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# PEDOMETRICS 2011 – *INNOVATIONS IN PEDOMETRICS*

BOOK OF ABSTRACTS

**THE PEDOMETRICS COMMISSION OF THE IUSS**

**THE CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE**

AND

**THE CZECH SOCIETY OF SOIL SCIENCE**

EDITED BY: ONDŘEJ JAKŠÍK, ALEŠ KLEMENT, LUBOŠ BORŮVKA

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# Contents

# Welcome to Participants

Dear Colleagues,

It is my pleasure to welcome you to the conference Pedometrics 2011 organized by the Pedometrics Commission of the IUSS, the Czech University of the Life Sciences Prague, and the Czech Society of Soil Science, held at the Castle Hotel Třešť in the beautiful countryside of the Czech – Moravian Highlands. The title of the conference is 'Innovations in Pedometrics', which might seem a little ambitious, as the whole pedometrics is fairly innovative among other soil sciences. I hope that each of us will find something interesting among the contributions. We tried to choose up-to-date principal topics of pedometrics, including the overlaps with other soil science branches. We have three interesting keynote lectures, including that of Jaap de Gruijter, the holder of the Richard Webster medal. In total, we have almost one hundred contributions. I am looking forward to discussions about them. I believe that these discussions can bring new ideas and new scientific acquaintances and co-operations, which will bring even more innovations in pedometrics in the near future.

We thank you all for coming and sharing your time, findings and ideas with us. We appreciate especially the participation of our colleagues who came from distant countries all over the world. We thank the members of the scientific committee for reviewing the papers and for their help in setting up the scientific program. We thank also those of you who agreed to chair the sessions. I take this opportunity to thank my colleagues who significantly helped with the organization, particularly to Ondřej Jakšík who has been very busy with it and with whom most of you communicated quite often in recent weeks.

Some of you might regret that the conference is not held in Prague, known as one of the most beautiful cities in the world. Nevertheless, I believe that you will appreciate to spend your time in this nice castle and to see other beautiful parts of the Czech Republic, especially if you participate on the field trip, where two sites from the UNESCO World Cultural Heritage List were included, namely the Pilgrimage Church of St. John of Nepomuk at Zelená Hora and the historical town of Telč. Moreover, you will have the opportunity to hear some Czech classical music and Moravian folk music, and to try some local cuisine. I hope that you will like it and that you will come here again, either to another scientific event, or as tourists.

I wish us all that the conference be interesting, useful and fruitful.

On behalf of the organizing committee

***Luboš Borůvka***

# Keynote lectures

# Development of formal Bayesian approaches for efficient and robust uncertainty quantification of environmental models: theory, concepts, and applications

*J.A. Vrugt*

*jasper@uci.edu*

*Department of Civil and Environmental Engineering, The Henry Samueli School of Engineering, University of California, Irvine, CA 92697-2175, U.S.A.*

Many environmentals contain parameters that cannot be measured directly but can only be meaningfully inferred by calibration against a historical record of input-output data. In the past decade much progress has been made toward the development of efficient model calibration strategies. Yet, much of this work has focused on finding the best values of the model parameters, without recourse to estimating their underlying probability distribution. Here, I will present some recent emerging Monte Carlo methods that are especially designed to efficiently derive posterior parameter and model predictive distributions. These methods can be used to process the calibration data in batch (MCMC simulation) or recursively using particle filtering methods. I will demonstrate these developments using a variety of different applications in hydrology, soil physics, ecohydrology and geophysics.

## Soil monitoring challenges: A case study in the Florida Everglades

*B.P. Marchant*

ben.marchant@bbsrc.ac.uk

*Rothamsted Research, Harpenden, AL5 2JQ, United Kingdom*

Soil monitoring surveys are increasingly required to identify and quantify threats to soil quality. There are a number of generic challenges associated with the interpretation of these surveys such as the selection of appropriate indicators, sampling designs/protocols and statistical analyses. We illustrate these issues with reference to a survey designed to monitor the effectiveness of efforts to control phosphorus enrichment in the Florida Everglades.

We demonstrate that in the Everglades many standard monitoring practices lead to poor predictions of the underlying change in soil phosphorus. The normal indicator of phosphorus enrichment is found to be sensitive to fluctuations during the hydro-period. The study region includes isolated hot-spots of phosphorus variability that are not compatible with standard geostatistical models and that cannot be adequately described by standard sample designs. We describe strategies to overcome these problems which employ a different indicator, novel geostatistical models and sample designs which incorporate remote sensing data. These strategies lead to predictions of significant decreases in soil phosphorus content in regions where soil remediation measures have been effective. These decreases were not evident from the initial analyses. The strategies also give new insight to the complex relationships between soil properties within the Everglades.

We consider the implications of these issues from a more general perspective and discuss how we can ensure that problems in soil monitoring analyses are quickly identified and rectified and how the standard methodologies can be made more robust to unexpected behaviour.

# Gapping the bridge

*J.J. de Gruijter*

[jjdegr@kpnmail.nl](mailto:jjdegr@kpnmail.nl)

Science is not done by an army of robots searching for nothing else than the Golden Discovery or the Ultimate Truth. It is done by humans with ego's, cultural backgrounds, feelings, intuitions and so on, apart from their intellect. We strive after objectivity with no other than subjective minds.

I look back at 43 years of work in pedometrics from this perspective. This leads to a story about some scientific developments, coloured with some personal reflection, using 'bridge' as a metaphor of interfaces between disciplines or paradigms. I have been mostly involved with introduction in pedology of quantitative methodologies developed elsewhere: cluster analysis, sampling theory and fuzzy sets. To single out an example, I will outline recent work on fuzzifying Boolean decision tables, e.g. for land evaluation.

Boolean models based on expert knowledge are often used to classify soils into a limited number of classes of a difficult-to-measure soil attribute. Although the primary data used for these classifications contain information on whether the soil is a typical class member or a boundary case between two classes, this is not retained in the Boolean model, but we can retain it by fuzzifying that model. Choices must then be made on the type of membership function, logical operators, and formulation of the assessment rules.

Combinations of different fuzzy union (**or**) and intersection (**and**) connectives were tested on a 2-dimensional example. Nearly all combinations gave results that partly contradict the associated *a priori* knowledge, the exception being the Bounded sum connective for **or**, and the Product connective for **and.** We also found that in formulating the rules, overlap of predictor classes and negation should be avoided. Unrestricted choice of fuzzy connectives and rule formulation will generally lead to inconsistencies. The selected methods were tested in two case studies.

Session: Pedometrical methods for soil assessment

## Quantification of soil compaction risk using Bayesian Belief Networks

*M. Troldborg, R. Hough, I. Aalders, W. Towers, A. Lilly, P. Hallett, G. Bengough, B. McKenzie, B. Ball*

m.troldborg@macaulay.ac.uk

*The James Hutton Institute, Craigiebuckler, Aberdeen AB15 8QH, Scotland, United Kingdom*

Soil compaction generally refers to the loss of porosity through mechanical damage to soil and is identified as one of the main threats to soil functioning particularly in highly managed agricultural systems. Soil compaction is known to have many adverse effects on farming systems including decreases in crop yield and soil productivity, increasing management costs, and reduced water infiltration into the soil leading to accelerated run-off and risk of soil erosion. The rise in high-axle loads resulting from the development of larger and heavier machines and intensified production enhances the risk of soil compaction. Methodologies for assessing soil compaction risk are needed in order to reduce this threat and protect soil quality for future generations as well as to identify the areas at greatest risk. However, an assessment of the risks is hampered by the complex nature of soil compaction, which results from the sometimes poorly understood interaction of various soil physical properties, climatic factors and land management practices. We present here a Bayesian Belief Network (BBN) approach that combines available analytical and morphological data from standard soil surveys with qualitative expert knowledge to estimate the risk of soil compaction. The BBN structure follows a standard risk assessment approach, where the risk is quantified by combining assessments of vulnerability and exposure. The soil's vulnerability to compaction is determined from inherent soil and site characteristics as well as from climatic factors influencing the soil water content, while the exposure estimate is based on an evaluation of the stresses inflicted by land management. The BBN is applied to quantify the risk of compaction and identify the distribution of this risk for Scotland using data from the National Soils Inventory of Scotland. Future work will explore the impact of different climate scenarios and management strategies on compaction risk.

# A multiscale approach to global soil mapping

*T. Hengl, R.A. MacMillan, H.I. Reuter*

tom.hengl@wur.nl

*ISRIC - World Soil Information P.O. Box 353, 6700 AJ Wageningen, Netherlands*

We present a framework for global soil mapping using a concept of nested multiscale regression-kriging. The method predicts values for soil properties at various sclaes using a number of global and regional datasets: it fits regression models using the coarse (5.6 km) global covariates (50-100 layers; complete Open Soil Profiles), then fits the residual variation using 1 km continental covariates (20-50 layers; continental subset of the Open Soil Profiles), 250 m predictors (10--20 layers; regional subset of the Open Soil Profiles), and 100 m predictors (5--10 layers; local subset of the Open Soil Profiles). The final residuals are dealt with using ordinary kriging. The predicted signals can be summed to produce the final estimate of soil properties. The method was tested using a soil profile dataset for Malawi (890 profiles); focus was put on mapping pH, organic carbon and clay content over the whole profile.

## Scale location characterization of nonlinear soil systems

*A. Biswas and B.C. Si*

asim.biswas@usask.ca

*Department of Soil Science, University of Saskatchewan, 51 Campus Drive, Saskatoon, Saskatchewan, S7N 5A8, Canada*

Soil spatial variability is generally a product of the combined effect of soil physical, chemical, and biological processes that operate in different intensities and at different scales. The trends in factors controlling these processes make the spatial series of soil property nonstationary. At the same time, the non-additive nature of these processes makes the system nonlinear. Wavelet analysis is mainly a linear analysis method and is useful in characterizing the scale and locations of nonstationary soil spatial variation. In this study, we have extended the use of this method in characterizing scales and locations of variations of soil properties in nonlinear soil system. The squared amplitude of wavelet coefficients as a function of space and frequency (wavelet spectra, WS) from wavelet transform provides the scale-location specific variations in any soil properties. Wavelet coefficients take on maximum values at the instantaneous frequency (IF), which is the dominant frequency component in a signal at each instant in space. The value of IF at space-frequency domain can be represented by a skeleton plot known as wavelet instantaneous frequency spectrum (WIFS). IF identifies the nonlinearity in the system. In addition, the instantaneous spectral bandwidth is the secondary measure of the IF and thus the nonlinear characteristics. The WS, WIFS, and the bandwidth of the IF will be used to characterize the spatial variations of soil properties (soil water storage) in nonlinear soil systems.

# Local downscaling of regional soil organic carbon predictions: A regression based method for disaggregation with local environmental covariates

*A.B. McBratney, I. Wheeler, B. Minasny*

ichsani.wheeler@sydney.edu.au

*Faculty of Agriculture, Food and Natural Resources, S208 JR Woolley Building A20, Camperdown, The University of Sydney NSW 2006, Australia*

Regional predictions of the spatial distribution of soil organic carbon (SOC) are often conducted at resolutions above what is useful for farm scale applications. These applications potentially include input into management decisions, base-lining carbon sequestration projects and initial sampling strategies for stock-difference based SOC assessments. Conversely, fine resolution predictions of SOC at larger scales are more sensitive to sampling bias and increased covariate variation potentially confounds relationships distinguishable only at larger resolutions.

In order to address this problem, a statistical downscaling method is proposed to obtain spatial predictions of SOC at fine resolutions from coarser regional scale models. This method utilises the iterative application of Generalized Additive Models (GAM) to predict fine-scale SOC concentration based on environmental covariates whilst constraining these values by the membership average in relation to the coarser resolution pixel.

To illustrate this concept a 250 m regional prediction of SOC is disaggregated on the basis of fine resolution covariates to a 30 m resolution at the farm scale. Fine-scale environmental covariates were selected on the basis of locally understood covariate relationships. A general downscaling method based on GAM is employed. The algorithm iteratively estimated carbon content at a finer scale while maintaining the whole farm total carbon concentration.

The subsequent disaggregated fine resolution SOC maps are assessed against previously collected farm-scale soil profile information and the application of such products is explored. Variations in the success of the downscaling methodology for assessed locations and the depth of the regional SOC prediction are also discussed.

## Discrimination of Australian soil horizons and classes from their visible–near infrared spectra

*R.A. Viscarra Rossel and R. Webster*

*raphael.viscarra-rossel@csiro.au*

*CSIRO Land and Water, Bruce E. Butler Laboratory, PO Box 1666, Canberra ACT 2600, Australia*

A soil's refectance spectrum in the visible and near infrared (vis-NIR) is rich in information. It is an integrative property of the soil that measures its colour, the abundance of iron oxides, clay minerals and carbonates, the amount of water and organic matter and its particle-size. We explored the merit of discriminating between soil horizons, of which we had 13 654 samples, and soil orders from the Australian Soil Classification (ASC), of which we had samples from 1697 proles with designated horizons, by analysing quantitatively their diuse reflectance spectra in the range 350 to 2500 nm, i.e. in the vis-NIR.

We resampled the spectra to 10-nm intervals and converted them to logarithms of deviations from their convex hulls. We then transformed them to canonical variates, which we display as scatter diagrams in low-order canonical planes. The minerals, colour and organic constituents thought to be responsible for their discrimination are identied. Each spectrum was re-examined and allocated to the group whose centroid it was nearest in the canonical space. Topsoil horizons (A, A2 and transitional AB and AC horizons) were distinguishable from subsoils (B, C and transitional BC horizons). Vertosols, Ferrosols, Podosols (Podzols), Organosols, Calcarosols, Rudosols, Sodosols, Hydrosols, Kandosols and Kurosols were in general well separated from other soil orders and were assigned to their own orders such that 80% or more were correctly allocated. These orders possess characteristics that are easily distinguished by vis-NIR spectroscopy. Reallocations to other orders were interpretable and could be related to identifying features of the ASC classication. Our results show that spectra distinguish soil horizons and soil type. They suggest that vis-NIR spectroscopy could make an important contribution to the denition and identication of classes in an effective system of soil classication.

# Session: Uncertainty analysis, error propagation and accuracy assessment

# Quantification and visualization of uncertainty information in digital soil mapping

*A-X. Zhu, J.E. Burt, M. Harrower*

[azhu@wisc.edu](mailto:azhu@wisc.edu)

*Department of Geography, University of Wisconsin-Madison, Madison, Wisconsin 53706, U.S.A.*

*State Key Laboratory of Resources and Environmental Information Systems, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China*

Information on uncertainty in soil maps, particularly information on the spatial variation of uncertainty, is important when soil maps are used in watershed modeling and to aid decision making. Such information is typically not available to end users due to the lack of techniques to quantify and visualize the uncertainty in soil maps. This paper presents an approach to characterize and visualize spatial variation of uncertainty in soil maps. The approach is based on a similarity representation of soil spatial variation. Under this representation soil at a location is expressed as a set of similarities to a set of predefined entities (categories) (either taxonomic classes or prototypes or other user defined entities). The distribution of the similarity values across the set of predefined entities can be assessed to characterize two types of uncertainty: the exaggeration uncertainty and the ignorance uncertainty. The exaggeration uncertainty is the deficit of the highest similarity value from unity (the similarity value when the local soil is the exactly the same as the entity). It expresses the amount of exaggeration would be introduced if the local soil is approximated by that entity (the entity to which the local soil bears the highest similarity). The ignorance uncertainty is the standardized sum of similarity values besides the highest similarity values. It was designed to express the amount of uncertainty would be induced due to ignoring these similarity values if the local soil is approximated by the entity with the highest similarity. These uncertainty measures can then be visualized along with the information on soil spatial variation using color models. A case study in digital soil mapping shows that this approach is a viable and effective way for quantify and visualizing uncertainty in soil maps.

# An error budget for different sources of error in digital soil mapping

*M.A. Nelson, T.F.A. Bishop, I.O.A. Odeh, J. Triantifilis*

michael.nelson@sydney.edu.au

*Faculty of Agriculture Food and Natural Resources, The University of Sydney, Biomedical Building, 1 Central Ave, Eveleigh ,2015, NSW, Australia*

Digital soil mapping is gathering momentum across the globe, driven by a need for soil information and made possible by the increasingly widespread availability of spatial data that can be used to represent Jenny's soil forming factors. Much of the focus is on the predicted values of soil properties but it is equally important to quantify associated prediction errors.

Previous studies have considered individual sources of error in a digital soil map but none have considered the combined effect of all sources. In this paper we develop an error budget procedure to quantify the relative contributions that positional, analytical, covariate and model error make to the prediction error of a digital soil map of clay content. We consider four scenarios corresponding to typical levels of data quality: (1) good , (2) legacy , (3) spectroscopy and (4) poor quality data.

The error budget procedure uses both geostatistical and Monte-Carlo simulation to produce numerous realizations of the data and their underlying errors. Linear mixed models are used to construct the digital soil map. In this implementation we consider the error associated with the measurement of the clay content, the location of the survey sites, the interpolation of the covariate (ECa), and the estimation of the fixed effects, random effects and interpolation from the linear mixed model.

For all data quality scenarios, the error from the model dominated the prediction error (MSE 67.24--72.41% Clay$^2$). Where the analytical error was small, the error attributed to the covariate was greater than that attributed to the analytical error. This relationship was reversed in the data quality scenarios where the analytical error was large. Under all data quality scenarios, the effect of positional error was negligible.

# Uncertainty in a predictive map of groundwater acidity in the Western Australian wheatbelt and implications for management

*K.W. Holmes, M.A. Nelson, T.F.A. Bishop, A. Lillicrap*

thomas.bishop@sydney.edu.au

*Faculty of Agriculture, Food and Natural Resources, The University of Sydney, Australian Technology Park, Eveleigh ,2015, NSW, Australia*

Digital mapping techniques provide new insights from existing environmental datasets by facilitating extensive mapping of specific properties or classifications in an efficient, reproducible way. For practitioners, one of the most compelling aspects of digital mapping is quantifying the distribution of uncertainty in the final map, both to understand map reliability, and to drive future data collection.

Our case study focuses on mapping naturally occurring acid groundwater (pH < 4.8) in Western Australia, which negatively impacts on plant growth, livestock health, native ecosystem function, biodiversity, and town infrastructure. Delineating spatial patterns in acid groundwater occurrence is paramount for identifying areas at risk, and for developing regulatory procedures to help prevent disturbance in at-risk areas.

A generalised linear mixed model approach was used to predict the probability of occurrence of acidic groundwater. This approach incorporates traditional Scorpan covariates (geology, terrain) but also accounts for spatial correlation in the residuals.

Using this modelling approach and stochastic simulation we assess the different sources of error in the final map with a particular emphasis on model and covariate uncertainty. Finally, we discuss the potential ramifications of presenting detailed spatial error information in association with a map for policy development and regulation.

# Ensemble modelling of drainage and actual evapotranspiration based on pedotransfer functions

*D. Jacques and D. Mallants*

djacques@sckcen.be

*Institute for Environment, Health and Safety, Belgian Nuclear Research Centre (SCK•CEN), Boeretang 200, B-2400, Belgium*

Estimation of soil water fluxes is a key parameter for different applications. However, exact soil hydraulic parameters are missing or are impossible to measure (e.g. when information for different soil units is needed). However, basic soil properties, such as the textural class or textural fractions, might be more available (e.g. in national databases) and are used to estimate parameters needed to calculate water fluxes through the soil cover by using pedotransfer functions (PTF). However, applying PTFs introduces a uncertainty because their accuracy is often limited. Predictions with multiple PTFs (so-called multi-model predictions) are carried out resulting in an ensemble (i.e. statistical) estimate of the variable of interest. In this study, an ensemble estimate of the average annual actual evapotranspiration and drainage is done using 27 PTFs available from the literature relating soil textural information to soil hydraulic parameters for 5 textural classes. A 37-year long record of daily values of meteorological data for the Campine region in Belgium (northern Belgium) is used in this analysis.

