ΠΕΔΟΜΕΤΡΟΝ

Newsletter of the Pedometrics Commission of the IUSS Issue 44, June 2019

From the Chair

Dear colleagues,
Welcome to the 44st issue of Pedometron. Summer has returned to Europe and along with it a new issue of the Pedometron. Just in time, before many of our colleagues leave their office to enjoy a well-deserved summer break. Only few weeks ago, we had Pedometrics 2019 in Guelph, Canada. It was great to see that so many of you attended this conference. The planning of Pedometrics 2021 has already started. Dr. Wirastuti Widyatmanti from Universitas Gadjah Mada, Indonesia and colleagues, kindly agreed to host the 2021 conference at Bali. She presented her plans during the Pedometrics Business meeting and it looks very promising.

In this issue we prepared for you the regular items, including the Pedometrics Comic, Poetry, Pedomathemagica and 'What's new in R'. An important contribution in this issue is the '*In Memoriam*' written my Richard Webster for John Gower, who passed away in May this year, at the age of 89. He was a mathematician whose influence on pedometrics has been profound.

It is good to see that the Pedometrics community is such an active community, resultingly we are organizing scientific workshops and sessions at many conferences. Aside from Pedometrics2019, we had SoilMapping2019 in Santiago, Chili. Here, the IUSS Pedometrics working groups Digital Soil Mapping and GlobalSoilMap combined their biannual meeting. In April, we had various sessions at the General Assembly of the European Geosciences Union.

From discussions we had during the workshops, we see that there is an increase in the use of machine learning for producing soil maps. Along with that, we start to critically review the use of such techniques. At Pedometrics, we opened the discussion by presenting our case on mapping soil carbon using pseudo-covariates. In this Pedometron, Alex McBratney and Budiman Minasny have made a contribution to the discussion with an article 'Pedometrics is soil data science +++'.

In the last issue, Gerard Heuvelink introduced the PM10 Challenges, in which he proposed to prioritize our research agenda. In this issue, we welcomed the contributions from our peers to discuss the agenda and complement it with new challenges. You will find contributions to the PM10 Challenges from Johan Bouma, Philippe Lagacherie, Zamir Libohova and Lin Yang.

We further introduce an inventory on how young scientists were trained in Pedometrics during their under- and graduate studies. We hope that with this inventory we can get a better insight on what students need during their studies and strengthen the university *curricula* on Pedometrics and soil science in general. Also, it is a great way to get to know the young pedometricians. It was not easy to find young scientists willing to contribute. So, hereby I invite all young pedometricians to make a contribution for the next Pedometron.

That is all for now! Happy reading and be inspired!

Titia Mulder
June, Wageningen, The Netherlands

In this issue

Delivered by

Chair
Titia Mulder
Vice-chair
Nicolas Saby
Editor
Alexandre Wadoux

Pedological legacy of John C. Gower 1930-2019

By R. Webster
Rothamsted Research, Harpenden AL5 2JQ, Great Britain
E-mail: richard.webster@rothamsted.ac.uk

Introduction

John Gower, who died in May of this year aged 89, was a mathematician whose influence on pedometrics has been profound but largely unrecognized by pedometricians. After graduating from Cambridge, John worked for two years at Manchester University with M.S. Bartlett before taking a post as statistician at Rothamsted in 1955. He spent the next 35 years there, eventually as head of the statistics department, the position previously held by R.A. Fisher and F. Yates. On 'retirement' from Rothamsted he had a brief spell in the university of Leiden before returning to Britain as professor in the Open University.

Multivariate statistics

John Gower is likely to be best remembered for his innovations in multivariate analysis. The 1960s were a decade in which controversy about soil classification peaked. Many pedologists of the day thought that classification of soil in a way akin to that of plants and animals was both feasible and the best way to store and communicate information about the soil. They did not agree, however, on what the rules should be or how to structure the information. There also emerged pedologists who thought that the techniques of numerical taxonomy which were successfully being used in bacteriology and botany could resolve some of the conflicting views. One of the leading lights in numerical taxonomy was bacteriologist P.H.A. Sneath of the National Institute of Medical Research just a few kilometres from Rothamsted (see Sneath, 1957, in which he set out and illustrated the principles). Sneath had sought help to write his programs and run them on the computer at Elliott Brothers headquarters.

John knew of Sneath's work, and he programmed Sneath's technique, which was essentially an agglomerative algorithm, on Rothamsted's Elliott machine for a visiting scientist. However, it was his colleague and soil scientist James Rayner who provided the major stimulus. Rayner (1966) wanted to apply Sneath's technique to soil profiles. He, however, along with soil scientists more widely, faced problems that Sneath had not encountered or could avoid.

Soil characteristics recorded for the purpose of classification comprise measurements on linear scales, presence-or-absence (binary) and unordered multi-state variables. Further, some binary variables are significant if they are present but not otherwise; and some multi-state characteristics cannot be coded if the characteristics do not exist. Examples of the last are the colours of mottles; they are important indicators of the degree of gleying and water-logging, but one cannot code them if the soil is not mottled. Gower (1971) solved the problem by devising his general coefficient of similarity between any pair of items. With this coefficient he and Rayner could compute a similarity matrix for a set of soil individuals (with some ingenious programming for matching profiles horizon by horizon) and then apply Sneath's techniques to create classification trees.

At the same time principal components analysis (PCA) of multivariate data was becoming feasible, thanks to the computer. It allows one to see relations among individuals in an informative subset of the Euclidean space defined by a set of variables on orthogonal axes. It was (still is) restricted to data on linear scales, however, and that limits its application. How could one represent multifaceted soil individuals? Gower's answer was to find what he called 'principal coordinates' (Gower, 1966). He scaled the similarities between individuals in the range 0 to 1, transformed them to distances and then transformed them further so that the individuals could be represented by points in a Euclidean space in a way analogous to that of PCA. He also showed how new individuals could be added to the configuration by his 'add-a-point' technique, thereby lifting the restriction on the number if individuals that could be ordered in that way.

