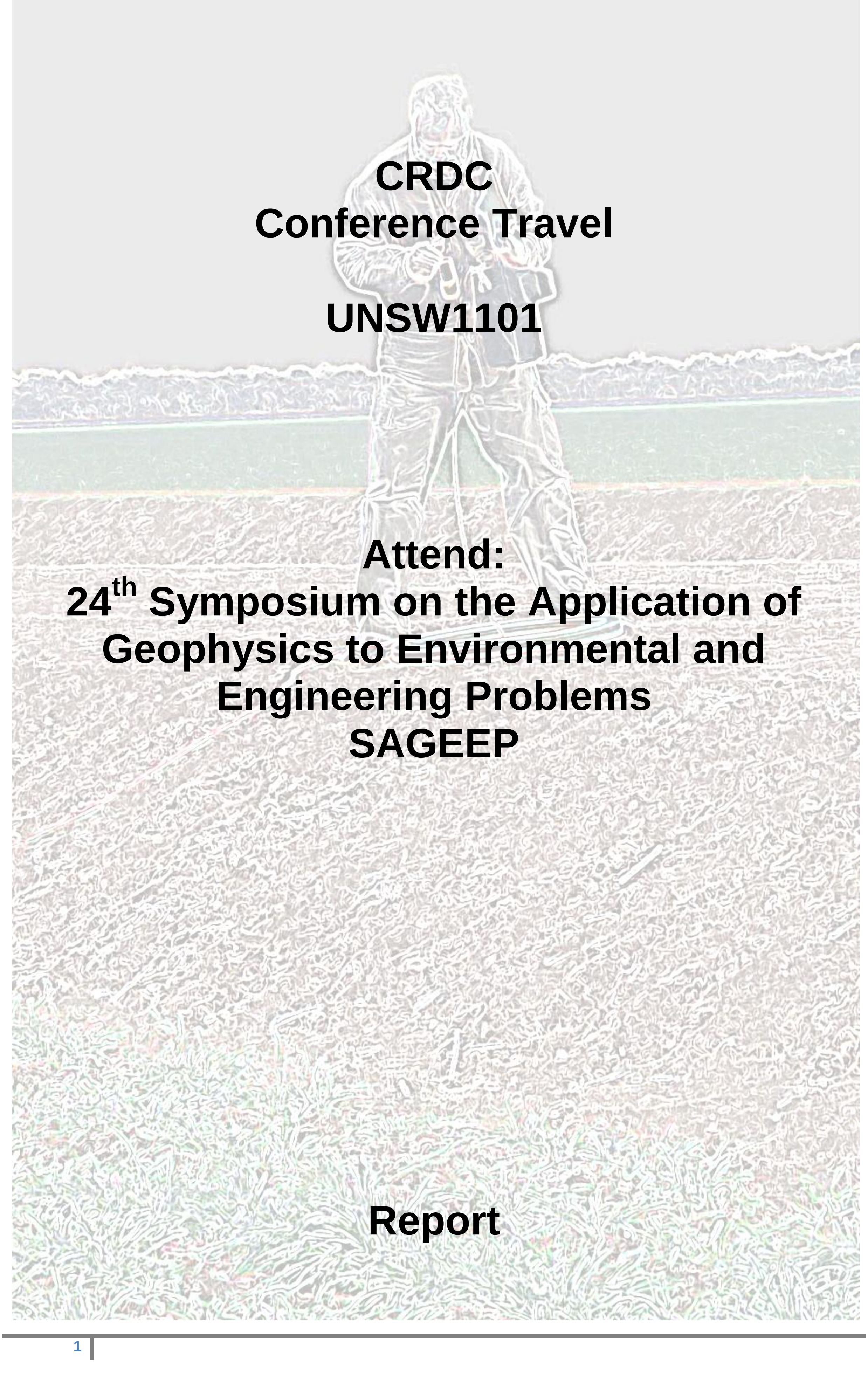


CRDC
Conference Travel

UNSW1101

Attend:
24th Symposium on the Application of Geophysics to Environmental and Engineering Problems
SAGEEP

Report

TRAVEL GRANT REPORT

Dr John Triantafilis is a Senior Lecturer in the School of Biological, Earth and Environmental Sciences at the University of New South Wales.

He works in the area of Digital Soil Mapping (DSM) which involves the computer assisted generation of soil maps using statistical and mathematical methods which couple remote (e.g. gamma-ray spectrometry) and proximal sensing (e.g. electromagnetic [EM] induction) data to soil information and for the ultimate purpose of mapping the soil and regolith in 2- and 3-dimensions.

A Conference Travel application was granted by the CRDC and in order for Dr Triantafilis to attend the 24th Symposium on the Application of Geophysics to Environmental and Engineering Problems between April 10-14 (2011) in Charleston, South Carolina USA.