The variability among the estimated hydraulic properties is large between the different estimates within one textural class. For each textural class, 27 values for average yearly drainage and actual evapotranspiration were obtained. Although the difference between the minimum and maximum values within a textural class was large, the interquantile range was small. Therefore, the medium of the 27 simulations was taken as a first estimate of the yearly drainage and actual evapotranspiration. The median shows a trend between the different textural classes: a decreasing sand content resulted in a decrease in average yearly drainage. This approach is also used to characterize the variability between year and within years (between the PTF) and can thus be used to define the uncertainty in the drainage and the actual evapotranspiration.

# Harmonization of different sets of legacy soil profiles for digital soil mapping. The case of the Cap Bon region (Northern Tunisia)

*R. Ciampalini and P. Lagacherie*

rossano.ciampalini@supagro.inra.fr

*UMR LISAH - INRA, IRD, SupAgro, "Laboratoire d'étude des Interactions Sol - Agrosystème – Hydrosystème", Bat. 24. 2, place Viala – 34060, Montpellier, France*

The spatial sets of soil profiles that have been collected for these past 70 years over the world constitute a major source of soil information that are indispensable for operational applications of Digital Soil Mapping. However significant biases between soil profile datasets issued from different soil surveys could occur because of differences in survey methods (field data collection, laboratory analysis, etc.). or in sampling dates. A pre-processing is therefore needed to detect and remove these biases and then obtain adequate inputs for digital soil-mapping models.

Such a pre-processing of legacy soil profile datasets is proposed in this study. It is applied to different sets of geo-referenced legacy soil profiles available in the Cap Bon Region (Northern Tunisia) and use a "reference" spatial sampling of soil surface data that fits with modern standards of soil analysis and was recently collected (2009).

The general approach includes three steps: i) define the comparison area (i.e. the intersection of the spatial samplings), ii) compare the distributions of soil profiles properties with the references and decide whether they are different or not and iii) if needed, apply a correction algorithm to remove the detected biases. Various implementations of this approach were undertaken and tested on theoretical and real soil sampling.

# An example of quantitative assessment of expert knowledge in a database

*N.I. Belousova and J.L. Meshalkina*

jlmesh@list.ru

*The Soil Science Faculty of Lomonosov Moscow State University, Leninskye Gory, GSP-1, h.1,bld.1, Moscow, 119991, Russia*

Databases in soil science not only contain the actual data on soils, but they are one of the main methods of expert knowledge keeping. Expert opinions are recorded in the classification identification of soil profiles, in soil horizons labels, in the list of attributes, in the soil-forming factors descriptions associated with the location of the soil profile, etc. If the data are collected from archive sources and from legacy data there is a need to quantify the diversity and completeness of the information contained in the original data. Such assessment is possible both in terms of the purpose-oriented data harmonization and in terms of fullness of the territory by soil profiles and the relevant soil information, including their territorial and classification diversity. Features of the assessment are discussed using the example of the Boreal soil database including more then 600 soil profiles. The material was gathered from scientific sources published over the last 60 years on boreal soils concerning loamy soil‑forming rocks situated in the Russian Federation. Shannon index and Pielou's evenness were used to measure the "diversity". In addition, the scheme reflecting the difference in levels of knowledge about the soil cover of Russia was proposed. The database Boreal was supplied with an assessment of potential fullness by soil profiles across regions on its basis. It was estimated as the number of soil profiles in a region divided by the region area and multiplied by a "knowledge" coefficient. The "fullness" of the database according to the classification types was calculated similarly. It was shown how the proposed estimates changed depending on the objectives of a study on two examples of the database use. Thus, examples of diverse quantitative assessment of the expert information contained in the database are given.

# Session: Soil sampling

## Sampling for a dual aim: design-based estimation of means and model-based mapping

*G. Bragato, D.J. Brus, F. Fornasier, D. Mosetti*

gilberto.bragato@entecra.it

*CRA-Centro per lo studio delle relazioni tra pianta e suolo, Via Trieste 23, 34170 Gorizia, Italy*

Tuber aestivum is an ectomycorrhizal fungus that produces edible truffles. Its presence leads to circular bare areas – called brûlis - where changes in soil physical properties take place. Besides the activity of soil enzymes may change, like alkaline phosphatase, arylsulfatase and β-glucosidase - related to P, S and C cycle, respectively. In this study we designed a sampling strategy that can be used both for design-based estimation of local means of enzyme activities and for model-based mapping, with the ultimate purpose to analyse their relationships with T. aestivum and symbiont tree species.

Sampling locations were selected according to a stratified random design. An area of 0.84 hectares in a truffle plantation of 25 years was divided into 6 main strata differing in presence/absence of T. aestivum, symbiont tree species and soil type. Each stratum was partitioned with the k-means approach (Walvoort et al., 2010) into 30 compact geographical sub-strata (geostrata) of equal area, and one location per geostratum was selected at random. In November 2010, 180 soil samples were collected in the 2-10 cm layer and the three enzyme activities were determined with fluorogenic substrates.

Main strata means were estimated by the unweighted average of observations per stratum. Since the geostrata of a given main stratum have equal area, these estimates are design-unbiased. The sampling variance of these estimated means were estimated by the collapsed strata technique (Cochran, 1977) Results showed significant differences between some strata. Model-based mapping was carried out after merging main strata with comparable means and calculating residuals from the design-based estimates of the means of merged strata. Variograms of residuals were pure nugget for alkaline phosphatase and arylsulfatase. For β-glucosidase a spherical variogram was fitted. Residuals were then interpolated by simple kriging with model mean 0. Maps were in the end obtained by summing residuals and the design-based estimates of the stratum means.

Cochran, W.G. 1977. Sampling Techniques, 3rd ed., Wiley, New York.

Walvoort, D. J. J., Brus, D. J., and de Gruijter, J. J. 2010. An R package for spatial coverage sampling and random sampling from compact geographical strata by k-means. Computers & Geosciences 36: 1261-1267.

# Optimizing nested sampling designs for multiscale investigation of the soil

*R.M. Lark*

*mlark@nerc.ac.uk*

*British Geological Survey, Keyworth, Nottingham, NG12 5GG, United Kingdom*

Pedometricians use nested sampling to partition the variance of soil properties between different spatial scales, using sample designs which are efficient to implement in the field. The earliest nested sampling designs were balanced, but it was recognized that this concentrates the degrees of freedom of the nested analysis in the finest spatial scales, and also makes the total sample effort very large if many scales are to be studied. Unbalanced designs have therefore also been used, including a 'maximally unbalanced' design in which the degrees of freedom are distributed equally between the scales. However, the question of which design is optimal, by statistical criteria, has not been addressed.

In this paper I describe how a space of possible nested designs can be defined with respect to a fully balanced design with 3 substations at level i within each substation at level i-1. The space of possible designs is the set of all subsets of the full design with a specified total sample size, and from which the variance components at all the scales are estimable. An objective function can be defined from the covariance matrix of the REML estimates of the variance components, and then optimized over the sample space by simulated annealing.

It is shown how the optimal design, in various circumstances, achieves a distribution of degrees of freedom between the scales which is not dominated by the fine scales (as in the balanced design) nor equal over the scales as in the maximally unbalanced design. Simulation showed that optimized sampling schemes allow us to achieve standard requirements of statistical power with smaller sample sizes than are required for commonly-used designs. Although the optimized design depends on the underlying covariance structure, sampling designs can be identified that perform better than the commonly-used ones over a wide range of conditions.

# A stepwise sampling method based on samples' representativeness and its application in digital soil mapping

*L. Yang[1], A-X. Zhu[1, 2], F. Qi[3], C.Z. Qin[1], B.L. Li[1], T. Pei[1]*

yanglin@lreis.ac.cn

*[1] State Key Laboratory of Resources and Environment Information System, Institute of Geographical Sciences and Resources Research,Chinese Academy of Sciences, Beijing 100101, China*

*[2] Department of Geography, University of Wisconsin-Madison, Madison, Wisconsin 53706, U.S.A.*

*[3] School of Environmental and Life Sciences, Kean University, 1000 Morris Avenue, Union, New Jersey 07083, U.S.A.*

Sampling design plays an important role in spatial modeling. Existing methods often require large amount of samples to achieve desired mapping accuracy but imply considerable cost. When there are not enough resources available, stepwise sampling has been conducted, especially in the case of field surveying in large areas. Present stepwise sampling mainly considers spatial coverage of samples of different batches, but may causes samples reduplicate in parameter domain, which will result in waste of resources. This paper proposes an effective stepwise sampling method based on samples' representativeness in parameter domain. The representative samples could be differentiated as those that represent global prototypes and those that represent only local variations of geographical features. Such a hierarchy of representativeness could be useful in guiding the sampling design in a stepwise fashion. The proposed sampling method approximates the hierarchy of representativeness of samples by determining the natural occurrence of clusters of geographical features at different scales through a fuzzy c-means clustering method. The order of sampling batches is then determined by the grades of representativeness. When applied in digital soil mapping, a series of soil inference was conducted using samples starting with the most representative grade and then with the addition from lower grades. Field evaluation indicated that the additions of sample batches from lower representative grades lead to improvements of accuracy with a decreasing speed. When cost-effectiveness is considered, the representativeness grades could provide essential information on the number of samples to be included for a feasible sampling design in practice.

## Multiphase sampling for soil remediation surveys

*B.P. Marchant, B. Minasny, R.M. Lark, A.B. McBratney*

ben.marchant@bbsrc.ac.uk

*Rothamsted Research, Harpenden, AL5 2JQ, United Kingdom*

We present a novel multiphase methodology for the design and analysis of a spatial survey of urban soil contamination and apply it to a survey of soil lead contamination in Glebe, Sydney. The aim of the survey is to identify the portions of the study region where remediation is required. The initial phases are used to fit a model of variation of the observed contaminant and to produce a coarse spatial prediction of the contamination. In the later phases the locations of observations are optimized by spatial simulated annealing (SSA) to minimize the expected cost of misclassifying the remediation requirements.

We use a copula-based methodology to analyze the data and decide whether remediation is required at a site. Copulas are favoured because they predict the entire probability density function (pdf) of the contaminant at each site, they can accommodate general non-Gaussian behaviour and they have a parametric form which is compatible with conditional simulation algorithms, uncertainty analyses and up-scaling methods. Loss functions are specified for false positive and false negative misclassifications of the contamination.

Previous attempts to design multiphase remediation surveys have prioritized sampling in later phases according to the uncertainty associated with the need for remediation at each site. They do not forecast the effect that the proposed phase of sampling will have on this uncertainty and therefore cannot be used to optimize a configuration of more than one observation without arbitrary assumptions about how much clustering should be permitted. We use an efficient Bayesian methodology within the SSA algorithm to forecast the expected effect of the new phase of sampling on the loss function and to rationally determine the resources which should be allocated to sampling. Monte Carlo Markov Chain analyses are used to test the effect of model uncertainty upon the predictions.

# A comparison of calibration sampling schemes at the field scale

*K. Schmidt, T. Behrens, J. Dauman, D.J. Brus, U. Werban, T. Scholten*

karsten.schmidt@uni-tuebingen.de

*University of Tübingen, Institute of Geography, Soil Science and Geomorphology, Rümelinstraße 19-23, 72070 Tübingen, Germany*

Sparse and effective data collecting plays a crucial role in high-resolution digital soil mapping. Within the EU FP7 iSOIL project one of the main objectives is to give recommendations on combining different geophysical sensors and data mining approaches to predict soil properties on the field scale. In this respect sampling design also plays a crucial role. However, there is not much literature available on comparisons of modern calibration sampling schemes.

For the Rosslau test site (Saxony-Anhalt, Germany) of the iSOIL project we compared a weighted conditioned latin hypercube sampling approach, fuzzy k-means sampling and response surface sampling. We compare the approaches based on different cross-validation schemes and against different regression approaches such as support vector machines and random forests. We mapped pH, SOC and texture at three depth intervals based on EM38, EM31 or Gamma. This enables us to give recommendations on sampling designs, regression approaches and sensor applications for field scale digital soil mapping at different soil depth.

# Session: Soil monitoring

# Detecting temporal changes of soil quality indicators: short-term variation versus long-term changes

*A. Keller, P. Schwab, S. Ammann and R. Meuli*

*armin.keller@art.admin.ch*

*Swiss Soil Monitoring Network (NABO) Research Station Agroscope Reckenholz-Tänikon ART Reckenholzstr. 191 CH - 8046 Zürich, Switzerland*

One of the main aims in soil monitoring is to detect temporal changes of soil quality and to communicate the implications of measured changes to policy makers. However, as recently summarized in the project Environmental Assessment of Soil for Monitoring (ENVASSO), there are only a few soil monitoring networks in Europe yet that performed repeated soil campaigns at well defined benchmark sites.

The objective of the Swiss Soil Monitoring Network (NABO) is to assess soil quality in the long term and to validate appropriate soil protection measures. The network was established in 1985, comprises currently 105 observation sites across Switzerland and sampling plots were stratified according to geology, soil type, land use and regional characteristics. The majority of the sites are on arable land (34), on permanent grassland and rural land (30) and under forest (28). The first soil sampling was conducted 1986, meanwhile we started with the 6th re-sampling campaign.

With the monitoring design we take into account background variation resulting from natural spatial and (short-term) temporal variation and from measurement procedure errors. The short-term background variation masks the temporal changes of soil quality indicators caused by anthropogenic activities. Consequently, long term soil monitoring of ecosystems deals with the detection of anthropogenic changes (signal) in comparison to natural changes and measurement procedure errors (noise). In this talk we will present selected results of the five re-sampling campaigns between 1985 and 2009. In our presentation we will focus on (i) the analysis of the background variation at the soil monitoring sites and (ii) on an analysis of variance of the short-term and long-term variation of soil quality indicators and their implications for the interpretation of the measured changes in soil monitoring.

# Design-based generalized least squares estimation of status and trend of soil properties from repeated surveys

*D.J. Brus and J.J. de Gruijter*

[dick.brus@wur.nl](mailto:dick.brus@wur.nl)

*Droevendaalsesteeg 4, Wageningen, Netherlands*

This paper introduces and demonstrates design-based Generalized Least Squares (GLS) estimation of spatial means at selected time points from repeated soil surveys with partial overlap, such as a rotational and a supplemented panel. The linear time trend of the spatial means can then be obtained as a linear combination of the estimated spatial means. The GLS estimator is the minimum variance linear unbiased estimator. Five space--time designs were compared under a first order autoregressive time-series model for the spatial means, through the average and generalized sampling variances of the estimated spatial means, and through the sampling variance of the estimated linear trend. None of the designs scored best on all three quality measures. If the aim of soil monitoring is estimation of both status and trend, then these two conflicting aims must be prioritized in order to choose an efficient space--time design. The methodology is demonstrated by a case study on eutrophication and acidification of forest soils. The linear trends in the spatial means of pH and the ammonium and nitrate concentrations at three depths in the soil profile, as estimated from a rotational design with four sampling times at an interval of one year, were small and not significant. Exceptions were pH in the subsoil and ammonium in the middle soil horizon. The linear trend is here defined as a linear combination of the true and unknown, but fixed spatial means. In quantifying the uncertainty of the estimated trend, only the sampling error in the estimated spatial means is accounted for. If there is a need to include uncertainty due to fluctuations of the true spatial means around a linear trend, then a super-population or time series model for the spatial means must be postulated which comprises a model error term. The linear trend is then defined as a model parameter, that can be estimated by Generalized Least Squares as in generalized linear modelling.

# Geostatistical approaches for predicting changes in soil organic carbon from data on large and variable spatial supports

*T.G. Orton, N.P.A. Saby, D. Arrouays, Ch. Walter, B. Lemercier, C. Schvartz, R.M. Lark*

thomas.orton@orleans.inra.fr

*INRA Orléans, US 1106, Unité InfoSol, Centre de Recherches d'Orléans, BP 20619, Ardon, 45166 Olivet Cedex, France*

We investigate geostatistical approaches for predicting changes in soil organic carbon (SOC) and quantifying the associated uncertainty, using data from the Franche-Comté region of France. The data, consisting of measurements of the SOC from farms across the region, were collected in two time periods (1995-1999, and 2000-2004). However, to protect the anonymity of the farms that took part in the surveys, the locations and values of individual observations were unavailable. Rather, we were only able to use summarizing statistics for the data from each commune: the average value, sample variance and number of observations from each commune. In this study, we consider two issues. First, the uncertainty due to the data being in the form of summary statistics: how should we deal with the variation in the number of observations per commune and the size and shape of these communes? We show how the residual maximum likelihood (REML) method can be applied to estimate variogram parameters based on data of this form, and calculate predictions using the empirical best linear unbiased predictor (E-BLUP). Second, we consider the dependence between the data from the two surveys. We use a linear model of coregionalization (LMCR) to account for this dependence, and show how the LMCR can be applied to data in the form of summary statistics. We estimate and map the changes in SOC between the times of the two surveys, and calculate the prediction variances associated with the estimated change. We use cross-validation to assess the performance of the methods, and compare the results to those of a naïve approach, which does not account for the form of the summary-statistics data. The results show improvements in terms of the estimated changes and associated uncertainty assessment.

# Application of a mixture model approach to large-scale simultaneous hypothesis testing in soil monitoring

*N.P.A. Saby, D. Chauveau, D. Arrouays, Ch. Walter, B. Lemercier*

nicolas.saby@orleans.inra.fr

*Unité INFOSOL, US 1106, Centre INRA d'Orleans, 2163 avenue de la Pomme de Pin, CS 40001 Ardon, 45075 Orlenas Cedex 2, France*

There is a general requirement for high intensity soil surveys and monitoring schemes to quantify the variation of soil properties at the national-scale and for monitoring to detect changes in soil properties. Unfortunately, National scale resampling programmes are cost prohibitive and therefore any extra information about soil changes should so be investigated. In France, farmers commission about 250,000 soil-testing analyses per year to assist them managing soil fertility. Compiling the results of these analyses into a database makes it possible to re-use these data within both a national and temporal framework. The French National Soil Tests database gathered more than 1.4 million soil tests not precisely georeferenced. Investigating the information of this database for soil monitoring produces multiple hypothesis testing problems with hundred or thousands of cases to consider simultaneously. A largely used concept of error control was provided by Benjamini and Hochberg (J. Roy. Statist. Soc. B 57 (1995) 289) who advocate control of the expected proportion of falsely rejected hypotheses which they term the false discovery rate or FDR. An alternative concept consists in considering the distribution of p-values as a mixture of null and alternative densities that are estimated, leading to local FDR (lFDR) estimation. In this work, we explore FDR and different solutions of lFDR using parametric and non parametric mixture models estimated by E-M or similar algorithms. The contributions of the different models to estimation of FDR and related criteria are illustrated on the results of simulated Wilcoxon's tests and on soil carbon content monitoring.

