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Evaluating Use of Ground Penetrating Radar and Geostatistic Methods for Mapping Soil Cemented Horizon

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Depth to a root restricting (cemented) layer affects both soil moisture and nutrient availability. The knowledge of the variability of cemented layers within the soil profiles provides valuable information to decision-makers for agricultural activities. Soil surveys generally are time consuming, labor-intensive and costly, whereas geophysical and geostatistical methods offer a rapid, inexpensive and non-invasive approach to mapping soil characteristics. The ground penetrating radar (GPR) is a geophysical tool that is a high-resolution electromagnetic technique used for many applications, including assessment of groundwater resources, mineral exploration, archaeological, and environmental and agricultural studies. The agricultural applications may include such things as determining limited soil depth restricted by bedrock; hardpan and cemented horizon, water table depth, soil moisture content, and mapping shallow underground soil features affecting agricultural production. GPR combined with the geostatistical method could be an efficient and valid approach to provide large-scale measurements with fine-resolution data of substrate distribution. The objectives of this study are to use GPR data and to explore the capability of geostatistical methods to incorporate these auxiliary variables for mapping cemented horizon in an arid region, Kerman province located in south-eastern Iran. The measurements were performed using an impulse GPR system with a center frequency of 250 MHz along ten parallel transects of 100 m length and 10 m distance between two consecutive transects. The processing of GPR data was performed with ReflexW7.0 Software. The GPR data were interpolated with geostatistical analyses were done by using the software package ISATIS. The results of the field observations on the pedons at study site showed the cemented horizon at a depth of 35-45 cm. The GPR radargram also showed a distinct interface between the two contrasting materials which usually corresponded to the occurrence of a strong reflection event. The strong reflection corresponded approximately to the top of cemented horizon. In addition the 3D soil model of GPR amplitudes signal by kriging method reproduces the quite variable depth of the cemented horizon and the extent of its lateral and vertical variation. In this study, the potential of geophysical and geostatistical to predict and mapping a cemented horizon was evaluated in an arid region. The variation of cemented horizon provided valuable information that is crucial in decision making for agricultural and engineering activities. The main advantages of GPR and geostatistical methods are the speed of obtaining data and continuous images, and rather good possibility to identify zones with markedly different properties.

keywords: *Cemented horizon, Geostatistic, Ground penetrating radar*

Digital soil mapping in areas of mussunungas: algoritmos comparission

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Mussunungas is an ecosystem of physiognomic forms ranging from grasslands to woodlands. It occurs over Spodosols originated from sandstones of the Barreiras Group from the Tertiary period, and is situated across the Atlantic Rainforest domain of southern Bahia and northern Espirito Santo States in Brazil. Areas of Mussunungas are particularly important for water infiltration dynamics and is under threat as its vegetation is not recognized as belonging to the Atlantic Rainforest Biome. This study aims at comparing classification algorithms to produce soil class maps of an area where Mussunungas occurs. The study area is the conservation unity, RPPN Rio do Brazil, located in Porto Seguro, Bahia, with an area of 1100 ha. A digital elevation model derived from an ALOS-PALSAR image of 12.5m spatial resolution was used to derive morphometric maps, to be used together with covariates such as geomorphology, euclidean distance between the points soil points and indexes derived from Landsat-8 images, CBERS-4, and Sentinel-1 imagery. A soil survey was carried out using a mixed-sample scheme combining data from a free-survey with data from regular grid. A total of 203 soil points were described collecting samples for chemical and physical analyses. R software was used for the classification using the "caret" package. Three classifiers were tested: Extreme Gradient Boosting (xgbTree), C5.0, and Random Forest, with 10-fold cross-validation. From the six soil classes identified in the area, Haplic Lixisol are dominant, and as this occurs with inclusion of Dystric Cambisols, they were mapped together. Dystric Gleysols occurs associated to Fibric Histosols and was joined in the same map unity. Stagnic Podzols and Xanthic Ferralsols were thus each mapped as a single class. The xgbTree showed better Kappa (0.68), followed by C5.0 and Random Forest with 0.65 and 0.63, respectively. The similar performance of the classifiers showed no statistical difference. Larger confusion occurred between Xanthic Ferralsol and Haplic Lixisol. The user's accuracy of Podzols was good, varying from 81 to 83% amongst classifiers. The morphometric covariates, elevation above sea, slope height and normalized height showed the highest importance for soil prediction. A field validation of the maps and visual interpretation of the maps overlayed with satellite images showed that the areas were well delineated, proving a good performance of all classifiers for produce a soil class map for the area of this study. We concluded that techniques of digital soil mapping can be used for mapping areas of mussunungas over Podzols.

keywords: *covariates, data mining, classification, Mussununga, Soil mapping*

Sensing of farm and district-scale soil moisture content using a mobile cosmic ray probe (COSMOS Rover)

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In dryland cropping systems a grower only needs to know soil moisture at a few times during the year when a management decision needs to be made, for example at the start of the season when determining sowing and fertilizer rates. The information needs to be at the resolution of an agricultural field (or finer) and for the whole profile. Cosmic ray probes are a technology that can directly measure soil moisture at these resolutions, namely the horizontal footprint is a 150m radius and the depth of measurement is up to 0.7m. There is a now a mobile cosmic ray probe platform (COSMOS Rover) which could be used to provide a farm or district scale soil moisture map at key times in the year for growers. However, there are a number of methodological issues which need to be considered which we present in this work.

The first is a calibration issue which requires field measurements of soil moisture, soil carbon and soil lattice water content. These are prohibitively expensive for real-world applications and in this work, we compare the accuracy of the calibration between a detailed field survey as compared to using readily available data such as existing soil moisture probes and existing soil maps.

The second issue is how to interpolate the soil moisture measurements while accounting for the spatial support of measurements, and also variations in land use and other controllers of soil moisture within the measurement footprint. The measurement interval is 30 seconds so the horizontal support is 150m either side of the vehicle pathway over the travel distance of the vehicle in 30 seconds. For interpolation, we adopt an area-to-point kriging framework to account for the varying spatial support in addition to incorporating dense covariates (land use, geology) to improve our spatial predictions.

The approach is illustrated with a case study in Muttama creek catchment in eastern Australia where the dominant land uses are grazing and cropping.

keywords: *Soil Moisture, COSMOS Rover, dryland cropping systems, calibration, spatial predictions*

Proximal sensing of soil crack networks using three-dimensional electrical resistivity tomography

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Soil cracks function as primary conduits for water transport in expansive clay soils. Understanding and predicting the impact of crack networks on the hydrology of such soils is difficult due in large part to the transient nature of crack networks. The size, position, and interconnectedness of soils crack networks changes with seasonal wetting and drying cycles. Currently, there are limited tools for monitoring soil crack networks. In order to understand the impact of soil cracks on hydrology, new tools are needed that can monitor the spatial-temporal dynamics of soil crack networks. In this study we demonstrate the feasibility of electrical resistivity tomography (ERT) as a non-invasive tool for proximal sensing of soil crack networks monitoring. Three-dimensional ERT surveys were collected on a smectitic soil during a seasonal drying cycle. At the end of the drying cycle, soil cracks were measured directly by in-filling cracks with cement and photographing cross-sections of the in-filled soil. Photographic data shows a good correlation with the ERT images, demonstrating the utility of ERT as a tool for spatial-temporal monitoring of soil crack networks.

keywords: *proximal sensing, soil cracks, electrical resistivity tomography, ERT*

Using digital microscopy for rapid determination of soil texture and prediction of soil organic matter

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Soil particle size analysis is an expensive analytical procedure. There are two primary methods accepted by certified soil analysis labs: hydrometer-based sedimentation and laser-based optical techniques. The first method requires substantial labour, while the second is conducted using costly equipment. This presentation describes a new system that is based on a commercially available digital microscope equipped with an array of light emitting diodes. It is deployed using a scratch resistant window in contact with measured soil. It takes just a few seconds to obtain a high quality image of dry, grounded and sieved soil that is typically used for conventional soil chemical tests. Our software uses an adopted wavelet decomposition technique to measure the percentage of particles within specified size intervals (e.g., sand, silt, and clay). Given that the level of magnification is known and the image resolution is around 2 micrometers, the instruments separate soil particles into their respected size category: clay - below 2 micrometers, sand - above 50 micrometers, and silt between clay and sand. The unique feature of this approach is that there is no need for sensor calibration and the results are expected to be comparable with those of conventional analytical soil laboratories. Based on our research, standard measurement errors range between 30 and 60 g per kg of soil, which is comparable to the observed dispersion among results obtained from different commercial soil labs. Furthermore, in addition to the image texture information component, image color was found to be suitable to predict soil organic matter content, which is another essential soil property when it comes to optimized management of soil resources. It was determined that, with proper calibration, soil organic matter content in mineral soil can be predicted with the standard error of measurements around 5-7 g per kg of soil. Based on these observations, we believe that the instrument developed can be used as an alternative to traditional soil particle size distribution techniques at a much lower cost and can preserve, or provide better measurement accuracy. Prediction of soil organic matter and in situ deployment of the instrument are additional options that could be pursued in certain environments.

keywords: *Proximal soil sensing, machine vision, microscope, soil texture, soil organic matter*

Analysis of complementarities of different spectral analytics to sense soil properties

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To date, the cost of soil sampling and analysis constitutes the greatest limitation for adjusting site-specific management of agricultural inputs according to local needs. New methods, with minimum distortion of proximal soil sensing, are being considered to replace the laborious and expensive wet chemistry analytical techniques. Spectra-based techniques, including visible, near-infrared, and mid-infrared spectroscopy, laser-induced break down spectroscopy (LIBS), as well as machine vision are among the most favoured. Individually each of these methods has provided positive results when attempting to predict specific physical and chemical soil properties. The goal of this presentation is to discuss the complementarities of these methods in order to optimize instrumentation and analytics for use in streamlining the analysis of solid soil samples. All of the measurements were performed using 35 compressed air dried soil samples and assessed in terms of measurement reproducibility and the accuracy of prediction. The results of leave-one-out cross validation of locally established prediction models were ranked among each combination of agronomic soil properties and measurement techniques as well as their combinations.

keywords: *proximal soil sensing, soil spectrometry, LIBS, NIR, MIR*

Long-term diachronic series for soil carbon saturation evidence. A case study on volcanic soils of reunion island under sugarcane crops.

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The goal of the international '4 per mille' initiative is to demonstrate that agricultural soils can play a crucial role for food security and climate change, and particularly in tropical areas where knowledge on soil carbon potential sequestration is still needed. The study is located at Reunion, a young tropical volcanic island in the Indian Ocean, 700km east of Madagascar, that presents a range of tropical soils comprising almost half of the 30 types recorded worldwide. Our work is focused on the drivers of soil organic carbon (SOC) content dynamics in the different types of volcanic soils under long-term sugarcane crops (more than 60% of the agricultural area). For doing so, a huge database on soil constituents has been mobilized. It was built over the last 20 years and represents more than 20 000 soil samples predominantly originated from sugarcane plots. Long-term diachronic series on SOC contents should be extracted from the database. Geolocated data combined with GIS tools allowed us to create a SOC map of Reunion and data mining tools, such as BRT, have been used to prioritize the drivers of SOC contents and evaluate the storage capacities of these young volcanic soils. In the conditions of the study, soil type was the main driver of SOC content, ahead of climate conditions and agricultural practices. Ferralsols, on the west and north coast, exhibit the lowest SOC content whereas Andisols, at higher altitudes, show the highest SOC contents for the 0-30cm layer. Long-term diachronic series showed almost constant SOC contents under sugarcane crops on the whole range of soils over time. Sugarcane cropping system produce high organic carbon inputs (residues and roots, 1.2 Mg C $ha^{-1}y^{-1}$) and agricultural practices in Reunion (mulching, one tillage every ten years on average) would maintain high SOC contents. All those considerations will suggest that soil carbon saturation is reached under sugarcane crops for all soil types. And hence, no more SOC storage is possible, but any land use change could decrease the soil organic carbon already stored in these soils. Soil carbon saturation rate, showed by long-term diachronic series, is therefore a better indicator than SOC content to develop soil carbon potential storage scenarios.

keywords: *Soil organic carbon, tropical volcanic soils, long-term diachronic series, sugarcane, soil analyses database, data mining*

Concept of entropy in spatial distribution of vegetation in satellite images

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The study of the dynamics of the vegetation cover is one of the most important applications of the observation of the Earth from the space and it is related to root zone soil moisture. Numerous studies have addressed the analysis of vegetation at different scales, spatial and temporal focusing on two aspects: the radiometric characterization of different types of vegetation and the spatial distribution of vegetation. The later is the result of a complex interaction between vegetation and certain environmental factors such as climate, animals and man activity. A previous step to understand the complex dynamics of the ecosystems is to be able to characterize the spatial patterns of this distribution in which soil play a major role.

In the present work we discuss the spatial distribution of vegetation based on entropy concept. However, ther are different expressions related to it: entropy dimension, relative entropy, configuration entropy and configurational entropy per cell. Each one of them presents differences and complementary information.

In order to establish these comparisons, a multispectral image acquired on 8 August 2000 by the Ikonos satellite was selected. This satellite, in orbit from September 24-1999 at a height of 681 km, is capable of providing panchromatic images with a spatial resolution of the order of 1 m, and multispectral images, with 4 bands covering the visible region and the near infrared of the electromagnetic spectrum, with a spatial resolution of the order of 4 m. Both with a radiometric resolution of 2048 levels of gray (11 bits).

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keywords: *entropy dimension, relative entropy, configuration entropy, configurational entropy per cell, soil moisture*

Digital Soil Mapping Method Based on the Similarity of Environmental Covariates in the Spatial Neighborhood

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It is a prevailing way to use soil samples to build soil-environment relationships and then to predict the soil properties of the study area. An assumption widely used for building soil-environment relationship is that those locations with similar environmental conditions have similar soils. Based on this assumption, the soil property at each unvisited location can be predicted according to its environmental similarity to each individual soil sample, which is often computed based on environmental covariate values just on this locations and soil sample locations. The spatial neighborhood information is ignored in this way, although the soil at each location is also affected by the environmental condition of its surrounding area. With the assumption that the more similar the environmental conditions in the spatial neighborhood between two locations the more similar the soils are, a digital soil mapping method based on the spatial neighborhood similarity of environmental covariates was proposed in this research. The proposed method identifies the characteristic neighborhood size of each environmental covariate for each unvisited location and each soil sample and then calculate the spatial neighborhood similarity on individual environmental covariate between the unvisited location and each soil sample. The similarity on environmental condition between the unvisited location and each soil sample is computed by integrating the spatial neighborhood similarities on individual environmental covariates. The soil property value on each unvisited location is estimated to be the average of soil property values of soil samples weighted by the corresponding similarities on environmental condition. The prediction uncertainty is also provided. As a case study, the proposed method was applied to mapping soil organic matter (SOM) content (%) in the topsoil for an area (about 60 km^2) in Heilongjiang province, China. The evaluation results with an independent soil sample set showed that the proposed method got higher accuracy due to its consideration of the spatial neighborhood information during computing the similarity of environmental condition.

keywords: *digital soil mapping, soil-environment relationship, similarity, spatial neighborhood, soil organic matter*

Multivariate and multi-layer soil mapping using structural equation modelling

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Soil properties interrelationships are rarely included in digital soil mapping (DSM) because most DSM models take a univariate approach and map soil properties individually. In some cases multivariate approaches have been used to incorporate correlations between soil properties. Cokriging is a well-known example of such multivariate approach. A more recent approach is structural equation modelling (SEM), which has the advantage that it can incorporate pedologically-driven system interrelationships. We explored the use of SEM as a multivariate technique for DSM in a 23 000 km^2 study area in the Argentinian Pampas. The modelling process of SEM is driven by a conceptual model, which is translated to a mathematical model that is calibrated with empirical data. Since soil processes operate along the soil profile, SEM may be suitable for multiple layer soil prediction. Hence, theoretical relationships between soil properties at different horizons can be included and used for prediction. The objectives of this study were: (1) to apply SEM for multilayer and multivariate soil mapping; (2) test SEM functionality for model improvement through model suggestions; and (3) assess whether the modelled covariation among soil properties matches the covariation observed in the data. We applied SEM to simultaneously model and predict the lateral distribution of the cation exchange capacity (CEC), organic carbon (OC) and clay content of three major soil horizons, A, B and C. We used petrological relationships between these soil properties to build a conceptual model. Next, we derived a mathematical model and calibrated it using environmental covariates and soil data from 320 soil profiles. Environmental covariates included digital elevation model derivatives, MODIS products and distance to river as a proxy of parent material distribution. Cross-validation of predicted soil properties showed that the highest amount of variance explained statistics were achieved for OC (24%) and for clay (60%) of the A horizon and CEC (50%) of the B horizon. We also assessed the covariation of soil properties and demonstrated that SEM reproduces the system error variance-covariance more accurately than multiple linear regression, which is generally applied in DSM. Accurate modelling of the covariation is important for stochastic simulation, such as required for uncertainty propagation analyses. We conclude that SEM can be used to predict several soil properties at multiple layers and, at the same time, provide graphical information of the relationships among system variables.

keywords: *structural equation modelling, mechanistic models, soil property interrelationships, covariation assessment, conceptual models*

Incorporating infrared spectroscopic data, land management, soil drainage and soil erosion observations into Bayesian framework for modelling soil erosion risk

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We have developed a framework for a Bayesian Belief Network (BBN) to model soil erosion. A BBN is a graphical probabilistic model which allows for the integration of different types of data from various sources as well as incorporating expert knowledge where data are lacking and explicitly accounting for uncertainty. We are currently developing the model to integrate observations of erosion, land management and soil spectroscopy. This work builds on an inherent erosion risk assessment based on soil drainage, topography and, as in many erosion risk assessments, where erodibility is defined as a function of topsoil texture (Lilly et al., 2002). A key aspect to this work is to improve the representation of soil erodibility in the model. To do this firstly we are exploring relationships between measured soil aggregate stability, land management and soil properties. Concurrently we are using infrared (IR) spectroscopy to provide additional information on the overall soil physical and chemical composition, in particular, the composition of clays and organic matter which influence erodibility. Ultimately, we aim to develop a robust and rapid method to predict those soil characteristics which define erodibility in-field using FTIR spectroscopy as a means to monitor soil quality.

keywords: *Soil erosion, Bayesian Belief Network, Infrared spectroscopy*

Comparing airborne and terrestrial laser scanning DTMs for high resolution topsoil pH modelling

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Terrestrial Laser Scanning (TLS) is increasingly used to create very high resolution digital terrain models (DTMs). However, little is known about the accuracy of TLS derived DTMs covering several hectares in heterogeneous environments. We investigated the accuracy of DTMs derived from TLS data and compared them to conventional, high-quality airborne laser scanning (ALS) based DTMs. Two different interpolation methods, TIN and IDW, where used to create DTMs with cell sizes ranging from 0.2 to 4 m. Furthermore, we examined the effect of the different DTM resolutions, accuracies and acquisition techniques on topsoil pH prediction models. The pH models were based on linear regression models with only terrain attributes as covariables. The study area is characterized by a complex mirco-topography which is covered by dense evergreen forest and dense ground vegetation. The pH of the topsoil varies in the study area between 3.5 and 7.0.

The results showed that up to a resolution of one meter, the TLS based DTMs were more accurate compared to the ALS DTMs for both interpolation methods. The accuracies of DTMs were also reflected in the performance of the pH models. Generally, the model performance decreased with decreasing resolution. However, the TIN based models with cell sizes of 0.2 m had a lower R2 than the models with 0.5 m resolution. The best soil pH model was based on a 0.5 m DTM derived from TLS. It explained 62% of the pH variance whereas the best ALS derived model explained 50% of the variance and was also based on a cell size of 0.5 m.

The pH models showed that submeter DTM resolutions are required to predict topsoil pH accurately in the study area because the pH varied over a large range within short distances. We conclude that TLS data significantly improve DTMs and pH models compared to the models based on high-quality ALS data in heterogeneous environments.

keywords: *DTM, Topsoil pH modelling, Terrestrial laser scanning, Airborne LiDAR, Accuracy, Terrain attribute*

Multi-sensor data fusion for supervised land-cover classification through a Bayesian setting coupling multivariate smooth kernel for density estimation and geostatistical techniques

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The data fusion is a growing research field, which finds a natural application in the remote sensing, in particular, for performing supervised classifications by means of multi-sensor data. From the theoretical standpoint, to address such an issue, the Bayesian setting provides an elegant and consistent framework. Recently, a methodology has been successfully proposed incorporating a geostatistical non-parametric approach for improving the estimation of the prior probabilities in the scope of the supervised classification. In this respect, a limitation affecting the Bayes computation in the multi-sensor data is the naïve approach, which considers independent all the sensor measurements. Obviously, such hypothesis is unsustainable in practice, because different sensors can provide similar information. Therefore, an enhancement of the previous described method is proposed, introducing the smooth multivariate kernel method in the Bayes framework to furtherly improve the probability estimations. A peculiar advantage of the smooth kernel approach concerns the fact that it is inherently non-parametric and consequently overcomes the multinormality data hypotesis. A case study is presented based on the data coming from the AQUATER project.

keywords: *Data fusion, Remote sensing, Multivariate kernel density estimation, Geostatistics*

Uncertainty in soil properties from the hydrological point of view: a call for new types of soil maps?

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Soil properties play an important role in modeling land surface hydrological processes. However, due to the strong variability detected at all spatial scales the characterization of the soil variability remains a crucial challenge, especially over large areas. For this reason, in several studies, soil parameters are inferred indirectly based on hydrological measurements (e.g., streamflow, soil moisture) to improve the predictive capability of the hydrological models. For that purpose, several approaches and strategies are available in literature. However, the characterization of the uncertainty itself has received much less attention. The aim of the study is to assess the effect of different uncertainties in soil properties on simulated hydrological states and fluxes at different spatial and temporal scales. The study is conducted based on the data collected in the Neckar catchment (Germany). The original soil map is perturbed based on three methods. These perturbation methods introduce the same error (variance) but with different spatial structures (correlation lengths) that are assumed to not be resolved in the original soil map. The generated soil properties are used as input for the distributed hydrological model mHM (www.ufz.de/mhm). The model outputs (e.g., river discharge and soil moisture) are aggregated to different spatial and temporal scales. The results show how the three perturbation methods produce different results depending on the observation scale. Streamflow acting as an integrative hydrological response of the catchment is affected only by the perturbation of long spatial structure. Soil moisture represents more local hydrological conditions and it is affected by the small-scale variability introduced. The study underlines the importance of a correct characterization of the uncertainty in soil properties. By that, soil maps with additional information regarding the unresolved soil spatial variability would provide a strong support to hydrological modelling applications.

keywords: *uncertainty, catchment, hydrological model*

Detecting soil microbial community shifts via field spectroscopy

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Reliable information on plant and soil health is important for early detection and prevention of pests, diseases or abiotic stresses. While diseases in agricultural systems can often be reliably assessed via remote sensing, it is unknown to what extent subtler changes in soil biodiversity could be detected. Plants have a multitude of positive and negative interactions with soil microorganisms which can all affect plant quality. Therefore, it seems plausible to detect shifts in soil microbial communities remotely by measuring plants response, on the leaf level or even above. We tested the hypotheses that 1) plants growing with different microbial communities will vary in leaf hyperspectral reflectance, and 2) the spectra from plant communities can be used to derive microbial communities. We measured hyperspectral reflectance patterns of Achillea millefolium and Trifolium repens and the whole mixed plant community with 7 plant species, growing on sterilized soils inoculated with field soil. Microbial communities varied in composition caused by serial dilution, resulting in decreasing bacterial diversity. Largest differences in the leaf vegetation indices were found between the most diverse soils and the non-inoculated control soils. The community level measurements showed stronger treatment signals than the leaf measurements. We will discuss the potential and constraints for detecting changes in soil microbial communities via plant hyperspectral reflectance.

keywords: *soil microbial biodiversity, field spectroscopy, plant proxies*

Using Near Infrared Spectroscopy in determining the mineralogical variations of the London Clay Formation, Whitecliff Bay, Isle of White, UK.

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Suggested geotechnical variations within the various lithologies of the London Clay Formation had been attributed to its mineralogical variations which required its constituent minerals to be further examined. Near Infrared reflectance spectroscopy has been extensively used in the prediction of various soil properties, identification of clay minerals and related soil chemical properties. The study uses the technique of Near Infrared (NIR) spectroscopy on soil samples obtained from a section of the cliff and foreshore exposures of the London Clay Formation at Whitecliff Bay, Isle of Wight, UK. The technique helps in the identification and quantification of clay minerals, particularly those that are responsible for susceptibility of the Formation to expansion and shrinkage. The soil samples were measured at reflectance intervals of 1300 nm to 2500 nm using ASD LabSpec 5000 spectrometer with the resultant spectra subjected to analysis using the statistical method and The Spectral Geologist (TSG) software. Results showed that the London Clay mineralogy is dominated by clay groups such as; Kaolins, White Micas, and Smectites. The research recognizes and identifies the mineralogy within the London Clay Formation by bringing together data relating to composition, mineralogy, and reflectance which helps provides valuable information on the geotechnical interpretation of the Formation using spectral techniques.

keywords: *Near-infrared Spectroscopy, Mineralogy, London Clay Formation*

Standardization of world soil profile data to support global mapping and modelling

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Procedures for collecting, compiling, standardizing/harmonizing and subsequently providing quality-assessed world soil profile data to the international community, as developed in the framework of WoSIS (World Soil Information Service), are described. Harmonization, as defined by the Global Soil Partnership (GSP), involves "providing mechanisms for the collation, analysis and exchange of consistent and comparable global soil data and information". Areas of harmonization include those related to: a) soil description, classification and mapping, b) soil analyses, c) exchange of soil data, and d) interpretations. Seen the breadth and magnitude of the task, so far we have focused on developing and applying procedures for handling and standardizing legacy soil profile data, with special attention for the selection of soil properties considered in the GlobalSoilMap specifications: organic carbon, pH, texture (sand, silt, and clay), coarse fragments (> 2 mm), cation exchange capacity, electrical conductivity, bulk density, and water retention. These properties are commonly considered in digital soil mapping and can be used to address a wide range of global issues, such as food security, combatting land degradation, and adaptation and mitigation to climate change.

The standardized data are served to the international community using two formats. Static snapshots in TXT format, with a time stamp and identifier (doi), are provided to allow for consistent citation purposes. For example, the 'July 2016' snapshot includes standardized data for some 94,000 profiles. Newly standardized data are gradually added to a dynamic version of the dataset that can be accessed '24/7' using WFS connection in GIS applications (some 109,000 profiles as of March 2017); the number of measured data for each property varies between profiles and with depth. Both the static and dynamic versions are freely available at: http://www.isric.org.

Future releases of WoSIS will consider a wider range of soil properties (e.g. content of nitrogen, phosphorus and other (micro) nutrients), including data derived from soil spectrometry. Instrumental to enhanced usability and accessibility of data managed in WoSIS will be the continued harmonization of soil property values and further standardization of soil analytical method descriptions. Development and testing of such procedures, in partnership with data providers, will allow for the fulfilment of (future) demands for global soil information, and enable further collation of standardized soil data shared by partners and third parties.

keywords: *soil profile data, data sharing, standardization, harmonization*

Soil and Environment software, a tool for soil management

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Government agencies dedicated to environmental protection often do not have soil scientists so it is necessary to generate easy-to-use tools to interpret soil properties in the evaluation of the environmental functions of soils. The objective of this work was the elaboration of a software by means of which the properties of the profile of the soil become interpretations of the environmental functions of the soils. Soil and Environment (SE) software can be used to: a) evaluate the environmental functions of soils; and b) to elaborate degradation and conservation scenarios based on the erosion process. The data required to operate the software are: thickness of horizons, bulk density, stoniness, organic carbon, cation exchange capacity and texture, and others. The environmental functions of the soil that can be evaluated with SE are: a) allowing deciding to select the best sites for housing construction considering their damping power of contaminants such as heavy metals and organic substances; b) To select the soils suitable as habitat for wild flora and fauna; c) To select sites for aquifer recharge; d) Identify soils that stores over of the organic carbon contributing to reduce climate change; e) Identify soils with archaeological importance (human history, such as ancient temples or buildings); f) To appreciate soils with geological importance (history of the land, such as soils with the bones of prehistoric animals, soils with evidence of ancient sea beds, etc.); g) Identify soils with greater aptitude for food production. The evaluation results of environmental functions and predictive models can be presented by graphs. Export of tabular and graphical information is possible as well as the spatial reference data into the GIS. Friendly interface for data input and output and database management is designed for users who do not know SQL query language.

keywords: *Environmental functions of soils, Soil properties, Software*

App Soil Calculator

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The Soil Calculator app has a database to store the properties of the soil, the data that can be registered and stored in the app are: a) profile information (profile name, geographic location, weather, photography and Site observations); b) basic properties (number and name of horizons, depth, aggregate stability, volume of coarse fragments, bulk density, textural class and pH); and c) auxiliary properties (nitrogen, carbon, K_2O, P_2O_5, cation exchange capacity, NO_3^-, field capacity and permanent wilting point). Soil Calculator offers aids to the user to capture the basic properties of the soil; these aids were created based on the guidelines for the description of soils in the field of FAO and the USDA. Soil Calculator allows calculations at the soil profile level for the amount of fine earth, organic carbon, nitrogen, phosphorus, potassium, cation exchange capacity and nitrates in units of weight per unit area, either per hectare or square meter. It also offers the conversion of units between the International System and the English System. Soil Calculator is a tool for professionals related to the study of soils, such as farmers, foresters, urban planners, agricultural entrepreneurs, architects, experts and non-experts in the soil science. Soil calculator is available for free download in the Play Store

keywords: *Soil properties, Database, Mobile app*

Algorithms for quantitative pedology

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The Algorithms for Quantitative Pedology (AQP) project was started in 2009 to organize a loosely-related set of concepts and source code on the topic of soil profile visualization, aggregation, and classification into an R package. Over the past 8 years, the project has grown into a suite of related R packages that enhance and simplify the quantitative analysis of soil profile data. Central to the AQP project is a new vocabulary of specialized functions and data structures that can accommodate the inherent complexity of soil profile information; freeing the scientist to focus on ideas rather than boilerplate data processing tasks. These functions and data structures have been extensively tested and documented, applied to projects involving hundreds of thousands of soil profiles, and deeply integrated into widely used tools such as SoilWeb. Components of the AQP project currently serve an important role in routine data analysis within the USDA-NRCS Soil Science Division. The AQP suite of R packages offer a convenient platform for bridging the gap between pedometric theory and practice.

keywords: *R, Software, Visualisation*

Saskatchewan Soils: Access and improvements to soil information

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Saskatchewan, a province in western Canada, has a total area of 651,900 km^2 and a population of approximately 1.2 million people, nearly half of whom live in the two largest cities. The land base is dominated by agriculture in the southern half and boreal forest in the north. The sparse population, coupled with intensive resource use, places high demand on the province's soils with limited capacity for management oversight. At present, although most of the provincial soil survey information can be downloaded for viewing on a GIS platform, the files are not user-friendly and hence are under-utilized. Most people still rely on paper or pdf copies of the original soil surveys. In addition, most of the provincial soil maps are at a scale of 1: 100,000, which limits their usefulness for landscape modeling and precision agriculture applications.

To overcome these limitations, we have undertaken to improve the accessibility and quality of Saskatchewan's soil information. The first phase of the project is the development of an open source, user-friendly platform for viewing and querying our soil information, with the ability to develop themed maps for several of the most commonly requested soil properties, and the option to query a full suite of properties for the province as a whole and/or for specific locations. This platform is designed to be user-friendly for an audience ranging from farmers to policy makers and for applications from education to research. It also includes the option to upload information. At this time, the focus is on facilitating the uploading of georeferenced point files (photos, publications, datasets), but the capacity for uploading new soil survey data is also in development. The latter is of particular relevance given the need for refining the resolution of our soil information. The second phase of the project involves testing and implementing digital soil mapping procedures that are feasible given the challenges we face in Saskatchewan. 1) We lack a high-resolution digital elevation model that captures the variable Prairie Pothole topography. 2) We lack sufficient point data to take full advantage of the emerging data driven techniques. The ultimate goal will be to develop DSM methodologies that can be implemented on a local to regional scale, leveraging the increasing use of drones for topographic mapping to gradually build a refined map at the 1: 10,000 scale or better. This presentation will provide an overview of our progress and challenges to date.

keywords: *Saskatchewan, digital soil mapping, crowdsourcing, spatial scale, Prairie Pothole Region, Canada*

Soil Spectral Library of Ethiopia (SSL-ETH), Version-I

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Infrared spectroscopy (IR) is currently being used in the Ethiopian Soil Information System (EthioSIS) project with the aim of predicting soil properties for Digital Soil Fertility Mapping on a large amount (>100 000) of soil samples. The objective of using the IR spectra, especially Mid-infrared (MIR) is primarily to be able to reduce analytical cost and secondly to reduce the problem of inter-laboratory variation in wet chemistry analysis. After air-drying and sieving the soil through a <2 mm sieve the samples have been analyzed for nutrients using the Mehlich-3 multi-nutrient extraction method and the extract has been analyzed with Inductively Coupled Plasma (ICP) for Ca, K, Mg, Na, P, S, Al, B, Cu, Fe, Mn, Zn, Co, Si, and Mo. CN analyzer is used to analyze the C and N contents, and the pH of the soils was determined in H2O using 1:2 soil to solution ratio using pH-meter. In this study, 61,331 soil samples collected from 80% of current crop land and 20% potential agricultural lands were collected from 540 administrative districts of Ethiopia. The samples represent topsoil, a depth of 0 - 20 cm for annual croplands and 0 – 60 cm for perennial croplands. The < 2mm sieve samples were further sub-sampled and sub-grinded to a mesh size of 0.5 mm, all the soil samples were scanned with replicates using a Bruker-TENSOR 27 spectrometer with the HTS-XT accessory. The spectra were captured using diffuse reflectance mode in the parts of MIR and NIR region (7,000 – 600 cm^{-1}). All the soil spectra were averaged and preprocessed using vector normalization, first derivative using the Savitzky-Golay smoothing method and CO2 region is removed. Kennard-Stone algorithm was used to select 20% calibration and 80% validation datasets. The reference soil dataset was log-transformed to best fit to partial least squares regression (PLSR) model and the model performed better in predicting C with R2 $\leq$ 0.91; Si with R2 $\leq$ 0.91; N with R2 $\leq$ 0.87 and pH with R2 $\leq$ 0.52; and the model performed poor in predicting B, P, Na, S and Mn. MIR soil spectral library of Ethiopia can be used to monitor spatiotemporal variabilities and digitally map some of the soil properties quickly and at a low cost.

keywords: *SSL-ETH, soil properties, IR spectra, ICP, prediction, digital soil mapping*

Detailed predictive mapping of acid sulfate soil occurrence using electromagnetic induction data

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Acid sulfate soils are often called the nastiest soils in the world (Dent & Pons, 1995). Releasing a toxic combination of acidity and metals into the recipient watercourses and estuaries, these soils represent a crucial environmental problem. Moreover, these soils can have a considerable economic impact through the resulting corrosion of concrete and steel infrastructures, or their poor geotechnical qualities.

Mapping acid sulfate soil occurrence thus constitutes a key step to target the strategic areas for subsequent environmental risk management and mitigation. Conventional mapping (i.e. soil sampling and subsequent pH measurements) has typically been used for acid sulfate soils. Recently, supervised classification modelling techniques were assessed for mapping acid sulfate soil occurrence and demonstrated promising predictive results at catchment or regional extent (Beucher et al., 2015, 2016).

Since acid sulfate soils contain large amounts of soluble salts, they yield strong electromagnetic (EM) anomalies, appearing as diffuse and round-shaped high electrical conductivity (EC) areas. EM induction data collected from an EM38 proximal sensor hence enabled the refined mapping of acid sulfate soils over a field (Huang et al., 2014).

Measuring the apparent soil electrical conductivity (ECa) can provide data on the spatial variation of soil salinity, which is associated with acid sulfate soil occurrence, but also of soil texture. The spatial distribution of different acid sulfate soil material types (clay, silt, sand, etc.) may have a great influence on the related environmental hazards (e.g. leaching of acidity) and their spatial variability at the extent of a field.

The present study aims at developing an efficient and reliable method for the detailed predictive mapping of acid sulfate soil occurrence. Different machine learning approaches will be assessed over a field located in western Finland, using soil observations and various environmental predictors (Quaternary geology maps, EM data collected from a DUALEM proximal sensor, and remote sensing data, such as airborne gamma-radiometric data, a LiDAR-based Digital Elevation Model and different terrain parameters derived from it).

Preliminary results show that soil texture variation could not be identified since fine-grained sediments homogeneously cover the study area. An inversion software called Aarhus Workbench (Auken et al., 2015) was also applied to create 2-D models of EC from the measured ECa. These EC models could enable detecting the transition zone, which represents the most acidic layer overlying the reduced parent sediment horizon (i.e. the sulfide reservoir with a high acidifying potential). This information appears as critical in the management of environmental risks related to acid sulfate soils.

Auken, E., Christiansen, A. V., Fiandaca, G., Schamper, C., Behroozmand, A. A., Binley, A., Nielsen, E., Effersø, F., Christensen, N. B., Sørensen, K. I., Foged, N., and Vignoli, G., 2015. An overview of a highly versatile forward and stable inverse algorithm for airborne, ground-based and borehole electromagnetic and electric data. Exploration Geophysics, 2015, 223-235.

Beucher, A., Siemssen, R., Fröjdö, S., Österholm, P., Martinkauppi, A., Edén, P., 2015. Artificial neural network for mapping and characterization of acid sulfate soil: Application to Sirppujoki River catchment, southwestern Finland. Geoderma 247-248, 38-50.

Beucher, A., Adhikari, K., Madsen-Breuning, H., Greve, M.B., Österholm, P., Fröjdö, S., Jensen N.H., Greve, M.H., 2016. Mapping acid sulfate soils in Denmark using legacy data and LiDAR-based derivatives. Emerging frontiers in Pedometrics. Special Issue, Geoderma. In press.

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Huang, J., Nhan, T., Wong, V.N.L., Johnston, S.G., Murray Lark R., Triantafilis, J., 2014. Digital Soil Mapping of a coastal acid sulfate soil landscape. Soil Research 52, 327-339.

keywords: *Acid sulfate soils, Digital soil mapping, Electromagnetic induction*

Supplementing predictive mapping of acid sulfate soil occurrence with Vis-NIR spectroscopy

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Releasing acidity and metals into watercourses, acid sulfate soils represent a critical environmental problem worldwide. Identifying the spatial distribution of these soils enables to target the strategic areas for risk management.

In Denmark, the occurrence of acid sulfate soils was first studied during the 1980's through conventional mapping (i.e. soil sampling and the subsequent determination of pH at the time of sampling and after incubation, the pyrite content and the acid-neutralizing capacity). Since acid sulfate soils mostly occur in wetlands, the survey specifically targeted these areas.

Recently, a digital soil mapping approach was assessed to create a predictive map for potential acid sulfate soil occurrence in the wetlands of Jutland (c. 6500 km^2; Beucher et al., 2016). An Artificial Neural Networks method was applied using 8000 soil observations and 16 environmental variables, including geology, landscape type and terrain parameters.

Visible-Near-Infrared (Vis-NIR) spectroscopy constitutes a rapid and cheap alternative to soil analysis, and was successfully utilized for the prediction of soil chemical, physical and biological properties. In particular, the Vis-NIR spectra contain diagnostic features for hydroxides, clay minerals, iron oxides and iron sulfates which are typically present in acid sulfate soils (Shi et al., 2014). Soil spectroscopy may thus efficiently supplement the mapping of acid sulfate soil occurrence.

The present study aims at predicting acid sulfate soil occurrence in the Skjern River catchment (c. 2500 km^2). Different machine learning approaches will be assessed using soil and environmental data, together with laboratory Vis-NIR spectral data available for the study area. Absorbance values (400–2500 nm) were measured for 600 soil samples with a DS2500 instrument (Peng et al., 2015). The spectral data were summarized using principal component analysis (PCA). The first two principal components (PC) explained 99% of the variability in the spectra. Kriging was applied to upgrade PC scores information from point to image scale for further use within the acid sulfate soil occurrence modelling.

Beucher, A., Adhikari, K., Madsen-Breuning, H., Greve, M.B., Österholm, P., Fröjdö, S., Jensen N.H., Greve, M.H., 2016. Mapping acid sulfate soils in Denmark using legacy data and LiDAR-based derivatives. Emerging frontiers in Pedometrics. Special Issue, Geoderma. In press.

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Shi, X.Z., Aspandiar, M., Oldmeadow, D., 2014. Reflectance spectral characterization and mineralogy of acid sulphate soil in subsurface using hyperspectral data. International Journal of Sediment Research 29, 149-158.

keywords: *Acid sulfate soils, Digital soil mapping, Vis-NIR spectroscopy*

3D prediction of soil moisture using data from varying horizontal and vertical supports

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Thomas Orton – University of Queensland, Australia
Niranjan Acharige – The University of Sydney, Australia

Soil moisture is a key property for managing and modelling our environment for many end users from hydrologist to farmers to climatologists. Due to its importance there are multiple approaches being used to estimate or measure it in the field. Examples include direct measurements with soil moisture probes and radar estimates of soil moisture. Each has their advantages and disadvantages and for the most part these are related to the spatial support over which the measurements are made. In this work we define the spatial support as the vertical and horizontal area over which the estimate is made. In the case of soil moisture probes we effectively have a point horizontal support as in most cases the measurement volume is quite small, and in most cases sensors are arrayed vertically giving discrete point measurements throughout the soil profile. In terms of mapping soil moisture, probes are generally sparse in density. Radar estimates of soil moisture offer full spatial coverage and have a horizontal support of 250m and up to 20-40 km, however their vertical support is the first few cms of the soil profile. Other types of measurements are also available, e.g. cosmic ray probes which has a horizontal support of 250 m and vertical support of $\sim$0.3-0.6 m. The issue is then how to use all of different types of soil moisture data in one model while accounting for their varying spatial supports.

To achieve this we present an approach which allows estimates of model parameters for datasets where observations have different spatially supports, and subsequent prediction with this data at any support vertically and horizontally. The approach is based on area-to-point kriging with residual maximum likelihood estimation of model parameters. We use 2 case studies with different soil moisture data streams. These include point measurements from soil moisture probes, remotely-sensed radar estimates, measurements from cosmic ray probes and whole-profile estimate of soil moisture from a water balance model.

keywords: *spatial support, linear mixed models, soil moisture*

Joint multifractal analysis of the influence of topography and soil texture on soil water storage

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Multifractal analysis describes the variability and heterogeneity in the distribution of a variable by characterizing and summarizing the variability across scales. Joint multifractal analysis has been widely employed to characterize scale relationships between two variables co-existing along a single geometric support. In this study, the joint multifractal analysis was carried out for three variables coexisting in the same geometric support in order to describe the influence of topography (relative elevation) and soil texture (sand content) on water storage within the soil profile. Soil water storage was measured down to 1.4 m depth along a transect of 576 m long from the hummocky landscape of central Saskatchewan, Canada along with sand content and relative elevation. Joint multifractal analysis was conducted considering both the strange attractor formalism and the method of moments. The variability in soil water storage, sand content and relative elevation were scale dependent. The spatial variability in relative elevation was strongly reflected on water storage across analyzed spatial scales but the joint multifractal spectrum for sand content and water storage suggested a lower degree of correlation. The change in multifractality was also observed when both relative elevation and texture varied highly. This clearly demonstrated the capability of joint multifractal analysis to completely characterize the scaling behavior among three variables.

keywords: *scaling, joint multifractal, three factors, soil water storage, topography, soil texture, geometric support*

Multitemporal Soil Pattern Analysis for Organic Matter Estimation on Arable Fields using Multispectral Satellite Data

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James A. Taylor – Newcastle University, United Kingdom

Due to the high socioeconomic and ecological relevance of soils, qualitative and quantitative soil data at multiple scales are urgently required for land and resource management, soil protection strategies, and more specific tasks in precision agriculture. For precision agriculture, soil data at multiple scales is important to help optimise farm inputs. Therefore, remote sensing data analysis can provide innovative, inexpensive and rapid tools for soil property prediction.

High-temporal, high-spatial resolution multispectral satellite imagery and time series offer great potential for soil information extraction, soil patterns derivation, mapping of potential site-specific management zones and soil surface units. The common problem with a single satellite image is the existence of heterogeneous spatial reflectance patterns associated with different land uses and vegetation conditions. This means static soil reflectance patterns persist aside from temporal patterns caused by crop types, vegetation phenology and field management practices. To reduce the disturbance of the temporal patterns, a Multitemporal Soil Pattern Analysis (MSPA) method for soil organic matter (OM) prediction using RapidEye time series has been developed and applied to German production fields. The method transferability was tested within the same soil landscape, showing a generally low prediction error (RMSE: 0.3 OM-%).

We present the MSPA method, which makes it possible to i) separate the static soil pattern from the temporal pattern, ii) identify most suitable bare soil images, and iii) evaluate the spatiotemporal variability of the soil reflectance pattern. This enables the generation of functional soil maps based on stable soil reflectance pattern at the field and the multiple-field landscape scale. The method consists basically of following steps: (1) selection of best suitable datasets (bare soil images) out of satellite time-series using automated classification based on NDVI thresholds; (2) soil reflectance pattern detection using standardised principal component analysis; (3) evaluation of spatiotemporal soil pattern stability using statistical per-pixel analysis; (4) functional soil mapping based on statistical analysis and stepwise exclusion of temporal effects. To enhance the operability of the MSPA approach, a further development is needed from a RapidEye-sensor independent approach to a hybrid method capable of utilising imagery from multiple satellite imaging sensors, such as RapidEye, Gaofen-2 and Sentinel-2. Furthermore, the MSPA method applicability to diverse soil landscapes is being studied on different geographical regions in China and the UK with greatly varying a) soil landscape genesis, b) climatic conditions, and c) cropping systems. Results from these studies will be presented.

keywords: *Precision agriculture, Multitemporal analysis, Reflectance Pattern, Bare soil, Soil organic matter, Remote sensing, Sentinel-2, RapidEye, Gaofen-2*

Spectral mixing for vis-NIR diffuse reflectance spectroscopy

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Anna Kühnel – Technical University of Munich, Germany

Diffuse reflectance spectroscopy has been widely used for rapid prediction of different soil properties. Nowadays soil spectra and corresponding reference soil properties can be accessed from global spectral libraries. However, to ensure accurate predictions at local scale, local data need to be incorporated into the model. To reduce the effort of acquiring local data, we suggest to use spectral mixing and to generate synthetic spectra. Those spectra can be used additionally to actually measured local spectra to increase the weight of local information. We use the Synthetic Minority Oversampling Technique (SMOTE) originally introduced by Chawla et al. (J. artif. intell. res., 2002, 16, 321-357) for classification problems and further developed by Torgo et al. (Progress in Artificial Intelligence, Springer, 2013, 378-389) for regression. SMOTE linearly mixes two soil spectra and calculates reference soil properties by a weighted average. We conducted a laboratory study to evaluate whether this method is suitable to generate useful synthetic spectra with accurate reference soil properties. Therefore, we mixed different soil samples with known reference carbon content and measured the spectral reflectance of the mixed soil samples. We generated synthetic spectra with the same mixing ratio to compare with the measured ones. Our first results show that SMOTE with its linear mixing assumption can indeed be used to produce synthetic spectra. However, their quality varies according to the similarity of original spectra and the mixing proportion. We present the results from our laboratory study and show how the synthetic spectra can be used for modelling of soil organic carbon.

keywords: *vis-NIR spectroscopy, soil organic carbon, spectral mixing*

Predictive mapping of the acidifying potential for acid sulfate soils

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Stefan Mattbäck – Dept. of Geology and Mineralogy, Åbo Akademi University, Finland
Henrik Nørgaard – Dept. of Agroecology, Aarhus University, Denmark
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Developing methods for the predictive mapping of the potential environmental impact from acid sulfate soils is important because recent studies (e.g. Mattbäck et al., under revision) have shown that the environmental hazards (e.g. leaching of acidity) related to acid sulfate soils vary depending on their texture (clay, silt, sand etc.). Moreover, acidity correlates, not only with the sulfur content, but also with the electrical conductivity (EC) measured after incubation. Electromagnetic induction (EMI) data collected from an EM38 proximal sensor also enabled the detailed mapping of acid sulfate soils over a field (Huang et al., 2014).

This study aims at assessing the use of EMI data for the predictive mapping of the acidifying potential in an acid sulfate soil area in western Finland. Different supervised classification modelling techniques, such as Artificial Neural Networks (Beucher et al., 2015), will also be evaluated to generate predictive maps.

In the study area, an EMI-survey using a DUALEM proximal sensor was carried out during the autumn of 2016. The collected apparent soil electrical conductivity (ECa) measurements were interpolated using ordinary kriging. An inversion software called Aarhus Workbench (Auken et al., 2015) was used to create 2-D models of EC from the measured ECa. An unsupervised classification method was applied on the interpolated ECa map and LiDAR-based elevation data to partition the study area into homogeneous units. A soil sampling scheme was carried out based on this information, samples being taken from each unit.

From every sampling site, five soil cores were taken down to two meters depth with a manually operated soil corer; one primary soil core in the middle and four soil cores distributed evenly around the primary soil core. The primary soil core was used for detailed characterization of soil properties (grain size, structure, texture, field-pH, oxidation depth, ground water level) and acidifying potential (incubation-pH and titratable incubation acidity) whereas the four other cores were used for checking the soil variability. Soil observations from the primary cores are used as calibration and validation data within the modelling.

In addition to the EMI data, the present study relies on other environmental predictors: Quaternary geology maps and remote sensing data, such as airborne gamma-radiometric data, a LiDAR-based Digital Elevation Model (DEM), and different land surface parameters derived from this DEM (e.g. slope gradient, distance to channel network, flow accumulation and wetness index).

Preliminary results show that the acidifying potential is generally high and that it varies within the soil cores. The interpolated ECa map and EC models both appear to indicate the field drainage system. EC models could also enable detecting the transition zone, which constitutes the most acidic layer overlying the anoxic horizon (i.e. the sulfidic parent material with a high acidifying potential). Additionally, soil texture variation could not be identified because fine-grained sediments homogeneously covered the study area.

Auken, E., Christiansen, A. V., Fiandaca, G., Schamper, C., Behroozmand, A. A., Binley, A., Nielsen, E., Effersø, F., Christensen, N. B., Sørensen, K. I., Foged, N., Vignoli, G., 2015. An overview of a highly versatile forward and stable inverse algorithm for airborne, ground-based and borehole electromagnetic and electric data. Exploration Geophysics, 2015, 223-235.

Beucher, A., Siemssen, R., Fröjdö, S., Österholm, P., Martinkauppi, A., Edén, P., 2015. Artificial neural network for mapping and characterization of acid sulfate soil: Application to Sirppujoki

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keywords: *Acid sulfate soils, Predictive mapping, Acidifying potential*

Can soil spatial prediction models from different areas be similar?

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Spatial prediction of soil properties in various scales is necessary for numerous applications and assessment. There is a vast number of prediction models in digital soil mapping differing in their complexity, target soil properties, structure of auxiliary data, resolution etc. This is caused both by available data and by different natural conditions. This contribution aims in an assessment of differences between soil spatial prediction models based on the same structure of input data, but developed for different regions.

Models for spatial prediction of soil organic matter (SOM) and clay content in soils were separately developed for three different districts of the Czech Republic, namely (i) Rychnov nad Kněžnou, ranging from flat area on the west to mountainous regions on the east, with expected principal influence of topography, (ii) Litoměřice, characterized by variable geology, and (iii) Tábor, with variable topography combined with frequent hydromorphic conditions. Available legacy soil data were used, supported by all possible primary and secondary relief parameters (altitude, slope, aspect, horizontal and vertical curvature, contributing area, topographic wetness index, etc.), land use from the CORINE (COoRdination of INformation on the Environment) database, and information from geological maps. Several model types were applied, including regression trees, random forests, multivariate adaptive regression splines, artificial neural networks, and geostatistics. The output of the models were tested by leave-one-out cross validation, as well as on an independent validation dataset.

The models built in different regions, though generally similar, differed particularly in the selection, importance and weight of individual environmental covariates, confirming thus different role of individual soil forming factors in different conditions. An attempt to combine the models to obtain a more universal prediction less dependent on the particular region was done. The combined models will be further tested on larger areas.

keywords: *digital soil mapping, spatial prediction, auxiliary data, environmental covariates*

Thermal remote sensing for digital soil mapping

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Incoming solar radiation reaching the earth's surface is reflected, absorbed, or transmitted. Reflected visible-near Infrared solar radiation has been extensively used to derive environmental covariates for digital soil mapping. Remote sensing which measures energy emitted in the mid-, and thermal-infrared range (i.e., thermal remote sensing) may be useful as a digital soil mapping covariate, but this has been little explored. We investigate the utility of thermal remote sensing for deriving covariates for digital soil mapping. We first briefly discuss challenges and opportunities in acquiring thermal remote sensing imagery and review how thermal imagery can be transformed into physically-based covariates. We then demonstrate the use of land surface temperature and thermal inertia derived from thermal remote sensing as physically-based covariates for modeling soil depth in a semi-arid environment.

keywords: *Thermal Remote Sensing, Digital Soil Mapping, Soil Depth*

Optimal stratification for validation of digital soil maps

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The quality of soil maps can best be estimated by collecting additional data at locations selected by probability sampling. The data can be used in design-based estimation of map quality measures such as the spatial mean of the squared prediction errors (MSE). In areas with large differences in accessibility it can be attractive to account for these differences in selecting sampling locations. Sampling at lower densities in remote areas may increase the sampling efficiency. One of the options is stratified random sampling. We consider the situation where no ancillary point-specific information is available on the prediction errors. A novel method is presented that can be used to construct optimal strata using an estimate of the point-specific sampling costs. The optimal strata are constructed for optimal allocation of the total sample size to the strata, assuming a constant variance of the prediction errors within the strata. The minimization criterion is the sum of the variance of the estimated MSE and a penalty term. This penalty term equals 0 when the expected total costs are less than or equal to the available budget, and is proportional to the difference between expected total costs and the available budget otherwise. The stratum boundaries and the total sample size are optimized by simulated annealing. A sequence of vectors with stratum boundaries (cost values) and of sample sizes is generated. For the vector with stratum boundaries this is done by selecting randomly one stratum boundary and replacing this boundary by a randomly selected new boundary within the interval defined by the neighbours of the selected stratum boundary. The stratification method is tested in a simulation study and a real-world case study in Anhui, PR China. In the simulation study the point-specific costs are simulated by drawing from an exponential distribution with rate parameter 0.1. The simulated costs were multiplied by a constant (1, 5 and 10) to obtain cost distributions with different variances, and a constant was added (5, 10 and 50) representing fixed sampling costs. In the case study a map of the accessibility costs, modelled as a function of hiking costs and car travel costs, is used. The proposed optimization method gave plausible results in limited computing time ($<$ 1 minute). We aim at extending the method so that prior knowledge about the prediction error, e.g. in terms of prediction error variances, is exploited in the optimal stratification.

keywords: *probability sampling, design-based estimation, mean squared error, accessibility, sampling costs, simulated annealing*

Spatial modeling of geomorphometric variables for natural hazard valuation to desertification in tropical zones

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This work aimed to generate a spatial model to estimate the natural hazard to desertification in tropical areas, using geomorphometric variables, used as hazard indicators for the desertification process. The selected geomorphometric attributes are obtained from the digital elevation model (DEM), and correspond to relief indicators showing trends of degradation, gratification and hydrological modeling of the landscape, associated to flows such as runoff, erosion, sedimentation, accumulation of materials and surface wetness. The calibration of the model was performed in the Amaime river basin in the Valle del Cauca department (Colombia - South America) from the STRM (Shuttle Radar Topography Mission) with a spatial resolution of 30 m. The attributes: slope, curvature (horizontal and vertical), topographic wetness index (TWI) and factor length-slope (L-S) were calculated. The data were processed using the algorithms of SAGA 2.0.8 (System for Automated Geoscientific Analyzes, University of Gottingen, Germany) for the calculation of the geomorphometric parameters and hydrological modeling. The results were graded using indicators tables elaborated in this research, with the assignment of dimensionless values to pre-established ranges and categories, regarding the degree of participation in the causes or processes of degradation and desertification. The calibration allowed to establish that the spatial modeling of geomorphometric indicators identifies and groups areas with similar level of geomorphometric hazard that forms part of the natural hazard that causes desertification processes in tropical zones. For the Amaime river basin, the natural hazard is conditioned by the expression of the topographic attributes in the different relief units. Areas with a high geomorphometric hazard occupy 44.8% of the area and comprise piedmont and mountain positions, where slopes ranging from slightly to strongly steep ($> 25\%$) predominate. As a consequence, with the slope predominating the slope length and inclination factor length-slope (L-S) is classified as medium to high, a condition found mainly on hillsides and mountain tops, where the loss of materials and moisture may be greater Magnitude favoring processes of degradation. 36.8% of the basin (38,457 ha) has a low hazard level, and correspond to sectors of deposit of materials and humidity located in the flat part and in smaller area between the valleys of the broken zone.

keywords: *DEM, Land degradation, Hazard, Geomorphometric*

Use of drone high resolution images to quantify soil erosion

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Precision agriculture has recently experienced substantial development and provides new management tools for the farmer and for soil protection. Here we present a case study that demonstrates the potential of remote sensing using drone as a new tool for sustainable agriculture. Aerial images were taken by a drone and for each flight an orthophoto and a digital surface model (DSM) were obtained. A digital terrain model (DTM) was then computed based on the DSM. These two models enable to compute a differential depth model (DDM) allowing the calculation of the eroded volume on open land. This DDM also enables automatic detection of erosion gullies based on the resulting depth difference. In this study, we show that such methods based on new technologies constitute useful tools for the farmer. The use of these different models, coupled to the RGB images enable (i) to understand the water flows on open land thanks to the DSM and (ii) to improve agriculture sustainability by differentiating cultural practices leading to increased erosion in a given place from those limiting the erosion risk. Moreover, such results also allow understanding the spatial causes of erosion (roads, plought rills). Adequate management measures can then be taken on the catchment scale in order to limit the loss of soil, which can be regarded as an almost non-renewable resource, considering that it takes one century to build one centimetre of soil.

keywords: *Drone, erosion, high resolution images, detection, GIS*

Predicting Scottish soil properties using X-ray powder diffraction

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The terrestrial environment, and its human exploitation, both depend on the ability of soil to perform key functions. Well-functioning soils sustain ecosystems and are vital to life in the Earth's critical zone. As demands placed on soil increase, there is a pressing need for its sustainable management, a prerequisite of which is up-to-date soil information. In recent years the use of spectroscopic techniques as a rapid, cost-effective and reproducible measure of multiple soil properties has gathered momentum. Such 'digital' approaches can reduce the cost of soil mapping by an order of magnitude compared to conventional surveying, therefore their application to monitoring soil over greater spatial and temporal resolutions is particularly valuable.