2. What were the:

a) major findings and outcomes

The application was made in order to present oral research papers pertaining predominantly to DSM of cotton growing areas and using legacy EM and soil data collected from various CRDC, Australian Cotton CRC and Natural Heritage Trust projects. The presentations included four oral (1-4) and one workshop presentation (5) and as follows:

i) Mapping Soil and Regolith Properties in 3-Dimensions Using Electromagnetic Imaging in the Lower Gwydir Valley, NSW, Australia, Kira Bruzgulis, John Triantafilis and Fernando Acacio Monteiro Santos;
ii) Digital Soil Class Mapping at the Regional Level Using Gamma-Ray Spectrometry and a Numerical Clustering Algorithm, John Triantafilis and Nina Earl;
iii) Digital Soil Mapping with Depth Using EM38 and EM31 Signal Data and a 1-D Laterally Constrained Inversion Model, John Triantafilis, and Fernando Acacio Monteiro Santos;
iv) Digital Soil Mapping of Available Water Content In the Lower Macquarie Valley, Australia, John Triantafilis, and Liam Gooley; and,
v) DSM: applications in 2-d and 3-d soil and regolith mapping in cotton growing areas using legacy soil and ancillary data, John Triantafilis.

b) other highlights

The major highlights were that several of the oral presentation papers described above were subsequently written up into research papers with some published in the Geophysics Special Issue based on papers presented at the Symposium and during the Workshop. In addition, several other papers have been published or are in review with a couple of others nearing the final stages of preparation. This includes:

i) Triantafilis, J., Monteiro Santos' F.A. 2013. Electromagnetic conductivity imaging (EMCI) of soil across a prior stream channel in the lower Gwydir valley. *Geoderma*, in prep,
ii) Triantafilis, J., Terhune IV, C.H., Monteiro Santos' F.A. 2013. Generating an electromagnetic conductivity image (EMCI) using a DUALEM-421 and EM34 signal data and inversion software (EM4Soil). *Environmental Modelling and Software*, in review, and
iii) Triantafilis, J., Gibbs, I.D., Earl, N.Y., 2012. Digital soil pattern recognition in the lower Namoi valley using numerical clustering of gamma-ray spectrometry data. *Geoderma*, in press,
iv) Woodforth, A., Triantafilis, J., Cupitt J., Malik, R.S., Geering, H., 2012. Mapping estimated deep drainage in the lower Namoi Valley using a chloride mass balance model and EM34 data. *Geophysics*, 77, WB245-256, and
v) Buchanan, S.M., Triantafilis, J., Odeh, I.O.A., 2012. Digital soil mapping of compositional particle-size fractions using proximal and remotely sensed ancillary data. *Geophysics*, 77, WB201-211.

In addition, inversion software (**EM4Soil Software**) which is being used to develop 2-d and 3-d models of legacy EM data which can be calibrated using legacy soil data was also show cased. Some details of the software are provided (see Page 3).

The work indicated above was recently presented as oral and **poster presentations** (see Page 4) at two international research conferences held in Australia (July and August, 2012).

EM4Soil Software

EM4Soil
Quick Start

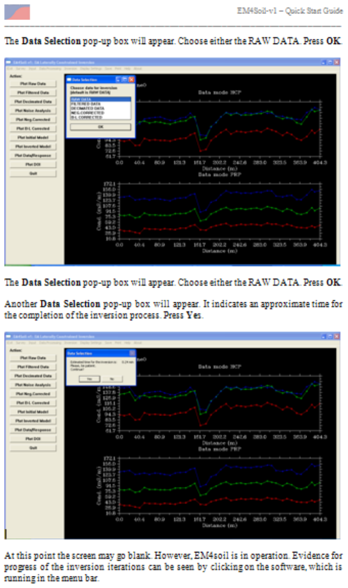
A program for 1-D laterally constrained inversion of EM data

Version-1.01

Fernando Monteiro Santos
John Triantafilis

This Software is produced by EM-TOMO
Email: emtomog@gmail.com

February 2012

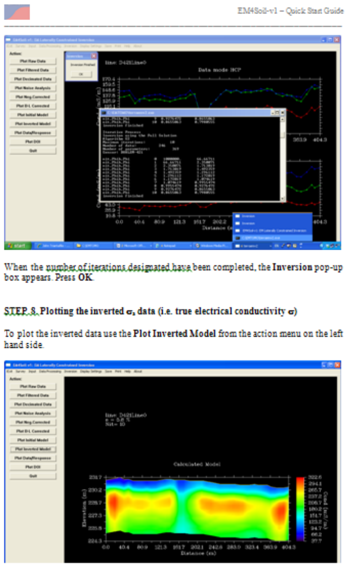


The **Data Selection** pop-up box will appear. Choose either the RAW DATA. Press **OK**.

The **Data Selection** pop-up box will appear. Choose either the RAW DATA. Press **OK**.

Another **Data Selection** pop-up box will appear. It indicates an approximate time for the completion of the inversion process. Press **Yes**.

At this point the screen may go blank. However, EM4soil is in operation. Evidence for progress of the inversion iterations can be seen by clicking on the software, which is running in the menu bar.



When the number of iterations designated have been completed, the **Inversion** pop-up box appears. Press **OK**.