## Probabilistic indicators of soil status for its monitoring

*I. Mikheeva*

mikheeva@issa.nsc.ru

*Institute of Soil Science and Agrochemistry, Sovetskaya street 18, Novosibirsk, 630099, Russia*

The concept is proposed to overcome a problem of significant soil variability which complicates estimations of soil status and its transformation under soil usage and climate change. It is proposed to use probability distributions functions (pdf) of soil properties, value of pdf divergence and statistical entropy as probabilistic indicators for holistic assessment of soil status, processes and changes for their monitoring. Initial data were materials of several soil surveys, repeated at the same large territory at the south of Western Siberia. Applying the statistical procedure to data samples we have identified pdf of soil properties for each soil series; and as a result, we received bank of pdf of soil properties at different stages of soil usage.

Results of our researches have shown and explained big variety of mathematical models of pdf of soil properties in reality. It is shown that they are suitable for reliable and integral evaluation of the effect of soil-forming factors on soil properties and, hence, for the comparison of past, current, and future anthropogenic and natural changes. In monitoring practice pdf of soil properties can serve as indicators which allow holistic assessment of changes of state of soil objects taking into account their variability. The pdf divergence value can help to single out most changed and vulnerable soil varieties, as well as to range natural and anthropogenic changes accordingly to degree of their influence on soil properties. Moreover it can serve as the measure of the actual interclass distances that is useful for evaluation of quality of soil classification in dynamics. It is proposed to consider the statistical entropy, calculated from pdf of soil properties, as reliable statistical characteristic of variability of soils. Results confirm complicated behavior of entropy in soil systems, despite of it criteria of sustainability is to be small increment of entropy.

# Spatial data analyses in soil geochemistry

*Ch. Zhang*

chaosheng.zhang@nuigalway.ie

*GIS Centre, Ryan Institute and School of Geography and Archaeology, National University of Ireland, Galway, Ireland*

Soil geochemical databases are being constructed at regional, national and international scales. The spatial analyses of the large volume of environmental geochemical data become a challenging task. This study discusses some issues during environmental geochemical mapping exercises. The topics discussed included spatial outlier identification, spatial variation and spatial modelling. Outliers in a dataset can cause biased statistical results and thus should be identified. Spatial outliers are indentified based on a comparison with their neighbouring data, and they may imply a different process from the background such as pollution. Spatial variation has been conventionally evaluated using visual interpretation based on maps, but the development of local statistics enable the quantification of spatial variation. Meanwhile, a geographically weighted regression can be applied to model the spatially varying relationships between environmental parameters, making it possible for spatial modelling in environmental geochemistry. These issues are demonstrated using soil geochemical data from Ireland.

## Spatial statistical methodology and its relationship to dominant large-scale pattern of Cs-137 soil contamination in Bryansk region (Russia)

*V.G. Linnik, A.A. Saveliev., A.V. Sokolov, A.P. Govorun*

vlinnik_53@mail.ru

*Vernadsky Institute of Geochemistry and Analytical Chemistry Russian Academy of Sciences, Kosygin street 19, 119991 Moscow, Russia*

The accident at the Chernobyl Nuclear Power Plant has contaminated vast areas of Russia. Owing to a wide variety of factors, radioactive contamination of landscapes resulting from the Chernobyl accident appears rather complicated. To effectively deal with tasks of forecasting radioecological situation at the contaminated territories research of spatiotemporal parameters of radionuclides distribution in soil at different scale levels is of great importance. To study spatial structure of Cs-137 contamination in its relation to relief parameters, some plots in the western part of the Bryansk region at a distance of about 170 km from the Chernobyl nuclear power plant have been chosen. All the plots with size about 100x100 m, are situated in various landscape positions. Soil radionuclide contamination was measured using in situ radiometric technique. Field radiometry is indispensable for receiving mass data while examining spatio-temporal structures of Cs-137 contamination with a different scale and for studying correlation of radionuclides distribution with parameters resulting from a local topography. In studying patterns of Cs-137 contamination we apply steps of 10, 2, and 0.5 m. The purpose of this work was to examine spatial variation of Cs-137 contamination at a field scale using techniques of geostatistics, GAM, and digital terrain modelling. This would contribute to better understanding statistical behaviour of soil radioactive contamination variability. A generalised additive model was used to model the dependence of Cs-137 spatial distribution on the relief features. For hydromorphic areas of the sites, the variogram analysis showed that the Cs-137 spatial distribution was characterised by patchy patterns with a typical size from meters to tens of meters. For watershed areas, the Cs-137 spatial distribution was random and did not form any patterns.

# Session: Soil-landscape and space-time modelling

# High resolution 3D modeling of soil organic carbon in a complex agricultural landscape using continuous depth functions

*M. Lacoste, B. Minasny, A.B. McBratney, Ch. Walter, V. Viaud, D. Michot*

marine.lacoste@rennes.inra.fr

*INRA, UMR1069 Soil Agro and hydrosystems Spatialisation,*
*65 route de Saint Brieuc, 35000 Rennes, France*

Soil organic carbon (SOC) is a key element of agroecosystems functioning and has a crucial impact on global carbon storage at world scale. SOC spatial variability and temporal dynamics are strongly affected by natural and anthropogenic processes occurring at the landscape scale, such as soil redistribution in the lateral and vertical dimensions by tillage and erosion processes. This study aims at modeling SOC distribution in A-horizons, at high spatial resolution, for an area of 1 000 ha in a complex agricultural landscape (NW France). The study site is characterized by high short distance heterogeneity due to an important diversity of soils (with varying redoximorphic conditions, depth), soil parent material (Aeolian loam cover, granite, hard and soft schist), topography, land use (annual crops, temporary or permanent grasslands) and hedge density. We used learning methods based on soil point data, characterized by soil description, SOC content and bulk density measurements. 200 points were selected using conditioned Latin hypercube sampling in order to cover the whole range of ancillary variables (elevation, Modified Compound Topographic Index, K emissions and land use). This sampling strategy enables to select a limited number of sampling sites coverering the study site heterogeneity. Additive sampling was designed to investigate SOC distribution near hedges (112 points sampled at fixed distances along 14 transects crossing hedges). Predictive environmental data consisted in the data used in the conditioned Latin hypercube sampling, at which were added topographic attributes derivated from the DEM and geological variables. We will discuss the ability of our model to capture and predict the SOC, considering the general SOC distribution trend at the landscape scale and the finer SOC distribution in landscape, at hedgerow proximity. The SOC 3-D map obtained will be used as soil data input in a soil evolution model, coupling SOC dynamics and soil erosion modeling.

# Regional 3D spatial prediction of soil organic carbon for three contiguous bioregions in New South Wales, Australia

*I. Wheeler, B. Minasny, A.B. McBratney, E. Bui*

ichsani.wheeler@sydney.edu.au

*Faculty of Agriculture, Food and Natural Resources, S208 JR Woolley Building A20, Camperdown, The University of Sydney NSW 2006, Australia*

Digital soil mapping (DSM) provides a flexible mechanism by which legacy soil information can be combined with environmental covariates to produce continuous regional predictions of SOC content. Regional predictions of the spatial distribution of soil organic carbon (SOC) are needed to help understand local drivers of SOC levels and to identify potential project locations for soil based sequestration.

Whilst legacy databases are an excellent source of SOC profile information for SOC mapping, they often collate numerous surveys utilising differing profile sampling strategies. This can limit the vertical resolution for which SOC predictions can be made as well as introduce considerable sampling error into the DSM process. In order to obtain continuous depth functions an equal-area spline was applied to all legacy SOC profiles (n = 1145) to produce observed values for both discrete (0-30 cm; 30-50 cm; 50-100 cm) and aggregated depth slices (0-10 cm; 0-50 cm and 50-100cm).

In addition to more traditional climatic, topographic and pedological factors, recently produced covariates utilised by this study include a 100 m resolution gamma radiometric map, a gamma derived weathering index, 250 m decadal Dynamic Land Cover Mapping derived from MODIS input as well as numerous secondary terrain attributes were collated for three predominately agricultural bioregions totaling ~150 000km2 within south eastern Australia.

A piecewise linear decision tree approach was employed on a 75:25% data split to produce spatial estimates of average SOC for 6 depths at a resolution of 250 m. Model performance on the test dataset yielded R2 values ranging from 0.5 for the 0-10cm layer to 0.15 for the 50-100cm layer. In addition, the concept of threshold values and changing covariate relationships to SOC are explored within vertically discrete and vertically aggregated depths.

# Contextual mapping approaches for terrain based digital soil mapping

*T. Behrens, K. Schmidt, L. Ramírez–López, T. Scholten*

thorsten.behrens@uni-tuebingen.de

*University of Tübingen, Institute of Geography, Soil Science and Geomorphology, Rümelinstraße 19-23, 72074, Tübingen, Germany*

We present new digital terrain analysis approaches for digital soil mapping, referred to as contextual elevation mapping (ConMap). In contrast to common digital terrain analysis, ConMap is not based on standard terrain attributes. The first and previously published method (Behrens et al., 2010) is based on elevation differences from the centre pixel to each pixel in multiple circular neighbourhoods as analytical topographic indices. When applied for predicting topsoil silt content in a loess region of 1150 km2 in Rhineland-Palatinate, Germany using 342 samples, a 20-m resolution DEM, and neighbourhood sizes up to 24 km in diameter, cross-validation RMSE values decrease from 16.1 for standard digital terrain analysis to 11.2 using ConMap, which corresponds to $R^2$ values of 0.16 and 0.61.

The second ConMap method, which will be in the focus if this talk is not based on elevation differences but on statistical measures. For each radius various statistical measures are derived. This comprises the mean, the median, the standard deviation, the minimum value and the maximum value. In this setup the statistical approach is free of any directional information. An extension of this feature set by including the directions to the minimum and maximum values adds directional components. However, the amount of analytical directional values is much lower compared to the differences approach. The basic idea is achieve a better interpretability of the predictions results and further options to analyse and interpret the effect of the integration of multiple scales in a single prediction approach.

# Curvelet transform for soil properties in rolling landscape

*B.C. Si and A. Biswas*

*bing.si@usask.ca*

*51 Campus Drive, Saskatoon, SK, Canada S7N 5A8*

Soil properties in the landscape can have anisotropy and representation of ridges using wavelets is not efficient. The objective of this study is to analyze soil properties in a two-dimensional rolling landscape with curvelets. The efficiency of curvelet as compared to wavelets will be demonstrated.

# Diversity of thermal conditions within the paleocryogenic soil complexes of the East European Plain: experimental research and mathematical modelling

*T. Arkhangelskaya*

arhangelskaia@rambler.ru

*Faculty of Soil Science, Moscow State University, Leninskie Gori, 119991 Moscow, Russia*

Temperature regimes of arable soils of paleocryogenic complexes common in the periglacial area of the East European Plain differ distinctly. In summer, soils with the second humus horizon are cooler than those without this horizon; for the depth of 50 cm, temperature difference between soils located at a distance of 2-3 m may exceed 3˚C. In winter, soils with the second humus horizon freeze later and to a smaller depth, as compared to soils with mineral subsoil horizons, though being located quite similarly in the landscape. The observed differences in thermal conditions are explained by the differences in soil thermal diffusivity. Its average values for water-saturated samples of Vladimir Opolie soils were $3.73\times10^{-7}$, $4.20\times10^{-7}$, $5.15\times10^{-7}$ and $4.81\times10^{-7}$ $m^2/s$ for Ah, AE, EB and B horizons, respectively.

The experimental k(θ) curves, where k is soil thermal diffusivity, θ is water content, were parameterized with a 4-parameter approximating function. The obtained parameters were used to calculate soil thermal diffusivity of the studied horizons for 2×2 $m^2$ grid within the 16×10 $m^2$ plot. Mathematical modelling of soil temperature regime was performed for 70 cm layer for the period from May 1 to July 23, 2003; the initial profile distribution of temperature was set equal to 4˚C at all depths; the water content was set constant and equal to 0.25 $g/cm^3$ for all gridpoints. The dynamics of upper boundary conditions was set by weather data and was the same for the whole plot. The model underestimated soil temperature by about 1.5˚C, but reflected quite correctly the pattern of temperature spatial distribution. Mathematical modelling has confirmed that the subsurface heterogeneity of soil thermal diffusivity is sufficient to explain the formation of a laterally heterogeneous thermal field within the studied complexes.

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## Spatial prediction of forest soil properties from a dataset influenced by seasonal variation

*L. Borůvka, V. Tejnecký, M. Bradová, K. Němeček, O. Šebek, O. Drábek*

boruvka@af.czu.cz

*Department of Soil Science and Soil Protection, Faculty of Agrobiology, Food and Natural Resources, Czech Unversity of Life Sciences in Prague,*
*165 21, Prague 6 – Suchdol, Czech Republic*

Soil monitoring typically brings a lot of data from different times and places. For spatial prediction, there might be a problem with characteristics influenced by temporal changes. The aim of this contribution is to show an attempt to eliminate the effect of temporal variability in data on an example of dataset from a seasonal monitoring of forest soil properties. Results of soil sampling in two adjacent forest stands with beech and spruce forest, respectively, in monthly intervals for three years during the vegetation periods (April to October) were used. Each time, three new soil pits were dug and individual soil horizons were sampled on each site. In total, more than 600 soil samples were collected. Soil pH, dissolved organic carbon (DOC), water-soluble anions and Al forms were determined in the samples. In the data, seasonal pattern and the differences between the years were analysed first. The second step was to standardize the data to an early spring period by subtracting the seasonal and annual patterns. In the third step, the standardized data were interpolated using kriging interpolation. For further prediction, the kriged map can be used, with adding the seasonal pattern again. This approach provided good results for the properties with a clear seasonal pattern, as for example pH and DOC in the surface organic horizons. Characteristics with less pronounced seasonal effect, particularly the characteristics of deeper mineral horizons, showed only little or no improvement. Also the characteristics with very high spatial variation, like the water-soluble Al forms, did not show any significant improvement of spatial prediction. Nevertheless, for characteristics with strong seasonal pattern, this rather simple approach can be a good alternative to more complicated spatio-temporal models.

# Session: 3D modelling and data assimilation

## Building a three dimensional soil model by combining data sources of various degrees of uncertainty

*D.J.J. Walvoort, D.J. Brus, G G.B.M. Heuvelink*

dennis.walvoort@wur.nl

*Alterra - Wageningen University & Research Centre, PO Box 47, 6700 AA Wageningen, Netherlands*

Groundwater models are indispensable tools for evaluating national and European policy. In the Netherlands, the REgional Geohydrologic Information System (REGIS) is available for providing these models with the necessary inputs. REGIS is a three dimensional hydrogeological model of the subsoil. It contains information on lithology and hydraulic properties like transmissivity and hydraulic conductivity. In the current version of REGIS, information about the first two meters below the soil surface is under-represented. Therefore, research has been started to upgrade these first two meters by means of data in the Soil Information System of the Netherlands (SIS). For this purpose, a method has been developed to build a three dimensional model of soil textural fractions (clay, silt, and sand contents) and soil organic matter content. These soil properties can subsequently be used to estimate soil hydraulic properties. Three data sources have been used to build the three dimensional soil model: a soil map, REGIS and SIS. These sources provide information on similar properties, but with different levels of detail and different degrees of uncertainty.  A procedure has been developed to combine these sources and to simulate equiprobable realizations of sand, silt, clay, and organic matter contents at the nodes of a fine three dimensional grid. In our presentation we will outline the method and illustrate it by means of a case study. Special attention is being paid to the compositional nature of the soil textural fractions.

# Analyzing mCT images: soil pore size distributions and permeability estimations using simple network models

*A.A. Tairova and K.M. Gerke*

cheshik@yahoo.com

*Laboratory of Geomechanics and Fluidodynamics, Lenisnkiy prosp. 38/1, Moscow, Russia*

For structure analysis of soils thin sections or mCT scans are usually used. In case of 2D investigations pore space connectivity is usually can not be achieved (e.g. pore phase does not percolate from one side of the digitized image to another). However 3D structure can be reconstructed using only 2D information (e.g. simulated annealing, multipoint statistics, Gaussian filters), connectivity of the reconstructed pore space is usually significantly reduced. One of the reasons for this to happen is that real porous media are strongly anisotropic. In this work we check the degree of anisotropy for numerous soil samples based on their mCT scans. Analysis is mainly based on pore size distribution calculation using median axis determination, connectivity evaluation with 'burning' algorithm, and orthogonal permeability estimation using simple network model. Methodology developed can be used for comparison of different soils structure or quality of reconstructions, for pore and throat sizes evaluation and pore-network development. If generic pore is defined as a volume around medial axis curve there end point are intersections with other medial axes, conventional thin section morphological analysis can be extrapolated to 3D. Our results confirm that soils are mainly anisotropic in three dimensions.

# Variability of soil structure within the same profile studied by the means of mCT

*K.M. Gerke, E.B. Skvortsova, D.V. Korost*

cheshik@yahoo.com

*Laboratory of Geomechanics and Fluidodynamics, Lenisnkiy prosp. 38/1, Moscow, Russia*

X-ray computer microtomography is an invaluable tool in pedometrics and was extensively used for soil structure, preferential flow paths and solute movement studies. Here we present the results of mCT scanning and digital data processing for five undisturbed soil samples taken from different genetical soil layers within the same profile of soddy-podzolic loamy soil derived from mantle loam and covered by the 100-aged spruce forest (southern taiga subzone, Moscow region, Russian Federation): humus-accumulative (0-4cm), humus-eluvial (6-11cm), eluvial (18-23cm), illuvial (55-60cm), parent material (150-155cm) horizons. Studied soil layers had highly variable texture: 5.9-9.6% of loam (grains < 0.001 mm) in humus-eluvial, and 24.4-35.4% in illuvial-parent material horizons. Internal structure of all samples studied was visualized and characterized using different parameters in 3D. Analysis showed a big structural, and volume, shape and orientation of the pore space difference between generic horizons, which was mainly affected by texture difference and biota activity. Finally, we make an insight into differences between soil structure studies using 2D and 3D approaches.

# Application and assessment of a multiscale data integration method to saturated hydraulic conductivity in soil

*N. Li[1] and L. Ren[2]*

renl@mx.cei.gov.cn

[1] *School of Water Resources & Environment, China University of Geosciences, China*
[2] *Department of Soil and Water Sciences, China Agricultural University, Key Laboratory of Plant-Soil Interactions, MOE, Beijing, China*

Saturated hydraulic conductivity ($K_s$) is one of the most important physical properties of the soil. Inherent spatial variability of soil properties makes it necessary to obtain sufficient and reliable Ks in order to reduce the uncertainty in hydrological modeling. In this study, we employ a Bayesian hierarchical modeling framework combined with upscaling techniques and an efficient adaptive Markov Chain Monte Carlo (MCMC) method, namely, Delayed Rejection Adaptive Metropolis (DRAM), for spatial modeling of fine-scale Ks in soil conditioned on coarse-scale Ks data and some prior information. Within this hierarchical framework, the posterior distribution of the fine-scale Ks field is formulated to incorporate all of the conditional information from different scales, which involves upscaling operators of non-explicit form and especially is high dimensional. The computational challenge of exploring the posterior distribution with complicated structure is solved by means of the DRAM algorithm. Two synthetic examples involving integration of two or three different scales of conductivity data are used to illustrate the implementation of these approaches. Further validation is provided using distributed in situ measurements of Ks from soils in northwest China. Subsequently, a series of representative numerical experiments are conducted to demonstrate the power and utility of these approaches under a range of soil conditions with varying levels of spatial heterogeneity, correlation length, and anisotropy. Overall, the Bayesian hierarchical modeling framework combined with upscaling techniques and DRAM sampling strategies was shown to be a viable tool for reconciling different scales of saturated hydraulic conductivity in soil. Our numerical investigations provide a comprehensive numerical validation of the method, illustrating its applicability and limitations.