Gower's general coefficient of similarity and his principal coordinates analysis have had enormous impact in biology, psychology and geology, to name a few fields of endeavour. The two papers mentioned have attracted more than 7000 citations. The combination has given us pedometricians the means of matching soil profiles to one another and provided us with a deep insight into the multivariate distribution of populations of soil profiles. We have discovered that samples from such populations almost always appear as single clouds of points with no gaps and no distinct clusters in the vector space. The analogy with biological populations has proved false; the structure of soil populations is not hierarchical, and the early agglomerative techniques of numerical taxonomy, *pace* Sneath, are unsuited for soil. It was a revelation that caused pedometricians to switch attention to non-hierarchical classification, a result that is still with us today.

Spatial statistics

A problem that has taxed soil surveyors for decades and taxes them still is how to sample terra incognita: how intensely should one sample to discover the spatial scale(s) on which the soil varies and then to map in a region about which one knows little or nothing? Youden & Mehlich (1937) were the first to spell out the problem in statistical terms, and they illustrated a solution with a simple hierarchical balanced design with four stages spanning separating distances between 3 m and 1600 m in 10-fold increments apart from the last. They sampled two regions to this design, measured the soil's pH and analysed their data by a straightforward hierarchical analysis of variance (ANOVA) to estimate the components of variance at the four stages.

So far so good. But a four-stage design with 10-fold increments in distance is rather crude; it might not provide the guidance one seeks. One might well want greater detail before spending time and money on further sampling, possibly wastefully. One would like a more refined solution with more stages with, say, 3-fold increments in distance. If one tries to maintain balance, however, one encounters another problem because the number of sampling points increases exponentially as the number of stages increases and soon becomes unaffordable. It also happens to be unnecessary; one does not need the huge numbers of degrees of freedom in the lower stages of the design; one can add stages without replication in all its lower branches.

Margaret Oliver recognized the need for such a design in her survey of the soil of the Wyre Forest in the West Midlands of England. She and I designed a five-stage hierarchy, sacrificing balance for economy (Oliver & Webster, 1987). The ANOVA for such designs is no longer straightforward. Gower (1962) had set out the formulae for analysing data from unbalanced hierarchical schemes, and we programmed them to estimate the components of variance. We have since replaced Gower's method by the more efficient residual maximum likelihood (REML) method (see Webster *et al*., 2006) with further refinements by Lark (2011). The design and analysis, whether by Gower's method or REML, are now available for any pedometrician's tool kit for obtaining a first estimate of the variogram in unfamiliar territory. We have to thank John Gower for his part in the solution of our problem.

Gower, J.C. 1962. Variance component estimation for unbalanced hierarchical classification. *Biometrics*, **18**, 168-182.

Gower, J.C. 1966. Some distance properties of latent root and vector methods used in multivariate analysis. *Biometrika*, **53**, 325-338.

Gower, J.C. 1971. A general coefficient of similarity and some of its properties. *Biometrics*, **27**, 857-871.

Lark, R.M. 2011. Spatially nested sampling schemes for spatial variance components: scope for their optimization. *Computers & Geosciences*, **37**, 1633-1641.

Oliver, M.A. & Webster, R. 1987. The elucidation of soil pattern in the Wyre Forest of the West Midlands. II. Spatial distribution. *Journal of Soil Science*, **38**, 293-307.

Rayner, J.H. 1966. Classification of soils by numerical methods. *Journal of Soil Science*, **17**, 79-92.

Sneath, P.H.A. 1957. The application of computers to taxonomy. *Journal of General Microbiology*, **17**, 201-226.

Webster, R., Welham, S.J. Potts, J.M. & Oliver, M.A. 2006. Estimating the spatial scale of regionalized variables by nested sampling, hierarchical analysis of variance and residual maximum likelihood. *Computers & Geosciences*, **32**, 1320-1333.

Youden, W.J. & Mehlich, A. 1937. Selection of efficient methods for soil sampling. *Contributions of the Boyce Thompson Institute for Plant Research*, **9**, 59-70.

Announcements from the Pedometrics Award Committee

Pedometrics Best Paper 2018

During the last few months, the Awards Committee of the Pedometrics Commission received nominations from an open call for the Best Paper 2018 competition. With nominations from the panel members a total of 27 papers were considered. Each committee member selected their top 15 papers in rank order (excluding papers on which they were coauthors) and the top five papers in terms of support across the committee as a whole were put to an open vote. With great pleasure, inform you that Thorsten Behrens and co-authors received the award for Best Paper 2018 on their work:

Thorsten Behrens, Karsten Schmidt, Robert A. MacMillan, Raphael Viscarra Rossel. (2018). Multi-scale digital soil mapping with deep learning. Scientific Reports 8:15244.

The result was announced at the Pedometrics 2019 Meeting at Guelph in June 2019, where Bob MacMillan was handed over the award on behalf of all the authors. They will be invited to write a short communication about their work for the next Pedometron.

Abstract: We compared different methods of multi-scale terrain feature construction and their relative effectiveness for digital soil mapping with a Deep Learning algorithm. The most common approach for multi-scale feature construction in DSM is to filter terrain attributes based on different neighborhood sizes, however results can be difficult to interpret because the approach is affected by outliers. Alternatively, one can derive the terrain attributes on decomposed elevation data, but the resulting maps can have artefacts rendering the approach undesirable. Here, we introduce ‘mixed scaling’ a new method that overcomes these issues and preserves the landscape features that are identifiable at different scales. The new method also extends the Gaussian pyramid by introducing additional intermediate scales. This minimizes the risk that the scales that are important for soil formation are not available in the model. In our extended implementation of the Gaussian pyramid, we tested four intermediate scales between any two consecutive octaves of the Gaussian pyramid and modelled the data with Deep Learning and Random Forests. We performed the experiments using three different datasets and show that mixed scaling with the extended Gaussian pyramid produced the best performing set of covariates and that modelling with Deep Learning produced the most accurate predictions, which on average were 4–7% more accurate compared to modelling with Random Forests.

Margaret Oliver Award, 2019

The Margaret Oliver Award is made biennially by the Pedometrics Commission of the International Union of Soil Sciences. The award is named in honour of Professor Margaret Oliver, and to mark her particular commitment to developing and supporting young pedometricians. The award is made to an early-career scientist, active in pedometrics and in promoting and supporting the discipline who, at the time of nomination (February 2019), had held the degree of PhD for less than six years. In 2019 a total of six candidates were nominated for the award, a measure of the enthusiasm and energy within pedometrics, and the diversity and geographical spread of its practitioners.