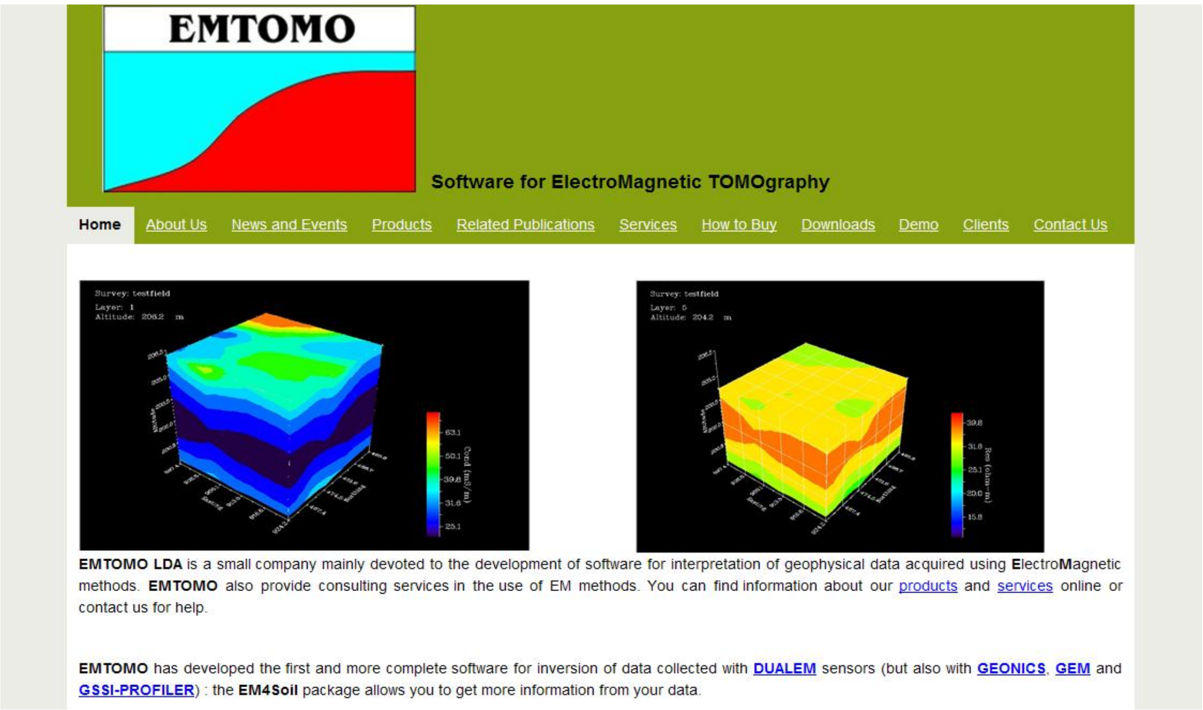
STEP 8. Plotting the inverted σ_a data (i.e. true electrical conductivity σ)

To plot the inverted data use the **Plot Inverted Model** from the action menu on the left hand side.

The EM4Soil software is currently available from the EM-TOMO website (http://www.emtomo.com/home/) and is being used by students here at UNSW as part of various honours projects.

The software is increasingly being purchased by geophysical, environmental and earth science consultants (e.g. Precision Agronomics, Australia) and for use in natural resource management and mineral exploration. The software will also be extended and in the near future will be capable of developing 3d models of the regolith.

It is further envisaged that the software will be enhanced by various postgradaute students and will be used in developing teaching modules in first (GEOS1211-Environmental Earth Science) and third year (GEOS3721-Australian Soil Use and Management) courses.

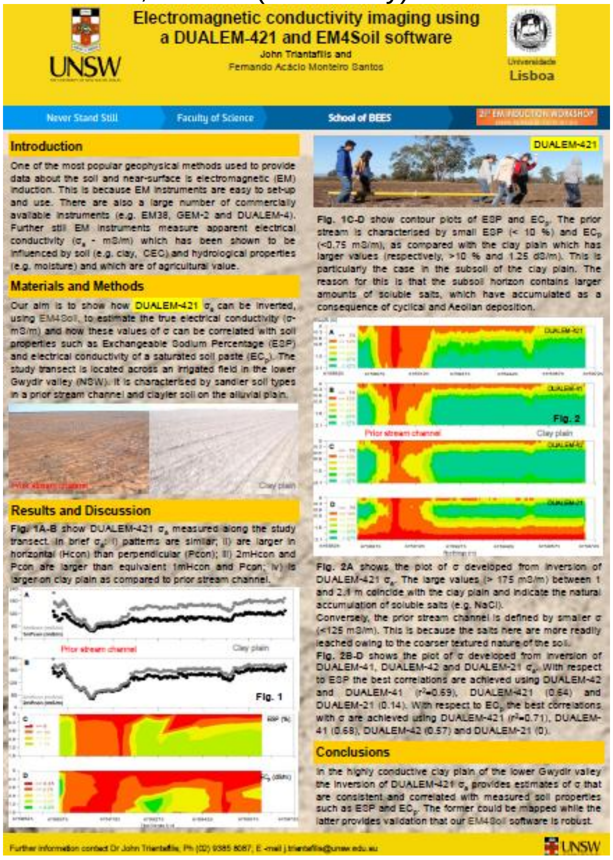


EMTOMO LDA is a small company mainly devoted to the development of software for interpretation of geophysical data acquired using **E**lectro**M**agnetic methods. **EMTOMO** also provide consulting services in the use of EM methods. You can find information about our products and services online or contact us for help.