# Estimation of unsaturated soil hydraulic parameters using ensemble Kalman filter

*L. Ren and Ch. Li*

renl@mx.cei.gov.cn

*Department of Soil and Water Sciences, China Agricultural University,*
*Key Laboratory of Plant-Soil Interactions, MOE, Beijing, China*

The parameters of the soil hydraulic functions are essential to the accurate simulation of soil moisture based on the Richards equation. The optimal values of the parameters can be calibrated by inverse modeling, in which the not fully consideration of various errors may influence the parameter estimation results, thus further limit the accuracy in modeling and forecasting. The ensemble Kalman filter (EnKF) is a sequential data assimilation method which is excellent in explicitly considering various sources of errors and sequentially using the time series of observations. Recently, the EnKF was extensively examined in parameter estimation, which is rarely reported in soil hydrology. In this study, EnKF was used to estimate the parameters of soil hydraulic functions by assimilating observations of soil water pressure dynamics. The results of the synthetic experiments that covered the twelve soil textures indicated that, the EnKF estimates can quickly approach stable estimates. In contrast to the batch calibration process using simple least squares objective function, EnKF reduced the risk of obtaining sub-optimal estimates. EnKF also performed well in the multi-parameter estimation scenarios with synthetic observations and in the application in a heterogeneous soil profile with in situ field observations of previous study. We further explored the potential factors that may influence the estimation results, including the initial estimate, the ensemble size, the observation error and the model error, and the assimilation interval. The primary result of this study implies that the EnKF scheme is a prospective method for parameter estimation in vadose zone hydrology.

# Session: Soil geostatistics

# Expert elicitation of the variogram

*P. Truong, G.B.M. Heuvelink, J.P. Gosling*

gerard.heuvelink@wur.nl

*Wageningen University, Department of Environmental Sciences,*
*PO Box 47, 6700 AA Wageningen, Netherlands*

The variogram is the key instrument of geostatistics. Estimation of the variogram typically relies on a sufficiently large number of observations of the target variable. However, budget constraints may cause that a too sparse data set is used to estimate the variogram, which will impair the subsequent geostatistical analysis. In some cases it may even be impossible to collect observations to estimate the variogram, such as when in scenario studies the spatial variability of a variable defined in the future is to be assessed. In addition, prior information about the variogram may also be very useful to design an optimal sampling scheme in field surveys and in Bayesian geostatistics. It is, therefore, sensible to explore approaches to estimate the variogram other than through a structural analysis of observations. In this paper we explore how the variogram can be elicited from experts. Experts can be very knowledgeable about the spatial variability of target variables, but directly asking experts about the nugget, sill, range and shape of the variogram may not be sensible because many experts are not familiar with these concepts. The variogram is typically estimated by the average squared increments of the target variable over various lags, but robust estimation of the variogram uses the median of the absolute differences of the target variable over distances. Statistical expert elicitation is well developed to extract the median of uncertain quantities from experts. Thus, the median of the absolute increment is a sensible target quantity of the elicitation procedure. We developed an expert elicitation methodology on this principle, by eliciting the median for multiple separation distances and fitting a variogram. First, a protocol of a well-structured elicitation procedure was designed. Next a web-based tool for online elicitation was built that is composed of three main components: (1) web-GIS interface for elicitation and feedback, (2) statistical calculation and mathematical aggregation to merge the opinions of multiple experts and (3) database management. The prototype was tested and evaluated in a case study on elicitation of the variogram of soil pH. The evaluation showed that the online elicitation tool is satisfactory, although currently it is only a prototype that needs to be further developed.

# Spatial modelling of soil hydraulic properties, a geostatistical approach

*A. Horta, M.J. Pereira, A. Soares*

[ahorta@ist.utl.pt](mailto:ahorta@ist.utl.pt)

*CERENA - Centro de Recursos Naturais e Ambiente, Departamento de Engenharia Civil, Arquitectura e Georrecursos, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal*

Intensive agricultural activities in many regions of Europe are affecting the quality of main environmental resources. It is of crucial importance to identify these environmental problems and to propose solutions to minimise the potential risks for public health and the ecosystems. With this purpose, models are developed to describe soil water regimes and nutrient dynamics as a tool to evaluate the transport of chemicals for environmental monitoring or crop yield. The application of these models is fully dependent on the availability and quality of soil unsaturated hydraulic properties (SUHP) that will determine the accuracy of modelling results. The techniques used to obtain direct measurements of SUHP are time consuming and therefore costly. One way to overcome this limitation is to use indirect methods for the prediction of SUHP such as pedotransfer functions (PTF). PTF relate SUHP to more easily measurable soil data such as soil texture or organic matter content. However, PTF are dependent on edafo climatic conditions and extrapolation to other areas should be regarded carefully. One possible way to overcome PTF limitations is to integrate the concept of spatial variability in a spatial inference model. This can be implemented using geostatistical models to obtain the spatial distribution of SUHP and assessing their spatial uncertainty. Hence, this work proposes SUHP assessment using collocated cokriging and direct sequential co-simulation with bi-distributions (Horta and Soares, 2010). This algorithm allows the combination of different support data (e.g. bulk samples and topsoil samples) and will be improved using local bi-distributions according the soil types. For implementing and testing our methodologies one study area will be selected in the South of Portugal, for which a soil hydraulic database is available The results will be compared with present estimates provided by PTF for the selected study area.

Horta, A., Soares, A. (2010).Data integration model to assess soil organic carbon availability, Geoderma, 160 (2), pp. 225-235, ISSN 0016-7061, DOI: 10.1016/j.geoderma.2010.09.026.

# Adaptive Markov Chain Monte Carlo simulation for parameter inference in model-based soil geostatistics

*B. Minasny, A.B. McBratney, J.A. Vrugt, B.P. Marchant*

budiman.minasny@sydney.edu.au

*Faculty of Agriculture, Food & Natural Resources, The University of Sydney, NSW 2006, Australia*

Geostatistics has been the core tool used by pedometricians in quantifying spatial variation and also for making predictions of soil properties. Recently there has been much interest in model-based geostatistics (Diggle et al., 1998) in pedometrics.

The conventional way of estimating the variogram parameter is now labelled classical geostatistics. These classical methods have been criticised by statisticians, in particular the ad hoc methods of inference for the variogram parameters. Likelihood-based methods that are more rigorousare therefore preferred by statisticians. Nevertheless, residual maximum likelihood (REML) or related methods only attempt to find the maximum likelihood values of the variogram parameters without recourse to estimating their underlying posterior uncertainty. This posterior probability distribution function (pdf) contains important information about the uncertainty and correlation of the various geostatistical parameters and can be used to derive meaningful estimates of spatial prediction uncertainty.

This paper implemented a new algorithm called DiffeRential Evolution Adaptive Metropolis (DREAM) to jointly summarise the posterior distribution of variogram parameters and the coefficients of a linear spatial model, and derive estimates of predictive uncertainty.

This approach is tested using different data sets from Australia involving variogram estimation, and spatial prediction of soil propertes. The results showed some advantages of MCMC over the conventional method of moments and REML estimation. The posterior pdf derived with MCMC conveys important information about parameter uncertainty, multi-dimensional parameter correlation, and thus how many significant parameters are warranted by the calibration data. The variation of estimated soil variograms due to parameter uncertainty can be quite large at large lags.

The results show that parameter uncertainty constitutes only a small part of total prediction uncertainty for the case studies considered herein. The prediction accuracy using MCMC and REML is similar. The variogram estimated using conventional approaches (method of moments, and without simulation) lies within the 95% prediction uncertainty interval of the posterior distribution derived with DREAM.

## Using bivariate multiple-point geostatistics and proximal soil sensor data to map fossil ice-wedge polygons

*E. Meerschman and M. Van Meirvenne*

eef.meerschman@ugent.be

*Research Group Soil Spatial Inventory Techniques, Department of Soil Management, Faculty of Bioscience Engineering, Ghent University, Coupure 653, 9000 Gent, Belgium*

Multiple-point geostatistics (MPG) is a geostatistical toolbox aiming at the reconstruction of spatially continuous patterns. Although little research has been done on applying MPG in soil science, several case studies require the reconstruction of repetitive soil features and an improved modeling of their spatial interconnectivity. We investigated the possibilities of MPG to estimate the location of fossil ice-wedge polygons in the subsoil with the help of proximal soil sensing data, i.e. apparent electrical conductivity (ECa). These cryogenic features are of interest since they cause abrupt changes in the subsoil composition and the morphology of their polygonal network is important for paleoclimatological reconstructions. Based on an aerial photograph showing polygonal crop marks, a field was selected and surveyed with an EM38DD ECa soil sensor. The resulting map clearly showed the polygonal pattern due to the lower clay content of the wedge filling. A fuzzy k-means classification delineated the major ice-wedge casts but did not show sufficient connectivity for the smaller polygons, since small wedges were only visible through local ECa contrasts. As an alternative, we performed a bivariate reconstruction with the recently developed Direct Sampling software (Mariethoz et al., 2010). We built a bivariate training image with a categorical image of a regular hexagonal network as primary variable and a continuous image of the corresponding ECa values as secondary variable. The exhaustively known conditioning data for the secondary variable, i.e. the ECa map, guided the simulation of the unknown primary variable, i.e. wedge occurrence. The resulting E-type served as probability map for the wedge occurrence, also connecting small polygons. Our case study showed that bivariate MPG can be used to estimate the location of repetitive soil features based on proximal sensing data. The use of the proximal sensing data as secondary variable guarantees local accuracy, while a predefined connectivity model ensures pattern reconstruction.

Mariethoz, G., Renard, P., and Straubhaar, J. 2010. The Direct Sampling method to perform multiple-point geostatistical simulations. Water Resources Research 46 (W11536).

# Spatial implementation of the empirical mode decomposition and its applications in digital soil mapping

*P. Roudier, B.M. Whelan, A.B. McBratney, B. Minasny*

roudierp@landcareresearch.co.nz

*Landcare Research, Private Bag 11052, Manawatu Mail Centre, Palmerston North 4442, New Zealand*

Empirical Mode Decomposition (EMD) is a signal-processing method that has been designed to analyse nonlinear and non-stationary data. Initially developed to analyse time series, its purpose is to decompose a multiresolution signal into a finite and limited number of elementary signals according to the various frequencies that are present in the original signal. Unlike wavelet-based methods, a major advantage of the EMD is that no choice of a filter is required: the algorithm adapts itself to the characteristics of the data to be processed. Moreover, the frequency range that is analysed by the EMD is not fixed a priori.

This paper introduces an implementation of the EMD algorithm for two-dimensional spatial data (regularly or irregularly gridded). The EMD algorithm is centred around an iterative process called sifting. First, local extrema (minima and maxima) are identified in the original dataset. This can be done using either a k-nearest neighbours algorithm or a Delaunay triangulation. Then, using those two subsets of points, minima and maxima envelopes are interpolated on the support of the original dataset. This interpolation step uses multi-level B-splines. From the extrema envelopes, a mean envelope is easily derived. Finally, that mean envelope is substracted from the original signal. If the result answers certain conditions, it is called an Intrinsic Mode Function (IMF), which is a decomposition layer of the original signal. The sifting process is iteratively repeated on the residual signal until no significant amount of information remains in the residual signal.

Examples on gridded and ungridded data sets will present some potential applications of the spatial EMD to Digital Soil Mapping (DSM). First, the spatial EMD is used to spatially filter a given range of frequencies. Secondly, this decomposition method provides a new tool to achieve multi-resolution analysis of a set of predictors in order to predict a given soil property.

# Application of indicator kriging for the regionalization of Kreybig legacy soil profile data

*L. Pásztor, Z. Bakacsi, A. Laborczi, J. Szabó*

pasztor@rissac.hu

*Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, Department of Environmental Informatics,*
*Herman Ottó út 15., H-1022 Budapest, Hungary*

Digital Kreybig Soil Information System (DKSIS) is the most detailed nationwide spatial dataset in Hungary, which consists of approximately 100,000 soil mapping units and 250,000 sampling plots. Detailed soil properties are available for the latter in the form of hard (sampled/measures) and soft (trasferred) data. Since the majority of profile related variables are categorical, indicator kriging is a useful tool for their regionalization, being a nonparametric method without assumption on concerning the distribution of the modeled variables.

For the modeling water movement in the unsaturated zone a 3D, regional scale, spatial dataset was elaborated based on the thematic, horizontal and vertical harmonization, fitting and interpolation of hydrophysical parameters originating from DKSIS and an agrogeological database. For the harmonization of hydrophysical data, texture classes were used as common interface. Non-equidistant layers were transferred into a regular vertical layer distribution. Categorical point information in each layer was interpolated using indicator kriging. Decisions on categorization were done based on probabilistic class membership values.

DKSIS was also applied for the delineation of areas affected by natural handicaps in Hungary concerned by common European biophysical criteria. Soil data linked to DKSIS profiles and mapping units were spatially analyzed for the compilation of digital maps displaying spatial distribution of specific limiting factors. Fulfillment of a specific criterion had to be regionalized, thus the final product was a binary map displaying yes/no categories. Decisions were carried out on SMU and soil profile level by proper SQL queries of the profile database. Joining the results to the spatial entities resulted in spatial features categorized in binary (indicator) form. In contrast to SMUs, providing complete spatial coverage, point information had to be even spatially extended. Indicator kriging provided probability (spatial) distribution maps, indicating the probability of fulfilling the criteria within the 1 ha blocks used for the calculation.

# Forest stands history affects the spatial variability of soil pH

*P. Gruba, J. Mulder, P. Pacanowski, J. Socha*

rlgruba@cyf-kr.edu.pl

*Department of Forest Soil Science, University of Agriculture,*
*Al. 29 Listopada 46, 31-425 Krakow, Poland*

Small-scale pattern of soil properties is often believed to be a result of single trees influence, however, many investigations did not confirm the visible effects of such tree-soil relationship. The aim of this study was to investigate small-scale variability of soil pH under homogeneous forest monocultures of different origin. Investigations were carried out in forested areas of Southern Poland. Eight 20x20 m plots were laid out in homogeneous, mature (40-80 years) pine (four plots), oak (three plots) and spruce (one plot) forests. Soil samples were taken from top 10cm of mineral soil (E horizon of podzols) in regular 1x1m grid, i.e. we obtained 441 samples per plot. Sampling was performed using a cylindrical auger. All samples were analyzed for pH($CuCl_2$). In sixteen points (the inner 4x4m grid of each plot) the sampling was done twice, to get additional soil sample for extended analysis: pH ($CuCl_2$), the content of organic carbon and a number of other soil parameters. From the variability of pH values in the double sampling at the same point, the semivariance at zero distance was calculated, and included into semivariograms. Geostatistical analysis (semivariograms, with special attention to their anisotropy) showed that spatial variability of pH in the top mineral soil horizon was not much related to the position of trees. In oak, the pattern of soil pH was mostly related to soil disturbance by windthrow, and the semivariograms did not show a directed anisotropy. In contrast, the soil pH in pine and spruce showed a “stripped” pattern, with directed anisotropy, as suggested by the semivariograms. Most probably this pattern is explained by the history of site preparation of the pine and spruce stands, where the strips of higher and lower pH remained after soil ploughing.

# Session: Signal processing of remote and proximal sensing applied to soils

# Investigating the spatial variation in soil aggregates at nanometre- to micrometre-scales with the discrete wavelet transform

*A. Milne, J. Lehmann, D. Solomon, A. Neal, T. Geraki, F. Mosselmans, R.M. Lark*

alice.milne@bbsrc.ac.uk

*Rothamsted Research, Harpenden, Herts, United Kingdom*

Micro-scale technologies, such as near-edge X-ray fine-structure spectroscopy (NEXAFS) and X-ray fluorescence, present researchers with the opportunity to explore the soil structure and composition at nm-scales. In many cases the data that result from applying these technologies are interpreted visually. Although this can be informative it does not allow quantitative conclusions to be drawn.

We propose that discrete wavelet methods are suited to investigate the fine-scale spatial variation in soil data of this kind. To illustrate this we consider two examples, the first is measurements of the optical density of different carbon forms made on a cross-section of a soil micro-aggregate. The measurements were made using NEXAFS and resulted in a two-dimensional dataset. We considered both one- and two-dimensional wavelet methods, selecting transects of data for the former analyses. In the aggregate considered, we identified the scale-dependent correlations of the different forms of carbon. For example, aromatic and carboxylic carbon were positively correlated at the coarsest scales, and negatively correlated at finer scales, suggesting that the two forms of carbon were deposited in common clumps, but at finer scales one form dominates. We found evidence that the spatial distribution of carbon at these fine scales is complex.

In our second example, we analysed measurements of Zn, Cu and Fe made on cross-sections of soil micro-aggregates. The measurements were made using X-ray fluorescence. Six aggregates were considered, each had received applications of liquid sludge, metal salts or sludge cake. Our results supported the hypotheses that Zn strongly associates with Fe in the soil. The scale-dependent correlations between the variables changed with application type, raising questions for scientists to ponder.

We argue that as micro-scale technology advances, so must the development of quantitative methods of analysis (such as discrete wavelet methods) otherwise the potential in these valuable datasets will not be realised.

# Learning a new soil vis–NIR distance metric by using a manifold based approach

*L. Ramírez–López, T. Behrens, K. Schmidt, R.A. Viscarra Rossel, T. Scholten*

leonardo.ramirez-lopez@uni-tuebingen.de

*Institute of Geography, Physical Geography, University of Tübingen,*
*Rümelinstraße 19–23, 72074, Tübingen, Germany*

In soil vis–NIR spectroscopy, distance metrics and similarity search play a key role in assessing unknown soil samples, composition elucidation, outlier detection, etc. In this presentation we introduce two new methods of similarity search and evaluate the performance of commonly used distance metrics (Euclidean (ED), Mahalanobis (MD) and principal component (PC) distances) compared to our approaches.

The first method uses a Surface Distance Spectrum (SDS) and works in the spectral space. The second one works in a projected space and is based on the SDS–Locally Linear Embedding (SDS–LLE) algorithm, where the LLE is an unsupervised metric learning algorithm based on manifold projections. We also propose an optimized PC distance (o–PC) method which is based on a simple parameter optimization to determining the number of PCs to retain before distance computations.

In order to test our approaches we used a global soil vis–NIR spectral library composed of 3643 samples (700 as test set (Xu) and 2943 as reference set (Xr)). We evaluated the performance of our methods by their ability to identify soil spectrums with similar clay content. The SDS distance and the SDS–LLE distance were used to search for compositional similarity between Xu and Xr.

The SDS method ($R^2$=0.71)) outperforms the ED (R2=0.50) and MD ($R^2$=0.19) based methods in the spectral space. For the projection space methods we found that the SDS–LLE ($R^2$=0.79) also outperforms the PC ($R^2$=0.57), o–PC ($R^2$=0.72) and LLE based methods ($R^2$=0.70).

The experimental results show that the SDS and SDS–LLE methods are suitable for similarity searching, returning better results than the standard methods.