In contrast to spectroscopic techniques, the application of X-ray powder diffraction (XRPD) to the prediction of soil properties has yet to be realised. The use of XRPD in soil analysis is typically associated with identification and quantification of the crystalline mineralogy from the diffracted signal, whilst there is also a diffuse background signal related to amorphous constituents. The combination of crystalline and amorphous information in each soil diffractogram can be utilised in the same way that visible and infra-red spectra have been used to produce predictive models of soil properties.

Here, XRPD was used to measure 1,246 Scottish soil samples taken from an objective 20 km surveying grid used for the National Soil Inventory of Scotland. Organic soil horizons were excluded for this investigation, leaving 844 mineral soil samples. Cubist, a machine learning algorithm, was then used to develop calibrations for the prediction of 8 soil properties (total carbon, total nitrogen, pHH2O, cation exchange capacity, aqua-regia extractable potassium, and the sand, silt and clay size fractions) from the XRPD measurements. Data were separated into calibration (75%) and test (25%) sets by random sampling. Upon applying the calibration models to the test sets, the R2 of the Cubist predictions (compared to laboratory measurements) ranged from 0.51 (pHH2O) to 0.91 (carbon). For direct comparison, Cubist models were also computed for the same soil samples measured using near infra-red spectroscopy (NIRS). Evaluation of both calibration models shows the use of XRPD to outperform NIRS (higher R2, lower root-mean-square error) for the prediction of all tested soil properties except for pHH2O and base saturation. The results ultimately highlight the potential for XRPD to be used for the prediction of soil properties, and also in developing our understanding of soil property – mineralogy relationships.

keywords: *Soil mineralogy, Soil properties, Data mining, X-ray powder diffraction*

Digital Soil Mapping of soil properties across GB: case studies from Scotland and England

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Soil data harmonisation is a prerequisite for digitally mapping soils across Great Britain (GB) as, historically, soils data were collected by two separate survey organisations operating in Scotland and in England and Wales. It is therefore fundamental to firstly create a unified dataset of soil properties prior to developing models to predict those properties across GB. After investigation of the laboratory and sampling methods across Scotland and England and Wales, a dataset of key soil chemical and physical properties was derived. This study focusses on the depth distribution of these soil properties in two test areas: north eastern Midland Valley in Scotland and western England for six standard depth intervals specified in the GlobalSoilMap project (0-5, 5-15, 15-30, 30-60, 60-100, 100-200cm). The depth function of these soil properties was modelled using a mass preserving spline and predictions of soil property values across the areas were trained using Multivariate Adaptive Regression Splines (MARS) which were then deployed to the test areas. The model used a range of environmental covariates, based on the SCORPAN model (McBratney, 2003) and maps were generated at a resolution of 100m cells. The results for each soil property at their specific depths are presented. The models performed well in these areas though they had different covariates. Further work is needed to investigate whether these models can be developed and applied to the whole of GB.

keywords: *data harmonisation, Great Britain, Soil properties, GlobalSoilMap, Multivariate Adaptive Regressive Splines (MARS)*

A routine chemometrics approach to estimate soil organic carbon in croplands exploiting LUCAS topsoil database.

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The importance of spectroscopy for the quantification of the soil organic carbon (SOC) content and other soil properties is reflected by the increasing number of large soil spectral libraries collected in the world. In this regard, we tested two different routine chemometrics approaches to estimate SOC in three local spectral libraries (Belgian loam belt, Wallonia and Luxembourg), without the need for chemical laboratory analyses. In the first approach we used a regional library (REQUASUD) collected within the Wallonia region (Belgium) and currently used for routine soil fertility analysis, while the second approach is based on a standardized multivariate model exploiting the European topsoil database (LUCAS) in order to predict soil properties in a comparable manner across Europe.

In the light of the huge variability of the spectral responses to SOC content and composition, a rigorous classification process is necessary to subset large spectral libraries and to avoid the calibration of global models failing to predict local variation in SOC content. In this regard, the LUCAS topsoil database was subset into seven soil classes using a clustering analysis based on a large number of soil properties. Consequently, the samples belonging to each class were used to calibrate specific partial least square regression (PLSR) models to estimate SOC content in the three local libraries.

The REQUASUD library provided a satisfactory overall accuracy: RMSE is 4.6 g kg^{-1} and the RPD 2.10. However, the accuracy reached by REQUASUD model is lower than that obtained using the LUCAS dataset, except for Belgian loam belt, where the statistics were identical.

Using the LUCAS database, SOC was estimated with a good accuracy both within each local library (RMSE: 1.2 ÷ 5.4 g kg^{-1}; RPD: 1.41 ÷ 2.06) and for the samples of the three libraries together (RMSE: 3.9 g kg^{-1}; RPD: 2.47). The use of LUCAS database could improve the estimation accuracy provided by a regional model, allowing, in theory, to estimate SOC everywhere in European croplands according with a uniform approach.

keywords: *Soil organic carbon, Spectral library, Croplands, LUCAS topsoil database, chemometrics*

Integration of GPR measurements with sparse textural data for characterizing forest soils: an application of data fusion in southern Italy (Calabria)

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Geophysical sensors, coupled with traditional laboratory analyses, are useful to study soil properties over large areas with fine spatial resolution. The study was aimed to evaluate the potential of ground penetrating radar (GPR) to characterize forest soils of a catchment in southern Italy (Calabria). The catchment (139 ha) is located in the Sila Massif at a mean elevation of 1130 m a.s.l. and mainly covered by Calabrian pine. Chestnut and crops also occur. The bedrock consists of weathered Paleozoic granodiorithic rocks whereas terraced Holocene sands crop out in the eastern sector of the catchment. The soils are classified as Typic Xerumbrepts and Ultic Haploxeralf (USDA).

GPR data were collected with a monostatic system with a central frequency of 250MHz (Noggin Sensors & Software Inc, Mississauga, Ontario, Canada), using a global positioning system (GPS) device for recording profile location. The data were processed to enhance the signal to noise ratio and corrected to compensate for changes in surface elevation, and depth conversion. Temporal amplitude maps (time slices) were transformed to depth maps by using the estimated velocity of radar wave propagation of 9.3 cm/ns. In addition, 140 soil samples were collected up to 0.20-m depth and analysed in laboratory for soil texture. A multivariate data fusion geostatistical approach was used to map the GPR signal amplitude over the whole catchment up to the soil depth surveyed by GPR using a local DEM of 5-m scale resolution and texture as auxiliary information.

Preliminary results showed higher attenuation values of GPR signals near the valley sides and where colluvial soils with higher clay content occur, intermediate attenuation in the shallow soils near the water divide, whereas higher amplitude of GPR signal resulted where loose sandy soils crop out. The spatial relation was inverted at the deeper depths. The work demonstrates the potential of non-invasive geophysical method for forest soil characterization and the issue is worth being investigated further.

keywords: *Data fusion, Geostatistics, Forest soil, Ground penetrating radar, Bonis catchment*

Determination of naturally occurring concentrations of trace elements in New Zealand soils

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In the last decade, largely due to legislative imperatives, there has been a substantial effort placed in determining the ambient background concentrations of various soil trace elements for managing land, especially in Europe. These studies have typically involved large-scale systematic sampling efforts, with detailed data analysis using spatial techniques. In New Zealand no similar studies have been conducted, although there are regulatory requirements for knowledge of background concentrations of naturally occurring elements for the purposes of managing land. Previous New Zealand studies on background soil concentrations have been undertaken at regional levels and have used different pedological and geological groupings to define background concentrations, which does not allow for the assessment of inter-regional similarities and differences in concentrations and the factors influencing these. This in turn, limits the ability to predict likely concentrations in locations for which no data is available. We note that there are numerous terms used to define the 'background' concentrations of soil trace elements, which are often used interchangeably or defined differently in different contexts.

To fill this data gap, we collated existing data from Regional Council soil quality monitoring programmes, regional background soil studies, and one regional grid-based sampling programme. This yielded highly clustered regional data with varying land use across New Zealand. The site-based trace element data was complemented with data from three GIS-based polygon spatial databases that regionally and/or nationally delineate areas interpreted to have distinct common pedological and/or geological properties. Specific parameters were extracted from these databases to provide some assessment of the geological origins of the soil, since the underlying geology is generally regarded as a major contributor to the geochemical signals in soils and surficial material. The range of trace elements varied greatly between regions, but our analysis was limited to arsenic, cadmium, chromium, copper, lead, nickel, and zinc.

Land-use effects were evident for most trace elements considered, with the effects observed differing for the individual trace elements. Spatial correlation was evident, due to the clustered nature of the samples, and the predicted spatial concentration distributions of log-concentration were formed using a Generalised Least Squares model. A rock-group based parameter was found to provide the best fit and was used to generate predicted background concentration distribution. These predictions provide a first-pass estimate of trace element background concentrations across most of New Zealand with data available at https://lris.scinfo.org.nz/ to facilitate usage by consultants and regulators.

keywords: *Soil trace elements, Background concentrations, Spatial models*

Mapping spatial variability of soil organic carbon, phosphorus and soil acidity in Zambia

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Successful agricultural crop production is highly dependent on the soil nutrient status and configuration. However, the spatial distribution of most soil parameters has been mapped only to a limited extent in Zambia. This entails that the country depends on global estimates of soil parameters for various applications. This study was carried to map the spatial distribution of soil organic carbon (SOC), phosphorus and acidity. The study was based on 1715 geocoded field data points across Zambia at which soil samples were collected. The soil samples were analysed for oxidizable carbon using the Walkley-Black procedure. The soil reaction (pH) was determined by the electrometric method while the available phosphorus (P) was determined by the Bray and Kurtz 1 method. Ordinary kriging (OK) was applied to model the spatial distribution of available P and soil pH with spherical variograms. Given that the data points were sparsely distributed across the entire country, OK was selected as the method of interpolation since there was adequate data for computation of variograms. Results indicated that there was a variation in the spatial distribution of available P, SOC and soil pH across the country. The average standard error was 0.5660 which was approximately equal to the RMSE of 0.5644 in the OK model used to map soil pH, and the RMSE standardized close to one (1). This means that the predicted soil acidity map was correctly assessing the variability of soil pH across the country. In the case of SOC which was mapped with IDW, the mean prediction error was -0.0035 indicating that the predictions were not biased. However, the prediction errors in the OK model for soil P were very large with the RMSE standardized of 0.7 indicating that the model used was underestimating the variability of P at locations that were not sampled. Therefore the SOC and soil pH maps could be used to guide management strategies for soil acidity and SOC. The map for soil P can be used to refine sampling strategy so as to improve its reliability.

keywords: *spatial variability, soil pH, Soil organic carbon, available phosphorus*

A Method Research on Digital Soil Mapping Using ES-RS-GIS in Semi-arid Sandy Land: A Case Study of Horqin Left Back Banner

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Abstract: The digital soil mapping (DSM) has been one of the hottest issues in soil science, while the conventional soil survey mapping need a lot of manpower and material resources. DSM is based on the relationship of soil and landscape. This study explored methods for DSM in semi-arid sandy area, taking into consideration pedogenesis and soil distribution. Horqin Left Back Banner, located in Inner Mongolia, is a typical semi-arid sandy area. The distribution of soil types is mainly determined by terrain in the county as climate and parent material are consistent. For example, Swamp soil is around lakes, Meadow soil is in periphery of the lake and between dunes. With the high salinity of groundwater, Meadow soil develops into Saline-alkali soil. Because Swamp soil, Meadow soil and Saline-alkali soil are subject to the impact of groundwater, soil moisture is high. Aeolian sandy soil is in the upper part of dune without the impact of groundwater and has the largest distribution in Horqin Left Back Banner. According to vegetation coverage and soil fixed condition, Aeolian sandy soil can be divided into shifting, semi-fixed and fixed. Although the terrain is the mainly controlling feature, it is difficult to use DSM to obtain soil map without high precision terrain date. The remote sensing data is sensitive to soil moisture and vegetation coverage; therefore, we took a new remote sensing data analysis as DSM with the knowledge of soil genetic characteristics and distribution in this study. Swamp soil was interpreted according to drought condition in springtime. Meadow soil and Saline-alkali soil were classified in terms of reflectance of image. Shifting, Semi-fixed and Fixed aeolian sandy soils were distinguished by vegetation coverage in summer when the vegetation growth was well in one year. Based on ES, GIS and RS, DSM results were as follows: Aeolian sandy soil, Meadow soil, Swamp soil and Saline-alkali soils take percentages of 83.29%, 15.68%, 0.49% and 0.54%. In Aeolian sandy soil, Shifting, Semi-fixed and Fixed aeolian sandy soil take percentage of 0.62%, 19.47% and 79.91%.

keywords: *Semi-arid region, Soil genetic classification, Digital soil mapping*

Soil classification of multi-horizontal profiles using support vector machines and vis-NIR spectroscopy

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The need for rapid and inexpensive techniques for high-resolution soil information has led to improvements over traditional methods, and in particular those based on visible near-infrared (vis–NIR) spectroscopy. While vis–NIR has been used for soil classification for some preliminary studies, how to combine spectral information from soil profiles remains a substantial challenge. This study was undertaken to investigate the potential of vis–NIR to discriminate soil classes on profiles containing various soil horizons.

We took 130 soil profiles at Zhejiang province, of which were classified in the field at suborder level according to Chinese Soil Taxonomy (5 soil orders and 10 suborders). Subsoil samples were taken by diagnosis layers (A, B and C). Support vector machine (SVM) algorithm was used to determine the soil classes, by analyzing quantitatively their diffuse reflectance spectra in the vis–NIR range. For SVM is a binary classification algorithm, the qualitative analysis was conducted by combining the votes of each sample from the same profile and the class got most votes in one profile was defined as their predicted soil class. Readily available variables (soil color) and well-predicted properties (soil organic matter, soil texture and pH) using vis-NIR spectra were added as auxiliary information.

Using synthesized model (spectra plus auxiliary soil information), SVM produced better classification performances at soil order level and suborder level (accuracy were 68.29% and 63.51% respectively) than spectra independently (accuracy were 60.69% and 58.54% respectively). They suggest that vis–NIR spectroscopy combining votes gained from SVM could make an essential contribution to the identification of soil classes in an effective approach of soil classification even when profiles contain various soil horizons.

keywords: *Soil Classification, Multi-horizontal Profiles, Vis-NIR spectroscopy*

Using new sparsity genomic methods to improve soil chemometric models

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Diffuse reflectance spectroscopy (DRS) is a multi-collinear, multivariate problem that attempts to relate the reflectance response of a soil sample to its measured properties. Partial least squares regression remains the default and most reliable parametric method for prediction of published soil DRS studies. However, this method has drawbacks in that all bands included contribute to the final model. While the number of bands used can be reduced by using known absorption regions, it is difficult to know a priori which bands are related to the target property, as there can be complex interactions between minerals, organic matter, and particle size. The problem then becomes how to reduce the number of variables while simultaneously improving results.

To address this issue, new methods from the field of genomics, that deal with very high dimensional multi-collinear datasets, were evaluated for application in soil DRS modeling. The first method, sparse partial least squares regression (SPLSR), is an extension of PLSR that imposes sparsity on the dimension reduction step of PLSR so that at each step of the algorithm, it searches for relevant variables through optimization of direction vectors. Sparsity is imposed by a thresholding parameter, which must be tuned by cross-validation along with the number of latent variables. The second method, heteroscedastic effects model (HEM), is an extension of ridge regression. Like genomics, chemometrics is interested in retaining variables that are relevant, however weak they may be. Similar to ridge regression, HEM applies a shrinkage factor across all variable but instead of the shrinkage factor being equal across variables, a larger penalty is leveraged against unimportant variables thereby reducing their influence on the model output.

We applied these methods to datasets collected from two agricultural villages in southern India, Kothapally and Masuti, and compared them to PLSR. In Kothapally, SPLSR improved model metrics for clay, pH, and available soil phosphorus, copper, and zinc, while HEM improved model metrics for clay, SOC, pH, TN, and available soil potassium, phosphorus, and boron. In Masuti, SPLSR improved model metrics for silt, sand, SOC, pH, and available soil copper, while HEM improved model metrics for clay, sand, IC, and available soil copper. The results demonstrate that SPLSR and HEM can improve prediction results compared to the standard method PLSR. Although the improvement was small in these case studies, these methods may prove useful for predictions on different types of soils.

keywords: *Diffuse reflectance spectroscopy, chemometrics, visible-near-infrared, sparsity*

Transferring and spiking of soil spectral models between two south Indian villages

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Soil spectral prediction models are typically calibrated and validated using data collected from a specific geographic region. Models can be transferred to new regions in an attempt to extend the model but they typically suffer from increased uncertainty in estimations. Spiking has been proposed as a means of alleviating the issue of uncertainty when transferring models. Spiking involves taking a subset of samples from the target area, recalibrating the model with the subset, and applying the new model to the target area. Multiple methods have been devised mostly using a larger national or regional level model with several local sets.

We evaluate a local-to-local assessment of transferring and spiking using local datasets from two agricultural villages in southern India separated by 300 km. Both villages have similar climatic conditions (semi-arid tropics) and soils. From each village, ∼255 topsoil samples were taken, analyzed, and scanned in the visible-/near-infrared (VNIR) spectral range. Spiking was done in both directions with each village serving as the source and target area. The initial calibration model was generated from the source area using 70% of the samples. The target dataset was then split 50/50 into the spiking and validation datasets. From the spiking dataset, subsets were generated that represent 1, 2.5, 5, 10, 15, 20, 30, 40, and 50% subsets. The spiking subset generation was performed using random subsetting and systematic subsetting, where samples are selected along the distribution of the soil property. Each larger subset was ensured to contain the samples from the next smallest subset so that direct comparisons could be made. Unspiked and spiked models were then applied to the target validation set.

Results show that clay and sand models transfer relatively well with (R2: 0.63-0.81), albeit with higher root mean square error (RMSE) (7.71-18.3%). After 5% spike, results improved and leveling off after 30% spike. SOC and IC models did not transfer well (R2:0.01 - 0.27). Spiking improved models for SOC and IC but only in one direction of spiking with results leveling off at 30% spike. Total nitrogen models improved with spiking but only in one direction. Models for exchangeable potassium and soil available boron did not see much improvement with spiking, even at higher levels. Soil available Zn only improved in one direction with systematic sampling. Our results show that spiking improves models for soil properties with discernable spectral features with 30% of samples needed to improve prediction results.

keywords: *Spiking, Diffuse reflectance spectroscopy, Visible-near-infrared, Chemometric*

Mapping the Impact of Zero Tillage on the Biophysical Properties of Soil

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Approximately 40% of the world's land surface, and up to 68% in the UK is managed by ploughing to provide optimal conditions for crop establishment and growth. As ploughing involves the mechanical mixing of soil to a depth 20 cm, it can degrade soil structure increasing the chances of soil erosion, and so contributing to the pollution of water bodies. These concerns have led to increased interest in conservation agriculture including zero tillage, a practice defined as planting into unprepared soil whilst disturbing less than a third of the soil surface. Zero tillage presents many potential benefits, including increased soil organic matter, greater aggregate stability and reduced soil erosion. There is, however, conflicting literature on its potential to sequester more carbon and reduce greenhouse gas emissions. We report a study to assess how zero tillage alters soil biophysical properties on paired fields of ploughed and zero tilled soils across the East Midlands of England, and map these variations and estimate their effects across the region. The study entailed sampling close pairs of fields, one in zero tillage and the other under conventional cultivation. As a consequence of the sites being selected opportunistically, after surveys to find farmers willing to collaborate, all analyses are model-based. Preliminary results indicate an increase in organic matter content, microbial biomass carbon and water content under zero tillage, with a decrease in global warming potential, increasing over time in comparison to ploughed soils. Ploughed soils, imaged by X-ray Computed Tomography had a more porous structures in the top 5 cm whilst soils under zero tillage the upper layers were more consolidated. Further investigation into the effect of macro scale variables by modelling greenhouse gas fluxes and analysis of X-ray images will demonstrate the key mechanisms driving the biophysical changes between zero tilled and ploughed soils, study the climate change mitigation potential of zero tillage and enhance our understanding of the relevant processes at larger scales.

keywords: *Zero tillage, Greenhouse gas emissions, X-ray computed tomography, Carbon, Co-kriging*

Analysis of total carbon in soils from Itatiaia National Park: relationship with profile attributes and terrain covariates

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Itatiaia National Park (INP) was the first conservation unit established in Brazil, in order to protect endemic species, and due to singularity of landscapes features and ecology and geomorphology, unusual for Brazilian Southeastern region. Despite many studies in the INP, with botanical and faunal themes, knowledge about soils is still scarce. In this sense, the study goal was to analyze, using R software and Algorithms for Quantitative Pedology package (AQP), the variability of some soil properties (C, N, H+Al) and their relationship with terrain attributes, as a support for characterize the profiles and to define units for soil digital mapping in the INP high altitude Plateau, Rio de Janeiro State. The soil dataset was compounded by 53 soil profiles, with a total of 231 horizons/layers, and the total carbon content (C), total nitrogen (N) and potential acidity (H+Al) contents along the soil profile were analyzed. The terrain attributes comprised topographic covariates and remote sensing data. The total carbon and total nitrogen were superior in the folic and histic horizons (O and H, respectively), due to the Histosols typical process of formation. The potential acidity showed a larger range in the folic horizons, with values varying between 5 cmolc.dm 3 and 45 cmolc.dm 3, and there was a general decrease of C, N, and H+Al with depth. Exception for the Histosols with drainage restrictions (histic horizons) and located in the lower portion of valleys, with colluvial deposition and different sources of organic material. The mineral soils were deeper, showed lower potential acidity and usually were covered by Atlantic forest vegetation, differing form the Histosols that have a sparse vegetation typical of high altitude fields. The INP soils are predominantly shallow, have high contents of C and H+Al, and are highly vulnerable to degradation, an aspect that should be taken in account in the park's management plan. The slice-wise method allowed to represent the soil attribute values in a 1 cm layer, in the soil profile collection. This is useful to study soil attributes variability along soil depth and the inter relations between soil attributes. The correlation between C and terrain attributes showed positive trends regarding to elevation (above sea level), and negative for data obtained from the spectral bands (RapidEye sensor). The information obtained from the soil survey and analyzed through AQP package is valuable to support decision-making regarding the park's management plan, as well as providing material for future research.

keywords: *Quantitative pedology, Histosols, Soil attributes*

Proximal sensing of soil surface properties in relation to crusting, and rainfall-runoff processes: from portable to UAV-based platforms

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The adverse impacts of surface runoff and erosion processes are well known. At present, accurate and reliable assessments of runoff and soil loss are complicated by the fact that the relevant underlying mechanics are strongly affected by small-scale spatial and temporal variability. Consequently, runoff and erosion models, as a support for mitigation practices, are limited in their predictive capabilities as the required input data is typically not available.

Given the recent development in light-weight (imaging) spectroscopy sensors, we performed a pilot study to assess the capability of a set of UAV-borne sensors to detect changes in key soil surface properties affecting runoff and erosion: these include soil crusting stage, micro-scale roughness and residue cover.

During a first phase, a set of laboratory experiments with a rainfall simulator and soil box-plot samples have been carried out to artificially generate soil crusts in structural and depositional stages. Water and sediment discharge have been collected and measured during the rainfall simulation, before and after crust development. The evolution of particles segregation and reflectance changes of the crust has then been captured, under sunlight conditions, with three multi-spectral cameras operating in the VIS and NIR domain, differing for band selection, band width and image resolution (Parrot Sequoia, Tetracam, Canon S110 NIR) and one miniature spectrometer (OceanOptics STS series). A ASD FieldSpec was used for reference measures. A similar experiment was carried out under real-life conditions on a bare, agricultural field, before and after natural rainfall events. With the same sensors, at this time mounted on a UAV, we acquired images at different altitudes (thus with different GSD – Ground Sampling Distance) of permanent plots, to evaluate the capability to distinguish crust types and residue cover through multi-spectral analysis, and roughness through photogrammetry.

Preliminary results from the laboratory experiment show that specific spectral signatures can be employed to distinguish crusted from non-crusted soil, also in accordance with previous studies. On the field, uncertainties on spectral results in crust detection raise with the GSD, while roughness and residue cover can be determined with acceptable accuracy. Finally, and based on this analysis, we discuss the potential and limitations of UAV-borne spectral sensors to detect the spatial and temporal variability in soil surface conditions.

keywords: *proximal sensing, soil surface, rainfall-runoff, soil crusting, imaging spectroscopy, UAV*

The spatial variability of soil's plant-available water capacity, and its implications for site-specific management

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The plant-available water capacity (PAWC) of soil is an important determinant of yield, and has been identified as one of the major sources of variability in grain yield within a field. Knowledge of the spatial variability of PAWC within a field is useful for site-specific management. However, field measurements of PAWC are costly and time consuming. We measured the spatial variability of apparent electrical conductivity (ECa) using Geonics EM38 sensor at times when soil the profile was wet and dry, in order to infer PAWC for three cropping fields near Biloela (Site 1; 64 ha; 24º33' S, 150º54' E), near Goondiwindi (Site 2; 257 ha; 28º18' S, 150º31' E) and near Moree (Site 3; 189 ha; 29º03' S, 149º81' E) in north-eastern Australia. The simple regression model showed a significant relationship between ECa (measured in both vertical and horizontal dipole modes at the wet and dry profiles) and profile volumetric moisture to 1.5 m. The coefficient of determination between measured soil water and profile-average ECa in vertical dipole mode were substantially higher than profile-average ECa in horizontal dipole mode, therefore, we used profile-average ECa in vertical dipole mode to predict soil profile's PAWC. Variability of predicted PAWC with measured PAWC showed reasonably good agreement ($r2 \leq 0.29$-0.49). The areas with low PAWC matched reasonably well with areas that had higher concentrations of subsoil Cl- and higher surface-soil exchangeable sodium and/or magnesium. We delineated potential management classes using spatial and temporal variability of grain yield and ECa in vertical dipole mode. To determine if management by potential management classes was justifiable over conventional uniform field management, we conducted on-farm replicated experiments and simulated grain yield using a farming system model APSIM (Agricultural Production SIMulator) run for different growing seasons for winter wheat (1970-2012). Consistent with on-farm experiments, the simulation results justified dividing Site 1 and Site 3 into management classes, though differences between the simulated yields for the two zones at Site 2 were not significant. Results from on-farm experiments also suggested that application of ameliorants in low PAWC areas, and varying fertilizer nutrients input with spatial variability of PAWC, could improve profitability, and also reduce nitrate-N losses. The results underpin the value of PAWC at fine spatial resolution, for farm-scale decision making to improve economic and environmental outcomes.

keywords: *Plant-available water capacity, Electromagnetic induction, Management classes, Agricultural Production SIMulator, On-farm experiments*

Evaluating recent and sub-recent magnetic impact records of air pollution by combined soil and bio-magnetic monitoring

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Particulate matter (PM) from several emission sources typically exhibits an elevated level of magnetism compared to uncontaminated soils or plants. Through prolonged deposition of these particles, historical pollution can be reflected by an increase in soil magnetism, whereas the seasonal emission impact is captured in the vegetation. Our study combined soil magnetic susceptibility mapping with bio-magnetic vegetation monitoring to assess the impact of airborne pollution and to distinguish between sub-recent and recent air pollution, respectively.

Magnetic measurements were conducted across a 90 ha pinewood near the Ghent (BE) harbor area, situated on a large coversand ridge. The diamagnetic sandy soil rendered only negligible magnetic influence, so that anthropogenic enhancement of soil magnetism could easily be discerned from the natural background signal. Topsoil and downhole mapping revealed enhanced magnetic signals in the upper, organic soil horizont, while the spatial surface distribution revealed a clear pattern of higher values towards the harbor area. Lastly, the correlation between the magnetic signal and heavy metal concentrations in soil samples was investigated, revealing correlations up to 0.88 for selected elements. As such, the magnetic soil map can be interpreted in terms of a qualitative pollution distribution map.

While extreme magnetization was also attested on understorey vegetation samples (blackberry and fern leaves), the observed spatial distribution was more diffuse, potentially relating to the complex short-term deposition and throughfall processes of PM in the forest. In addition, poorer correlations were observed between the magnetic signal of the vegetation and the heavy metal loadings (up to 0.66). This could possibly relate to the abovementioned processes, to recent changes in industrial emission patterns or to the internal uptake of heavy metals by plants.

These preliminary analyses show the potential of evaluating the impact of recent and sub-recent airborne pollution by soil magnetic proxies and bio-magnetic monitoring. However, specific issues (e.g. upscaling, varying land use, vegetation and soil heterogeneity) need to be taken into account when optimizing the reproducibility of such an approach. Along with a presentation of the preliminary analyses of combined mapping of soil and vegetation magnetization, we will therefore discuss the potential and pitfalls of the approach.

keywords: *environmental magnetism, bio- and soil monitoring, anthropogenic pollution*

Ecosystem services provided by groundwater dependent wetlands in karst areas: carbon storage and sequestration

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Turloughs are topographic depressions in Irish karst, which are intermittently flooded on an annual cycle via groundwater sources and have substrate and/or ecological communities characteristic of wetlands. Turloughs are designated a Priority Habitat in Annex 1 of the EU Habitats Directive (92/43/EEC) as well as GWDTEs under the Water Framework Directive (WFD).

These ecosystems, if properly managed, yield a flow of services that are vital to humanity, including the production of goods (e.g., food), life support processes (e.g., water purification), and life fulfilling conditions (e.g., beauty, recreation opportunities), as well as the conservation of options (e.g., genetic diversity for future use). One of these services is the sequestration of carbon which is linked to climate change, one of the most serious environmental threats facing humanity.

The InVEST software was used to estimate the potential for carbon storage and sequestration. InVEST is a multi-module tool developed to inform decisions about natural resource management. Maps of land use and stocks in four carbon pools (aboveground biomass, belowground biomass, soil, dead organic matter) from previous surveys were used to estimate the amount of carbon currently stored in the landscape. Additional data on the market or social value of sequestered carbon and its annual rate of change, and a discount rate were also used in an optional model that estimates the value of this ecosystem service to society.

keywords: *Turloughs, groundwater dependent wetlands, Irish karst, ecosystem services, soil carbon sequestration, climate change*

Spatial explicit prediction of soil organic matter using a hybrid model composed of random forest and ordinary kriging

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Soil organic matter (SOM) has been identified as a key element in soil fertility and also in the global carbon cycle. SOM content of 0–20 cm topsoil is the essential to regional agro-ecosystem models. Reliable assessment of the spatial distribution of SOM content and its dynamics provides a valuable base against subsequent evaluation of soil measurements and agro-ecosystem models. Most digital soil mapping (DSM) relied on spatial correlation (e.g., Kriging, IDW) only, which is not always effective for DSM. Hence, this should be improved by integrating external auxiliary data. This study conducted a extensively soil investigation on cropland of Zhejiang, eastern China from 2007 to 2008, and a total of 35,571 soil profiles was collected. Soil properties, including SOM, soil total nitrogen, soil pH, bulk density and cropping pattern, were measured/recorded in laboratory tests/soil investigation. The satellite-derived data, such as nomalized difference vegetation index (NDVI), elevation, and land cover, was also extracted and integrated with soil properties and climate data as the external auxiliary data. Then, A hybrid method (RFOK), which is composed of random forest (RF) and ordinary kriging (OK), was adopted to evaluate spatial characteristic of SOM concentration. In this RFOK method, RF was used to address the association between external auxiliary data and SOM content, OK was used to address spatial correlation among the residuals generated in the RF stage. Meanwhile, the SOM spatial distribution was also interpolated by using ordinary kriging (OK) method for comparison purposes. The results showed that the prediction accuracy of SOM by using RFOK with the inclusion of auxiliary information in the hybrid model ($R2 \leq 0.73$, $RMSE \leq 5.63$) was better than using only OK ($R2 \leq 0.56$, $RMSE \leq 8.09$). The partial dependence plot showed that soil total nitrogen, bulk density, the climatic factors are considered as the most important indicators, while the effect of the soil texture, slope and elevation on the SOM content is negligible. It was also observed that the mean SOM concentration ranged between 2.3 g kg−1 and 46.8 g kg−1 in the top 20 cm, and the spatial distribution of the SOM content with a 250m spatial resolution in eastern China was achieved. Incorporating satellite-derived data, soil properties and land cover information can improve accuracy of SOM mapping and this is expected to be useful in future DSM activities.

keywords: *random forest, nomalized difference vegetation index (NDVI), regression model, residues kriging, variable importance*

Identifying soil management zones in a sugarcane field using proximal sensed electromagnetic induction and gamma-ray spectrometry data

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Over 70% of the Australian sugarcane industry operates in alluvial-estuarine areas characterised by sodic and infertile soils. There is a need to supply ameliorants and improve fertilisers and minimise off-farm pollution to the Great Barrier Reef. Therefore, information is required about the spatial variation in soils. However, traditional approaches are cost-prohibitive. Herein we showed how a digital soil mapping (DSM) approach can be used to identify soil management zones. In the first instance, ancillary data, including electromagnetic induction and gamma-ray spectrometry data were collected. Using a fuzzy k-means clustering algorithm management zones from two to six were identified. Using restricted maximum likelihood (REML) analysis of various topsoil (0–0.3m) and subsoil (0.6–0.9m) physical (e.g. clay) and chemical (e.g. exchangeable sodium percentage [ESP], exchangeable calcium and magnesium) properties, 3 zones were determined from minimising the mean squared prediction error. To manage the moderately sodic topsoil ESP of zones 3A and 3C and sodic 3B, different gypsum requirements were prescribed. Lime can also be added differentially to address low exchangeable Ca in zone 3A, 3B and 3C. With regard to exchangeable Mg, zones 3A and 3C do not require any fertiliser, whereas zone 3A requires the addition of a moderate amount. The results were consistent with percentage yield variance, suggesting the lower yield in 3C due to topsoil sodicity and strongly sodic subsoil with higher clay content. We concluded that the DSM approach was successful in identifying soil management zones and can be used to improve structural stability and soil fertility.

keywords: *DUALEM-421S, RS-700, fuzzy k-means, digital soil mapping, sodicity, yield*

Evaluating the potential of simulated soil clay content by SoilGen2 model as soft data in Regression Kriging in sparsely sampled areas

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Models for soil evolution are progressively becoming invaluable tools to provide soil information. SoilGen2 model is one of such models with capabilities to simulate soil formation over multi-millennia time scale. This research aims to evaluate the potential of simulated soil clay content by SoilGen2 model as soft data in Regression Kriging in sparely sampled areas. An area of 201 km^2 was chosen in the North of Vietnam to collect 100 soil observations which were then analyzed for Clay content of the topsoil in the laboratory. Besides, SoilGen model was used to simulate the Clay content for 2000 years at the same locations, using a uniform substrate (both spatially and in depth) as initial status. The simulated clay contents (soft data) then replaced, after an error correction by linear regression, the measured clay contents (hard data) in the input dataset for regression kriging with 4 proportions: 100% of hard data, 50% of hard data and 50% of soft data, 25% of hard data and 75% of soft data, 100% of soft data. In regression kriging, the hard data will get the weight 1 and the soft data get a weight representing 1/1+variance. There are six predictive covariates linked to the soil formation factors including geology, land use, elevation, slope, topographic wetness index (TWI), land use normalized difference vegetation index (NDVI). In order to estimate modelling uncertainty and compare model performance for different dataset combinations, a 10-fold cross validation scheme was computed. The results in terms of RMSE and ME are calculate for each dataset combination to evaluate the added value of simulated data in Regression kriging. The research results may help to improve the efficiency of Digital Soil Mapping by adding soft data in developing countries like Vietnam where the funds for soil sampling are very limited.

keywords: *SoilGen2, Regression Kriging, Clay content*

Orthogonalisation and standardisation as alternatives to improve predictions of soil properties and lime requirement using on-the-go Vis-NIR-SWIR spectroscopy

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Reflectance spectroscopy has increasingly been proposed as an alternative to describe soil properties. Acquisition of on-the-go spectral data in the field has several advantages over static approaches, like deriving information with high spatial density. However, some issues arise from this acquisition approach due to sensor movement and heterogeneous soil condition in the field. Methods for correcting for these matters, like external parameter orthogonalization (EPO) and direct standardization (DS), have been applied so far mainly to correct for "in situ" factors when static field measurements were taken. In this study, EPO, DS and orthogonal signal correction (OSC) are tested in the context of on-the-go spectra acquisition for prediction of soil properties, in special properties related to liming (i.e. pH in CaCl2, pH in SMP buffer, organic matter, calcium and magnesium content, potential acidity, sum of basis, cation exchange capacity and its saturation by basis, lime requirement and moisture content). Correction methods slightly improved prediction accuracy of lime requirement, for instance, with RMSE reduction from 1.43 to 1.17 ton ha^{-1}, for study site 1 after OSC, and from 0.59 to 0.44 ton ha^{-1}, for study site 2 after DS. However, models based on laboratory data still had considerably better performance with RMSE of 0.99 and 0.43 ton ha^{-1} for site 1 and 2, respectively. "Global" (i.e. one general correction model for a given field) or "specific" models (i.e. multiple correction models, derived according to clusters indicated by fuzzy k-means algorithm applied to OSC components) performed considerably worse in comparison to other studies, and application of "specific" models did not improved correction results. Probably on-the-go data acquisition causes inconstant issues and interaction between them can occur, which decreased efficiency of the correction methods tested. Considering the high sensitivity of predictions based on field data to the approach used to interpolate spectral information and the relatively poor performance of correction methods, more investigation is need to improve predictions based on on-the-go spectral readings using external parameters removal. Homogeneous spatial distribution of factors not related to the properties of interest (i.e. external factors), or at least in a degree allowing correction, may not happen when current measurement systems are used and these need further development considering these issues.

keywords: *soil chemical properties, proximal soil sensing, external parameter orthogonalization, direct standardization, orthogonal signal correction.*

Use of GPR in evaluation of iron ore tailings deposition characteristics in the River Doce Basin - Brazil

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The disruption of the Fundão dam in Mariana-MG-Brazil in 2015 led to the spill of 46 million m^3 of iron ore tailings in the Rio Doce basin, one of the most damaging in Brazilian history, and worldwide. Knowing the dynamics of tailings deposition features and depth. along the terraces and floodplains, under traditional agro-pastoral uses, is fundamental for developing tailored recovery plans. The objective of this work was to evaluate the best electromagnetic frequency to identify the depth and internal fesatures of the sedimentary tailings in a tributary of the Rio Doce through the Ground Penetration Radar (GPR). GPR techniques allow detecting different layers of materials according to their dielectric properties. GPR emits and receives electromagnetic waves through antennas that, when processed in a computational environment, generate radargrams where it is possible to distinguish and analyze the behavior of soil characteristics in subsurface. The study area is located at coordinates 20.29635 ° S / 043.19537 ° W. We used the GPR model SIR-3000 and 3 antennas with frequencies of 200, 400 and 900 MHz, using ranges of 7, 3 and 1 meter respectively. A 10-fold constant was adopted for the tailing, classified as sandy loam by textural analysis A transect of 36 meters perpendicular to the river bank was done to evaluate the behavior of the tailings. Undisturbed samples were collected at depths 0-10 and 10-20 cm and soil density and moisture of the tailings were evaluated by volumetric method. The GPR data were processed in the Radan program 7, in which radargrams obtained were submitted to filters to remove noise and improve the electromagnetic signal. It was observed that the deposition depth varied from 10 cm to 1 meter, with a clear limit with the subsurface truncated horizon of the underlying soil. At between 10-22 meters from the river bank, we noticed a atipical signal in the radargram, where large differences in grain size and moisture of the tailings were detected. This anomaly is observed at a depth of 5.5 meters, and captured by the 200 MHz antenna. With the 400 MHz antenna that penetrated to the depth of 2.5 meters it was possible to better distinguish wetter areas, while with the antenna of 900 MHz gave the best radargram detail at 80 cm range. Moisture analyzes in the horizon of 0-10 cm and 10-20 cm were 0.13% and 0.15%, respectively, with no significant differences. However, the radargram showed great contrast between the talings deposit (wetter) and the underlying soil. The 900 MHz antenna allowed a better distinction of the surface material, but no resolution for estimating the depth, easily identified by the 400 MHz antenna. Thus the combined use of 900 and 400 MHz antennas were efficient for the in situ analysis of the tailings depth and features.

keywords: *Dielectric constant, Iron mining, Technosols*

A graphical user interface in R to perform preprocessing, multivariate modeling and prediction using spectroscopic data

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Alrad Spectra is a graphical user interface (GUI) implemented in R programming language. It uses spectroscopic data to process the spectra and then generate models to predict the Y variable. The GUI was developed to accomplish tasks such as perform a large range of spectral preprocessing techniques, implement several multivariate calibration methods, statistics assessment, graphical output, validate the models using independent data sets, and predict unknown Y variables. Alrad Spectra has four main modules: Import Data, Spectral Preprocessing, Modeling, and Prediction. Data file can easily be loaded by the Import Data module. In Spectral Preprocessing module, the preprocesses available are smoothing, binning, absorbance, detrend, continuum removal, Savitzky-Golay derivatives, standard normal variate, multiplicative scatter correction, and normalization. The spectral curves and data table of each preprocessing can be saved whenever required. In the Modeling, predictive models can be built by different multivariate calibration methods such partial least squares regression, support vector machines, random forest, artificial neural network, and Gaussian process regression. The Prediction module is implemented in order to predict the Y variable using the built models. The capacity of performing multiple tasks, being free and open-source, easy to operate, and requiring no initial knowledge of R programming language are features that make Alrad Spectra a useful tool for general public, researches, precision agriculture managers, and for the usage in analytical laboratories. The implementation of Alrad Spectra is demonstrated by applying visible near-infrared reflectance spectroscopy for soil organic carbon prediction. The greatest SOC prediction performance was achieved by partial least–squares regression model with standard normal variate spectral preprocessing ($R^2 \leq 0.81$, RMSE$\leq$0.51%, RPIQ$\leq$2.84).

keywords: *Chemometrics analysis, Visible Near-infrared spectroscopy, R programming, Soil organic carbon*

Rapid detection of alkanes and polycyclic aromatic hydrocarbons (PAH) in oil-contaminated soils using visible near-infrared spectroscopy and chemometrics

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The recent developments and applications of rapid measurement tools (RMT) such as visible near-infrared (vis-NR) spectroscopy can provide 'fit for purpose' and cost effective data for informing risk assessment and managing oil-contaminated sites. While vis-NIR spectroscopy has been used to detect and quantify on-site hydrocarbons in soils and sediments, it is not appropriate for the elucidation of hydrocarbon compound structures and therefore advanced chemometrics methods are needed to expand the applicability of vis-NIR spectroscopy. In the present study, 74 oil contaminated soil samples collected from the Niger Delta were scanned using an analytical spectral device spectrophotometer with a spectral range of 350-2500 nm. The vis-NIR signal for each soil sample was then analyzed using partial least squares regression (PLSR) and random forest (RF) regression. Reference alkanes and PAH fingerprints of the oil-contaminated samples were determined using sequential ultrasonic solvent extraction followed by gas chromatography- coupled to mass spectrometry (GC-MS) analysis. Prior to the model development, spectra were subjected to pre-processing including successively, noise cut, maximum normalization, first derivative and smoothing. The pre-processed spectra were divided into calibration (75%) and validation (25%) sets. The alkane and PAH concentrations determined by GC-MS and the vis-NIR based spectra were subjected to PLSR and RF with leave-one-out cross-validation (LOOCV) to establish calibration models. Results showed that RF calibration models for both alkanes and PAH outperformed PLSR, indicating that vis-NIR signal acquisition followed by RF can provide a rapid and cost effective means to inform risk assessment for oil-contaminated sites.

keywords: *Total petroleum hydrocarbons, vis-NIR spectroscopy, chemometric methods, site investigation*

A combination of soil sensors provides useful and efficient landscape genesis information for archaeological prospection

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A combination of EMI, GPR, gammaspectrometry and archaeological soil profiling was used in a commercial project to map the landscape genesis, soil lithology and the archaeological potential of a 50 ha development area. This was more efficient and yielded better and more detailed results than a traditional archaeological mapping with twice the budget could have done. The area consists of recently equalised river terraces of the river Meuse in the Netherlands which have formed by a meandering river on top of braided river sediments that have been effected by wind erosion. The three sensor techniques were applied on a 10 m grid. 30 ha were measured with a MS4000 gammaspectrometer and 300 MHz Zond GPR and 30 ha were measured with a Dualem 21S EMI system. The zones had a 5 ha overlap. The raw geophysical data were used for planning the archaeological test pits and soil profile transects perpendicular to the variation (196 soil profiles of 0-2 m). These results were then used to interpret the geophysical data. This provided a detailed insight in paleo- and current landscape genesis and lithology up to 2 to 4 m depth. Based on both paleolandscape and current disturbances the archaeological potential was derived and verified using 300 new soil profiles. This validation showed that 80 % of the lithological variation in this complex area had been mapped. The high level of detail, the improved understanding of the spatial structure and the joint coordination of geophysical and archaeological mapping allowed for a better comprehensive geomorphogenical and archaeological interpretation than would have been possible otherwise. The techniques applied, although of limited use separately, complemented each other in depth range and precision, spatial detail and type of soil texture information. This led to a high quality result within a limited budget. The gammaspectrometer raw data provided a reliable variation map of the topsoil, concurrent with soil type variation. The GPR showed detailed soil textural layering and accurate depths in combination with the profiles. Especially the archeologically relevant gravel layer was mapped well. The EMI yielded detailed shallow soil texture variation, some old ditches and recently disturbed zones. It also provided rough texture indications for the deeper soil layers. As a recommendation to the Province of Limburg, the client, an optimal workflow has been formulated using GPR, EMI and archaeological profiling. The results are also useful in the geotechnical planning of the development area.

keywords: *Soil sensing, EMI, GPR, Gammaspectrometer, Archaeology, Lithology, Prospecting, Geomorphogenesis, Lithogenesis, River-terrace*

Assessment of soil ecosystem services at landscape scale by direct soil monitoring and modelling.

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Soil is a natural capital that provides several ecosystem services that ensure human wellbeing and sustainable socio-economic development. Among international researchers, the landscape scale is considered the relevant scale to assess soil ecosystem services. This spatial scale allows a biophysical evaluation to take into account both landscape features and management practices. The aim of this study was to develop a methodology to quantitatively evaluate and map two environmental regulation ecosystem services - carbon sequestration and erosion regulation. In a 10 km^2 study area in north-western France (Brittany), sixty-four soil observations were selected using the conditioned Latin hypercube sampling method. This approach used elevation, a topographic wetness index, natural gamma emission of potassium, and grassland frequency over 15 years to select points with a good representation of the study area. The biophysical quantification of climate-regulating ecosystem service was based on the changes in the soil organic carbon (SOC) stock over a period of seven years. The assessment of erosion regulation ecosystem service was based on the observed difference between potential and present soil erosion, both estimated by the Revised Universal Soil Loss Equation (RUSLE). To characterize spatial distribution of climate-regulating ecosystem service, two approaches were used. The first was to spatialize the changes in SOC stock using a soil digital mapping approach with the Random Forest method and a calibration dataset of 64 points. The second was to assign a value of the indicator for each type of land use. Uncertainties related to the soil ecosystem services estimations were also investigated using the Monte Carlo approach. The main results of this study were: 1) inherent soil properties especially soil waterlogging and land use trajectory were the most explanatory factors for the spatial distribution of carbon sequestration; 2) the erosion regulation ecosystem service was highly correlated with topographical factors; 3) interactions (situation of synergy and antagonism) between selected soil ecosystem services were mainly dependent on landscape features and land use. Overall, providing a biophysical evaluation of soil ecosystem services in coherence with agronomic decision scales, is still a challenge. Moreover, multiscale assessment of soil ecosystem services, taking account of the various soil processes evolution over time, allows comparison of actual situations with the five dimensions of soil security. These projections have implications for future planning monitoring of agro ecosystems, and can be integrated into land use decision-making.

keywords: *Direct soil monitoring, Soil ecosystem services, Landscape scale, Conditioned Latin hybercube sampling method, Uncertainty propagation*

Measuring functional pedodiversity using spectroscopic information

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Pedodiversity studies greatly depend on the discretization of the soil continuum via various soil classification standards. Soil taxonomic systems are constructed considering soil properties and their organization in the soil profile. Therefore, it seems logical that the pedodiversity of an area could be calculated by considering the simultaneous variation of multiple soil properties within that area. With the aim of creating a bridge between these two lines of thinking, this study presents the development of two new indices of pedodiversity (HULLdiv and EIGENdiv) which consider continuous variables as input.

The soil input information tested was a) Visible and Near Infrared (Vis-NIR) reflectance values and b) values of five soil properties predicted from Vis-NIR spectra. Both indices were employed to measure the pedodiversity at different extents in two perpendicular transects containing 27 (North to South) and 22 (East to West) locations respectively in New South Wales (NSW), Australia. Each location considered natural and intervened land use. The indices successfully represented the pedodiversity of the area of study, however they were different depending on the input soil information i.e., raw Vis-NIR and predicted properties. HULLdiv was affected by extreme soil observations and as a result its discrimination power between areas with different soil diversity was inferior.

On the other hand, EIGENdiv represented well the pedodiversity of an area, despite the extreme observations. The results showed good agreement with conventional methods for assessing pedodiversity i.e., Shannon's and Simpson's indices. However, the new indices were more discriminating by being able to better represent the landuse effect. This study represents the first attempt to measure pedodiversity in a continuous way using Vis-NIR information.

The previous results are presented in Fajardo et al. (2017). This work will give an insight of the practical use of these indices as well as examples using other datasets not presented in the original publication.

Fajardo, M.P., McBratney, A.B., Minasny, B., 2017. Measuring functional pedodiversity using spectroscopic information. CATENA 152, 103-114.

keywords: *Pedodiversity, Functional Diversity, Multidimensional space, Convex Hull, Eigenvector*

Slakes: A soil aggregate stability android application

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We have developed a new methodology for the assessment of soil slaking in the form of a smart phone application (Android). First, we had developed an image recognition algorithm that measures the projected area of soil aggregates immersed in water at regular intervals. Our results showed that the kinetics of the slaking process can be effectively modelled using a three coefficients model (a, b and c), which are closely related to selected soil properties and land-use.

Coefficient a, is equivalent to the maximum slaking potential of the samples, and is found to be linearly related to exchangeable sodium, pH, clay percentage, calcium/magnesium and total carbon/nitrogen, and non-linearly related to total carbon. The coefficients b and c reflect the initial slaking and the slaking rate respectively and these were found to be linearly related to nitrogen and total carbon.

The originally methodology was presented in Fajardo et al. (2016) using a dataset covering great part of the agro-ecological variability of New South Wales (NSW), Australia. In this dataset, the coefficient a, was significantly lower in the natural sites reflecting a higher aggregate stability in those soils.

Having observed the potential of the methodology, we developed a smart phone application that is capable to measure the projected area of soil aggregates immersed in water in time, fit a model and return coefficients that can be finally used as a soil aggregate stability indicator.

Fajardo, M., McBratney, A.B., Field, D.J., Minasny, B., 2016. Soil slaking assessment using image recognition. Soil and Tillage Research 163, 119-129.

keywords: *Android, Image recognition, Soil Aggregate stability, Digital Soil Morphometrics*

Soil NIR-spectra and high-resolution satellite images to monitor the characteristics of active layer most related to permafrost thermal behaviour, Crater Lake CALM site, Deception Island, Marine Antarctica.

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The test was performed in Crater Lake CALM (Circumpolar Active Layer Monitoring) site. The CALM site is equipped among others with 5 sensors of surface soil temperature, 7 deep boreholes, and 2 air temperature sensors. There are also a CALM net consisting of 16 shallow boreholes (depth of 45 cm) homogenously distributed every 20 meters in the CALM plot. The boreholes are equipped with i-button sensors, which have been recording permafrost active layer temperature data every three hours, every day since 2008. In December 2016, during the last steps of the snow cover melting and the beginning of the permafrost active layer, the surface soil layer of the CALM site was sampled. Soils around the 16 short boreholes were taken. Using a fine borer, the thickness of the active layer was also measured in each short borehole during five consecutive times in alternate days. In laboratory, texture and mineralogy of all samples were analysed. NIR-spectra of the samples were also taken to obtain the spectral signature and quantify the soil colour. The main objective of this test is looking for relationships among the measured soil properties, thermal behaviour, and the evolution of the active layer thickness in the early stages of the snow cover melting. NIR-spectra of soil will be used to build transference functions between the active layer properties most related to the thermal behaviour and satellite images with high spatial resolution, such as QuickBird and WorldView II.

keywords: *permafrost, active layer monitoring, NIR spectra, satellite images*

Large scale modelling of soil organic matter using DTM variables and geographically weighted regression

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Terrain attributes derived from digital elevation model (DEM) have been used widely for mapping soil organic matter (SOM). There are significant correlations between terrain variables and SOM. Terrain variables are exhaustive and spatially extensive and provide potentially voluminous data sets with relevant information at unsampled locations. Nevertheless, at large scales and depending on the geological and geomorphological setting the correlations between DEM variables and SOM could have geographical variations. The use of Geographical Weighted Regression method (GWR) could be very useful to discover spatial patterns of SOM associated to geomorphological features. In this paper 350 soil samples distributed over an area of 10.600 km^2 was used to analyse the relation between relive variables and SOM. Altitude, slope, distance to the coast, aspect, seasonal radiation and climate variables as average annual temperature and precipitation were calculated at 200 m of pixel size. The calculated DEM variables and concentration of SOM were analysed using GWR. As result the variables distance to the coast, altitude and winter radiation explain the most part of the variance (R, 54) in the model. But the coefficients of the regression equations show geographical dependence. These results have to be interpreted in relation to the lithology and geomorphological evolution of the studied area.

keywords: *Soil Organic Carbon, Digital Elevation Model, Geographical Weighted Regression, Mapping soil*

Laser scanner technologies to monitoring mountain peatlands recovering

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The present research is part of a Life Project entitled "Inland Wetlands North of the Iberian Peninsula: Management and restoration of wetlands and hygrophilous environments" TREMEDAL (LIFE 11/ENV/ES/707), in which 25 wetland sites spread all over the north of Spain were selected to be analyzed. In fact, the aim of the project is to protect and restored those sites as well as to improve their conservation status and store seeds of bog plant species.

Comella Polje, a glacio-karstic depression site in Picos de Europa National Park (in Asturias Principality) harboring the most biodiverse peatland plant communities in the Cantabrian Mountain Range is one of the TREMEDAL test sites. The total exclusion of livestock and wild herbivores in three parcels of this area is expected to be followed by changes in top soil morphology and water table regimes with consequences in the evolution of peatland hubs and vegetation.

To quantify the impact of grazing exclusion in the evolution of peatland hubs and rates of vegetation growth, a series of very detailed topographic surveys were made using a terrestrial laser scanner (TLS). The point cloud obtained has a great density (about 0.2 points/cm2), providing a good approximation to the real topography. Both, the terrain inside and outside the parcel are being measured at intervals of one year and compared in order to find differences in the vegetation growth patterns. In 2013, 2014, 2015 and 2016 points clouds were obtained. The comparation between the four DTM obtained show significant differences in terrain elevation between points inside and outside the plot. Also, the recovery of natural vegetation along the analyzed time period provokes irregular distribution of the altitudes inside plot. This result confirms the initial hypothesis that the impact of animals on the vegetation growth could be quiantify using lasser scanner technologies.

keywords: *Recovery vegetation monitoring, Laser scanner, Digial Terrain Models*

Using a Portable XRF for Classifying Volcanic Paddy Soils of West Sumatra, Indonesia

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This study investigates geochemical data obtained rapidly from a portable X Ray Fluorescent can be used to classify paddy soils derived from volcanic ash in Western Sumatera, Indonesia. Seventy-nine paddy topsoil samples were collected in along an altitudinal gradient of 44 – 1220 m a.s.l along areas if mountain (Mt) Marapi, Mt. Sago, Mt. Singgalang, Mt. Tandikek and Caldera Maninjau. Geochemical analysis was carried out using a portable x-ray fluorescent spectrometer (XRF).

Linear discriminant analysis was carried out using 10 geochemical concentration of soils as input (SiO2, Al2O3, Fe2O3, CaO, MgO, K_2O, SO3, P_2O_5, Ti and Zr). The results showed that geochemical characteristics of topsoils derived from different volcanoes are distinct. Mahalanobis distance statistic clearly separated soils of Mt. Sago with other four soils. Soils from Mt. Marapi were also dissimilar with other three soils, while soils from Mt. Singgalang-Tandikek and Maninjau were more related. Clear differentiation among weathering indices was also observed, and the following sequence of the degree of weathering can be inferred: Sago > Maninjau > Marapi > Singgalang-Tandikek.

In conclusion, although the soils have been cultivated with paddy for hundreds of years, they still retain distinct geochemical signatures that can be revealed using a portable XRF. Portable XRF offers a rapid analysis and classification of volcanic soils.

keywords: *Weathering indices, Discriminant analysis, X-ray fluorescent, Andisols.*

Quantifying the uncertainty in a model reconstruction of a soilscape for archaeological land evaluation

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Process-based soil development models can be applied as temporal interpolators to estimate soil properties at points in time. In geo-archaeological studies, the (pre-)historical state of soil and landscape is reconstructed to better understand the land occupation history and its spatial patterns. We reconstructed a Middle Bronze Age (MBA, 1331 BCE) soilscape for part of Flanders using a simulation model for groundwater flow (MODFLOW) in combination with a soil formation model (SoilGen). The reconstructed groundwater data related to 40x40 m2 cells at full spatial coverage while the reconstructed soil data pertain to the pedon scale at 97 locations. As these data were to be used for a land evaluation for a Bronze Age Land Utilization type, the reconstructed soil data must be interpolated to full extent.

At the simulation locations, values of soil and groundwater properties were known from the mapping (1953) so that simulation errors could be quantified. Under the assumption that model errors were similar in the MBA and 1953, we investigated how errors in the modelling and the spatial interpolation contributed to the uncertainty in the land evaluation. The effect of error of the soil and groundwater models was assessed by generating perturbations of soil and groundwater data using Choleski decomposition of the error-covariance matrix at the 97 locations. The effect of the interpolation of the soil data was assessed by Sequential Gaussian Simulation of the error variogram of regression kriging. The effect of both uncertainty contributions was quantified by inserting the perturbations or realisations in the land evaluation procedure. The error leads to a diversity value connected to the land evaluation outcome at the pixel level. Diversity maps resulting from the model error and the interpolation error were created and compared, and the soil properties that were the main contributors to uncertainty were identified. This approach gives useful information on priorities to increase reliability of such soilscape reconstruction by aiming at either a better model error (for specific properties) or a higher spatial density of point simulations.

keywords: *soil development model, soilscape reconstruction, uncertainty analysis, archaeology*

Soil hydrological classification mapping in Scotland using DSM and Random Forests

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The nature and spatial distribution of soils and their attributes have a profound influence on catchment hydrology and runoff characteristics. The Hydrology of Soil Types (HOST) classification is a classification scheme based on regional soil maps of the UK which uses expert knowledge to link soil hydraulic indicators (identified during soil surveys) with dominant runoff processes in the form of different conceptual models of subsurface runoff processes and pathways through the soil profile and/or parent material. The HOST decision scheme has been optimised by regressing base flow index (BFI) and standard percentage runoff (SPR) (both used to estimate catchment runoff response) to the proportions of various HOST classes occurring within the watersheds of selected test catchments. HOST class information in Scotland is available as dominant class (based on higher areal coverage) within each polygon of the National Digital Soil Map (1:250 000 scale).