EMTOMO has developed the first and more complete software for inversion of data collected with **DUALEM** sensors (but also with **GEONICS**, **GEM** and **GSSI-PROFILER**) : the **EM4Soil** package allows you to get more information from your data.

Poster presentations

21th EMIW, Darwin (25-31 July)



Electromagnetic conductivity imaging using a DUALEM-421 and EM4Soil software

John Triantafilis and
Fernando Acácio Monteiro Santos

Introduction

One of the most popular geophysical methods used to provide data about the soil and near-surface is electromagnetic (EM) induction. This is because EM instruments are easy to set-up and use. There are also a large number of commercially available instruments (e.g. EM38, GEM-2 and DUALEM-4). Further still EM instruments measure apparent electrical conductivity (σ_a - mS/m) which has been shown to be influenced by soil (e.g. clay, CEC) and hydrological properties (e.g. moisture) and which are of agricultural value.

Materials and Methods

Our aim is to show how DUALEM-421 σ_a can be inverted, using EM4Soil, to estimate the true electrical conductivity (σ- mS/m) and how these values of σ can be correlated with soil properties such as Exchangeable Sodium Percentage (ESP) and electrical conductivity of a saturated soil paste (EC_p). The study transect is located across an irrigated field in the lower Gwydir valley (NSW). It is characterised by sandier soil types in a prior stream channel and clayier soil on the alluvial plain.

Results and Discussion

Fig. 1A-B show DUALEM-421 σ_a measured along the study transect. In brief σ_a: i) patterns are similar; ii) are larger in horizontal (Hcon) than perpendicular (Pcon); iii) 2mHcon and Pcon are larger than equivalent 1mHcon and Pcon; iv) is larger on clay plain as compared to prior stream channel.

Fig. 1C-D show contour plots of ESP and EC_p. The prior stream is characterised by small ESP (< 10 %) and EC_p (<0.75 mS/m), as compared with the clay plain which has larger values (respectively, >10 % and 1.25 dS/m). This is particularly the case in the subsoil of the clay plain. The reason for this is that the subsoil horizon contains larger amounts of soluble salts, which have accumulated as a consequence of cyclical and Aeolian deposition.

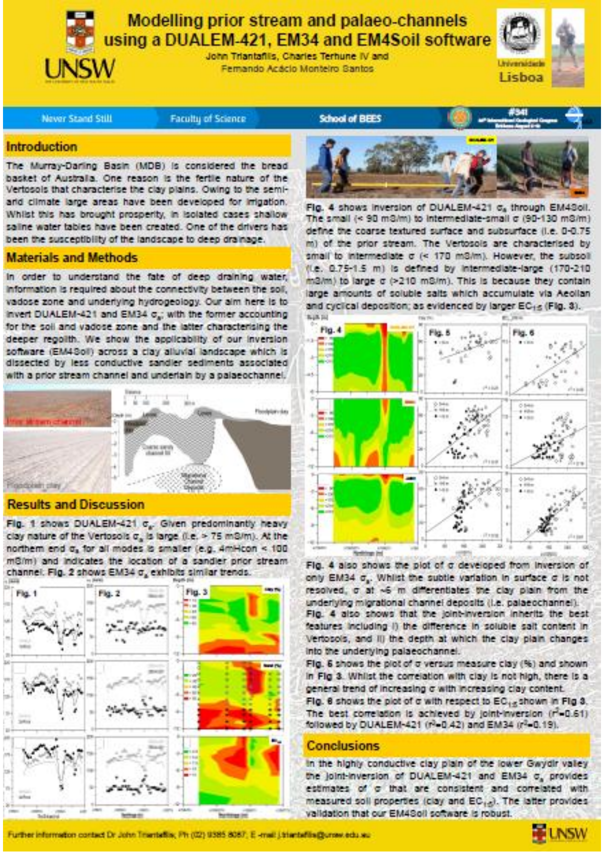
Fig. 2A shows the plot of σ developed from inversion of DUALEM-421 σ_a. The large values (> 175 mS/m) between 1 and 2.1 m coincide with the clay plain and indicate the natural accumulation of soluble salts (e.g. NaCl).
Conversely, the prior stream channel is defined by smaller σ (<125 mS/m). This is because the salts here are more readily leached owing to the coarser textured nature of the soil.
Fig. 2B-D shows the plot of σ developed from inversion of DUALEM-41, DUALEM-42 and DUALEM-21 σ_a. With respect to ESP the best correlations are achieved using DUALEM-42 and DUALEM-41 (r^2=0.69), DUALEM-421 (0.64) and DUALEM-21 (0.14). With respect to EC_p the best correlations with σ are achieved using DUALEM-421 (r^2=0.71), DUALEM-41 (0.68), DUALEM-42 (0.57) and DUALEM-21 (0).