# Can hyperspectral images help us to gain insight into the real spatial structures of soil properties?: some learnings from a case study in southern France

*P. Lagacherie, C. Gomez, G. Coulouma*

lagache@supagro.inra.fr

*INRA LISAH Campus de la Gaillarde 2 place Viala 34060 Montpellier, France*

Spatial samplings from classical field work and laboratory analysis have been the most current inputs of the soil geostatistic studies in the past. Because of the severe limitations in spacing and extent, the spatial structures of soil properties captured from these samplings could be considered as caricatures of the real soil patterns. Imaging spectrometry can now provide images of soil spatial variations that largely outperform these spatial samplings both in spatial resolutions and extents with however local prediction errors and restrictions in space due to vegetation presence.

We examined how a 5 meters resolution hyperspectral image (HYMAP) available over a set of 192 bare soil fields scattered in a 24.6 km² pedologically contrasted area can be used for representing the spatial structure of height primary soil properties. Experimental variograms built from classical spatial samplings were first compared with those obtained from hyperspectral data at the same locations. Experimental variograms were then built from the entire set of locations with hyperspectral data. The large number of locations allowed to derive experimental variograms for different mapping units of a 1:25 000 scale soil map.

The results showed that i) the experimental variograms of some soil properties built from hyperspectral data and from classical spatial samplings were close enough to build permissible linear co-regionalisation models, ii) the experimental variograms built from the entire set of locations with hyperspectral data strongly differed from the formers, providing a more accurate description of the short range soil variabilities iii) there was significative differences of spatial structure between groups of soil mapping units.

From these results, it can be predicted that an extensive use of imaging spectrometry can provide significant improvements in spatial sampling optimisations, soil property interpolations, existing soil map updates and verifications of driving factors of soil formation hypothesis.

# Applying blind source separation on hyperspectral data for clay content estimation over partially vegetated surfaces

*C. Gomez, W. Ouerghemmi, S. Naceur,*
*P. Lagacherie*

*cecile.gomez@supagro.inra.fr*

*IRD, Laboratoire d'étude des Interactions Sol Agrosystème Hydrosystème (LISAH),*
*UMR 144, El Menzah 4, Tunis, Tunisia*

Hyperspectral imagery has proven to be a useful technique for mapping soil surface properties. However vegetation cover has a significant influence on spectral reflectance and the applicability of hyperspectral images for soil property estimations decreases when surfaces are partially covered by vegetation. To maximize information extraction from hyperspectral data, we apply a "double-extraction" technique: 1) extraction of a soil reflectance spectrum S, using blind source separation (BSS) techniques from mixed hyperspectral spectra without any information about the proportion of the components in the mixture nor the original spectra that composed the mixed spectra, except an average soil spectrum from the region of interest, and 2) extraction of soil property contents from the soil reflectance spectrum S by classical chemometric methods. The Infomax algorithm is used as the BSS algorithm for this approach, and the chemometric method is the partial least squares regression. The estimated soil property after soil signals extraction is the clay content, and the hyperspectral datasets are from Hymap airborne data.

First, experiments were performed using simulated linear spectral mixtures of one soil spectrum and one vegetation spectrum (vineyards). Second, the "double-extraction" method was applied to grids of 3x3 Hymap mixed spectra, which correspond to surfaces partially covered by vineyards. Our simulated experiments and applications to Hymap data show that the BSS concept extract soil reflectance spectra which allow an accurate estimation of clay content compared to physico-chemical values (the mean error of estimation is always inferior to 50 g/kg in simulated experiments and predominantly inferior to 90 g/kg in Hymap mixed pixels treatments). We conclude that the "double-extraction" method, which requires no a priori information except an average soil spectrum of the region of interest, is a promising method for soil property prediction using hyperspectral imagery over partially vegetated surfaces.

# Posters

Topic: Soil sampling for survey

## Soil sampling procedure of the EuroGeoSurveys project 'Geochemical Mapping of agricultural and grazing land soil of Europe'

*M. Ďuriš, M. Poňavič, C. Reimann, A. Demetriades, M. Birke, the EuroGeoSurveys Geochemistry Expert Group*

michal.ponavic@geology.cz

*Michal Poňavič, Czech geological survey – Division of mineral resources,*
*Tomanova 22, 162 00 Praha 6, Czech Republic*

The soil sampling stage of any project is the most important, since if any mistakes are made at the beginning of a project are carried forward to the succeeding stages, and most importantly to the final interpretation of data and report writing. The members of the EuroGeoSurveys Geochemistry Expert Group, with their long experience in multi-national soil geochemical projects, are aware of the significance of good sampling procedures. The on-going GEMAS project's objective is to produce a harmonised geochemical database for agricultural and grazing land soil of Europe, in order for industry to provide the administration of REACH, among other variables, the baseline at the beginning of the twenty-first century against which future datasets will be compared. Before starting this multi-national project, not only the sampling methodology had to be decided, but also the national leaders participated in a field training workshop. Directly after the workshop, a field sampling manual was written, giving all the necessary details.

Items, purchased centrally, and provided to each national team, were (a) trace element free clear plastic sample bags, (b) strip-locks, (c) small clear plastic zip-lock bag for sample number card, (d) small cards for sample number, (e) scalebar for photographs, and (f) black permanent markers. Other field equipment was purchased locally, e.g., spade and pick axe (if painted, the paint was removed by sandblasting), stainless steel knife, white plastic scoop, GPS, digital camera, topographical maps, and boxes for packing samples.

Composite samples of (i) agricultural soil (Ap horizon, 0-20 cm) from regularly ploughed fields, and (ii) land under permanent grass cover (0-20 cm) were collected from five sub-sites from a 10 x 10 m square plot, i.e., from each corner and the centre. Each soil sample was placed into the provided plastic bag, and securely closed with a zip-lock immediately after collection, and finally opened at the sample preparation laboratory. This harmonised procedure ensures the collection of representative soil samples across Europe.

# Sampling to estimate the mean of soil properties of 90-m grid cells for digital soil mapping

*R. Kerry, M. Oliver, B. Rawlins, B. Ingram*

ruth_kerry@byu.edu

*Department of Geography, Brigham Young University, 690 SWKT, Provo, UT, 84602, U.S.A.*

The globalsoilmap.net project was launched recently in the digital soil mapping community. The final specifications of the outputs from the project[1] state that values of the key soil properties chosen should be reported on 90 m by 90 m grid cells and "the value reported for each 90 m by 90 m grid cell will represent a bulked mean within the entire extent of the grid cell." As for any bulking strategy, the aim is to remove the local variation in the soil property that occurs within a grid cell.

Burgess and Webster (1984) described how to determine the number of soil cores required for bulking when the variogram of a soil property is known. Variograms of soil OC, pH, P, K and Mg, and ancillary data were calculated for specific parent materials from the data of the Tellus survey of Northern Ireland. Individual variograms were standardized to zero mean and unit variance and averaged for a given parent material. The standardized average variograms were then used to simulate values on a fine grid for each parent material. Following Burgess and Webster's (1984) approach, the parameters of the standardized average variogram were used to determine the estimation error for a given number of samples to be bulked. Graphs of estimation error plotted against sample size were used with the notion of acceptable error for the selected properties to determine appropriate sample sizes for bulking. The simulated values were randomly sampled 100 times for each sample size to quantify and validate the estimation error associated with each sample size. The bulking strategies suggested by variograms from the ancillary data were compared with those suggested by variograms of soil data to determine if the former can be used as a guide to bulking when no soil data are available.

[1] http://www.globalsoilmap.net/Rome/May20_2010_Final_Specifications_for_Output_Products_GSM_Nov_2009_V8.pdf

Burgess, T. M., & Webster, R. (1984). Sampling and bulking strategies for estimating soil properties in small regions. Journal of Soil Science, 35, 127–140.

# An ecological condition of soil of a vertical zone in the Beshtash national park of Talas region

*Z. Koichumanov*

[kzamirbek@yahoo.com](mailto:kzamirbek@yahoo.com)

*Talas State University, Lomonosov 51, 724200 Talas, Kyrgyz Republic*
*Masaryk University, Kotlarska 2, 611 37 Brno, Czech Republic*

Pedology of soils in different altitudes in the Beshtash national park of Talas region has been studied. The attention was given mainly to the mechanical and chemical properties of soils to evaluate soils in physical-chemical and agrochemical point of view.

In total 20 soil samples have been taken from 5 pits of the following soil types (Kolos 1977): 1. Upland-soil (dark northern serozem, located 1200 m a.s.l); 2. Upland-soil (light-kastanozem, 1600 m a.s.l.); 3. Mountain soil (dark-kastanozem, 2000 m a.s.l.); 4. Mountain soil (chernozem, 2400 m a.s.l.); 5. Alpine soil (meadow-steppe sub-alpine soil 2800 m a.s.l.).

A regular increase of humus and nitrogen content can be seen in soils from northern dark serozems to light-kastanozem; from dark-kastanozem to chernozem with rising of the altitude is increases the fertility of soils. Mountain soils show decreasing pH values from alkaline soils to slightly alkaline and neutral soils with increasing altitude.

The weathering index of Parker (WIP) is calculated as: WIP = (100) [(2Na2O/0.35) + (MgO/0.9) + (2K2O/0.25) + (CaO/0.7)] and is based on the gradual loss of alkali from the silicate rocks during weathering, (Parker, 1970). The result of WIP shows differently on the first pit on the northern serozems (1200 m a.s.l.) the most weathered horizon is A2 with a value of 45.7. The second pit on light-kastanozem (1600 m a.s.l.) more weathered horizon is C (58,6). Third, fourth and fifth pits of the most weathered horizon was A1 with values 41, 30 and 41. Concentrations of arsenic in soils were very high, especially in the upland-soils (dark northern serozem, 1200 m a.s.l.) and alpine soils (meadow-steppe sub-alpine soil, 2800 m a.s.l.). The average concentration of arsenic in soils from all samples is 116 mg / kg. This is 58 times higher than background, and 7 times higher than the hazard rate (USSR State Committee for Nature, 1990).

Parker, A., 1970. An index of weathering for silicate rocks. Geological Magazine, 107, 501-504.

Threshold limit value (TLV) of chemical substances in soils and permissible levels of their content on the hazard indicators (USSR State Committee for Nature, № 02-2333 of 12.10.1990).

Kolos, M., 1977. Soils classification and diagnostics of the USSR.

## Soil sampling with increased accuracy

*M. Mesic, I. Vukovic, I. Kisic, Z. Zgorelec, A. Jurisic*

mmesic@agr.hr

*Faculty of Agriculture, University of Zagreb, Department of General Agronomy, Svetosimunska cesta 25, 10000 Zagreb, Croatia*

Conventional soil sampling usually implemented in Croatia considers sample weight of 2 kg per 4-5 ha area, which means that representative sample in relation to soil mass up to 30 cm depth is presented through the ratio 1:10 000 000. New sampling method changes the ratio to 1:625 000, thus increasing amount of sampled soil 16 times with assumption that such sample better describes investigated area. Moreover, new soil sampling probe can be used for precision farming purposes where the central point of the probe ring is positioned with precision of ±1 cm and represented with 4, 8 or 16 samples taken in 50 cm radius from the center. Soil probe prototype was tested on agricultural land of 4 ha area with total number of 200 samples and on the 12 ha area with total of 12 samples. To justify application of new constructed probe, this study gives results of geostatistical analysis of spatial variability in soil pH values up to 30 cm depth. Ordinary kriging was used as interpolation method. Spatial structure of soil parameter was analyzed by calculating semivariograms and approximated by exponential model. Root-mean-square error (RMSE) of prediction was used as measure for the best model evaluation. Interpolation analysis of reduced number of samples per investigated area of 4 ha resulted in deviation in RMSE of 13,2% when 50% less samples were randomly introduced, and 41% with 60 samples, compared to total of 200 samples. Using new soil sampling method for soil survey and applied geostatistical tools provides a solution for quantifying spatial variability of soil properties, possibilities for commercial activities and a way to introduce variable rate technology in agricultural input application which can optimize farm profitability through improving yield, reducing input costs and minimizing input losses to the environment.

Topic: Soil monitoring

## Geostatistical monitoring of soil salinity in Uzbekistan by repeated EM surveys

*A. Akramkhanov, D.J. Brus, D.J.J. Walvoort*

api001@yahoo.com

*ZEF-UNESCO Khorezm Project, 14 Khamid Alimjan Street, Urgench, Uzbekistan*

Soil salinity in the lower reaches of Amudarya is a constant threat. The shallow groundwater table contributes to salinization of the rooting zone which is tackled by leaching at the end or beginning of the vegetation season. However, there is growing concern that the efficiency of the leaching with application of high amounts of water is very low. The objective of this study is (i) to look at soil salinity change within the vegetation seasons; and (ii) to monitor the trend of salinity change over the three-year period from 2008 to 2010.

The electromagnetic induction meter EM38 was used to assess the soil salinity. Measurements in vertical dipole mode, the sensing depth down to 1.5 m, were made before and after the leaching events and at the end of the vegetation season each year. The EM device coupled with GPS was utilized to obtain geo-referenced locations of transects. To classify readings of EM38 into salinity classes the log transformed readings were converted into ECe using calibration data fitted with a simple linear model.

Maps of ECe at the selected time points were obtained by simulating multiple maps of log(EM) using the ordinary kriging model. Besides, multiple vectors of regression coefficients were simulated, which were used to transform the simulated log(EM) maps. Finally simulated maps of regression residuals were added to the transformed log(EM) fields, and backtransformed. Maps of the temporal change in ECe between two time points were obtained by simulating multiple pairs of maps of log(EM) by cokriging. Simulated maps of ECe and of the change in ECe were used to derive, for instance, a map of the probability that ECe exceeds a critical threshold, and a map of the probability that soil salinity is increased.

# Using soil organic matter as indicator of degradation prone areas in Mediterranean environment

*G. Buttafuoco[1], M. Conforti[2], G. Robustelli[2], F. Scarciglia[2]*

*gabriele.buttafuoco@cnr.it*

*[1] CNR - Istituto per i Sistemi Agricoli e Forestali del Mediterraneo (ISAFOM), Institute for Agricultural and Forest Systems in the Mediterranean, National Research Council of Italy, Via Cavour, 4-6, 87036 Rende (CS) – Italy*

*[2] Department of Earth Sciences, University of Calabria, Italy*

Mediterranean area is often characterized by accelerated soil water erosion which is widely recognisable as one of the major cause of land degradation. Soil organic matter (SOM) represents a key soil property in evaluating soil degradation and geostatistics is generally preferred among spatial interpolation techniques because it allows to take into account spatial correlation between neighbouring observations. A way of increasing the accuracy of predictions of sparsely observations of the primary attribute is using ancillary information from more densely recorded data such as digital elevation models (DEMs). The test area was the Turbolo catchment (Calabria, southern Italy) extending over an area of about 30 km$^2$ and representative of a larger surrounding land, characterised by a high susceptibility to soil degradation. For this study, 215 topsoil samples were collected and analysed.

The main objective of the study was to demonstrate if using widely available secondary data (elevation) provides more accurate estimates of soil organic matter than the ones obtained by using standard popular interpolation procedures. The interpolation techniques were ordinary kriging, linear regression analysis, regression kriging, kriging with external drift and multi-collocated ordinary cokriging. Their results were compared using an independent validation data set and the comparison of predictions was based on three measures of accuracy: the mean absolute error, the mean-squared error of prediction and the mean relative error. An additional objective was to identify degradation prone areas where the SOM content was less than a value deemed critical for soil degradation. These areas were delineated using the geostatistical stochastic simulation and showed in terms of probability of not exceeding a critical SOM value. The results obtained in this case study showed that among the method considered no one performed univocally better. The proposed methodology allowed highlighting areas characterized by higher probability of soil degradation and there was an evidence of a strict correlation between degradation prone areas and land use.

# Acquisition and data analysis related to changes in some forest soils properties after prescribed fire action

*A.C.M. Castro[12], J.P. Meixedo[12], J.P. Carvalho[3]*

*ana.meira.castro@eu.ipp.pt*

*[1] CIGAR, Centro de Investigação em Geo-Ambiente e Recursos, Faculdade de Engenharia da Universidade do Porto, Portugal*
*[2] ISEP - Instituto Superior de Engenharia do Porto Departamento de Matemática, Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal*
*[3] INESC-ID, Instituto Superior Tecnico, Lisbon, Portugal*

Controlled fires in forest areas are frequently used in most Mediterranean countries as a preventive technique to avoid severe wildfires in summer season. In Portugal, this forest management method of fuel mass availability is also used and has shown to be beneficial as annual statistical reports confirm that the decrease of wildfires occurrence have a direct relationship with the controlled fire practice. However prescribed fire can have serious side effects in some forest soil properties.

This work shows the changes that occurred in some forest soils properties after a prescribed fire action. The experiments were carried out in soil cover over a natural site of Andaluzitic schist, in Gramelas, Caminha, Portugal, that had not been burn for four years. The composed soil samples were collected from five plots at three different layers (0-3cm, 3-6cm and 6-18cm) during a three-year monitoring period after the prescribed burning. Principal Component Analysis was used to reach the presented conclusions.

# Carbon sequestration monitoring; processes and its effect on soil conservation in the tropics

*R.Ch. Eneje*

chizma2001@yahoo.com

*Department of Soil Science And Agro-climatology, Michael Okpara University of Agriculture Umudike, Nigeria*

Soil carbon sequestration is the process of transferring $CO_2$ from the atmosphere into the soil through crop residues and other organic solids and in a form that is not immediately remitted. It occurs through direct and indirect fixation of atmospheric $CO_2$, direct sequestration occurs when inorganic chemical reactions convert $CO_2$ into soil inorganic carbon compounds such as calcium and magnesium carbonates, while indirect carbon sequestration occurs when plant biomass is decomposed to release soil organic carbon. $CO_2$ is naturally captured from the atmosphere through biological, chemical and physical process. Conservation agriculture or agro-biological agriculture enhances biological functioning of the soil with evident increases in soil fauna and microflora, these systems of land use also protect the soil physically. Thus crop residue management factor is an important method of sequestering C in the soil and the associated positive effects of using crop residues to induce C sequestration is estimated at 0.2Pg Cyr-1 with transformation of 15% of the total C (1.5Pg C globally). This review also reported linear relationship between organic matter in the first 15cm of soil and the quantity of crop residue applied. Generally crop land tillage is the most important practice that affect the C pool either negatively (conventional ploughing) or positively (conservation tillage), soil aggregation and C sequestration process were strongly associated.

# A 30-year long large-scale multi-processes soil monitoring project in a complex engineered cover system: Perspectives and challenges for pedometrics

*D. Jacques, D. Mallants, E. Laloy*

djacques@sckcen.be

*Performance Assessments Unit, Institute for Environment, Health and Safety,*
*Belgian Nuclear Research Centre (SCK•CEN), Boeretang 200, B-2400 Mol, Belgium*

The Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS) will construct in 2012 a complex engineered earth cover system as a demonstration and large-scale monitoring project. By this ONDRAF/NIRAS seeks process understanding at the scale of a field plot about 2400 $m^2$ large from which confidence can be built in its long-term evolution. The test cover consists of two alternative 5-m deep profiles of following sequence: a biological layer, a bio-intrusion layer and an infiltration barrier made from at least a 1-m thick clay layer. Soil monitoring equipment will be installed for a detailed spatio-temporal evaluation of processes including variably-saturated water flow, erosion, vegetation-soil-atmosphere interactions, biological processes (development of surface and subsurface vegetation characteristics, bioturbation, respiration), soil chemical processes (pore water and solid phase composition and evolution) and mechanical processes (settlement, stability). The foreseen measurement period is at least 30 years. As leak detection (failure of the infiltration barrier) is an important aspect for controlling the performance of the cover, in-situ measurement techniques, non-invasive measurement techniques, advanced 2D or even 3D variably-saturated water flow models, process identification and state-of-the art parameter and predictive uncertainty estimation techniques (e.g., the global optimizer DREAM) will be combined. Because changes in soil physical, chemical, thermal, and mechanical properties may result in a modified behaviour of the earth cover, especially within a time scale of several decades, an interdisciplinary approach is called upon, including time series analysis and data assimilation, to further corroborate such time evolution. An international expert panel will guide the scientific objectives and results of the test cover. The ONDRAF/NIRAS test cover project is intended to be a research platform open to challenging and complementary investigations related to both technological developments and data interpretation. In this presentation the project objectives, methodologies, challenges, and potential international collaboration are addressed.