It is my great pleasure, as Chair of the Awards Committee of the Pedometrics Commission, to announce that the committee has made the 2019 Margaret Oliver Award to Dr Vera Leatitia (Titia) Mulder, assistant professor in the Soil Geography and Landscape group at Wageningen University in the Netherlands.

Titia is a graduate of Wageningen, with the distinction of holding two masters degrees from that institution, one on soil–landscape modelling and one on the inference of soil properties from measurements of spectral reflectance. She undertook a PhD at Wageningen on the use of spectroscopy for digital soil mapping, in the course of which, along with extensive computation, she did both field work (in Morocco) and laboratory analyses. After successfully defending her thesis in October 2013, Titia held post-doctoral positions at the University of Zürich (Switzerland), the INRA InfoSol Unit (France) and the Vrije Universiteit Brussel (Belgium) where she focussed on modelling and mapping soil organic carbon at global and regional scales.

Titia has made substantial contributions to the development of pedometrics throughout the undergraduate and postgraduate curriculum at Wageningen, developing and teaching courses on proximal sensing and machine learning. She supervises a PhD student and is due to take on three more this year. She has also established a soil spectroscopy laboratory at Wageningen, and has been energetic in developing collaborations both within and outwith the university.

Titia serves the wider scientific community through service on the editorial boards of two soil science journals. She works in Pillar 4 Working Group of the Global Soil Partnership. Of particular relevance to this award is her election as Chair of the Pedometrics Commission of IUSS at the 2018 World Congress of Soil Science.
Within a short period of obtaining her PhD Titia has contributed substantially to the field of pedometrics, both through her research and teaching, but also through her energetic and commited engagement with the scientific community and her willingness to offer both support and leadership to the discipline. It is clear that she has made an impressive start to her career, and we all look forward to seeing how she progresses in the years to come. Given the objectives and focus of the Margaret Oliver award, there can be no doubt that she is a worthy winner, and this was reflected in the views of the committee.

IUSS Pedometrics Working Group Updates

IUSS WG Digital Soil Mapping

The vice-chair of the WG Digital Soil Mapping Luboš Borůvka has been the vice-chair of the DSM workgroup for over 4 years. During the last WG conference in Santiago, Chili, he officially finished his term. The new vice-chair of the WG DSM is Allesandro Samuel Rosa from the Federal University of Technology – Paraná, Brazil. We would like to thank Luboš for all the great work he did for the working group and welcome the new vice-chair Allesandro. We asked them to elaborate on the achieved outcomes of the WG over the past 4 years and new foreseen activities.

Former DSM WG Vice-chair Experience

Luboš Borůvka
Czech University of Life Sciences Prague, Czech Republic

I had the honour and pleasure to serve as a vice-chair of the Working Group on Digital Soil Mapping of the IUSS under two chairs, Mogens Humlekrog Greve and Laura Poggio. Mogens invited me to be his vice-chair at the global workshop in Nanjing, China, in 2014, and I was agreed by the participants. During this first period, Mogens worked hard to get the working group website active again. Later on, I assisted a little in the preparation of the global workshop at his home institution, University of Aarhus, Denmark. I think it was a good event, thanks to Mogens, not me. Then we prepared together the DSM topic for the World Congress of Soil Sciences in Rio de

Janeiro, Brazil, 2018, where I finally became convenor, as Mogens could not attend. In 2016 in Aarhus, I did not want to become chair after Mogens, but I was happy to continue as vice-chair under the new chair, Laura. We continued in preparation of the DSM part of the 25^{th} anniversary Pedometrics 2017 conference in Wageningen, the Netherlands, and then the joint DSM and GSM workshop in Santiago de Chile in 2019.

Each of the two chairs is different and has a different style, but I do not want to compare them, they both are excellent bosses. Fortunately, none of them was too demanding on me. Actually, my major task was sending information to the community through the google-group connection. Nevertheless, I had the opportunity to express my opinion on various issues, and to participate at several discussions and communications, like that about cooperation with the newly established Global Soil Map working group. I thank both chairs for the opportunity to work with them and to be involved in the decision making, it was really a pleasure and I enjoyed it. And I hope that my contribution, though small, had an effect, too. During that time I could see also the progress in the field of digital soil mapping. While in Nanjing in 2014, random forests seemed to be the leading and most frequently used method in DSM, automatic machine learning and ensemble methods take probably the lead in 2019. Moreover, the DSM community is still increasing and its approaches are more and more widely used.

I wish to Alessandro Samuel-Rosa as the new vice-chair at least as good feeling at the end of his service period as I had. Though he has not attended many DSM workshops (which was my only “qualification question” in Nanjing), he helped me together with Laura with convening the DSM session on the World Congress in Rio and I am sure that he can bring new ideas, approaches and a lot of new energy into the DSM working group. Good luck, Alessandro!

New DSM WG Vice-chair

Alessandro Samuel-Rosa
Department of Agronomy, Universidade Tecnológica Federal do Paraná, Brazil

Introducing myself

I am a lecturer and researcher at the Federal University of Technology – Paraná, Brazil. After my first studies (2004-2010) at the Federal University of Santa Maria (UFSM, Brazil) on the interactions between land use and soil quality, I moved to the field of pedometrics. In the following years I developed pedometric studies, mostly on digital soil mapping, in collaboration with researchers from the National Soil Research Center (Embrapa Soils, Brazil), the International Soil Reference and Information Center (ISRIC, the Netherlands) and the Federal Rural University of Rio de Janeiro (UFRRJ, Brazil). As a researcher, my main interest is on the development of spatial sample optimization strategies, the selection of environmental covariates and calibration of (geo)statistical models for digital soil mapping, and bottom-up approaches for open soil data compilation and sharing. I have published some relevant articles on these topics in national and international journals. I am also the author of three packages for R – pedometrics, spsann, and febr – and maintainer of the Free Brazilian Repository for Open Soil Data (febr). As a lecturer, I guide students to develop the necessary field, laboratory and computer skills to understand soil processes, produce soil information and layout sustainable land uses.