Conclusions

In the highly conductive clay plain of the lower Gwydir valley the inversion of DUALEM-421 σ_a provides estimates of σ that are consistent and correlated with measured soil properties such as ESP and EC_p. The former could be mapped while the latter provides validation that our EM4Soil software is robust.

Further information contact Dr John Triantafilis; Ph (02) 9385 8087; E-mail j.triantafilis@unsw.edu.au

34th IGC, Brisbane (5-10 August)



Modelling prior stream and palaeo-channels using a DUALEM-421, EM34 and EM4Soil software

John Triantafilis, Charles Terhune IV and
Fernando Acácio Monteiro Santos

Introduction

The Murray-Darling Basin (MDB) is considered the bread basket of Australia. One reason is the fertile nature of the Vertosols that characterise the clay plains. Owing to the semi-arid climate large areas have been developed for irrigation. Whilst this has brought prosperity, in isolated cases shallow saline water tables have been created. One of the drivers has been the susceptibility of the landscape to deep drainage.

Materials and Methods

In order to understand the fate of deep draining water, information is required about the connectivity between the soil, vadose zone and underlying hydrogeology. Our aim here is to invert DUALEM-421 and EM34 σ_a; with the former accounting for the soil and vadose zone and the latter characterising the deeper regolith. We show the applicability of our inversion software (EM4Soil) across a clay alluvial landscape which is dissected by less conductive sandier sediments associated with a prior stream channel and underlain by a palaeochannel.

Results and Discussion

Fig. 1 shows DUALEM-421 σ_a. Given predominantly heavy clay nature of the Vertosols σ_a is large (i.e. > 75 mS/m). At the northern end σ_a for all modes is smaller (e.g. 4mHcon < 100 mS/m) and indicates the location of a sandier prior stream channel. Fig. 2 shows EM34 σ_a exhibits similar trends.

Fig. 4 shows inversion of DUALEM-421 σ_a through EM4Soil. The small (< 90 mS/m) to intermediate-small σ (90-130 mS/m) define the coarse textured surface and subsurface (i.e. 0-0.75 m) of the prior stream. The Vertosols are characterised by small to intermediate σ (< 170 mS/m). However, the subsoil (i.e. 0.75-1.5 m) is defined by intermediate-large (170-210 mS/m) to large σ (>210 mS/m). This is because they contain large amounts of soluble salts which accumulate via Aeolian and cyclical deposition; as evidenced by larger $EC_{1:5}$ (**Fig. 3**).

Fig. 4 also shows the plot of σ developed from inversion of only EM34 σ_a. Whilst the subtle variation in surface σ is not resolved, σ at ~6 m differentiates the clay plain from the underlying migrational channel deposits (i.e. palaeochannel).
Fig. 4 also shows that the joint-inversion inherits the best features including i) the difference in soluble salt content in Vertosols, and ii) the depth at which the clay plain changes into the underlying palaeochannel.
Fig. 5 shows the plot of σ versus measure clay (%) and shown in **Fig 3**. Whilst the correlation with clay is not high, there is a general trend of increasing σ with increasing clay content.
Fig. 6 shows the plot of σ with respect to $EC_{1:5}$ shown in **Fig 3**. The best correlation is achieved by joint-inversion (r^2=0.61) followed by DUALEM-421 (r^2=0.42) and EM34 (r^2=0.19).

Conclusions

In the highly conductive clay plain of the lower Gwydir valley the joint-inversion of DUALEM-421 and EM34 σ_a provides estimates of σ that are consistent and correlated with measured soil properties (clay and $EC_{1:5}$). The latter provides validation that our EM4Soil software is robust.

Further information contact Dr John Triantafilis; Ph (02) 9385 8087; E-mail j.triantafilis@unsw.edu.au

3. Detail duration of visit and purpose of visit to people/places.

Attend
24th Symposium on Application of Geophysics to Environmental and Engineering Problems
April 10-14, 2011
Charleston,
South Carolina, USA.

4. a) Are there any potential areas worth following up as a result of the travel?

The potential to exploit the development of EM inversion software, and as demonstrated during the oral and poster presentations, is substantial owing to the large amount of legacy EM data collected as part of several CRDC, Australian Cotton CRC and Natural Heritage Trust Grants. This is because the results can be calibrated against extensive legacy soil data bases collected and compiled from the same grants.

b) Any relevance or possible impact on the Australian Cotton Industry?

The significance and relevance of this to the Australian Cotton Industry is that the results have widespread application and with respect to natural resource management.

In the first instance, and owing to the diminishing amount of water available for irrigation owing to pressures from other users (e.g. coal mining) and for environmental flows, one of the most important priorities is identifying where there are inefficiencies in the water distribution network on-farm and in water storage reservoirs. The problems arise where there is connectivity between prior stream channels and underlying palaeochannels or where there is insufficient depth of clay above a palaeochannel (Jim Purcell, private communication).