The study presented here is part of an ongoing project which aims to explore the application of Digital Soil Mapping (DSM) techniques for mapping soil hydrological properties and regulatory functions. In particular, this study aims to investigate the performance of Random Forests (RFs) for the spatial prediction and disaggregation of HOST classes at a target 100m grid resolution. RFs were selected as the statistical inference engine due to their ability to utilise both discrete-valued and continuous valued covariates and their successful application in the spatial prediction and disaggregation of soil types. For comparison reasons, two study catchments are selected in NW and NE Scotland that have distinct differences in their soil type composition, topography and hydrological response characteristics . Training sampling points in the two catchments are determined using a random weighted-area spatial sampling scheme and the training dataset is developed using the HOST class values at each point location along with attributes derived from a collated database of environmental covariates (SCORPAN factors). Validation of the predicted HOST class spatial distribution within the study catchments is performed in two ways: a) comparison of predicted to calculated HOST class values at the profile locations of the National Soil Inventory of Scotland (NSIS) and b) comparison of catchment hydrological response based on the proportions of predicted and existing HOST classes. Study results are expected to help improve hydrologic response predictions at small ungauged catchments and provide new insight on the coupling of DSM and hydropedological datasets.

keywords: *HOST, hydropedology, DSM, Random Forests, spatial prediction*

GIS-based multivariate predictive models for gully erosion susceptibility mapping in calcareous soils

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Gully erosion susceptibility mapping (GESM) is essential to take preventive or control measures, reduce environmental damages and economical costs produced by gully erosion in arid and semi-arid area. The purpose of this study is to produce GESM using different data mining models in calcareous soils at Ekbatan Dam drainage basin. Three modeling technique, Generalized Linear Model (GLM), Random Forest (RF) and Multivariate Adaptive Regression Spline (MARS) are used and their results are compared for GESM. The study area is an 18.5 km^2 located at Ekbatan Dam drainage basin (Hamadan-Iran), where agriculture activities are limited by intense erosion. By means of extensive field surveys, GPS route of gullies and visual interpretation of satellite images available from Google Earth, we prepared a digital map of the spatial distribution of gullies in the study area. To prepare explanatory variables that affected soil erosion, using the conditioned latin hypercube sampling (cLHS) technique and free survey 130 locations were sampled to create spatial distribution of some soil properties. DEM-derivatives, land use and normalized difference vegetation index (NDVI) maps created by stereo imagery of Spot-6 satellite. Geology map digitized from 1:100,000 scale geological scanned map of Hamadan Province. Road and river networks, derived from 1:25,000 scale topographic maps. The functional relationship between gully erosion occurrence and controlling factor were calculated using the mentioned models (GLM, RF, and MARS). The performance of each models was evaluated using the receiver operating characteristic (ROC), including the area under the curve (AUC), in 10-fold cross-validation. According to the results, RF showed the better performance (with mean AUC$\leq$94.92%) in compared with MARS (with mean AUC$\leq$87.31 %) and GLM (with mean AUC$\leq$82.88%) for calculate the probability to host a gully for each point of study area. Actually these results show that the GLM, RF, and MARS models produced reasonable accuracy in gully erosion susceptibility mapping. The outcome maps can be a useful tool for regional planners, because they assist in identifying areas at risk of gully erosion and improve our understanding of landscape evolution.

keywords: *Gully erosion susceptibility, Data mining models, ROC curve, Iran*

The I4S approach to site-specific soil fertility management based on proximal soil sensing

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In precision agriculture the lack of affordable methods for mapping relevant soil attributes is a fundamental problem. It restricts the development and application of advanced models and algorithms for decision making. The project "I4S - Integrated System for Site-Specific Soil Fertility Management" combines new sensing technologies with dynamic soil-crop models and decision support systems. On the one hand, model based knowledge about processes in soil and crops should dictate the selection of sensors for assessing soil fertility factors. However, quite often a factor cannot be measured directly by a single sensor. Using sensors with different measurement principles improves the estimation of soil fertility factors such as plant available K, P, Mg, humus and soil texture. On the other hand, soil sensors can detect properties that were not regarded in soil-crop models as inputs up to now. This may even lead to switching from mechanistic "white-box" modeling to machine learning "black-box" modeling. To become effective in soil management, sensor system and models have to be user friendly and affordable. Involving many sensors can cause technical difficulties due to interference and is expensive. Some sensor systems may emit harmful radiation such as x-rays or high power laser pulses. Choosing the appropriate set of sensors will become an important aspect of decision making in precision agriculture. So, sensor based

site-specific soil fertility management is only feasible if a decision support system regards natural processes, technical, and socio-economic options and limitations.

keywords: *Proximal soil sensing, fusion of soil sensors, soil-crop models, decision support systems, site-specific soil management*

Effects of Measurement Protocols and Data Mining Techniques on Soil Proxy Model Extraction: A Czech Case Study

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Soil spectroscopy has shown to be a fast, cost-effective, environmental-friendly, nondestructive, reproducible, and repeatable analytical technique. However, not only the soil components but also types of instruments, protocols, sampling methods, sample preparation, spectral acquisition techniques, and analytical algorithms have an influence on the spectral performance. Therefore it's important to characterize these differences and to establish a simple common standardization procedure in order to minimize the technical factors that alter reflectance spectra which will enable all users to create robust spectral models over large geographical extents. To quantify this alteration and propose a standardization method, a joint project between Czech University of Life Sciences (CULS) and Tel-Aviv University (TAU) was conducted to estimate Cox, pH-H2O, pH-KCl, Fe-d, Fe-ox, Mn-d, and Mn-ox. 78 soil samples from five agricultural lands from different parts of the Czech Republic and two different protocols for soil spectral and chemical measurement and two data mining techniques were analyzed. Spectral measurement at both laboratories was done using ASD spectroradiometer. CULS protocol was based on employing Dark Box (DB) environment, Partial Least Square Regression (PLSR) model and k-fold cross validation, while TAU protocol was carried out using a Contact Probe (CP) and Internal Soil Standard (ISS) procedure. At TAU, spectral modelling was performed using the PARACUDA II, a new machine learning and data mining engine which automatically develops 512 individual models for each soil property and evaluates the model population behavior and the best model selection under the internal calibration-validation 75%-25% technique. The results demonstrated that spectra based on the CULS setup demonstrated significantly higher albedo intensity and reflectance values relative to the TAU setup reflectance. The TAU protocol also improved the analytical results as compare to the CULS (NON-ISS) protocol; however, keeping the spectral measurement stages constant by a strict setup reduces the effectiveness of ISS significantly. The paper also highlights that PARACUDA II engine proved to be a powerful tool to assess higher results than the regular scheme such as PLSR that is traditionally used by many users. Such initiative is not only a way to unlock current limitations of soil spectroscopy, but also helps the soil society for development of an agreed-upon protocol to contribute to the construction of the Soil Spectral Libraries (SSLs).

keywords: *Soil spectroscopy, Protocol and standard, Data mining, Internal soil standard, Soil spectral library*

Soil organic carbon stocks prediction in Brazil

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This study evaluated an approach for predicting soil organic carbon (SOC) stocks in the Brazilian territory down to 1m depth for all biomes and soil types using environmental and bioclimatic variables. To obtain the highest performance of prediction we tested five machine-learning algorithms: Cubist, Random Forest, Linear Regression, Support Vector Machine, and ExtraTrees. Soil data were obtained from a compilation made by the Brazilian Agricultural Research Agency (Embrapa), based mainly in the RADAMBRASIL country survey. The dataset totalized 8,530 soil profiles with 37,939 samples, in which the main chemical and physical properties are available. From the dataset, 3,278 samples were used to adjust a pedotransfer function for estimating bulk density for missing depths, based on SOC and clay contents, using the linear regression method. To model the vertical distribution of SOC stocks we used mass preserving equal-area quadratic splines to interpolate the distribution of SOC and bulk density at standard depth intervals (0−5, 5−15, 15−30, 30−60, and 60−100 cm). The covariates database was composed of 78 variables including bioclimatic (temperature and precipitation), soil and biome maps, vegetation indexes and morphometric maps derived from a digital elevation model, with a grid of 1 km^2. To select the most important covariates for each depth we used the Recursive Elimination Feature of the Random Forest, in which the main variables selected were: precipitation, temperature, slope height, soil class, standardized altitude, terrain surface convexity and vegetation indexes (NDVI, EVI). Predictions of all machine-learning algorithms were compared using nested ten-fold cross-validation and independent validation. Independent validation was performed separating the dataset into 10 sets with 90% for training and 10% for validation. Accuracy assessments of predictions were compared by means of statistical indexes: root mean squared error (RMSE) and R-squared (R2). Overall, Random Forest showed the best performance in predicting SOC stocks for all depths, with a highest performance for 15-30 cm soil depth ($R2 \leq 0.30$, $RMSE \leq 0.94$ kg m^{-2}) and was selected for the spatial prediction of SOC stocks. In total, the soils store approximately 87 PgC within the top 1 m and the 0-30 cm layer reaches 48 PgC. Also, 30% of the total carbon stock is present in protected areas (conservation units). The Amazonia biome possesses the highest amount of carbon (44 PgC). Regarding SOC stock among soil classes, more than 53% of the total SOC stock was found in the Oxisols and Ultisols. This study is the first in predicting SOC stocks for the whole of Brazil's territory using machine-learning algorithms and could be used for future soil carbon inventories and to highlight the importance of nature reserves for protecting soil organic carbon.

keywords: *Carbon stock, Machine-learning, Organic carbon, Soil mapping*

Variation of soil property depth functions

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Soil property depth functions can be used to identify soil processes that involve translocation and transformation as well as to locate pedological and lithological discontinuities. Within a given soil, every soil property has its own vertical distribution pattern that can be expressed as a depth function. We constructed depth functions using 10 cm interval sampling in 3 soils: a Mollisol, an Alfisol, and an Entisol. We used soil property data to estimate soil property depth function types. We found that the depth function type of a soil property can vary considerably between soils. The Ca concentration depth function types were irregular (Mollisol), disjoint (Alfisol), and exponential (Entisol). We found that, within a soil, the depth function type varies between soil properties. In the Alfisol, the depth function types were exponential for soil organic carbon (SOC) concentration, minimum-maximum for pH, disjoint for Ca and Ti concentration, maximum-minimum for Al concentration and peak for Fe concentration. Some soil property depth functions reflected changes in soil horizon or parent material. The depth functions of Ca concentration in the Alfisol and SOC concentration in the Mollisol matched horizon boundaries. The Ti concentration depth function in the Alfisol reflected the change in parent material. Other depth functions (i.e. Al and Fe concentration) showed continuous changes with depth that did not overlap with horizons boundaries. It is expected that fine resolution sampling of soil profiles will result in an increased use of soil depth functions as a pedological research tool.

keywords: *digital soil morphometrics, pedology, soil depth function*

Raster sampling of three soil profiles from Wisconsin, USA

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Three soil profiles in Wisconsin, USA were sampled using a 10x10 cm raster: a Mollisol (1x1 m), an Alfisol (1x1 m), and an Entisol (1x0.5 m). The profiles were described in the field, and samples were taken from each cell and analyzed for soil color (HSV cylindrical-coordinate representation), soil organic carbon (SOC) concentration, and soil texture. SOC, texture, and color were used to revise delineation of horizons and their boundaries. Raster data verified the boundary of the Mollisol A2/Ab, the Alfisol Bt/2Bw, and the Entisol Ap/Bw1 horizons. Using clay content, an E horizon was identified in the upper part of the field-delineated Bt horizon of the Mollisol. Clay content, color and SOC concentration were also used for the Ap/Bt horizon boundary in the Alfisol. Raster data also showed considerable variation of soil properties within horizons. It is concluded that raster data can detect horizons that were not identified in the field, and can revise or verify field-delineated horizon boundaries.

keywords: *soil carbon, digital soil morphometrics, soil profiles, pedology, Mollisol, Alfisol, Entisol, soil color, soil texture, soil horizons*

High resolution modelling of soil organic carbon in West Greenland

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The soil organic carbon (SOC) pool in the first 300 cm of arctic soils includes about 50 % of the estimated global terrestrial belowground organic carbon, which makes about 1024 Pg C and up to 496 Pg within the upper permafrost one meter. The Arctic is sensitive to climate change. Hence, thawing of permafrost-affected soils to greater depth and for longer periods increases the release of CO2 and CH4 to the atmosphere, which queries soils as an important carbon pool. Especially in arctic environments, sparse soil data and limited knowledge of soil processes cause underestimation of SOC stocks. Due to different regional climatic conditions, changing soil-environmental conditions result in varying soil organic carbon contents in Greenland. In West Greenland, coastal oceanic conditions turn into continental climate at the ice margin showing less precipitation, higher insolation and increasing permafrost thickness.

This study comprises a prediction approach of SOC at two different study areas in West Greenland using digital soil mapping (DSM) and data mining (DM) techniques (e.g. Random Forest, RF). The objectives are (i) to identify major environmental factors controlling spatial variation of SOC, (ii) to create high-resolution maps of SOC (iii) and to estimate SOC stocks.

Respecting different climatic conditions, one study area is situated next to the ice margin in the Kangerlussuaq area and the second one is located near Sisimiut at the coast. Both study areas (2 km^2) are representative for each region and have similar environmental settings. Soil samples (SOC, bulk density) were taken from depth increments (0-25, 25-50, 50-100, and 100-200 cm) at 40 sampling locations in each study area. Input data of the DSM model includes soil data from fieldwork, a set of terrain attributes and remote sensing data.

First results comprise area-wide calculation of SOC stocks and dominant covariates for both study areas using RF (R^2/RMSE). Within the Kangerlussuaq study area, the average SOC stock of the upper 25 cm is 7.56 kg/m^2. There, the most important environmental variables of the RF model (0.62, 1.22) are aspect and soil moisture. At Sisimiut, using RF (0.65, 6.24) results in an average SOC stock of 12.12 kg/m^2 of the upper 25 cm and identifies elevation, aspect and vegetation as most important environmental variables. We assume for the Sisimiut area that south facing areas have high SOC stocks due to higher biomass production because of higher insolation.

keywords: *digital soil mapping, carbon stocks, machine learning*

Past, present and future of physical, chemical and biological process knowledge in pedometrics

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'Pedo' and 'metrics' emphasize two perspectives, where the former highlights pedological knowledge and the latter the methodology and computational tools used to understand the past, current, future conditions and change of soils. This understanding of pedology and physico-, biological- and chemical transformations has been transposed into sophisticated maps and models. The main focus in this talk is on the "Why" and "How" soils develop, degrade, improve or are sustained in terms of their performance to meet needs (e.g., crop yield in context of food security), functions (e.g., soil carbon sequestration), values and benefits (e.g., water holding capacity), conditions (e.g., various soil properties) or overall perceptions (soil health, quality, and security). Since the invocation of pedometrics we have seen shifts in how physical, chemical, and biological process knowledge has been incorporated in soil models. An increased understanding of relationships between environmental factors and soil properties as well as biogeochemical cycles derived from empirical measurements (e.g. vadose zone) have afforded to improve our body of knowledge. Trends to couple these soil models explicitly with the human and life dimensions are underway to move from simpler model representations (e.g., incorporation of land use) to models that explicitly account for human actions, values, beliefs, decisions, and other organisms (e.g., microbial processes) allowing improved back- and forecasting (e.g., global climate change) and evaluation of scenarios (e.g., adaptation in soil management). Improved soil-environmental data availability through remote and proximal sensing technologies combined with advancements in computational ability have afforded to build ever better soil factorial models rooted in empirical science. Specialized process-based soil models to simulate soil change (quasi)mechanistically have been used in standalone mode or embedded in holistic Earth System Simulation Models and ecosystem models. Trends and issues related to how we transpose what we know about soils at a point (site) to spatial and temporal model scales and associated uncertainties will be addressed. I will also discuss the mainstream paradigms in pedometrics rooted in empiricism and reductionism (i.e., deduct data and process-knowledge at finer and finer scales and build more detailed and complex models) in light of the needs to synthesize soil knowledge to resolve the global grand challenges and crises of our time.

Organic carbon in Swiss cropland soils 1985-2014

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Peter Schwab – Swiss Soil Monitoring Network NABO, Switzerland
Daniel Wächter – Swiss Soil Monitoring Network NABO, Switzerland
Felix Stumpf – Swiss Soil Monitoring Network NABO, Switzerland
Armin Keller – Swiss Soil Monitoring Network NABO, Switzerland

Soil organic carbon (SOC) is a key factor regarding most soil functions. However, consistent long-term data on SOC contents at national level are scarce. The Swiss Soil Monitoring Network NABO assessed SOC contents of 31 cropland sites sampled six times from 1985 to 2014. The results provide insights into the temporal evolution of SOC in Swiss croplands in the context of the agricultural management. Furthermore, the sensitivity of the used monitoring scheme may be assessed.

keywords: *soil monitoring, soil organic carbon, minimum detectable change*

Seeing inside a pedologists head: are machine learning algorithms landscape specific?

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In digital soil mapping (DSM) often only one inference method is applied or a couple are tried and the best performing is chosen based on the model validation statistics. Whilst this is a valid approach from a pedometric point of view it does not tell us if there are any underlying pedological reasons why x method was better than y. This kind of information is useful when operating at the landscape scale when strategic or policy decisions are commonly made within these contexts.

We compare a DSM taxonomic soil map produced at a national scale by Random Forests and a Bayesian network. The final soil associations were selected based on the best performing model after validation using independent field data. It is evident that some areas favour one method over the other and in other areas there is little differentiation between the two models in the landscape. Where there is a fragmented pattern in the optimal model selection this is often due to the efficacy of the training data. In landscapes where one model is obviously more successful over a wider area we discuss why this may be the case. In these areas the way the inference system makes a decision (ensemble decision trees vs conditional probabilities) and the pattern of soils within the landscape may be compatible. It could potentially identify areas where the soil patterns are more stochastic or where there are feedbacks between some of the covariates. This additional information is useful when using the soil map for strategic purposes for example for identifying areas for monitoring soil conditions or to predict a likely outcome to a perturbation such as climate change or land management.

keywords: *digital soil mapping, soil landscapes, soil monitoring*

The Pedon is at the Core of Digital Soil Morphometrics

Alfred Hartemink – University of Wisconsin, USA

The pedon is at the core of many soil investigations whether that is for digital soil mapping purposes, site characterization, or pedological research. In this talk an overview is provided how the pedon, and its two-dimensional representation (the soil profile), is studied. An overview is presented of the measurement of soil properties and morphometric characteristics, soil depth functions, and soil profile imaging and mapping. The overall purpose is enhanced understanding including more objective ways of identifying and delineating soil horizons and treating the soil as a continuum with depth. Digital soil morphometrics can be viewed as the use of proximal soil sensors and other instruments to study soil profiles. There has been considerable progress in the in-situ measurement of soil properties and soil functions linking a range of instruments with soil inference systems. Some progress has been made in the mapping of the soil profile that includes raster sampling of a soil profile wall, digital image analysis of soil profiles, and monolith scanning. This has resulted in improved soil horizon delineation and assessment of soil horizon purity, and the realization. At last, there may be a recurrent pattern in soil feature at different levels that can be studied using similar pedometrics approaches.

Validation of the 250m Soil Grids in Canada

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Xiaoyuan Geng – Government of Canada, Canada
Bert Vandenbygaart – Government of Canada, Canada
Tim Martin – Government of Canada, Canada
Tomislav Hengl – ISRIC, Netherlands
Robert MacMillian – LandMapper Environmental Solutions Inc., Canada
Cindy Shaw – Government of Canada, Canada

The latest version of SoilGrids at 250m resolution has been released. Regional assessment and verification of the released data are still needed in order to guide the use and future improvement of the data. Two sets of independent point soil data were selected to validate the predicted soil total organic carbon (TOC) of the 250m SoilGrids. The first set of point data was acquired from the Canadian Forest Service (CFS) for the non-agriculture areas in Canada. The second set was retrieved from the Canadian National Pedon Database(NPDB).

The LFH and organic horizons information is widely recorded from the pedons from non-agricultural areas. In contrast, the recorded top horizons of the pedons from agriculture regions generally of mineral provenance. The two groups of the pedon data were used separately in the validation method. All of the validation pedon points were preprocessed and modeled to uniform depths. The zero depth of each pedon was adjusted to the terrain surface, which meant no negative depth values Soil TOC values at the five standard depths (5, 15, 30, 60, 100 cm) were retained using the SPLINE tool (Malone et al. 2009). The TOC values of the 250m SoilGrids at similar depth intervals were extracted at each of the validation points.

With the independent measured and the predicted SoilGrid soil TOC data, the validation included examination of scatter plots, calculation of RMSE (Root-Mean-Square-Error), bias (mean error of prediction), and R2 (the coefficient of determination). Log-transformations were applied where normality of the distribution was not attained for calculating the R2. The R2 values and the scatter plots suggested that the SoilGrid predicted TOC in the non-agricultural areas better than that in the cultivated regions. However, the linear relationship between the measured and predicted data was weak to moderate, and the R2 values ranged from 0.01 to 0.55. The RMSE and bias of the TOC values for both the non-agriculture and agriculture land were large especially at the 5 cm depth. However the RMSE and bias were reduced as the depth increased. In summary, the TOC prediction of the SoilGrids is better in non-agriculture areas than that in cultivated regions. For the future revision of the 250m SoilGrid, more training point data should be used from Canada. Organic and Peatland soils should be modeled separately from mineral soils. Environmental covariates that are unique to Canadian soil development may contribute to the improvement of future predictions.

keywords: *Soil, Soil Carbon, DSM, Canada*

How universally is soil carbon increasing in New Zealand's hill country?

Carolyn Hedley – Landcare Research, New Zealand
Pierre Roudier – Landcare Research, New Zealand

Hill country represents a significant part of New Zealand's agricultural land. These landscapes are characterized by steep slopes, and are prone to erosion. Previous studies indicate the rate of soil carbon accumulation in hill country is highly variable, and processes affecting stock changes differ for contrasting topographic units. In the recent years, resampling of 23 National Soil Database sites at mid-slope positions provided strong evidence of soil carbon increase for these specific sampling sites since the 1980s. However, there is little data available for other topographic units (such as swales, summits, gullies): the spatial pattern of these variations of soil carbon is largely unknown.

This poster will introduce a new project that will establish a soil monitoring framework for New Zealand hill country, leveraging the wealth of environmental data-layers now available. This will guide the selection of new National Soil Database sites for resampling in places previously under-sampled to reduce uncertainty in estimates of changes in soil carbon stock at different slope positions and for different soil orders. The framework will provide a statistically robust method for monitoring ongoing soil carbon changes for New Zealand hill country, and for National Carbon Accounting and Emission Trading Scheme systems.

keywords: *Soil monitoring, Soil carbon, Spatio-temporal variability*

Soil texture estimation via mobile gamma-spectrometry: advanced evaluation using support vector machines

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Stefan Pätzold – University of Bonn, INRES, Soil Science and Soil Ecology, Germany

High resolution soil data are an essential prerequisite for the application of precision farming techniques. Sensor-based evaluation of soil properties may replace laborious, time-consuming and expensive soil sampling with subsequent measurements in the lab. Gamma spectrometry generally yields information that can be translated into topsoil texture data after adequate calibration. Yet, preliminary studies show that transferability of local or regional calibration models is restricted because of widely differing mineralogical soil composition and pedogenesis. However, nonlinear models using support vector machines shall be developed in order to be extrapolated to a wide range of different landscape settings. Applying such models would make sampling, analyses and local calibration dispensable. Our recently published results in this regard (Heggemann et al. 2017, Soil Till. Res.) refer to spectra that were recorded directly in the field using a tractor-based spectrometer, but in a stationary stop-and-go mode. In an ongoing project ("I4S - Intelligence for Soil") in the frame of the German Federal BonaRes program we actually evaluate the preciseness and usability of spectra and universal models recorded on-the-go, i.e. from a driving tractor. Predicting sand, silt and clay contents while driving over the field would enable us to directly adapt texture-related agronomic measures such as lime and fertilizer application "on-the-go".

keywords: *proximal soil sensing, online sensor, machine learning*

The power of Random Forest for the identification and quantification of technogenic substrates in urban soils on the basis of DRIFT spectra

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Xandra Michaelis – Ruhr University Bochum, Germany
Bernd Marschner – Ruhr University Bochum, Germany
Britta Stumpe – University of Wuppertal, Germany

In the past, large amounts of domestic waste and unwanted by-products from industrial processes, such as ashes from municipal solid waste incineration and slags from metallurgy processes were produced and often were deposited unregulated in the urban environment. The incineration of municipal solid wastes has been increasingly adopted around the world to deal with the ever-growing amounts of waste. Slags, on the other hand, are generated as solid by-products during metal production, with annual worldwide production reaching over 50 million tons. Some of these technogenic substrates contain high concentrations of hazardous substances, such as salts, PAHs, or heavy metals, so that an identification of such substrates is necessary.

As traditional methods are slow and costly, we developed a spectroscopic based data mining method to identify different technogenic substrates in soils. Out of 174 soil samples, 13 different samples were chosen, finely ground (<200 µm), and mixed with different finely ground incineration plant ashes and zinc furnace slags at different levels of concentration from 5 – 50%. The spectra of pure substrates and mixtures were determined using diffuse reflectance Fourier transform spectroscopy (DRIFT) in the mid-infrared region (MIR, 4000–400 cm–1) at a resolution of 2 cm^{-1}. The DRIFT spectra were used to develop classification models using the random forest algorithm (RF), one of the latest improvements in ensemble learning. Prior to analysis, different mathematical pretreatments were performed to improve the model performance.

RF was able to separate the pure substrates perfectly, without any pretreatment. Soil/substrate mixtures could be classified at a low uncertainty for technogenic substrate concentrations 10%. Forming the first derivative of the spectra reduced the model error by the factor of two to 4 – 7%. For the detected substrates, RF was also able to determine the level of concentration (low, medium, high), albeit with higher error rates. We showed that RF can be a powerful classification system to identify potential pollutants in soils. With our approach, we present a rapid and cost-effective method to identify and determine technogenic substrates in soils, an approach which could be adapted to a broad range of pollutants, also to other media than soil.

keywords: *Urban soils, Technogenic substrates, Diffuse Reflectance Spectroscopy, Data Mining, Random Forest*

Mapping the patterns of organic matter decomposition in a high mountain environment

Niels Hellwig – Institute of Geography, University of Osnabrück, Germany
Kerstin Anschlag – Institute of Geography, University of Osnabrück, Germany
Gabriele Broll – Institute of Geography, University of Osnabrück, Germany

High mountain environments are characterized by a high heterogeneity of landscape attributes. Moreover, soil sampling in these areas faces limited terrain accessibility. Spatial modeling of soil properties thus requires techniques that cope with both scarce data and small-scale variations of environmental factors.

In the context of the D.A.CH. project "Effect of climate on coarse woody debris decay dynamics and incorporation into the soils of forested Alpine areas" (DecAlp) soil ecological relationships and processes were investigated in an area in the Northern Italian Alps (Val di Sole / Val di Rabbi, Trentino). Data on humus forms serve as valuable information about the decomposition of organic matter. The aim of this study was to map spatial patterns of decomposition processes inside the forested parts of the study area by implementing models from the local to the landscape scale.

Spatial modeling was based on humus form data and included topography and vegetation as relevant covariates. Different approaches were used according to the model scale: At the local scale, humus forms were associated with the ground cover at the forest floor and the microtopography in a rule-based approach. At the slope scale, random forests were utilized to spatialize patterns of decomposition processes, depending on terrain attributes (from a digital terrain model), forest characteristics (from a vegetation map) and quantitative field estimates of the forest ground cover (e.g. no vegetation, moss, grass). At the landscape scale, modeling was based on decision tree analysis and fuzzy logic. The model results were assessed in terms of the goodness of fit, the validity of the model structure, the uncertainty of the humus form data and the applicability regarding varying landform types.

The model predictions reveal a high spatial variability of decomposition processes. At the local scale, variations of humus forms coincide with small-scale variations of the forest ground cover (e.g. no vegetation, moss, grass). At the slope and landscape scale, forest humus forms show a trend according to factors such as elevation and slope exposure. At high elevations and north-exposed slopes, environmental conditions for the decomposition of dead organic matter are generally less favorable in comparison to low elevations and south-exposed slopes. The model assessment highlights the suitability of different model approaches depending on the scale, but also reveals uncertainties in some places of the study area due to the scarcity of humus form data.

keywords: *Upscaling, Tree-based modeling, Fuzzy logic, Humus forms, Italian Alps*

End of kriging? Or how tree-based Machine Learning Algorithms can be used to generate more accurate spatial predictions with combined geographical and feature space covariates

Tomislav Hengl – ISRIC, Netherlands

Kriging (the best linear unbiased prediction for spatial data) has been for over 40 years among the most used technique for spatial prediction of soil variables. This talk will demonstrate, using real-life data sets, that Machine Learning Algorithms (MLA) that utilize buffer distances between sampling points as covariates can be used to produce equally good, frequently more accurate predictions than kriging; if auxiliary or feature space covariates (e.g. RS images) are added to the model then MLAs generate more accurate predictions than regression-kriging. The advantages of MLAs (the focus of this work is on tree-based MLAs such as Random Forest, Gradient Boosting, Cubist and/or Bayesian Additive Regression Trees) vs linear geostatistical models will be demonstrated using several standard soil mapping data sets (Ebergotzen, Meuse, Edgeroi). It will be further shown that advantages of MLAs over kriging methods are especially distinct in cases where relationship between soil variables and geographical and feature space covariates is non-linear and complex, and when models are based on millions of measurements. In addition, it will be shown that MLAs show also numerous other advantages over kriging due to increasing possibilities for interpretation of modelling results (sorting of the predictor variables based on importance, visualization of complex non-linear relationships, detection of possible outliers and blunders in the input data). These discoveries imply that, in principle, MLAs could be used to partially or completely replace kriging in soil mapping. There are still many challenges, however, in front of MLA users: how to improve computational efficiency? how to derive spatial uncertainty for MLA-based predictions? how to generate spatial simulations? how to include variable uncertainty in soil measurements in model fitting? and similar.

keywords: *machine learning, random forest, regression-kriging, soil predictive modelling, automation, big data*

Hyperspectral Imaging of Soil Cores

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Stefanie Kriegs – Technical University of Munich, Germany

Obtaining reliable and accurate data regarding the spatial distribution of different soil components is difficult due to issues related with sampling scale and resolution on the one hand and laboratory analysis on the other. When investigating the chemical composition of soil, studies frequently limit themselves to two dimensional characterisations, e.g. spatial variability near the surface or depth distribution down the profile, but rarely combine both approaches due to limitations to sampling and analytical capacities. Furthermore, when assessing depth distributions, samples are taken according to horizon or depth increments, resulting in a mixed sample across the sampling depth. Whilst this facilitates mean content estimation per depth increment and therefore reduces analytical costs, the sample information content with regards to heterogeneity within the profile is lost.

Hyperspectral imaging can overcome these sampling limitations, yielding high resolution spectral data of down the soil profile, greatly enhancing the information content of the samples. This can then be used to augment horizontal spatial characterisation of a site, yielding three dimensional information into the distribution of spectral characteristics across a site and down the profile.

Soil spectral characteristics are associated with specific chemical components of soil, such as soil organic matter or iron contents. By correlating the content of these soil components with their spectral response, high resolution multi-dimensional analysis of soil chemical composition can be obtained. Here we present a hyperspectral approach to the characterisation of soil organic matter down cores obtained from agricultural soil profiles in Germany, outlining advantages and issues associated with the methodology.

keywords: *Vis-NIR, Deep soil, Multivariate analyses*

High resolution estimation of peat depth using electromagnetic induction in a Scottish peatland

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Richard Hewison – James Hutton Institute, United Kingdom
Jingyi Huang – UNSW, Australia
James Taylor – Newcastle University, United Kingdom
John Triantafilis – UNSW, Australia

There is widespread recognition of the significant value of peatlands and their ability to store large amounts of soil organic carbon. Recent surveys have been undertaken to assess the condition of peatlands and this includes calculating the amount of carbon stored. An important factor in this calculation is the accurate determination of peat depth, i.e. the depth of highly organic material which is above mineral soil or parent material. Several different methods are used to measure peat depth in the field. For instance, there have been some attempts to use ground penetrating radar. Manual measurement using augers are still commonly used, but this is time-consuming and only provides a depth reading at a single point. Some previous studies have reported on the use of electromagnetic induction (EMI) to non-invasively estimate the depth of peat. These studies have been limited in scope and there have not been any published EMI studies on peatlands in the UK. In this study, a DualEM 21S was used to record the electromagnetic signal along a transect of the Moidach More peatland in north-east Scotland, UK. The Moidach More has been the site of numerous intensive studies since the 1950s and thus, there is a large amount of legacy peat depth data. The peat depth varied significantly along the transect and the maximum depth surveyed was 3 m. The EMI transect was undertaken in the summer (1 September) when the antecedent moisture levels were moderate. The EMI data were processed and inverted using EM4Soil software. The inverted EMI data were modelled to see if the depth of the peat could be predicted. A Generalized Additive Model was used to capture non-linear relationships. The initial model was between peat depth and the mean of the conductivity data in a moving window of 10m around the measured depth locations (∼20 points). The initial results showed a 38% of explained deviance and an R2 of 0.4. Further modelling will include environmental covariates, such as morphological features (elevation, slope) and remote sensing indices (vegetation, moisture). Given the small number of peat depth measurements available particular attention will be paid to model selection to avoid overfitting. These results show some promising potential for EMI data to be used for peat depth surveying. It is proposed that future research is undertaken on a larger dataset (>100) which should reduce uncertainty and provide a more powerful predictive relationship.

keywords: *peat depth, soil organic matter, EM inversion, EM4Soil, Generalized Additive Model*

3-D geostatistical interpolation of soil organic matter in the Netherlands

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Dick Brus – Wageningen University and Research centre, Netherlands
Dennis Walvoort – Wageningen University and Research centre, Netherlands

Detailed and accurate information on soil organic matter (SOM) content is important for many applications, like the assessment of greenhouse gas emissions, carbon sequestration and the fixation and leaching of pesticides. In the Netherlands the fate of pesticides in the soil-plant system is modelled with GeoPEARL, a dynamic, multilayer model. Previous research showed that SOM content was the most important source of uncertainty in the prediction of the leaching concentration with this model. The aim of this research was to use all information in the Dutch Soil Information System, both data on point support and soil maps, to construct a three-dimensional (3-D) map of SOM. A large part of the point data on SOM were field determinations. These field determinations of SOM were calibrated against laboratory measurements, to eliminate bias and to obtain an estimate of the precision of the field determinations. SOM predictions at multiple depths were obtained by 3-D simple kriging with varying local means. The local means were modelled as a stepwise trend in three dimensions, the spatial structure of which was derived from typical soil profile descriptions of the units of the Soil Map of the Netherlands 1:50 000. For the topsoil (15 cm) the stepwise trend was further differentiated according to three land use categories. The local means, averages of log-transformed SOM-values, were estimated from a stratified random sample of 1210 locations. Legacy data at points selected by non-probability sampling were not used for estimating the local means to guarantee unbiasedness. Residuals of the local means at 766,000 locations were interpolated by 3-D simple kriging based on the sum metric 3-D variography in both horizontal space and depth. Leave one out cross-validation on the 1210 locations showed that the mean prediction error was 0,029 and the root means squared error was 0,034. The mean squared deviation ratio is 0.79, indicating that the estimated prediction accuracy is an overestimation and actual errors at the validation locations are smaller.

keywords: *Three-dimensional Interpolation (3-D), Geostatistics, Kriging, Digital soil mapping, Organic matter, Carbon, pesticides, Soil information system, Soil map*

High Resolution Mapping of Soil Properties Using Remote Sensing Variables in South-Western Burkina Faso: a Comparison of Machine Learning and Multiple Linear Regression Models

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Gerhard Welp – University of Bonn, Germany
Michael Thiel – University of Wuerzburg, Germany

Accurate and detailed spatial soil information is essential for environmental modelling, risk assessment and decision making. The use of Remote Sensing data as secondary sources of information in digital soil mapping has been found to be cost effective and less time consuming compared to traditional soil mapping approaches. But the potentials of Remote Sensing data in improving knowledge of local scale soil information in West Africa have not been fully explored. This study investigated the use of high spatial resolution satellite data (RapidEye and Landsat), terrain/climatic data and laboratory analysed soil samples to map the spatial distribution of six soil properties – sand, silt, clay, cation exchange capacity (CEC), soil organic carbon (SOC) and nitrogen – in a 580 km^2 agricultural watershed in south-western Burkina Faso. Four statistical prediction models – multiple linear regression (MLR), random forest regression (RFR), support vector machine (SVM), stochastic gradient boosting (SGB) – were tested and compared. Internal validation was conducted by cross validation while the predictions were validated against an independent set of soil samples considering the modelling area and an extrapolation area. Model performance statistics revealed that the machine learning techniques performed marginally better than the MLR, with the RFR providing in most cases the highest accuracy. The inability of MLR to handle non-linear relationships between dependent and independent variables was found to be a limitation in accurately predicting soil properties at unsampled locations. Satellite data acquired during ploughing or early crop development stages (e.g. May, June) were found to be the most important spectral predictors while elevation, temperature and precipitation came up as prominent terrain/climatic variables in predicting soil properties. The results further showed that shortwave infrared and near infrared channels of Landsat8 as well as soil specific indices of redness, coloration and saturation were prominent predictors in digital soil mapping. Considering the increased availability of freely available Remote Sensing data (e.g. Landsat, SRTM, Sentinels), soil information at local and regional scales in data poor regions such as West Africa can be improved with relatively little financial and human resources.

keywords: *Soil property mapping, Remote Sensing, RapidEye, Landsat, Multiple linear regression, Random forest regression, Support vector machine, Stochastic gradient boosting*

Soil water nowcasting in 2-d and 3-d using electromagnetic conductivity imaging and the ensemble Kalman filter

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Mapping and immediate forecasting of soil water content (theta) and its movement can be challenging. Although apparent electrical conductivity (ECa) measured by electromagnetic induction has been used, it is difficult to map the depth-specific theta along a transect or across a field. Across a 3.95-ha field with varying soil texture, an ensemble Kalman filter (EnFK) was used to monitor and nowcast theta dynamics in 2-d and 3-d over 16 days. The EnKF combined a physical soil-water tipping bucket model fitted with theta measured by soil moisture sensors and an artificial neural network model established using estimates of true electrical conductivity (sigma) generated by inversion of DUALEM-421S ECa data. Results showed that the spatio-temporal variation in depth-specific theta along the transect and across the field can be successfully modelled using the EnKF approach (Lin's concordance $\leq$ 0.89, RMSE $\leq$ 0.03 cm3/cm3), which was superior to the physical and empirical models. Soil water dried fast at the beginning of the irrigation and decreased with time and soil depth, which were consistent with the classical soil drying theory and experiments. It was also found that the soil dried fast in the loamy and duplex soils across the field, which was attributable to deep drainage and preferential flows. It was concluded that the EnKF approach can be used to better the irrigation practice so that variation in irrigation is minimised and irrigation efficiency is improved by applying variable rates of irrigation across the field. In addition, soil water status can be potentially nowcasted using this method with weather forecast information, which can provide guidance to farmers for real-time irrigation management.

keywords: *DUALEM-421S, data assimilation, deep drainage, irrigation efficiency, real-time irrigation management*

Sequential creation of a generic soil classification system using taxa from existing systems

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We can create a classification based on a common set of principles. In order to do this, there is the requirement for a universal database. This database needs to be comprehensive, non-duplicated, have the capacity for other suitable taxon to be added to it, and at the same time to be small and simple. As an initial step, soil profile description data and taxa from two differing taxonomies have been successfully combined into a single database, referred to as the Total Reference taxonomic database, or TRex. This has the data range to suit most soil properties in both Australia and the United States, but there is extensive duplication and issues of equivalence (whether a taxonomic tier such as Order, Suborder or Great Group of one taxonomic system is equivalent to the same tier of another taxonomic system). We propose an additive model by which the impediments of redundancy and equivalence can be countered and demonstrate how a combined data set can be created that is just as effective for the purpose of creation of a world taxonomy, yet has less unnecessary overlap. These ideas are incorporated, creating a hybridized data set that covers that same ranges as TRex in principal component space, yet is significantly smaller, making distance calculations and optimizations of various kinds much faster. This system is tested by the addition of taxa from an independent data set in New Zealand. The possibility of merging and simplifying of such different systems and the addition of independent third party data demonstrates the possibility of similar mergers with taxonomies of other nations, creating a global data pool for a world taxonomic system.

keywords: *Soil classification, Soil Taxonomy, Soil profile description, Soil taxonomic description*

Developing desktop, on-line, and mobile applications to support soil experts and soil data end-users

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László Pásztor – Institute for Soil Sciences and Agricultural Chemistry, CAR-HAS, Hungary

We develop modularly built software group for desktop, on-line, and mobile platforms in order to support and promote soil data collecting, -data sharing, and -data utilization. Software modules are available independently, and freely. Data visualization and distribution for end-users is served by SiteViewer module. In this module soil maps or tabular soil data are available for the desired locations. The module serves the tasks of landowners and forest managers. The SiteProfessional module is suitable to create and manage personal or shared soil databases among the users. It serves the needs of soil experts in surveying or mapping tasks to optimize sampling density and to check data availability of the given area. It is also suitable to build quality checked, national soil profile database. Our initiative supports the best utilization and archiving of existing data came from either former or future surveys. We also want to provide a virtual place and data store for co-operating expert groups. Last but not least we want to support land managers to access high quality soil data.

keywords: *sharing soil data, personal and joint soil databases, software development, biulding soil database*

Mapping the Suitable Sites for Rice Production Using Analytical Hierarchy Process and Geographical Information System

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Tofael Ahamed – University of Tsukuba, Japan
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Bangladesh is the smallest country in the South-Asia with high density of population. Food security is not just an economic issue but also a political and societal problem in Bangladesh faces today. To feed the huge population there is no more alternatives without increase the agricultural production; maximum utilization of land resources. But the production is not so upright due to appropriate knowledge and scientific application of Soil.

Land is called the unique source of all material wealth. Soil is a vital part of the natural environment. The importance of land is therefore too much as it is influencing the standard of living. Usually Rangpur division is vulnerable than any other part of Bangladesh. To rise production, it is essential to secure lands for achieving optimum application of resources. Land Suitability Assessment (LSA) is one of the most important tools to increase rice production in the poverty prone areas. Therefore, the aim of the study was to identify the suitable sites for rice farming in the northern part of Bangladesh. To satisfy the research, a multi-criteria analysis was done and produced a suitable map for rice production with the integration of Geographical Information System (GIS) and Analytical Hierarchy Process (AHP). Data were collected from ground truth information and regional offices, Landsat and MODIS satellite databases of vegetation indices provided by USGS. The recent raster image from Google Earth Pro was used to confirm the consistency of suitability analysis. The suitability levels were ranked based on FAO land suitability classification as: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), Currently Not Suitable (N2), and Permanently Not Suitable (N1).

To create the suitability map for rice weighted sum overlay tool in ArcGIS 10.3 was used. Then, the suitability map for rice production in the study area was designed. The weighted overly was done and found that 32.67% (192087 ha) was permanently not suitable and 1.19% (6997 ha) was currently not suitable for rice farming which occupied with settlement, water bodies, river and forest. Instead, 22.74 % (133702 ha) of study area was highly suitable, while 28.54% (167804 ha) was moderately suitable, 14.86% (87371 ha) was marginally suitable. This research provided info at local level that could be used by rice producer to select suitable fields and then it can be apply in other crops. It will also helpful for the extension workers and policy makers who serves in the agricultural sector.

keywords: *Land Suitability Assessment (LSA), Geographical Information System (GIS), Rice Farming, Bangladesh, Analytical Hierarchy Process (AHP)*

Soil salinity assessment through novel application of satellite thermography

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An increased soil salinity is one of the severe land degradation factors that inhibits growth and development of crops. Therefore, up to date soil salinity information at increasing spatial and temporal resolution is vital for appropriate management practices and reclamation strategies. But conventional soil sampling are slow, expensive, and often cannot deliver the temporal and spatial resolution required.

The canopy temperature change is one of the stress indicators in plants. Its behaviour in response to salt stress on individual plant level is well studied in controlled experiments, but its potential for landscape scale studies is not investigated yet. In our study, possibilities of satellite thermography for landscape scale soil salinity assessment of cropped areas were studied. The performance of satellite thermography is compared with other approaches that have been used before, like Normalised Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). The study areas were Syrdarya province of Uzbekistan and four study areas in Australia. The diversity of the study areas allowed us to analyse behaviour of canopy temperature of different crops (wheat, cotton, barley) and different agriculture practices (rain fed and irrigated). MODIS and Landsat TM multiannual satellite images were used to measure canopy temperature. As ground truth for Uzbekistan study area we used a provincial soil salinity map. For the Australian study areas we used the EC map for the whole country. ANOVA was used to analyse relations between the soil salinity maps and canopy temperature, NDVI, EVI. Time series graphs were created to analyse the dynamics of the indicators during the growing season.

The results showed significant relations between the soil salinity maps and canopy temperature. The amplitude of canopy temperature difference between salinity classes varies for different crops, but the trend of temperature increase under increased salinity is present in all cases. The calculated F-values were higher for canopy temperature than for all other compared indicators. Also the visual comparison of the soil salinity map and the canopy temperature map show similar spatial patterns. The NDVI and EVI maps look more random and noisy and patterns are less pronounced than for the canopy temperature map. The strongest relation between the soil salinity map and canopy temperature was usually observed at the end of a dry season and in the period of maximum crop development.

Satellite thermography appeared to be a valuable approach to detect soil salinity under agricultural crops at landscape scale.

keywords: *soil salinity, satellite thermography, landsat, modis, vegetation indices*

The German National Soil Inventory - Soil sampling for climate change abatement

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Due to several international agreements on climate change abatement (UN Framework Convention on Climate Change, Decision 529/2013/EU of European Parliament and of the Council) Germany is in duty to report greenhouse gas emissions from agricultural soils. Moreover, enhanced carbon storage in soils can be accounted for as greenhouse gas mitigation strategies. For such reports and policy decision making, a harmonized, representative, and reliable database of soil carbon stocks was missing so far. Thus, the German National Soil Inventory started over in 2011 assessing soil carbon contents and stocks in a nation-wide harmonized sampling system. A 8*8 km grid defined the 3100 sampling points under arable land, grassland and plantation crops. Landscape and soil type were described for each point and disturbed and undisturbed soil samples were taken from a 1 m3 pit. Sampling depths were 0-10, 10-30, 30-50, 50-70, and 70-100 cm. Further, from soils rich of carbon, an additional sampling of the subsoil was conducted at 100-150 and 150-200 cm. In order to evaluate the spatial heterogeneity on the field scale, eight additional soil cores were taken in a distance of 10 m around the pit. All samples were analyzed in the same lab following standardized protocols. In order to evaluate effects of arable management on soil carbon contents, farmers managing the field of a sampling point filled in a questionnaire covering the last ten years before sampling. Thus, we are able to link land use and arable management (tillage, fertilization...) information with the carbon stock measured.

This enormous database of harmonized soil carbon data is a valid basis of several ongoing and future subprojects. Currently, the team is working on (i) site specific and anthropogenic drivers of arable soil's carbon stocks via machine learning, (ii) vulnerability of carbon in organic and mineral soils via density fractionation and incubation, (iii) predictability of soil carbon fractions via near infrared spectroscopy, (iv) models which predict an arable site as a sink or a source for soil carbon, (v) stratification of the sampling area (Germany) in order to enhance the predictability of soil carbon stocks, and (vi) regionalization of soil carbon data for the generation of maps via machine learning. The poster will present the design of the project and selected results.

keywords: *arable soil, soil carbon, soil management*

Prediction of soil organic carbon fractions using near infrared reflectance spectroscopy

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Soil carbon fractions (C-fractions) are important to understand terrestrial carbon fluxes and ecosystem processes that affect soil carbon (C) stocks. Soil samples can be divided into fractions that are labile and easily decomposable (LA) and fractions with more stabilised resistant C (RE), where access by microorganisms is restricted. Various methods have been proposed to separate the soil samples into C fractions, however all of them are very time-consuming. Near-infrared (NIR) reflectance spectroscopy has been used as fast method to evaluate various soil properties with reasonable accuracy and low costs. The aim of the present study is to test a more rapid alternative to quantify LA and RE soil C-fractions based on the NIR analysis of bulk soils. The C-fractions of 140 topsoil samples (0-10 cm) from the German Agricultural Soil Inventory (GASI) were obtained by conventional methods. These samples were also scanned in the NIR region to obtain their spectra. We developed quantitative NIR models to predict the C-fractions in the GASI samples. In this presentation, we analyse what degree of accuracy can be expected from NIR spectroscopy for predicting different levels of Fractionation of soil organic carbon.

keywords: *soil organic carbon fractions, near infrared reflectance spectroscopy, memory-based algorithms*

Developing Combined Soil-climate Indices for Crop Suitability Recommendations

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Assessment of land capability for a crop requires the bringing together of data on soils, climates and crop requirements. In Malaysia, the main method to identify suitable species for agriculture is soil-crop suitability classification based on a range of soil properties that can impose limits on crop growth. This method has been used widely by governmental agencies to propose crop diversification projects since the 1970s. As information on genotypic and agronomic characteristics of crops and environmental factors such as climate become available, new methods of suitability assessment can be designed and tested. For instance, climate suitability indices that consider suitability as a function of temperature and rainfall at any location can be combined with the soil data to improve the accuracy of crop recommendations. In this work we combined a soil-based method with a climate suitability index to develop a recommendation tool primarily for currently underutilised crops. The assessment tool was then tested with data from globally available soil and climate datasets to validate the accuracy of the augmented suitability criteria. Crop, soil and climate data were acquired from the FAO EcoCrop database. This data includes optimal and absolute minimum and maximum temperatures and rainfall for each cultivated species, together with the length of the growing season. Other information such as optimal soil pH level, depth, texture, fertility level, salinity resistance and drainage requirements were also incorporated into the tool. Soil data was extracted from the ISRIC global soil grids dataset; this database provides maps that are the result of interpolations of soil profiles across the globe. Climate information was extracted from the WorldClim dataset which provides gridded maps of historical averages at the global scale. A script for data processing and suitability calculation was developed using R statistical language. The combined soil-climate-crop suitability assessment tool was tested in the Bera district of Pahang, Malaysia. We will demonstrate the advantages of the new analytical tool in comparison with the traditional method of land capability assessment and its use by farmers to determine how their cropping systems might be diversified. We will also discuss the implications of using globally available datasets for the purpose of local crop suitability assessments.

keywords: *crop suitability, soil, climate, classification*

Comparison of multinomial logistic regression and random forest classifiers in digital mapping of soil in western Haiti

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Due to the low availability of data on the soils of Haiti, digital soil mapping is suitable for providing quick and accurate spatial information to support decision makers in agricultural and environmental planning programs. This study aims to map soils in western Haiti by comparing Multinomial Logistic Regression (MLR) and Random Forest (RF) classifiers. Digital soil mapping (DSM) techniques were evaluated to delimit soil classes in western Haiti (∼4300 km^2). A soil survey was carried out through a mixed sampling strategy, describing 140 soil profiles, for which samples were taken for physical and chemical analyses. The algorithms MLR and RF were applied in the classification process based on soil-landscape relationship, involving climate, lithology and landscape attributes as predictor variables. Classifier performances were assessed using Kappa index derived from a confusion matrix and map validation was carried-out using an independent sample of 118 points. A comparison between the classifiers was carried out through Z statistic. Kappa index determined in this process 0.47 for MLR and 0.33 for RF indicate that the classification performance can be characterized as good for MLR and moderate for RF. A statistically significant difference between Kappa values was encountered with a Z statistic of 1.98 at a 5% significance level. Kappa index in validation of the final map was 0.49; while the overall accuracy value was 0.59. Map units with the largest percentage in the study area were: Entisols (32.4%), rock outcrops (22.1%) and Mollisols (13.2%). The approach proved to be promising as a method to map the soils of other parts of the country.

keywords: *Soil survey, Soil Mapping, Auxiliar data, Data mining*

Pre-processing of on-the-go mapping data

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On-the-go proximal soil sensors offer promising benefits to the mapping of soil spatial variability, as they provide an increased density of measurements at a relatively low cost. Numerous on-the-go sensors have been developed based on a variety of design concepts. Among them, mapping apparent soil electrical conductivity (ECa), along with field elevation, has become a standard practice in mapping field heterogeneity. In this study, a DUALEM-21S sensor and a real-time kinematic (RTK) Trimble AgGPS 542 global navigation satellite system (GNSS) receiver were fused and the data from both sensors were logged using the dedicated DUALEM_DAQ software. The generated ECa and elevation maps reflect systematic and random sources of soil variation as well as numerous errors caused by the mapping procedures. Taking the ECa data as an example, a general framework for processing the data was developed. Pre-processing of the data was mainly based on the time intervals, the distance between every two point measurements (i.e. speed) and the change of the variables within a small window of neighbor measurements. Other parameters were also considered, for example, pitch and roll. The detailed steps include (i) raw data screening, (ii) median filtering each ECa value, (iii) removing the starting (warm up) uncertain values, (iv) removing the start- and end-pass delays, and the stop-and-go segments within the field, (v) removing the points with over speed limits, (vi) removing ECa values outside the user-defined minimum and maximum ECa limits, (vii) removing small patches or narrow strips with extremely low or high ECa that are not closely related to the immediate neighbors, and (viii) removing the values when pitch or roll changes are outside the acceptable limit. The pre-processing procedures for the logged RTK elevation data, as well as other on-the-go sensors, are similar. In this study, several fields from Quebec and Ontario, Canada, were selected as examples to demonstrate the detailed pre-processing procedures. About 5% to 20% of the data were regarded as erroneous data and were thus removed from the raw data for different fields. This technique allows more accurate representation of soil electrical conductivity and field variability, which provide important data layers in algorithms for prescribing variable rates of production inputs.

keywords: *on-the-go proximal soil sensing, pre-processing, apparent electrical conductivity, elevation*

The use of proximal soil sensor data fusion and digital soil mapping for precision agriculture

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Proximal soil sensing (PSS) is a promising approach when it comes to detailed characterization of spatial soil heterogeneity. Since none of existing PSS systems can measure all soil information needed for implementation precision agriculture, sensor data fusion can provide a reasonable alternative to characterize the complexity of soils. In this study, we fused the data measured using a gamma-ray sensor, an apparent electrical conductivity (ECa) sensor, and a commercial Veris MSP3 platform including a optical sensor measuring soil reflectance at 660 nm and 940 nm, a soil ECa sensor and a pH sensor, with the addition of topography for the prediction of several soil properties, i.e. soil organic matter, pH, buffer pH, phosphorus, potassium, calcium, magnesium, aluminum. A total of 65 sampling locations were selected from a 38.5 ha field in Ontario, Canada. Among them, 35 locations were selected by a random stratified sampling strategy. The stratification grid was 1 ha. Sampling was prohibited in areas near the field boundaries and within a safety margin from the drainage system. 20 locations were selected using a neighbourhood search approach , a spatial data integration strategy. These two sample datasets were used as the calibration dataset to build the model between soil properties and readings from different proximal soil sensors. The remaining 10 sensing locations were used as an independent validation dataset. Partial least square regression (PLSR) was performed on the data from each individual sensor and different sensor combinations (sensor data fusion). For most soil properties, predictions based on sensor data fusion were better than those based on the output of individual sensors. By fusing the data from all of the proximal soil sensors, more properties can be predicted simultaneously (R2>0.5, and RPD>1.50). After choosing the optimal sensor combination for each soil property, different digital soil mapping methods, including support vector machines (SVM), random forest (RF), multivariate adaptive regression splines (MARS), regression trees (RT) and back-propagation artificial neural network (BP-ANN) were used to estimate variograms and pursue regression kriging. High resolution maps were thus interpolated with the most successful methods. The performance of the two different sampling strategies was compared by the prediction accuracy from the validation samples. We thus conclude that proximal soil sensor fusion paired with the digital soil mapping method is a promising way to offer the essential soil information needed for precision agriculture.

keywords: *vis-NIR spectroscopy, Gamma ray, electrical conductivity, topography, sensor fusion, data fusion, digital soil mapping*

Effect of different soil compaction levels on prediction of soil properties using MIR spectra in situ

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Mid-infrared (MIR) diffuse reflectance spectroscopy can provide rapid and relatively accurate predictions for a number of soil properties. Along with air-dried ground spectral measurements in the laboratory, much attention has been given to determining soil properties in situ. The soil moisture effect has received much attention while research on other effects is scarcely reported. The differences in soil compaction has a significant influence on structure and porosity and thus, on the reflected spectra. The objective of this study was to create different soil compactions on natural wet soil samples in the laboratory and examine their effects on the MIR spectra, and compare them with in situ collected spectra. A total of 120 (56+64) locations were selected from two agricultural fields from Macdonald farm of McGill University: one organic field and one mineral field. At each location, the MIR spectra were recorded in situ using a portable MIR spectrometer (898-1811cm^{-1}). The level of compaction was measured using a portable penetrometer at the same time. After which, bulk samples were collected and packed into plastic bags, sealed to avoid the loss of soil moisture and sent to the laboratory. Spectroscopic measurements using the same equipment were carried out in the laboratory on those 120 samples at three different compactions (initial compaction, medium compaction and high compaction). After the spectral measurements, a range of properties were measured. Partial least square regression models were developed between these properties and the spectra measured at four different compactions (in situ, c1, c2 and c3). By comparing the predictions, we concluded that the influence of different compaction levels on mineral soil and organic soil is different. For both fields, with some compaction level, prediction with spectra on compacted soil in the laboratory is always more accurate than for in situ conditions. Predictions with compacted soils are closer to those with air-dry non-ground samples.

keywords: *mid-infrared spectroscopy, in situ, soil compaction, organic soil, mineral soil, soil organic matter, soil texture*

Can organic carbon in soil cores be predicted by VNIR and MIR techniques in alpine landscape?

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1. Introduction

Carbon is the essential component of all organic matter. The Qinghai–Tibet Plateau is an important part of the global terrestrial ecosystem because it is a large and concentrated distribution area of frozen soil at low latitudes. It is not only sensitive to global climate change, but also plays an important role in the Asian climate and global climate change. To our knowledge, no studies have reported the potential to predict SOC in individual soil cores (0–100 cm) in an alpine region. The aim of this research was to evaluate the potential of predicting the SOC concentration in individual soil cores using VNIR and MIR DRS.