Announcements

My ideas concerning the vice-chair

The Digital Soil Mapping Working Group is one of the most active working groups of the IUSS. The WG deals with several challenges that go from sampling to uncertainty communication, which are revisited every two year at the DSM Workshop. As vice-chair of the DSM WG, I will work closely with the WG chair Dr. Laura Poggio, establishing a constructive relationship and sharing responsibilities. Among these responsibilities is the organization of the DSM Workshop and related IUSS events. I also plan to work on improving the communication among the WG members and of these with digital soil mappers from countries that have had few opportunities to participate in the WG events and discussions. The main goal is to broaden the community, bringing together more pedometricians to address DSM's most pressing challenges.

IUSS WG Global Soil Map

In the previous issue of Pedometron we announced that the IUSS WG GlobalSoilMap prepared a motion to the Global Soil Partnership (GSP) to be invited to INSII meetings and become a member of the Global Soil Partnership Pillar 4 WG. Last November, at the GSP INSII meeting at FAO, that motion was excepted by the working group members and the International Network of Soil Information Institutions (INSII). On June the 6th, while we were all attending Pedometrics 2019, the GSP Plenary Meeting was held and the motion was accepted. Congratulations to Dominique Arrouays, Pierre Roudier and Zamir Libohova! This is an important milestone for GlobalSoilMap and as well for Pedometrics because it will open doors for our community to broaden the scope of our research.

The motion describes how the IUSS WG GlobalSoilMap can 1) help drafting specifications for new products asked to GSP countries, 2) act as a R&D WG helping to improve methods for bottom-up mapping and further harmonization, 3) improve methods for uncertainty assessment and mapping and transfer them to INSII and P4WG of the GSP, and 4) help with training and capacity building.

Special Issues

Geoderma Regional – Virtual Special Issue entitled 'DSM and GSM'. This special Issue is related to the the IUSS WG's GlobalSoilMap and Digital Soil Mapping conference SoilMapping2019, March 2019, Santiago, Chili. Submission deadline is 15 July. You can submit your paper by selecting the VSI: DSM and GSM online https://www.journals.elsevier.com/geoderma-regional

Remote Sensing Special Issue "Digital mapping in dynamic environments", edited by Budiman Minasny and Brendan Malone. Submission deadline is 30 December 2019. More details can be found here: https://www.mdpi.com/journal/remotesensing/special_issues/digital_mapping

Geoderma – special issue related to the IUSS Pedometrics2019 conference, June 2019, Guelph, Canada. The special issue is not yet online but details will be send via the pedometrics mailing list as soon as possible.

Upcoming conferences and call for abstracts

2 – 7 September, 2019, TERRAenVISION2019: Working towards the sustainable development goals, Barcelona, Spain. Abstract submission deadline 15 July for oral presentations but it remains open for poster submissions.

6-11 October, 2019, 7th International Symposium on Soil Organic Matter: Soil Organic Matter in a stressed world, Hilton Adelaide, Australia. Abstract submission deadline passed but is open for poster submissions.

In conversation with Margaret Oliver

We asked Prof. Margaret Oliver to discuss her experience as Editor-in-Chief of the European Journal of Soil Science (EJSS).

You have a strong track-record in Soil Science and you have made great contributions to Pedometrics and geostatistics over the years. What was your main motivation to do soil science?

My first introduction to soil science was at school in Advanced Level Geography. We were learning about the links between different types of soil, climate and vegetation. I found it absolutely fascinating, and the two soil types that made a great impression on me were Podzols and Chernozems. They were so different from each other and I was keen to learn what kinds of processes led to such differences. I was also studying physics, chemistry and geology and I wanted to link these in some way, in particular the geology. I found a University science and geology. We had a marvellous soil science lecturer (Len Curtis) who inspired many people to follow a career in soil science such as Steve Reynolds and Stephen Nortcliff, to name but a few. After my undergraduate degree I was keen to do a PhD, but I had a gap of a few years when I got married and had two children.

I began my PhD part time at the University of Birmingham (UK) with Professor Roland Moss as my supervisor. The original task I was given was to apply the USDA Seventh Approximation to the soil of the Wyre Forest. I went through the Seventh Approximation in some detail and also did some preliminary surveys of the soil of the Wyre Forest; the task seemed impossible. The soil of this area, which is on deltaic sediments of Carboniferous age, did not lend itself to the very prescriptive classification of the Seventh Approximation. I then had lengthy discussions with two eminent soil surveyors from the Soil Survey of England and Wales at the Wolverhampton office and I also went in the field with one of them. Noting how the soil was surveyed and mapped, I decided that I didn't want to follow the Soil Survey of England and Wales's approach. What to do?

I decided to apply multivariate statistical methods of analysis to the soil of the Wyre Forest after much thought and discussion with Mike Hodgson (one of the two soil surveyors I had most contact with). I sampled at the usual intensity of the Soil Survey of England and Wales, but in a random stratified way so that the data would be suitable for statistical analysis. The result was 201 sampling points at which there were small pits and I sampled at three fixed depths. The eventual data were based on Soil Survey properties for comparison with the existing classification.

The ordination showed that there were no well-defined clusters although there were considerable differences in the soil over the area. The hierarchical numerical classifications produced poor results with no stable clustering by the various methods. A non-hierarchical approach resulted in a more apt and useful classification. I was aware during the sampling sessions that the soil varied considerably from place to place and found the degree of variation intriguing. Nevertheless, the ordination suggested that the variation was a continuum. I then plotted the classes on a map and suffered a major disappointment at the lack of spatial coherence between the classes. The average sampling interval was 160 m and there was little spatial extent to any of my six classes. It was clear that something was amiss with the sampling interval and I was faced again with what to do next. I had been using Richard Webster's original book *Quantitative and Numerical Methods in Soil Classification* published in 1977. Mike Hodgson encouraged me to contact Richard about some of the difficulties I was having with my analyses. This was 1979 and I had read various papers about sampling including some on nested sampling, which by then seemed the way forward. I first met Richard in April 1979 knowing that I needed to take a different approach to sampling to understand spatial scale. And so the path to geostatistics was established and provided me with a focus for the research that followed. If my initial sampling had yielded reasonable results – I would probably not have ended up in geostatistics. This was an important lesson when doing research, i.e. not to let negative results be a setback. They might be the most crucial in many ways because they force one to look further.

Geostatistics appealed greatly because of my long term interest in spatial variation and the desire to gain insight into the underlying processes, and linked with these a growing interest in spatial scale and how this affects our appreciation of the variation. It is complex and that was a further appeal.

How did you manage to balance your private and professional life throughout your career?

