-fire found after excavation in grid-1.

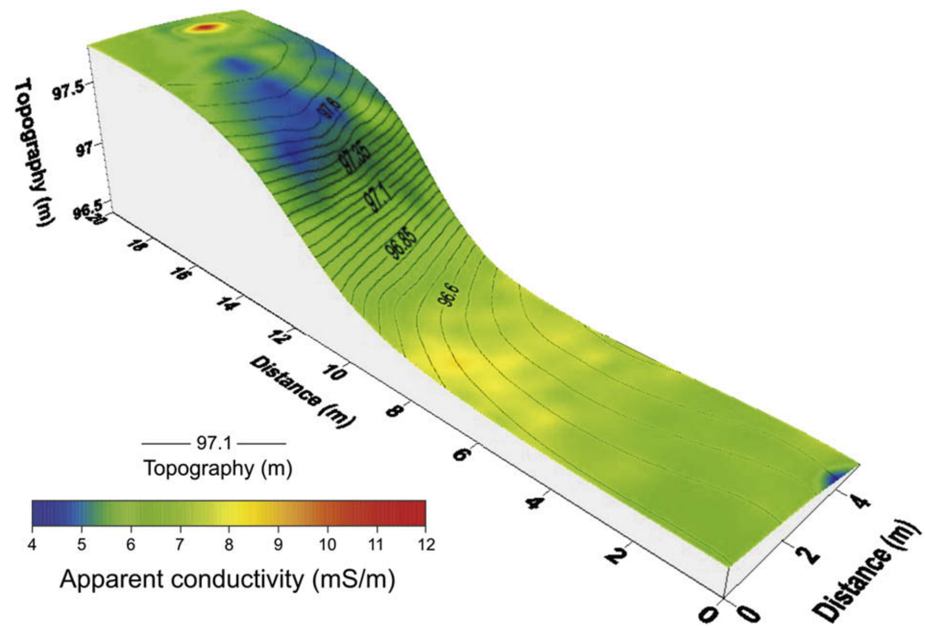

Fig. 11. Map of apparent electric conductivity (raw data) overlapped to topographic variation to grid-2.

a fire-place was found in grid-1 area (Fig. 10) corresponding to conductivity anomalies (C1), and magnetic susceptibility (M1).

4.2. Grid-2

Fig. 11 shows apparent conductivity data in relation to topographical variation for grid-2. In such area it is observed topographical effect is not so clear in relation to previous area, this could occur due to the more homogeneous terrain, with no water influence or conductive sediments, probably deeper.

Fig. 12 again shows the map of apparent electric conductivity for raw data (a), the map of background apparent electric conductivity (b), the map of residual apparent electric conductivity (c), and the map of magnetic susceptibility (d).

A strong anomaly of apparent conductivity (C2) in raw data is observed. Note regional anomaly is not too high as shown in