2. Materials and methods

The study area is located on the Sygera Mountains in the southeast of the Qinghai–Tibet Plateau, China. Elevation of forest land ranges from 3300 to 4300 m above sea level, and alpine shrub and meadows are found above 4300 m. We examined 24 soil cores (0–100 cm) from the Sygera Mountains on the Qinghai–Tibet Plateau, considering field-moist intact VNIR, air-dried ground VNIR and air-dried ground MIR spectra at 5-cm intervals. According to the elevation, two thirds of soil cores in each class, shrub meadow, forest and total dataset, were divided into a calibration set and the remaining cores were divided into a validation set. Preprocessed spectra were used to predict SOC in the soil cores by partial least square regression (PLSR) and support vector machine (SVM).

3. Results and conclusions

The SVM models performed better in three predictors with the ratio of performance to interquartile distance (RPIQ) and R2 values typically exceeding 2.00 and 0.80, respectively. The SVM using the DRS technique indicated accurate predictive results of SOC in each core. The RPIQ values of the shrub meadow, forest and total dataset predition by air-dried ground VNIR were respectively 1.97, 2.68 and 1.99, compared to the values by field-moist intact VNIR (1.95, 2.07, 1.76) and air-dried ground MIR (1.78, 1.96, 1.74). Generally, the results were more accurate at 0–60 cm soil depth than at 60–100 cm, indicating suitability of spectroscopic techniques for the prediction of SOC stock density. We conclude that the DRS technique is an efficient and rapid method of SOC prediction and has potential in dynamic monitoring of SOC stock density on the Qinghai–Tibet Plateau.

keywords: *soil profile, VNIR, MIR, organic carbon*

Application of portable XRF and VNIR sensors for rapid assessment of soil heavy metal pollution

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Rapid heavy metal soil surveys at large scale with high sampling density could not be conducted with traditional laboratory physical and chemical analyses because of the high cost, low efficiency and heavy workload involved. This study explored a rapid approach to assess heavy metals contamination in 301 farmland soils from Fuyang in Zhejiang Province, in the southern Yangtze River Delta, China, using portable proximal soil sensors. Portable X-ray fluorescence spectroscopy (PXRF) was used to determine soil heavy metals total concentrations while soil pH was predicted by portable visible-near infrared spectroscopy (PVNIR). Zn, Cu and Pb were successfully predicted by PXRF (R2 >0.90 and RPD >2.50) while As and Ni were predicted with less accuracy (R2 <0.75 and RPD <1.40). The pH values were well predicted by PVNIR. Classification of heavy metals contamination grades in farmland soils was conducted based on previous results; the Kappa coefficient was 0.87, which showed that the combination of PXRF and PVNIR was an effective and rapid method to determine the degree of pollution with soil heavy metals. This study provides a new approach to assess soil heavy metals pollution; this method will facilitate large-scale surveys of soil heavy metal pollution.

keywords: *portable X-ray fluorescence spectroscopy, portable visible-near infrared spectroscopy, soil heavy metals contamination*

Validation of the coarse-scale remotely sensed soil moisture data by using ground measurements with a hybrid geostatistical downscaling method

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Monitoring the surface soil moisture (SM) acts a critical role in applications such as hydrology, meteorology and agriculture. The passive microwave remote sensing as a monitoring tool for large regions has been widely applied. However, these sensors always own a coarse spatial resolution of about 25 to 50 km. To validate these satellite SM data, addressing the scale mismatch between its coarse-scale estimates and local scale measurements is one of the key issues. Downscaling is considered to be an implement method to predict SM at fine resolution for matching the scales. Following the available data sources, the downscaling approaches of passive microwave remotely sensed SM data fall into two basic categories. One is to combine the passive and active microwave estimates, and the alternative is based on optical/thermal remotely sensed data. The latter is preferred because of the accessibility and high temporal-spatial resolution of optical/thermal remotely sensed data. This paper aims to examine the potential of a hybrid geostatistical downscaling method named area-to-area geographically weighted regression kriging (GWATARK) for validating passive microwave remotely sensed SM product.

The GWATARK method is applied to improve the spatial resolution of Advanced Microwave Scanning Radiometer 2 (AMSR-2) and Soil Moisture and Ocean Salinity (SMOS) SM products. This downscaling model involves a trend component and a residual component, employing optical/thermal remotely sensed data as explanatory variables (e.g., land surface temperature, vegetation index, temperature-vegetation index, apparent thermal inertia and soil evaporative efficiency). The downscaled SM predictions of 1 km resolution during one-year period are obtained over the upstream area of the Heihe River Basin in northwestern China where includes a ground-based monitoring network. The downscaled predictions are compared with the area-averaged SM of 1 km resolution from in situ measurements within the study area. Furthermore, the SM data are validated for different temporal and spatial by using statistical parameters, such as bias (BIAS), root mean square error (RMSE), correlation coefficient (R) and the slope of the linear regression (S). It shows that GWATARK downscaling method improves the statistics of SM data for both AMSR-2 and SMOS products, indicating that the downscaled predications can explicitly represent the variability of SM at fine resolution. The GWATARK has strong potential to be as a tool to evaluate coarse-scale remotely sensed soil moisture data.

keywords: *soil moisture, downscaling, validation*

Monitoring soil heavy metal distribution over three different time periods using trivariate linear mixed models

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Remediated sites that have been previously contaminated may still have the potential to cause harm to humans and the surrounding environment. It is for this reason that many remediated sites require monitoring to ensure managed soil contaminants do not become exposed or leach into groundwater. If contaminants enter waterways or groundwater, the area of impact can extend beyond the site of the contaminant source.

Bicentennial Park - a recreational area within Sydney Olympic Park (Sydney, Australia), was a wetland system treated as a landfill for industrial and municipal waste. The area was remediated in 1988 by covering the landfill with ∼50cm of soil and transforming it into parkland. In contrast, more recent remediation methods use clay capping and geotextile fabric to prevent leaching and re-emergence. The method used for remediation of Bicentennial Park in combination with soil movement and erosion over time elevates the risk of human and environmental exposure of contaminants.

Relatively few studies involve monitoring of previously contaminated sites and those that do generally compare samples pre- and post-remediation; even fewer compare between multiple sampling events. A significant amount of time has passed since Bicentennial Park's opening in 1988 and over the years it has been surrounded by remediation work and major road networks with increasing traffic density. During this time it is possible that in addition to original contaminants being exposed, new sources of contamination have emerged.

The objectives of this study are to determine whether there has been any change in soil heavy metal concentrations over time, and whether or not subsequent recontamination has occurred. We will compare heavy metal concentrations in soil samples obtained from Homebush Bay in 1990 not long after creation of the parklands, samples taken in 2002 following remediation of Sydney Olympic Park, and samples taken in 2015- 25 years since the initial survey.

To compare the three datasets the study will use trivariate linear mixed models to build a space-time model for the three datasets. This will be used to predict at three spatial supports - over a 20 metre grid, block support of different previous land uses, and across the entire site. For each spatial support we will examine contrasts for years 2002-1990, years 2015-2002 to determine whether there has been any change in concentrations and whether there are re-emerging sources.

keywords: *Monitoring, Linear mixed modelling, Remediation, Environmental change, Sydney, Soil contamination*

Estimating soil profile attributes with proximal sensors and a spectral inference system

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Proximal soil sensors are moving the domain of quantitative soil science from the laboratory into the field. To utilise these sensors effectively platforms must be developed to access sensor information and predict soil properties in near real-time. We present a framework to predict soil attributes in-situ from the conjoint use of visible and near-infrared (VisNIR) diffuse reflectance spectroscopy and portable x-ray fluorescence (pXRF) spectroscopy. We further demonstrate how information from these sensors can be combined with a spectral inference system (SPEC-SINFERS) to greatly amplify the number of properties predicted. The effectiveness of the platform was assessed on fifteen soils across the state of New South Wales, Australia. At each location a soil pit was dug and three 1 m vertical transect surfaces were prepared at 0.5 m lateral spacing. Each transect was scanned using VisNIR and pXRF at 2.5 cm intervals to give a total of 123 (3 x 41) scans per device at each soil pit. Scanning took place under field moist conditions and bulk samples were taken at 10 cm intervals for laboratory analysis. We explore if these devices can provide effective characterisation in terms of a range of attributes including: mineral composition; texture; organic carbon; pH; and cation exchange capacity. This information may be utilised in the field for improved decision making, including multi-phase mapping techniques, management zone delineation and pedogenesis investigations.

keywords: *proximal soil sensing, digital soil morphometrics, soil inference system*

Spatial modelling of soil carbon in Sri Lanka using sparse datasets with samples collected with different depth supports

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In many developing countries the availability of soil data is limited and often collected through different small geographic soil surveys each with varying depth supports. In this study we used two soil survey datasets of soil carbon collected using non-probabilistic sampling schemes namely; (a) country-wide soil survey ($n \leq 387$) with data available based on soil horizons and (b) regional soil survey ($n \leq 166$) with data available based on fixed depth support. Rather than pre-processing the data with equal-area quadratic splines or other depth functions to harmonise the depths of observations, we used the approach by Orton et al. (2016) based on area-to-point kriging to fit one model for all depths to the data in its original vertical support. We split the individual datasets separately as model calibration (85 %) and validation (15 %) using a conditional latin hypercube sampling algorithm using a variety of environmental covariates that coincided with the individual sampling locations. A linear mixed model (LMM), with spatially- and vertically-correlated random effects modelled through a product-sum covariance model, was used for analysis. Thereby all data could be modelled in a single step without need for prior harmonization. Fixed effects were modelled based on a linear function of covariates (terrain, climate, remote-sensing data), and models with and without interaction terms with depth were compared. We present validation results and finally maps of predictions across Sri Lanka for three depth intervals (0-0.3 m, 0.3-0.6 m and 0.6-1.0 m) at a spatial support of 100 m. This constitutes the first ever country-wide soil attribute mapping carried out in Sri Lanka using modern digital soil mapping techniques. The outcomes of this work will provide valuable information on the soil carbon distribution across the tropical island. Additionally, information generated will act as a base towards development of a country-specific national carbon accounting model. This study also demonstrates spatial modelling of soil attributes with limited data collected over varying vertical supports, a common problem in most developing countries.

keywords: *Digital soil mapping, sparse datasets, 3 D modelling*

The Effect of Topography on Spatial Variation in Soil Health

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Profound changes in soil characteristics and soil health are observed due to land degradation processes. This affects human nutrition and health through impacts on food production. There is, therefore, a growing need and an interest in soil health mapping to assist decision-making regarding land use policies and soil management. Soil health tests developed recently are provided as quasi-point data in specific plots and there is, therefore, a crucial need to develop techniques to provide soil health mapping over wide areas, for example, to increase farming efficiency via precision agriculture.

Here, we address the landscape scale at which spatial variability is affected mainly by three factors: soil type; surface topography; and water distribution. Topography and water distribution, as soil functions that affect soil quality, include the ability: i) to accept, hold, and release nutrients and other chemical constituents; and ii) to accept, hold and release water to plants and surface and groundwater recharge. It is, therefore, hypothesized that soil health can be predicted efficiently in space by evaluating soil attributes simultaneously using regression kriging with topography and/or its derivatives as covariates.

The aim of this study was, therefore, to explore the potential to map soil health over an agricultural catchment using topographic terrain indices as covariates. Secondary aims were assessment of model residuals and validation of the use of Landsat 7 data as further auxiliary variables.

Based on the stratified random sampling method, 130 point measurements of the soil were distributed spatially in the Harod valley, Israel, and 15 soil properties were measured at each, during 20-23/03/2011. Based on these data, the Cornell Soil Health Test (CSHT) was evaluated using scoring functions. The CSHT was then interpolated in the Harod valley basin using Regression Kriging. Terrain indices, wetness index, Stream power index, Sediment transport index, Profile curvature, Planar curvature, and Topographic slope were used as covariates to predict hydromorphological processes as they were reported as correlating with erosion, deposition, compaction and saturation.

The results show that there is a spatial pattern in the model residual's which is correlated with remotely sensed vegetation indices and landform attributes. The use of NDVI, NDIMDIR as auxiliary variables together with Terrain indices, reduced the RMSE in the interpolated map. However, the reduction in RMSE could lead to biased representation of soils, due to foliage at planted fields in the catchment. Reclassification of Terrain indices into more discrete groups reduced this variability in the interpolation procedure.

keywords: *Soil Health, Geostatistcs, Regression Kriging, Spatial interpolation*

Application of colorimetric analysis of soils using flatbed scanners

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The physical characterization of soil horizons based on colour is a key diagnostic method in the description of soil profiles, and has been integrated in to diagnostic keys such as the World Reference Base for Soil Resources [2]. The Munsell colour system has been the primary qualitative or semi-quantitative means to describe soil colour.

At the same time, the main quantitative way to describe colour in soil science is through the CIE L*a*b* system. In this colour space system, the colour coordinates (a*, b*) are separated from the lightness (L*) coordinate [3].

Flatbed scanners have been used previously for colorimetric characterization of rocks and sediments [1].

In this study, we explore the feasibility of using flatbed scanners to derive colorimetrically accurate images and data of soil samples, and hence assess the suitability of the method as a diagnostic tool for soil characterization. The basic principle underlying our approach is to characterise and calibrate scanners using a variety of colour charts/targets. We tested the accuracy of these calibrations through analysis of a soil sample set containing 161 spectrophotometrically analysed soils.

The efficacy of our approach was tested with 2 low-cost scanners, and included analysis of 2 commercial colour charts, 6 printed colour charts, and 3 editions of the Munsell Soil Colour chart to assess optimum colorimetric calibration methods. For both scanners tested, we found that accurate colour characterization could be achieved for >95% of the studied soil samples (ΔEab* colour errors of <3, equating to a colour difference barely perceptible by the human eye).

Of all the studied printed charts, the Munsell soil colour charts gave the best result to characterize scanners colorimetrically. This is an encouraging result given their popular use amongst soil scientists. We find that using a Munsell chart for scanner calibration can provide mean ΔEab* of <2, with ΔEab* <3 for more than 90% of tested samples.

These results demonstrate the merit and efficacy of this rapid and low cost approach for soil colour evaluation.

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keywords: *soil colour, digital soil morphometrics, flatbed scanner, the Munsell charts*

Gamma radiometric mapping of soil texture at field and regional scale

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Within-field variation of soil properties is increasingly imaged by geophysical soil sensing (ground penetrating radar, electrical conductivity (ECa), resistivity (ER) and, more recently, gamma ( ) radiometry) and on-the-go measurements at field scale are progressing well. Continuous ground and airborne -spectrometry, respectively, are known to be a good choice for topsoil investigation at field scale, but still need to be tested for consistency and transferability in case of regional approaches. For quite some time, airborne -ray spectrometry is used to explore and map geological units across large areas. Here, we question the ability of airborne information to reflect areas of soil textural properties within a hummocky ground moraine landscape with comparable parent material.

Two regions of the Uckermark, Kraatz (10 km^2) and Dedelow (12 km^2), were investigated by a helicopter mission in autumn 2014 equipped with a -device (RS-500, Radiation Solutions Inc., CAN). Two fields (25 ha each) in both regions were mapped at about the same time by a tractor-driven -device (RS-700, Radiation Solutions Inc., CAN) and accompanied by ground truth soil sampling (120 positions). At field scale, ground- and airborne based -spectrometric maps of K, U, Th and total counts were used to be related to site (point) specific soil information. For regional aspects, existing soil maps of textural units were compared with the airborne maps.

Gamma derived maps of different raster cell sizes were analysed for their spatial association with soil texture at reference points, their spatial validity and transferability to other fields. At field scale the ground-based information was more accurate in reflecting point information compared to the airborne information. We attribute this to the very large footprints of airborne measurements. Nevertheless, for the regional purpose the airborne information seems an unavoidable means to support digital soil mapping for larger environments and its spatial patterns.

keywords: *Gamma spectrometry, proximal soil sensing, field scale, regional scale, soil texture*

Assessment of Uncertainty on a Digital Soil Map: a sensitivity analysis on the uncertainty indicators

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Digital Soil Map uncertainty is usually evaluated from a set of independent soil observations – i.e. that are not used for calibrating the DSM model -. As any statistical parameters derived from a set of individuals, the uncertainty indicators – e.g., R2, ME, PICP,...- could be sensitive to the number and the locations of these soil observations. To our knowledge, this issue has not be considered yet in the literature since it would require performing a sensitivity study from a base spatial sampling that had to be dense and extended enough for picturing the real underlying soil pattern and allowing the test of multiple sampling schemes, which is not feasible in practice.

In this paper, such sensitivity analysis is performed from the virtual pattern of topsoil clay content of bare soil surfaces at 5 meter resolution over 300 km^2 in the Cap Bon region (Tunisia). This pattern, derived from a hyperspectral image, was accurate enough (R2val $\leq$ 0.75), free of visible artefacts and pedologically plausible for being considered as a fair representation of reality.

We estimated the uncertainty of a DSM model obtained by calibrating from virtual values of clay content a Quantile Random Forest using relief soil covariates and geographical location (the r and n of "scorpan"). Different sampling methods and numbers of validation sites were considered, each time with 100 repetitions. The result showed that i) the range of variation on the uncertainty indicators raised a lot below a given number/density of validation sites, whatever the sampling method; ii) a non-negligible uncertainty range may remain for large/dense validation datasets.

We will discuss these results in the perspective of better assessing the quality of the Digital Maps of soil properties that are currently being produced across the world.

keywords: *Digital Soil Mapping, Uncertainty assessment, Spatial sampling, Imaging spectroscopy*

Predicting and Mapping Total Si over the main territory of France

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The biogeochemical cycle of Si has become a subject of increasing interest in recent years because of its interconnection with the C cycle and global change. Recent studies have suggested that land use and particularly agriculture can modify the Si cycle. However, the consequences of such a modification for the global Si cycle and for the growth of crops which are Si accumulators (most of the cereals) are still not well constrained. The bioavailable Si fraction is govern by several factors, among which the amount in total Si (Si-tot) that represent the long term weatherable pool. This amount has thus to be quantified at the territory scale. However, its determination is time consuming and costly. It is performed by ICP-AES after mineralization by sodium peroxide and sodium carbonate fusion. We thus propose an alternative estimation of the Si-tot at the French territory scale, within the project BIOSISOL (ANR-14-CE01-002), based on the samples of the French soil monitoring network (RMQS). This network consist in 2130 sites sampled in a regular 16 $\times$ 16-km grid. We measured topsoil Si-tot at 630 sites of the RMQS network consisting in one point out of four from this network (that is 450 points) and a set of 150 points selected randomly among the remaining sites. Mid-infrared reflectance and a large set of soil properties were measured at all sites of the RMQS. These soil properties are particle-size distribution, pH water, organic carbon, Total N, soluble and total P contents, calcareous, CEC and exchangeable cations (K, Ca, Mg, Na), Bo and 8 trace elements (Cd, Cr, Cu, Co, Ni, Pb, Tl, Zn). The dataset was then divided in 3 sets: Calibration, validation and test sets. The two formers were defined using a repeated folding step within the 650 sites and the latest corresponded to the 1500 remaining sites. Using a regression rule algorithm called CUBIST, we found that Si-tot was very well predicted by the mid-infrared spectroscopy (validation $R^2 \sim 0.98$ and test $R^2 \sim 0.97$) and by conventional pedotransfer functions using soil properties (validation $R^2 \sim 0.98$). This last model was used to evaluate the MIR model. Based on the MIR predictions, we then mapped the concentration of Sitot across France using digital soil mapping techniques.

keywords: *Si, Monitoring, Digital Soil Mapping, Spectroscopy, predictive models*

Comparison of methods to fill data gaps in soil profile databases

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Legacy soil profile databases are among the most important sources of information for many mapping and modelling approaches among others. Although soil profile information is collected for several decades, changes in sampling and soil laboratory methods often makes regional and global database diverse in many scales. Many harmonization approaches have been made, and global soil databases are available for the users, but these databases are heavily loaded with missing data, either for individual soil horizons, or complete parameters for the soil profile.

In this study different data mining and missing data filling methods are compared using legacy soil profile databases including the WISE 3.1 database and the AfSIS legacy soil profile database. Methods using only the studied soil profile to fill data gaps were also used along with methods using a training dataset to fill in missing information. Data mining methods were also tested with the use of the complete database and also tested using sub databases with soil profiles within the same taxonomic group. Results show that in the case of an available quality checked training database data filling results compared to methods like equal area spline function can yield similar results for some soil taxonomic groups and better for taxonomic groups with soil property changes difficult to model with an equal are spline function.

With the definition of a complete reference global soil profile database data mining techniques could improve the soil profile data filling approaches and could result in better base information for mapping and modelling of soil properties and classes.

keywords: *soil profile data, data gaps, random forest, equal area spline*

Optimizing spatial sampling for multiple objectives

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In the early days of pedometrics its practitioneres were quick to observe that when we have a variogram of a soil property we can use it to find the best choice of sample grid spacing to support prediction by kriging. Given a maximum acceptable kriging variance we can find a grid-spacing that achieves this. Since then the idea of optimizing spatial sampling to achieve objectives couched in terms of the precision of predictions or estimates has become a commonplace. The use of spatial simulated annealing has allowed sampling schemes to be optimized with respect to various objective functions so that, for example, the overall prediction error variance, expressed as a combination of the kriging variance (which depends on spatial coverage) and variance parameter error (which requires some spatial clustering of sample points), can be optimized within irregular regions, perhaps in the presence of existing data or exhaustive covariates.

In practice we may be interested in more than one objective function. In addition to achieving acceptable precision of estimates or predictions we may also want to have an acceptable probability of detecting plumes of a pollutant. Other secondary objective functions may include the total distance to be covered visiting the sample points or the technical properties of a wireless sensor network (such as the number of alternative routes for data transmission, or the total power consumption). A simple approach to this problem is to optimize a weighted combination of all objective functions. However, the weights in such a case are generally arbitrary, and it is known that not all good solutions are accessible this way.

In this paper I shall present an approach to multiple objective optimization which searches for design solutions on a Pareto front. These solutions are mutually non-dominating, which means that no one solution is better than any other on all criteria. The Pareto front consists of a set of solutions which are Pareto efficient, in this sense, and from which an acceptable subset can be selected. The challenge is to find the front. I shall show how this can be achieved using a version of simulated annealing, the AMOSA algorithm, which has been used for various tasks in optimization including the design of electronic components.

keywords: *Sampling, Optimization, Multiple objectives*

Past, present and future of mathematical methods in pedometrics

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Pedometrics as a science is concerned to understand the variation of the soil in space and time in quantitative terms. This science underpins the provision of meaningful predictions of soil properties at a location and support in space and time, which is required for management or policy decisions. In order to count as meaningful a prediction should have some non-arbitrary measure of its uncertainty. In both senses pedometrics is underpinned by mathematics, most commonly statistical sampling theory or the theory of random functions. Sometimes, when these approaches seem inadequate, pedometricians turn to computation with little or no mathematical underpinning. In my view this is a mistake, but it may be a fruitful one if we can identify the shortcomings of current methodology and then engage in informed speculation about what established or emerging mathematical apparatus might help us to make progress. That, after all, is how Beckett, Webster, Burrough and others developed pedometrics out of soil survey in the period from around 1965 to 1980. In the course of this review I shall look back, examining how ideas from stochastic geometry, information theory, spectral analysis and state-space modelling have contributed to pedometrics. I shall ask why we do things the way we (usually) do, and what problems this may cause (whether we spot them or not). I shall then make some suggestions about where new terrain for further pedometrical cultivation might be found in the mathematical landscape.

Mapping root depth soil water in sub-Saharan Africa

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Soil root zone plant-available water holding capacity (RZ-PAWHC) is one of the most sensitive soil parameters determining crop growth. This study produced the first map of the rootable depth and the RZ-PAWHC of sub-Saharan Africa (SSA). First, geo-referenced data for 28,000 soil profiles were used as input for digital soil mapping techniques to produce soil property maps of SSA (sand, silt, clay, bulk density, organic carbon, cation exchange capacity, exchangeable aluminium and sodium, pH-H O, electric conductivity, coarse fragments, drainage class and depth to bedrock). The variance explained R2 varied between 52% and 77% for these basic soil properties but was critically low (<30%) for coarse fragments content and drainage class. Next, these maps were used as input data to (pedotransfer) functions, rules and criteria, which we developed and parameterised based on literature review, to produce derived maps of soil water retention at field capacity and wilting point, the soil fine earth fraction from coarse fragments content and, for maize, the soil rootable depth. Mapped versus observed water retention had an R^2 of 72% and a RMSE of 0.10 cm^3/cm^3. The map of rootable depth could not be adequately validated due to lack of adequate data on rootability. Results were aggregated to a RZ-PAWHC map of SSA with a spatial resolution of 1 km^2. RZ-PAWHC ranges between 0 and 235 mm with an average of 74 mm. In soils with unrestricted rootability to 150 cm (maximal rooting depth of maize), the average effective PAWHC is 113 mm and, excluding coarse fragments, 137 mm. The total soil volume of SSA potentially rootable for maize (approximately 30,000 km^3) was reduced by one-third (10,500 km^3) due to soil conditions restricting root zone depth, of which 4,800 km^3 are due to inadequate aeration and 2,500 km^3 due to sodicity. The overall assessment of RZ-PAWHC could not be adequately validated but the accuracy seems most limited by the accuracy of the soil property maps from which the maps of RZ-PAWHC and especially rootable depth were derived.

keywords: *soil depth, root depth, soil water, soil map, Africa*

Building a national (german) mid infrared database for soils

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Mid infrared spectroscopy (MIRS) is a lab based analytic technique, which allows to derive a lot of soil parameters at little expense and effort. MIRS is actually a link between very precise conventional lab analyses and often less precise non-invasive sensors which gather data directly in the field (e.g. EMI, Vis-NIRS). Since MIR spectra only deliver proxy information on interesting soil parameters, calibrations are required. They provide statistic relations between the results of conventional lab analyses and MIR spectra (e.g. via PLSR). As a rule, these calibrations are only locally valid; this hampers a more broad use of MIRS in soil analysis. Within our BonaRes-I4S study, our aim is to minimize this drawback by setting up a national MIR database. This primarily means to contact various soil archives and to collect thousands of soil samples which already have been analyzed by conventional lab methods. We will record MIR spectra of these samples. Our hypotheses are that a broad and comprehensive spectral database may allow two things: (A) Robust, multivariate statistics make it possible to construct calibration models being supraregionally valid. (B) For new soil samples to be analyzed, their MIR spectra may be used, to select the most similar spectra in the database. These spectra are then used to build a quasi-local calibration model. A dataset of about 1000 soil samples from the LUCAS archive of the Joint Research Center in Ispra (Italy) is used to demonstrate that supraregional calibration models are possible for diverse soil characteristics.

keywords: *proximal soil sensing, MIRS, topsoil quality*

Have extractable phosphorus and potassium contents evolved in French agricultural soils since 2004?

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In the last 25 years, amounts of phosphorus and potassium brought to soils through mineral fertilisers have decreased by 70% in France, without organic compensation. This situation conduced to a reduction of nutrients balances. The aim of this study was to estimate if the decreased fertilisation could be linked with a significant decrease of extractable P and K contents in soil. The French National Soil Test (FNST) database was used to study this hypothesis. It gathers results of physico-chemical analysis performed on agricultural topsoils samples, at farmers' request. The spatial and temporal sampling strategy were not controlled. The sampling year is known and the localisation is given by the municipality of origin of the sample. Two periods were compared: 1990-2004 and 2005-2014. A total of 2,516,743 and 2,161,811 soil test results for K_2O and P_2O_5 respectively were available in the FNST database, equitably allocated between the two periods. Analytical results were grouped within administrative spatial entities (cantons - groups of municipalities; small agricultural regions - 713 units in France), and statistical estimator of nutrients contents were calculated after a resampling procedure (Monte Carlo approach) aiming at limiting sampling biases. Two indicators were studied: the evolution of extracible nutrients contents and the evolution of the agronomic diagnosis performed with the software RegiFert. The agronomic diagnosis evaluates the necessity of fertilisation to reach the potential yield considering the crop, the soil nutrient status and other soil characteristics. Results are provided according to 3 diagnosis classes: low, intermediate and high fertility. Evolution of contents was assessed using the non-parametric Mann–Whitney test, and evolution of diagnosis was assessed using the adequation ^{2} test with a limit p-value of 0.1, combined with expert rules on the evolution of the count of results into each fertility class between the two periods. Extractable P contents exhibit a clear decrease: P content decreased by more than 10% in 42.2% of the total cultivated area (TCA), with contrasted regional situations according to intensity of the animal production. The evolution of extractable K content was very low: it decreased for only 4.5% of the TCA. Evolution of agronomic diagnosis is very narrow, meaning that evolution in nutrients contents was too limited to significantly impact fertilisation recommendations. However, the overall decline in nutrients availability in soils encourage vigilance and soil fertility monitoring through regular soil testing.

keywords: *Soil monitoring, extractable nutrients, soil tests, National scale*

Modelling the electrical conductivity of soil in the Yangtze delta in three dimensions

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Numerous processes, past and present, have given rise to lateral and vertical variation in the soil and to its indi-vidual properties such as its salinity and electrical conductivity. The resulting patterns of variation are complexand appear to comprise both random and deterministic components. The latter dominates vertically as trendsin most soil profiles, and in the situation we describe it is prominent in the horizontal plane, too. Describing this variation requires flexible choice of covariance function. The processes of model estimation and predictionby kriging in three dimensions are similar to those in two dimensions. The extra complexity of the three-dimensional variation requires practitioners to appreciate fully the assumptions that their choices of modelimply and to establish ways of testing the validity of these assumptions. We have examined several covariance-functions more commonly used to describe simultaneously variation in space and time and adapted them tomodel three-dimensional variation in soil. We have applied these covariance functions to model the variationin salinity in reclaimed land in the Yangtze delta of China where the apparent electrical conductivity (ECa) hasbeen measured at numerous points down to 1.1 m. The models take into account random and deterministic com-ponents in both the horizontal and vertical dimensions. The most suitable mixed model was then used to krigethe ECa on a fine grid from which three-dimensional diagrams of the salinity are displayed.

keywords: *Saline soil, Electrical conductivity, Three-dimensional variation, Space–time covariance functions, REML, E-BLUP*

Sensing of soil organic carbon with portable spectrometers

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The development of portable vis–NIR (vis–NIRp) and mid-infrared (mid-IR) spectrometers is enabling the rapid, real-time and accurate proximal sensing of soil properties. However, before using these techniques in field applications, we need to assess their performance under laboratory conditions. Here we assessed two portable spectrometers: a mid-IR (mid-IRp) and a vis–NIR (vis–NIRp) for the determination of soil organic carbon (SOC) concentrations. We also compared their predictions to those made using the bench-top mid-IR (mid-IRb) spectrometer. Our aims were to determine the accuracy and uncertainty of scanning mid-IR and vis–NIR spectroscopy to estimate the SOC content of soil to a depth of 1 m using portable spectrometers.

For our experiments, we used 578 soil specimens systematically sub-sampled from four depths of each of 150 soil cores sampled to a depth of one-meter from a 600 ha farm in northern New South Wales, Australia. The sub-samples were ground dried, crushed and ground to particle sizes of 2 mm and 0.5 mm for our analysis. We developed predictive models using the machine learning algorithm Cubist and used 50 bootstraps to derive robust predictions and assess the uncertainty of our models.

As might be expected, the prediction of SOC with the mid-IRb ($R2 \leq 0.96$, $RMSE \leq 0.17$) on 0.5 mm particle size outperformed predictions made with spectra of mid-IRp ($R2 \leq 0.91$, $RMSE \leq 0.26$) and vis–NIRp ($R2 \leq 0.88$, $RMSE \leq 0.30$). Predictions made using mid-IRp and 0.5 mm particle size were more accurate than those made with vis–NIRp, but their uncertainties were larger. There is no clear difference found from the prediction results for mid-IRp ($R2 \leq 0.84$, $RMSE \leq 0.35$) and vis–NIRp ($R2 \leq 0.81$, $RMSE \leq 0.38$) on 2 mm particle size.

We conclude that the both potable mid-IRp and vis–NIRp spectrometers performed well to estimate SOC under laboratory conditions. Particle size has more impact than spectral ranges on the prediction of SOC concentrations. Though better prediction accuracy can be obtained using finer particle size, preparation requires more effort. The accuracy of predictions using samples ground to 2 mm were sufficiently accurate and would enable many more sample measurements, which can benefit the spatial characterisation of soil organic C.

keywords: *mid-IR, vis-NIR, particle size, soil core, uncertainty*

How does particle size, water and excitation time affect proximal soil sensing by X-ray fluorescence?

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Portable XRF technology has gained acceptance as an analytical approach for the estimation of soil elemental and chemical properties. The technique is relatively easy-to-use, rapid real-time and non-destructive. However, there have been few studies that have assessed the XRF technique under different conditions. Thus, our aims here was to design an experiment to assess the effects that different particle sizes, water contents and excitation times have on the XRF spectra of four different soils with different clay contents from four intact soil cores.

We sub-sampled each of them into 5 replications and used a 3-way factorial design, with three particle sizes (1 mm, 2 mm and natural aggregates), three gravimetric water contents (air-dry, 10% and 20%), and three excitation times (15, 30 and 60 seconds). X-ray spectra were recorded using a portable XRF spectrometer to give 540 spectra in all. Six (Si, K, Ca, Ti, Fe and Cu) of characteristic elemental peaks were identified for analysis. We used an analysis of variance (ANOVA) to identify significant differences between our factors and using the peak intensity and peak area of six elemental peaks as our response variable.

As might be expected, longer excitation times generally improved detection limits. There was a strong linear relationship between intensity of XRF spectra and measurement times. The results from the ANOVA showed that, for Si, all treatments were significantly different for both mean peak intensity and area. For K, Ca, Fe and Cu there was no significant difference in mean peak intensity and area between 2 mm particle size and the soil aggregate. However, peak height and area for Ti were significantly different. There were significantly difference in peak intensity and area between the 1 mm particle size and the soil aggregate, except in the case of Cu. Similarly no significant difference for moisture was found between air-dry and 10% moisture content except in the case of Cu for peak area. When the soil wetter, for Ti, K, Ca, Ti and Fe there were significant difference in peak intensity and area between air-dry and 20% moisture content, except Cu in terms of peak intensity.

Our results suggested that measurement time has the biggest effect on signal intensity, while particle size and moisture are secondary effects. However, signal intensity was better for drier soil with smaller particle sizes. Thus, all of these factors will affect the accuracy of proximal soil sensing with portable XRF.

keywords: *portable, XRF, ANOVA*

Fine spatial resolution mapping of soil organic carbon in China

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Accurate digital soil maps of soil organic carbon (SOC) are needed to evaluate soil fertility, estimate soil organic carbon stocks, and for ecological and environment modeling. We used 5982 soil profiles collected during the second national soil survey of China with 19 soil landscape-environment predictors to derive a spatial model of the concentration of SOC in the 0–20 cm. The environmental predictors relate to the soil forming factors and include elevation, vegetation and climate. We developed the model using the machine learning algorithm Cubist combined with the non-parametric bootstrap to derive estimates of model uncertainty. We optimized the Cubist model using a 10-fold cross validation and the best model used 17 rules, 5 committees and 5 neighbors. The cross validation correlation coefficient between the observed and predicted values was 0.62 and the relative error was 0.72 g/kg. We then generalized the model over China and mapped the SOC distribution at 90 m resolution. The predicted spatial distribution of SOC over China shows larger values area in the eastern Tibetan Plateau, the north of Heilongjiang province, the northeast of Mongolia, and the small part of the Tianshan Moutain in Xinjiang. The small concentrations of SOC occur in the Loess Plateau and most of the desert areas in Northwest China. Results show that the average SOC content in surface soil is 24.82 g/kg. Our work provides an up-to-date map that can decision-making in the formulation of policy for carbon offset schemes. The map will also help the design of future soil surveys and the development of monitoring networks in China.

keywords: *soil carbon, digital soil mapping, big data mining, uncertainty, China*

The anatomy of errors from soil property measurements and predictions (soil pH example)

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Spatial predictions of soil properties are performed in digital soil mapping and error predictions are assessed against measured values when available. Rarely the errors associated with measurements, pedotransfer functions and database transections are directly assessed in error spatial predictions. Because of discrepancies between soil measurements and spatial predictions, one to one comparisons for error assessments are difficult and impractical, especially in the context of large databases. Thus, various data generalizations are used, which could also affect the spatial error predictions. The objective of this study was to assess the soil pH errors associated with the use of: (i) different measurement methods; (ii) pedotransfer functions and (iii) database transections. Data from the International Soil Exchange protocol were used to assess the accuracy of measured soil pH by various laboratories. Pedotransfer functions to convert soil pH 1:1 water to soil pH 1:5 water and equal-area spline functions and soil horizon weighted means were used and compared for the GlobalSoilMap standard soil thickness (0-5, 5-15, 15-30, 30-60, 60-100; and 100-200 cm). The accuracy of soil pH 1:1 water measured by various laboratories across the world on same soil samples was 0.7 pH, while the accuracy within laboratories varied between 0.2 and 0.3 pH. The use of a simple linear regression equation to predict soil pH 1:2 water from pH 1:5 water had a root mean square error (RMSE) of 0.44 pH. The errors between spline function and weighted means for soil pH 1:5 water for the STATSGO database varied from 0.2 to 0.4 pH between standard depths, but only from 0.1 to 0.2 for the SSURGO database. The errors of splined soil pH 1:5 water between SSURGO and STATSGO for all standards depths varied between 0.5 and 0.7 pH. However, the errors of splined soil pH 1:5 water between measured data (KSSL) and STATSGO and SSURGO were greater and varied between 0.7 and 0.8 pH. An ideal comparison to assess the impact of different measurement methods, pedotransfer functions and database transections would require that spatial predictions and measured values be made on the same scale, from the same area and on the same samples. Given that such comparisons are the exception and not the norm, the quantification of the errors that result from differences in measurement methods, pedotransfer functions and database transections are a good indicator of the accuracy predictions to be considered for informing management decisions.

keywords: *error predictions, pedotransfer, soil pH*

Can conditioned latin hypercube sampling capture pedodiversity?

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Conditioned latin hypercube sampling (clhs) has advanced to be a standard sampling approach for statistical soil-landscape modelling, also known as digital soil mapping. Latin hypercube sampling (lhs) was developed to sample a number of n parameters in such a way that the density function of each of the n parameters is well represented by the selected k samples. This is achieved by subdividing the density function of each parameter into k quantiles and selecting one sample per quantile. Finally, the so obtained k values for each parameter are combined with those of the other parameters, either randomly or in some predefined way. However, if these parameters represent soil forming factors within the reality of an actual landscape or their respective proxies from satellite images, digital elevation models, geophysical sensors etc., then the selection of a certain landscape position for sampling and, hence, the selection of a certain parameter value in one of the parameter quantiles, automatically results in the selection of values in one of the quantiles of the other parameters as well. As a consequence, the selection of one sample per quantile needs to involve an optimisation approach as implemented in clhs. Meanwhile, several adaptations were made to overcome practical difficulties that might arise during the actual sampling campaign in the field, other problems remain widely unnoticed: (1) The values which fall into the various quantiles of a certain parameter do not have the same probability of being selected as was the case in lhs, a flaw which is even enhanced while more parameters are considered and/ or more points are selected. And (2) as a consequence to the optimisation process, the selected points are not independent from one another. Finally, (3) due to the selection of one particular parameter combination, important other landscape positions cannot be sampled and will neither be present in the dataset, nor in the thereby obtained statistical soil-landscape model. So the power of clhs to capture the heterogeneity and, hence, the pedodiversity of a landscape is very limited as it will always result in a too simplified version of the reality within the selected samples, and will, therefore, most probably lead to biased models. Stratified random sampling methods, which sample landscape units formed by e.g. methods of pattern recognition, are more suitable for this purpose.

keywords: *conditioned latin hypercube sampling, digital soil mapping, sampling design*

Spatial variations and controlling factors for estimation of soil organic carbon stocks in three rural soil areas of Taoyuan, Taiwan

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The spatial variations of soil organic carbon (SOC) stocks and controlling factors in mainly agricultural area of Taoyuan, northwestern Taiwan, was less concerned in last decade. In this study, dataset for estimating the SOC stock in agricultural soils was obtained from a detail soil survey by Taiwan Agricultural Research Institute (TARI) recently. The databases have all the SOC and few soil bulk densities of three townships of Taoyuan, near 27,559 ha, with different land uses. Near 4410 soil profiles were sampled in every 250 meters by 250 meters by soil auger from surface to 150 cm depth. The bulk densities were estimated by pedotransfer function for arable soils in Taiwan. SOC contents and SOC stocks in 3 soil depths (0-15, 15-30, and 30-60 cm depth) were interpolated by ordinary kinging methods with GS+ and ArcGIS. Results showed that the average SOC contents (g/kg) in 3 soil depths were 20.4 g/kg, 15.8 g/kg, and 12.9 g/kg, respectively. The distribution of SOC contents decreased with increasing the soil depth. The SOC stock (mean $\pm$ standard deviation) was 29.3 $\pm$ 7.03 ton/ha for 0-15 cm depth, 24.0 $\pm$ 6.10 ton/ha for 15-30 cm depth, 40.6 $\pm$ 11.3 ton/ha for 30-60 cm depth and 93.9 $\pm$ 23.9 ton/ha2 for 0-60 cm depth (whole soil layer). The average SOC stocks in 0-15 cm and 0-30 cm are higher than those of arable land of Taiwan in previous studies. The total SOC stock of 3 townships areas was 0.81 Mt (megatons) in 0-15 cm depth, 1.47 Mt in 0-30 cm depth and 2.59 Mt in 0-60 cm depth, respectively. The spatial distribution of SOC stocks decreased with decreasing the elevation, where the higher ones were mainly distributed in the eastern part close to the hill land area, and the lower ones were mainly distributed in the western part along the seashores and the rivers. The spatial variations of SOC contents and SOC stocks were the same. Additionally, the effects of elevation, aspect, slope, curvature, drainage, terrain ruggedness index (TRI), terrain wetness index (TWI), and normalized difference vegetation index (NDVI) on SOC content and SOC stock can be evaluated by GLMM model with SAS. Analysis results indicated that the elevation ($p< 0.0001$), NDVI ($p\leq 0.0002$), drainage ($p\leq 0.0005$), aspect ($p\leq 0.001$) and TWI ($p\leq 0.0158$) are the mainly controlling factors on the spatial distribution of SOC content and SOC stocks in 3 townships of Taoyuan, Taiwan.

keywords: *SOC contents, SOC stocks, ordinary kinging, spatial variations, ontrolling factors, rural soils*

Secondary soil information extraction from 3D soil mapping products

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Three-dimensional (3D) digital soil mapping can produce a complete soil property distribution. However, even with the complete distribution, important soil information such as the patterns of depth and thickness of soil diagnostic or impeding layers are still seriously lacking, which limits the application of 3D soil mapping results for eco-hydrological modeling and land management. In this study, we developed a method for extracting the presence/absence, depth and thickness of specific soil layers from 3D soil mapping results. The approach was demonstrated in the Heihe river basin, northwestern China. We predicted 3D continuous distribution of soil CaCO3 content using its relationship with climate, parent material, terrain, and vegetation conditions. Based on the predicted 3D soil data, we extracted key points of vertical variation at each pixel location and then divided the profile of this location into different layers. For each layer, we identified the presence/absence, depth and thickness of soil calcic layers. The results showed that the spatial patterns of the depth and thickness of calcic layers can be accurately extracted. It was found that the depth of calcic horizons becomes shallower with the increase of aridness while its thickness exhibits an opposite pattern. We concluded that the proposed method is effective for extracting secondary soil information from 3D soil mapping results.

keywords: *3D digital soil mapping, secondary soil information extraction, soil calcium carbonate, calcic horizons*

Estimation of surface soil moisture from remotely sensed data using random forests

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Accurate information about the concentration of soil moisture in the top 5 cm soil layer is very important in many applications, such as drought prediction, watershed management, irrigation scheduling, precision farming, climate change analysis and meteorology. Soil moisture products acquired from passive satellite missions have been widely applied in environmental studies. However, a primary limitation for using such products for local scale assessment is their low spatial resolution (e.g. 9 km for the NASA's Soil Moisture Active Passive - SMAP - Level 4 product). Thus, estimation of soil moisture with higher spatial resolution is needed for many applications. In this study, the random forest (RF) algorithm is used to estimate surface soil moisture (SSM) over a region representative of grasslands and agricultural landscapes, located in the east of the Colombian territory, for a rainy season in 2015. The main body of the paper describes application of the RF algorithm to construct a regression model from variables based on remotely sensed datasets: (i) downscaled gridded precipitation data from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS); (ii) the normalized difference water index (NDWI), (iii) the normalized burn ratio thermal index (NBRT) from Landsat; (iii) the enhanced vegetation index (EVI) from Landsat; and (iv) topographic attributes derived from the Shuttle Radar Topographic Mission (SRTM) digital elevation database. Soil moisture field measurements collected in 2009-2011 were used to train and test two RF models, one for the wet season and the other one for the dry season. Then, the RF regression model is used to estimate SSM over the study area at 30-m spatial resolution in June 2015. Accuracy of the estimation was assessed using the root mean square difference (RMSD) and the mean absolute difference (MAD) between the predicted soil moisture and a reference dataset obtained from a 3-km SMAP Level 3 product. Results demonstrate that, while the RF model is able to accurately estimate surface soil moisture for the wet season, its estimation is less accurate for the dry season. The paper examines what are the most informative variables in the RF models and discusses whether topographic and multispectral indices, based on SRTM and Landsat datasets, could replace precipitation data for surface soil surface estimation. It concludes stating advantages and limitations of using remotely sensed data for surface soil moisture estimation at local scales. Interested readers can find details on data, methods and results at https://goo.gl/IL2utQ and https://goo.gl/5hLwjU .

keywords: *soil moisture, remote sensing, random forests, SMAP*

Can large spectral libraries improve local calibrations of soil organic carbon?

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Diffuse reflectance spectroscopy in the visible and near infrared (vis-NIR) can measure soil properties, such as organic (C). Compared to conventional laboratory methods, it enables practical and inexpensive measurements at finer spatial and temporal resolutions, which are needed to improve the assessment and management of the environment. However, the accuracy of the measurements, and the economic viability of the technique depends on the costs associated with the development of spectral libraries for calibration. Soil spectral libraries (SSL) developed at the regional, continental and global scales, have demonstrated the usefulness of vis–NIR for soil analyses. Calibrations derived using these libraries, however, are often shown to predict poorly at local scales. Here we present a new method - RS-LOCAL – that uses re-sampling and a small representative set of local samples to 'tune' large spectral libraries so to improve calibrations at local scales. We demonstrate the implementation of RS-LOCAL by estimating soil organic C at two sites with very different soil types in Australia and New Zealand. We found that with as few as 12 to 20 local samples and a large SSL RS-LOCAL could accurately predict soil organic C, and that it outperformed all other local techniques that we tested. Thus, RS-LOCAL can reduce analytical cost and improve the economic viability of soil spectroscopy.

keywords: *spectroscopy, visible near infrared, soil organic carbon, local calibration*

Predicting the spatial pattern of soil particle-size distribution using a pedogenesis model

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Particle-size distribution (PSD) plays an important role in influencing a number of soil physical, chemical, and biological properties such as bulk density, hydraulic conductivity, water holding capacity, erodibility, carbon storage and many others. This paper aims to predict the spatial pattern and evolution of soil texture (sand, silt and clay), the most common descriptor of PSD, at a catchment located in Hunter Valley, NSW, Australia, using a mechanistic pedogenesis model called SSSPAM.

The SSSPAM model simulates spatial and temporal variation of soil texture within a soil profile based on erosion due to overland flow and physical weathering within the profile. Using an existing 30m DEM as input, the model simulated soil evolution over 70,000 years with particle size output every 100 years. We ran the model over this period to ensure that the particle-size distribution had reached a steady-state condition, typically before 100,000 years. To validate and analyse the influence of different process parameters and dynamics of particle size, the model was calibrated using a digital soil map and observed soil texture for some sites within the study area.

We found a strong relationship between runoff excess generation, exponential weathering rate and the soil particle-size distribution. Lower discharge produced finer particles. Higher exponential weathering rates broke down the large particles more rapidly and allowed finer particles to be retained. Increasing the erodibility factor did not change the results dramatically. Other parameters like weathering fragmentation geometries, depth-dependent weathering (humped exponential and dynamic reversed exponential) functions and the exponents of the equations will be further studies in the subsequent paper.

The model is able to explore the soil particle-size distribution and how the particle size will change only considering physical weathering mechanism and erosion from overland flow. We will discuss how such soil formation model combined with the empirical spatial data can be used to predict the variation of soil properties accurately together with associated uncertainty analysis.

keywords: *Particle Size Distribution, Spatial Pattern, Pedogenesis Model*

Soil Properties Prediction Using Diffuse Reflectance Spectroscopy, Attenuated Total Reflectance Spectroscopy and Fourier Transform Infrared Photoacoustic Spectroscopy

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The approach of spectral analysis is one of proximal sensing methods in soil science such as soil management and precision agriculture. Soil properties can be measured and revealed as a spectral curve according to spectra scans when deal with numerous soil samples in a rapid and non-pollution method. There is continuous and growing interest in mid-infrared ranges for soil properties characterization.

As the sensitive, efficient and accurate techniques in soil science, the diffuse reflectance spectroscopy, the attenuated total reflectance spectroscopy and Fourier transform infrared photoacoustic spectroscopy have their own advantages on soil identification and soil quantitative analysis. In this article, we selected 1456 paddy soil samples in in eastern of China and collected diffuse reflectance spectroscopy, the attenuated total reflectance spectroscopy and Fourier transform infrared photoacoustic spectroscopy of the samples, respectively. The purpose of the study was to using the complementarity of three techniques to develop spectral library for quantitative assessment of soil nutrients such as pH, SOM, N and P for survey and management. A self-adaptive model was constructed based on PLS model for soil identification and prediction. The results showed that attenuated total reflectance spectra can provide more accurate prediction in pH and P values, and the diffuse reflectance spectroscopy can get good results in SOM and N values. Moreover, the Fourier transform infrared photoacoustic spectroscopy can provide more functional groups information. It might provide a supplemental method for use in soil management.

keywords: *Diffuse Reflectance Spectroscopy, Attenuated Total Reflectance Spectroscopy, Fourier Transform Infrared Photoacousticspectroscopy, Soil Properties Prediction, A self-adaptive model*

Managing quantifiable uncertainty for digital land suitability assessments

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We are seeing an increasing activity in land resource assessments (LSA) at varying spatial scales throughout the world. These efforts have been largely assisted by suites of digital information technologies such as digital soil and climate modeling and mapping, and associated environmental resource mapping such as remote sensing data and digital elevation models. A common scenario however is that these digital LSAs are made with the assumption that the input information is error free. Similarly, the criteria with which assessments are made are often discretely defined.

In this paper we briefly review the status quo of digital land suitability analysis. The study then focuses on Tasmania, Australia where there has been the integration within Government policy and directives, a fully digital LSA system for a number of specific agricultural enterprises. Here we address two issues that present limitations to current LSAs. First we take into account the quantified uncertainties of the input variables. Secondly, we adopt membership functions rather than discrete threshold values for the assessment criteria.

For taking into account the input variable uncertainties, simulations are used to generate plausible realisations of soil and climatic variables for input into an LSA. It is found that when comparing to a LSA that assumes inputs to be error free, there is a significant difference in the assessment of suitability. Using an approach that assumes inputs to be error free, 56% of the selected study area was predicted to be suitable for hazelnuts (our selected agricultural enterprise). Using the simulation approach it is revealed that there is considerable uncertainty about the 'error free' assessment, where a prediction of 'unsuitable' was made 66% of the time (on average) at each grid cell of the study area. In the specific case of our study area, the cause of this difference is that digital soil mapping of both soil pH and conductivity have a high quantified uncertainty in this study area. The use of parameter membership functions and or adopting expert rules around soil properties that can be easily managed, we find penalties for taking into account uncertainties are not as severe. Despite differences between the comparative methods, taking account of the prediction uncertainties provide a realistic appraisal of enterprise suitability.

keywords: *Digital soil assessment, Quantifying Uncertainty, Land Suitability Analysis, Agriculture*

Useful applications of conditioned Latin hypercube sample for digital soil mapping

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The conditioned Latin hypercube sampling strategy (cLHS; Minasny and McBratney 2006) provides the necessary facility of efficiently sampling variables from their multivariate distributions. It is particularly applicable for digital soil mapping projects, where within a given target area one wants to derive a more-or-less optimal sampling configuration given prior information in terms of exhaustive ancillary data such as from digital elevation models, remote sensing data etc. cLHS basically ensures biases in the decision-making of a soil surveyor are removed during a soil sampling campaign, and provides the means for actually visiting all areas of the target area landscape in the most efficient way possible.

Some questions that may arise during the planning and implementation of cLHS for digital mapping purposes are: 1) How many samples should be collected? 2) How does one further improve the efficiency of cLHS by taking into account prior sampling locations within the target area? 3) How can one generalize cLHS in the situations where selected sites cannot be visited? This paper presents some relatively simple solutions to these questions.

For the first question, we can answer it via an iterative approach observant to the law of diminishing returns. Here we assess a distance criterion between population and sample for increasing sample sizes and select the configuration that minimises the work required while also ensuring the population multivariate distributions are efficiently sampled. For the second question, we evaluate the data space occupied by the prior sampling points, before implementing a cLHS on the data space that has low occupation. For the third question, we use either a Gower's similarity index or fuzzy membership approach to rank alternative sites to visit if an original location needs to be moved somewhere else.

We illustrate solutions to these questions using combinations of spatial data that are both continuous and categorical format.

keywords: *Soil sampling, Conditioned Latin hypercube, Digtial soil mapping, Optimisation*

Comparison of Multifractal parameters between binary and grayscale synthetic images

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In soil science image analysis has become increasingly popular during the last decade thanks to the technological advances, particularly in X-ray computed tomography (CT) to characterize the spatial distribution of soil pore structures. This is a key factor to obtain different parameters that will influence in several models related to water flow and/or microbial growth processes. One important process often used, as one of the first steps in image analysis, is binarization. Actually, there are several segmentation methods that have been applied to CT soil images. To check the robustness of these methods, different authors have created different synthetic images.

Recently, Torres et al. (2017) showed the multiscale nature of CT- soil images. Based on the scaling properties of these images, Martín-Sotoca et al. (2017) developed a Truncated Multifractal method (TMM) that is able to construct a 2D synthetic image, used to test the Singularity-CA binarization method. In this method, a multifractal algorithm is used to create an air-filled pore space and a pebble space that simulates the granules of high intensity that typically appear in CT soil images. Therefore, the TMM can simulate the two main characteristics that some CT soil images present: the scaling nature of the gray scale image and the low contrast at the solid/pore interface with non-bimodal greyscale value histograms.

In this work we present the relationships found between the multifractal parameters used to create the 2D grayscale image and the histogram and multiscale parameters found. In order to obtain so different intensities of noise were applied in the generating process. A comparison with real CT- soil images will be showed.

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keywords: *CT-scan soil images, synthetic images, multiscale analysis*

Development of a stakeholder-oriented communication strategy for raising acceptance of soil protection measures

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Soil functionality is crucial in the production of food, feed or renewable resources as well as for the ecosystems themselves. Over the past decades, the trend to larger machinery increased the pressure on soil functionality. On-farm soil protection measures can promote a higher level of sustainable land use, e.g., weather-dependent field traffic and machinery that prevents compaction damage. Nevertheless, different types of data from different sources (e. g., weather data, machine parameters and specifications, etc.). Also, new ways of decision-making for farmers and decision support for policy-making and good governance are needed in this context and present an ambitious goal.

To reach this goal, SOILAssist analyses important agricultural trade publications in Germany, with a focus on articles about soil protection. First, a frequency analysis reveals the most common topics and the frequency of keywords used. Secondly, there will be results on how stakeholder knowledge can improve by knowledge transfer. Do farmers like to use real-time information on soil humidity, deformation rates and other soil functions? Fortunately, there is access to real-time information on soil, so the transfer of research to on-farm soil management is ensured. Then, the results of a nation-wide farmer survey done in early 2017, show recent data on soil protection knowledge. Bringing together all three aspects, a stakeholder-oriented communication and advice strategies can be initiated. The use of this experience-based and somewhat uncertain, but valuable, knowledge guarantees to be useful for getting a better picture of the acceptance of soil protection measures. Agricultural extension and new governance principles can also profit from easier decision processes on field traffic. In addition, a decision support tool might not only deliver standardized data on soil, but also help to apply sustainable land use practices, and last but not least a web-based knowledge portal.

This abstract refers to the project “SOILAssist” launched in October 2015 as a part of the German research program ‘BonaRes – Soils as Sustainable Resource for the Bioeconomy’ (funded by the Federal Ministry for Education and Research, BMBF 031A563A).

keywords: *Sustainable agriculture, soil quality, soil information system, decision support system, soil management, soil compaction, knowledge transfer, governance*

Crossing the bridge between soil ecology and pedometrics at global scale

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Understanding soil functioning is critical for soil and ecosystem management in response to global change. Soil functioning is the result of the interactions between biotic and abiotic component of soils. Understanding soil functioning requires understanding these interactions in the great variation of situations existing on earth. Biotic and abiotic components of soils are typically studied by different fields of science, hampering our understanding of these interactions. One of the challenge is to develop approaches on relevant spatial and temporal scales. Indeed soil science typically focuses on large spatial areas and on long periods of time, while soil ecology typically focuses on processes at the scale of the soil profile and on short time scale. Consequently, soil macrofauna is poorly considered in models of soil formation, and soil context is poorly taken into account in soil ecology. In such context, it is critical to develop studies of soil biota on large areas, with a focus on groups with a strong impact on soil processes, such as soil macrofauna.