I have been working in soil science since the early 1980s. I was a late starter in research having two children early on. Before I had my daughter I taught geology and some geography in a secondary school, but realised that my heart was in research. After my daughter was born I taught in local colleges of further education for two days a week, and after my son was born for just one day. When Andrew went to school I decided to do a PhD part time. I still did a little teaching as well. I have been fortunate to have a supportive husband throughout my career, but when the children were young his job meant that I had to be available for them at any time. Working or doing research part time fitted in well, but it did slow down my progress in academia. However, I have no regrets about the path I took, but in today's climate it might have been quite different. I have made up for the slow start since and am still working long after I retired officially from my University position in 2004. I have been very fortunate to love what I do and it has never seemed like a job.

You were appointed as editor-in-chief in 2015 of the European Journal of Soil Science (EJSS). What motivated you to accept the role of editor-in-chief for EJSS?

It was not an easy decision to make to accept the role of Editor-in-Chief (EiC) because I knew that it would be a very hard task to follow in the footsteps of so many excellent editors of EJSS and to maintain the high standard that these editors had achieved. I was originally an Associate Editor for about six years with Derek Rose and then Richard Webster as EiCs and then Deputy Editor for four years from 2011 to 2015 with Steve Jarvis as EiC. I was knowledgeable about how the journal functioned, but I knew that the step from Deputy Editor to EiC was a major one. I was concerned to maintain the strong standards, but at the same time to respond to the many changes in soil science. I was also the first female EiC of EJSS and this also meant some additional pressure to maintain standards.

Considering that EJSS published an early paper on geostatistics in 1980 by Richard Webster, we have published fewer Pedometrics papers more recently. I was keen to redress this by having a special issue of papers from the 2017 Pedometrics meeting. This was published in January this year and comprises a strong collection of papers. I hope that this will continue into the future given that early Pedometrics papers were published in the EJSS.

What makes the EJSS unique compared to other journals?

The EJSS is the oldest soil science journal and it has focused on the basic science of the subject. It includes all aspects of soil science, but not management which is the remit of our sister journal *Soil Use and Management.* The journal has always placed a strong emphasis on the quality of statistical analyses and this probably reflects the strong early links with Rothamsted Research where many methods of analysis were developed.

In conversation with Margaret Oliver

What has changed mainly at EJSS under your leadership?

I am sure that everyone who has taken on the task of EiC of EJSS has wanted to make some changes. I wanted to broaden the remit of the journal to embrace topics relevant to soil in relation to humans. Soil and human health is an interesting but complex topic and I hope an area that will develop further over time. We have had one small special section on soil and health and there will be another later this year.

The journal changed remarkably during my four years as EiC with many more papers from China being submitted and published. The standard of Chinese papers has increased markedly over this period. The number of papers involving microbiology, DNA and omics also increased greatly during my four years as EiC.

A major change during my time as EiC was to have a statistics editor who dealt mainly with problems related to the analysis of variance (ANOVA). With the advent of 'push button' statistics, ANOVA suffered greatly because of a basic lack of understanding of the assumptions and the basis of the analysis in relation to the experimental design of the authors. Pat Bellamy helped authors to understand what they were doing and ensure that the results fitted the design. We have been the only soil science journal to offer such comprehensive support to authors. In addition, Murray Lark continued to chair the statistics committee which deals with more complex and unusual analyses. This was introduced by the previous EiC, Steve Jarvis.

About your experience as editor in chief. Over the years, you have gained a lot of insight in the reviewing process?

Simply, yes. The whole process of getting a paper from submission to publication is long and complex. It involves many people that authors are not aware of. Papers were handled by two members of the senior editorial team on submission; this team comprised me and the deputy editors. At this stage papers on topics that were unsuitable for EJSS were rejected. We always aimed to explain the reasons for the rejection to authors and to suggest other potential journals. Another major reason for rejection was lack of novelty in a paper, an important remit for EJSS. Sometimes we felt that this could be redressed, but at others there was little chance of this. Poorly constructed papers might be rejected unless the topic was sufficiently interesting to warrant a further submission. Papers that seemed suitable at this stage would be sent to an Associate Editor (AE) with the relevant soil science expertise and they would then select reviewers. It has become increasingly difficult to get people to review papers because of the pressures they are under and also there are so many more papers going through the system. Some reviewers are very conscientious and produce a detailed report on time, whereas others can overrun seriously and yet others produce inadequate reports. Once the reviewers' reports were in, the AE would assess them and recommend whether the paper should go for some level of revision or be rejected. The paper would then be passed to me and I would read the reports and decide whether or not to follow the advice of the AE. There were occasions when I made a decision different from their recommendation, but they were not frequent. At that stage I would assess the state of the statistics and recommend authors to deal with any problems identified. If it seemed likely that the paper would be accepted eventually I would sent it to the statistics editor or panel for further advice.

When the revised paper came back in, it would go to either an AE for assessment and possible rereview depending on the level of the original review or it would come to me for editing. Often at this stage there would be some revision of the statistics required and also editing for style and structure of the paper.

Can you give us an idea of how many manuscripts are submitted and subsequently handled by you?

Over the past two years and this year appears to be no different, we received well over 400 papers. This was more than a hundred more than previous years. The EiC was likely to handle at least 80 to 100 papers a year at the final stages, but some of these I would have seen several times. It involved checking reviews, editing for clarity and style and checking proofs when they come through.

In conversation with Margaret Oliver

How much time does an editor-in-chief spend on the task?

This varies considerably from paper to paper. Papers that are poorly structured or with poor English require considerable time input, whereas others require considerably less. The time I spent increased considerably during the last two years because of the large number of papers being submitted and going through the system. The deputy editors were fully occupied with new scripts and some of the editing, and Pat Bellamy consistently spent more time than he was allocated.

Is it complicated to find suitable reviewers that have enough experience and time to deliver high-quality reviews?

Obtaining reviewers has become very difficult and authors should remember that they need to review at least two papers for every one that they publish. The difficulty is that everyone in academia and research is so busy with the multitude of tasks they are expected to deal with, and so it leaves little time for reviewing. Worldwide there appears to be more bureaucracy which takes valuable time from our science. Supervisors and senior members of staff need to train their PhD students and postdoctoral staff to review papers. It helps them immensely in their own research and publication programme.