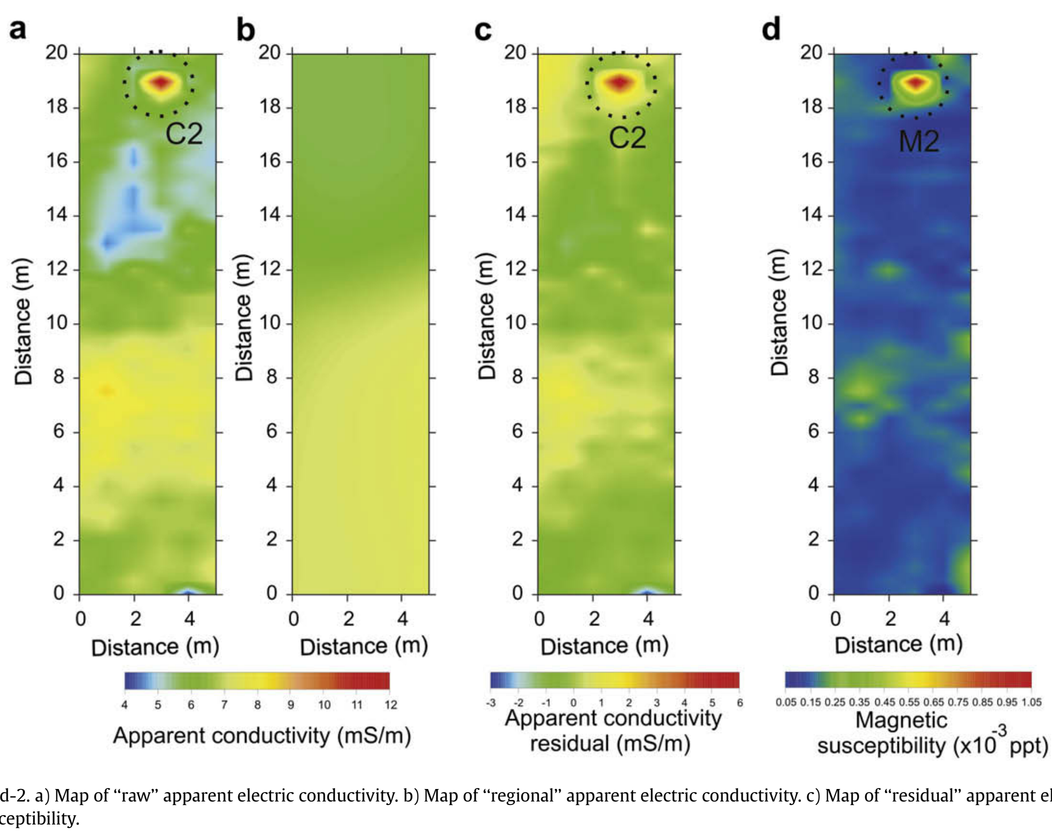

Fig. 12. Results to grid-2. a) Map of "raw" apparent electric conductivity. b) Map of "regional" apparent electric conductivity. c) Map of "residual" apparent electric conductivity. d) Map of magnetic susceptibility.

Fig. 13. Ceramic material found after excavation in grid-2.

Fig. 12b. Then, the effect of topographical correction for this anomaly was not so significant. Information about magnetic susceptibility for grid-2 also defined the existence of a strong magnetic anomaly (M2).

In grid-2 area a concentration of ceramic material (Fig. 13) corresponding to conductivity (C2) and magnetic susceptibility (M2) anomalies was found. Geophysical results obtained in here were fundamental to time optimization, and involved resources with drilling steps. Archaeological researches are in progress, and their excavated archaeological material samples were sent for dating.

5. Conclusions

Correction of topography effect in apparent electric conductivity data through its normalization by background conductivity mean was effective for the two study areas located in *sambaqui* archaeological site from Santa Marta, Santa Catarina state, Brazil. Electric conductivity anomalies were enhanced by improving possibilities of success in archaeological excavation. This procedure could be used to enhance masked archaeological anomalies by influence of topographical variation.

Geophysical anomalies of electric conductivity corrected from topography and magnetic susceptibility for both grid-1 and grid-2 study areas emphasized the identification of two areas with high archaeological potentials. These results that orientate archaeological excavations allow exposing a fire-place in grid-1 area, and a concentration of ceramic materials in grid-2 area.

Acknowledgements

We are grateful to *Fundação de Amparo à Pesquisa do Estado de São Paulo* (FAPESP) Brazilian research agency for providing the financial support (Grant 04/11038-0 and Grant 09/07980-5). The fourth author is grateful to FAPESP for his doctoral fellowship at IAG/USP (Grant 04/13191-0). IAG/USP is acknowledged for providing infrastructure support. We thank Ernande Costa Santos and all students for helping for geophysical data acquisition. Finally, we thank reviewers for their valuable critiques and suggestions, which improved this paper.