The goal of this presentation is twofold. First we will show the key results of the project MACROFAUNA. During this project, we studied the biodiversity and abundance of soil macrofauna at the global scale in more than 2000 sites, with a standardized ISO method: the TSBF protocol. In particular, we will see how large environmental gradients - such as climate - interact with local conditions - such as human activities and soil properties – to shape soil macrofauna biodiversity and abundance. The second objective of this talk is to invite soil scientists to join the next version of the project. We want to make the project more relevant for the understanding of the role of soil macrofauna on soil formation and maintenance. For this we need to ground the project in the existing framework of pedometrics. In particular we need guidelines on how to improve our spatial sampling strategy, and to identify simple measures of soil biota which would be useful as inputs or parameters for models of soil formation.

keywords: *soil biota, soil biodiversity, global scale, sampling strategy*

Contribution to the study of erosive dynamics in the Ghézala dam watershed (Northern Tunisia)

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In Tunisia, about 25.3 million of m3 of sediment deposited annually in dams reservoirs. Given the irregularity and complexity of erosion -transport- deposition process and for the rational management of water resources and soil, modeling as a study tool and decision support has become necessary. The current situation of the watershed Ghézala dam located in the basin of Lake Ichkeul (Northern Tunisia) shows that the combined action of various factors of the natural environment and human action contributes to the degradation of soils in the watershed. Indeed, the pressure exerted on the soil by plowing as well as overgrazing to meet the needs of the population of this area has exposed the soil to a continued deterioration manifested by different erosive phenomena endangering the only source of revenue for the area. The control of sedimentation in the dam reservoirs provides a global evaluation of the process of erosion and transportation of sediments taking account the bed-material load. The knowledge of sedimentation is also useful for dam management. In Tunisia, little was known about erosion, transportation and sedimentation phenomenon having regard to their consequences. The depth measurements on Ghézala dam reservoirs were carried out in 1993 and 2011. Measurements give, in spite of lack of precision, first information as on sedimentation quantity and variability, so on method of sediment deposits. According the results of measurements for 2 years of the turbidity of the major rivers in the extreme northern Tunisia and watersheds of Lake Ichkeul, the average turbidity of the Ghézala River is 6.56 g/l. This corresponds to an average annual erodibility of 1885 t/km^2/yr. It remains however to be done to refine and especially quantify our knowledge of the chain of events erosion-sediment transport, spreading and sedimentation; this study is a contribution to the study of these problems which are increasingly aware of specialists and non-specialists. Using a distributed physical parameters runoff and erosion model throughout the watershed, can improve the understanding of the variability of the factors responsible for soil loss and thus solve the problems related to the conservation soil. Sediment discharge is quite sensitive to hydrologic simulation, as the topography and the rain's intensity affecting the sediment transport capacity and their delivery to river course.

keywords: *water erosion, sedimentation, dam watershed, human action*

Pedometrics Quadrancentennial

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Speculations and climaxes
Delphic detonations
A tot of yesteryear
A tad of pedography
A parsec or two
On precociousness
On perspicacity
Scaling the Wageningense Berg
Blown goals and far misses
Dazzling (de)feats
Specular notions
Salted and peppered past
A gorgeous destiny
And perchance an air

Improvements in spatial soil sample design efficiency

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Samuel Carrick – Landcare Research New Zealand, New Zealand
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The questions asked of the pedometrician are becoming more complicated over time, in response to increasingly intricate and searching questions from end users. Examples include the need for longitudinal models for soil properties, the characterisation of spatial models over the landscape, and monitoring of critical levels of anthropologically-influenced soil properties. While usually underpinned by a functional model, the parameters of the model are ultimately derived from field data, which is gathered from historical surveys, serendipitously-acquired data, and custom-designed field campaigns. This blend of data frequently suffers from a degree of non-representativeness and lack of relevance to the study at hand, but their inclusion is important since the resources required to acquire completely new data for a new study can be very expensive.

In our present work, we need to acquire data to meet the requirements of several broadly related research questions. Historical data provides useful information but will not meet the requirements for the studies in terms of statistical power and spatial coverage. Some criteria (e.g. topographic slope) are common to many projects, while others have more specific requirements. The key research question here is how to achieve the power so that the results are conclusive, while also minimising the field resources required, and simultaneously sharing data and resources.

We use a combination of tools to minimise resource cost and maximise the power of all studies. First, simulation is used for estimation of statistical power, driven by historical soil information. Second, we use a relatively new spatially balanced design method (balanced acceptance sampling) to optimise efficiency and spatial balance. Finally, we use an optimisation model to simultaneously maintain statistical power and minimise resources over several different projects.

There are several practical issues with this approach. First, a gain in the field sampling efficiency depends on the overlap in requirements for different projects; broadly, the more specific a project's requirements, the less likely that sample locations for that project will benefit other projects. Second, achieving field sampling efficiency gains across projects does not guarantee that the statistical power of a given project will be satisfactory; a project might share useful effort from another survey and yet might be under-powered. Despite these limitations, these tools provide an objective way to explore sampling requirements, field effort, and statistical power across several projects to reveal potential benefits for effort and efficiency in field sampling.

keywords: *Sampling design, Spatial sampling, Sampling efficiency, Balanced sampling, Sampling optimisation*

Digital soil mapping in hilly relief area in Southeastern Brazil

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Maps of soil are important guiders in land use planning. Governmental organizations dealing with land use repeatedly use conventional mapping method despite the increasing confidence in data obtained from remote sensing and auxiliary data applied to landscape studies. Digital soil mapping (DSM) is also increasingly gaining confidence producing soil maps for land use planning. The main objective of this study was to compare a soil map generated by a digital soil mapping technique with the conventional soil map. The area of study is the Denis Gonçalves Rural Settlement, located in the Zona da Mata Region, State of Minas Gerais, Brazil. The area has a complex relief formed by hilly mountains defined as "Mares de Morros". We registered 133 points, among soil profiles and observations, where samples were collected for chemical and physical analysis to perform the soil classification and conventional mapping. For DSM we used ArcGIS software's to process data and R for the classification using variables of generated with Digital Elevation Model, Landsat Imagery, and WorldClim data, in addition to derived covariates. Seven classifiers (i.e. Random Forest, Support Vector Machines with Linear Kernel, Support Vector Machines with Polynomial Kernel, Extreme Gradient Boosting, Ranger Random Forest, Weighted Subspace Random Forest and Bagged AdaBoost) among a pool of 15 classifiers, were chosen for the classification, based on their performance (Kappa index > 0.50). For map comparison, we transformed the conventional map to a raster format and used map algebra. As the conventional map is made of associations of soil classes, the concordance between the DSM and the conventional soil maps considered the agreement of a given pixel in the DSM map with the correspondent soil class associated in map unity of the conventional map, regardless the component of association. The conventional map showed that the soil with greatest occurrence in the area was Dystric Xanthic Ferralsol (DXF), which in association with Dystric Chromic Ferralsol (DCF) and Dystric Haplic Cambisol (DHC) occurs in 35.1% of the area, followed by Dystric Chromic Ferralsol, Dystric Xanthic Ferralsol and Dystric Chromic Acrisols (DCA) with 34.7%, followed by Dysric Xanthic Ferralsol alone with 12.1%, Gleysols (GX) associated with Cambisols with 10.38%, and Cambisols associated with Dystric Xanthic Ferralsol with 3.6%, Dystric Haplic Gleysols alone with 3.0%, and associations of Leptosols (RL), outcrops rock and Cambisols with 1.1%. The assessment of digital classification using a cross-validation, showed that the Ranger classifier presented the highest Kappa (0.55) with overall accuracy of 0.65. The confusion matrix of Ranger classifier shows that confusion wish higher between Ferralsos and Cambissols, due to their association on the landscape. The best map of DSM showed an agreement of 62% with the soil map generated by the conventional method of mapping, with main disagreements occurring on areas of Gleysols. The most intensely occupied area occurs over soils at the bottom of the valley, which are on the banks of the Gleysols. It occurs as result of the soil higher fertility, the flat relief and to the access to water. We concluded that DSM can be used for producing soil map of Rural Settlements, and can be used with god confidence to optimize the Agrarian Reform policy by generating maps.

keywords: *Pedology, Soil mapping, Ranger classifier*

Spatial data infrastructures for handling soil data

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Distribution of soil data using Internet Technologies (IT) is known to be complicated [1][7]. Many technical, maintenance and legislative requirements have to be addressed. Spatial Data Infrastructures (SDI) are frameworks or platforms specially prepared to facilitate distribution of metadata and data in a simple and effective way. With SDIs, it is easier to organize metadata following ISO (International Organization for Standardization) standards, visualize data, download and transform data formats. Here we will describe the soil SDI structure implemented at ISRIC - World Soil Information.

ISRIC's data portal [2] is an SDI-based on open source technologies and open web services defined by OGC (Open Geospatial Consortium), and aimed specifically at soil data. The SDI has 4 major components: Geonetwork [3], Geoserver [4], Geonode [5] and WoSIS (PostgreSql/PostGIS) [5][6]. The Geonode and Geoserver are integrated components, where visualization and data download is done in Geonode with resources from Geoserver; with these two systems the aspects of data visualization and access are addressed. Metadata for each dataset are described according to ISO 19115:2003/19139. Metadata are stored and publicly available in the Geonetwork system indicating permissions (licences) for use of the associated datasets. A short metadata description is provided in Geonode to help users.

The fourth component of the SDI is WoSIS (World Soil Information Service), a large soil profile database (PostGIS) that provides standardised data (point data) for multiple depths and soil parameters. WoSIS is connected to Geoserver to allow data download from Geonode.

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[2] http://geonode.isric.org
[3] http://geonetwork-opensource.org/
[4] http://geoserver.org/
[5] http://geonode.org/
[6] http://www.isric.org/data/wosis/

keywords: *spatial data infrastructures, soil data, metadata, web services, open source*

SoilML data exchange format and soil web services

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World soil data and information is dispersed and managed by many organizations in multiple formats, causing problems when researchers are interested in global data for studies. The idea of a common data exchange format, soilML, based on XML (eXtensible Markup Language) has been proposed and is derived from a conceptual model that describes soil features like soil body, horizon and profile. Developing a common data format for soil data exchange is essential for cooperation between multiple entities.

Previous implementations of data exchange formats like eSOTER [1], soil INSPIRE [2], Digital exchange of soil-related data (ISO 28258:2013) [3], and ANZSoilML [4] have been recognized as valuable approaches for soil science activities, but have not been taken up widely by user communities [5]. Implementation of a developmental version of soilML has been demonstrated by CSIRO, LandCare Research NZ, and ISRIC, USGS and others in an interoperability exercise sponsored by the Open Geospatial Consortium (OGC) [6]. Soil data web services using soilML were implemented by/and standardised data successfully exchanged. In the same exercise, CeRDI (Centre for eResearch and Digital Innovation - Federation University Australia) developed a prototype viewer [7] that pools soilML encoded data from multiple sources, demonstrating the feasibility and utility of soilML.

The soilML data web services are delivered through Web Feature Service (WFS) complex features and describe soil properties and pedon characteristics. The WFS output data can also be consumed by Web Processing Services (WPS) where pedotransfer functions are applied to soilML data creating new data.

[1]SoTerML Schema Specification: http://www.isric.org/specification/SoTerML.xsd

[2] INSPIRE specification: http://tinyurl.com/inspire-soil

[3] ISO soilML: http://tinyurl.com/iso-soilml

[4] Simons B, Wilson P, Ritchie A, Cox S. ANZSoilML: An Australian - New Zealand standard for exchange of soil data. EGU General Assembly 2013, held 7-12 April, 2013 in Vienna, Austria, id. EGU2013-6802.

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[6] Ritchie A. OGC Soil Data Interoperability Experiment (Engineering Report) - 16-088r1. https://tinyurl.com/soilie-report

[7] http://data.cerdi.edu.au/soil_demo.php

keywords: *soilML, data format, data exchange, web services, pedotransfer, soilIE, Web Processing Service*

Uncertainty and results stability of three digital soil mapping algorithms applied to the soil cover of a farm situated on the north of Udmurt Republic, Russian Federation

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One could generate multiple soil maps for the same territory with advanced DSM algorithms. Some areas will belong to the same classification unit on all maps produced by the algorithm. Such areas may be named "zones of stability". The other areas will be classified differently with the same algorithm. The aim of this study was to identify which territory of the study area are zones of stability with a probability of 100%, 95% and 75%. Traditional soil map (under Russian classification) was done for a farm situated on the North of Udmurt Republic of Russia. Eight soil types and subtypes that are typical for the south taiga zone for the Central Russian Plain were detected on the territory of 19 square km. Several digital soil maps (100 for an algorithm) were produced using multinomial logistic regression, support vector machine and random forest algorithms on the base of covariates: legacy data, terrain attributes and land use. Independent random sample was used to test all soil maps. Traditional soil map was the most accurate and gave 82% of right profiles classifications. MNLR, SVM and RF algorithms gave less than 70% of right profiles classifications. Maps of 100%, 95% and 75% stable soil diagnostics were produced for each algorithms. Three algorithms showed similar results. The proportion of 100% stable land areas was about 40%. Stability zones matched the arable lands on the watersheds. Territories under forests and areas situated in ravines and gullies showed the highest level of uncertainty of classification using digital soil mapping algorithms. Slope territory manifested the intermediate level of uncertainty.

keywords: *Uncertainty of digital soil mapping, Albeluvisols Umbric, Territories with stable soils diagnostics*

Applying the diagnostic approach for the definition of soil functions – a pilot example on carbon sequestration and storage

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Diagnostic units (horizons, properties and materials) are commonly applied in a number of international and national classification systems, including WRB, Soil Taxonomy, Hungarian and Irish systems. Diagnostic units can be established in the field, with laboratory analyses or derived from existing soil survey databases. These diagnostic units are designed to support the process of objective soil classification. The soil diagnostic units however carry important information by themselves and can be mapped and provide a better visualisation of the soil -landscape continuum, as and have been demonstrated in different projects (such as the e_SOTER).

The LANDMARK project (EU 2020) has applied the diagnostic unit approach to explain five key soil functions evident in agricultural systems; 1) primary productivity, 2) water purification and regulation, 3) carbon storage and regulation, 4) provision of a habitat for biodiversity and 5) cycling of nutrients. Modelling the capacity of a soil to deliver multiple of these soils functions is the main approach of the LANDMARK project, with a focus at farm, regional and European scales. The diagnostic unit classes is one application currently being considered to define the functional behaviour of our soils. This presentation will use the e_SOTER database and maps to provide an example of how the diagnostic approach can be applied. The procedure will be demonstrated on a pilot area in Hungary exemplified for carbon related (sequestration and storage) and primary productivity functions.

keywords: *Soil classification, Diagnostics, Soil Functions, Digital Soil Mapping*

Information assessment of uncertainty of the soil's isomorphism in pedons and elementary soil areas

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The concept of isomorphism is the general scientific concept which characterizes the relation between any objects expressing somewhat identity of their structure. It has important philosophical value and is directly connected with categories of distinction, identity, similarity, reliability, etc. As the structure of an object assumes its consideration in the form of the set of its elements (or, in certain cases, in the form of association of its parts and subsets), so consideration of isomorphism usually speaks about the relation between systems, sets of any elements. The systems of elements which are in the isomorphism relation are called isomorphic. This concept shouldn't be mixed with a concept of isomorphism in chemistry which has close connection with the concept of consideration by us; however it isn't special case of isomorphism in strict sense.

Determination of types as the some idealized objects — standard practice of any science by means of which it removes a contradiction between real originality of specific objects and action in them general laws. The type of the soil is generalized, idealized subject of classification but it is having a certain distribution in space. General laws for all soil cover are isomorphic, but they are shown in a special way, rather individually for some set of the objects entering type. This is a reason of spatial soil changeability and soil uncertainty. We had proposed considering three conceptual categories of it. They are heterogeneity for significant changes in soil-forming factors, variability for their insignificant changes, and fluctuation for leveled soil-forming factors. Last two changeability categories are the reason of soil uncertainty, they could be observed at different organization levels of the soil and soil cover.

In our opinion, the quantitative evaluation of relationships between different changeability categories of soil properties is necessary for assessing the stability of the soil cover as a hierarchical system. Entropy is one of reliable scientific parameters to assess it. In the same time, the alterations of soils are inevitable process under change of climate and intensive agricultural and other usages, and changes of natural ecology. Information divergence is parameter which could assess alterations of soil uncertainty under soil evolution. We have conducted such investigation in the case study of main soil types at dry steppe zone in the South of Western Siberia.

keywords: *isomorphism, information, assessment, soil cover, pedons, elementary soil areas, uncertainty, entropy, information divergence*

A Novel Pedometrics-econometrics Approach to Assess Soil Carbon Capability

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The quantitative assessment of soil quality, health, and security is critically important to sustain soil resources at regional and global scales. Numerous indicators and indices (In/Ix) have been developed to quantify soil resources. According to index number theory, the axiomatic features required for an ideal indication system include 1) Homogeneity, 2) Time-reversibility, 3) Transitivity, and 4) Dimensionality. We identified four other axioms for indication system specific to soil science which are 5) Homology in space, 6) Time and space sensitivity, 7) Monotonicity, and 8) Spatial transferability. Widely used methods to assess soil-specific In/Ix have used scoring, ordination, or multivariate regression methods that do not meet those axiomatic features. Another shortcoming is that soil properties have been predicted or modeled instead of soil In/Ix that quantify soil functions, capability, efficiency, risk, or security. An optimum level or status of soil can be expressed using 'soil efficiency (or capability)' that identifies the possibly largest/highest output(s) based on a given set of input(s). For example, the efficiency to sequester carbon in soils to the highest level is co-dependent on the soil-environmental conditions, use, and carbon inputs that control the functionality of soil to sequester carbon. We present a novel pedometric-econometric approach that has been rarely used in soil science.

Our objective was to employ the Data Envelopment Analysis (DEA) to assess the Soil Carbon Sequestration (SCseq) Capability In/Ix (SCI) based on the SCseq rate and pedogenic, climatic, biotic, and hydrologic factors in Florida, USA. The SCseq was calculated based on lab-measured soil organic carbon (SOC) stocks in the top soil ($\sim$ 20cm). Historic and current SOC measurements, covering about 45 years, were used to calculate the SCseq rate. After identifying important environmental variables by the Boruta selection method and Spearman correlation coefficient, the DEA was employed along with the SCseq rate and the selected variables to produce the SCI scores.

The scores ranged between 1.00 and 1.09, with values close to 1 expressing high efficiency for carbon sequestration. The SCI score infers on the optimum capability based on a given set of relevant environmental parameters. Thus, the SCI scores produced useful information to guide management and optimize the soil function compared to previous In/Ix assessments. Additional benefit of using the DEA analysis is its transferability to other geographic regions providing a standardized indication system to quantify specific soil functions. Our pedometric-econometric approach indicates its potential to assess other soil functions and security.

keywords: *soil carbon sequestration, index number theory, soil index, soil organic carbon, pedometric-econometric approach, Data Envelopment Analysis*

Modelling Pedo-Econometric carbon scores with VNIR spectroscopy

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Visible-near infrared (VNIR) spectroscopy has shown success for cost-effective, rapid, and accurate assessment of various soil properties, including soil organic carbon (SOC). Proximal sensing offers potential to provide soil estimates that can be used in complex soil models that assess soil functions, capability, risk, or security. The Data Envelopment Analysis (DEA) is one of the pedometrics-econometrics methods suited to assess soil capability or efficiency. However, the relationship betweensoil capability derived from the DEA with analytical lab-based soil measurements and the one derived from VNIR- soil estimates are not well known. Our objective was to compare the soil carbon sequestration (SCseq) capability index (SCI) derived using SOC measured in the laboratory (SOCm) and SOC estimated using VNIR spectra (SOCe) in Florida, USA.

The SCseq rate was calculated based on both historical and current datasets that contained SOCm collected from the top soil (∼20 cm depth) in 1965-1995 and 2008-2009, respectively. Some pedogenic and environmental factors relevant to soil carbon sequestration were selected by the Boruta variable selection method as well as the Spearman correlation method. The DEA was conducted with the SCseq and the selected variables to produce the SCI scores. The VNIR spectrum was calibrated using Partial Least Square Regression method and Random Forest (RF), after 25 preprocessing methods were applied. The model with the highest prediction accuracy was chosen to generate the SOCe. The DEA was implemented based on these VNIR estimates to predict the SCI scores. The accuracy of the SCI prediction derived from the SOCe using the RF algorithm showed the highest R2 of 0.7. This implies that the SCI scores are site-specific yet predictable using field-based spectroscopy data. The successful estimation of the DEA-SCI scores via VNIR spectra show promise for future applications that assess soil quality, health, and security.

keywords: *Soil health, Soil quality, Soil security, Visible-near infrared spectroscopy, soil organic carbon, soil carbon sequestration, Data Envelopment Analysis, Partial Least Square Regression, Random Forest, Boruta Analysis*

Predicting artificially drained areas by means of a selective model ensemble

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Subsurface drain pipes in agricultural fields have a large impact on crop yields, the hydrological cycle, the leaching of nutrients and pesticides and numerous soil properties. However, the location of artificially drained areas is often unknown. In Denmark, drainage activities have been carried out since the mid-19th century, and it has been estimated that half of the cultivated area is artificially drained (Olesen, 2009).

A number of machine learning approaches can be used to predict artificially drained areas in geographic space. However, instead of choosing the most accurate model produced with one of these approaches, a better prediction can be achieved by combining the predictions of several models (Caruana et al., 2004, Sollich and Krogh, 1996).

As more approaches become available, the importance of the method used for selecting the models for use in the ensemble increases.

The study aims firstly to train a large number of models to predict the extent of artificially drained areas using various machine learning approaches. Secondly, the study will develop a method for selecting the models, which give a good prediction of artificially drained areas, when used in conjunction.

The approaches employed include decision trees, discriminant analysis, regression models, neural networks and support vector machines amongst others. Several models are trained with each method, using variously the original soil covariates and principal components of the covariates.

With a large ensemble, the time necessary for producing a map can easily exceed the practical limits set for the task. For this reason, the study aims not only to produce the ensemble which gives the best prediction of artificially drained areas, but also to take into account the time necessary for producing a map with each method, when selecting the models.

In this way, the developed method should be able to produce a highly accurate and robust map of artificially drained areas within a limited span of time.

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keywords: *Soil drainage, Model ensemble, Mapping*

Soil map disaggregation improved by soil-landscape relationships, area-proportional sampling and random forest implementation

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Detailed soil information is often needed to support agricultural practices, environmental protection and policy decisions. Several digital approaches can be used to map soil properties based on field observations. When soil observations are sparse or missing, an alternative approach is to disaggregate existing conventional soil maps.

At present, the DSMART algorithm represents the most sophisticated approach for disaggregating conventional soil maps (Odgers et al., 2014). The algorithm relies on classification trees trained from resampled points, which are assigned classes according to the distribution of soil types within the polygons. Vincent et al. (2016) successfully implemented soil-landscape relationships into the algorithm.

The study tests the sensitivity of the algorithm towards the input data by using conventional soil maps for Denmark produced by Jacobsen (1984) and the Commission of European Communities (CEC, 1985) respectively, both using the FAO 1974 classification. Furthermore, the effects of implementing soil-landscape relationships, using area proportional sampling instead of per polygon sampling, and replacing the default C5.0 classification tree algorithm with a random forest algorithm were evaluated. The resulting maps were validated on 777 soil profiles situated in a grid covering Denmark.

The experiments showed that the results obtained with Jacobsen's map were more accurate than the results obtained with the CEC map, despite a nominally coarser scale of 1:2,000,000 vs. 1:1,000,000. This finding is probably related to the fact that Jacobsen's map was more detailed with a larger number of polygons, soil map units and soil types, despite its coarser scale.

The results showed that the implementation of soil-landscape relationships, area-proportional sampling and the random forest implementation generally improved the algorithm's ability to predict the correct soil class. The implementation of soil-landscape relationships and area-proportional sampling generally increased the calculation time, while the random forest implementation reduced the calculation time.

In the most successful experiments, the disaggregation provided a good prediction of the soil types, despite the coarse scale of the input maps.

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keywords: *Disaggregation, Models, Soil classes*

Digital Soil mapping Based on Airborne Gamma-Ray Imagery and Fuzzy logic : a Case of Upper Pasak Watershed, Thailand

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Airborne gamma-ray imagery (AGRI) provides coarse-resolution (approximately 400 × 400 m pixel) spatial in-formation on gamma-ray emitting elements, i.e. potassium (K), thorium (Th) and uranium (U), in the upper half meter of the soil. These radioelements are a potential information source for soil mapping since their abundance is related to soil geochemistry, specifically the chemical composition of parent materials and their weathering products resulting from geomorphic and pedogenic processes.

The aim of this study was to evaluate the potential of AGRI for improving digital soil survey process in a mapping soil applying digital soil mapping method in complex landscapes. The study was conducted in a well-characterized complex soil landscape: the 560 km^2 upper Pa Sak watershed in Petchaboon province, Thailand. Clustering of gamma ray and elevation data (DEM) was carried out using fuzzy logic to generate various classification layers. Final map was produced using total weighted inverse distance of all the classes in a 3 by 3 window. Class label was assigned to the one with the largest total inverse distance over the entire set of fuzzy classification bands.

The result shows relatively higher classification accuracy for soil parent material differentiation (overall accuracy of 72%) as compared to the classification for soil types (67%).

keywords: *Digital soil mapping, Soil mapping, GIS, Remote Sensing, Fuzzy, Watershed, Thailand*

A 2D multifractal analysis based on detrended fluctuation analysis applied to El Pardo landscape

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Multifractal detrended fluctuation analysis (MFDFA) has been well known technique applied to 1D signal, time series and soil transect data (Morató et al., 2017). It has the advantage that removes the trend of the data making possible a multifractal analysis. Recently, MFDFA algorithm has been generalized to deal with two-dimensional signals (Caiping Xi et al., 2016). This type of analysis could be a potential tool to easily simulate distinctive topography spatial distribution and to simulate erosion or understand the main factors that creates a complex dynamic in the landscape evolution.

We present an application of 2D MFDFA to landscape data for the first time based on the altitude. The study zone is a matrix of 2053 x 2053 pixels, with a resolution of 5m (25 m2 by pixel), obtained from a digital terrain model (DTM) using the latest informatics tools. This zone corresponds to quite homogeneous region with respect to soil characteristics and climatology but with topographic distinctive areas, known as "Monte de El Pardo" (Aguado et al., 2014), due to the directions of the two river basins, Trofa and Manzanares, and the gradual change in the direction of the Trofa river towards Manzanares river along the centuries.

A detailed description of the application of the 2D MFDFA is showed: the statistical accuracy, the sensitivities of the sample size, the selection of scaling range, the choice of the q-orders and the calculation amount. Several interpretations are made based on the results obtained and a comparison is established with the 1D MFDFA (Castellanos et al., 2017).

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keywords: *modelling landscape, detrended fluctuation analysis, multiscaling, anysotropy*

Implementing Pedometrics Outside the Discipline: Context, Translation and Scalability

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The discipline of pedometrics can serve as a vehicle for the integration of multiple scientific disciplines (e.g. statistics, math, engineering, information technology, environmental physics, pedology, edophology) but can also provide an opportunity to translate soil science knowledge and understanding to real-world applications. Improving this translation requires pedometric tools to be evaluated in terms of fitness for use: considering not only the mathematical rigor of a tool/approach, but how well it will perform the function society needs it to perform. Key considerations for implementing pedometrics outputs should include availability and translatability of pedometric tools, access to pedometric tools/practitioners, and compatibility of pedometric approaches with existing institutional structures. We will show examples of success where pedometric tools and products can be integrated to solve problems by scientists in other disciplines, agribusiness, as well as by land managers. These examples will identify some missing components of common pedometric practices, such as insensitivity to the context of where/who/when the tool will be employed. As novel pedometric tools are being discovered and products are being produced, they need to be evaluated and developed with an understanding/consideration of the societal and scientific context where they are to be used (paradigm).

keywords: *proximal sensing, digital soil mapping, scaling, translation*

Soil-landscape controls on the impact of extreme warm and dry events on terrestrial ecosystems within continental Europe and the Mediterranean Basin

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Vegetation activity within continental Europe and the Mediterranean Basin is changing and extreme warm and dry events cause substantial reductions in vegetation activity. This region covers a wide variety of climate regimes, soil and land cover types. Distinguishing the response of the vegetation to extreme heat, drought and compound events as a function of land cover type, climate regime and soil type allows to better explain regional and local differences in vegetation response. This research analyses the temporal evolution of the impact of extreme heat, drought and compound events on the observed NDVI during the growing season, aggregated by land cover, soil and climate types. The results show 31% reduction of the median vegetation activity, though highly variable depending on local conditions in climate, soil and vegetation type. The maximum impact was observed for extreme warm and dry compound events, one month after the extreme event occurrence, and recovery took up to 4 months. Furthermore, the impact of extreme heat and drought on vegetation activity increases when moving to colder climates with the largest change occurring in high latitude natural land cover types.

The soil properties affecting the impact of extreme droughts on vegetation activity were mainly related to root depth limitations, water regulating properties and ecophysiological properties. Within a temperate climate, water availability and water regulating properties of the soil were found most important; in water limiting conditions those showing limiting root development conditions linked to abrupt textural changes (e.g. Luvisol), accumulated salts (e.g. Solonchak) or unfavorable soil structure (compaction, swelling/shrinking) were more impacted and had a slower recovery. Within a hot and dry temperate climate, there were major differences in the overall productivity rather than a different response to extreme events. These differences were mainly related to growth limiting conditions due to accumulated salts in the soil profile (e.g. Calcisol, Solonchak). Furthermore, it was found that vegetation activity of stable forest ecosystems was strongly impacted by extreme climatic events, especially in Northern Europe. The controlling factors defining the impact of extreme warm and dry events were found to be a complex combinatory of soil, climate and ecophysiological properties (e.g. Podzols and mycorrhiza networks in Northern Europe).

With the expected increase of extreme climatic events, the current stable and productive systems will be most affected and large reductions in vegetation activity can be expected, partly due to the lack of ecophysiological adaptation of plants towards the change in climate.

keywords: *Soil-landscape controls, Extreme climatic events, Terrestrial ecosystems, Large extent*

Pedometric methods to optimize sampling and improve classification on a pilot site in the Mount Kenya region

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The objective of the study was to evaluate the variability of SOC in different Reference Soil Groups (RGS) and to compare the determined classification units with the KENSOTER database based on a soil sampling campaign carried out on the agricultural lands of the Upper Catchment of Tana River (Meru County, Kenya) covering an area of 1200 km^2. The geology of the area consists mainly of volcanic rocks (Pliocene lahars, phonolites, tuffs basalts, ashes) and recent superficial deposits. A total of 28 open and 49 augered profiles were evaluated, which were selected using Conditioned Latin Hypercube sampling design. During the field work the profiles were classified according to the World Reference Base for Soil Resources (WRB) 2015. A total of 269 soil samples were collected, which samples were analyzed for total carbon, organic carbon, particle size distribution, percent bases, cation exchange capacity and pH among others. Based on the earlier surveys, geological and environmental setting, Nitisols were expected to be the dominant soils of the sampled area. Based on this study the major differences to KENSOTER database are the presence of high activity clays (CEC value range 27.6 cmol/kg - 70 cmol/kg), high silt content (range 32.6 % - 52.4 %) and silt/clay ratio (range of 0.6 - 1.4) keeping these soils out of the Nitisols RSG. There was good accordance in the morphological features with the earlier survey but failed the silt/clay ratio criteria for Nitisols. This observation calls attention to set new classification criteria for Nitisols and other soils of warm, humid regions with variable rate of weathering to avoid difficulties in interpretation. To address the classification problem, this paper further discusses the taxonomic relationships between the studied soils. On the contrary most of the diagnostic elements (like the presence of Umbric horizon, Vitric and Andic properties) and some qualifiers (Humic, Dystric, Clayic, Skeletic, Leptic) represent useful information for land use and management in the area.

keywords: *World Reference Base, Nitisols, Classification, Latin Hypercube Sampling, Taxonomic relationships*

Comparison between random forest and partial least square regression of on-line vis-NIR spectroscopy measurements of soil total nitrogen and organic carbon

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Accurate and detailed spatial soil information about within field variability is essential for variable-rate applications of farm resources. Soil total nitrogen (TN) and organic carbon (OC) are important fertility parameters that can be measured with on-line (mobile) visible and near infrared (vis-NIR) spectroscopy, whose the calibration method may considerably affect the measurement accuracy. This study aims at comparing the performance of local farm scale calibrations with those based on spiking of local samples into an European continental dataset (ECD) for TN and OC estimation using two modelling techniques, namely, random forest (RF) and partial least squares regression (PLSR). An on-line sensor platform equipped with a mobile, fiber type, vis-NIR spectrophotometer (AgroSpec from tec5 Technology for Spectroscopy, Germany), with a measurement range of 305–2200 nm was used to acquire soil spectra in diffuse reflectance mode from two fields in the UK. After dividing spectra into calibration (75%) and validation (25%) sets, spectra in the calibration set were subjected RF and PLSR with leave-one-out cross-validation to establish calibration models of TN and OC. On-line predicted values of TN and OC were used to develop maps using ordinary kriging in ArcGIS software (ESRI, USA). Results showed that RF outperformed PLSR models for both datasets used, whereas the lowest model performance was obtained with the local dataset. The effect of spiking local samples into the ECD was significant, and resulted in high coefficients of determination (R2) values of 0.97 and 0.98, low root mean square error (RMSE) of 0.01 and 0.11, and high residual prediction deviations (RPD) of 5.78 and 7.17, for TN and TC, respectively. The on-line predicted maps showed better spatial similarities between laboratory measured and RF predicted maps, as compared to PLSR predicted maps. Therefore, these results suggest that ECD vis-NIR RF calibration models can be successfully used to predict TN and OC under on-line measurement conditions.

keywords: *Vis-NIR spectroscopy, spiking, random forest, partial least squares regression, soil mapping*

Geochemical Signatures of Pristine Volcanic Ash and Soils from Krakatau as revealed by a Portable XRF spectrometer

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The Krakatau complex was formed after the well-known eruption of the late Mt. Krakatau in 1883, the complex consists of four islands: Sertung, Panjang, Rakata and Anak Krakatau. Mt. Anak Krakatau was formed from the 1930s and is composed of lava and pyroclastic deposits after the devastating eruption of the late Mt. Krakatau in 1883. Anak Krakatau is still active, with frequent eruptions producing volcanic ashes. Nearby was Sibesi, an island in the Sunda Strait between Java and Sumatra, which was completely destroyed during the eruption of Mt. Krakatau in 1883. We collected and investigated the volcanic ash samples from Mt. Anak Krakatau, Rakata, Panjang and Sibesi islands. Geochemical analysis was carried out using a portable x-ray fluorescent spectrometer (XRF). In addition, chemical weathering indices were calculated from the geochemical elements. The linear discriminant analysis was used to separate out materials from the 4 islands using their geochemical concentration (SiO2, Al2O3, Fe2O3, CaO, MgO, K_2O, SO3, P_2O_5, Ti and Zr). While the four islands were nearby and influenced by the eruption of Mt Krakatau, the analysis showed that the geochemical characteristics of volcanic ash for each of the island is distinct. Mahalanobis distance differentiated samples of Anak Krakatau with other three soils. Base loss in Sibesi islands was larger compared to Rakata, Panjang and Anak Krakatau. Meanwhile desilication was larger in Rakata compared to Sibesi, Panjang and Anak Krakatau. The following sequence of weathering can be summarized: Sibesi $>$ Rakata $\leq$ Panjang $>$ Anak Krakatau. As a conclusion, the portable XRF allows a rapid acquisition of geochemical signatures of volcanic ash samples. Comparison between sites, allow differentiation of origins of the materials and a calculation of a relative weathering sequence.

keywords: *Dyscriminant analysis, Krakatau, Geochemical signatures*

Challenges in using mid-infrared spectroscopy for the determination of soil physical, chemical, and biochemical properties on undisturbed soil samples

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Diffuse reflectance infrared Fourier transform (DRIFT) spectroscopy in the mid-infrared range (MIR) has become an established analytical tool for quantitative and qualitative analysis of soil samples. The heterogeneity of soil requires sample preparation procedures to optimize the reproducibility and accuracy of the spectroscopic measurement. These procedures have not been standardized. Generally, soil is dried and finely ground before measurement to avoid reflections of surface water films and minimize the intra- and inter-particle variability, respectively. Additionally, the sample surface is levelled to a plain surface for an ideal reflection. However, these sample preparation techniques are limited to disturbed samples only. Thus, a potential DRIFT mapping of undisturbed soil samples requires an adjusted calibration to allow for an accurate prediction of soil properties.

In this study, we developed a method for calibrating the prediction of DRIFT spectra collected from undisturbed soil samples. In a first step, differences of spectral information measured from undisturbed and ground soil samples have been evaluated. Therefore, we record the DRIFT spectra of 120 German and 120 West-African (Ghana and Burkina Faso) chemically well characterized soils. DRIFT spectra of both, ground and sieved only soil samples are recorded and both calibrated against different physio-chemical soil properties, such as texture, CEC, organic carbon, pH, or iron oxides. In preliminary experiments, we found that spectra of sieved and ground sampled significantly differed in specific spectral regions representing clay minerals, as well as organic matter. It can be assumed that the prediction of surface related soil parameters, such as CEC, could be superior using sieved soil spectra, as grounding alters the surface structure of the soil.

In a further step, microtopgraphy effects on spectra quality from disturbed as well as undisturbed soil samples have been evaluated. Therefore, spectral information has been taken from two dimensional disturbed and undisturbed soil samples at a high spatial resolution of 2 mm. The spectra quality was significantly higher in the disturbed soils since microtopography was absent in these samples. Thus, a digital elevation model (DEM) will be constructed using close-range digital photogrammetry to correct for these topography effects of the DRIFT mapping data from undisturbed soil samples.

With this new method, there is a potential of imaging soil parameters on a microscale that can help considerably in locating and understanding soil processes on a small scale.

keywords: *diffuse reflectance infrared Fourier transform spectroscopy, microscale soil mapping, microtopography correction, soil imaging*

Rapid sensing of petroleum-contaminated soils with mid infrared spectrometers

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Petroleum contamination in soil has been recognized as a global issue. With potentially millions of contaminated sites around the world, there needs to be rapid and efficient assessment technologies to detect contamination in the soil. Conventional soil analysis in the laboratory is not only time-consuming, but also expensive. This study evaluates the usage of a portable mid-infrared (MIR) spectrometer as an alternative to conventional soil analysis to assess petroleum contamination based on its absorbance on various wavelengths. A laboratory study was first done to evaluate the effect of common soil factors, such as soil texture, organic matter content, and the types and concentrations of contaminants on infrared absorbance. By utilizing continuum removal technique on the spectra, the effect of those factors can be isolated and quantified. The absorption peaks affected by petroleum contamination (currently reported as TRH: Total Recoverable Hydrocarbon) were found in the 2990 - 2810 cm−1 region which is related to the aliphatic –CH2 and –CH3 band assignments. The addition of organic matter as compost affected peaks between 2100 – 1700 cm^{-1} region (particularly the peak at 1980, 1870, and 1790 cm^{-1}), which is attributed to quartz overtone but not the 2990 - 2810 cm−1 region. Meanwhile, soil texture was mainly affecting the absorbance peaks in the 2990 - 2810 cm−1 region. Soil that has finer particle sizes tends to scatter more of the light; and therefore, reducing the overall absorbance. Statistical models were then developed from the identified absorption features to predict the concentration of total recoverable hydrocarbon (TRH) as a whole, and as fractions of semi-volatiles: C10-C16, C10-C16 minus Napthalene (F2), C16-C34 (F3), C34-C40 (F4). These models were then validated with field contaminated samples. This study will also try to model the prediction of components of polycyclic aromatic hydrocarbons (PAH), particularly naphthalene (the most volatile PAH), benzo(a)pyrene and dibenz(a,h)anthracene (the most toxic PAH compounds).

keywords: *Soil contamination, Soil sensing, Spectroscopy, Mid infrared, Petroleum hydrocarbon*

Predicting and Mapping Topsoil Black carbon of France

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Black Carbon (BC) in soil is considered a stable or resistant form of carbon, and thus it is important to determine its amount relative to the Total C (TC). As measurement of BC is quite time-consuming, involving chemo-thermo-oxidation at 375°C, decarbonation, and elemental analysis, it is anticipated that BC can be predicted using a rapid sensing analysis such as the mid-infrared spectroscopy. BC was only measured for topsoil at 158 sites in the French soil monitoring network. On the other hand, total carbon, and mid-infrared reflectance were measured at 2130 sites on a regular 16 × 16-km grid. Contrary to what was found in the literature, we found that BC was poorly predicted by the mid-infrared spectroscopy (Validation R2 $\sim$ 0.25). Nevertheless, BC was well predicted just using 3 soil variables (clay content, pH and Total C) with a mean validation R2 of 0.45. Including soil properties along with the infrared spectra did not improve the prediction. We concluded that this form of thermally-resistant Carbon is a combination of various organo-mineral and pyrogenic forms of carbon, which may not have unique spectral feature. BC content also varies across the area with a median BC/TC value of 0.05, and a minimum of 0.01 and a maximum of 0.32. Based on soil properties prediction, we map the concentration of Black Carbon across France.

keywords: *Black carbon, Mid Infrared Spectroscopy (MIR), Pedotransfer Functions, French soil monitoring network*

Using digital soil morphometrics to study landscape – vegetation pattern relations

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Peatlands are hotspots for soil organic carbon: despite covering just 3% of the earth surface, about 20% of all terrestrial soil carbon is locked away in northern peatlands. These carbon store of global importance are put under pressure by changes in land use and climate, which have the potential to destabilize soil carbon stocks. Such transitions may occur smoothly or as a 'tipping point', where peatlands may abruptly and unpredictably 'tip' to a state of carbon uptake to a state with carbon emissions after exceeding a climatic threshold. Recent advances indicate that changes in spatial patterns of vegetation may function as 'early warning signals' to predict impending tipping points. Yet, such indicators critically rely on the assumption that the landscape is uniform.

In this research we study the effect of landscape on vegetation patterning in a peatland in northern Sweden. Digital soil morphometrics are derived from Digital Terrain Models (2 2m) and related to metrics describing peatland pattern characteristics, which are calculated from classified vegetation maps using aerial images. Our results are of importance for understanding the complex interactions between soil formation and vegetation in 'real' rather than theoretical peat-landscapes, and are important in understanding the resilience of peat carbon stocks to forthcoming climatic changes.

keywords: *Peatlands, Soil organic carbon, Digital soil morphometrics, Vegetation, Climate, Aerial image classification*

Prediction of mineralizable nitrogen (N) in soils using ensembles of regression models

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Mineralization of nitrogen (N) is the process by which organic N is transformed into inorganic forms that are available for plant uptake. The N-mineralization is one of the key soil processes which enable plant growth and efficient crop production. Soils that provide large quantities of plant-available N through mineralization of soil organic matter require less fertilizer N applications per unit yield.

The supply of soil N through mineralization processes can vary largely between different soil types and is effected by soil and crop management, and environmental conditions. Knowledge of soil N supply will help to improve the use efficiency of applied N fertilizers. Therefore, there is a critical need to develop models for predicting mineralization of N in agricultural soils.

In this study we use chemical, physical and diagnostic soil attributes to predict the potential soil mineralization of N. The data were provided by Teagasc, Ireland, and describe 93 permanent grassland sites across Ireland. The soil samples covered a broad range of soil types and physio-chemical properties, sampled between March and October 2012 - 2014. They were taken for surface horizons only, which varied in depth, but generally were 0-25 cm depth.

To predict the mineralizable N potential of the soil, we applied several tree-based ensemble methods for regression. The ensemble methods used in our research were bagging, random subspaces, random forests and combination of bagging and random subspaces. The predictive performance of different ensemble methods was evaluated with 10-fold cross-validation. The obtained models achieved very high predictive performances (correlation coefficient around 0.9), with random subspaces performing the best.

Since the Random Subspaces algorithm does not provide interpretable models, but only predictions, we used the feature ranking method ReliefF to select the most relevant attributes for the prediction of the mineralizable N in the soil. The five most relevant attributes that were selected are: total carbon, organic carbon, active iron, active aluminum and total nitrogen in the soil. The results of this study show that mineralizable N in the soil can be accurately predicted using only a few chemical soil parameters, which means that the soil sampling requirements for prediction of mineralized N can be considerably simplified.

keywords: *Nitrogen mineralization, Ensemble regression models, Feature Ranking, Random Subspaces*

Insights in the possibilities of an electromagnetic induction sensor to map the military remains, buried in the former World War 1 front zone

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On November 11th 1918, the military impact on the Western front zone was called to an end. Almost a hundred years later, traces of this war are still reflecting in the landscape: cemeteries, mine and shelling craters, bunkers, high concentrations of metal shrapnel, bomb shells rising from the subsoil, etc. … These above surface remains are easy to identify in the current landscape. A more rising question is what is still buried beneath the surface. This unknown data is one of the research topics in the UGent's integrated research project 'Non-invasive landscape archaeology of the Great War' (2014-2018). For this project, 220 ha were already scanned at the former front zone in Belgium with an electromagnetic induction sensor (EMI) by the Department of Soil Management to investigate the buried remains of this War. Site selection and archaeological feature interpretation of the scan results were guided by the expertise and photograph database of the Centre for Historical and Archaeological Aerial Photography (Ghent University, In Flanders Fields Museum). This collaboration opened up a series of insights in the possibilities and limitations to investigate buried WW1 archaeological structures in a non-invasive way. Because of the scale and the spread of the EMI-surveys, we can compare data parameters collected at several locations in this formal war zone. For example: by applying a metal filter on the EMI data, we perceive that fields in the northern area of the Belgian front zone indicate a lower rate of metal shrapnel than the southern part. Our research showed also that EMI metal parameters can be correlated with the shelling densities seen on historical aerial photographs. Based on this secondary data source which almost entirely covers the front zone, the level of metal shrapnel pollution can be simulated for this region. Only field validations (excavations) of metal objects are the missing link to simulate metal quantities, buried beneath Flanders Fields.

keywords: *World War One, Electromagnetic induction, Soil scan, Destruction map, Historical aerial photographs*

Comprehensive evaluation of statistical approaches for digital soil mapping with large sets of environmental covariates

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Spatial assessment of soil functions requires maps of basic soil properties. Unfortunately, these are either missing for many regions or are not available at the desired spatial resolution or down to required soil depth. Conventional map acquisition remains costly. Meanwhile, soil legacy data and comprehensive sets of spatial environmental data are available for many regions. Digital soil mapping (DSM) approaches – relating soil data (responses) to environmental data (covariates) – are facing the challenge to build statistical models from large sets of covariates originating for example from hyperspectral remote sensing or multi-scale terrain analysis.

We evaluated six approaches for DSM in three study regions in Switzerland (Berne, Greifensee, ZH forest) by mapping effective soil depth available to plants, pH, soil organic matter (SOM), cation exchange capacity, clay, silt, gravel content and bulk density for four soil layers (0-10, 10-30, 30-50 and 50-100 cm, totalling 48 responses). Models were built from 300-500 environmental covariates by 1) model selection for linear models through grouped lasso, 2) robust external drift kriging (EDK), 3) geoadditive models selecting penalized smoothing spline terms by componentwise gradient boosting (geoGAM), and two tree-based methods 4) boosted regression trees (BRT), 5) Random Forest (RF). Lastly, we computed 6) weighted model averages (MA) from predictions by methods 1–5.

Lasso, georob and geoGAM successfully selected strongly reduced sets of covariates (subsets of 3-6 %). To automatically select a sparse trend model for EDK was however difficult and the applied ad hoc procedure was computationally inefficient and overfitted the data. Differences in predictive performance, tested on independent validation datasets, were mostly only small and did not reveal a single best method over all 48 responses. Nevertheless, RF was on average often best among 1–5 (29 out of 48 responses), but was outcompeted by MA at 15 out of these 29 responses. At the same time also RF tended to overfit the data. At the same time also RF tended to overfit the data. Performance of BRT was similar to RF, but slightly lower. GeoGAM performed poorly on some responses and was only best on 5 out of 48 while predictive precision of lasso was in between. Models had generally low bias. Only the computationally very efficient lasso had slightly larger bias larger while it tended to under-fit the data.

keywords: *Methods comparison, Geoadditive modelling, Componentwise boosting, Machine learning, Model averaging, Overfitting*

Effect of variable manure rate applications on grass yields and implementation of knowledge about soil conditions

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GPS techniques have significantly changed agricultural management. Smart Farming Technologies integrate GPS-techniques, local knowledge and farmers 'strategies, spatial information such as yield maps and soil maps and variable rate applications. In horticulture, Smart Farming Technology is nowadays very common in developed countries; however, for grassland production it is still in its infancy. Since 2015 a trial is carried out with yield maps generated by a forest harvester on grassland. The goal of this trial is to investigate in which way variable rates of manure, based on a yield maps, can help improve yield and soil quality as a basis for sustainable production of grass. The trial is executed at eight hectares grassland on sandy soil at Hardenberg, the Netherlands. Two strips were treated with a regular rate of manure and two strips with variable rates of manure. In 2015, results showed that variable rate based on yield of the previous cut, did not result in a higher yield (Nysten et al., 2016). In 2016 the knowledge about the growing conditions (such as groundwater table, nutrition level, weather etc.) and the potential yield for the different cuts (both spatial and temporal) were considered in the fertilization strategy. Locations with a higher potential yield received a higher rate of manure prior to that cut.

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keywords: *Smart Farming, GPS, Grass yields, Variable manure rate application*

Spatial prediction model applied to digital soil mapping of the Marinheiro stream watershed, Sete Lagoas (Brazil)

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The information coming from soil surveys, such as the physical and chemical properties and the spatial distribution, is essential for the management and the land use planning, for the optimization of urban and rural expansion, and for environmental preservation policies. Due to the growing demand for detailed soil surveys, Digital Mapping Soil techniques emerge as an important set of tools for the prediction and distribution of soils, which allow to optimize the mapping services, making them faster, replicable and economically more viable. In this context, the aim of this study was to develop and to evaluate the performance of a soil prediction model (SPM) for the Marinheiro stream watershed, Sete Lagoas (Brazil). The proposed model was created from the "Weights of evidence" method, implemented in the open source software Dinamica EGO. The sampling input was composed of 42 soil profiles and 157 field checking points, all of them analyzed and described in fieldworks. Probability maps were generated for each of the 16 sampled soil classes, which showed high spatial correlation with the landscape. The high probability (over 95%) maps of each class were combined into a single soil map, which resulted in 12 mapping units (MU). The "Latossolos", "Argissolos", "Nitossolos" and "Cambissolos" (Brazilian soil classification system's classes) were the most frequent classes among the MU, with the "Latossolos" class having the largest total area, approximately 50%. When compared visually, the predicted and conventional soil maps showed similarities between the outlines and the distribution of mapping units. However, some soil occurrences in the predicted map did not match to the conventional map, e.g. "Chernossolos" spots of the mapping unit "MX". The validation of the predicted map was performed by two ways: the first by the method of comparison, overlaying 500 randomly generated points sampled in the predicted to the reference map, and the second, selecting another random set of 27 extra points, which were checked in later fieldworks, and compared to both maps. The results show a concordance of 81.8% and 81.5%, for the first and the second methods, respectively. In general, the digital model performed satisfactory in predicting the spatial occurrence of the soil classes in the watershed, being a promising technique for mapping, optimizing costs and saving time.

keywords: *soil survey, weights of evidence, Dinamica EGO, soil mapping units*

Prediction of Soil Carbon Stock in Oxisols of the Eastern Plains in Colombia by VNIR Spectroscopy

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Carbon content is a key indicator of soil quality and ecosystem functions. Changes in land use influence soil carbon (SC) content and accumulation of carbon dioxide (CO2) in the atmosphere. SC content monitoring is used to record long-term changes due to anthropic actions. During the last decades evidence of substantial opportunities for the soil organic carbon (SOC) sequestration has been found in the soils of the Eastern Plains of Colombia. It is necessary to have reliable data to generate the quantitative and precise evaluation of the soil carbon stock (SCS), which is useful as a "baseline" to estimate the total C content. However, this tracking requires a high investment in laboratory analysis.

The use of sensors and diffuse reflectance spectroscopy is an increasing alternative to provide spatial, reproducible distribution, with efficient resource management, to determine SCS at appropriate regional scale. This work aim was predict the C content in Oxisols of the Eastern Plains of Colombia by visible plus near infrared spectroscopy (VNIRS) and calibrate and validate a reliable SC prediction model that allows monitoring and develop methodologies for an continuous and efficient monitoring of SCS in these soils.

A rigid network sampling system was use at the Carimagua Experimental Station of the Colombian Research Corporation - Corpoica (04°34'25"N and -71°20'15"W), in an area of 5100 ha. Samples were taken in horizons A and B. The main soils are Typic Hapludox. Soil was dried at 40°C until constant moisture, and screening in mesh 2 mm. Waste plants were removed.

The total carbon content was determined by elemental analyzer (CN TruSpec Nitrogen Carbon Determinator, LECO co., St. Joseph, MI, USA). Soil Carbon range determinated (%C) was: in the A horizon 1,19 to 2,25 and in B horizon 0,49 to 1,4. The spectral responses were acquired in laboratory by sensor ASD Pro FieldSpec 350-2500 nm (Analytical Spectral Devices Inc.), with 64 scans and spectral resolution of 1 nm for the spectral region of 355-2500 nm. The regression algorithm used was Partial Least Square Regression (PLSR).

The accuracy and precision assestment of SC prediction model was R2: 0.880; RMSE: 0.185(%C); and RPD 2.90. The model predicted at least 70% of SCS analytically determined in A and B horizons. There is a positive correlation between the closeness to the drainage network and the predicted C content. Negative correlation was determined with the slope value, indicating that there may be movement of material that favors carbon accumulation near the drainage network. The results of this research can be used as a base for the SC accumulation monitoring in this area of the country.

keywords: *Soil Carbon Prediction, Model Prediction, Soil Monitoring, VNIRS, Oxisols*

Estimating regression parameters in the presence of spatial and temporal correlation: A case study to quantify costs of soil constraints to the Australian grains industry

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Soil salinity, sodicity, acidity, elemental toxicities and compaction are important soil constraints to agricultural sustainability in many soils of Australia. There is considerable variation in the existing information on the costs of each of the soil constraints to Australian agriculture. To quantify the costs of forfeited grain yield due to soil constraints, we have fitted models that predict yield across Australia as a function of climate and soil. The type of regression model we fit is a model tree, based on the Cubist software (i.e. a collection of multiple linear regression models, each fitted on a different subset of the data); this approach was selected because of its ability to deal with complex interactions and non-linear relationships. An important source of error in the model is the lack of management data, which coupled with the irregular soil data locations mean that it is important to consider the structure of the dataset (the spatial and temporal sampling locations) when fitting parameters. The collection of multiple regressions from a model tree can be written as a linear fixed-effects function in the framework of a linear mixed model. Therefore, these regression parameters can be fitted while accounting for the correlation of residuals, specifically through the restricted maximum likelihood (REML) method. We investigate the effect this has on the fitted parameters and the importance this might have on predictions derived from the model. We apply the methods to our case study and present maps showing the cost of lost yield due to acidity and sodicity across Australia. This work is presented in a model fitting framework, but has relevance to regression kriging where some form of regression tree is assumed to give the trend, as is often the case in digital soil mapping studies.

keywords: *parameter estimation, regression, Cubist, spatial correlation, soil constraints*

DSM online service: from the soil to the cloud

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A digital soil mapping exercise over a large extent and at a high resolution, is a computationally expensive procedure. It may take days or weeks to obtain the final maps and to visually evaluate the prediction models when using a desktop workstation. To increase the speed of time-consuming procedures, the use of supercomputers is a common practice, but managing the big amount of raster data typically used, and implementing the code is not trivial, and access to the required infrastructure is not always possible. Google has developed a product specifically designed for mapping purposes (Earth Engine), allowing users to take advantage of its computing power and the mobility of a cloud-based solution. We explore the feasibility of using this platform for digital soil mapping and we delineate what an application specifically designed for DSM would need to become a fully functional cloud-based soil mapping solution.

keywords: *Cloud Computing, Digital Soil Mapping, Big Data*

Predicting soil organic carbon in Ap horizons in Sistan region, eastern Iran

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Understanding spatial distribution of soil organic carbon content (SOC) in the arid areas is necessary for the management of these regions. In the present study, the distribution of SOC was investigated using digital soil mapping for an area of $\sim$ 227,000 ha in Sistan region, Sistan and Baluchestan province, eastern Iran. The study area is a flood plain with a slope of 1-2% and is an arid region with mean annual precipitation of about 65 mm. It has intense winds and high wind erosion in the springer and summer. 163 soil samples were collected from Ap horizon at the different soil series. 24 environmental variables were used in modeling and 8 variables were selected in the final models. The random forest technique was used to link between environmental variables and SOC. 10-fold cross-validation was used to evaluate models. Results showed that the mean soil organic carbon value was very low with a value of 0.52% in the study area. The most important environmental variables were channel networks, elevation and clay content, aspect and valley depth. The optimal values of RMSE and R2 of the estimated map were obtained 0.23, and 0.17, respectively. The predicted map indicated a general feature from the soil organic carbon status in the Sistan region.

keywords: *Flood plain, Digital soil mapping, Random Forest*

Digital mapping of soil salinity in eastern Iran

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Soil maps are the major sources of information for land management, natural resources and environmental. Soil salinity is one of the most important factors of limiting product in Sistan plain, eastern Iran. Digital soil mapping can be used for predicting soil properties such as soil salinity. In this study, 460 soil samples were collected from 0-30 cm depth on a 750 m grid in 41000 ha from the lands of Zahak of Sistan plain and then the electrical conductivity of saturation paste was measured. 361 samples were used for training and 99 for testing. Random forest technique was used to link between soil salinity (EC) and environmental covariates. Different terrain analyses were derived from digital elevation model (DEM) map and NDVI and SI were extracted from the satellite images. The results showed that soil salinity ranges from $<$ 4ds/ m to $>$ 32ds/ m in the study area. NDVI, aspect and SI were the most important covariate in the prediction of soil salinity. RMSE and ME were 10 and -0.3 for data train and 19.5 and -4.1 for data test, respectively. Produced map showed that soils close to the river had lower salinity and soil salinity increased with distance from the river. The results showed that produced map corresponds with the facts in the study area. The use of other covariates in modeling that do not use in this study can be produced a higher accurate map.

keywords: *Low Relief, Random Forest, Dry region, Sistan*

Accounting for the measurement error to improve the accuracy of spatial modelling of soil carbon

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Infrared soil spectroscopic data is considered as a timely, low-cost input for spatial modelling of soil carbon. However these data are associated with a comparatively higher measurement error than the standard dry combustion technique. Geostatistics is centred on building models of spatial dependence and optimal prediction of the spatial process. This optimal prediction can be hindered by such measurements errors. Therefore, it is vital to have a mechanism to filter out the measurement error variability for an optimal prediction. This study establishes a methodology to filter out the measurement error variability through the inclusion in the covariance structure of the spatial model. We investigated the applicability of residual maximum likelihood (REML) and Markov Chain Monte Carlo (MCMC) simulation methods to generate parameters of the Matérn covariance function directly from the data in the presence of measurement error. The study was carried out in the lower Hunter Valley, New South Wales, Australia where a combination of laboratory measured, and vis-NIR and MIR inferred soil carbon data on topsoil and subsoil are available. The results revealed that the measurement error can be effectively recognised through the inclusion in the covariance structure of the spatial model. When the measurement error was included in the spatial model, the prediction variance was almost halved. Therefore, the results ultimately yielded a greater certainty in spatial predictions of soil carbon content when the measurement error was acknowledged. Further, the MCMC technique was successfully used to define the posterior distribution of measurement error. This is an important finding, as the MCMC technique can be used to estimate the measurement error if it is not explicitly quantified.

keywords: *Infrared spectroscopy, measurement error, variogram, REML-EBLUP, MCMC, filtered kriging*

Monitoring of salt content in soil profile by hyper spectral imaging spectroscopy

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Visible and near infrared spectroscopy is a critical technology to predict soil attributes, however, when monitoring the changes of soil properties in soil profile, it is not a good choice to use those spectrometers based on sampling point. In order to acquire the vertical changes of soil salt content under evaporation condition, in this study, the ImSpector, a direct sight imaging spectrograph, was used to collect the spectral reflectance of saline soil profiles. The external parameter orthogonolization (EPO), a spectral preprocess method, was incorporated in the calibration model to remove moisture effects on soil spectra. The results showed an improved prediction of soil salt content for soil profile after EPO. In conclusion, the hyper spectral image was an effective tool to monitor the changes of soil profile.

keywords: *soil salt content, soil profile, imaging spectroscopy, external parameter orthogonolization*

DSM based renewal of the Hungarian Soil Spatial Data Infrastructure

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Present soil data requirements increasingly demand advanced or new kinds of spatial soil information, which cannot be fully satisfied by legacy soil maps or formerly elaborated spatial databases. Several national programs have emerged recently in Hungary, whose successful completion necessitates the application of suitable data, which need to be spatially exhaustive and consistent as well as both globally and locally reliable. Also, accurate soil information is needed not only for primary soil properties, but for specific basic and or higher level soil features, which formerly had not even been mapped. The DOSoReMI.hu (Digital, Optimized, Soil Related Maps and Information in Hungary) project was started intentionally for the renewal of the national soil spatial infrastructure aiming to significantly extend the potential how countrywide soil information requirements could be satisfied.