One way of generating information about the connectivity between prior stream channels, depth of clay and the location of palaeochannels is developing 3-d models of the regolith using legacy EM data (and EM4Soil Software) which can be calibrated and validated using existing legacy soil data. Using this approach it should be possible to identify where susceptible water reservoirs are currently located and where improvements can be made to water distribution networks and/or where more suitable locations exist for their relocation.

The approach also has applications to potentially identify the presence of good quality and/or saline ground water whose extent can be mapped in 3-d.

5. How do you intend to share the knowledge you have gained with other people in the cotton industry?

It is envisaged that Australian Cotton Grower Articles will be written in the near future.

Acknowledgement

I thank the Cotton Research and Development Corporation, and in particular Mr Bruce Pyke, for the funding ($2,500) to allow me to attend the 24th Symposium on Application of Geophysics to Environmental and Engineering Problems April 10-14, 2011 Charleston, South Carolina, USA.

Triantafilis et al., (2012).
Geophysics 77, WB99-107.

GEOPHYSICS, VOL. 77, NO. 4 (JULY-AUGUST 2012); P. WB99–WB107, 5 FIGS., 2 TABLES.
10.1190/GEO2011-0507.1

Modeling the electrical conductivity of hydrogeological strata using joint-inversion of loop-loop electromagnetic data

J. Triantafilis[1], V. Wong[2], F. A. Monteiro Santos[3], D. Page[1], and R. Wege[1]

ABSTRACT

In coastal-estuarine agricultural landscapes that are inherently rich in sulfidic sediments and saline water-tables, natural resource management data need to be collected to describe the heterogeneous nature of the soil, underlying regolith, and interactions with groundwater. Geophysical methods, such as electromagnetic (EM) induction instruments, are increasingly being used. This is because they measure apparent soil electrical conductivity σ_a-mS/m, which has previously been successfully used to map the areal distribution of soil (e.g., salinity) and hydrological (e.g., water-table depth) properties. We explored the potential of a next-generation DUALEM-421 and EM34 to be used independently and in conjunction with each other to provide information we can use to represent the pedological and hydrogeological setting of alluvial and estuarine sediments. A 1D laterally constrained joint-inversion algorithm can account for the nonlinearity of large σ_a (i.e., >100 mS/m). We applied this algorithm to develop 2D cross sections of electrical conductivity (σ-mS/m) from DUALEM-421 and EM34 σ_a data acquired across an estuarine landscape and situated within Quaternary fluvial sediments adjacent to Rocky Mouth Creek on the far north coast of New South Wales, Australia. We compared this joint-inversion model with inversions of the DUALEM-421 and EM34 σ_a data independently of each other. For the most part, the general patterns of the inverted models of σ compare favorably with existing pedological and hydrogeological interpretations, based on results achieved during a previous geoelectrical survey. However, the joint-inversion provides a more realistic model of the location and extent of a saline water-table and associated with the location of sulfidic sediments.

INTRODUCTION

In coastal-estuarine agricultural landscapes, the main aim in natural resource management (NRM) is to ensure that the intended land use is carried out in sympathy with the landscape and minimizes deleterious impacts on the soil and/or the water resource. Unfortunately, there are many instances where the introduction of agriculture in these areas has led to the degradation of natural resources. For example, on the estuarine floodplains on the far north coast of northern New South Wales, extensive networks of drains have been constructed to lower water tables and allow for land uses such as improved pastures for beef cattle and sugarcane production. These floodplains are, however, commonly underlain by sulfidic sediments that are dominated by FeS_2. Lowering of water tables due to drainage results in oxidation of the sulfidic sediments. This leads to the mobilization of large amounts of sulfuric acid, and the formation of acid sulfate soil. Agriculturally, decreasing soil pH mobilizes aluminum and other trace metals to toxic levels, which in turn leads to loss of productivity. The environmental consequences include, but are not limited to, the production of Fe flocs which coat benthos, and chronic and acute discharge of acidity and associated trace metals (Sammut et al., 1996).

To improve NRM outcomes in these landscapes, geophysical methods such as electromagnetic (EM) induction instruments might be useful in characterizing the pedological and hydrogeological setting. This is because EM instruments such as the EM38 (McNeil, 1990) measure apparent soil electrical conductivity (σ_a-mS/m), which has been used successfully to assess soil variations, such as depth to clay (Sudduth et al., 2010) and salinity (Yao and Yang,