# Assessing the spatial change of soil carbon levels in agro-production systems: A case study of the Cox's creek catchment in Namoi valley, Australia

*S.B Karunaratne[1], T.F.A. Bishop[1], I.O.A. Odeh[1], J. Baldock[2]*

skar2438@uni.sydney.edu.au

*[1] Faculty of Agriculture, Food and Natural Resources, University of Sydney, Suite 412, Biomedical Building, 1 Central Avenue, Australian Technology Park, Eveleigh NSW 2015, Sydney, Australia*
*[2] CSIRO Land and Water - Waite Campus, Glen Osmond SA 5064, Australia*

The objectives of this study are to assess the changes in soil carbon in the Cox's creek catchment in the Namoi valley, Australia and use this information to give guidelines on future resampling schemes. Changes in space and on average across the catchment are considered. Legacy soil carbon data collected by the Department of Climate Change and Water, NSW between June and August 2000 were used as the base data for the analysis. The sampling design used to collect these soil samples was haphazard and based on access to properties and roadside cuttings. Resampling was carried out in November 2010 using a two-stage random sampling design. The primary unit for the sampling was determined by grouping different combinations of land use and soil classes. At each primary site a second site was chosen 30 m away in a random direction. Geostatistics was used to identify where soil carbon changed across the catchment. Finally the results were used as a guide to: (i) determine the number of samples required to detect a significant change in carbon; (ii) design an optimal resampling scheme, given the initial haphazard sampling design used for the legacy soil data.

# Aggregate stability of soils impacted by soil erosion

*O. Jakšík, R. Kodešová, I. Stehlíková*

[jaksik@af.czu.cz](mailto:jaksik@af.czu.cz)

*Department of Soil Science and Soil Protection, Czech University of Life Sciences Prague; Kamycka 957, 16521 Praha 6 – Suchdol, Czech Republic*

The aim of the study was to assess soil aggregate stability as property indicating degree of soil degradation within the area impacted by soil erosion. Aggregate stability influences soil porous system, and consequently soil water regime, soil biota and soil nutrient availability, soil erodibility etc. The study site is located in loess region in Southern Moravia in the Czech Republic. The region has been under uninterrupted agricultural use since the middle of the Holocene. Haplic Chernozem is an original dominant soil unit in the wider area, nowadays progressively transformed into different soil units along with intensive soil erosion. An extremely diversified soil cover structure resulted from the erosion. Detailed research of soil types was carried out on one study plot (strip part of an arable land, area of 6 ha) in Brumovice cadastre (Zádorová et al., 2011b). Soil samples for analysis were taken from 32 points in representative terrain and soil cover positions at the same study plot in August 2010. Organic carbon content, $pH_{H2O}$, $pH_{KCl}$, $CaCO_3$ content, and soil particle density were measured in the laboratory. Aggregate stability was assessed using the indexes of water stable aggregates (WSA). In addition the actual soil water content was measured in the field using the SM200 sensor when sampling. Topographic derivatives (slope; plan, profile and mean curvature; topographic wetness index; sediment transport index; stream power index) were also obtained from a detailed digital elevation model (Zádorová et al. 2011b). Multiple linear regressions showed that WSA index depended on the organic carbon content, actual soil water content and mean curvature. Relationship between WSA and other analytic properties was not approved, which is in contrast to findings published by Kodešová et al. (2009), but in agreement with results obtained based on pilot sampling at this area in November 2009 (Zádorová et al., 2011a).

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Zádorová, E., Jakšík, O., Kodešová, R., Penížek, V. (2011a): Influence of terrain attributes and soil properties on soil aggregate stability. Soil and Water Research, 6, in print.

Zádorová, T., Penížek,V., Šefrna, L., Rohošková, M., Borůvka, L. (2011b): Spatial delineation of organic carbon-rich Colluvial soils in Chernozem regions by Terrain analysis and fuzzy classification. Catena, 85 (1), 22–33.

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# Spatial soil material redistribution due to soil erosion studied using magnetic susceptibility mapping

*O. Jakšík[1], R. Kodešová[1], I. Stehlíková[1], A. Kapička[2]*

jaksik@af.czu.cz

*[1] Department of Soil Science and Soil Protection, Czech University of Life Sciences Prague; Kamycka 957, 16521 Praha 6 – Suchdol, Czech Republic*

*[2] Institute of Geophysics, Academy of Sciences of the Czech Republic, Prague, Czech Republic*

The aim of this study is using specific mass magnetic susceptibility as a indicator for estimating soil properties within the area affected by soil erosion. The study site is located in loess region in Southern Moravia in the Czech Republic. The region has been under uninterrupted agricultural use since the middle of the Holocene. Haplic Chernozem is an original dominant soil unit in the wider area, nowadays progressively transformed into different soil units along with intensive soil erosion. An extremely diversified soil cover structure resulted from the erosion. Detailed research of soil types was carried out on one study plot (strip part of an arable land, area of 6 ha) in Brumovice cadastre (Zádorová et al., 2011). Soil samples for analysis were taken from 99 points in representative terrain and soil cover positions at the same study plot. Organic carbon content, $pH_{H2O}$, $pH_{KCl}$, soil particle density, and mass specific magnetic susceptibility were measured in the laboratory. Regression analysis showed that organic carbon content was negatively correlated with $pH_{KCl}$ ($R^2$ = 0.58) and soil particle density ($R^2$ = 0.607 - evaluated only for 36 points where measured). Similarly the mass specific magnetic susceptibility was negatively correlated with $pH_{KCl}$ ($R^2$ = 0.729) and soil particle density ($R^2$ = 0.66). The positive correlation was therefore found between the organic carbon content and magnetic susceptibility ($R^2$= 0.90). No significant correlation of $pH_{H2O}$ with the other measured soil properties was found. Values of organic carbon content, $pH_{KCl}$, magnetic susceptibly and particle density are spatially distributed depending on terrain position. Greater values of organic carbon content and magnetic susceptibly, and lower values of $pH_{KCl}$ and particle density were measured at the flat upper part and at colluvial fan. The lowest values of organic carbon content and magnetic susceptibly, and higher values of $pH_{KCl}$ and particle density were obtained on the steep valley sides. However, poor correlation between measured soil properties and terrain attributes (which were evaluated from the digital elevation model) were found.

Zádorová, T., Penížek,V., Šefrna, L., Rohošková, M., Borůvka, L. (2011): Spatial delineation of organic carbon-rich Colluvial soils in Chernozem regions by Terrain analysis and fuzzy classification. Catena, 85 (1), 22–33.

Projects No. GA CR 526/08/0434 and No. MSM 6046070901.

## Using in situ near infrared reflectance spectroscopy to investigate field scale heterogeneity of soil properties

*J. Miltz and A. Don*

jasmin.miltz@vti.bund.de

*Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries, Institute of Agricultural Climate Research, Bundesallee 50, 38116 Braunschweig, Germany*

Near infrared reflectance spectroscopy (NIRS) has been shown to be an effective method to substitute time consuming analysis of chemical soil characteristics, such as carbon quality and fractions. The advantage of this method is that it's non-destructive and can be applied to large numbers of samples in a rapid and cheap way. Several soil properties can be derived simultaneously from one spectrum. This lab experience gave much motivation to use NIRS in the field with on-the-go measurements. The innovation of in situ-measurements is the direct recording of field soil properties without time consuming sampling, sample preparation and lab analytics. This method leads to a better understanding of the spatial heterogeneity of soil properties. Variability and spatial heterogeneity in soil properties on large scale (region, field) and also on small scale (soil pit) hampers any soil monitoring. The objective of this study was to investigate field scale heterogeneity of the carbon and nitrogen content in different agricultural soils horizontally (near-surface) and vertically (profile). The fields were mapped with a tractor mounted Veris VIS-NIR-spectrometer: a shank (horizontal measurements near surface) and a probe (profile measurements on a fixed grid). By using both, the VIS and the NIR region, a measuring range from 350-2200 nm with a resolution of 8 nm could be covered. The optical sensor was pulled through the soils at parallel lines with a distance of 8 m and a speed of ~ 4-5 km/h. Second, the optical window of the probe was pushed into the soil profile down to one meter. Calibration samples were taken for both methods and analyzed for organic carbon. Calibration for organic carbon from spectral data were developed using PLSR regression. First results show that the mobile VIS-NIR system is a good method for a cost effective organic carbon mapping of different agricultural soils.

# Using model-based geostatistics to develop design-based sampling guidelines for estimating arsenic contamination around cattle dip sites

*N.K. Niazi, T.F.A. Bishop, B. Singh*

thomas.bishop@sydney.edu.au

*Faculty of Agriculture Food and Natural Resources, The University of Sydney, Sydney, NSW 2006, Australia*

In the past Arsenical pesticides were used across New South Wales, Australia to control ticks in livestock at now disused cattle dip sites which resulted in the contamination of surrounding soils with elevated and extremely variable As concentrations. Estimating the spatial distribution of As in soil is imperative to delineate its level and spread of contamination. Therefore, the aims of this study were to (1) quantify spatial-variation in soil As content around a cattle dip site and map this using linear mixed models, and (2) use the information on the spatial variability pattern to give guidelines on the sample size required to estimate the mean soil As values. The soil cores (n=102) were taken in a systematic design (0.3 m×0.35 m) to a depth of 0−0.6 m and cut into three sections to give 0−0.2, 0.2−0.4 and 0.4−0.6 m depths. The results demonstrated that total (at 0–0.2 m depth) and phosphate extractable (at three depths) As concentrations varied over short (< 1 m) distances at their corresponding depths, and this extreme variability was apparent in the predicted maps. Both total and extractable soil As concentrations significantly ($p < 0.001$) increased towards the cattle dip (northings-trend). Using the information of this spatial variability trend, we suggest that for this site a sample size of 15 would be sufficient to statistically prove that mean total As (826 mg/kg) with standard error of mean (sem) of 99.0 and a confidence interval of [613.7, 1038.3] in the surface soil was higher than the ecological investigation level (20 mg/kg) limit of As in soil. Based on this we propose that a generic sampling scheme should have 5–20 samples, where sampling area around the dip bath can be stratified based on the closeness to the cattle dip.

Topic: Soil geostatistics

# Improved regionalization of soil surface properties using gamma-ray spectrometry and geo-statistics at field scale

*S. Meyer[1], M. Blaschek[2], U. Werban[3], G. Cassiani[4], R. Deiana[4], R. Duttmann[2], R. Ludwig[1], A. Soddu[5]*

s.meyer@lmu.de

*[1] Department of Geography, LMU Munich, Germany*
*[2] Institute for Landscape Ecology and Geoinformation, Department of Geography, University of Kiel, Germany*
*[3] Monitoring & Exploration Technologies, UFZ Helmholtz Centre for Environmental Research, Germany*
*[4] Dipartimento di Geoscienze, Università degli Studi di Padova, Italy*
*5 AGRIS Sardegna, Cagliari, Italy*

The European FP7-Project CLIMB (CLimate Induced changes on the hydrology of the Mediterranean Basins) is aiming to employ and integrate advanced field monitoring techniques in the framework of an hydrological model ensemble to quantify and reduce existing uncertainties in climate change impact assessment and analysis.

Process-based hydrological models require numerous soil and vegetation parameters in an appropriate spatial and temporal resolution. Although it is known that the response of those models is sensitive to the quality of soil data, adequate soil information is missing in most cases. This holds true for the field as for the catchment scales. In order to improve the quality of soil property prediction on the one hand side and to reduce uncertainty on the other, the applicability of non-invasive “mapping” techniques has to be tested.

This study focuses on the regionalization of soil physical properties (top soil texture, bulk density, soil moisture), geophysical data (Electro-Magnetic-Induction and Gamma-Ray Spectrometry) and terrain attributes calculated from a DEM as co-variables for statistical and geostatistical analyses. Different deterministic and geostatistical approaches (IDW, MLR, Simple Kriging and Ordinary Kriging, Regression Kriging) are compared to assess their prediction performance.

The study is based on data from an extensive field campaign in the Rio Mannu Catchment, Sardinia, Italy, in October 2010. About 90 soil samples were taken as validation data in two depths (0-30 cm and 30-60 cm) and lab-analyzed.

First results on the field scale show high correlation coefficients between soil properties and the geophysical co-variables and a strong autocorrelation of the residuals.

# Soil surface images analysis

*A. Saa-Requejo, J.L. Valencia, M.C. Díaz, A.P. Gonzalez, A.M. Tarquis*

anamaria.tarquis@upm.es

*CEIGRAM, E.T.S. Ingenieros Agrónomos, UPM, Avda Complutense s.n., 28040 Madrid, Spain*

Soil erosion is a complex phenomenon involving the detachment and transport of soil particles, storage and runoff of rainwater, and infiltration. The relative magnitude and importance of these processes depends on several factors being one of them surface micro-topography, usually quantified trough soil surface roughness (SSR). SSR greatly affects surface sealing and runoff generation, yet little information is available about the effect of roughness on the spatial distribution of runoff and on flow concentration.

The methods commonly used to measure SSR involve measuring point elevation using a pin roughness meter or laser, both of which are labouring intensive and expensive. Lately a simple and inexpensive technique based on percentage of shadow in soil surface image has been developed to estimate SSR in the field in order to obtain measurement for wide spread application.

One of the first steps in this technique is image de-noising and thresholding to estimate the percentage of black pixels in the studied area.

In this work, a series of soil surface images have been analyzed applying several de-noising wavelet analysis and thresholding algorithms to study the variation in percentage of shadows and the shadows size distribution.

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# Spatial variability of soil properties, wheat grain quality and yield: implication for precision agriculture

*V. Sidorova[1], V. Yakushev[2], E. Zhukovskiy[2], P. Lekomtsev[2]*

sidorova@krc.karelia.ru

*[1] Institute of Biology, Karelian Research Centre Pushkinskaya str. 11, 185910 Petrozavodsk, Russia*

*[2] Agrophysical Resarch Institute, St. Petersburg, Russia*

Precise information on spatial variability of soil properties and yield is essential for developing site-specific soil management. We conducted this study to determine the magnitude of within-field variability of soil properties, wheat grain quality parameters and yield in order to characterize their spatial structure. A total of 72 paired soil and wheat grain samples were collected at harvest. For all indices we found strong dependence on the position of the sampling points. Multiple determination coefficients ranged from 13 % (protein content) to 63 % (soil K). All the soil properties displayed well-defined spatial structures with strong spatial dependence. Carbon content, pH and hydrolytic acidity variograms had range values over 100 m. Ranges for P and K variograms were shorter, 63 m and 73 m respectively. Semivariograms for measured wheat yield parameters showed that these properties had moderate spatial dependence. The range distances varied from 68 m (the quantity of spikes) to 180 m (grains mass). Thus, kriging estimated maps of soil properties and yield parameters may be used for better understanding of the spatial variability and, potentially, for refining agricultural management practices at a field scale. With the aid of these maps it is possible to isolate sections with differing values of important agrochemical properties, and then, dependently on the localization and sizes of these zones, to make decision on the differentiated working of the soil. Also it is recommended the use of other methods, such as co-kriging or factor kriging, for establishing connections between the indices of productivity and soil properties. Wheat grain quality parameters did not show any spatial correlation. More detailed studies are needed to evaluate grain quality spatial structure.

# Relation of disturbance history and soil variability on different spatial scales in primeval mountain spruce forests

*M. Valtera, P. Šamonil, K. Boublík, M. Svoboda, J. Douda*

mvaltik@seznam.cz

*VUKOZ, v.v.i., Lidicka 25/27, 602 00 Brno, Czech Republic*

Pedological as well as dendrochronological field survey took place in Picea abies-dominated primeval montane forests in the Calimani National Park and Giumalau forest reserve in north-eastern Romania. At both localities the data were collected at 40 resp. 42 randomly located plots within 100 x 100 m squares of regular grid. Pedological invastigation consisted of the assessment of 9 soil profiles separated by the distances of 1, 3, 5, 7 and 15 m in slope and contour line directions at each sample plot. Total 360 soil profiles in Calimani and 378 profiles in Giumalau were assessed from the wiev of basic soil properties: soil taxonomical unit, thickness and form of all organic and upper mineral horizons and some anomalies (windthrow pith-mound, proximity to a tree thrunk, etc.). We evaluated also micro- and mezo-topographical forms of the relief. Dendrochronological tree cores from the representative number of 15-25 trees at each sample plot were used for evaluation of disturbance history using standard techniques. About 1000 tree cores were collected at each locality.

Spatial variability of soil properties was analysed using omnidirectional as well as directional quantitative and indicator variograms. Coefficients of variance were used on overall (locality level) and local (sample plot level) spatial scales. The variability of soil data were compared with disturbance history (pith-mounds occurrence, spatial patterns and time elapsed after the last disturbance event). Our results suggest the effect of disturbance history on soil formation and soil variability in primeval mountain spruce forests.

Topic: Fuzzy logic in soil science

# Fuzzy Boolean nets investigation of the alteration of some physical forest soil properties due a prescribed fire action

*A.C.M. Castro[12], J.P. Meixedo[12], J.P. Carvalho[3]*

*ana.meira.castro@eu.ipp.pt*

*[1] CIGAR, Centro de Investigação em Geo-Ambiente e Recursos, Faculdade de Engenharia da Universidade do Porto, Portugal*

*[2] ISEP - Instituto Superior de Engenharia do Porto Departamento de Matemática, Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal*

*[3] INESC-ID, Instituto Superior Tecnico, Lisbon, Portugal*

Portuguese northern forests are often and severely affected by wildfires during the summer season. Some preventive actions, such as prescribed (or controlled) burnings and clear-cut logging, are often used as a measure to reduce the occurrences of wildfires. In the particular case of Serra da Cabreira forest, due to extremely difficulties in operational field work, the prescribed (or controlled) burning technique is the the most common preventive action used to reduce the existing fuel load amount.

This paper focuses on a Fuzzy Boolean Nets analysis of the changes in some forest soil properties, namely pH, moisture and organic matter content, after a controlled fire, and on the difficulties found during the sampling process and how they were overcome.

The monitoring process was conducted during a three-month period in Anjos, Vieira do Minho, Portugal, an area located in a contact zone between a two-mica coarse-grained porphyritic granite and a biotite with plagioclase granite. The sampling sites were located in a spot dominated by quartzphyllite with quartz veins whose bedrock is partially altered and covered by slightly thick humus, which maintains low undergrowth vegetation.

Topic: Data assimilation

# Development of an open-source platform for pedometrics

*D.E. Beaudette and P. Roudier*

pierre.roudier@gmail.com

*Landcare Research, Private Bag 11052, Manawatu Mail Centre,*
*Palmerston North 4442, New Zealand*

A staggering quantity of soils information has been collected to support soil survey operations, natural resource inventories, and research over at least the last 100 years. Soils are routinely sampled and characterized according to genetic horizons, resulting in data associated with the dimensions of location, depth, and property space.