The predictand soil properties are selected on thorough demand assessment and then are multi-mapped by the aid of selected sets of reference data, spatial auxiliary information and inference methods. Optimized products are achieved by iteration, which is based on the results of accuracy assessment supplemented with the evaluation of the implemented resources. Reference soil information on target variables comes from survey originated, typically legacy data sources. The relevant auxiliary environmental variables, were selected partly to characterize local soil formation, partly to provide direct information on the surface and certain indirect information on subsurface conditions ruled by the predicted soil features. Spatial inference has been carried out using a variety of geostatistical and machine learning tools: regression kriging, stochastic simulation, classification and regression trees, random and quantile regression forests. The uncertainty of prediction has been also modelled by detailed accuracy assessment targeting both global and local uncertainty.

The main result of DOSoReMI.hu is a collection of spatial soil information in the form of unique digital soil (related) map products, which were optimally elaborated for the regionalization of specific soil features. Significant part of them were never mapped before, even nationally with high spatial resolution. Based upon the collected experiences, the full range of GSM.net products is also targeted to contribute to the worldwide activities. Based on indigenous data infrastructure, it is suggested that national initiatives could produce more accurate and reliable products. It is hoped to achieve further progress in the performance by expanding the pool of environmental co-variables and by testing additional methods and combining some of them. The web publishing of the results has been also elaborated.

keywords: *DSM, GlobalSoilMap, spatial data infrastructure*

Soil, scale dependence and spatial variability: A new approach for assessing how soil variability changes with scale.

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Understanding how soil variability changes with scale is critical to soil scientists' ability to model and manage the soil resource. Improving our understanding of the link between spatial scale (e.g. resolution, extent, support, and spacing) and variability can improve efficiency in soil survey, accuracy of mapping, up and downscaling, and our understanding of how much variability is captured at any given scale.

This study aims to investigate how soil variability changes with spacing and extent. Using a legacy dataset with soil texture observations spanning continental Australia we calculated variograms at different scales. We changed the extent and bin sizes to model spatial variability at scales from a few meters to the entire continent. We calculated the Hausdorff Besicovitch Dimension (D value). This provided us with a measure of roughness that is readily comparable between scales and properties. We first calculated this dimension from distinct variograms modelled at different scales using the 'variogram method'. We also trialed an alternative method which allows the calculation of a continuous D value. This method calculated a continuous D value from a 'composite variogram' which combined variograms from multiple scales.

When applied to Australian soil texture data, we found that soil is highly variable at short scales and that roughness or spatial variability decreases over smaller areas at finer scales. We find that as scale changes, the D values change gradually, rather than abruptly. We extend this analysis to consider other environmental properties and regions.

keywords: *variogram, soil texture, scale, fractal*

Comparison of Mid and Near Infrared Spectroscopy for Prediction of Soil Properties for a National Spatial Dataset

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Soil monitoring, and the modelling of soil data in time and space, rely on a good source of accurate data. In the case of soil, a highly complex and variable matrix, data also need to be abundant in order to accurately represent such variability. As an alternative to tedious and expensive conventional soil laboratory analyses, infrared (IR) spectroscopic techniques have increasingly been used to obtain accurate estimates of chemical and physical parameters of soil in a quick and cost-effective manner. The two main regions of the IR spectrum, near (NIR 750-2500 nm) and mid infrared (MIR 2500-25000 nm), can provide interrelated chemical information about a soil sample, each with different capabilities. The less demanding sample preparation and ease of use of NIR spectroscopy has made this technique more popular for soil monitoring purposes. In combination with predictive calibrations, NIR spectroscopy has been widely used to assess various soil properties –typically moisture, texture, and nutrients. There has been significantly less use made of MIR spectroscopy, which has often been used for qualitative interpretation purposes rather than for prediction of soil properties. Nonetheless, calibrations using MIR data have also been reported, and in many cases they have proved more accurate than NIR calibrations for estimation of certain soil parameters. Such improvements may be due to the extra fundamental information contained in the MIR spectrum, which compared to NIR, provides a more detailed overview of the chemical, mineralogical and, in turn, geological characteristics of soil.

The aim of this study is to investigate the benefits of using MIR spectra, if any, to produce predictive calibrations for simultaneous estimation of multiple soil properties and therefore advance towards the development of this fast and cost-effective tool for soil monitoring. We used MIR spectra of soil samples from a national scale spatial dataset, collected between 2007-2009 across Scotland on a 20 km grid, and that covers a wide range of soil types and land uses. Known reference values for an extensive collection of chemical and physical soil properties were available for these samples. We report results from multivariate calibrations developed using some of this data and compare them against NIR calibrations already available for the same dataset and soil parameters. Results are discussed from a comparative point of view, reflecting the strengths and limitations of each technique in terms of spectral information, accuracy and number of parameters successfully predicted with either technique.

keywords: *mid infrared spectroscopy, near infrared spectroscopy, calibration, soil monitoring*

Combining inventory data with ancillary datasets to predict forest soil organic carbon

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The national forest inventory (NFI) of the United States has worked over the past several years to replace estimates of carbon (C) stocks obtained from country-specific models with estimates leveraging field observations. Early work focused upon standing and downed dead wood, and the newest report to the international community includes field-based estimates of C stored in the forest floor and the mineral and organic soil. Previous estimates of forest floor C stocks employed region- and forest type-specific coefficients describing net C accumulation based on the assumption that litter C mass increased with age. Earlier estimates of soil organic C (SOC) stocks relied upon correlations between forest communities and soil map units (i.e., the State Soil Geographic (STATSGO) and Soil Survey Geographic (SSURGO) databases) that were populated generally by expert opinion across forested landscapes as systematic soil sampling traditionally focuses upon agricultural lands; changes in these stocks were modeled as a response to changes in forest structure. We developed the new models using machine learning (i.e., RandomForests) to assess a suite of potential predictors. For the forest floor, the final models included elevation, longitude, aboveground biomass, the ratio of precipitation to potential evapotranspiration, forest-type group, mean annual maximum temperature, and latitude. The best model of SOC in the mineral soil continues to use soil map unit descriptions as categorical predictors (i.e., soil order), but it also includes a new set of region- and site-specific predictors to improve accuracy: latitude, longitude, elevation, forest-type group, precipitation, mean annual maximum temperature, the ratio of precipitation to potential evapotranspiration, soil order, and surficial geology. We also developed generalized depth models (by soil order) to facilitate estimates of forest SOC across depth. Our new estimates increased the relative size of the SOC pool from 44% to 56% of the total forest C stock. Perhaps most noteworthy, our revised, field-based estimates of forest floor C reduced the stock by 44% (2081 $\pm$ 77 Tg), suggesting that defaults in the Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories may be substantially overestimating the contributions of this pool in temperate forest ecosystems.

keywords: *forest soils, soil organic carbon stocks, inventory, estimation, machine learning*

The Interactive Digital Soil Map of Sweden - a free web application for downscaling

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The Digital Soil Map of Sweden (DSMS) is a public soil geodatabase covering > 90% of the arable land in the country. It contains e.g. a 50 × 50 m2 raster of topsoil clay content that has been predicted from fusion of detailed airborne gamma radiation measurements, airborne laser-scanning data of elevation and Quaternary deposit maps. A free online decision support system (DSS; markdata.se) makes the DSMS clay content data available for free for fields selected by the user and makes it possible to design and export prescription files for e.g. variable rate seeding or liming. This type of free DSS has rendered a large interest among farmers. However, it is also common that farmers already have results from their own soil analyses, and it is of interest to use these soil analyses in combination with DSMS.

Therefore, the aim was to develop an interactive function within DSMS with which local soil analyses can be uploaded. Automatic modelling of DSMS data in combination of uploaded soil data was tested. In the present study, we compared the accuracy (cross validation mean absolute error, MAE) of the following clay content maps for 403 farms:

- Map only: DSMS.
- Map + samples: DSMS locally adapted by residual kriging.
- Map + samples: DSMS locally adapted by regression kriging.
- Samples only: Map derived by inverse distance weighting interpolation

In 31% of farms, the DSMS was better (had a smaller MAE) than maps obtained by IDW. The opposite was true for 15% of the farms. In the remainder of the farms, the most accurate map was obtained by local adaptation/downscaling the DSMS by residual or regression kriging using the farmers' own samples. Consistently choosing the best method for each farm, significantly ($p < 0.001$) reduced the MAE of produced soil maps compared to consistent usage of a specific method.

In the developed web tool, farmers can upload laboratory results and DSMS is currently locally updated by residual kriging, using an automated procedure with a standard variogram model circumventing the general principles of the number of observations generally required in geostatistics. The MAE of all mapping methods are presented, and the user can choose the one with lowest MAE, or the one with a preferential spatial variation pattern – i.e. the one they think look nicest.

The DSMS is published under CC-BY licence by the Geological Survey of Sweden (SGU).

keywords: *Downscaling, Digital Soil Map, Clay content, Precision Agriculture, Decision Support System*

Soil Microbial Diversity Across Different Agroecological Zones in New South Wales (NSW)

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A synergistic relationship between soil (pedodiversity) and microorganisms (biodiversity) is emerging as never before. Understanding this relationship will enable us to improve and protect crucial biogeochemical processes which underpin soil ecosystem services. We explored the multidimensional disposition of this biotic-abiotic functioning by modelling the biogeographical patterns of soil microbes using biomolecular sequencing, pedometrics and digital mapping approaches. Understanding the main factors controlling soil microbial spatial patterns is a need that has been recognised in many scientific disciplines, from the molecular to the environmental sciences. From a soil scientific perspective, we hypothesise that the extent of soil microbial diversities relies on basic but multivariate units defining soils (e.g. soil horizons, profiles classes) instead of any single discrete 'factor' (e.g. soil pH). In this research, we have evaluated this hypothesis analysing bacterial, archaeal and fungal communities at a large spatial extent along latitudinal and longitudinal environmental gradients of about 900 km each across NSW, Australia. Soil microbial and physicochemical attributes, obtained from 98 sampling sites using Illumina DNA sequencing (11,557,499 sequences; 423,740 OTUs) and pedometric approaches (19 soil properties; 13 environmental covariates), were analysed from linear to more complex multivariate associations. We first studied the local diversity (-diversity) of paired conserved and disturbed (e.g. cropping) ecosystem sites. This enabled the spatial prediction and mapping of the three microbial kingdoms at a resolution of 1 km across all of NSW. These maps showed microbial diversity following a combination of soil and environmental attributes in which western NSW showed larger microbial diversity than eastern NSW. Despite this gradient, fungi and archaea were consistently lower and higher in Vertosols (Australian Soil Classification System), respectively, whereas the distribution of bacteria is less clear. Our results suggest that microbial -diversity is intimately related with most physicochemical soil attributes but this association, whether linear or not, varies not only upon the microbial taxa but also because of other additional soil factors. Therefore, microbial diversities are more consistent with grouped features defining soil entities (e.g. horizons and profiles classes) rather than on individual soil factors. Further work will include a more detailed analysis of microbial/pedological dissimilarities (e.g. -diversity) in a multiscale approach.

keywords: *Soil biodiversity, Biopedometrics, Soil microbiology*

Spatial modelling of landscape heterogeneity in soil moisture content with the assimilation of optical and radar remote sensing data

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Soil moisture is a major factor influencing ecosystem processes and it is therefore important to both understanding and modelling ecosystems at a range of spatial scales. Given its ecological significance and ability to account for the heterogeneity in several observed patterns, it is important to determine the spatial and temporal heterogeneity of the moisture characteristics of soils at the landscape scale. Soil moisture is difficult to measure over regions and remotely sensed soil properties could be used as an indicator. Recent radar data such as Sentinel-1 provide useful information to model soil hydraulic properties at national and regional scale especially when combined with other optical remote sensing data and with morphological information.

This study models soil hydraulic properties such as field capacity (FC) and wilting point (WP) for topsoil layer in mineral soils of Scotland. Relatively few measured locations are available: 67 from the National Soil Inventory of Scotland and 221 from other experiments. This is not a sufficient spatial distribution and variability for further modelling with remote sensing data. Therefore a Generalized Additive Model (GAM) was built to obtain FC and WP values at further locations using other available soil properties as covariates, such as organic matter content (loss on ignition), pH and soil texture. The obtained values were used to spatially model FC and WP. The approach used was scorpan-kriging with GAM for the trend and kriging for the residuals.

The results show a good spatial structure and relationships with the landscape. The use of radar data improved the model when compared to only optical and morphological information. The use of radar data allowed also an initial assessment of seasonality of soil moisture in Scotland. These information are important for the modelling of soil functions and ecosystem services, especially in the context of climate change and potential improvement of soil quality and productivity.

keywords: *soil water content, scorpan-kriging, sentinel data, uncertainty*

Using in situ Vis-NIR combined with other sensing data to map clay content, soil organic carbon, and bulk density at the field scale

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While there has been substantial research on the use of proximal soil sensors for digital soil mapping, questions remain as to how data from multiple sensors with different sampling densities and interrogation depths can best be combined statistically to generate 3D soil maps. In this study, we used a combination of soil Vis-NIR spectra and insertion force collected with a penetrometer foreoptic, apparent electrical conductivity (ECa), Normalized Difference Red-Edge index (NDRE) and terrain indices to predict clay content, bulk density and soil organic carbon SOC across three agricultural fields in northern Idaho. With a hydraulic push-type soil coring systems for insertion (e.g. Giddings), we collected soil spectra and insertion force data along 41m x 41m grid points (2 fields – around 140 locations) and 50m x 50m grid points (1 fields – 152 locations) to 80 cm depth (10 cm step increment) for bulk density and clay content and to 30 cm depth for SOC (10 cm step increment). Based on terrain indexes, we stratified the fields and randomly selected 36 locations per field outside the grid points (12 for calibration and 24 for validation purposes). Next to the 36 points, we extracted two set of calibration cores. To generate soil maps, we applied three fundamentally different approaches. First, we developed a chemometric calibration of penetrometer data to predict clay content bulk density and SOC profiles at regular interrogated grid points. These predicted profiles were then interpolated with 3D and 2.5D regression-kriging, using NDRE, ECa and terrain indices as covariates. Second, we used 3D ordinary kriging to interpolate grid penetrometer VisNIR and insertion force measurements, then used these exhaustive data layers combined with NDRE, ECa and terrain indices in a regression-kriging framework to map the soil target properties. For the regression component in the hybrid interpolation technique, we adopted to different tree algorithms, the Random Forest algorithm and a combination of CUBIST algorithm with bootstrap technique. Finally, we used co-kriging to predict target soil properties using grid profile measurements of VisNIR and insertion force, combined with spatially exhaustive ECa and terrain indices.

keywords: *soil spectroscopy, precision agriculture, digital soil mapping*

Geophysical mapping of wetlands using DUALEM - challenges and possibilities

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How do we easily, cheaply and efficiently measure major flow path ways from agricultural fields to lowlands and wetlands? - an intriguing question and a somewhat hot topic in the public discussion in Denmark at the moment.

The Danish agricultural community will in few years need to substantially reduce the nutrient load from fields to fresh water bodies in order to comply to regulations of the European Water Framework Directive and the natural health of wetland ecosystems. Therefore, Aarhus University together with Copenhagen University and GEUS have joined forces in the TReNDS project where the path ways of drainage water are investigated and here natural wetlands may come into play as the perfect nitrate reduction site due to the presence of organic rich sediments e.g. peat. Natural wetlands are a common feature in the Danish landscape as places of converging water conduits (in the shape of streams, drains, ditches, diffuse flow, and groundwater discharge). Therefore, solid knowledge about major flow path ways in wetlands are of immediate concern.

The present study does not answer the whole question but digs into the possibilities of using fast ground conductivity meters (DUALEM421) for accessing relevant soil features in wetlands and the upland/wetland interface such as soil texture, location of organic sediments, presence of high permeability layers, and location of drains.

Although the equipment seems ideal for mapping shallow soil properties, we face significant challenges when using DUALEM in wetlands. These include practical issues when employing vehicles and sensitive measurement devices into rough topography and soft and periodically inundated soils. Also, soil parameters such as lithology, temperature, and water content affects the conductivity measurements and the penetration depth of the equipment in different ways. In our study, conductive organic layers such as peat and gyttja cause a low penetration depth, hence certain areas hold only little information and inversion results may be have significant uncertainty.

Data is inverted using Aarhus Workbench by Aarhus GeoSoftware.

keywords: *GCM, DUALEM, Workbench, Mapping, Wetlands, nitrate*

Soil agrochemical monitoring – source for country-scale predictions and fertilization optimization

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The soil agrochemical monitoring, also called soil fertility programme is the most large-scale monitoring programme in Estonia. This monitoring is aimed at identifying the status and changes of soil properties and determining the fertilization requirements of arable soils. Most of the arable soils in the fertility programme are under CAP subsidies which support environment friendly management and organic production. In 2015 there were 2923 applicants for these support measures. One of the requirements for getting this support is taking soil samples from their fields (except for permanent grassland) with five year interval. General scheme of the soil fertility programme is taking an average soil sample, consisting of 25-40 subsamples, for the area of 5 hectare. It's mandatory to determine available content of potassium and phosphorus as well as actual acidity in soil. Additionally, soil organic carbon concentration (SOC, %) has to be determined for a field. Thus, the collected data since 2002 are large (over 300 000 samples) and provides solid basis for further developments.

Optimizing fertilization is one of the key aspects that interests farmers and is also important in environmental aspect. Currently, Agricultural Research Centre (ARC) provides fertilization requirement maps for the farmers participating in the soil fertility programme. Then the farmer uses this information in planning their fertilization. The next step for the ARC would be providing the farmers with digital fertilization plan depending on the culture and soil properties, i.e., automatized and spatial support system. First attempts achieving this goal have been made. Additionally, SOC (%) data provides a basis for regional prediction of soil organic carbon in arable soils. Previous attempts of predicting SOC (%) all over Estonia were complicated due to the limited spatial coverage of the soil samples. In soil fertility programme, the data are scattered over the country. Therefore, the aim was to develop a prediction approach for soil type-specific SOC (%) of arable soils. The predictions are based on the Estonian large-scale soil map and soil fertility programme data using geostatistical methods. Results can be used in e.g., optimizing site-specifically nitrogen fertilization. This brings actual decision-making to farmers much closer and is not restricted to soil sampling in laboratory.

keywords: *legacy soil data, prediction models, soil organic carbon, fertilization*

Digital soil mapping with Soil Land Inference Model (SoLIM) considering the spatial distance to soil samples

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The Soil Land Inference Model (SoLIM) primarily proposed by Zhu et al. (1997) has been widely applied to digital soil mapping. With this model, the soil property value of each interest locations is estimated based on the similarity of environmental condition between the interest location and soil samples. Therefore, current SoLIM infers in attribute domain of environmental covariates (such as slope gradient, topographic wetness index, and parent material) and ignores the spatial distance between the interest location and soil samples. In this study we revised current SoLIM to consider the spatial distance to soil samples during predictive soil property mapping. This revised model is based on an assumption that the more similar environmental conditions and the shorter distance between an interest location and a soil sample the more similar soil property values will be. We tested the revised SoLIM with soil organic matter mapping in a low-relief watershed. Experimental results showed that the SoLIM can get lower prediction error when the spatial distance to soil samples was considered.

keywords: *digital soil mapping, Soil Land Inference Model (SoLIM), spatial distance*

High resolution land-use classification toward more accurate digital soil mapping of malagasy soils.

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Malagasy soil map of 1:200,000 only cover 20% of the national area and the remaining larger-scale studies don't cover more than 2% of the territory. Advanced research on soils showed that land-use map is an important tools for soil mapping. This study aimed to develop an updated high-resolution land-use map with remote sensing products for an accurate mapping of Malagasy soils. Landsat 8 OLI and SPOT 5 images of the study area (3,600 km^2 in the Ankeniheny-Zahamena Corridor, Eastern Madagascar) were used for mapping six studied land-uses including Water (W), Closed Canopy Forest (F), Tree Fallow (TF), Shrub Fallow (SF), Degraded Land (DL) and Bare Soil (BS). Automatic classification by Baraldi algorithm associating expert classification using Normalized Difference Water Index (NDWI) was applied on the Landsat Image with R and Monteverdi softwares. For SPOT5 image, an Oriented Object segmentation combined with hierarchical classification using vegetation and soil indexes was considered with E-cognition software. Results showed that with 199 validation points, precision of land-use map is 80% for Landsat and 82% for SPOT5 classification. Classification is slightly more accurate for Landsat (90%) than SPOT5 (88%). However, mapping of TF is difficult for both classifications (79%), DL for Landsat (72%) and SF for SPOT5 (70%). As soil properties depended on change in vegetation cover, a better differentiation on fallows areas still needs to be enhanced. However, the present study is an important step forward towards more accurate soil mapping. Automatic classification of land-use map can be useful for monitoring sustainable management of forest and agricultural land.

keywords: *Classification, Degraded land, Forest, Land cover, Vegetation Index*

Are data collected to support farm management suitable for monitoring soil indicators at the national scale?

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National-scale soil monitoring is required to quantify the status and the rate of change of soil indicators and to determine whether policy or management interventions are required to maintain soil functionality. Many countries are without an ongoing national-scale soil monitoring network (SMN). For example, in the UK there is no plan to resample any of the three existing SMNs. The European-scale LUCAS SMN does sample within the UK but not with the intensity required to produce maps of the variation in soil properties with sufficient accuracy and resolution to determine where threats are emerging. We explore the potential to use an alternative source of soils information to monitor soil indicators. Namely, the results of soil analyses requested by farmers to determine the fertiliser requirements for their fields.

NRM laboratories analyse around 350 000 soil samples each year for farmers and agronomists from across England and Wales. We use model-based geostatistical methods to predict maps of soil indicators such as P, K and Mg concentrations and soil pH from these data. The maps are generally consistent with the results of the existing SMNs and where differences do occur they can be explained by differences in analytical protocols. However, in contrast to the LUCAS SMN, the sites where the NRM samples are collected are selected according to the needs of farmers rather than a statistical design. The sampling could be biased in favour of areas where farmers have particular concerns and observed trends in the soil indicators might be the result of the changing priorities of these farmers rather than actual changes in the soil indicators. Therefore, we demonstrate how the data from LUCAS SMN can be harmonised or combined of with the NRM data within a linear model of coregionalization. This leads to high-resolution predicted maps of the indicators that are both unbiased and accurate since they benefit from both the unbiased sampling of the LUCAS SMN and the large spatial density of the NRM samples.

keywords: *Soil Monitoring, Farmers' data, Geostatistics, Linear model of coregionalization, Harmonisation of soil surveys*

Using combined model for soil pollution spatial analysis

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How to use the limited soil heavy metal survey point data to carry out regional soil pollution analysis, and provide a decision-making basis for soil management and pollution control has always been a difficult and hot issue. Various of Kriging and related geo-statistics methonds are widely used in these studies, but little attention is paid to the land situation as the host of soil. However, different land use and soil pollution of heavy metals in spatial distribution has obvious correlation. In 2014, to safeguard the country's food safety and create a healthy living environment,the concentration of five soil heavy metals (Hg, Cd, Cr, Pb and As) was measured in 120 sampling sites in Yuhuan, which is a highly developed island county in China, and located in southeast coast of Zhejiang. In this paper, we propose a combined model of Random Forest and Kriging interpolation to estimate the regional soil pollution by the 120 sampling data. Firstly, Random Forest was used to estimate the effect of the composition of land use types on the observed variables(5 kinds of soil heavy metals), and the regression model was established between various soil heavy metal observations and land use types. And then, it is used to predict the value of observation points and unknown points. Secondly, the Ordinary Kriging interpolation is applied to the residual value of each observation point to get the 'residual value' of each unknown point, which means areas to be predicted. Finally, the predicted values of unknown points for each unknown point are obtained by subtracting the 'residual value' from the forecast value of random forest. At the same time, we apply ordinary Kriging interpolation directly to the value of each observation point to estimate the values over the region. In the end, RMSE and R2 were selected to compare the accuracy among Random Forest, Ordinary Kriging and the combined model. The result shows that the proposed method can achieve better prediction of the spatial distribution of heavy metals in soil than independent models.

keywords: *combined model, random forest, ordinary kriging, soil pollution, spatial analysis*

Three-dimensional mapping of soil organic carbon (SOC) based on multi-scale digital terrain analysis and data mining in Jiangxi Province, PR China.

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Soils as limited resource are the largest terrestrial sinks of organic carbon (SOC). Spatial and depth related quantification of SOC offers substantial improvements in the delineation of specific soil functions, e.g. soil quality, water retention capacity and nutrient cycling. Previous models of SOC mostly use specific depth increments, so called standard depths, in a two-dimensional way to reproduce a virtual layered, but limited, three-dimensional mapping. Few approaches in soil-landscape modelling, especially in the application of machine learning techniques, utilize spatially modelled depth functions for SOC predictions. In the context of the biodiversity experiment BEF China located in the subtropics a framework based on depth functions and non-linear machine learning techniques, i.e. random forests (RF), multivariate adaptive regression splines (MARS) and support vector machines (SVM), was tested to quantify spatial and depth-related SOC. The initial datasets consist of 67 plot-based mixed samples and 90 subplot-based point samples with five depth increments (0-5, 5-10, 10-20, 20-30, 30-40, 40-50 cm). The workflow is ordered as follows: (i) derivation of descriptive environmental covariates on different scales (in total 290 covariates), (ii) derivation of depth functions at each sample point with 3rd order polynomials and natural logarithmic functions, (iii) spatial modelling of the polynomial coefficients, (iv) comparison of different non-linear machine learning methods and (v) solving the polynomial functions in given depths. The error (RMSE) of the depth functions ranges from 0.1 to 0.17 % SOC with a coefficient of determination (R^2) higher than 0.9. The spatial models of the four plot-based coefficients with SVM are better (mean R^2 of 0.32) than MARS (0.31) and RF (0.28). The mean of RMSE is 0.22 (RF), 0.23 (SVM) and 0.25 (MARS). Models of the point-based samples have a R^2 of 0.2 and RMSE of 0.35 in average. Therefore, SVM is used for the final prediction. Models that combine both samples are more uncertain ($R^2 \leq 0.14$). On the one hand this may be due to the spatial clustering of the point-based samples, on the other hand we suppose that the averaging of the plot-based samples reflects different scales of measurement and therefore should not be used complementary with the point-based samples.

keywords: *Soil organic carbon, Depth function, Multi-scale digital terrain analysis, Machine learning, Three-dimensional digital soil mapping*

Soil Organic Carbon Content of Central Chile and Its Projection Under Climate Change Scenarios

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Soil Organic Carbon (SOC) is the largest terrestrial carbon pool and it influences a number soil properties and processes in a landscape. Variation in SOC distribution is primarily influenced by topography, land use and changes in climatic variables. We estimated SOC content for Central Chile (147,959 km^2 area) using 484 pedon data and a range of environmental variables including temperature, rainfall, land use, topography, soil types and geological information as predictors. Random Forest was chosen as a prediction model and SOC content maps were created for 6 depths corresponding to the GlobalSoilMap specifications. Equal area splines were used to harmonize discrete SOC data from the pedons and values were weighted-averaged to 6 depths. Results showed SOC of 53 g kg^{-1} at 0-5 cm, 50 g kg^{-1} at 5-15 cm, 40 g kg^{-1} at 15-30 cm, 25 g kg^{-1} at 30-60 cm, 14 g kg^{-1} at 60-100 cm, and 6 g kg^{-1} at 100-200 cm depth intervals. Model validation using 25% pedons showed a R2 of 0.65, 0.71, 0.79, 0.77, 0.69, and 0.29 for 6 depths, respectively. The lowest RMSE (8.5 g kg^{-1}) was observed at 60-100 cm, and the highest (21.8 g kg^{-1}) at 0-5 cm. To quantify the response of SOC in a changing climate (temperature and precipitation), two future climate scenarios—RCP4.5 and RCP8.5—from NASA GISS models were considered and SOC contents were projected for year 2050 and 2080. Our estimation suggested that Central Chile would lose on average 11% SOC for the RCP4.5 and RCP8.5 scenarios in the year 2050, and 16% by 2080 compared to current estimation. In the next step, we estimate the projected SOC stock changes using pedon bulk density data which are still under processing

keywords: *digital soil mapping, soil organic carbon, climate change, soil legacy data*

Laser-induced breakdown spectroscopy (LIBS) for efficient quantitative determination of elemental plant nutrients in soils: A contribution to precision agriculture

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One important aim of precision agriculture (PA) is the optimization of crop growth by means of site-specific measures, e.g. fertilizer application. Thus, PA should contribute to a resource efficient and ecofriendly soil management. Due to the expenses associated with traditional methods of soil analysis, requiring sample collection and laboratory analysis, PA technologies are still not in widespread use. Therefore, the aim of the project "I4S – Integrated System for Site-Specific Soil Fertility Management" is the development of a field-deployed, sensor-based analysis system offering rapid, cost-effective and spatially-resolved fertilizer recommendations.

In this system, laser-induced breakdown spectroscopy (LIBS) could be ideally suited to assessing elemental nutrient contents of soils. In addition to low cost, durability and small size, a reliable quantification procedure is a crucial requirement for such a system. However, the texture as well as the composition of the soil can affect the spectra. This matrix dependence is the key challenge to be addressed in the application of LIBS for soil evaluation. The focus of this work was the establishment of a LIBS method for soil analysis in a laboratory environment for future field application.

Natural soil samples of various origins, textures and compositions were used to characterize the matrix dependence of the LIBS spectra. Reference samples were prepared by adding defined amounts of the target elements to the soils (standard addition). Signals not superimposed by peaks of other elements were identified for each element. The reference samples also provided calibration curves for the respective soil type when the initial concentrations in the soils were taken into account. Additionally, the common laboratory method ICP-OES following aqua regia extraction was used to obtain reference values. Various approaches of calibration free evaluation of the data were also evaluated. In addition to traditional single-pulse experiments, the advantages of dual-pulse LIBS in relation to signal intensity, reproducibility as well as overcoming the matrix dependence of soil spectra were investigated. These methods were subsequently applied to validation samples collected on a dense grid within a field.

keywords: *Laser-induced breakdown spectroscopy, LIBS, precision agriculture, elemental nutrients*

The use of Self Organizing Maps in hydrological modeling with SWAT

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Soil properties constitute an important aspect to take into account in environmental research and especially in hydrological modelling. This work presents the methodology applied for the set-up of the soil property database in the SWAT model (Soil and Water Assessment Tool) as a functional part for the simulation of the water resources in the Cega-Eresma-Adaja watershed (Douro river basin, Spain). During SWAT calibration, the most common and recurrent issues are related with soil parameters and the difficulty usually arises from the identification of the correct value ranges during iteration.

This case study covers an area of 8.000 km^2 from which 407 soil samples were used to create soil units implementing an optimized process through unsupervised learning of artificial neural network (ANN), better known as self-organizing maps (SOM). The goal of this research consists in generating a reduced number of soil units using two performance metrics for the SOM: the mean distance from the cluster centroid and the Devies-Boulding (DB) index. Low DB values represent low intra- and high inter-cluster variability indicating a more satisfactory clustering result from the mathematical point of view.

As a result, 16 clusters were identified as the most suitable number of clusters including the standard deviation for each soil property as a measure of the variability. The SWAT model was run twice using: (1) a map of the soil units (1:400.000 scale) with properties assigned by matching data from sampling points through rastering procedure and (2) soil map derived from SOM using also the soil sample data rasterized in the whole area and optimized to reduce the number of clusters. By comparing these two soil maps as elements for data input in the SWAT model, the SOM procedure clearly shows more advantages in terms of calibration accuracy.

keywords: *self-organizing maps, soil units, clustering*

Spectroscopy and remote sensing for assessment of peatland degradation

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Peatlands cover more than 20% of Scotland's land area, and habitat mapping and assessment of their condition is a key issue both at Scottish and EU level. These carbon-rich soils have a vital functional role and, importantly, degraded peatlands are net emitters of carbon. In order to return degraded peatlands to their naturally C sequestering state, restoration measures are often essential. However, for many areas, the location and extent of degradation is poorly defined. There is a real need for methodologies and approaches to support faster and cheaper monitoring of peatlands and other high organic soils, particularly on a large scale. The aim of this study is to use a combination of spectroscopy (FTIR, Fourier Transform Infrared) and remote sensing (RS) data to predict key attributes and properties of peat and highly organic soils, such as humification (Von Post), bulk density, carbon content and water holding capacity. This will then allow the rapid and novel assessment and modelling of above and below ground habitat (peatlands/highly organic soils) conditions and provisioning of ecosystem services, such as carbon storage, water quality, and biodiversity. The spectroscopic calibrations used to predict the key properties will provide rapid ground-truthing for remote sensing upscaling, with the initial focus on the calibration for the soil organic carbon content, using partial least square regression. This pilot study in Scotland is based on a raised bog in relatively good conditions (Dava Bog) where a lot of information is already available for soil, vegetation, land use and remote sensing data (Landsat, 30m resolution and Sentinel, 10m resolution) and where preliminary modelling conducted between physical properties, vegetation and remote sensing showed good results. Interpretation of the FTIR spectra for the Dava Bog will be reported, along with the calibrations developed to predict the organic matter content and preliminary results for the links to remote sensing data.

keywords: *peatland degradation, FTIR spectroscopy, Remote Sensing*

Digital soil mapping of available water capacity for metropolitan France

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Soil hydraulic characteristics are often required for modeling hydrological processes, crop productivity, biogeochemical cycles, and movement of pollutants. The objective of this study was producing a digital soil map of available water capacity (AWC) for metropolitan France following GlobalSoilMap (GSM) specifications. The digital soil mapping approach consisted in predicting sand and clay for the six GSM depth intervals and then applying pedotransfer functions (PTF) for estimating AWC (cm3 cm-3) by layer. We used the French SOLHYDRO database to develop continuous PTF for soil moisture at field capacity (pF $\leq$ 2.0) and permanent wilting point (pF $\leq$ 4.2) using sand and clay as predictor variables. The calibration dataset comprised profiles from the French Soil Survey program. The independent dataset consisted of profile data from the RMQS, which is distributed on a 16 km x16 km grid. Particle size measurements were processed with equal-area spline functions, and later transformed with the additive log ratio transformation (alr). Regression models were fitted for sandalr and clayalr, followed by cokriging of the residuals using a linear model or coregionalization. We considered the uncertainty of the input data by sampling from the conjoint distribution of sandalr and clayalr in a sequential Gaussian simulation approach, for producing uncertainty estimates for AWC by depth interval. Total AWC for the profile was calculated by aggregation to the predicted soil depth (Lacoste et al., 2016) to a maximum of 2 m. The lack of georeferenced observations for AWC did not allow us to validate both the spatial models and the PTF estimates together, and therefore we validated separately the performance of the PTF with cross-validation (R2 $\leq$ 0.67 – 0.84, RMSE $\leq$ 0.027 – 0.043 cm3 cm-3) and the spatial predictions of sand and clay.

Lacoste, M., Mulder, V. L., Martin, M. P., Arrouays, D., 2016. Evaluating large-extent spatial modeling approaches: a case study for total soil depth for France. Geoderma Regional, 7, 137 – 152.

keywords: *Available water capacity, Digital Soil Mapping, Pedotransfer functions*

Analyzing the effect of heavy metals' contamination on ecosystem services of urban soils in different functional zones of Moscow-city

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Urbanization is a global trend with important environmental consequences. Features, functions and key components of urban ecosystems differ considerably from those of natural ecosystems. Urban soils provide important ecosystem services, like purifying surface and ground water, neutralizing pollutants and supporting greenery. The absorption and neutralization of pollutants is one of the key regulating services of urban soil. Urban soils are polluted with heavy metals, oil products and poly-aromatics hydrocarbons (PAH). The main sources of urban soils' pollution includes industry, transport and household waste Urban areas consist from functional zones (i.e., industrial, residential and recreational), which affects high spatial diversity of urban soils and services they perform. Analyzing spatial distribution of heavy metals and benz(a)pyrene in (BP) in urban soils is needed to evaluate the regulatory services in various functional areas of the city.

The research focused on urban soils in Moscow city (Russia). Soil survey organized in 2015-2016 and covered various functional zones, including recreational (parks, squares, urban lawns) and residential zones. Samples were taken by depths 0.0-0.2; 0.2-1.0m and 1.0-2.0m, therefore both topsoil and subsoil layers were involved into analysis. In the collected samples, the following chemical properties were measured: pHKCl, petroleum, BP and heavy metals' content (Ng, Ni, Cu, Zn, Pb, Cd, As, Cr, Mn, Co). The results of chemical research were processed using the R studio to analyze and map the distribution of heavy metals using geostatistical methods.

In result, the contents of BP were above the health thresholds for all functional zones. The maximal 0.06 mg / kg were found in the residential area. An excess over health thresholds was shown for Pb (33,06 ± 3,64 mg / kg), Ni (8,20 ± 2,19 mg / kg) and Co (5,30 ± 0,78 mg / kg) in soils under lawns along roads. The contents of Cu (69,59 ± 6,31mg / kg) and Co (2,92 ± 0,18 mg / kg) exceeded corresponding thresholds in residential zones. The created maps of soil pollution were related to the standard values (relative permitted amount) for different soil acidity and texture. The resulted maps enable assessing the performance of the urban soils' regulating service to mitigate heavy metals' pollution in different functional zones of Moscow. It also allows selecting the areas with high-risk of pollution and to the opposite the most resistant zones to support soil management and land-use planning in cities.

keywords: *heavy metals, urban soils, urbanization, digital soil mapping*

A new look at soil phenoforms – definition, identification, mapping

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The "soil genoform" vs. "soil phenoform" distinction was introduced by Droogers and Bouma (1997) to account for management-induced physical differences among pedons with the same pedogenesis, sufficient to cause large differences in soil functions. We propose a rigorous conceptual and operational definition of soil genoforms and soil phenoforms, and suggest pedometric techniques to identify and map them. We define soil genoforms as soil classes as identified by a soil classification system. This avoids the difficulty of defining when human intervention has been sufficient to create new genoforms – by definition this is when new classes (e.g., Stagnic Anthrosols) are recognized in the classification system, based on diagnostic horizons (e.g., anthrostagnic) or properties. We then conceptually define soil phenoforms as persistent variants of a genoform with sufficient physical differences to substantially affect soil functions.

This excludes chemical variants, except as these are severe enough to cause physical differences, e.g., defloculation and structure change caused by addition of high-sodium water. Phenoforms must be non-seasonal and non-rotational; this excludes the normal cycle of tillage, crop growth, cover crops, and residue incorporation, etc. They must be persistent enough that substantial management interventions are necessary to change them. This excludes results of management such as surface crusting which can be broken up by a single tillage, but does include subsoil compaction that would require several years of recovery crops such as deep-rooted white radish combined with conservation tillage or no-till.

Soil phenoforms can be identified by measurements of soil physical properties at locations within a soil genoform with different management and investigating if these are different enough to affect soil functions, notably soil hydrology and crop yield.

Identified phenoforms can be mapped by digital soil mapping techniques, typically using current and historical management as covariates in mixed interpolators such as regression kriging.

Since phenoforms can be changed by management, such mapping exercises should be repeated every few years, especially when changed management in an area is observed.

keywords: *soil phenoforms, soil monitoring, soil functions*

Past, present and future of information technology in pedometrics

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Although pedometric approaches were taken as early as 1911 (Mercer & Hall, Student) and 1937 (Youden & Melich), the post-WWII development of information technology radically transformed the possibilities for pedometrics. The first development is of course the electronic digital computer. Early examples where this made pedometric techniques viable are numerical taxonomy of soils in the early 1960's and geostatistics from the mid 1970's. By the time of the first Pedometrics conference in 1992 sufficient computing power was available for stochastic simulation and complex geostatistical procedures such as cokriging and disjunctive kriging. In the intervening 25 years computing power has grown to almost magical proportions, allowing any individual scientist to carry out the most complex procedures. The second development is the growth of networking towards the internet. This has fostered much easier collaboration among dispersed pedometricians, rapid communication with journals, collaborative programming and publication, and easy access to resources. This is the third development: the tremendous growth in on-line storage, especially of open data, including GIS coverages and remotely-sensed images, and computer programs. This has allowed pedometricians working on geographic problems to integrate sources from multiple discplines, most notably in digital soil mapping using a wide variety of covariates related to soil genesis. It has also allowed the development of an open-source movement of collaborative development of computer programs useful for pedometrics. A fourth development is the explosive growth of sensors to provide data for pedometrics, including spectroscopy, electromagnetic induction, gamma-ray detectors etc., connected to each other and to central data stores. A fifth development is wireless technology, including mobile computing and telephony, again greatly facilitating rapid and extensive data collection – in pedometrics, the more dense the data, the greater the analytical possibilities and the lower the uncertainty. A final development is the Global Positioning System, making accurate georeference of field data a routine part of data collection, and thereby assuring the highest possible accuracy in maps made by predictive pedometric methods.

Mapping soilscapes using soil co-occurence networks

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Soils are arguably the most complex material on Earth, and present an important spatial variability. Across the landscape, different soils types will often be spatially intermingled. This is reflected by soil mapping units (SMU) being often composed of more than one soil taxa. The notion of soilscape reflects the fact that a landscape can be delineated into different such spatial units "including a limited number of soil classes that are geographically distributed according to an identifiable pattern" (Lagacherie et al., 2001).

The research field of network science offers new mathematical tools to visualize and analyze existing soil survey data, and explore its complex relational interactions. In this paper, we extract and visualize pedological information by analyzing the co-occurrence of soil taxa using a network approach.

For any level of a given hierarchical soil classification system, the co-occurence of soil taxa within and between neighbouring SMUs can be described as a network graph. The structural properties of the resulting graphs can be analyzed, and tools such as community structure detection are used to classify their different nodes. Soilscapes are then delineated by mapping the identified communities back in geographical space. This approach also gives a method for quantifying the pedological complexity of different regions based on their constituent soil types, using metrics such as graph connectivity. Different levels of granularity for both the regional data and the soil classification data allow for views at different scales.

Network science offers the opportunity of new insights from looking at existing data in a new way. Soil survey data from S-Map (NZ) and USDA-NRCS (USA) are used to illustrate the value and originality of these new approaches.

keywords: *Networks, Soil classification, Soilscapes*

Approximation on the reconstruction of pore spaces in 3D CT soil images by cubic interpolation

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The soil mechanics depends on its solid-pore architecture, and this also influences the biological, chemical, and physical processes that happen on it. Actually, non-destructive imaging techniques, as X-ray computed tomography (CT), can be used in order to study the features of a particular soil.

The analysis of 3D CT images of soil samples can be carried out by experts, though this can be done automatically through image processing. In the latter case a set of 2D images, corresponding to equally spaced images from the original 3D CT images, have to be previously segmented for the identification of the pores. Then, and from the pores in each 2D image, different interpolation techniques can be used to approximate the 3D pore spaces.

In this work an approach, based on cubic interpolation, was applied for the reconstruction of the pore spaces, and interesting results are provided as it allows visualizing and quantifying some morphometrics parameters of soil samples, which can be used afterwards to different purposes.

This novel approach has potential for various applications in soil science.

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keywords: *CT-scan soil images, segmentation, 2D interpolation, soil pore structure*

Designing soil monitoring schemes for large areas based on high resolution digital soil mapping products: a case study from France

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Throughout the world, there is an urgent need to determine where soil quality and functionality are threatened by dynamic processes such as loss of organic matter, contamination, acidification, etc. However, there are a number of challenges and difficult choices associated with the implementation of soil monitoring networks to track these processes. For instance, the designers need to decide where they should measure and how frequently. Should they select sites at random or sample on a purposive design such as a regular grid? Sampling is also constrained by the financial and other resources available. Thus an efficient sampling strategy is sought for applications also in soil survey for mapping. Digital soil maps have been produced at continental and regional extents at various spatial resolutions. These maps of soil properties along with their uncertainty can be used to establish a network for soil monitoring sites. In this work, we used a design-based sampling methodology, called Ospats which optimised spatial stratification and allocation for stratified random sampling of points. Ospats uses a grid of points from digital soil maps with known uncertain predictions of the target variable. We demonstrate its application for establishing a network of monitoring sites in France using the digital soil maps of carbon content at various resolutions (5km, 2.5Km and 90 m). We developed a specific algorithm to handle large spatial datasets. This algorithm allows allocating additional grid points to an existing Ospats stratification constructed using a coarser grid. We compared the Ospats stratification to two extremes: a stratification close to those by the cum-root-f method and, a compact geographical stratification based only on the locations of the grid points. We based our comparisons on the data from the soil French soil monitoring network. Our results clearly showed that Ospats considerably improves the efficiency of the stratification. We also explored the sensitivity of the method for incorrect quantification of the uncertainty of the initial carbon map. This method is potentially useful for setting up new monitoring networks.

keywords: *monitoring, design-based statistics, statistical design, carbon, digital soil mapping, France*

The use of Zipf's –Pareto law to describe the structure of soil cover of Bryansk Opolje

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The soil cover of any landscape is, on the one hand, a continuous formation, on the other hand, it may be considered as a set of different soils on some hierarchical level of a soil classification. Analysis of correspondence between the entities of a soil classification and the soil cover allowed E. Dmitriev (1988) to propose the concept of pedo-coenosis. The Zipf's –Pareto law is used in biology to describe the structure of coenoses. This law is widely applied in various scientific fields for the analysis of community structure in a broad sense.

The study was performed on example of the Bryansk region landscapes, which are the part of the Russian Plain. Peculiarities of soil units' areas distribution on the soil maps of scale 1:50,000 were studied. The main features of the Opolje are a relatively high location (elevation marks about 180-200m above the sea level) and the presence of loess-like loams. The soil cover is dominated by automorphic gray forest soils (Phaeozems Albic), to date almost completely under cultivation. Light erodibility of loess-like loams causes the development of erosion processes. The hydromorphic analogues of gray forest soils (Phaeozems Gleyic) were associate to depressions. A small amount of sod-podzolics soils (Albeluvisol Umbric) and alluvials meadow soils (Fluvisols Umbric) were marked as part of the territory. Three areas of Bryansk Opolje were studied. The number of allocated soil map units was 220, 303 and 417, respectively. The areas of the units ranged from 2800 m2 to 1 ha.

Rank-order graph of the logarithms of the areas of the soil maps units of all three sites under consideration to the rank logarithms consisted of several linear segments. The coefficients of determination for each of them were higher than 0.95, provided that even for the shortest segment the sample volume exceeded 30 values. The first line segment corresponded to the soil map units with the largest area. It was a few map units with not eroded gray forest soils and complexes of gullies and ravines soils. In the middle part of the graph gray forest soils and gray forest gleyic and gley soils with little participation of sod-podzolics soils were placed. Gray forest soils with different degrees of erosion appeared more often with the rank increasing. The last graph segment corresponds to the map units of a very small area arising as a result of mapping errors or when digitizing paper map.

keywords: *Zipf's –Pareto law, Phaeozems Albic, soil cover patterns*

Stacked generalization of statistical learners - a case study with soil iron content in Brazil

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When modeling soil-landscape relationships we generally test a handful of statistical learners. Having limited data, we use cross-validation to select the best performing learner. In this study we evaluate the benefits of combining learners for soil prediction using stacked generalization. It consists of calibrating multiple learners and submitting them to 10-fold cross-validation. Cross-validation predictions are used as covariates in an interceptless linear regression of the target variable. Constrained to be non-negative, the estimated regression coefficients are the stacking weights expressing the importance of each learner. When making predictions, each learner is used in turn and the weights used to optimally combine multiple predictions into a single prediction.

The data was downloaded from the national database maintained by Embrapa. The target variable was the soil iron content (g/kg). Covariates ($p \leq 7$) were constructed using soil profile data. The $n \leq 22{,}981$ records remaining after some data cleaning were split into calibration ($n\_cal \leq 16{,}086$) and validation ($n\_val \leq 6{,}895$) sets. Six learners were used: linear regression with stepwise selection (lm), multivariate adaptive regression splines (mars), regression random forest (rf), single-hidden-layer neural network (nnet), weighted k-nearest neighbor regression (knn) and support vector machine with polynomial kernel (svm).

rf and knn severely overfitted the data, while lm, mars and svm were the most stable learners. The first two yielded the lowest absolute and squared errors (rmse < 45 g/kg) and explained more of the variance (ave $\sim$ 0.6). mars, nnet and lm were the least biased learners (me $\sim$ -0.1 g/kg), while svm was the most biased (me $\leq$ -5.14 g/kg). lm explained the smallest amount of variance (ave $\leq$ 0.49).

rf received the largest stacking weight ($w \leq 0.55$), knn and svm received moderate weights ($w \sim 0.2$) and nnet and mars received the smallest weights ($w < 0.1$) – lm was dropped from the stack ($w \leq 0$). Combining learners lowered all absolute and squared errors (rmse $\leq$ 43.23 g/kg), yielded a considerably small bias (me $\leq$ 0.53 g/kg), and explained the same amount of variance explained by rf (ave $\leq$ 0.61).

Staking learners was more beneficial than using the single best performing learner because it reduced generalization errors. The magnitude of the benefits seems to depend upon the diversity of learners (over and underfitting, biased and nonbiased). Besides, by using least squares regression to compute stacking weights we can estimate the prediction error variance of any combination of learners.

keywords: *Digital soil mapping, Model combination, Cross-validation*

'spup' – an R package for uncertainty propagation analysis in spatial environmental modelling

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In many environmental studies, including soil science, variables of interest are spatially distributed. These variables are often used as input to spatial analyses and spatial models, such as in land evaluation systems, erosion models and crop growth models. Since mapped variables are only approximations of the real world uncertainty is introduced, which will propagate through the analyses and models. Currently, advances in uncertainty propagation and assessment have been paralleled by a growing number of software tools for uncertainty analysis, but none has gained recognition for a universal applicability and being able to deal with case studies with spatial models and spatial model inputs. Due to the growing popularity and applicability of the open source R programming language we undertook a project to develop an R package that facilitates uncertainty propagation analysis in spatial environmental modelling. In particular, the 'spup' package provides functions for examining the uncertainty propagation starting from input data and model parameters, via the environmental model onto model outputs. The functions include uncertainty model specification, stochastic simulation and propagation of uncertainty using Monte Carlo (MC) techniques, as well as several uncertainty visualization functions. Uncertain environmental variables are described by probability distributions. Both numerical and categorical data types are handled. Spatial auto-correlation within an attribute and cross-correlation between attributes is also accommodated for. For uncertainty propagation the package has implemented the MC approach with efficient sampling algorithms, i.e. stratified random sampling and Latin hypercube sampling. The MC realizations may be used as input to the environmental models called from R, or externally. Selected visualization methods that are understandable by non-experts with limited background in statistics can be used to summarize and visualize uncertainty about the measured input, model parameters and output of the uncertainty propagation. We present the 'spup' package and illustrate it with a simple example of deriving the C:N ratio from maps of organic carbon and nitrogen for a 33x33km area in Madagascar. We show that even for such a simple example, the outcomes of the uncertainty analysis yields valuable insight.

keywords: *R language, uncertainty analysis, uncertainty propagation, spatial models, Monte Carlo*

Reflectance spectra and Land Surface Temperature integration obtained from Landsat on the soil granulometric quantification

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Soil attributes have direct influence on surface temperature. Despite studies with soil spectra obtained from satellites, soil evaluation through Land Surface Temperature (LST) is still scarce. The broad availability of satellite thermal data and the development of algorithms to retrieve LST facilitated its use in soil studies. In this study, an image of Landsat 5 was used for extracting LST using the inversion of Planck's function in band 6 (10.4 – 12.5 µm), and land surface emissivity was estimated using Normalized Difference Vegetation Index threshold method. We also extracted reflectance values from bands 1, 2, 3, 4, 5 and 7. Most of the area was with bare soil and plowed. The study area (198 ha) is located in Sao Paulo state, Brazil. Soil texture varies from loamy fine sand to clayey. Soil samples were collected in a regular grid of 100 x 100 m (depths: 0-0.2 and 0.8-1.0 m); soil granulometry was determined by laboratory analysis. Models for soil texture determination were performed using Linear Regression (LR), with soil samples from 62 auger points distributed in 14 toposequences. Simple LR was applied for generating prediction models for clay and sand based only on LST and also only on elevation data extracted from a Digital Elevation Model (DEM). Multiple LR was applied in order to generate models for the same variables but using atmospherically corrected spectral reflectance from Visible, Near-infrared and Shortwave infrared (Vis-NIR-SWIR) as predictors. Multiple LR was also applied for the prediction of clay and sand using simultaneously Vis-NIR-SWIR, LST and elevation. Predictive performance of models was assessed based on adjusted R^2 and Root Mean Squared Error (RMSE, g kg^{-1}) obtained in validation. Using as co-variables only LST we had $R^2_{adj} \leq 0.35$ and RMSE ≤ 153.83 for clay and $R^2_{adj} \leq 0.36$ and RMSE ≤ 172.51 for sand; using only elevation, we had $R^2_{adj} \leq 0.14$ and RMSE ≤ 169.15 for clay and $R^2_{adj} \leq 0.15$ and RMSE ≤ 187.03 for sand; using Vis-NIR-SWIR bands, $R^2_{adj} \leq 0.67$ and RMSE ≤ 100.86 for clay and $R^2_{adj} \leq 0.55$ and RMSE ≤ 131.20 for sand. The best model was obtained using all co-variables for clay, reaching $R^2_{adj} \leq 0.73$ and RMSE ≤ 89.84 and Vis-NIR-SWIR plus LST for sand, with $R^2_{adj} \leq 0.64$ and RMSE ≤ 121.72, enhancing the importance of considering not only spectral data for generating soil texture maps, but also LST information, which improves soil attributes mapping.

keywords: *Land Surface Temperature, Soil Attributes Mapping, Thermal Infrared, Satellite Imagery Analysis*

Visualizing Soil Landscapes

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The ready availability of high quality digital soils data, particularly in the U.S., makes it possible to visualize soil landscapes in new ways. The Integrating Spatial Educational Experiences (Isee) project utilizes the most detailed US soils information from the USDA SSURGO soil survey dataset, the best available digital elevation models from the National Elevation Data Set, and other data sources to prepare informative maps of a variety of soil properties. Maps for seven U.S. states (Indiana, Illinois, Kentucky, Ohio, Texas, West Virginia, and Wisconsin) are currently online. Maps for Dominant Soil Parent Materials, Natural Soil Drainage Classes, and Soil Orders are available for all the states, and some states have additional maps. These maps can be studied using the free Isee app for the Apple iPad (https://appsto.re/us/nbdy7.i) and the new SoilExplorer.net website. Details of soil landscapes can be explored by zooming to a scale of 1:18,000, while popups provide additional information about each map unit. The project is a collaborative effort of the Isee Network (http://isee.network).

keywords: *soil landscape visualization, soil parent materials, soil property maps*

Detection of soil microbial dynamics with high spatial and temporal resolution using infrared thermography and radiocarbon imaging

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Soil microbial activity is highly important in the context of soil fertility, soil carbon loss, and soil contamination. However, up to now, high resolution spatial and temporal analysis of the microbial activity in soils has not been possible due to methodological, instrumental, and analytical challenges. Thus, new techniques, such as active and passive infrared thermography in combination with radiocarbon imaging, are used to develop a method to monitor spatial microbial dynamics in undisturbed soil samples. The infrared thermography technique is used because microbial activity produces heat due to respiration.

In this study, three agricultural and one forest soil sample, varying in soil biological properties, have been used. For pre-incubation, the soils were re-wetted to 50% water holding capacity and placed in microplates in an airproof-glove box, with an adjusted relative humidity about 92%, for one week. After pre-incubation, 14C-glucose was applied to the soil samples in droplet form or laminary with a robotic spraying system to increase the microbial activity to a detectable limit. After the glucose application, the spatial microbial activity in the soil samples was monitored, scanning the surface temperature dynamics with an infrared thermography (IRT) camera. The IRT camera was installed above the samples and recorded the surface temperatures of each sample for every minute over a period of one week. Additionally, radiocarbon images of the soil samples were continuously taken during incubation, to detect the spatial 14C-glucose mineralization process as well as to relate the mineralization rates to the spatial microbial dynamics. Since soil moisture dynamics are potentially influencing the surface temperature dynamics, temporal and spatial changes of the soil water content have been continuously monitored with active thermography techniques as well.