In your opinion, what are the most 'common mistakes' authors make and how can they be avoided?

I will enumerate these for clarity:

1. Failure to read the journal's guidance notes for authors. This would save authors, editors and reviewers a great deal of time. For example, we ask authors to state clearly what is novel about their paper, but this is often omitted with the possibility of rejection.
2. Failure to read the journal's remit. We receive many papers on management and applied soil science that are not in the journal's scope – again this wastes authors' time and that of the editorial team.
3. Poorly structured writing and lack of logical flow in a paper. Authors should remember that most of our AEs and reviewers are non-English speaking, therefore, if your paper is difficult to read and understand a reviewer or AE is likely to reject it or send it for major revision. Straightforward logical construction makes your work easier to understand and value. This also applies to the language – long complex sentences do not help research to be understood.
4. Sampling and experimental design. So often we have had to reject papers because the sampling or experimental design do not comply with the analysis the author wants to do. Before undertaking a study, a researcher and potential author should think of how they might want to analyse their data at a later stage. I learned the hard way by following a prescribed format for sampling intensity even though I had spent some time considering this before my survey. It is always worthwhile talking to a statistician at the start of a programme of research to avoid the pitfalls of inadequate sampling or poor design. Supervisors should be alert to this and the Pedometrics community is probably the most careful in this respect.
5. Statistical analysis and other techniques. Authors often mention a method or technique and assume all readers will know what is meant. All methods and techniques should have a short description and reference to more detailed description that readers can follow up. Often it is a sign that the author does not understand the method or technique and this might be evident in what comes later.

Is there a message you wish to convey to the Pedometrics community?

I was heartened at the Pedometrics meeting of 2017 to see that it was so well attended and that there was a healthy mixture of males and females. The Pedometrics community has the expertise to gain insight and to provide explanations from the detailed data coming from the various branches of soil science – keep the boundaries of our subject soft so that the whole can evolve. Avoid seeing negative results as a setback they are what will lead to new ideas and so allow the subject to evolve.

Conference report

Digital Soil Mapping and GlobalSoilMap Workshop

By Yannik Roell

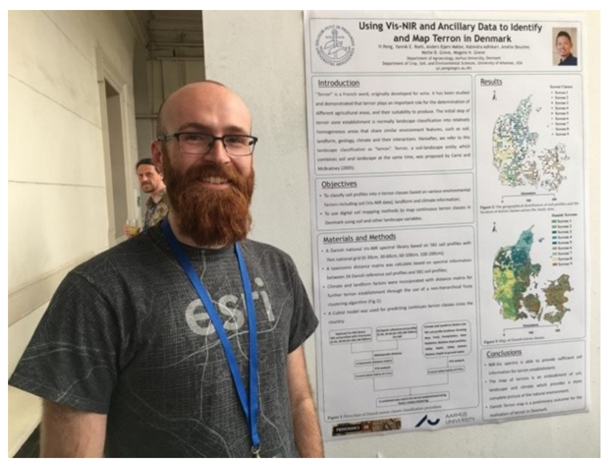
Flying nearly 10,000 kilometers is a rough start to any conference but the experience was well worth the travel. Being new to the digital soil mapping (DSM) community, the conference was a perfect opportunity to finally put faces to names after a year of reading papers. The 2019 Joint workshop for Digital Soil Mapping and GlobalSoilMap was hosted by the University of Chile in Santiago, Chile. Attending the conference from March 12-16 in the southern hemisphere was a great way to absorb new information and much needed sun.

Day 1: Technical Workshop

To kick off the conference, a technical workshop was offered to the participates. José Padarian started the day with R codes that introduced some new libraries and handy functions that I was not aware of. It's always refreshing to put new code into the coding arsenal. After lunch, Google Earth Engine (GEE) was in the spot light. José demonstrated the functionality of GEE and how it can benefit our mapping workflows. Due to the power of GEE performing models on the fly, anyone performing large scale modeling should incorporate GEE at once. This rousing day of new codes and insightful demonstrations of GEE ended with a welcome event. The social event started off with finger food of many kinds and local Chilean wines. After meeting fellow participates of the conference, we were entertained with an exciting demonstration of dances from all the different cultures of Chile. The dancers were captivating and showed real pride in their performance.

Day 2: Presentation Day

With the icebreaker behind us and the technical workshop over, it was time to start the presentations. The day was full of talks from all over the world. The beginning of the day focused on the GlobalSoilMap. The last session of the day was student presentations with my work on terrons in Denmark being the last talk of the day. Putting the last year's work in five minutes was difficult but always a fun challenge. These short five minute student presentations were a great way to end the day before the general discussion. With my presentation done, I was ready to explore the city with fellow participates and have dinner in the lively part of town.



Day 3: Listening and Learning

With only two more days of presentations, we had a lot of information to cover. Thus, we started the day with a great overview from Laura Poggio. Laura's presentation was entitled "DSM and its applications". Her overview covered the history, current work and where we should be going with DSM. These topics were an ideal way to start off the day. Having completed my presentation yesterday, I was able to focus on soaking up new techniques and seeing how people are implementing DSM into their workflows. After lunch, there was a small poster session. While the number of posters were limited, this allowed for a more thorough read and discussion that is not possible in poster sessions with hundreds of posters. We capped the rest of the day off with short presentations and finished with a general discussion that lead to some thought-provoking points. We all went back to our respective accommodations for a short period of time before the conference dinner was served. The meal was delightful and ended with a dessert that was exquisite. The dinner setting provided a perfect opportunity for a variety of intriguing conversations. Nicolas Lito, one of the local helpers at the conference, entertained the crowd with Chilean songs from his charango. The few and proud (mainly those not presenting the next morning) remained at the conference dinner until we were kicked out from the hotel banquet hall at midnight. All in all, the day was a success.

Day 4: Closing remarks and Sunshine

The morning, starting sharply at 9 am, was started off by Axel Schmidt talking about using DSM in the field in regions with much less data than we are typically accustomed to. The day was short but still filled with great talks. A handful of short presentations were given prior to the general discussion. The day ended with awards that included a bottle of liquor from the university's research station. With the day ending early, I had additional time to explore the town and enjoy the sunshine. The night finished with a few of us joining for dinner on a quaint street off the main drag. The presentation days were jammed packed full of outstanding presentations and useful nuggets of information that I will be implementing into my own work.