The high dimensionality and grouped nature of large soil profile collections can complicate standard analysis, summarization, and visualization. It is also complicated by difficulties associated with processing horizon data that vary widely in depth and thickness. Moreover, while the investigation of soil profile characteristics and horizon-level morphology are strongly based on visual and tactile cues, the challenge of communicating these data is traditionally addressed using written narrative or tabular form.

The aim of this paper is to present the development of an extensible, open-source framework that address the difficulties associated with processing soils information, specifically related to visualization, aggregation, and classification of soil profile data. AQP (Algorithms for quantitative pedology) is an R package that supports the quantitative analysis and interpretation of massive soil databases through numerical extensions to traditional methods of visualizing, aggregating, and classifying soils information. It can be used on a desktop machine, but can also be run on a high-performance computer in order to scale up with the growing size of soil databases.

Specialized data types (classes) are included to support the multivariate hierarchy of linked spatial data (e.g. coordinates), site data (e.g. landscape position), and horizon data (e.g. clay content at 10 cm). Examples of the AQP functionalities are proposed on different soils database, for data visualisation, analysis and classification.

# Estimation of national carbon stock in Hungary by the spatio-temporal integration of soil data originating from different sources

*L. Pásztor, Z. Bakacsi, J. Szabó*

pasztor@rissac.hu

*Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, Department of Environmental Informatics,*
*Herman Ottó út 15, H-1022 Budapest, Hungary*

Realistic estimation of national carbon stocks should be based on timely reliable and spatially detailed mapping of the distribution of soil organic matter. The Hungarian Soil Information and Monitoring System (SIMS) is a national monitoring system, with about 1,200 observation sites. Thematically very wide range of soil characteristics are covered by SIMS thus providing a unique opportunity for detailed monitoring of the state of Hungarian soils and follow up of major trends in their conditions. Nevertheless SIMS locations were definitely not selected to be spatially representative, the sampling was not designed for spatial inference of spatial information collected at SIMS points. As a consequence SIMS provides vast, suitable information on temporal changes in soil conditions while spatial features of this information are rather unsatisfactory. To provide reliable spatial inventories on the state of national soil resources, SIMS based information should be regionalized by adequate spatial inference of the collected data which can be supported by spatially more detailed soil information. This process requires the existence of an adequate national spatial soil information system with appropriate data structure and spatial resolution as well as a proper methodology for the integration of the different type of datasets. Digital Kreybig Soil Information System (DKSIS) represents a suitable candidate being the most detailed nationwide spatial dataset which covers the whole area of the country. In our paper we present how the two dataset were integrated for the spatial inference of recent SOM related data collected in the frame of SIMS which then were used for the mapping and calculation of carbon stock in Hungary.

Topic: Pedometrical methods for soil assessment

# Mapping soils using pedometrics methods in erosion-threatened region of Rišňovce (Slovakia)

*J. Balkovič, V. Hutár, J. Sobocká, Z. Rampašeková*

*j.sobocka@vupop.sk*

*Soil Science and Conservation Research Institute Bratislava,*
*Gagarinova 10, 827 13 Bratislava, Slovakia*

The paper introduces steps of spatial soil and terrain data acquisition, coding and processing to assess soil cover and related erosion processes in a large scale study (Rišňovce, Slovakia). We implement pedometric methods, including multivariate analysis, continual classification and geostatistical mapping. In total, 112 soil profiles were sampled in the study area with a total cover of 38 ha, and basic morphological and physical properties were described and encoded for all the profiles. Fuzzy k-means method was used as a classification tool to partition soil profiles into typologically meaningful units (Phaeozems, Luvisols and Regosols), and its membership values were analysed with respect to the terrain data. The terrain data are based on the detailed Digital Elevation Model (DEM), which was interpolated from field measurements taken by the Global Navigation Satellite System (GNSS) equipment operating in the high accuracy mode (Real Time Kinematics, RTK) using SKPOS service (Slovak permanent service for the exploitation of GNSS). The regression-kriging model was deployed to create membership value maps of soil typological units, which were evaluated with respect to erosion processes. Continuous soil classification and grid-based mapping represent an efficient pedometric tool to assess soil cover and erosion processes in the study area.

# Soil staining and concentration quantification using fluorescent dyes: main tracer considerations

*K.M. Gerke, R.C. Sidle, G.N. Fedotov*

cheshik@yahoo.com

*Laboratory of Geomechanics and Fluidodynamics, Leninskiy prosp. 38/1, Moscow, Russia*

To visualize water fluxes or leaching of chemicals, both usually influenced by preferential flow, staining techniques are usually used by applying staining substance solution to the soils by sprinkling. Recently, concentrations of this dye in the natural soil profile have been evaluated to elucidate subsurface flux, in addition to the more traditional assessment of stained and unstained portions of soil profiles. Compared to common dyes (e.g., the most popular staining agent Brilliant Blue FCF), fluorescent substances have some remarkable advantages: (1) they are visible in soils of different colors, including very dark soils; (2) two or more fluorescent dyes with separated excitation and emission wavelengths can be used simultaneously; and (3) they permit examination of the soil profile for any wavelength different from excitation range of the staining dye employed. Different fluorescent dyes were used as staining substances, including pyranine, rhodamines, sulforhodmine B, brilliant sulfaflavine, oxazine 170, uranine. However, no criterion for using these tracers was established and no comparison of dyes properties, significant for soil staining was reported. Here we study different properties of fluorescent dyes considering their usability as staining tracers for vadose zone and develop criteria to evaluate any potential fluorescent substance. Main properties to consider were found to be: molar absorption coefficient, photodecomposition rate and concentrations applied. We also show that fluorescent dye uranine satisfies these criteria best among already mentioned dyes and give simple yet powerful methodology to quantify this dye in soil profiles using UV light and digital camera. We also reveal the mechanism of sorption and fluorescence quenching that seems to be aroused by interaction with organics. Finally, we point out that discarding usual practice to excite fluorescence on its excitation maximum can be extremely useful: to decrease molar absorption coefficient, or to adjust other fluorescent properties of the dye or reflection properties of the soil profile.

# Using high resolution LIDAR information and regression-kriging for improved spatial prediction of soil bulk density in floodplains in Luxembourg

*U. Leopold and Ch. Hissler*

ulrich.leopold@tudor.lu

*Resource Centre for Environmental Technologies, Public Research Centre Henri Tudor, 66 rue de Luxembourg, L-4221 Esch-sur-Alzette, Luxembourg*

Bulk density is a key parameter for the determination and prediction of a wide range of soil functions. To assess the impact of soil management practices on soil properties which affect water retention and nutrient storage in soil and soil biological activity often requires information on the spatial distribution of soil bulk density. However, it is rarely determined routinely due to the time consuming and the expensive way of its field sampling. Studying the relationship with other soil parameters, such as organic matter and texture, pedo-transfer functions have been developed to predict the spatial distribution of soil bulk density. Recent studies propose more innovative, non-destructive techniques, such as gamma ray computer tomography. Nevertheless, these methods still remain expensive and are not always available. The objective of this study is to determine the usability of high resolution slope information derived from a LIDAR based DEM for spatial prediction of soil bulk density in alluvial areas (floodplains) with small inclination in Luxembourg. In floodplain areas, the soil bulk density can be related to the geomorphological parameter slope, which determines the spatial distribution of the organic matter in the floodplain area. High resolution LIDAR data can improve bulk density maps where no or only sparse soil information is available and where sampling errors will be large. In order to test the efficiency of the LIDAR's predictive potential we compare with three approaches using 100 sampling locations as input data: 1) the standard pedological approach by computing the average value per soil unit from available sampling points, 2) an ordinary block-kriging approach, and 3) a regression-block kriging approach using slope and SOM as additional information. To account for sampling errors we incorporate the sampling error into the spatial prediction. The different approaches are compared to a subset of independent sampling locations determined via a stratified random sampling scheme to assess the prediction error.

# Proposal of a stepwise method to harmonize legacy soil data

*I. Sisák and T. Pőcze*

talajtan@georgikon.hu

*Deák F. st. 16., H-8360 Keszthely, Hungary*

The objective of our study was to harmionize legacy soil data and covariates on the watershed of Lake Balaton to provide better assessment of phosphorus load. The texture of the surface soil layer was evaluated in this study. Point data of the Kreybig and Géczy soil maps were digitized for a 266 $km^2$ study area at Keszthely and agrochemical data and land evaluation data have been recorded for the same area. The input data were diverse in time (1940-1990) and content (field texture assessment, liquid limit like soil physical property, capillary rise in 20 hours). We have developed a stepwise methodology of harmonization. First, we have standardized the data and used simple statistics to clean the original dataset from erroneous observations. Then, we applied ordinary kriging for the four individual datasets to obtain continuous estimates. In the next phase, we have sampled the estimated four surfaces at random locations with a point density of ten hectars per point and performed principal component analysis to extract the the essence of the four maps. The first principal component (PC1) expressed 47 % of the total variance. We used PC1 equation at the observed 525 points of the combined data set to generate best estimate of textuere while the real value of the observed variable and estimates of the other three variables were considered. Slope categories, hypsometry categories, geological classes and most of their interactions were significant predictors of the soil texture at the 525 observed point. The significant effects were subtracted from the observations and ordinary kriging was applied for the residuals. The sum of the fixed effects from classification and the spatially autocorrelated results from kriging gave the final spatial assessment which was recalculated to the liquid limit like textural property and it was validated against independent samples with satisfying agreement.

Topic: Signal processing of remote and proximal sensing applied to soils

## The potentials and limitations of soil properties prediction on arable land by medium resolution imaging spectrometers

*L. Brodský, R. Kodešová, T. Zádorová, A. Klement*

brodsky@af.czu.cz

*Department of Soil Science and Soil Protection, Czech University of Life Sciences Prague; Kamycka 957, 16521 Praha 6 – Suchdol, Czech Republic*

The potentials and limitations of soil properties prediction by means of reflectance spectroscopy applied to medium resolution imaging spectrometers MERIS and MODIS were analyzed. Large mapping area is the main potential benefit.

In a laboratory study the influence of number of bands for prediction model accuracy was initially elaborated. Soil organic matter (SOM) and pH measured at 82 locations in the Czech Republic were used. Spectra were collected by FieldSpec-3 (350–2500 nm). Cross validation statistics of partial-least-squares-regression was evaluated as number of bands decreased from 2151 to 11. The bands in the subsets were selected evenly. The models coefficient of determination decreased by approximately power function. The best prediction result was $R^2$ = 0.75 and 0.61 for pH and SOM, while the minimum $R^2$ = 0.52 and 0.39 for 11 bands was achieved. This proves that there is considerable information in the spectra continuum. The $R^2$ of 0.6 was achieved for about 50 bands for pH, while of 0.5 for SOM was achieved for 100 bands.

The spectra were further degraded to MERIS and MERIS-MODIS spectral characteristics. The inference model showed, however, lower $R^2$ values. Simulated MERIS 14 bands resulted in $R^2$ = 0.41 and combined MERIS-MODIS 21 bands showed $R^2$ = 0.38 for pH, while for SOM $R^2$ was below 0.3. The decrease in $R^2$ relates to MERIS band wavelength. Further on, 231 soil samples and respective MERIS acquired spectra were analysed with resulting low $R^2$ values. Effects of spectral but also spatial resolution and land use plays probably role in the analysis.

SOM significantly influences the general brightness of spectral continuum. The MERIS-MODIS data can potentially provide approximation of the continuum. There can be identified about four general soil spectral curves in the overall library. The potential of general spectra reconstruction by continuum approximation needs investigations.

# Correlation between spectral features and heavy metal contents in contaminated soils

*Aleš Klement, Šárka Dlouhá, Lukáš Brodský, Luboš Borůvka*

klement@af.czu.cz

*Department of Soil Science and Soil Protection, Czech University of Life Sciences Prague; Kamycka 957, 16521 Praha 6 – Suchdol, Czech Republic*

Visible and near-infrared (VNIR) diffuse reflectance spectroscopy is a progressive emerging method used for prediction of soil properties. It is a relatively accurate and less expensive alternative compared to the traditional soil survey.

This study analyzed the relationship between soil reflectance properties and the content of Cd, Cu, Pb, and Zn on 44 soil samples from the heavily polluted alluvium of the Litavka river in the Czech Republic. The soils in this region were contaminated with heavy metals after several breakdowns of flotation settling ponds with deposited ashes of a lead ore smelter, and from subsequent discharge of polluted wastewater and mud to the Litavka river. Another source of anthropogenic contamination in this area is the atmospheric emission of lead-smelting plants. Prevailing soils in the area are Fluvisols and Gleys. Heavy metal contents were determined after extraction with cold 2M nitric acid. Basic soil characteristics (pH, SOC) were determined using common methods. Laboratory soil reflectance spectra in the range of 350 to 2 500 nanometres were measured in the laboratory on dry solid soil samples with spectrometer FieldSpec® 3.

For the description of the relationship between spectrum and soil properties, step-wise multiple regression, principal component regression (PCR), partial least squares regression (PLSR), regression trees, and artificial neural network (ANN) were used in addition to conventional methods.

The results showed that the success of prediction of soil properties depended largely on the statistical method. In most cases, the PLSR method performed pretty well. Nevertheless, the correlations of soil spectral features with heavy metal contents were generally much weaker than the correlation with SOC and pH.

# Development and validation of spectral indices for mapping physical and chemical properties of soil: a multi-temporal and spatial approach.

*J.D. Sylvain[1], A.R. Michaud[2], G.B. Bénié[3]*

*jeandaniel.sylvain@gmail.com*

*[1] Sherbrooke University*

*[2] IRDA (Institut de recherche et de développement en agroenvironnement),*
*2700, rue Einstein, Québec, (Québec), G1P 3W8, Canada*

The aim of this study was to evaluate the quantitative relationships between reflectance and soil properties in order to produce maps supporting the diagnosis and intervention in agricultural land as part of management activities and amendments soil in a Quebec watershed.

To do this, the existing relationships between soil properties and radiometric signal were studied à three scales of observation; laboratory, field and catchment scale. At the laboratory, radiometric measurements were taken on 119 undisturbed soil cores during a drying process with a high resolution field spectroradiometer to simulate spectral bands of the Landsat-TM7 satellite. These reflectance were then correlated with analytical data in order 1) to study the influence of humidity and permanent properties on soil reflectance and 2) derive new spectral indices able to quantify moisture, color, organic matter and soil texture. In the fields, radiometric measurements were acquired at two different periods on 47 of the 119 sampling sites to assess the accuracy of spectral indices. At the catchment scale, the spectral indices were applied on Landsat images and then compared with 265 morphological profiles through discriminant analysis. Discriminant functions were inverted and used to predict textures groups (A and B horizon) and drainage conditions at the watershed scale.

At Laboratory, the normalization of radiometric measurements taken in wet condition with a dry condition measurement has produce a new spectral index that exhibits a significant linear relationship with soil moisture (R2: 0.80). Results also show that green band could be used to estimate the amount of organic matter (R2: 0.89) present in soil. These relations have been validated at field scale for both soil moisture (R2: 0.81) and organic matter (R2: 0.81). Finally, prediction models derived from discriminant analysis confirm relevance of spectral indices for digital soil mapping of texture (horizon A and B) and drainage.

Topic: Soil-landscape modelling

# Spatial delineation of organic carbon-rich Colluvial soils in Chernozem regions by terrain analysis and fuzzy classification

*T. Zádorová[1], V. Penížek[1], L. Šefrna[2], M. Műhlhanselová[1], L. Borůvka[1]*

zadorova@af.czu.cz

*[1] Department of Soil Science and Soil Protection, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences in Prague, 165 21 Prague 6 – Suchdol, Czech Republic*

*[2] Department of Physical Geography and Geoecology, Faculty of Science, Charles University in Prague, Albertov 6, 128 43 Prague, Czech Republic*

Colluvial soils are considered to be the direct result of accelerated soil erosion, resulting in accumulation of humus-rich soil material in terrain depressions and base parts of slopes. The organic carbon concentration in these soils and their depth make them an important organic carbon storage. Mapping the Colluvial soils, therefore, represents an important contribution in total carbon stock estimation. A method of delineating Colluvial soils is proposed by applying a combination of high resolution digital elevation model analysis and detailed field survey. Two models based on fuzzy classification of soil units were created using different topographic derivatives as the only input parameters to predict the Colluvial soil area on a morphologically diverse study site in the Southern Moravia, Czech Republic. The model that considers only the derivatives with a strong relationship to Colluvial soil occurrence reached 71% accuracy in Colluvial area delineation, while the model combining six commonly used derivatives showed less favorable results. The main advantage of the method lies in a low demand of input soil data and its relatively high accuracy.

# Spatial scale analysis in DSM using machine learning techniques

*S. Cavazzi, R. Corstanje, T. Mayr*

*s.cavazzi@cranfield.ac.uk*

*National Soil Resources Institute, Cranfield University, Bulding.37, MK43 0AL, Cranfield, England, United Kingdom*

With a growing demand for soil data by the scientific community, practitioners and policymakers, quick and accurate DSM methods are needed to provide high quality digital soil maps. Terrain attributes are the most widely used predictors in DSM because of their primary role in soil formation and the broad availability of DEM. Covariates vary at different scales and at some scales may be more strongly correlated with soil than at others. Therefore some scales will be more powerful in prediction than others. The determination of an optimal grid size for environmental factors to use in DSM is still an unsolved issue.

The objective of this project was to empirically compare two commonly used machine learning techniques: artificial neural networks and random forest at different scales (considered as the interaction between pixel and window sizes). To study the performances of these two methods, we used three distinctive areas from the Irish landscape: drumlin belt, the central plain and the southern hill. The testing areas cover approximately 300km2 and had respectively 13, 19 and 27 associated soil series. To evaluate the effects of spatial resolution, the original 20m DEM was resampled by calculating the mean elevation value at resolutions of 30, 40, 50, 60, 80, 100, 120, 140, 170, 200, 230, 260 and 500m. To assess the scale effects, the selected methods were used to all DEMs using moving windows of 3×3, 5×5, 7×7, 9×9, 11×11, 13×13, 15×15, 17×17, 19×19, 21×21 and 51×51 cells.

The results show that artificial neural networks are more capable of discriminating between different scales. Regarding the optimum DEM resolution, the results demonstrate that the best range depended on the landscape characteristics of each study area. This was predictable because each soil series is associated and influenced by different terrain parameters.

# Enhancing digital soil mapping in southeastern Brazil: incorporating stream density and soil reflectance from multiple depths

*G.M. Vasques, J.A.M. Demattê, R.A. Viscarra Rossel, L. Ramírez–López,F.S. Terra, R.Rizzo,*

*gustavo@cnps.embrapa.br*

*Embrapa Solos. Rua Jardim Botânico, 1024, Rio de Janeiro, RJ, CEP 22460-000, Brazil*

There is need to integrate methods to enhance soil maps across large areas. This study proposes a novel and simple method to incorporate laboratory soil spectral data in the production of digital soil maps. We integrated laboratory, field and remote sensing data to derive maps of soil suborder (second highest hierarchical level) with and without additional textural information based on the Brazilian Soil Classification System. We described and classified 289 soil profiles in an area of ~13,000 ha with great soil, geologic, and topographic variation in the state of São Paulo, southeastern Brazil. Classification models using multinomial logistic regression were derived to classify soils based on diverse GIS layers (geology, topography, geomorphology, emissivity, vegetation index, and land cover) and laboratory soil visible/near-infrared reflectance at three depths (0-20, 40-60, and 80-100 cm). The maps derived by the models were compared with two maps at different scales (1:100,000 and 1:20,000) produced using conventional soil survey methods. Soil suborders with and without texture were correctly classified for 44 and 52% of the soil profiles, respectively. The derived soil suborder maps agreed with the 1:100,000 and 1:20,000 conventional maps in 20 and 23% (with texture), and 41 and 46% (without textural information) of the area, respectively. Stream density was included in all classification models and closely related to the spatial distribution of soil classes, showing great potential as a new variable for digital soil mapping. Laboratory soil reflectance also improved the classification models. In complex environments, inclusion of comprehensive terrain (i.e. stream density) and easy to measure (i.e. soil reflectance) variables can greatly advance digital soil mapping, especially in large areas with scarce soil and ancillary data.