In general, all soil samples revealed a significant increase of the surface temperature two days after 14C-glucose application. Furthermore, significant differences in surface temperature dynamics have been detected between the four soil samples. The spatial surface temperature dynamics correspond well with the spatial 14C-mineralization detected by radiocarbon imaging. Thus, the application of glucose to soil samples enhances microbial activity up to a level which is detectable with passive thermography techniques. Water content calibration against active thermography parameter shows that active thermography has a high reliability in predicting soil sample moisture with a high spatial and temporal resolution. The differences in surface temperature dynamics between the soil samples can be partly explained by different soil water contents.

keywords: *infrared thermography, radiocarbon imaging, undisturbed soil, spatio-temporal analysis, active thermography, passive thermography, microbial activity*

Exploring extrapolation risks of spatial prediction models at global, continental and regional scales

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Statistical spatial prediction models are frequently used for spatial interpolation. However, when the calibration data do not completely cover the feature or geographic space then interpolation may turn into extrapolation. This is not without risk, because extrapolation is more difficult than interpolation, and can produce maps that are highly inaccurate for parts of the area of interest. However, the extrapolation risk is often overlooked in the literature. In this paper, we investigated the extrapolation risk of global depth to bedrock mapping using random forest regression. To evaluate the extrapolation risk, we proposed a method called "cross-validation by region", which involves partitioning a sample of data into subsets by regions, calibrating the spatial prediction model using one subset of a region, and validating the model using the other subsets. Then, we examined the relationship between the model performance and the spatial distance (and the feature space similarity). Results show that extrapolation gives less extreme values and is much less accurate than interpolation. The extrapolation risk was reduced when the calibration area was changed from continent to region. Even if a model yielded a high accuracy in interpolation, it did not necessarily give a high accuracy in extrapolation. The overall accuracy of extrapolation for regional models had a negative correlation ($R \leq -0.39$) with spatial distance and a positive correlation ($R \leq 0.26$) with feature space similarity. The extrapolation risk depends on the degree of spatial autocorrelation, the degree of feature space similarity, and numbers of situations that were not covered by the calibration data set occur in the extrapolation area. We emphasize that the risk of extrapolation may be high even if the feature space (i.e. environmental conditions) is covered well by the training data set, indicating that the relationship between the dependent and independent variables do not carry from one region or continent to another. Cross-validation by regions was recommended to evaluate the extrapolation risk.

keywords: *Extrapolation, Interpolation, Spatial prediction model, Mapping, Depth to Bedrock, Machine Learning, Cross Validation*

Proximal soil sensing:new tools for pedometricians

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This presentation will provide a historical perspective of proximal soil sensing (PSS) and describe some of the early to current day proximal soil sensors, as well as current research, and the challenges for PSS into the future. Proximal soil sensing has gained prominence in the soil and environmental sciences over the past 35 years, and specially in the past 15 years, due to advances in sensing technologies, data analytics, modelling and computation capabilities. PSS provides good quality soil information more efficiently compared to traditional laboratory methods of soil analysis, which can be complex, expensive and time consuming.The rationale for PSS is that many less precise spatial measurements that are more easily taken are better and more informative than a few discrete measurements that are very precise. Interest in PSS is now more widespread, currently there is much research and development and a wide range of technologies are commercially available. . By its own merit, PSS is now a new discipline and is a topic of considerable interest in the soil, agricultural and environmental sciences, and engineering. Importantly, PSS can provide precise and quantitative data at fine spatial and/or temporal resolutions, to help Pedometricians better understand the soil as a phenomenon that varies over different scales in space and time. Currently, there is much research on the development of proximal multi-soil sensor systems to simultaneously measure many physico-chemical soil properties in the field, and to develop sensor systems to measure soil biota. Proximal soil sensors produce big data, which can be analyzed using modern statistical, geostatistical and machine-learning methods. As such, there is research also on sensor data analytics, modelling and sensor data fusion. Proximal soil sensing is also enabling sensor-based digital soil mapping at different scales, from field to continental scales. The challenges for PSS are to: (i) continue to develop new integrated sensing systems that combine the sensing technologies with robust data analytics, modelling and easy-to-use user interfaces, (ii) improve the accuracy, robustness and application of existing techniques, (iii)focus on the assimilation of proximal and remote sensing because these technologies are largely complementary,(iv) explore new applications and (v) maintain the enthusiasm and support for the working group on proximal soil sensing (WG-PSS) from soil scientists and pedometricians, which provides a mechanism for continued engagement, collaboration and support for our community . Continued use and development of proximal soil sensing is imperative if we are to improve our understanding of soil processes, and assist soil science in the development of solutions to our current environmental dilemmas.

Spatial variability of peat soil properties for different sampling scales

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The objective of this research was to determine the spatial variability of pH values and soil organic carbon content at different scales using both traditional statistics and geostatistics. The investigation was carried out at Korzinskaja lowland in Southern Karelia (North-West of Russia). The dominant soils at the plots included Agric Podzols, Histic Gleysols, Sapric and Hemic Histosols. The field have been drained in 1963. Actually it is used as a hayfield.

In a detailed scale the plot was a square 100 100 m. A regular sampling grid scheme with the lag 10m was used. For the study in a middle large scale soil samples were collected at 78 locations on a 1 km^2 field. Sampling lag was about 100 m. In a large scale the plot represented the southern and middle part of the lowland with an area of approximately 12 km^2. A locally-regular scheme with randomly-regular arrangement with the lag 250m was used.

Such parameters as the scale of the values, variance and coefficient of variation were almost twice higher in a large scale than in a detailed scale. This is due to the fact that increasing of the surveyed area increases soil diversity. In addition, the large scale investigation includes fields with different land-use practices.

Spatial variability of soil properties was examined by variography. Semi-variograms were approximated by nested models. Spatial coherence was evaluated as medium. Spatial structure of soil properties showed anisotropy in the N-S (along the drain) and E-W (across the drain) directions.

Generally, the E-W direction was regarded as the main direction of spatial variability. We distinguished the following levels of heterogeneity of soil properties. The first level was nugget variation at distances less than 10 m. The second level was a periodical change with a period of 30 m, which might be ascribed to the influence of the drains. The dimensions of the third level of heterogeneity were about 300 m, and the last level of heterogeneity also represented periodical changes with a period of 500-600 m. Periodical component reflected the influence of two different drainage systems.

Variograms in N-S direction regularly increased for the all scales. Thus, the range in this direction exceeded 1000 m. As the drainage system was constructed along a slope, we hypothesized that there was a natural trend along a slope.

The research was supported by the grant of Russian Science Foundation, project No. 17-17-01293.

keywords: *peat soil, spatial variability, sampling scale, anisotropy*

Statistical analyses of landscape controls and vertical variability of soil organic carbon in permafrost-affected soils

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The circumpolar permafrost region occupies around 24 % of the global land area and stores around half the global soil organic carbon (SOC). Yet, very little pedometric research exists on permafrost affected soils and SOC stored in these regions. This is partly due to the remoteness and inaccessibility, but also due to unique thermal and morphological properties of permafrost affected soils. In our research, we document this extreme spatial and vertical variability caused by periglacial landforms such ice-wedge polygons and non-sorted circles. Permafrost affected soils can be seen in the most simple way as a two layer system, including the seasonally unfrozen active layer and the permafrost layer. Yet, due cryoturbation of entire soil horizons caused by freeze and thaw cycles, there is a strong vertical variability and enrichment of SOC at depth. This variability requires standardization for sampling and intensive data harmonization.

We present results from analyzing landscape controls and the vertical variability of SOC and key soil properties from the Arctic Lena River Delta in NE Siberia (Siewert et al., 2016). These key properties are C%, N%, C/N, bulk density, visible ice and water content. We sampled, classified and harmonized a total of 50 soil pedons representing one of the largest and most coherent soil pedon datasets for a remote study area in permafrost regions. The pedon data was subdivided into 1 mm increments down to 100 cm and then aggregated, compared and visualized. We used statistical testing to compare landscape groupings of soil pedons. We compared different vertical subdivisions according to permafrost properties, soil horizons and metrical depth increments. High vertical resolution plots document the high variability with depth and help to understand soil development. This allows clear recommendations for sampling and analyzing these soils with depth. Major geomorphological units of the Lena River Delta control SOC storage and explain more soil variability than soil taxonomy or vegetation cover. The landscape mean SOC storage is estimated to 19.2 $\pm$ 2.0 kg C m^{-2} for the top meter highlighting the large amounts of SOC stored in permafrost regions. We further discuss implications of this variability for digital soil mapping.

Siewert, M.B., Hugelius, G., Heim, B., Faucherre, S., 2016. Landscape controls and vertical variability of soil organic carbon storage in permafrost-affected soils of the Lena River Delta. CATENA 147, 725–741. doi:10.1016/j.catena.2016.07.048

keywords: *Soil organic carbon, permafrost, sampling, Statistical analysis*

Mapping Soil Properties for achieving Soil Functions

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Soils play an important role in ecosystems and provide important services for humans known as "soil functions": i) primary production, ii) carbon sequestration, iii) water provision and purification, iv) habitats for biodiversity and v) nutrient cycling. Under changing conditions, different soils are better in performing some soil functions than others.

There are few studies that have linked soil properties to ecosystem services while most studies lack completely the soil component for evaluating ecosystem services. Most of the mapping and modelling exercise use proxies to infer soil information, often in the form of land use and land cover data to produce spatially distributed biophysical parameter values needed for production function models. Soil property maps however provide quantified spatial information, which could be utilized more versatility for the spatial inference of soil functions and services. This study utilises a large soil survey conducted in Ireland between 2009 and 2014. This survey provided detailed soil descriptions, a range of soil properties down to 1 m depth and identification of diagnostic features for 228 soil profiles. This has allowed detailed analyses relating to several soil functions, which are applied to this soils database. In Ireland, four soil function maps have been derived including; potential soil carbon sequestration map, soil water infiltration and drainage map, soil microbial diversity map and potential N mineralisation map.

1)Soil carbon sequestration map has been derived from detailed soil fractionation studies of 45 grassland sites down to 1 m depth for a range of soil types in Ireland.

2)Soil infiltration and drainage maps are based upon soil water characteristic curves which have been created for 564 profiles (from legacy and recent sources) throughout the country, utilising the RETC programme.

3)Soil microbial diversity maps indicate microbial abundance (microbial biomass) and functional capacity (respiration of multiple substrates) measured at 156 soil profiles across Ireland.

4)Potential N mineralisation was measured at 93 grassland sites across Ireland. The soil samples covered a broad range of soil types and physiochemical properties. They were taken for all surface horizons, which varied in depth, but generally were 0-25 cm depth.

These soil function maps are derived in conjunction with the main soil survey map to allow extrapolation using key diagnostic or modelled with profile soil properties to predict the general capabilities of soils. Soil property maps have been compiled with proper DSM techniques to combine soil-site datasets from legacy and recent sources and expert pedological knowledge.

keywords: *Soil properties, Soil functions, Soil Carbon sequestration map, Soil infiltration map, Soil drainage map, Soil microbial diversity map, Potential N mineralisation map, DSM techniques*

Refinement of soil maps of forested areas with help of geological maps, digital elevation model and remote sensing of vegetation

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Spatial forest databases contain data on tree species and soil types in Hungary. Average unit in the database of Bakonyerdő Ltd. has a size of 3.8 hectare with a range between 0.01 and 36 hectare. However, only 55 % of the units have data on soils and even more interestingly, only 69 % of the units have data on tree species although space images and aerial photographs clearly show dense forest stands in those areas. Further, soil type map for forested areas is more an intelligent guesswork rather than result of thorough investigation. So, soil maps of forested areas in Hungary are incomplete and less reliable thus there is a need for more precise assessments to properly manage forests. Map of surface geology is publicly available in Hungary at 1:100,000 scale and it has much better spatial resolution and accuracy than soil spatial databases. Digital elevation model is available at 10x10 meter ground resolution. Space images and aerial photographs are widely accessible with a few meters ground pixel sizes. Our hypothesis was that we can establish strong relationships between these data and soil types then the relationships can be used to assess a complete, detailed and accurate soil map. First, we developed a stepwise method to semi-automatically delineate homogenous vegetation patches by using space images from four different times of the vegetation cycle between spring to autumn. We have found that early and late stage images in the annual cycle are much more suitable to tell apart canopies of different species, ages and conditions. We have used tree stand data from the company database where only a few species were present to establish signal library for the individual species and we used this core data to assess presence of tree canopies for the remaining area where tree species were not known or many species were present in mixtures or in small patches. Then, we have established relationships between vegetation polygons, elevation, geological units and the individual soil types by using two step classification method. The assessed final soil map was more detailed than the original rough database. The estimated soil map included Rendzic Leptosols, Chromic Cambisols, Haplic Luvisols, Haplic Cambisols, Nudilitic Leptosols and Eutric Arenosols among others. Assessment on vegetation and soil types were tested by visiting 40 test points within an 8 squere kilometre test area and the accuracy was above 80 %.

keywords: *incomplete soil map of forests, space images, soil-tree caniopy relationships, two step clustering*

Analysing spatial patterns of soil pollution profiles in floodplain exposed to historical environmental load using correlation of proportional similarity matrices with spatial matrices

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The Czech Republic belongs to the countries with long-term industrial history, especially along the Czech – Saxony border, where the industrial rapid growth was led by coal processing. High TEs contents may be attributed to a spatial interaction of various pollution sources (long-term airborne pollution due to combustion of fossil fuel and chemical industry, geochemical anomalies of metallogenic zones). High environmental load caused by various sources interference may be reported in the adjacent watersheds of the Ohře River. A regional analysis of soil contamination in floodplain soils (100-year flood inundation areas) was conducted by trace elements (Be, Cd, Co, Cr, Cu, Hg, Pb, Ni, V, Zn) assessment with the objectives of revealing both the spatial patterns of pollution magnitude as well as pollutants' composition. There were compared trace elements contents (2M nitric acid extract) with national background values and geoaccumulation indices were calculated for each sample. Proportional similarities (cosine-theta matrix) between all the samples were calculated after the relative contributions of each element to the overall index had been calculated and transformed (range transformation, constant-row sum normalization). We correlated the proportional similarities matrix (cosine-theta matrix) with various spatial matrices (simple matrix of Euclidean distance derived from spatial coordinates, river network spatial distance) by the Mantel correlation test. There was found statistically significant Mantel correlation between proportional similarity and both spatial matrices. A multivariate Mantel correlogram was then computed to analyse spatial correlation changes of proportional similarities among the samples in relation to distance binding (a normalized Mantel statistic between a similarity matrix among sites and a matrix where pairs of sites belonging to the same distance class receive value 0 and the other pairs, value 1). There was proved that the proportional similarity of pollution profiles of soil samples diminished with the sample distance increase (from the distance of 20 km the Mantel correlation became insignificant and continued to approximate zero). The used methodology seems to be a promising tool to supplement geostatistical analyses of pollution magnitude and may bring a new angle to environmental gradients in riverine landscape because the spatial relations of proportional similarity may reflect various aspects of soil pollution - geochemical variation, pollution sources incidence, soil/environmental conditions changes along the watercourse.

keywords: *spatial analysis of floodplains' pollution, proportional similarity of soil pollution profiles, correlation between similarity and spatial matrices*

Near infrared index to assess soil texture and carbon content effects on soil hydrodynamic properties.

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Characterization of soil hydraulic properties is important for assessing soil water regime in agricultural fields. In the laboratory, measurements of soil hydrodynamic properties are costly and time consuming. Numerous studies recently demonstrated that reflectance spectroscopy can give a rapid estimation of several soil properties including those related with soil water content. The main objective of this study was to evaluate the ability of near-infrared spectroscopy (NIRS) to predict the effects of soil texture and soil organic carbon (SOC) content on soil hydrodynamic properties.

The study was carried out on A-horizon soil samples collected from the Armorican Massif (Brittany). In order to cover the spatial variability of the regional range of soil types, fifteen undisturbed soil blocks were sampled in 2014 from various sites.

Our soilsamples display a wide range of soil textural classes, from sandy loam to clay loam, and of SOC contents, from 8 g/kg to 62 g/kg, conforming with the typical textures and SOC content levels observed within Brittany.From each soil block, four aggregates of at least 3-4 cm width and 5-6 cm height were extracted.

The whole aggregates were set at different moisture contents (10 matric potentials), from saturation up to permanent wilting point (pF$\leq$4.2). Atgiven pressure head, soil samples were scanned in triplicate to acquire reflectance spectra between 400nm and 2500 nm using a handheld spectroradiometer. Reflectance spectra were converted to continuum removal to highlight the absorption features of soil samples. Then, we have focused on absorption band around 1920nm, which is linked to combination vibrations of water. We defined a new index based on the full width at half maximum (FWHM) of this band. Our results showed a linear relationship between this NIR index and volumetric water content (R^2>0.9), whatever soil aggregate. Moreover, it appears from these results that the slope of the line was well correlated with clay content and parent material. Overall, our findings indicate that the parameters of this linear relationship offer a new way to study the hydrodynamic properties of soils in relation to their physical properties (texture, structure, etc.).

keywords: *NIR index, hydrodynamic properties, NIRS, soil texture, soil organic carbon*

Mapping subsoil ripening using Bayesian Generalized Linear Modelling

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One of the first soil forming processes in marine and fluviatile clay soils is ripening, the irreversible change of physical and chemical soil properties, especially consistency, under influence of air. We used Bayesian Binomial Logistic Regression (BBLR) to update the map of subsoil ripening for a reclamation area in the west of The Netherlands. Similar to conventional Binomial Logistic Regression (BLR), in BBLR the binary variable (the soil is ripened or unripened) is modelled by a Bernoulli distribution. The logit transform of the 'probability of success' parameter of the Bernoulli distribution is modelled as a linear combination of the covariates soil type, water ditch level and ground water table depth. To capture all available knowledge, Bayesian statistics combines two information streams, i.e. pre-observation knowledge summarized in a 'prior' probability distribution, and the actual observations. We combined subsets of different size (ranging from 5% to 50% of the original dataset of 676 observation locations) with different priors (based on legacy data) to investigate the effect of sample size and prior distribution of the quality of the map. The posterior parameter distributions, calculated by Markov Chain Monte Carlo simulation, vary in dispersion as well as in central values, especially for the smaller datasets. More informative priors decreased dispersion and pushed posterior central values towards prior central values. Interestingly, the resulting prediction maps were almost similar, probably because of the relative low predictive power of the BLR model. However, the associated prediction uncertainty maps were different: a more informative prior decreased prediction uncertainty. Validation showed that more informative priors resulted in stabilized and slightly better results, as quantified by the measure for separating power Area Under Curve; again this effect is more pronounced for smaller datasets. In our research, Bayesian Binomial Logistic Regression proved to be a flexible mapping tool, that – depending on the strength of the prior - stabilizes estimated parameters as well as prediction maps in case of small datasets.

keywords: *Bayesian Statistics, Informative priors, Clay soil ripening, Generalised Linear Model, Spatial prediction, Spatial prediction uncertainty*

Investigating the effect of moisture for using field-portable X-ray fluorescence spectrometry for 2.5D high-resolution geochemical mapping

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Portable X-ray fluorescence spectrometers have the capability to be used for in-field measurements of the soil's elemental concentration. In soil science they are therefore predominantly utilized to delineate areas of soil contamination, to infer a range of soil constituents but also recently to understand areal soil profile development through 2.5D high-resolution geochemical mapping. However, acquiring pXRF data in the field is affected by various factors including soil moisture and sample heterogeneity. Soil moisture can either attenuate the X-ray signal or cause increased scatter of the X-rays.

In this study, we investigated the effect of soil moisture on pXRF measurements, with the aim to establish a function to correct for the influence of soil moisture. We conducted this study on the farm- and paddock-scale at the Sydney Institute of Agriculture's agricultural research station Nowley, near Gunnedah, NSW, Australia. Differing topography and parent materials have given rise to a variety of soil types across the property, ranging from deep and dark-coloured heavy clays to texture-contrast soils with a sandy topsoil and clayey subsoil. This allowed us to also study the influence of soil texture on pXRF measurements. Soil samples were collected based on stratified random sampling. 120 surface soil samples (farm-scale) and 30 soil core samples of 1 m depth (paddock-scale) were measured with an Olympus Innov-X Delta Premium pXRF under field and laboratory conditions. In the laboratory, measurements were conducted on air-dried samples that were ground to pass a 2 mm sieve. Wetness (%) was determined gravimetrically by measuring the amount of water in the soil after oven-drying at 105°C for 24 h.

We found that variable field soil moisture conditions reduced the elemental signal-to-noise ratio, which resulted in lower concentrations of the target variables in field condition as compared to laboratory conditions. This, however, did not obscure the spatial pattern. The relationship between field-moist and air-dried concentrations of the target variables was highly linear which enabled us to correct for moisture content by establishing an empirical correction function.

keywords: *proximal soil sensing, soil geochemical mapping, portable X-ray fluorescence spectrometry*

Desertification status mapping using recent machine language techniques

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There is a need for up-to-date assessment of desertification/land degradation maps which are dynamic in nature at different scales for comprehensive planning and preparation of action plan. The present paper aims to develop the desertification vulnerability index (DVI) and predict the different desertification processes operating in Anantapur district, Andhra Pradesh, India based on recent machine language techniques. Climate, land use, soil and socioeconomic parameters were used to prepare desertification vulnerability index by multivariate geostatic model. Computed desertification vulnerability index along with climate, terrain and soil properties were used as explanatory variable to predict the desertification processes by using Random Forest Model. About 14.2 % of area was created as a Training dataset in 9 different places for modeling and remaining area was tested for prediction of desertification processes. We used desertification status map of Anantapur district (1: 50 000 scale) prepared by Space application Centre under Desertification status mapping of India – 2cycle (DSM -2cycle) as a reference dataset and calculation of accuracy indices. Kappa and Overall classification accuracy index were calculated for training and validation data sets. We recorded Overall accuracy rate and kappa index of 85.5 % and 75.8 % for training datasets and 71.0 % and 51.8% for testing datasets. The results of predicted map showed that 19.2, 2.12 and 19.77 % of district is affected by soil erosion, salinisation and vegetal degradation processes respectively against 19.6, 6.2 and 22.5 % of area actually mapped for soil erosion, salinisation and vegetal degradation processes respectively under DSM-2cycle project. The prediction for salinisation is low due to less number pixels selected for training data and it could be improved by selecting more pixels and using additional covariates like EC, parent material and drainage in environmental modeling. The results of variable importance analysis of Random Forest model showed that Desertification vulnerability index (DVI) was the most important predictor followed by Evapotranspiration and NDVI (Normalised Difference Vegetation Index) for prediction of desertification processes. The results from the present work give new thought of using the existing knowledge on prediction of the desertification at unvisited areas and also quick update of DSM maps.

keywords: *Desertification, Desertification vulnerability indices, Random Forest model, prediction, variable importance*

Updating digital soil maps with new data: a case study of soil organic matter in Jiangsu, China

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The rapid developments in the acquisition of data on soil should enable pedologists to update existing soil maps readily. The methods by which that is done must take into account temporal change of soil properties and local differences in spatial variation, and the common mapping techniques will have to be modified to make full use of digital data. We show what can be achieved with a case study of updating maps of soil organic matter (SOM) in Jiangsu Province, China, with three sets of soil data collected in the 1980s, 2000 and 2006. Our results showed that temporal changes in SOM between the three sampling periods occurred in only very small parts of the regionareas, although F and t tests based on global statistics indicated significant change. Models of spatial variation of SOM based on the datas collected in the 1980s and 2006 for the whole region differed somewhat, whereas models based on the data collected in the 1980s, 2000 and 2006 for the Taihu region (south Jiangsu) were significantly different. As updating with Bayesian Maximum Entropy continued, prediction accuracy increased and prediction variance decreased. Finally, our study leads us to suggest improved technologies for updating digital soil maps with new data.

keywords: *Updating, Digital soil mapping, Bayesian maximum entropy, Soil organic matter, Temporal change of soil*

Comparative examination of various uncertainty assessment approaches based on geostatistical approaches and machine learning algorithms

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Predictive soil maps are subject to uncertainty since they are simplified representations of more complex (and partially unknown) patterns of soil variations. Therefore, the effective quantification and communication of the inherent uncertainty in digital soil mapping products would be indispensable to stakeholders (e.g. policy makers) as it has already been stressed by GlobalSoilMap.net. Nowadays, various methods (e.g. geostatistical approaches, machine learning algorithms) are used to assess uncertainty. Nevertheless, the adequacy of these quantifications are rarely evaluated in detail. Furthermore, only a few papers deal with the comparison of these methods, as well as their pros and cons. The aim of our present study was to compare the most commonly used uncertainty quantification methods and highlight their pros and cons using independent control data set for their evaluation. Soil organic carbon (SOC) content of the topsoil layer (0-30 cm) was selected as target variable, due to its stressful relevancy in environmental related decision-making and planning. For the area of Hungary we tested the following methods: (1) quantile regression forest, (2) sequential stochastic simulation, (3) prediction error variance of regression kriging (using random forest as trend estimator), and (4) prediction error variance of regression kriging (using multiple linear regression as trend estimator). These methods use probabilistic framework to model and quantify uncertainty, which can be modelled by a probability density function at any location. For each method we mapped the SOC content, as well as its associated uncertainty using the upper and lower limits of the 90% prediction interval, respectively. In addition, we derived and mapped the prediction interval range for each method. Based on an independent control data set we evaluated the adequacy of the quantified uncertainty using classical indicators (e.g. mean error, root mean square error, percentage of explained variance), the percentage of prediction interval coverage, as well as accuracy plots. Furthermore, in the course of the evaluation and comparison, we highlighted the pros and cons of the applied methods. According to the results of the evaluation and comparison process, we ranked the applied uncertainty quantification methods. Our poster will present the results of evaluation and comparison, the rank of the applied methods, their pros and cons, as well as some of our conclusions drawn from the experiences.

keywords: *accuracy assessment, DSM, geostatistics, machine learning, SOC*

Predicting of soil properties with geostatistical and statistical models using a stratified regular sampling grid

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The challenging steps of mapping soil include defining a sample design, finding suitable covariates and selecting a predictive model. The primary objective of this study was to assess the accuracy of soil property predictions (pH, CEC, OM, clay, silt and sand) by assessing geostatistical (Ordinary Kriging (OK) and Regression-kriging (RK)) and statistical (Multiple Linear Regression (MLR) and Random Forest (RF)) models with a stratified sampling grid. The secondary objective was to determine which digital elevation model (5, 10, 30 or 90 m spatial resolution) derived the highest number of morphometric covariates correlating with soil properties. This study was carried out in the Rio Pongal Basin ($\sim$ 14,000 ha) which is located on the southern coast of the State of Espírito Santo in Brazil. Soil was collected from a depth of 15 to 30 cm using a sample scheme which combined 118 samples from a regular hexagonal grid (750 m/side) and 36 samples from a regular grid (<750 m/side). For model assessment, 20% of samples were used validation in an external validation. A total of fourteen maps of terrain attribute were derived from each DEM: elevation, slope, aspect, curvature, profile of curvature, multiresolution ridge top flatness (MRRTF), multiresolution valley bottom flatness (MRVBF), mean slope position (MSP), terrain ruggedness index (TRI), topographic wetness index (TWI), total solar radiation, direct solar radiation, diffuse solar radiation and duration of direct solar radiation. Using the t Test the correlation of terrain covariates and the soil attributes (p-value <0.001) was performed and it was selected the DEM of 5m as it presented the highest number of covariates correlated with the soils. A data mining approach considered correlation and collinearity analyses to select the most important set of predictive covariates among those derived from the digital elevation model (DEM), gamma spectrometry images and satellite imagery of Landsat-8. The data mining was used to select covariates for predicting soil property using RLM and RK, while prediction using RF model employed all covariates. The morphometric covariates were predominant in the group of selected predictors, for all soil properties and it was the only group of predictors for clay. Covariates derived from gamma spectrometry images were selected as predictors for three out of six soil attributes, while covariates generated with spectral data from the satellite image were selected as predictors for all soil attributes. For pH and silt, the selection combined predictors from morphometric, spectral and spectrometric data. The soil spatial variability analysis showed that with exception of pH, which showed no spatial pattern, all other variables showed spatial dependence for semivariogram adjustment. pH presented pure nugget effect, hence, it was only predicted using RLM and RF models. A part of pH, which had no marked difference in prediction using RF and RLM, for all other properties, predictions showed best performance by RF, followed by RK and MLR models. The best model (RF) explained round 20% of the variance of sand and silt, while for CEC, clay and OM, variance explained was 53%, 32% and 30% respectively. With this study, we conclude that using adequate sampling density, the success of predicting soil properties depend on the choosing model.

keywords: *digital soil mapping, regular grid, sampling density, spatial variability, organic matter*

Performance of a Less Expensive Radiometer for Estimating Soil Organic Carbon

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Soil is a very valuable natural resource. As the interface of all Earth spheres it plays a vital role to human survival, being the main source of food and of ultimate importance for atmospheric carbon sequestration. The main objective was to teste the capabilities of a lower cost spectrometer, operating in the 325–1075 nm, in providing valuable data to predict SOC through chemometric techniques. Soil samples were collected at 44 locations in central region of Santa Catarina State, Brazil. Sampling followed Globalsoilmap.net specifications from 0 to 200 cm earning a total of 249 samples (174C/75V). SOC (%) was determined through Walkley–Black wet digestion. For reflectance measurement all air-dried grounded samples were scanned using a FieldSpec HandHeld II spectrometer. For chemometric modeling high noise-to-signal ratio at the edges of spectra were removed (325–400 and 980–1075 nm), thus reflectance values from 400-980 nm were used. A set of nine spectral preprocessing techniques were tested: Smoothing, Binning, Absorbance, Detrend, Continuum Removal, Savitzky-Golay Derivatives, Standard Normal Variate, Multiplicative Scatter Correction, and Normalization. Followed by six spectroscopic modeling Multiple Linear Regression (MLR), Partial Least Squares Regression (PLSR), Support Vector Machines (SVM), Random Forest (RF), Artificial Neural Network (ANN) and Kernel–Based Memory Learning (KBML). All data handling was carried out through a graphical user interface (GUI) called AlradSpectra developed in R programming language available at <https://github.com/AlradSpectra>. The attribute soil texture characterizes those soil samples as being mainly of Clay soil class. SOC varied from 0,02 - 4,83%, reaching those high carbon contends due to constant resupply of new organic material in vegetated areas in the more shallow samples. Predictions of SOC with Binning preprocessing coupled with SVM modeling reached the best results for this study with a $R^2 \leq 0{,}80$ and RMSE$\leq$0,49%. Predictions using PLSR reached from second to fifth best results, with averaged results of $R^2 \leq 0{,}72$ and RMSE$\leq$0,56%. PLSR reached good results nearly independently of the preprocessing technique. Prediction of SOC with ANN and MRL earned the worst results in between all tested models. Those results are very significant, especially if one takes into consideration that the spectrometer ($\sim$16,000 USD) used in this study, is four times less expensive than the more widely used spectrometer ($\sim$64,000 USD) capable of collecting a broader range of the spectrum. In addition, spectral data collected with such less expensive spectrometer can still yield better results through research in different accessories-spectrometer combinations, besides preprocessing and modeling strategies.

keywords: *Diffuse reflectance spectroscopy, Proximal soil sensing, Soil reflectance*

Proximal soil sensing – steps needed to be taken from research to real-world applications

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Proximal soil sensing has great potential to satisfy worldwide demand for soil analytical and advisory services. Advantages include easy sample and sensor handling, low requirements on competence level of sensor operators, low investment and operating costs, and high reproducibility. Nevertheless, in order to migrate from research to real-world applications, the following crucial building blocks are required: i) a database of calibration samples, ii) well standardized wet-chemistry lab practises, iii) selection of stable spectrometers, iv) validated sample handling and scanning procedures, v) derivation of prediction models, and vi) monitoring of spectrometers in network and spectral quality. SoilCares Research developed the so-called "Lab-in-a-box" (LIAB) for soil testing by following these building blocks. The LIAB is based on sensor fusion of mid-infrared (MIR) and X-ray fluorescence (XRF) spectroscopy. The LIAB is used to produce information on soil composition, field and crop specific fertilization, and management recommendations. The fusion prediction models employed by the LIAB are hosted as a cloud service and are updated monthly. Model performances – r2, RMSEP (root mean standard error of prediction), and bias – on an independent validation set at the end of 2016 ($n \leq 467$-1230 depending on the soil property) are as follows: soil organic carbon (0.97, 3.1 g/kg, 0.6 g/kg), pH value (0.90, 0.4 pH units, 0.04 pH units), clay content (0.95, 3.4 g/kg, 0.2 g/kg), Mehlich-3 extractable P (0.78, 39 mg/kg, 8.6 g/kg), and total Sulphur (0.91, 0.11 mg/kg, 0.05 mg/kg). The spatial point density of calibration samples directly influences the RMSEP. With 20% point density, the RMSEP is on average 24% larger (ranging from 11-42%) than 100% point density for the above elements, although 60% or larger point density has little difference to 100%. The RMSEP is also range dependent for many elements. Fertilization recommendation schemes often rely on soil property range classes to produce single recommendations for the range instead of the absolute value. Because of this farmers and advisors find the percentage of correctly predicted samples per class the most important indicator. The LIAB is a scientifically founded, real-world application that provides information to about 15 customers in 10 countries. In this presentation we further expand upon the results obtained so far and the remaining challenges.

keywords: *soil, mid-infrared spectroscopy, xrf-spectroscopy, sensor fusion, fertilization*

Spatial Variations of Soil Organic Carbon Stocks and the Related Environmental Factors in Volcanic Ash Soils in Northern Taiwan

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It has been recognized that volcanic soils can store large amount of soil organic carbon (SOC). The Yangmingshan National Park (YMSNP) is the only one volcanic park in Taiwan which is characterized by complex terrain across the whole area (∼11,000 ha). The objectives of this study were to estimate the SOC stocks to 1 meter depth of YMSNP and to evaluate the impact of some environmental factors on SOC stocks. Soil organic carbon, bulk density and stone content of different depths for 83 pedons and some of their environmental factors were collected from different landscape positions and vegetation types within YMSNP. The semivariograms were characterized and modeled using the GS+ software package. Parameters of the best fitting variogram models were used in the ordinary kriging interpolation to create the distribution maps of SOC stocks by using ArcGIS. Topographic wetness index (TWI), topographic ruggedness index (TRI) and slope were derived from a 20m-DEM. MODIS-based NDVI (normalized difference vegetation index) was used as a proxy of vegetation cover. Representative landform and aspect of each pedon was decided based on former studies in YMSNP. We used a generalized linear mixed model (GLMM) to evaluate the effects of elevation, aspect, slope, TWI, TRI, SOC content and NDVI on SOC stocks by performing the GLIMMIX procedure in SAS software package. The estimates of SOC stocks were 9.29 ± 0.43 kg C m^{-2} for 0-30 cm, 12.68 ± 0.60 kg C m^{-2} for 0-50 cm, and 17.09 ± 0.90 kg C m^{-2} for 0-100 cm, respectively. Spatial distribution of the SOC stocks showed that higher values were occurred in the southern and western part of YMSNP, while soils in the northern and eastern part had relatively lower SOC stocks. The total SOC stock in the upper 1 m of soils in YMSNP is 1.55 Mt (megatons) and the average value is 137 ton C ha^{-1}. Landform, aspect, elevation and SOC content were controlling factors of SOC stocks regardless of the soil depth ($p < 0.05$). NDVI significantly affected SOC stocks in the upper 50 cm of soil pedon as well; on the other hand, slope also exerted a significant influence on SOC stock in deeper soil layers. A former research indicated that the elevation was an effective factor for predicting SOC stocks of YMSNP, and our study further confirmed the influence of other environmental factors in the study area.

keywords: *soil organic carbon stock, volcanic ash soil, spatial distribution, environmental factors*

Estimation of current soil organic carbon stocks and evaluating the carbon sequestration rates under different management practices in arable soils of Taiwan

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Accurate estimates of soil organic carbon (SOC) stocks is of crucial importance to detect the potential for carbon sequestration rate or emission rate under climate change. For Taiwan, spatial distribution map of SOC stocks has not yet been compiled. This study was the first attempt to generate a digital mapping of SOC stocks of whole arable soils in Taiwan by using a detail survey database (n > 110,000) which was conducted by Taiwan Agricultural Research Institute (TARI) between 2000 and 2010. Soil pedons were sampled by auger along a 250 m × 250 m cell-sized grid in the field, in other words, every 6.25 ha of the arable land has a representative soil pedon. The results showed that the average SOC stock in the upper 15 cm of arable soils was 2.86 ± 1.43 kg m^{-2}, 2.57 ± 1.44 kg m^{-2} in the 15-30 cm layer, and 4.56 ± 2.99 kg m^{-2} in the 30-50 cm layer. The total SOC stocks of arable land in Taiwan were 50.0 Tg, 86.7 Tg and 107.0-133.4 Tg in the 0-30, 0-50 and 0-100 cm soil layers, respectively. SOC sequestration rates of applying various practices in cultivated soils were estimated based on two long-term experiment studies in Taiwan. The annual increase rates of SOC was 0.46 ton C ha^{-1} yr^{-1} for organic farming and 0.83 ton C ha^{-1} yr^{-1} for applying compost with commercial inorganic fertilizer in the topsoil. Therefore, 0.74 to 1.33 million tons of carbon per year can be sequestrated by the cultivated soils in Taiwan. The COP21 Climate Summit in Paris recommended the "4 per 1000" program which advocate for increasing the global SOC pool by 0.4% per year. If the SOC stock of all the topsoil (0-30 cm) in Taiwan was estimated as 152.5 million tons, then the annual increase of SOC must be higher than 0.61 million tons (0.21 ton C ha^{-1} yr^{-1}). According to our estimation, SOC sequestration rate of various practices in cultivated topsoil of Taiwan (0.46 to 0.83 ton C ha^{-1} yr^{-1}) is much higher than that of global goal (0.21 ton C ha^{-1} yr^{-1}).

keywords: *soil organic carbon stocks, arable soil, carbon sequestration rate*

High - fidelity mobile proximal soil sensing (350 -2500 nm) system

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Visible and infrared spectroscopy can effectively characterize the upper layer of the soil body and serves as a tool for proximal soil analysis. The spectra encode information on the inherent composition of soil, providing a unique capability to describe several important soil properties both quantitatively and qualitatively in a rapid, precise and inexpensive way.

This paper introduces a high fidelity mobile proximal soil sensing system (MSSS) allowing on-the-go measurements in open field conditions with a commercial full-range Vis–NIR spectroradiometer under standardized measuring conditions. For that purpose a mobile dark chamber with the ability to host any commercial spectroradiometer has been developed with a controlled and an independent illumination source that covers the effective spectral region of the spectroradiometer. The MSSS is towed by a tractor providing some advantages over conventional backpacker and soil penetrator systems such as the fast and high power data acquisition in a near- real time domain. The acquired data base can be then processed on board for the attribute in question and krigging into a thematic map, for the benefit of the end user.

The testing and validation of the measurement protocol have been carried out. To that end the incident light stability and homogeneity, the geometrical positioning of the fiber optic and limitations of the surface properties and dust evolved during the ride, have been studied and aligned in a series of test pilots.

A demonstration of the above MSSS capability has been carried out by modelling several soil properties (e.g. pH and soil organic matter) using a machine learning algorithm (Cubist) with one-leave-out cross validation. For that purpose we used proximal spectral data (60 samples) that were acquired from a test field in Greece, representing the demonstration area. The accuracy of the spectroscopic models ranged from R2 0.68 and RPD from 1.36. After extracting the high performance spectral based model we applied it to the spectral information obtained by the MSSS and generate a thematic maps of the selected soil properties. We encountered that soil roughness and moisture are playing a major role in the implementation of the calibration model and aimed at studding these effects further in the future in order to allow a reliable proximal sensing on-the-go application.

keywords: *soil spectroscopy, mobile soil sensor, soil spectral library, proximal soil sensing, soil monitoring*

Towards a pedogenic approach in quantitative soil sampling and element stocks estimation

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Quantitative soil sampling for element stocks estimation is a time and cost demanding work, while comparability of the results is usually limited. The sampling is typically based either on collection of undisturbed soil samples of known volumes (core method), or on estimating the volume and the mass of soil excavated from a pit (excavation method; ISO 11272:1998). However, there are several limits of these methods that handicap their application in soil science. The separate core method usually underestimates the contents of larger stones (and roots) not included in the samples, while the excavation method requires complicated volume measurements due to cavities and asymmetries in the pit walls or sampling depths, which usually restricts soil sampling to fixed depth intervals. The proposed modified approach takes advantages of the two standardized methods, providing accurate estimation of bulk-densities, as does the core method, while maintaining the accuracy in coarse fragments quantification, as enables the excavation method.

The following variables can be measured for each soil horizon or sampling interval, and used for the estimation of element stocks: (1) element concentration in the fine earth; (2) bulk density of the soil fraction excluding stones (arbitrary classification); (3) the mass proportion of gravel (2 mm) in the stone-less fraction; (4, 5) total volumetric proportion of stones and living roots not included in the element stock; and (6) thickness of the soil horizon or sampling interval. Moreover, this method enables reliable estimation of element stocks even for wavy or irregular soil layers, such as often the diagnostic horizons, so the associated analytical data are also applicable for classification purposes and pedogenic inferences. Moreover, the separation of horizons is a key prerequisite for reliable interpolation of soil data within sampled intervals, thus enabling comparability of the results among studies and datasets that use different sampling depths. The proposed method may provide good performance especially in soils with low or moderate rock fragment contents, and/or with scattered occurrences of boulders, but may fail in very stony soils or soil layers, where the core extraction is not feasible.

keywords: *bulk density, stone content, soil horizons, excavation method, sampling design*

NDVI stratified sampling based on soil homogeneous areas. An application to rice crop in Babahoyo canton-Ecuador

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In index based insurance, it is very important to define a threshold on the index that correlates well with losses in the entire insurance area application. Sometimes, the application area, usually defined by political boundaries, includes heterogeneous zones mainly in soil properties. For this reason, it is necessary to consider these possible differences in the study area, before to establish one global representative index thresholds.

In a previous study (Valverde-Arias et al., 2017), we generated an Agro-ecological Homogeneous Zones (AHZ) map in this region by principal component analysis. This map has defined seven areas with similar soil characteristics on rice crop in Babahoyo canton. We used AHZ as stratification criterion to find out, if we should use one index for the entire study area, or if we need to define more than one index.

From the seven AHZ, we only kept the more representative of them, which were f7 and f15 that reach the 91% of the total rice crop area in this canton. Over the area of f7 and f15, we generated random points that cover at least the 10% of the study area. NDVI_ 16days_Layer (MODIS_MOD13Q1V6) imagery set were downloaded and processed, 2 images for each month during the crop cycle (January to May) during 14 years (2001 to 2014) that included campaigns with low rice yield due to drought. The corresponding Normalized Difference Vegetation Index (NDVI) values were calculated for the sample points in each year, as an index to evaluate the rice crop stage. On this set several statistical analyses were done.

The results distinguish years in four categories according accumulated NDVI (NDVI acc) in low, low medium, upper medium and high corresponding statistically with the yield registered in those years. NDVI acc at f7 (2.32) and at f15 (2.46) areas were statistically different pointing out the importance of soil properties. At the same time, f7 area accumulated more low years (4 years) than f15 (0 years), which shows that f7 area is riskier than f15 for rice crop. The implications of these results will be discussed in the based index insurance context.

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keywords: *Soil, sampling, stratify, NDVI, index-based insurance, rice*

Towards high-resolution modeling of global hydrology and the added value of detailed soil information

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Towards high-resolution modelling of global hydrology and the added value of detailed soil information

Over the past decade global hydrological models been applied increasingly at finer spatial resolutions and under more detailed scenarios to investigate the impact of global environmental change. Increasingly, scenarios do not only focus on anthropogenic climate change but also explore expected trends in water demand and land cover change. This provides more detailed information on future pathways and allows for the identification of potential hotspots of water scarcity. Yet, these detailed scenarios are not balanced by information on soil conditions. Typically, global scale hydrological models continue to rely on the coarse, pedon-scale information FAO Digital Soil Map of the World or use regional datasets such as CONUS. As a consequence, the quality of the information is globally inconsistent and disconnected from the more detailed information on land cover and land use, which is available at the local scale. In a recent development, the information of the FAO Digital Soil Map of the World has been downscaled using local information (e.g., S-World, Stoorvogel et al. 2016). This leads potentially to a more detailed soil parameterization that can be consistently to linked to changes in the land cover conditions.

In order to investigate the sensitivity of a global-scale hydrological model to an improved soil parameterization and to quantify the added value in terms of local information and uncertainty, we apply the global-scale hydrological model PCR-GLOBWB with different parameterizations derived from the S-World product and existing pedotransfer functions (Balland et al., 2008). This allows us to quantify the soil parameterization at different resolutions, ranging from the original FAO pedon-scale to 5 arc minutes, and explore the resulting changes in terms of water availability and demand for different scenarios; to this end, we combine soil conditions with combinations of SSPs and RCPs representing the consensus of future developments of socio-economic developments and climate change over the 21st century. In this way, we are able to quantify the added value of more detailed soil parameterizations in comparison to the expected changes of climate change, land cover change and water demand. On a basin scale, changing soil conditions has a small but appreciable effect on the median discharge that is of the same order as that of land cover change but distinctly lower than that of climate change. However, the influence of changing soil conditions becomes more important when considering low flows, i.e. under drought conditions. This change can be explained by the ability of the soil to accommodate rainfall, leading to a change in the overall runoff volume and the partitioning of net rainfall into fast runoff at the surface or delayed runoff through the groundwater system. This also explains the associated changes in soil moisture storage and water availability to crops which is amplified locally. With this information, we can improve

the representation of soils in global hydrological models and inform policy makers on consistent trends and the underlying uncertainty.

keywords: *Soil parameterization, Global hydrological models, Pedotransfer functions, Scenario modelling, Sensitivity analysis*

Proximal landfill sensing: new research grounds for high-resolution electromagnetic induction surveys

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Landfills are the ultimate example of man-made soil. A bottom-up inventory performed in 2015 revealed that Europe counts between 150 000 and 500 000 landfills. The vast majority of these sites date from before the current stringent regulations on landfill construction and management. Because of lacking environmental protection measures, many are likely to head for costly remediation scenarios. Former landfills typically were created outside the boundaries of urban settlements. However, due to the progressive urbanization in the recent decades, many landfill sites are now being included in urban (re)development projects. The spatial heterogeneity of landfills poses obvious objections to conventional localized sampling, in addition to the risk of damaging possible landfill liners preventing contamination through leaching. Non-invasive data collection via proximal sensing can provide high-resolution images of the landfill subsurface. The first applications of EMI for landfill investigation go back to the early 1990s (De Carlo et al., 2013), yet, most previous studies focus on landfill-related environmental problems as groundwater contamination and methane gas emissions. The recently established concept of enhanced landfill mining (ELFM) provides an incentive to aim attention to landfill characterization in function of sustainable site redevelopment and potential resource recovery (Jones et al., 2013).

This paper presents a compilation of four case studies on the value of high-resolution electromagnetic induction surveying in view of ELFM. The landfills considered differ in size (from 1 to 10 ha), construction setting (waste disposal in wetland areas to backfilling of former quarries) and type of waste (construction and demolition debris to municipal solid waste). Challenges are identified in terms of practical implementation, data processing and interpretation and opportunities are highlighted for the general application of proximal soil sensing in complex urban environments.

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keywords: *Landfill investigation, Multi-receiver electromagnetic induction, Enhanced landfill mining, Urban redevelopment*

Characterizing soil organic matter, soil texture, and soil redistribution patterns in a frequently burned and a rarely burned prairie landscape

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The determination of spatial patterns of soil properties is encountering challenges such as short distance heterogeneity. Although, Statistical modelling of soil characteristics with landscape properties has proved to be a promising tool, our knowledge of soil-landscape relations remains incomplete. One complicating factor is the fact that such relations differ substantially between climate zones, between geological settings and between ecosystems. To increase our knowledge, and to aid statistical modelling of soil characteristics, I have examined the patterns of and relations between soil characteristics, soil redistribution processes (e.g. erosion and deposition), and landscape properties within two watersheds in a Long-Term Ecological Research Site, the Konza Prairie, Kansas.

The Konza Prairie is a semi-natural and frequently burned tall grass prairie, which is subdivided in 65 watersheds with different grazing and burning management. The studied watersheds are similar in geology, topography and hydrology, but fire frequencies vary between yearly and once every 20 years. To characterize and quantify soil characteristics (e.g. soil organic matter and texture) and soil redistribution, composited soil and bulk density samples were taken on the basis of a Conditional Latin Hypercube sampling design. During this field work, a range of soil and landscape properties were as well visually evaluated. Afterwards, the composited soil samples were analysed on water content, root mass fraction, stone fraction, soil organic matter, soil texture, and Plutonium^{-2}39 activity within a laboratory. These lab established characteristics, the field analyses, and auxiliary data were combined in a database and analysed. Statistical analyses included among others ANOVA, linear regression, regression kriging and spatial autocorrelation.

The presented results encompass information on soil organic matter, soil texture, soil redistribution patterns related to topography (e.g. slope and curvature) and hydrology (e.g. Topographic Wetness Index). These illustrate the impact of burning on soil characteristics at a landscape scale. Finally, I will discuss possible drivers causing variation in soil-landscape relations between previous research and the two watersheds.

keywords: *Soil organic matter, SOM, Soil texture, Soil erosion, Soil deposition, Topography, Slope, Fire management, Kansas*

Topography reconstruction in eroding landscapes – a case study from a hummocky ground moraine in NE Germany (CarboZALF-D)

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Erosion processes often change the topography to a point where the original landforms are not recognizable anymore. This forms a problem in soil and landscape evolution modeling, because the evolving topography might change the direction and rates of soil and landscape forming processes. Several studies used the truncation of soil profiles to reconstruct the initial topography, with a constant initial soil thickness as reference. However, the effects of this constant thickness on the quality of the reconstructed topography were not quantified.

We present a set of paleotopographies for the hummocky terrain of ground moraines in north-east Germany. The closed kettle hole catchment of landscape laboratory CarboZALF-D, with more than 260 profile descriptions, enabled us to develop a mass balance of erosion on the slopes and sedimentation in the central depression. Next to that, we used several fixed initial soil thicknesses as reference to estimate erosion. These thicknesses were derived from soil profiles which can be regarded as non-eroded. The amount of erosion or sedimentation was estimated by comparing the reference soil thickness with interpolated current soil and colluvium thicknesses. A special emphasis was put on how to handle censored soil descriptions. The reconstructed topographies were validated using cross-validation and by counting the amount of mispredictions of erosion and sedimentation positions.

The reconstruction with the average reference soil thickness of 1 m gave the best result. This depth was comparable with the average undisturbed soil thickness observed in the surrounding regional Quillow catchment (250 km^2) and is in line with a global trend between decalcification depths and initial CaCO3 content and rainfall. However, the assumption of a constant initial thickness induced errors on locations where the real initial thickness was lower. Also the small scale variations in erosion or sedimentation patterns provided errors in the reconstruction. The large data set from CarboZALF enabled the identification of these small patterns. Random subsets of the data did not result in higher errors, but did increase the variation in estimated eroded and deposited mass. Erosion processes smoothed the slopes and filled the hillslope sinks and the former wetland in the depression, impacting the hydrological system. Recent erosion seems to contribute only for a small part to the total erosion and sedimentation in the area, indicating that past erosion events played a much more dominant role than previously thought.

keywords: *paleotopography, CarboZALF-D, Erosion, Landscape change*

A new era: drone-borne gamma ray surveying to characterize soil

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Soils and sediments can be characterized or "fingerprinted" by their content of naturally occurring radioactive isotopes of potassium, uranium and thorium. These isotopes emit small but measurable amounts of gamma radiation. This radiation can be measured in the lab as well as in the field using a gammaspectrometer. The amount of radiation is a direct measure of the texture of the topsoil (0-30 cm). Gamma radiation mapping therefore is a valuable tool to gain insight in the textural variation of for instance agricultural fields.

The last two decades, the use of gamma-ray systems is slowly becoming a commodity in agricultural mapping. However, present gammaspectrometers are still relatively bulky and need expert knowledge to operate and interpret data. Still many advancements can be made, both in instrumentation hardware and software, as in interpretation of the radiation data. Present systems are mostly used "landborne" or proximal, that is mounted on a vehicle. With the advent of commercially useable drones (UAVs) however, the call for systems that can be used underneath such a small flying frame has been firmly increasing. UAVs provide the possibility to develop relatively low budget and flexible gamma radiation sensing from the air.

Application of gammadetectors underneath drones poses some severe challenges to the sensor hardware. Drones have (very) limited payload and power capacity, imposing serious restrictions on the weight and power consumption of the sensors used. At Medusa we have picked up this challenge by developing a lightweight and low power drone detector system that can be used under commercially available drones. The overall weight of the system has been reduced by more than a factor 2, without compromising data quality. And – maybe more importantly – we have automated and integrated a large part of the processing needed to translate the measurements to useable data into the system itself. The system has an embedded webserver that allows any wifi-enabled device such as a smartphone or tablet to connect and inspect its operational status. It performs on-the-fly full spectral analysis of the radiation data allowing for direct inspection of radionuclide concentrations.

The integration of the system with a commercial drone (DJI S1000+) has been carried out in collaboration with Wageningen Environmental Research (WUR). The paper will present the system and the first results of the tests.

keywords: *Gammaspectrometer, UAV, soil sensing, gamma radiation, full spectrum analysis, airborne surveying*

Comparing UAV airborne and proximal measurements of a gammaspectrometer for soil texture mapping

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A gammaspectrometer is a proven geophysical tool or soil sensor for mapping soil textural properties at high resolution at field level. It measures the concentration of radionuclides in the (top)soil (0-30 cm) which is a proxy for soil texture in areas with similar provenance. However, the use of this technique depends on the accessibility of fields for the vehicles carrying the sensors. Being able to apply soil sensors by using a UAV instead of a quad, tractor, airplane or helicopter increases their applicability. Using an UAV ("drone") is more flexible and better suited to smaller areas than an airplane. And it can fly when crops or natural vegetation are present or when difficult driving conditions prohibit the use of a vehicle. To evaluate the usability of a gammaspectrometer for UAV application we designed a comparison study for the prediction of physical soil properties measured by a gammaspectrometer under an UAV and on a tractor in a 40 ha (8 fields) area in Flevoland, the Netherlands. The study area is situated in a 60 year old polder made on top of Pleistocene sands. The tillage layer and gammaspectrometer depth range of 30 cm has 0 - 20 % clay. Land use is arable land and pasture. The area is measured with a MS2000 gammaspectrometer on a tractor and a MS1000 gammaspectrometer on a DJI S1000+ Spreading wings UAV. For calibration, 15 samples are taken and analysed in the lab on % clay, % silt, grain size, organic matter content and on the concentration of radionuclides. The spectral dataset of the gammaspectrometer on the UAV is corrected for elevation. Both spectral datasets are analysed using full spectrum analysis and translated to soil parameters using regression analysis. An independent set of 44 validation samples was taken and analysed in the lab on the same properties. Sample locations were allocated using stratified random sampling. Using these data we can compare the two gamma-ray measurements on their ability to predict physical soil properties, their footprint and accuracy. The ground borne dataset is used as a reference. The effect of elevation and the difference in spatial and spectral resolution is assessed. A comparative cost analysis is performed, comparing the cost of the methodology (euros) to the acquired detail, the accuracy of the result and the benefit of not disturbing the land. This enables a user to have a well-considered choice of soil mapping methodology.

keywords: *Gammaspectrometer, UAV, Proximal, Soil sensing, Soil texture, Comparison, Validation*

Approaches for commercial Digital Soil Mapping, examples from South Africa

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Digital soil mapping (DSM) has been in the production phase for several years, allowing for several industries to benefit from high quality soil mapping products created with considerable cost savings. Unfortunately, the uptake of commercial DSM in South Africa has been slow, and local industry has not yet harnessed the benefits of the technology. Over the last 13 years local research to make DSM commercially viable have produced three different approaches, each with unique strengths and weaknesses, to fulfil the needs of entities requiring affordable, timeous spatial soil information. In this project, we compare the three approaches, land type disaggregation, expert knowledge and geostatistical methods, to each other on a site with a simple (Cathedral Peak) and a site with a complex soil distribution pattern (Ntabelanga). The Cathedral Peak site is overlain with basalt, has a uniform topography and the soil database comprises 59 soil observations. Ntabelanga is covered with siltstone, sandstone and dolerite, has a varying topography and the soil database is larger with 87 observations. The aim was to map soil classes for each of these sites. At Cathedral Peak, the land type disaggregation approach achieved a Kappa value of 0.66, expert knowledge 0.57 and the best geostatistical method 0.53. It must be noted that the land type disaggregation method produced a map with only three mapping units, compared to the six of the other two approaches. Despite the relatively good results of the geostatistical approach, comparison between the map and the soil surveyor's knowledge of the area showed little resemblance. At Ntabelanga the picture differs. The kappa values were 0.2 (land type disaggregation), and 0.57 each for the expert knowledge and geostatistical approaches. Again, the land type disaggregation method had less map units, but the geostatistical method resembled the soil surveyor's knowledge better than the expert knowledge approach. The results show that the three different approaches are suitable for different scenarios. Although the land type disaggregation does not require field work, it only gives a general idea of soil distribution in landscapes with a simple soil distribution pattern. The expert knowledge approach gives acceptable results, but requires a relatively small dataset. As the dataset size increases, the geostatistical approach outperforms the expert knowledge approach. These three approaches give the soil surveyor the necessary tools to produce soil maps for commercial use, using digital soil mapping.

keywords: *disaggregation, expert knowledge, geostatistics, soil survey, budget*

What is the value of understanding? Comparing mechanistic soil formation and geostatistical modelling.

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There is a need for better understanding the processes influencing soil formation and the resulting distribution of soil properties. Soil properties can exhibit strong spatial variation, even at the small catchment scale. Especially soil carbon pools in semi-arid, mountainous areas are highly uncertain because bulk density and stoniness are very heterogeneous and rarely measured explicitly. In this study, we explore the spatial variability in key soil properties (soil carbon stocks, stoniness, bulk density and soil depth) as a function of processes shaping the critical zone (weathering, erosion, soil water fluxes and vegetation patterns). We also compare the potential of a geostatistical versus a mechanistic soil formation model (MILESD) for predicting these key soil properties.