Day 5: Getting Dirty

The excursion after the conference was wonderful. We drove to a nearby research station to view a few soil profiles. With soil not being my background and being new to this community, I always wondered what would happen if a soil profile was presented to a bunch of soil scientists. As expected, people grabbed the different tools and started observing the soil right away. It was clear to see who were the soil scientists and who were the computer scientists. Never seeing soil from Chile, I rolled up my sleeves, got my fingers dirty, and tried to learn the main differences between Danish and Chilean soils. After checking out the few soil profiles, a Chilean barbeque was for lunch at the university's vineyard. We all ate our fill on the delicious spread and relaxed before trying to learn some traditional dances from Nicolas. Some might say we were successful at learning the dances but I think most would agree it was more entertaining to watch. The short bus ride back to Santiago concluded the workshop and we all shared our goodbyes before departing our separate ways.

With my first DSM and GlobalSoilMap workshop completed, I was happy to walk away with new contacts and new ideas for my own work. I was not looking forward to flying back to winter, but I was ready to get back to work with my new inspiration. I am looking forward to seeing what this hard-working community has to offer in the future.

[Photos provided by Kabindra Adhikari]

Thanks!

Conference report

Pedometrics2019 conference, Canada

By Dongxue Zhao

Travelling to “The Royal City” of Ontario, Pedometrics 2019 (June 2-6) was a trek to the galaxy of pedometricians. Hosted by Assistant Professor Asim Biswas and colleagues at the University of Guelph it was the first international conference I’ve ever attended.

The conference theme: “Connecting Existing to the New Data and Methods for Process-based Ecosystem Modelling” and its proceedings paved way to the kingdom of knowledge. It was a great experience.

Travelling in the Knowledge

There were a lot of impressive presentations. I absorbed much new information and techniques. One of the most interesting and stimulating presentations was from Professor Dominique Arrouays (INRA) who mentioned Soil was at the crossroads of Global Issues and essential to achieve many of the sustainable goals.

He reinforced to me that the soil is not only essential for food production, but also a filter to pollutants, as a biological reserve, reservoir for water and potentially carbon storage. This presentation nourished my understanding of soil science and its significance as a central part of environment. His discussion about the GlobalSoilMap project intrigued my thoughts about current challenges and future directions in the field of DSM at global scale.

Another notable presentation was from the Richard Webster Medal winner, Professor Richard Murry Lark (University of Nottingham) who illustrated his understanding on big data, digital soil mapping, and the role of pedometric in pursuit of sustainable development.

I also enjoyed the talks from Professor Alex McBratney (University of Sydney) and Professor Budiman Minasny (University of Sydney). Prof McBratney discussed model performance to predict soil properties in 2.5D or 3D and noted the importance of including depth as a covariate. Prof Minasny’s talk gave insights into application and advantages of different portable near-infrared sensors on the predictions of soil properties.

Another interesting presentation was from Dr Wenjun Ji (Swedish University of Agricultural Sciences) who talked about fusion of data from different on-the-go sensors; including Vis-NIR, electromagnetic induction (EM) and Gamma ray spectrometer to assess soil variability. She went on further to assess whether 3D regression kriging could be used to predict soil properties along depth.

Conference report

Field trip

The field trip was also a highlight. It was amazing to look at the glacio-lacustrine soil at “Hipple Farm” and understand it with respect to the various soil forming factors and processes. What I will remember most, is the fact the sediments, which the soil formed from, were deposited at the bottom of a lake where icebergs melted releasing fine clays and silts and the odd large bolder or two

Our visit to Niagara Falls was stunning and incredible. The volume of water flowing was a natural wonder to behold. I think I will take up the recommendation of my supervisor (Associate Professor John Triantafilis) and take some soap and shampoo because by the time you are finished you are so saturated you are “dripping wet.” P.S. A towel to dry off with is an absolute minimum!

Exchanging ideas

I really enjoyed the discussion at the end of each session. I realised that many of the questions I had were common among the participants and it was an excellent opportunity to share experiences and learn from each other. I like that many high-level scientists asked inspiring questions and gave insights and guidance on future research topics for the younger scientists.

The conference also allowed me to meet scientists whose work I had read many times over. While it is nice to read, sometimes I never quite understood what it all meant. However, meeting them in person was a fabulous experience.

In this regard, I was able to meet Professor Murry Lark. He was very gracious with his time and gave me further insights into his papers on loss function and wavelet transform. The conversation has given me new impetus to try to work through the papers again and use it in my own research.

It was my honour to attend Pedometrics 2019 and to meet so many old and new friends. After four days of conferencing, my “bag” was full of new ideas to help guide my research. I look forward to exploring these as soon as I get to “hardly” working. Through this conference I have also got clearer picture on how my time during my PhD at #UNSWSoilScienceCentral2019 is shaping my ideas. My supervisor (Associate Professor John Triantafilis) is always there to give unconditional support although sometime the “love” is a little too tough! In spite of

From left to right: Dongxue Zhao, Murray Lark, Nan Li

this, he has imbued in me a passion to be precise and persistent in presenting our research as best as I can. His philosophy to "hardly" work and "play hard" paid off on this trip.

I was also very proud of my fellow PhD students (Maryem Arhsad, Nan Li, Tibet Khongnawang and Ehsan Zare) who accompanied me to Pedometrics and also the 5th Proximal Soil Sensing Workshop (Columbia Missouri). Seeing them also shine brightly and bring their research to the light of other Pedometricians was very satisfying.

This is particularly so because we also teach and encourage each other. It was nice to see them in the audience, smiling like family members looking at me with pride and admiration. I am pleased that I got the chance to represent #UNSWSoilScienceCentral2019 on two world stages.

Acknowledgments

I acknowledge the financial support of the UNSW Graduate Research School, School of BEES and PANGEA for providing me with financial support which enabled me to attend Pedometrics 2019.

I also thank my colleagues at #UNSWSoilScienceCentral2019 for being my family away from home and on or epic odyssey from New York, Chicago, Springfield, Hannibal, Columbia (Proximal Soil Sensing), Indianapolis, St Louis, Toledo, Guelf, Ann Arbour and Chicago.