References

Barbetta, P.A., 2002. Estatística Aplicada às Ciências Sociais. In: UFSC.
Bennett, D.L., George, R.J., 1995. Using the EM38 to measure the effect of soil salinity on *Eucalyptus globulus* in south-western Australia. Agricultural Water Management 27, 69–86.
Bevan, B.W., 1991. The search for graves. Geophysics 56 (9), 1310–1319.
Borges, W.R., Porsani, J.L., 2003. Caracterização geofísica rasa do sítio controlado do IAG-USP: resultados preliminares. In: Proceedings of the Eighth International Congress of the Brazilian Geophysical Society, Rio de Janeiro, 14–18 September 2003 CD-ROM.
Carpenter, G.S., Deignan, T.M., 1993. Large scale, high resolution survey for burial pit and trench mapping. In: Proceedings of the SAGEEP, San Diego (California, USA), 18–22 April 1993.
Cisar, D., Dickerson, J., Novotny, T., 1993. Electromagnetic data evaluation using a neural network: initial investigation – underground storage tanks. In: Proceedings of the SAGEEP, San Diego (California, USA), 18–22 April 1993.
Clay, R.B., 2001. Working with the EM38 Earth Conductivity Meter: Geophysical Survey at the Hopeton Earthwork, Chillicothe, Ohio, May 2001. Cultural Resource Analysts.
Conyers, L.B., Goodman, D., 1997. Ground Penetrating Radar – an Introduction for Archaeologists. Altamira Press.
Conyers, L.B., 2004. Ground Penetrating Radar for Archaelogy. Altamira Press.
Corwin, D.L., Lesch, S.M., 2003. Application of soil electrical conductivity to precision agriculture: theory, principles, and guidelines. Agronomy Journal 95, 455–471.
Dalan, R.A., 1991. Defining archaeological features with electromagnetic surveys at the Cahokia Mounds State Historic Site. Geophysics 56 (8), 1280–1287.
DeBlasis, P., Eggers, E., Lahr, M.M., Figuti, L., Afonso, M., Gaspar, M.D., 1998. Padrões de assentamento e formação de *sambaquis* em Santa Catarina. Revista do Museu de Arqueologia e Etnologia 8 (3), 319–321.
DeBlasis, P.D., Kneip, A., Scheel-Ybert, R., Giannini, P.C.F., Gaspar, M.D., 2007. Sambaquis e Paisagem: Dinâmica natural e arqueologia regional no litoral do sul do Brasil. Arqueologia Sul-Americana 3 (1), 29–61.
Gaspar, M.D., DeBlasis, P., Fish, S.K., Fish, P.R., 2008. Moundbuilding societies from South America Atlantic coast. In: Silverman, Helaine, Isbell, John (Eds.), Handbook of South American Archaeology, Kluger.
Geonics, 1998. EM38 Ground Conductivity Meter Operating Manual. Geonics Ltd, Mississauga, Ont. Canada. 27pp.
Gomes, M.J.S., 2003. Utilização de métodos geofísicos em sambaquis fluviais, região do Vale do Ribeira de Iguape – SP/PR. Master Dissertation, Faculdade de Filosofia Letras e Ciências Humanas, Museu de Arqueologia e Etnologia, Universidade de São Paulo, 135pp.
Keller, V.G., Frischknecht, F.C., 1966. Electrical Methods In Geophysical Prospecting. Pergamon Press, Oxford. 517pp.
Maclean, H.D., Dickerson, J.W., Hasbrouck, J.C., Cotter, E.T., 1991. Geophysical surveys for underground storage tank locations: Hickam Air Force Base, Hawaii: a case study. In: Proceedings of the SAGEEP, Knoxville (Tennessee, USA), 11–14 March 1991.
McNeill, J.D., 1980. Electromagnetics Terrain Conductivity Measure at Low Induction Numbers. Tech. Note TN-6. Geonics Ltd, Mississauga, Ont., Canadá. 13pp.
Monier-Williams, M.E., Greenhouse, J.P., Mendes, J.M., Ellert, N., 1990. Terrain conductivity mapping with topographic corrections at three waste disposal sites in Brazil. In: Ward, S.H. (Ed.), Geotechnical and Environmental Geophysics. Environmental and Groundwater, Society of Exploration Geophysicists, vol. 2, pp. 41–55. no. 5.
Oliveira, C., Porsani, J.L., Shiraiwa, S., Borges, W.R., 2005. Caracterização do solo para uso em agricultura de precisão através de métodos elétricos e eletromagnéticos (GPR): resultados preliminares. In: Proceedings of the Ninth International Congress of the Brazilian Geophysical Society, Salvador, 11–14 September 2005 CD-ROM.
Reynolds, J.M., 1997. An Introduction to Applied and Environmental Geophysics. John Wiley & Sons, New York, NY, USA. 796pp.
Rodrigues, S.I., Porsani, J.L., Santos, V.R.N., DeBlasis, P.A.D., Giannini, P.C.F. GPR and inductive electromagnetic surveys applied in three coastal sambaqui (shell mounds) archaeological sites in Santa Catarina State, South Brazil. Journal of Archaeological Science, in press, doi:10.1016/j.jas.2009.05.013.
Sudduth, K.A., Drummond, S.T., Kitchen, N.R., 2001. Accuracy issues in electromagnetic induction sensing of soil electrical conductivity for precision agriculture. Elsevier. Computers and Electronics in Agriculture 31, 239–264.
Tabbagh, A., 1986. Applications and advantages of the Slingram electromagnetic method for archaeological prospecting. Geophysics 51 (3), 576–584.
Telford, W.M., Geldart, L.P., Sheriff, R.E., 1990. Applied Geophysics, second ed. Cambridge University Press, United Kingdom. 770pp.
Triantafilis, J., Laslett, G.M., McBratney, A.B., 2000. Calibrating an electromagnetic induction equipment to measure salinity in soil under irrigated cotton. Soil Science Society of America Journal 64, 1009–1017.
Venter, M.L., Thompson, V.D., Reynolds, M.D., Waggoner Jr., J.C., 2006. Integrating shallow geophysical survey: archaeological investigations at Totógal in the Sierra de los Tuxtlas, Veracruz, México. Journal of Archaeological Science 33, 767–777.