Soil core samples were collected from 67 locations at 6 depths. Total soil organic carbon stocks were 4.38 kg m^{-2}. Solar radiation proved to be the key variable controlling soil carbon distribution. Stone content was mostly controlled by slope, indicating the importance of erosion. Spatial distribution of bulk density was found to be highly random. Finally, total carbon stocks were predicted using a random forest model whose main covariates were solar radiation and NDVI. The model predicts carbon stocks that are double as high on north versus south-facing slopes. However, validation showed that these covariates only explained 25% of the variation in the dataset. Apparently, present-day landscape and vegetation properties are not sufficient to fully explain variability in the soil carbon stocks in this complex terrain under natural vegetation. This is attributed to a high spatial variability in bulk density and stoniness, key variables controlling carbon stocks. Similar results were obtained with the mechanistic soil formation model MILESD, suggesting that more complex models might be needed to further explore this high spatial variability.

keywords: *soil carbon, stone content, soil depth, soil formation, mechanistic model, random forest*

Soil class mapping in the Quadrilátero Ferrífero, Brazil: a methodological approach of sampling and selection of covariates

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This study aims at evaluating methods of variable selection to predict soil class map from disaggregated soil map unit (SMU). The study was carried out for an pedological diverse area of 1,625.32 km^2, located on the Quadrilátero Ferrífero, Brazil. A legacy soil map, with 75 SMUs, at scale 1:50.000, was taken as reference to extract soil information and to derive simplified maps according to the categorical level of soil unities and similarity among components of soil associations. Three maps were generated with 9, 24, and 34 SMUs. A sampling density of one point per 5 ha was adopted, generating a total of 32.500 random points, over the area for each four SMU maps. A set of 141 maps associated with the soil formation factors (i.e. relief, climate, organisms and parent material) was used as soil covariates. The maps was derived from SRTM image, climatic data of WorldClim, Landsat-8 satellite imagery and data from Gama-ray spectrometry (thorium (Th), uranium (U) and potassium (K), additionally geomorphological, geological and maps of relieve maps were used, as well as spatial location represented by the geographic coordinators. Random forest classifier was applied for variable selection and to predict soil classes using R packages. Four methods of selection were evaluated, two within the Random Forest algorithm, Ginni index and mean decrease accuracy, and additionally the selection based on the percentile and the linear correlation. To assess the prediction‘s accuracy, a wall-to-wall comparison between the reference and the predicted maps was performed and analysed by means of the indexes from the confusion matrix. The kappa index ranged from 0.66 to 0.77. A significant decrease in the number of variables, with lower decrease of accuracy, was observed in all method evaluated. After the data mining, the largest number of variables represented 25% of the total variables. The most accurate soil map was predicted using 13% of the variables, selected by the percentile method, with 34 SMUs. The variability of data source on the set of variables selected strengthens the importance of using variable related to more than one soil formation factor. Geophysical variables of gama ray spectometry were selected with high frequency by different methods, highlighting its, yet not fully explored potential for digital soil mapping.

keywords: *Digital soil mapping, Legacy data, Quadrilátero Ferrífero, Random forest, Soil map unit*

Digital soil classes map of Minas Gerais State, Brazil

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Sampling is a key issue in soil surveys as it has direct influence on the cost and quality of the mapping. Despite the effectiveness of Conditioned Latin hypercube (cLHS) in sampling design for digital soil mapping, the method is sensitive to disproportions in areas of soil classes. This disproportion generates unbalanced samples which hamper soil class mapping for areas with soils of low occurrence. This study proposes the use of cLHS as a sampling method, which balances the cost of sampling based on the size of the area of soil classes. The sampling method proposed was evaluated the State of Minas Gerais, southeast Brazil. The area is pedologically diverse, comprises three biomes, and has soil of all thirteen orders of the Brazilian System of Soil Classification. A legacy soil map of scale 1: 650,000 was used for extracting information of 19 soil classes classified until the second categorical level, additionally, water body, urban and mining areas was included on the classification. The cLHS-balanced sampling was compared to random sampling and to cLHS without balancing. We used five sampling densities: 1.500, 2.000, 5.000, 10.000, and 23.500 samples. Random Forest classifier was used to predict the soils, using as predictors maps of environmental covariates related to the parent material, climate, relive and spatial positon. The cLHS-balanced mapped all soil classes for all sampling density tested, while cLHS left out one class for sampling density of 1.000 and 2.000 samples, on the other hand, using random sampling resulted in the highest number of soil not mapped, ranging from one to five classes missing when using sampling density 5.000. Assessment through the error matrix for individual classes showed that cLHS-balanced presented lower error for most of classes compared to classification with other sampling schemes. Despite no statistical difference in kappa of the whole map, the cLHS-balanced was more efficient in predicting soil classes for the Minas Gerais State as all classes were mapped with lower uncertainty. We conclude that using sampling balanced by area improves the mapping of soil with low occurrence.

keywords: *Random Forest, Sampling, Soil mapping*

Modeling urbanization effect on soil functions in the New Moscow, Russia

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Urbanization is responsible for substantial environmental consequences worldwide. Urban soils are substantially different from those in natural environment. Urban soils provide important functions and services, including fertility, carbon (C) sequestration, filtering and purifying surface run-off, performing as habitat of microorganisms and supporting biodiversity. Urban soils' formation and functioning are directly and indirectly influenced by human, which shall be considered when analyzing and modeling urban soils' features and functions. This study aimed to analyze the urbanization effect urban soils' functions in the New Moscow.

New Moscow is a recently urbanized 1500 km^2 areas, included into the boundaries of the Moscow city in 2012 to decentralize the urban development, mitigate the traffic congestion and environmental pollution. New Moscow project will result in substantial urbanization on lands, primarily covered by croplands and forests. Land-use maps for two time periods in 1980 and 2014 were created based on the available historical data, including topographic maps, satellite images and Open Street Maps. Nine different land-use categories, including urban functional zones were distinguished for each time period and land-use change was analyzed. Land cover dynamic (LCD) model was implemented to analyze the patterns in land-use change (with especial focus on urban functional zones) as a function of environmental and socio-economical factors, neighborhood and land-use history. The investigated land-use change patterns were extrapolated to predict future changes. The resulting map of future urbanization was overlaid with the Master plan of New Moscow urban development and the mismatches were analyzed.

The effect of future urbanization on soil functions was analyzed based on the existing soil map (Shishov and Voitovich, 2002) and soil data collected in New Moscow in 2015. Soils located in different functional zones and having different land-use history (e.g. parks located on prior forested areas or residential blocks, occupying prior fallow lands) were sampled to the depth of 0-150 cm. Chemical, physical and biological properties were analyzed in collected samples. Data on SOC stocks, pH, nutrient contents, contaminants' concentrations and microbiological activity were used to analyze such functions of urban soils as fertility, C sequestration and habitat for microorganisms. Land-use modeling and the analyzed functions of urban soils with different land-use history allowed predicting possible effects of urbanization on soil functions in the New Moscow.

keywords: *digital soil mapping, land dynamics, urban soils, functional zones, carbon stocks, basal respiration, heavy metals*

Estimation of Soil Profile Properties Using Field and Laboratory VNIR Spectroscopy

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Diffuse reflectance spectroscopy (DRS) soil sensors have the potential to provide rapid, high-resolution estimation of multiple soil properties. Although many studies have focused on laboratory-based visible and near-infrared (VNIR) spectroscopy of dried soil samples, previous work has demonstrated that in-situ DRS may be an efficient and viable alternative to laboratory DRS. The objective of this study was to compare estimates of soil properties using VNIR spectra generated in the laboratory with an in-situ profile DRS spectrometer. Soil cores were obtained to approximately 1 m depth from multiple sites in the Midwestern United States, representing a wide range of soil types and agricultural management practices. At the time of core collection, in-situ profile DRS spectrometer scans were obtained at each sampling location. In the laboratory, soil cores were split by horizon, air-dried, sieved (< 2mm), and scanned with the laboratory DRS spectrometer. Laboratory measurement of soil properties including soil organic carbon (SOC), total nitrogen (TN), active C, and texture fractions is underway. Soil properties will be estimated from spectra using partial least squares regression and models will be compared using R2, RMSE, and RPIQ. If in-situ DRS performs well for profile soil property estimation, it may become a cost-effective and practical tool for large-scale soil investigations examining soil health, carbon sequestration, and other important topics related to environmental protection and agronomic sustainability.

keywords: *proximal soil sensing, precision agriculture, soil spectroscopy, soil properties, reflectance spectra, in-situ sensing*

The cost-efficiency of methods for monitoring soil organic carbon stock

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The Australian government has developed and legislated methodologies, based on either direct measurement or modelling, which can be used to recompense landowners for capturing and accumulating additional C in soil.

To qualify for the direct measurement approach, proponents should measure the soil C stocks present within carbon estimation areas (CEA) by performing a baseline survey at the start of the project and then repeatedly over time to accurately quantify the magnitude of the temporal change in C stocks within the CEA. Currently, this method uses stratified random sampling using compact geographic strata of equal area and composite sampling across strata. The composite samples are analysed in a laboratory to measure the soil organic C stock.

Alternatively, proximal soil sensing can also be used for baselining and monitoring soil C stocks. Mobile multi-sensor system can help design sampling strategies and map soil C, and visible–near infrared spectroscopy and gamma-ray attenuation can be used to measure soil organic C and bulk density, respectively.

Our aims here were to (i) quantify the soil organic C stock in two CEAs, one used for cropping and one for grazing, using the method based on compositing and laboratory analysis and a proximal soil sensing approach that uses sensor stratification and sensor measurements of the soil organic C stocks and (iii) compare the two schemes in terms of their precision and cost, *i.e.* their cost-efficiencies.

We found that proximal sensing produced unbiased and more accurate estimates of the mean organic C stock in each CEA compared to those derived with the conventional method. Although compositing was more affordable than the sensing, it was inaccurate and its estimated variance was the most uncertain and unreliable. Significantly for C accounting and demonstration of a minimum detectable difference in organic C stocks over time, the variance of the estimated mean of soil organic C stocks and the uncertainty of the variance of the estimated mean from proximal sensing were considerably smaller than those from the compositing method. In terms of the quality of the estimates and the total cost of the sampling designs, sensing was considerably more cost-efficient. The additional advantage of the sensing approach is of course, that one can also derive continuous maps of soil organic C. Finally, sensing provides a viable and cost-efficient approach for monitoring soil C stocks for accounting and as we have shown here, the financial advantage of compositing does not outweigh its disadvantages.

keywords: *organic carbon, soil sampling, proximal soil sensing, compositing, stratification, visible near infrared*

Utilizing the Legacy Soil Data of Macedonia:The Creation of the Macedonian Soil Information System and its use for digital soil mapping and assessment applications

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Soils in the Former Yugoslav Republic of Macedonia (FYROM) are very diverse because of the diversity of its forming factors including parent material, topography, climatic conditions and the land use. Soil survey in FYROM started in the 1950's. The result of a more than four decades long systematic soil sampling, laboratory analyses and delineation of soil mapping units was a substantial collection of more than 4000 geocoded soil profiles and 140 sheets of the 1:50,000 national soil map. Still in paper form this important legacy soil data was largely unused and under-exploited. The need for digital soil information had emerged for evidence based decision making on sustainable agriculture, soil and environment protection, natural resource management and the adaptation to climate change. To provide with the required soil information to a variety of end-users, the Macedonian Soil Information System (MASIS) was developed with the technical and financial support of the FAO.

This contribution presents the complex process to rescue soil legacy data and convert it into digital soil property maps and derived applications using the digital soil mapping methods (DSM). In the first step the soil profile data were verified, harmonized, improved and digitized. The separate soil maps were checked, semantically improved and vectorised. The soil mapping units were edge-matched and merged to create a seamless polygon-based digital soil map of Macedonia in a scale 1:50,000. In the second step, DSM techniques were utilized to create datasets of key soil properties (soil depth, topsoil OM content, silt, sand, clay, and pH). A scorpan-krigin approach was followed and the covariates were derived from digital elevation model and a mosaic of remote sensing images (Landsat 7). Applicability of the soil property maps was demonstrated through a soil suitability assessment, thus completing MASIS data structure. The web-GIS portal (www.maksoil.ukim.mk) was developed to give open access to the improved MASIS soil legacy data as well to the new DSM-based soil information to a wide range of end-users.

keywords: *legacy soil data, soil information system, modelling, digital soil mapping*

Mapping soil properties using a non-stationary variance geostatistical model

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Geostatistical mapping of soil properties is decisive for agricultural activities and land use planning. In particular, soil clay content is critical for plant production since it controls soil hydraulic properties and may hinder irrigation. Spatial prediction of soil clay from measured location is therefore highly relevant for farmers. Commonly used spatial prediction methods such as kriging assume intrinsic stationarity of the residual variance. This assumption is implausible for mapping soil clay in a mountainous watershed because the mean and variance are linked to topographic attributes. Over the past years, substantial progress has been made to deal with non-stationary spatial processes in kriging. Various well-documented geostatistical models relax the assumption of stationarity in the mean, while recent studies show the importance of considering non-stationarity in the variance for environmental processes occurring in complex landscapes. In this study, we propose an extension of the Kriging with External Drift (KED) model for prediction of soil clay content. The model incorporates both non-stationarity in the mean and in the variance, which are modelled as linear functions of external covariates such as slope, elevation and geology. Covariates are selected based on Akaike's information criterion whereas model parameters are estimated with Restricted Maximum Likelihood (REML). The proposed approach is compared with the stationary variance model based on the log-likelihood, standardised squared prediction error and accuracy plots of the two fitted models. The methodology was tested using a case study predicting clay content in a small watershed in the centre of China. Results show that the proposed non-stationary variance model outperforms the stationary variance model for all criteria and that the stationary variance model lead to unrealistic prediction error variances of clay content in the watershed.

keywords: *Geostatistics, Soil clay, Kriging, Non-Stationary Variance, Soil Mapping*

Modelling the mid-infrared information content of European soils

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Assessing soil properties using visible and near infrared (Vis-NIR) spectroscopy have emerged as a powerful tool in digital soil mapping. In particular for the Mid-Infrared (MIR) region (400-4000 cm^{-1}), common calibration methods coupled with laboratory analyses predict soil properties with high accuracy. The reason is that the fundamental molecular vibration occurs in the MIR when only the overtones and combinations occur in the Vis-NIR. Hence, the bending or stretching vibration at a precise wavelength allow qualitative diagnostic on the soil components without any coupled chemical analysis. Recent studies show the importance of the soil information summarised into a few wavelengths of the spectrum. However, very little is known on how to the use such information for soil monitoring. In this study, we propose a pragmatic approach to assess the relationships between soil attributes and environmental covariates by using MIR spectroscopy. The method consists in fitting each band of the MIR region as a linear model with spatially correlated errors. Model parameters are estimated by robust (Restricted) Maximum Likelihood whereas the quality of the predictions is assessed using Leave Group Out Cross Validation (LGOCV). This method does not require any prior explicit knowledge of the soil attribute values.

Our method is tested using the GEMAS dataset based on 4000 MIR spectra from soil samples spanning 33 countries of the European continent. The multivariate relationship between spectra and covariates is qualitatively interpreted based on spectrograms derived from robust linear models. The results show that soil mineralogy bands and particularly clay minerals are strongly linked to the climatic conditions as well as to the slope. In contrast, soil organic matter bands are difficult to interpret, showing reasonable correlation with temperature and precipitation only for the amide and humic acid groups. In this work, we show how our method may be used to make pedological interpretations and describe soil spatial distribution without prior knowledge on the soil property spatial variation.

keywords: *Soil Spectroscopy, Mid-Infrared Spectra, Robust Linear Model, GEMAS dataset*

Prediction of Soil Organic Matter Using VisNIR and PXRF Spectroscopy

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Soil organic matter (SOM) plays an important role in many chemical and physical processes in soils. However, measuring SOM via traditional chemical methods is typically time consuming and expensive. In this study, we combined portable x-ray fluorescence (PXRF) and visible and near-infrared (VisNIR) diffuse reflectance spectrometry to predict SOM. Partial least square regression (PLSR) and random forest (RF) were used to calibrate prediction models for VisNIR spectra only, PXRF measured elements only, and both VisNIR spectra and PXRF elements (VisNIR + PXRF). The general order of predictions can be summarized as VisNIR + PXRF > VisNIR > PXRF regardless of PLSR or RF. In conclusion, the combination of PXRF and VisNIR was shown to be a viable method for SOM prediction.

keywords: *soil organic matter, visible and near-infrared, portable x-ray fluorescence*

Potential of LUCAS for the development of regional-scale spectral models for the prediction of soil properties

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Imaging spectroscopy is a powerful, non-destructive and inexpensive tool to predict key soil properties in local areas provided that ground truth soil data are available for model calibration. The availability of hyperspectral satellite imagery in the near future has a great potential to improve the methods for predicting key soil properties which is essential to achieve advances in global soil mapping and monitoring. Nevertheless, when changing from local to regional or even broader scales, spectral modelling is challenged by a higher variability of soil characteristics and the models are dependent on related soil databases. This study aims at investigating the potential of large soil spectral databases such as the EU-wide LUCAS (Land Use/Cover Area frame Statistical Survey) database concerning the development of regional soil spectral models for an improved derivation of more precise and up-to-date spatial information of soil properties. Such methods will provide new options for a more sustainable soil usage and for monitoring and preventing soil degradation.

We are focusing on the link between geo-chemical soil properties and spectral variabilities within the soil database LUCAS. LUCAS constitutes to date the most complete and consistent soil spectral library at continental scale, with 20,000 top-soil samples collected following the same sampling protocol. It includes thirteen chemical and physical properties, including Vis-NIR reflectance, which were analysed following standard procedures. Our intention is to group the large number of samples within the database into smaller, more homogeneous clusters to improve overall prediction accuracies at larger scales. We focus on agricultural areas because they can be mapped by remote sensing when they are temporarily free of vegetation. Different clustering approaches (e.g. a random sampling machine-learning approach) based on spectrally pre-processed data, are tested to find the best method. Afterwards, multivariate modelling approaches (e.g. PLSR) are used for each cluster to predict soil organic carbon (SOC) and other soil properties based on the spectral information. Preliminary results show that clustering can improve the prediction results in comparison to non-clustered LUCAS data.

A further goal is to validate this approach with new spectra and transfer it to hyperspectral images from test sites which will be assigned to the clusters. This includes the application of the established models to simulated EnMAP image data. This contribution will focus on presenting the results achieved so far in terms of LUCAS database clustering and development of cluster-specific soil spectroscopic models to derive SOC and other parameters.

keywords: *hyperspectral database, LUCAS soil spectral library, Vis-NIR reflectance spectroscopy, soil organic carbon, multivariate modelling, clustering, EnMAP*

Time sequence division of high standard farmland construction based on cultivated land quality uniformity in administrative village and obstacle factors

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As an important constitute of the land consolidation, high standard farmland construction is the important means to protect the quantity , quality and ecological environment of cultivated land.Through this paper we tried to explore the method of cultivated land evaluation and construction zoning to facilitate the process of decision and implementation for high standard farmland construction. Taking land comprehensive improvement project area in Quzhou county as a case study, the whole process of the study was composed of three steps: 1) establishing the evaluation model of cultivated land quality uniformity based on regional optimum cultivated land quality and constructing the uniformity evaluation index system of cultivated land quality which was constructed from the aspects of soil quality, engineering quality, space quality, ecological environment quality and aesthetic quality that based on the new concept of cultivated land quality; 2 calculating the cultivated land quality uniformity through grading indicators, assigning score and weighting sum; 3) according to the principle of priority to the easy in order to carry out high standard farmland construction timing partition through analyzing regional cultivated land quality difference and obstacle factor index restriction.The results show that the evaluation model and index system can satisfy the evaluation of the farmland quality and the diagnosis of obstacle factors to facilitate the subsequent construction decision; The value of farmland quality uniformity is different between various administrative villages. Through the natural breaks method, the project area is divided into three sections of quality uniformity level of cultivated land, including the high-level area,the middle-level area and the poor level area, and the quality of cultivated land plots are from high to low. The project area is divided into four time sequence partitions including the major construction area, the secondary construction area, the general construction area and the conditional construction area , and the construction difficulty of these four areas is from easy to difficult; The most restrictive factors in the project area are medium and low transformation difficulty indicators,including soil organic matter content, forest density, field regularity and scale of field, and there are high difficulty indicators in some areas, such as sectional configuration. The study can be a reference for the practice of high standard farmland construction, and provide new ideas and methods for related research.

keywords: *high standard farmland, cultivated land quality uniformity, obstacle factor, time sequence division*

Is a national Vis-NIR library useful for filed scale predictions of soil type?

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Although cost-efficient, large-scale Vis-NIR calibration models have often proven to lack in precision at the farm or field scale. And often the large models are not validated on this local scale. Small local calibrations, on the other hand, have previously been shown to be successful, but then quite a large number of samples need to be analyzed the traditional way and much of the advantage with spectroscopy is lost. So called spiking, amending a large scale library with a few local samples, and memory based learning (MBL) techniques, has been suggested to improve precision and reduce errors. Here we compare these methods with plain large scale PLS calibrations as well as small local PLS calibrations. We used 11425 topsoil samples distributed over Swedish agricultural soils for calibrations and 11 farms between 42 and 165 ha for field scale validation. The Swedish library was divided into a 7619 sample calibration set and a 3806 sample validation set was used for validation at the national scale. The validation samples were never involved in any calibration. Soil from 4 of the farms were analyzed with the same Vis-NIR range instrument as the Swedish library. The 7 other farms were analyzed with an instrument operating in the NIR-range only. For predictions of these farms, Swedish library spectra were transformed for a better match. Spiking and local calibrations were performed with 10, 20 and 40 samples. Field scale validation samples were always the same, independent of calibration set. Results showed that local calibrations with 40 samples were the best for most farms, but spiking with 10 or 20 samples was almost as good or better than local calibrations of the same size. These findings were more pronounced for farms analyzed with the Vis-NIR instrument. General MBL and especially plain large scale PLS calibrations performed substantially worse with some farms suffering from large bias. We concluded that general calibrations from large libraries are not reliable at the farm scale and that local calibrations of sufficient size perform best in most cases. But to gain from the advantages with the simplicity of Vis-NIR spectroscopy spiking with 10-20 samples is an interesting alternative that make use of the stability from the large library and the special features of the local soil type. Spiking also seemed to overcome some of the issues still remaining after the transformation of the national Vis-NIR spectra to match the NIR instrument.

keywords: *Near infrared spectroscopy, Spectral library, Memory based learning techniques, Spiking, Field scale, Clay content, Soil organic matter*

Hydro-geomorphic Spatial Modelling for Multi-scale Coastal Acid Sulfate Soil Mapping

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Coastal acid sulfate soils (ASS) occurrences in tropical region are largely controlled by the seasonal energy of marine and upper catchment. However, the ASS occurrence prediction and mapping using soil-landscape modelling that consider the multi-temporal and multi-scale hydrology and geomorphology spatial data variables that represent that seasonal energy has been limited. As a matter of fact, inadequate number of variables calculated in this model will under- or over-estimate the ASS occurrences and their properties. This paper aims to develop a hydro-geomorphic spatial model for predicting the presence and absence of ASS and their properties, and to classify the mapping variables that needed in different scale of ASS mapping.

The multi-temporal and multi-resolution remotely sensed data (SRTM 1 Arc-second Global, Landsat 8, QuickBird/Ikonos satellite imageries) and geographic information system (GIS) approaches were utilized to spatialize the variables that control the ASS formation. Multi-level data aggregation approach was applied to combine the spatial data of the sources of iron, organic matter, sulfate, the energy level of estuary and coastal environment, the information of regional climate, sea level rise, and alternately fresh and brackish water dominance and waterlogged environments during rainy and dry seasons. Field survey included the soil sampling for field and laboratory analysis, water salinity and elevation measurement, and ebb and tide observation. The result shows that for the regional scale, the hydrology and geomorphology data of the catchment level become the main variable that control the ASS occurrences, reaching 85% accuracy test, using matrix correlations. On the local scale, the seasonal energies during the dry and rainy seasons predominantly influence the properties of the ASS.

keywords: *acid sulfate soil, hydrogeomorphic spatial modelling, multi-temporal, multi-scale, remote sensing and GIS*

A VNIR penetrometer for soil profile sensing

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Visible and near-infrared (VNIR) reflectance spectroscopy has been proven as an effective method in estimating important soil properties such as textures, organic and inorganic carbons, and moisture. Due to its ability to derive multiple soil properties from a single scan and its rapid, nondestructive, and low-cost nature, researchers have made efforts to develop proximal sensors using this technology to enable horizontal soil sensing. Similarly, this technology can be used to design and develop vertical soil sensors which can aid in precision agricultural and environmental focused decisions. The objective of this research is to design and develop a penetrometer system to enable the acquisition of soil spectra and penetration resistance along the depth. To achieve this objective, a penetrometer with an optical module was designed and developed to obtain reflectance spectra along the soil profile. A load cell and a distance sensor were integrated with the penetrometer to measure the penetration resistance and insertion depth. The developed system was attached to a Giddings probe and tested for its field functionality in several fields located in Lincoln, NE, USA. All the sensor readings were logged in real-time using a LabVIEW program. Field test of the system demonstrated its ability to read and log soil spectra, penetration resistance with depth in real-time and the acquired data were used to predict various soil properties along the soil profile. Results will discuss the contribution of penetration resistance to analysis of soil properties.

keywords: *Visible and near infrared reflectance spectroscopy, soil penetrometer, vertical soil sensing, soil carbon, soil textures, penetration resistance, soil moisture*

The Rapid Carbon Assessement Project: a modern soil carbon stock baseline for the conterminous United States

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The Rapid Carbon Assessment Project (RaCA) was undertaken to quantify the soil organic carbon (SOC) stocks across the conterminous US at one point in time. Sample locations were chosen using a multi-stage stratified-random sampling frame and cover all areas in CONUS with SSURGO certified maps as of Dec 2010. Sampling was stratified into 17 regions for logistical reasons. Within each region, soils groups and land use/cover classes were used to further stratify sampling. Each region had 375 – 400 sites, for a total of approximately 6,400 sites. At each site, basic information about land use, vegetation and management were collected as appropriate and available. Samples were collected from 5 pedons (a central and 4 satellites) per site to a depth of 1m, at 0 – 5cm and by genetic horizon. A volumetric sample was collected for horizons above 50 cm to determine bulk density. For horizons below 50cm (or when a volumetric sample could not be obtained) bulk density was modeled from morphological information. All samples were air dried and crushed to <2mm. The central pedon was analyzed for total and organic carbon at the Kellogg Soil Science Laboratory in Lincoln, NE. A visible near-infrared (VNIR) spectrophotometer was used to predict organic and inorganic carbon contents for all satellites samples. A Hierarchical Bayesian statistical approach was used to estimate C stocks, concentrations, and uncertainty for each sampling level (i.e., CONUS, region, soil group, land use/cover and site). Carbon stocks were summarized by fixed depth increments for sites, soil groups, and land use/groups and mapped by linking the values to a raster of SSURGO (Jan 2012) that includes map unit and land use/cover classification. The CONUS SOC stock to 1m of soil depth was estimated at 84.6 Pg +/- 3 Pg .

The mean area weighted SOC stock to 1m of soil depth for CONUS was 110.4 Mg C ha^{-1} with a 95% creditable interval ranging from 106.8 to 114.3 Mg C ha^{-1}. Soil groups explained the greatest portion (45.5%) of CONUS SOC stock variance (1m) followed by the inter-site level (32%), the regional scale (12.8%), and land use/cover explained the least (9.7%). Due to large variability land use/cover classes are not statistically different, but wetlands have the largest SOC stocks and account for 30% of the CONUS total. This SOC stock baseline data set will be useful for modeling, monitoring and tracking SOC changes for many disciplines.

keywords: *soil organic carbon, soil sampling design, continental scale*

Predicting the soil adsorption behavior of two model Persistent Organic Pollutants (POPs) to the soil solid phase based on spectral data and multivariate statistical analysis

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Persistent organic pollutants (POPs) are known to have adverse effects on human health and the environment. Thus, an effective risk assessment with concern on POP behavior in the soil compartment is of high interest. Therefore, the objective of our study was to develop a reliable, rapid, and low-cost method, which can predict the adsorption and desorption behavior of two model POPs, 4-n-nonylphenol (NP) and perfluorooctanoic acid (PFOA), in soils. NP and PFOA were selected as model pollutants since they are highly resistant against microbial degradation. As consequence, their environmental fate will be mainly controlled by adsorption and desorption processes in soils. As FTIR spectra reflect the total soil composition, we used FTIR spectroscopy in combination with supervised statistical classification procedures to develop a prediction tool for the fate of NP and PFOA.

For the model development 72 soil samples were analyzed for particle size distribution, manganese and iron oxide concentration, and organic carbon content to characterize the chemical soil composition. FTIR spectra of all soil samples were measured in the mid-infrared region. The ad- and desorption of the model POPs to the soil samples were analyzed in batch experiments.

Generally, the adsorption of NP and PFOA was linear in all soil samples. However, significant differences between the KD-values of PFOA (KD $\leq$ 2 to 40 ml g^{-1}) and NP (KD $\leq$ 25 to 1000ml g^{-1}) were observed. Via multiple regression analysis we demonstrated that the PFOA adsorption is mainly controlled by the soil organic carbon as well as by the iron oxide content. The adsorption of NP was controlled by the soil organic carbon content only.

Since different adsorption mechanisms of NP and PFOA have been observed we decided to develop different prediction models for both pollutants. Because FTIR spectra are reflecting all soil components in different spectral intervals, initially, the spectral intervals representing organic carbon and iron oxides were statistically identified for further model developments. The relevant spectral intervals were used to create prediction models based on the random forest algorithm, whereas different intervals were used for NP and PFOA due to their different adsorption mechanism. The prediction of NP and PFOA adsorption reveal model error rates of 3 and 7%, respectively. Likely, the higher error rate of the PFOA model could be explained by coated iron oxides in the batch experiments masking the oxide adsorption potential.

keywords: *sorption, FTIR spectra, random forest algorithm, 4-n-nonylphenol, perfluorooctanoic acid, persistent organic pollutants, multivariate statistics*

Fine-resolution mapping of soil carbon stock in Japanese forest based on machine-learning regression kriging

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Spatial information of soil organic carbon (SOC) is important in global carbon cycle and climate change research. The information is still limited at fine spatial-scale in Japanese forest that is mainly distributed in mountainous regions with complex topography. Digital Soil Mapping (DSM) approach may contribute to the spatial prediction of SOC stock in the regions at both fine (local) and regional spatial-scale using the dataset of National Forest Soil Carbon Inventory (NFSCI), various terrain attributes and other environmental factors. Our objective is to evaluate DSM approach for predicting SOC stocks in 0-30 cm depth in the whole area of Japanese forest (ca. 250,000 km^2), with grid-resolution of 50 × 50 m. We compared the accuracy of 5 methods; random forest (RF), support vector machine (SVM), ordinarily kriging (OK), and their combinations known as machine-learning regression kriging (RFRK and SVMRK).

The training dataset of SOC was obtained from NFSCI that is conducted in FY 2006–2010. The survey plots were installed in some of 4 × 4 km grid points over the forest sector of Japan (N ≤ 2462). As for explanatory variables, we estimated environmental factors from traditional map (e.g. soil, geology, vegetation, and tephra) and climatic database, and various terrain attributes from high resolution DEM. We determined optimal parameters of SVM and RF by a grid search method. As for spatial parameters of RFRK, SVMRK and OK, a distinct two spatial-structures with the ranges of ca. 10 km and 60 km were observed in the experimental semi-variograms and well fitted to the spherical models. Finally, the accuracy of the maps was evaluated by RMSE and correlation coefficient using the cross-validation approach. We also tested the sensitivity of the accuracy to the number of the training data for each method.

As a result, this study confirmed the high accuracy and reproducibility of the SOC map by SVMRK in comparison with the map by OK. Particularly the accuracy of SVMRK and RFRK (machine-learning regression kriging) was less sensitive to a decrease in the number of training data points whereas the accuracy of OK reduced with a decrease in the number of the data points. These results suggested that SVMRK performed better and is more flexible to the number of the sampling plots than traditional kriging for fine-resolution mapping of SOC stock in Japanese forest. Additionally, we highlighted the contribution of the explanatory variables to the spatial variation in SOC stock.

keywords: *Soil organic carbon, Regression Kriging, Machine-learning, National-scale soil mapping, Japanese forest, Mountainous region*

A MGWRK technique for mapping soil electrical conductivity in the Heihe River Basin, northwest China

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Spatial information of soil electrical conductivity (EC), which is a good proxy for soil salinity, has attracted increasing attention in arid-semiarid region as it largely determines plant growth. The relationships between EC and environmental variables are usually used to map its spatial variation. However, digital soil mapping EC in large and complex environmental settings remains challenging due to its spatial non-stationarity and spatial dependence. For the spatial non-stationarity, the relationships between soil properties and environmental covariates may be invariant or varying over spaces. For the spatial dependency, soil property observations and their environmental covariates are not independent each other. The current regression models have been constructed either to address the former issue or to solve the latter one. Yet, few researches paid attention to explore the spatial dependence of environmental covariates and to investigate the fixed or varying relationships between soil properties and environmental covariates.

As the second largest inland river basin in northwest China, the Heihe River Basin ranges from 900 m a.s.l. to 5,500 m a.s.l by altitude. The upstream, midstream and downstream correspond to alpine, oasis and desert environments respectively. The ECs in these contrasting settings are highly heterogeneous and the relationships between EC and environmental variables are spatially non-stationary.

In this study, a mixed geographically weighted regression kriging (MGWRK) is introduced to examine the correlations between environmental covariates and EC to better estimate the spatial distribution of EC in the Heihe River Basin. Results from OK, MLR, RK, GWR, GWRK and mixed geographically weighted regression were used for comparison with those from MGWRK. The key environmental variables were refined from spatial information on topography, climate, vegetation, land use/cover, soil parent material, and soil type. Two hundred and forty-four georeferenced top soil samples were divided into two subsets, i.e. the calibration dataset (80%) and the validation dataset (20%). MAE and RMSE were used for evaluating the performances of the aforementioned approaches. EC ranged from 31 to 182100 $s \cdot cm^{-1}$ for the all soil observations. The mean value is 3335.1 $s \cdot cm^{-1}$ and the coefficient of variation is 44.8%. Geostatistical analysis showed that the isotropic variogram model was best fitted by Gaussian model, and the C0/(C0 + C) ratios of fitted variogram model fell between 0 and 25%, which means that EC exhibited extensive spatial autocorrelation. These preliminary results suggest that MGWRK has the potential to address the spatial dependency and spatial non-stationarity issues for EC.

keywords: *soil salinity, MGWRK model, Heihe River Basin*

Accounting for fieldwork costs in validation of soil maps: a comparison of design-based sampling strategies

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The quality of soil maps can best be estimated by collecting additional data at locations selected by probability sampling. These data can be used in design-based estimation of map quality measures such as the spatial mean of the squared prediction errors (MSE). In areas with large differences in fieldwork costs related to differences in accessibility it can be attractive to account for these differences in selecting validation locations. Sampling at lower densities in remote areas may increase the sampling efficiency. We compared two types of sampling design that take fieldwork costs into account: sampling with probabilities proportional to size (pps) and stratified simple random sampling (STSI). In pps the inverse of the square root of the point-specific costs was used as a size variable. Two estimators were applied, the Hansen-Hurwitz and Hajek estimator. In STSI optimal strata were constructed for optimal allocation of the total sample size to the strata. Simple random sampling (SI) was taken as a reference design. The sampling strategies were compared on the basis of: 1) the variance of the estimated MSE; 2) the variance of the total costs. The comparison was done at equal expected total costs. The sampling strategies were compared in a simulation study and a real-world case study in Anhui, China. In the simulation study the point-specific costs are simulated by drawing from an exponential distribution with rate parameter 0.1. The simulated costs were multiplied by a constant (1, 5 and 10) to obtain cost distributions with different variances, and a constant was added (5, 10 and 50) representing fixed sampling costs. In the case study car traveling costs, hiking costs and costs spend on the spot were considered in computing total sampling costs per point. Hiking and travel costs were based on the topographic condition, surface friction and road data. The simulation results show that pps(Hajek) and STSI were equally precise. The gain in precision compared to SI depends on the frequency distribution of the point-specific costs. The larger the variance of the costs, the larger the gain. Also, the larger the fixed cost constants, the smaller the gain in precision. The variance of total sampling costs was the smallest for STSI, showing that control of total sampling costs with STSI was the best. In Anhui the gain in precision of pps(Hajek) and STSI was about 30% accounting for hiking costs only, and about 5% accounting for all three cost components.

keywords: *validation, probability sampling, accessibility, sampling with probabilities-proportional-to-size, stratified random sampling*

Identifying soil landscape units at the district scale by numerically clustering remote and proximal sensed data

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Identifying soil landscape units at a district scale is important as it allows for sustainable land-use management. However, given the large number of soil properties that need to be understood and mapped, cost-effective methods are required. In this study, we used a digital soil mapping (DSM) approach where remote and proximal sensed ancillary data collected across a farming district near Bourke, were numerical clustered (fuzzy k-means: FKM) to identify soil landscape units. The remote data was obtained from an air-borne gamma-ray spectrometer survey (i.e. potassium-K, uranium-U, thorium-Th and total counts-TC). Proximal sensed data was collected using an EM38 in the horizontal (EM38h) and vertical (EM38v) mode of operation. The FKM analysis (using Mahalanobis metric) of the kriged ancillary (i.e. common 100 m grid) data revealed a fuzziness exponent (phi) of 1.4 was suitable for further analysis and that $k \leq 4$ classes was smallest for the fuzziness performance index (FPI) and normalised classification entropy (NCE). Using laboratory measured physical (i.e. clay) and chemical (i.e. CEC, ECe and pH) properties we found $k \leq 4$ was minimized in terms of mean squared prediction error (i.e. sigma2p,C) when considering topsoil (0–0.3 m) clay (159.76), CEC (21.943), ECe (13.56) and pH (0.2296) and subsoil (0.9–1.2 m) clay (80.81), CEC (31.251) and ECe (16.66). These sigma2p,C were smaller than those calculated using the mapped soil landscape units identified using a traditional approach. Nevertheless, class 4A represents the Aeolian soil landscape (i.e. Nb4), while 4D, represents deep grey (CC19) self-mulching clays, and 4B and 4C yellow-grey (II1) self-mulching clays adjacent to the river and clay alluvial plain, respectively. The differences in clay and CEC reveal why 4B, 4C and 4D have been extensively developed for irrigated cotton production and also why the slightly less reactive 4B might be a source of deep drainage; evidenced by smaller topsoil (2.13 dS/m) and subsoil (3.76 dS/m) ECe. The research has implications for providing meaningful DSM of soil landscape units for farmers at districts scales where traditional methods were restrictive in terms of time and cost.

keywords: *EM induction, fuzzy k-means, gamma-ray spectrometry, REML, digital soil mapping, Linear mixed model*

A prototype methodology for assessing within-field soil variation using digital soil mapping, legacy soil datasets and satellite imagery to aid precision farming

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Addressing matters of food security in the light of rapid population growth is an increasingly important challenge. Sustainable intensification of agricultural food production will be required to meet the future demands for food, and this can be facilitated by smart management of land resources offered by advanced precision agriculture technologies. The precision farming concept has been developed on the grounds of evidence that applying seed and fertiliser variably, based on localised geographical soil property patterns, helps maximise yields whilst saving resources and inputs. For precision farming to be effective, determining within-field soil variation is essential. Legacy soil data, however, rarely provide soil information at appropriate spatial scales to match precision farming requirements. Acquiring more detailed soil information using traditional soil survey methods is costly and time consuming, especially where data is required across entire regions or countries. Digital soil mapping, coupled with remotely-sensed, fine resolution digital datasets and advanced machine learning techniques, offers promising opportunities for mapping soil information at spatial scales appropriate for precision farming, but without the necessity for conducting extensive soil surveys.

We present a study exploring the capacity of such techniques to represent reliably field-scale soil variation, using an exemplar of fifty fields distributed across England. The work is undertaken within a recently-commenced two-year project, funded by the UK Natural Environment Research Council (NERC), InnovateUK and AgSpace Ltd., a leading precision farming company. This communication sets out a provisional methodology, with preliminary results, focusing on the application of the DSMART algorithm for spatial disaggregation of the national soil map for England and Wales (NATMAP), locating soil series within soil association mapping units at 1:250,000 scale. Results are verified with existing auger-bore observations and detailed soil series maps at 1:25,000 and 1:50,000 scales. The disaggregated maps are also compared to soil characteristic zone delineations, based on soil brightness mapping, developed by AgSpace from high-resolution multispectral remote sensing data.

keywords: *Precision soil mapping, Spatial disaggregation, DSMART*

Teaching digital soil mapping as an example of contemporary environmental survey methods

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Pedometrics, and in particular, digital soil mapping is taught at Cranfield University at the post-graduate level. Due to the modular structure of all Master courses at Cranfield the class is directed at students with varied backgrounds and as a result no assumptions of the prior knowledge of soil science nor advanced geostatistical or machine learning methods can be made. The class provides an example of handling and processing of spatially-explicit environmental data as part of the Environmental Resource Survey (ERS) module that aims at familiarising the students with the state-of-the-art methods in environmental survey design and data analysis. The class is therefore an opportunity to introduce machine learning methods for applications in environmental sciences and by doing so illustrates the concepts of data fusion and model data fusion explained to students earlier in the module. In particular, the class utilises an example of the Irish Soil Information System (ISIS) project where digital soil mapping was used to compliment the traditional soil survey and existing legacy data to generate a harmonised map of soil associations for the Republic of Ireland. The subject is taught over 4.5 contact hours, with the first hour dedicated to an introductory lecture covering the basic concepts of soil-landscape modelling, exemplified by the case study of the ISIS project. The remaining time is allocated to a step-by-step tutorial where students are acquainted with the process of the creation of a predictive soil map with the use of Random Forests models, followed by verification of the mapping accuracy. The structure of the class contributes to the following intended learning outcomes of the ERS module: 'to evaluate existing information and models which complement the survey method', 'to select and carry out appropriate modelling and statistical analyses', and 'to assess the accuracy of the results'. Both the lecture and practical are designed to engage students exhibiting various learning styles as well as level of proficiency in the presented methods, and are characterised with clearly defined learning objectives for each section of the teaching process.

keywords: *digital soil mapping, master-level education, environmental survey methods exemplar*

Data mining of soil color database

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Soil color is a very important morphological property which is determined by soil physio-chemical and mineral composition. It is an important indicator used in many current soil classification systems. Potentially soil color map also serves to determine soil reflectance features which are important for regional energy radiation-transfer models.

The determination of soil Munsell color (Cm) is influenced by many factors such as illuminance conditions, soil moisture status and the perceptual ability of the observers, which will lead to large differences between different replicate measurements or different observers. This study tries to compare and evaluate the consistency of Cm determined in different soil laboratories using reflectance spectroscopy, and to explore how soil color measurements influence the determination of diagnostic horizons with regard to soil color. A Soil color database, covering the geographic extent of both western and eastern China, with all typical soil types and a wide range of soil color, was constructed.

The average difference between predicted and observed Cm is 0.19, -3.28 and -0.70 units respectively for Hue, Value and Chroma. Spectrally predicted hue is generally more yellow and less red for soil hue in the range of 10R∼7.5YR; while for hue ranged from 10YR to 2.5Y, predicted hue is less yellow and more red. As for Value and Chroma, spectra generally gave lower values. Since soil spectra can give more objective and consistent prediction of soil color, thresholds for determination of soil color related diagnostic horizons (e.g., mollic epipedon, albic horizon) were proposed based on data mining of spectrally predicted soil colors. In addition, a comparison was made between soil color maps generated from observed and spectrally predicated data using geostatistical techniques.

keywords: *Munsell color, reflectance spectroscopy, data mining, mapping*

Soil big data: Requirement and Potential in China

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Soil fertility management challenge: To increase food production, the agro-chemical inputs have been raised by 3.6 times since beginning of 1980s, however, little improvement for land fertility management techniques of farmers has been achieved. Blind and excessive application of fertilizers, manures from large livestock and poultry farms, pesticides and irrigation have been common in crop production to compensate technical shortages. In recent years, fertilizer nutrients input has reached to 450 kg per hectare arable land and showed upward trend. It is causing serious soil quality degradation, over expending of ground water irrigation, heavy pollutions of soil, water, air as well as farm produce.

Little benefits to farmers from state soil investigation: Aimed to improve land fertility management techniques of farmers in China, a series nation-wide soil investigations, which involved 40 billion $, have been carried out and numerous soil fertility observations have been gained in recent years. However, the data obtained, which should be helpful to improve farmer's techniques, are storied in raw data format in different organizations or institutions mainly. The valuable data are either not understandable for farmers or not achievable to farmers.

To delivers farmers soil info: By using big data approach, raw soil observations from different investigations, time periods and regions can be extracted, integrated and interpreted to the info or recommendation which are easy for farmers to understand and to improve their land fertility management practices. The soil data processing, interpreting and knowledge delivering can be carried out by specialized state soil research institutes. Through GPS inserted in smart phone, each farmers can get the in-situ soil info and recommendation of his farms and field.

Potentials: In 2014 the users of mobile phone in China reached 91% of the whole population and smart phone reached 36%. Processing and interpreting of soil big data from different resources and delivering farmers with useful soil fertility management info and knowledge will be not only feasible but also very important for the country to realize a sustainable agricultural development.

keywords: *soil big data, China, soil fertility*

Development of China Digital Soil Map CDSM) at 1:50,000 Scale

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Objective: Temporal and spatial soil information with high resolution, as a new and indispensable tool for researchers and managers, can be applied to soil and environmental quality assessment, arable land conversation, flood and draught mitigation, erosion control, non-point source pollution control, soil and agricultural product pollution control and many other areas. Purpose of the study is to develop China Digital Soil Maps (CDSM) through extracting soil information from legacy data collected from the whole country.

Data resources of CDSM: In last decades, several nation-wide soil surveys have been conducted in China. The valuable and numerous soil data, in paper or digital raw data format from these investigation provided important basic for CDSM development

CDSM construction: To extract, integrate and interpret heterogeneous and massive soil raw data originated from different resources, periods, provinces and counties, a human-computer interactive data treatment working flow was developed. A computer software program IMAT (Intelligent Mapping Tools) have been developed.

CDSM content: CDSM was composed of two kind of soil geo info. One was map data with vector and raster format that describe soil types, soil organic matter, total nitrogen, available phosphorus, potassium and pH-value. The second kind was point data of about 100,000 soil profiles and 80,000 plough layer samplings, which describe soil parent material, mechanical composition, texture and other morphological features and the fast-changing soil properties as soil carbon and nutrient concentrations. By time series, space sequence or thematic order, required soil info with a map resolution of 100 m×100 m can be inquired and provided by CDSM. The information has been applied by a number of agricultural, environmental and land resource organizations, divisions and research institutes for knowing current soil quality and changing of soil quality.

Future works: With CDSM completion and continuing supplement, further works should be paid on: (1) data share to different scientific disciplines and part of data share through internet. (2) Further processing and interpreting, to deliver farmer soil info and recommendation, to improve land fertility management techniques.

keywords: *Digital Soil Map, China, large scale*

Intelligent Mapping Tools (IMAT) for big soil data processing

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Objective: To extract, integrate and make cartographic interpretation with soil data from different data resources and with heterogonous format and feature has been very time and manpower consuming by using mainstream software package such as ArcGIS, MapInfo and Map GIS, especially for making thematic maps with high resolution of vast continents. Purpose of the study is to develop a professional tool to process heterogonous big soil geo-info from different data resource. The software package should finish data processing and mapping human-computer interactively or automatically.

Software design and development: Procedures of soil data abstracting, classifying, integrating and cartographic representing were analyzed. These procedures are normally carried out by data analyzers with help of mainstream database and GIS software packages. Each segmental procedure were identified by their features of whether it can be done automatically or by human-computer interactive way. Based on requirement analysis, the software design were finished. The whole design consisted of system architecture, system data supporting platform, system modules and models. For IMAT software development, C# was used as the programming language, NET Framework 4 Extended was applied as development environment, functions and components from software packages of ArcGIS, Access and DotNet Bar were called.

IMAP Functions: IMAP has 38 independent modules and can provides the main functions for treatment big soil spatial data and drafting thematic maps. The advantages of system is its ability to process big soil data with heterogeneous format and structure. When making cartographic representations with IMAT, rules and parameters for the whole map that is composed of a large amount of map sheets can be set, through which differentiated data extracting and mapping for map sheets can be carried out. The data analysis and mapping procedures can be operated by intelligent and automatic way as well as human-computer interactive approach.

By using IMAP, processing of raw soil data collected from different regions of China and drafting soil map of the whole country, which composed by 24,000 map sheets, have been successfully finished just with a couple of data analyzers in acceptable time period, The maps are in good visual quality for official press as well as for internet browsing.

Conclusion: IMAT can be applied to analyze and express thematic elements such as soil types, texture, and soil nutrient and contaminant concentration In addition, it can be used mapping with different map scales or large amount map sheets based on big soil data.

keywords: *Intelligent Mapping Tools (IMAT), China, big soil data*

Mapping soil properties for ecological and hydrological modeling in the typical inland river basin of northwest China

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Soil plays a crucial role in regulating ecological and hydrological processes. To better understand ecosystem evolution and ecosystem services and the impacts of human activities and climate change, precise modeling of the ecosystem processes and change scenarios is essential. However, lack of sufficient soil data often limits a reliable modeling that can help make decisions for ecosystem management.

The Heihe River located in the northwest China is the second largest inland river where socio-economic development and ecological degradation have led to increasing demand of water use and caused conflicts in policy making for sustainable development. The recent grand efforts made by scientific community and policy makers for reliable prediction and ultimately efficient use of valuable water resource require sophisticated hydrological modeling which looks upon detailed spatial soil information.

In order to map the fairly large area with contrasting environmental conditions, digital soil mapping technique was adopted. Based on analysis of environmental covariates with a focus on environmental similarity, soil sampling was conducted to cover all representative sites as much as possible. In total about 300 sites were visited and soil profiles were sampled.

Important soil attributes especially those closely related to soil water movement were analyzed and adopted as target mapping objects, which include effective soil thickness, soil organic matter content, soil particle size distribution, soil bulk density, soil water holding capacity and saturated water conductivity. Due to limitation in obtaining some directly measured attributes such as water infiltration rate, pedotransfer functions were built for estimation of those soil parameters.

Digital soil mapping models were developed for various target soil attributes. In general, multiple linear regression models, fuzzy C mean cluster (FCM) based models, various kriging models, Random Forest models were tested and compared. Especially three dimensional predictions of soil organic matter content, soil particle size distribution as well as some soil hydraulic properties were made, which provided possible optimization of soil horizon parameters for hydrological modeling.

keywords: *digital soil mapping, inland river basin, hydrological modeling*

Digital mapping of soil carbon in a soil profile using image analysis

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In this study, we explored the CIEL*a*b* color coordinates extracted from a digital image as covariates for soil profile mapping of SOC in an Alfisol. The soil profile wall (1.0x0.9m) was divided into a 10x10 cm raster, and samples were collected at the center of each grid for SOC analysis. Digital images with a horizontal and vertical resolution of 300 dpi were taken. The digital image was cropped and georeferenced to the profile wall, and scaled to 1-cm resolution. The 90 soil samples were separated into a calibration (45) and validation dataset (45) by odd-even transect numbers. Regression kriging was used to build a SOC-color model. SOC concentrations ranged from 16.7 g/kg in the A horizon to 0.9 g/kg in the 2Bw horizon. Overall, SOC was correlated with b* (-0.75), and a* (-0.50), but not correlated with L* (0.08). Three vertical color layers were determined from the SOC map which were corresponded with the Ap (0-12cm), Bt (12-58cm), and 2Bw (58-90cm) horizons. Within the layers, there was considerable variation. Validation for the SOC map had a R2 of 0.80 and a RMSE of 1.64 g C/kg. The b* coordinate is useful for SOC mapping, the L* coordinate is sensitive to shadows caused by animal holes and other features, and the a* coordinate can be used to distinguish the 2Bw horizon. We conclude that CIEL*a*b* coordinates are suitable covariates for soil profile C mapping and may improve soil horizon delineation, as well as assessment of variation within soil horizons.

keywords: *soil profile, soil carbon, digital mapping, CIE L*a*b*, image analysis*

Review on the research of cultivated land quality monitoring in China

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The monitoring of cultivated land quality is an important technical support for the management of quantity, quality and ecology of cultivated land in China. The cultivated land is the fundamental guarantee of national food security, the foundation and the lifeblood of agricultural development and agricultural modernization, and the basic national conditions of many people and less land determine the special importance and strategic nature of China's cultivated land resources. Carrying out the monitoring of cultivated land quality is of great significance to implement the strictest cultivated land protection system, guarantee the national food security and realize the sustainable utilization of land resources.

keywords: *Cultivated land, soil, quality monitoring*

Methods comparison on prediction accuracy of soil properties derived from soil-landscape principles in a middle size watershed of Qinghai-Tibetan Plateau, China

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Huangshui river watershed is one of most important agricultural region in Qinghai-Tibetan Plateau, which supports more than 2/3 of population and food provision of Qinghai Province, and thus burgeoning an urgent demand on digital soil mapping that can tells not only the spatial distribution s of soil properties, but also the spatial variability and temporal dynamic of them. Given the facts of lacking expert knowledges on local soils, this paper adopted a purposive sampling strategy to collect comparative data on typical soil properties over yeas of 1980s to nowadays. The sample positions were firstly decided according to the location of typical soil profiles recorded in the Second Soil Census Data of China in 1980s, and then combined with some other factors such as area and accessibility etc. From which, a total amount of 61soil profiles with 215 layers of stratified soil samples was collected, which covers 15 major soil sub-types in this region.

Based on laboratory data of organic matter, total nitrogen, soil texture, pH, bulk density and content of CaCO3 of each sample, integrated with environmental variables of elevation, slope, aspect, slope surface curvature that derived from digital elevation map, and temperature, precipitation, land use/cover, geomorphology and geology that extracted from corresponding thematic maps, this paper conducted three soil-landscape reasoning works at different spatial scales, which including predictive mapping for soil sub-types in Minhe County within an area of 1900 km^2 that covers 14 sub-types, spatial distribution characteristics and its impact factors of soil organic matter in Beichuan River Watershed within an area of 3900 km^2 that covers 14 sub-types, and the spatial distribution and influencing factors analysis of cropland on soil total nitrogen in Huangshui River Watershed within an area of 162000 km^2 that covers 18 sub-types.

From which, we learned some specific rules of soil-landscapes at different scale and their significant difference on interpolation results for different attributes, which is very helpful in understanding the scale-dependent relationship between soil attributes and spatial interpolation accuracy. In addition, given the significant impacts of interpolation methods on producing a digital soil map, this paper also provided a set of interpolation strategy for non-uniform discrete point by comparing prediction accuracies of different methods, which including ordinary kriging interpolation, fuzzy reasoning and random forests etc. Given the fact of lacking such researches in this region, this work can provide an initial reference on producing a more accuracy digital soil map in future.

keywords: *digital soil mapping, soil-landscape modeling, fuzzy reasoning, purposive sampling, Huangshui river watershed*

Quantitative relationships between soil properties and hyperspectral characteristics and their possible application in soil classification in Qinghai Province, China

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Hyperspectral data, especially the visible near-infrared spectra, has been evidenced a powerful tool in interpreting relationships between soil properties and their spatial-temporal heterogeneity, which has been used widely in building inversion models between them and furtherly making predictive maps for many physical and chemical soil properties, such as organic matter, soil moisture, mineral composition and soil texture. However, limited by the complexity of soil property-spectral responses and the difficulties in defining soil groups by using a few of soil properties, the soil identification and classification via spectra data remains ascendant in many regions all over the world.

Facilitated by the fundamental project of Soil Series Survey in Western China, specifically in Qinghai Province, this paper first collected 161 soil profiles that covering mostly sub-soil types in this region, conducted both laboratory tests on major soil properties that tightly related to soil classification, including organic matter, total nitrogen, soil texture, pH, bulk density, content of CaCO3, effective phosphorus, rapidly-available potassium, total phosphorus, total potassium, and cation exchange capacity (CEC) etc., and reflectance spectra data for each stratified layers samples within all profiles. Then conducted the parameters inversion process by setting the cross-examination variances as the objective function, from which two sets of inversion models were produced, namely acceptable and unacceptable respectively. Thirdly, those acceptable inversion models were used furtherly into identifying and discriminating of different soil types, which is mainly extracted from the available soil map at 1: 4 000 000 scales that provided by Institute of Soil Science, Academia Sinica, Nanjing, China.

The result remains in processing right now, but one conclusion we can draw currently is that some valuable findings could be expected from this work, since it is the first time to do a systemic examination on the relationships between soil properties and their hyperspectral response characteristics in this region, which covers almost all soil types (163 soil species) of this region that recorded in the Second Soil Census Data of China, which is conducted in 1980s and used as the guidance principle of soil sampling in this work. Besides, an additional output of this work is an initial hyperspectral database for typical soil profiles at the stratified layers as well.

keywords: *Hyperspectral data, Reflectance spectra, Soil properties, Soil classification, Qinghai Province*

Rainfall magnitudes and digital soil mapping using land surface dynamic feedback patterns

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Previous studies demonstrated that the pattern of land surface dynamic feedback patterns captured by remote sensing images after a rainfall event can be used to derive environmental covariates for predicting soil spatial variation over low relief areas. The impact of the magnitude of rainfall on the performance of the derived environmental covariates for soil property prediction is still unknown. This paper shows our findings from our recent investigation of this impact in an effort to shed some lights on guidance for choosing suitable observation periods based on rainfall magnitude. A study area of over 2,000 square kilometers in Anhui Province of China was used for this investigation. An individual predictive soil mapping method (iPSM) was used to predict soil texture over space based on the environmental covariates derived from MODIS image based on land surface dynamics. Ten observation periods were selected after rainfall events with varying rainfall magnitudes. The results showed strong positively correlation between rainfall magnitudes and prediction accuracies. When the rainfall reaches a certain amount, the prediction accuracy became stable. The threshold of rainfall for the land surface dynamic feedback method in this study area is about 20 mm for both sand and clay content. The predicted maps based on different observed periods with similar rainfall magnitudes show only slight differences. It can be concluded that rainfall magnitudes have obvious effect on the prediction accuracy of soil texture mapping. Larger rainfall amount will improve the prediction accuracy when using the LSDF. It was also observed through this study that strong winds, high evaporation and low relative humidity during the observed periods also improve the prediction accuracy.

keywords: *Digital soil mapping, remote sensing, MODIS, SoLIM, Land surface feedback patterns, soil texture*

Predictive modelling of soil properties using hyperspectral images and different multivariate regression techniques

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Image spectral data, particularly airborne hyperspectral data, has been proven to offer efficient input data to map spatial variability of important soil properties like organic carbon or soil texture. However, there are still many limitations in the use of the image hyperspectral data for soil properties quantification. On one hand, there are restraints connected to data collecting and surface characteristics (soil covered with vegetation, litter, dust or soil crust). On the other hand, the spectral information is considerably influenced by soil properties (soil moisture, soil roughness, soil texture or size of soil aggregates) and heterogeneity of environmental settings.

Our study aimed to assess the influence of soil conditions, environmental settings and use of different multivariate regression techniques on the prediction accuracy of models assessing soil organic carbon and texture classes. The study was performed at six study sites about 1 km^2 large representing the most extensive soil units of the agricultural land in the Czech Republic (Chernozems and Luvisols on loess and Cambisols and Stagnosols on crystalline rocks). The adopted methods included extensive field sampling, laboratory analysis and predictive modelling of selected soil surface properties using aerial hyperspectral data.The influence of site-specific conditions on prediction of soil properties was assessed. Different multivariate regression techniques (Partial Least Square, Random forest, Support Vector Machine and Artificial neural network) were applied in the predictive modelling of soil properties.

The prediction accuracy (R2) of the best performing models predicting the soil properties varies in range 0.8–0.91 for soil organic carbon content, 0.21–0.67 for sand content, 0.4–0.92 for silt content and 0.38–0.89 for clay content. Among the applied methods, the machine learning Support Vector Machine and Artificial neural network methods showed the best prediction accuracy. The prediction accuracy was influenced by the spatial variability of soil units and parent material. Better model performance was in most cases achieved in more homogeneous Chernozem and Luvisol loess regions while the models applied in heterogeneous Cambisols and Stagnosols regions showed lower accuracy. The results showed that the sites with heterogeneous structure of the soil cover and parent material will require more precise local-fitted models and use of further auxiliary information such as terrain or geological data.

keywords: *soil properties, imaging spectroscopy, hyperspectral image, multivariate techniques*

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