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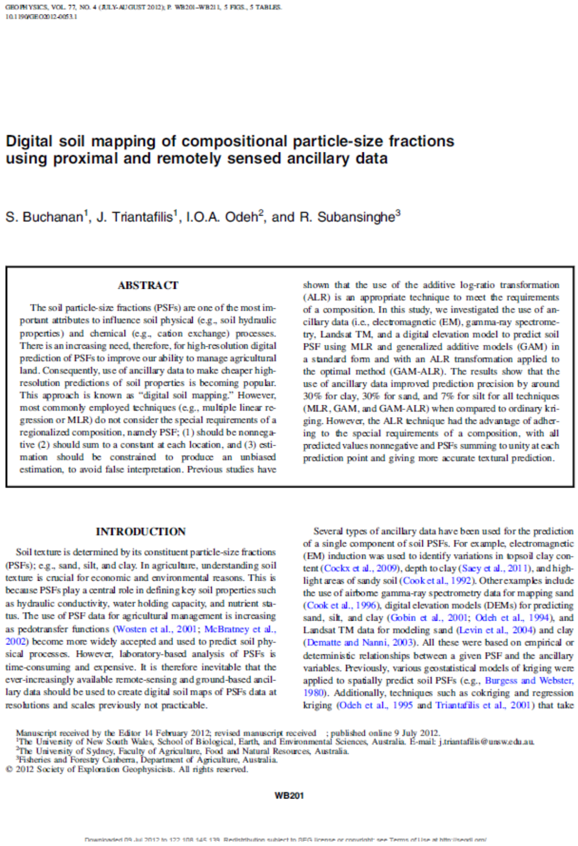
[1]The University of New South Wales, School of Biological, Earth, and Environmental Sciences, New South Wales, Australia. E-mail: j.triantafilis@unsw.edu.au.
[2]Monash University, School of Geography and Environmental Science, Victoria, Australia.
[3]Universidade de Lisboa, Instituto Don Luís- Laboratório Associado, Lisboa, Portugal.

WB99

Buchanan et al (2012).
Geophysics, 77, WB201-211.



GEOPHYSICS, VOL. 77, NO. 4 (JULY-AUGUST 2012); P. WB201–WB211, 5 FIGS., 5 TABLES.
10.1190/GEO2012-0053.1

Digital soil mapping of compositional particle-size fractions using proximal and remotely sensed ancillary data

S. Buchanan[1], J. Triantafilis[1], I.O.A. Odeh[2], and R. Subansinghe[3]

ABSTRACT

The soil particle-size fractions (PSFs) are one of the most important attributes to influence soil physical (e.g., soil hydraulic properties) and chemical (e.g., cation exchange) processes. There is an increasing need, therefore, for high-resolution digital prediction of PSFs to improve our ability to manage agricultural land. Consequently, use of ancillary data to make cheaper high-resolution predictions of soil properties is becoming popular. This approach is known as "digital soil mapping." However, most commonly employed techniques (e.g., multiple linear regression or MLR) do not consider the special requirements of a regionalized composition, namely PSF; (1) should be nonnegative (2) should sum to a constant at each location, and (3) estimation should be constrained to produce an unbiased estimation, to avoid false interpretation. Previous studies have shown that the use of the additive log-ratio transformation (ALR) is an appropriate technique to meet the requirements of a composition. In this study, we investigated the use of ancillary data (i.e., electromagnetic (EM), gamma-ray spectrometry, Landsat TM, and a digital elevation model to predict soil PSF using MLR and generalized additive models (GAM) in a standard form and with an ALR transformation applied to the optimal method (GAM-ALR). The results show that the use of ancillary data improved prediction precision by around 30% for clay, 30% for sand, and 7% for silt for all techniques (MLR, GAM, and GAM-ALR) when compared to ordinary kriging. However, the ALR technique had the advantage of adhering to the special requirements of a composition, with all predicted values nonnegative and PSFs summing to unity at each prediction point and giving more accurate textural prediction.

INTRODUCTION

Soil texture is determined by its constituent particle-size fractions (PSFs); e.g., sand, silt, and clay. In agriculture, understanding soil texture is crucial for economic and environmental reasons. This is because PSFs play a central role in defining key soil properties such as hydraulic conductivity, water holding capacity, and nutrient status. The use of PSF data for agricultural management is increasing as pedotransfer functions (Wosten et al., 2001; McBratney et al., 2002) become more widely accepted and used to predict soil physical processes. However, laboratory-based analysis of PSFs is time-consuming and expensive. It is therefore inevitable that the ever-increasingly available remote-sensing and ground-based ancillary data should be used to create digital soil maps of PSFs data at resolutions and scales previously not practicable.

Several types of ancillary data have been used for the prediction of a single component of soil PSFs. For example, electromagnetic (EM) induction was used to identify variations in topsoil clay content (Cockx et al., 2009), depth to clay (Saey et al., 2011), and highlight areas of sandy soil (Cook et al., 1992). Other examples include the use of airborne gamma-ray spectrometry data for mapping sand (Cook et al., 1996), digital elevation models (DEMs) for predicting sand, silt, and clay (Gobin et al., 2001; Odeh et al., 1994), and Landsat TM data for modeling sand (Levin et al., 2004) and clay (Dematte and Nanni, 2003). All these were based on empirical or deterministic relationships between a given PSF and the ancillary variables. Previously, various geostatistical models of kriging were applied to spatially predict soil PSFs (e.g., Burgess and Webster, 1980). Additionally, techniques such as cokriging and regression kriging (Odeh et al., 1995 and Triantafilis et al., 2001) that take

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[1]The University of New South Wales, School of Biological, Earth, and Environmental Sciences, Australia. E-mail: j.triantafilis@unsw.edu.au.
[2]The University of Sydney, Faculty of Agriculture, Food and Natural Resources, Australia.
[3]Fisheries and Forestry Canberra, Department of Agriculture, Australia.