# Soil nutrient and landscape interactions in a tropical dry forest: exploring alternatives to derive soil information in a region with limited data in Brazil

*G.M. Vasques, M.R. Coelho, R.O. Dart, R.P. Oliveira, W.G. Teixeira, M.L.M.S. Brefin,*

gustavo@cnps.embrapa.br

*Embrapa Solos. Rua Jardim Botânico, 1024, Rio de Janeiro, RJ, CEP 22460-000, Brazil*

The adoption of new pedometrical techniques for soil assessments often depends on a relatively large number of soil and ancillary environmental observations, hindering their application in areas where such data are limited. This study investigates the relationship among soil and environmental variables in the Mata Seca (Dry Forest) State Park, in Brazil, exploring alternatives to derive soil information based on an existing soil/environmental dataset. Soils in this tropical dry forest vary from those with incipient development (Entisols and Inceptisols) to deep gibbsitic soils (Oxisols). Contrary to moist forests, in dry forests the limited water supply delays plant succession and nutrient cycling, ultimately affecting soil formation, and possibly imprinting different physical, chemical and morphological signatures to these soils. Based on these premises, we aimed to characterize soil-soil and soil-landscape correlations in this unique environment, expecting to find some interesting and distinctive patterns relative to other tropical environments. Soil samples were collected (from boreholes or pits) at 272 locations along topographic and vegetation (i.e. succession) gradients. Pedotransfer functions were derived for soil nutrients (e.g. Ca, Mg, K), and were complemented by quantitative (e.g. linear), and discriminant (e.g. decision tree) models to characterize relationships among soil and landscape variables. Soil-soil and soil-landscape correlations varied depending on the variables and type of relationship (e.g. parametric vs. non-parametric) considered. Identified patterns generally corresponded to field expertise expectations, offering alternatives to derive soil information to support digital soil mapping and assessment in a data-scarce region. This study advances the understating of soils in tropical dry forests, which to this date have still received very little attention.

# Mapping the information content of visible–near infrared spectra of Australian soils

*R.A. Viscarra Rossel and C. Chen*

raphael.viscarra-rossel@csiro.au

*CSIRO Land and Water, Bruce E. Butler Laboratory, PO Box 1666, Canberra ACT 2600, Australia,*

We can use soil mapping to gain a better understanding of the soil and how it varies in the landscape. Good quality data sets that represent the survey area are important to develop quantitative spatial models for soil mapping and to evaluate their outputs. Over the past three decades, scientists have become interested in rapid, non-destructive measurements of the soil using visible–near infrared (vis–NIR) (400–2500 nm) and mid infrared (mid-IR) (2500–25,000 nm) diffuse reflectance spectra. These spectra provide an integrative technique that measures the fundamental characteristics and composition of the soil, including colour, iron oxide, clay and carbonate mineralogy, organic matter content and composition, the amount of water present and particle size. If adequately summarised and exhaustively available over large areas, this information might be useful in situations where reliable, quantitative soil information is needed, such as agricultural, environmental and ecological modelling, or for digital soil mapping. The aims of this paper are to summarise the information content of vis–NIR spectra of Australian soils and to use a predictive spatial modelling approach to digitally map this information across Australia on a 3-arc second grid (around 90 m). We measured the spectra of 4606 surface soil samples from across Australia using a vis–NIR spectrometer. The soil information content of the spectra was summarised using a principal component analysis (PCA). We used model trees to derive statistical relationships between the scores of the PCA and 31 predictors that were readily available and we thought might best represent the factors of soil formation (climate, organisms, relief, parent material, time and the soil itself). The models were validated and subsequently used to produce digital maps of the information content of the spectra, as summarised by the PCA, with estimates of prediction error at 3-arc seconds pixel resolution. The most frequently used predictors at the continental scale were factors related to climate, parent material (and time), while at landscape and more local scales, they were factors related to relief, organisms and the soil. Finally, we use our maps for pedologic interpretations of the distribution of soils in Australia. Our results might be useful in situations requiring high-resolution, quantitative soil information e.g. in agricultural, environmental and ecologic modelling and for soil mapping and classification.

Topic: 3D modelling in pedometrics

## Modeling and reconstruction of soil structure via correlation functions

*M.V. Karsanina and K.M. Gerke*

cheshik@yahoo.com

*Laboratory of Geomechanics and Fluidodynamics, Lenisnkiy prosp. 38/1, Moscow, Russia*

Soils, as any other heterogeneous materials or media, consist of different materials or phases. It is well established that microstructure of such media, as well as their transport, mechanical and other properties, can be characterized statistically only by an infinite number of n-point correlation functions. In practice calculation of a big set of n-point correlation functions for a medium sized digitized soil structure is not feasible. However, reasonably good characterization of isotropic heterogeneous materials can be achieved by using only different two-point functions. In this study we address the problem of soil structure characterization via two-point correlation functions, which is analogous to long-range multispin interaction of a spin system. For simplicity soil is considered to consist of only two materials: solid phase and pore space. Mainly, we focus on two problems: (1) how to characterize soil structure using correlation functions (which can be also easily related to other soil properties, e.g., hydraulic conductivity, water retention curve, hardness, etc.), and (2) how to construct/reconstruct soil structure based on a set of given correlation functions. To date heterogeneous materials were successfully reconstructed using multi-point statistics, Gaussian field, and simulated annealing methods. Using simulated annealing we demonstrate how soil structure can be constructed/reconstructed using two-point correlation functions and address the problem of soil structure characterization for numerous real soil structures obtained by either thin sectioning or mCT. An approach to deal with soil anisotropy is also considered.

# Using a 3D LISA statistic to identify soil structural units from electrical resistivity measurements of a soil core at different flow rates

*R. Kerry[1], P. Goovaerts[2], D. Gimenez[3], L. Slater[4], A. Binley[5]*

ruth_kerry@byu.edu

*[1] Department of Geography, Brigham Young University, 690 SWKT, Utah, 84602, U.S.A.*
*[2] Biomedware, Ann Arbor, MI., U.S.A.*
*[3] Rutgers University, New Brunswick, NJ., U.S.A.*
*[4] Rutgers University, Newark, NJ., U.S.A.*
*[5] Lancaster University, Lancaster, United Kingdom*

Electrical resistivity tomography (ERT) has been used to image the transport of solute in soil. Here we examine the usefulness of ERT for identification of hydrologically homogeneous structural units. An undisturbed soil column (0.32 m in diameter and 0.4 m long) from a forested area with 104 electrodes arranged in 8 horizontal planes was used. Water was applied to the top of the column at five flow rates of increasing magnitude. A total of 62, 208 electrical resistivity measurements in 3D were obtained for each flow rate. The resistivity data were analyzed with a modified Local Indicator of Spatial Autocorrelation (LISA). Local Moran's I is the most commonly used LISA statistic (Anselin, 1995). Positive values indicate that points belong to clusters (positive autocorrelation) whereas negative values indicate the presence of spatial outliers (negative autocorrelation). Determining whether the LISA value is significantly different from zero requires knowledge of the distribution of values under the null hypothesis of spatial randomness, which was built using Monte Carlo simulation. The False Discovery Rate (FDR) method was then used to correct for multiple testing and reduce the proportion of false positives.

The 2D LISA statistic is commonly used in medical geography but has seldom been used in soil science. Two major innovations of the proposed methodology are: 1) a multivariate LISA statistic was developed to test for clusters for all five flow rates simultaneously, and 2) the extension of the LISA statistic to 3D data. The 3D LISA method identified significant clusters of low and high values of electrical resistivity representing wet and dry regions in the soil, respectively. By identifying hydrological homogenous units, this technique could help quantify heterogeneity of soil processes at the column scale and it could potentially be extended to field applications.

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# Development of a field Vis-NIR spectroscopic method for soil carbon mapping

*P. Roudier, C. Hedley, C. Ross*

roudierp@landcareresearch.co.nz

*Landcare Research, Private Bag 11052, Palmerston North 4442, New Zealand*

Soil carbon sequestration mitigates against increasing levels of atmospheric carbon dioxide, and there is a need to develop new methods for assessing potential sequestration rates by estimation of soil carbon stocks and stock changes within the landscape taking into account spatial and temporal variability.

Our research is developing a field spectroscopic approach to soil carbon mapping. An on-the-go EM (electromagnetic) mapping system with RTK-DGPS was used to produce a map of a 90 hectare field, quantifying soil variability at high resolution (10m). This map was then used to target positions (n=100) for soil sampling and scanning. At each position we collected soil cores (0-10cm, 10-20cm, 20-30cm) and extruded them onto a liner. The side of the soil core was scanned at one centimetre intervals using an ASD FieldSpec 3 spectroradiometer. The soils were then analysed by Leco Induction Analyser for total organic carbon (0-10cm, 10-20cm, 20-30cm) and this data used to develop a calibration set for spectral processing. The spectral model is available to predict a 3D soil carbon datalayer to 30 cm, using the georeferenced spectra for each 1 cm depth increment. The spectral model will be compared with one developed using actual soil carbon analyses with ancillary datalayers [EM31, EM38 and DEM derivatives, including a wetness index] and a spline tool (Malone et al., 2009) used in the Global Soil Map project to predict soil carbon change with depth. The results of this project will be presented in this paper.

Topic: Uncertainty analysis, error propagation, accuracy assessment

# Feasibility of using Vis-NIR spectroscopy to determine soil organic carbon in subsoil

*F. Deng, M. Knadel, A. Thomsen, M.H. Greve*

fan.deng@agrsci.dk

*Dept. of Agroecology and Environment, Faculty of Agricultural Sciences, Aarhus University, Blichers Allé 20, Postboks 50, DK-8830 Tjele, Denmark*

It has been always a challenge to find an effective way to measure and monitoring soil organic carbon in the soil profiles. This paper aimed to explore the feasibility of using Vis-NIR spectroscopy to determine soil organic carbon in subsoils. All the samples were taken from a Danish soil profile library, their depth are all below 30cm, the soil samples are taken according to pedological soil horizons, the deepest sample is 240cm. Horizon destination refer to FAO standard. Reference soil organic carbon was analyzed by combustion method. All samples were scanned using the Labspec 5100 (350nm- 2500nm). Outliers were removed and the spectra were pretreated. Then principal component analysis and partial least square regression are used to build regression model between SOC and spectra, and they are all test by external validation. The performance of global calibration model for subsoil is R2 =0.71, RMSEC=0.45 (No. Of samples 1798, mean = 0.40, SOC content ranges from 0 to 9.16), for validation R2=0.76, RMSEP=0.32, RPD=1.7 (No. of samples 710, mean=0.37, SOC content range from 0 to 5.34%). Sub models where then developed major horizons. The E-horizon calibration model (mean = 0.5) with R2=0.8, for the validation RPD=1.4. The calibration model for the B horizon were R2=0.81, RMSEC=0.38(No. of samples 500, mean =0.53, SOC range from 0.06 to 6.73), while validation RMSEP=0.31, RPD=1.8(No. of samples 200, mean=0.48, SOC range from 0.06 to 5.05). The model for the C-horizon (mean = 0.26) showed a RPD =1.3.

The results shows good results for the B-horizon, but it also suggest that the SOC prediction model is not suitable for the E- and C-horizon. This is probably due to the very low TOC content. In the future we will try to build better model according to geology variation or landscape.

# Uncertainty analysis in field scale application of extended sorption isotherms

*L. Godbersen, S. Altfelder, J. Utermann, W.H.M. Duijnisveld*

levke.godbersen@bgr.de

*Federal Institute for Geosciences and Natural Resources,*
*Stilleweg 2, D-30655 Hannover, Germany*

A common method to asses the risk of groundwater contamination with trace elements is an assessment at the field scale using spatially aggregated values. The fate of trace elements in the soil- groundwater pathway is predominantly regulated by the sorption capacity of soil. Semi empirical pedotransfer functions (PTF) based on extended Freundlich equations can be applied to estimate the sorption behavior from common soil properties such as pH, Corg or cation exchange capacity. Such PTF have been derived by regression analysis on a national scale for soils used as arable or grass land (Utermann et al. 2005) and forest (Heidkamp 2005). Altfelder et al. (2006) splitted the residual variance between modeled and measured point scale trace element concentrations sorbed to the soil into on-site and between-site variance and approximated a ratio of 70% to 30%. Possible sources of variance are the model error, the uncertainty variability of soil properties and uncertainty resulting from analytical errors. The latter two can be summarized as input error. We focus on the effect of field scale uncertainty and field scale variability in sorption relevant soil properties and trace element concentrations on the results of three case studies with typical soil properties and land use for the Northern German lowlands. The uncertainty will be quantified as the bootstrap percentile confidence intervals of input variables. By first applying the PTF on a point support and subsequently aggregating the model output it shall be possible to differentiate input field uncertainty from input field variability. The model error will be estimated by examining the relation between measured and modeled field scale trace element concentration. We hypothesize, given the PTF is valid, that spatial variability of soil properties at the field scale will be the predominant source of prediction error.

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# What scale is my digital soil map? Scale and uncertainty in digital soil mapping

*M.A. Nelson, T.F.A. Bishop, I.O.A. Odeh*

michael.nelson@sydney.edu.au

*Faculty of Agriculture, Food and Natural Resources, The University of Sydney, Australian Technology Park, Eveleigh NSW 2015, Australia*

Digital soil mapping (DSM) is gathering momentum across the globe, driven by a need for soil information and made possible by the increasingly widespread availability of spatial data that can be used to represent Jenny's soil forming factors.

Much of the focus is on the predicted values of soil properties but it is equally important to quantify associated prediction errors.

Errors are introduced at every stage in the DSM process. These errors combine and propagate so that the final predictions and maps have errors associated with them. Given the errors in the final predictions, the end user of the digital soil map will be uncertain about the predictions, with this uncertainty quantified by the associated errors.

As digital soil maps are intended for use by policy-makers or other scientists it is important to provide estimates of the errors in the predictions. This quantification of the uncertainty can also be used by the digital soil map makers to consider where and how to improve future digital soil maps of an area.

Predictions are made at points or blocks or volumes of land, in the landscape. The scale, (or support) of a digital soil map refers to the dimensions of these blocks or volumes.

This research considers how errors introduced through the DSM process affect the scale at which predictions can be made with 'reasonable' levels of accuracy. We present a case study mapping soil organic carbon in the lower Namoi Valley, NSW Australia using a model-based geostatistics approach. We consider how positional, analytical, covariate and model errors combine to affect the accuracy of soil maps produced at various scales and discuss the potential ramifications of the findings.

# Evaluation of the relationship between infrared channel satellite imagery and organic matter content considering the positioning accuracy (case study)

*V.P. Samsonova, J.L. Meshalkina, Y.N. Blagoveshchensky*

jlmesh@list.ru

*The Soil Science Faculty of Lomonosov Moscow State University,*
*Leninskye Gory, GSP-1, h.1, bld.12, Moscow, 119992, Russia*

The aim of the study was to explore the relationship between organic matter content and the infrared channel of satellite image with the 2-m resolution, as well as to estimate the impact of sampling positioning accuracy.

The research was focused on the terrain of Bryansk Opolje, where the soil units change occurs at distances from 100 to 10 m. Soil samples were collected on the area of 8 ha at the depth 0-20 cm within 2 years (40 and 78 samples respectively).

The positioning error of the GPS Garmin receiver averaged 5m.

The QuickBird satellite 2 m resolution multispectral image was used. Soil surface was without vegetation at the time of survey.

Two types of modeling were carried out: a simultaneous displacement of the image on 1 - 6 pixels and a random shift of a particular point to 1-3 pixels in any direction (5000 results).

The correlation coefficient between organic matter content and the infrared channel is -0.42 and it is not dependent on the year of sampling. The correlation coefficients range from -0.377 to -0.601 in case of the simultaneous displacement of all pixels. The areas with an abrupt change of the spectral characteristics are strongly influenced the correlation coefficients. They corresponded to eroded soils.

The lower boundary of the correlation coefficients distribution in case of a random shift simulation is equal to -0.147 (the significance level 0.05), the median value is -0.332. Maximum equals to -0.567.

Thus, using the GPS navigators with a given accuracy, apparently, it is impossible to obtain the correlation coefficients above 0.60 for the relationship between organic matter content and the infrared channel of satellite image with the 2-m resolution.

Topic: Key applications of pedometrics

## Progress in global mapping of organic soil carbon — report from an expert workshop

*M. Köchy and A. Freibauer*

martin.koechy@vti.bund.de

*Johann Heinrich von Thünen-Institut, Institute for Agricultural Climate Research, Bundesallee 50, 38116 Braunschweig, Germany*

The EU project COCOS will convene about 20 experts in soil mapping to discuss ways to advance the global mapping of soil carbon stocks, especially in regions with high C stocks in July 2011. Topics include (1) harmonization of current methods, (2) ways for validation, (3) estimation of measurement uncertainties, (4) estimation of map accuracy, (5) remote sensing approaches, (6) recommendations for national soil survey, (7) approaches to include probability distributions of soil characteristics, (8) modelling approaches and data assimilation, (9) vulnerability assessments, (10) soil profile information not included in world data centres. In our presentation we give an overview of the discussions.

Topic: Linkages with other IUSS groups

## Concept-based correlation of the WRB and the Hungarian soil classification using taxonomic distance calculations

*I. Waltner, V. Láng, M. Fuchs, T. Szegi, E. Michéli*

waltner.istvan@mkk.szie.hu

*Szent István Egyetem - Talajtan és Agrokémia Tanszék,*
*Páter Károly u. 1., 2103 – Gödöllő, Hungary*

As a consequence of recent global and European initiatives, there is an increasing need for digital soil information. In many cases, this can result in the use of datasets with different soil classification systems, which presents the problem of harmonizing or correlating those datasets and classifications. Since 1998, the World Reference Base for Soil Resources (WRB) is the endorsed international correlation scheme for soil classification.

Previous studies shown that taxonomic distance calculations can be useful for exploring and testing the concepts within a soil classification system, and for finding correlation between taxonomic units from different systems.

The present study aims to make a comparison between the WRB and the Hungarian Soil Classification System (HSCS) in order to help further correlation and harmonization.

Diagnostic horizons, properties and materials were selected according to dominant identifiers recognized within the WRB. They were then cross-checked with concepts represented in the HSCS, resulting in a table displaying the possible occurrence of each horizon/property/material within each of the HSCS soil types and the WRB Reference Soil Groups. Based on these tables, taxonomic distances were calculated within the two systems, and also in between the groups represented in the two.

The results show that the method is promising, but also indicate the need for calculations on actual, harmonized soil data.

# List of authors