WB201

Woodforth et al., (2012).
Geophysics, 77, WB245-256

Mapping estimated deep drainage in the lower Namoi Valley using a chloride mass balance model and EM34 data

A. Woodforth[1], J. Triantafilis[1], J. Cupitt[2], R. S. Malik[2], R. Subasinghe[4], M. F. Ahmed[5], A. I. Huckel[5], and H. Geering[5]

ABSTRACT

INTRODUCTION

Triantafilis et al., (2012).
Geoderma, in press.

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Geoderma
journal homepage: www.elsevier.com/locate/geoderma

Digital soil pattern recognition in the lower Namoi valley using numerical clustering of gamma-ray spectrometry data

John Triantafilis[a,*], Issac Gibbs[b], Nina Earl[a]
[a] School of Biological, Earth and Environmental Sciences, The University of New South Wales, Sydney NSW 2052, Australia
[b] Formerly Faculty of Agriculture Food and Natural Resources, The University of Sydney, Sydney NSW 2006, Australia

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Remote sensing
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Geomorphology

ABSTRACT

Digital soil mapping involves the use of ancillary data (e.g. proximal and remotely sensed) as surrogates for soil information to produce maps of soil type or classes. Two of the most popularly used sources of ancillary data are the proximally sensing electromagnetic (EM) induction instruments and remotely sensed digital elevation model data (DEM). However, these data have limitations at the catchment level and are of limited use on predominantly flat alluvial landscapes, respectively. Another option is the use of remotely sensed gamma-ray spectrometry data which has successfully been used to map the regolith. In this paper, the use of gamma-ray spectrometry data (i.e. potassium–K, uranium–U, thorium–Th and total count–TC), coupled with a numerical clustering algorithm (i.e. fuzzy k-means (FKM) algorithm) is explored in order to identify soil series at the district and soil mapping units at a broader catchment level. We do this by using the Euclidean distance and the measures of fuzziness performance index (FPI) and normalized classification entropy (NCE) to identify $k=11$ classes and a fuzziness exponent (ϕ) = 2.0 for interpretation. The $k=11$ classes produce contiguous classes, which are consistent with geomorphological and geological interpretations of an eroded landscape, alluvial lands and dust-mantled alluvial lands at the district level. At the sub-catchment level the $k=11$ classes also match broad soil mapping units and also elucidate subtle differences of the alluvial lands which characterise the agriculturally significant parts of the lower Namoi valley. Fuzzy canonical analysis shows that K and TC contribute most to the discrimination of the classes associated with the trachyte rich parts of the eroded landscape, the alluvial lands and most of the dust-mantled alluvial lands, whilst U and Th discriminate the basaltic outliers and other geomorphological units of the eroded lands. We conclude that the approach allows soil management and landscape units to be identified with the information used as a first approximation to determine where soil samples locations need to be collected to validate the maps. In order to better incorporate and characterise subsoil properties the inclusion of EM signal data (e.g. EM38 or DUALEM-1) may also be appropriate.

1. Introduction

Traditional soil class mapping in Australia has relied on the use of reconnaissance soil survey information, a predetermined soil classification scheme and air-photo interpretation. One of the first National soil maps produced was the Atlas of Australian Soil (e.g. Northcote et al., 1965). It was generated using the Factual Key, which dates from the 1960's, and was based on a set of about 500 profiles mostly from south-eastern Australia (Northcote, 1979). It was commonly recognized that two of the main advantages of the system were; a) the simplicity of the hierarchical classification scheme, and ii) that most of the keying attributes are soil morphological characteristics that could be determined in the field. However, the traditional approach is often criticised among other things for using predefined soil taxonomy to identify mapping units based on soil morphological properties which may not have agronomic or management implications.

In order to avoid the subjectivity of classification schemes based on logical sub-divisions or keys (Webster, 1968), various authors attempted to determine the classes based on numerical clustering (e.g. Coventry and Robinson, 1983; Moore et al., 1972; Rayner, 1966). These early Pedometric approaches (i.e. application of mathematical methods for the study of the distribution and genesis of soil) were inhibited by computational limitations. With advances in computing and software, numerical clustering of soil data is once again *De rigueur*. One of the most popular algorithms is fuzzy k-means (FKM). McBratney et al. (1992) showed that profiles could be classified using FKM based on depth of horizons. Powell et al. (1992) similarly found that FKM classes, generated from clustering of Munsell colour, texture, pedality and pH, correlated well with landscape position. The applicability of the approach across a district level was demonstrated by Triantafilis et al. (2001a) who classified soil physical (e.g. soil particle size fractions) and chemical (e.g. pH, organic

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[*] Corresponding author. Tel.: +61 2 9351 3967; fax: +61 2 9351 5108.
E-mail address: j.triantafilis@unsw.edu.au (J. Triantafilis).

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