Pedomathemagica

Gerard Heuvelink & Luc Steinbuch

A fragile ground radar

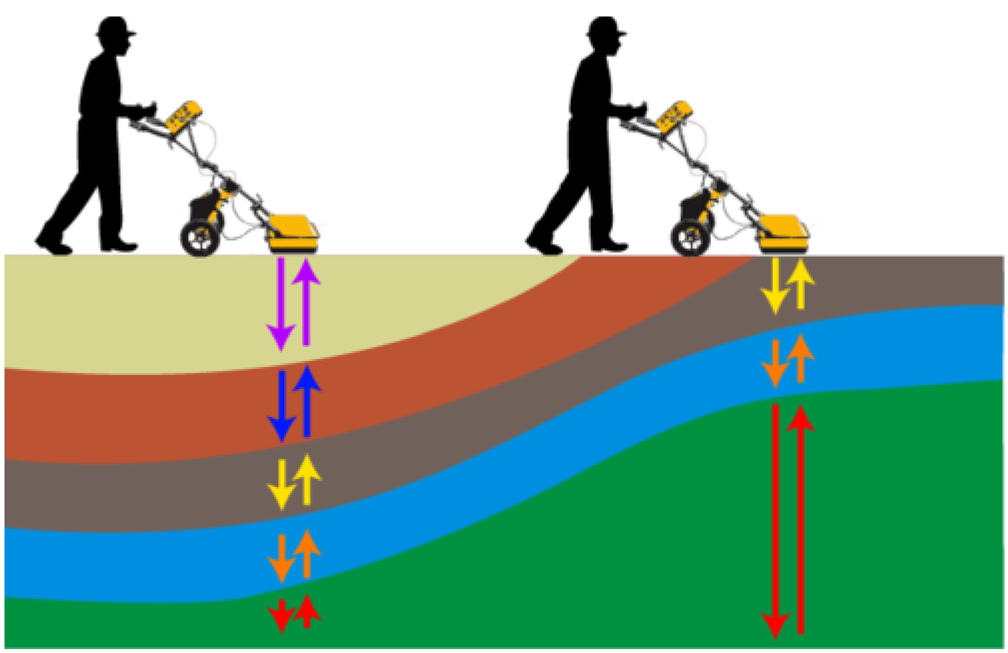
Our colleagues Don Tuse Expon *et al*. together with technician Reci Procal constructed a new type of ground radar. However, two of its components are quite fragile: The VHF/UHF high power transmitter has a mean time between failure (MTBF) of 10 hours and the titanium/iridium alloy ground-penetrating antenna also has an MTBF of 10 hours. The rest of the device always works, each component is essential for proper functioning, and any failure is very inconvenient but can be repaired immediately. Also, the failure of each component is independent of the failure of all other components. First question:

1) The technician – who is, by the way, not a statistician – states that the MTBF for the whole device is 5 hours. Can you reconstruct her calculation?

In the next development step, the normal receiver is replaced by an highly experimental Fourier transform based receiver which has an almost exactly defined MTBF of 8.4525 hours. So:

2) Our colleagues would like to know the new MTBF for the final device with those 3 fragile components, and

3) can you suggest a proper nickname for this final device?



(picture from https://www.indiamart.com/epitomegeotechnical/ground-penetrating-radar-survey.html)

Pedomathemagica—Answers from previous Pedometron

Puzzle 2: Organic matter (de)composition

For **Question 1**, first note that M_A, the unknown mass of sample A, loses half of its weight in 180 days because of its half-life of 180 days. Also, the unknown mass M_B loses half of its weight $\frac{Total\ time}{Half\ life} = \frac{180\ days}{45\ days} = 4$ times over, so retains $\frac{1}{2^4} = \frac{1}{16}$ of its original weight.

Now we have got two equations with two unknowns.:

$$M_A + M_B = M_{total\ begin}$$
$$\frac{1}{2}M_A + \frac{1}{16}M_B = M_{total\ final}$$

As we measured $M_{total\ begin} = 1$ kg and $M_{total\ final}$ = 0.4125 kg, we can calculate that $M_A = 0.8$ kg and $M_B = 0.2$ kg.

Question 2 follows the same logic, boiling down to three equations with three unknowns.

Question 3 brings us to the coincidence that C. D E A B = 2. 7 1 8 2, the first five digits from the base of natural logarithms e, also called *Napier's constant* or *Euler's number*, and discovered by Jacob Bernoulli in 1683. By the way, e is often used in decay functions.

A cartoon

By Anne Richer de Forges and Dominique Arrouays

On illuminating the uncertain future of the uncertain soil microbia

Vanessa Pino, Mario Fajardo & Alex McBratney

While historically the pedometric emphasis had been placed upon soil physicochemical attributes the largest (knowledge, spatial and temporal) uncertainties remain in soil biological aspects. A few potential questions here would be why quantitative soil ecology has not received much attention in pedometrics – despite the usual fascination for reducing uncertainties! – Why are digital mapping and spatial analysis of soil biodiversity or the use of remote sensing technologies for collecting soil biological data largely missing topics from the working groups and open discussions in our conferences, for example?

This is critical when considering the relevant role that soil biodiversity is playing these days e.g. see for example a trending topic promoted by FAO about agricultural biodiversity *versus* zero hunger. There are important international frameworks such as the Global Soil Biodiversity Initiative (GSBI) – working since 2011– a few years after GlobalSoilMap - in which pedometrics could be contributing more actively. What is interesting is that one recurrent call from these working groups is on the improvement of soil biodiversity assessments by mapping more and including more of the soil abiotic variability in the analysis. The truth is that most of the uncertainties in quantitative soil ecological studies are believed to be in the *in situ* soil variability (Nesme et al., 2016; Ramirez et al., 2018; Vos et al., 2013).

So, what is stopping us from exploring more on soil ecology and biodiversity? Definitely, an important reason could be the nature of the biological data. Soil ecology examines the interactions between biotic (e.g. microbes) and abiotic properties of the soil environment. These are multidimensional interactions that vary over different scales in space and time. From a pedometric point of view, there is nothing new here or anything with which the pedometricians are umfamiliar except for the biological information.

A first complication can arise when deciding what sort of soil biological parameters to work with. Carbon biomass and carbon respiration are, for example, popular ones – easily accessed and cost-effective. However, the highest resolution up to a molecular level such as soil DNA sequences seems to suit better when exploring soil

Hand-on soil biodiversity!

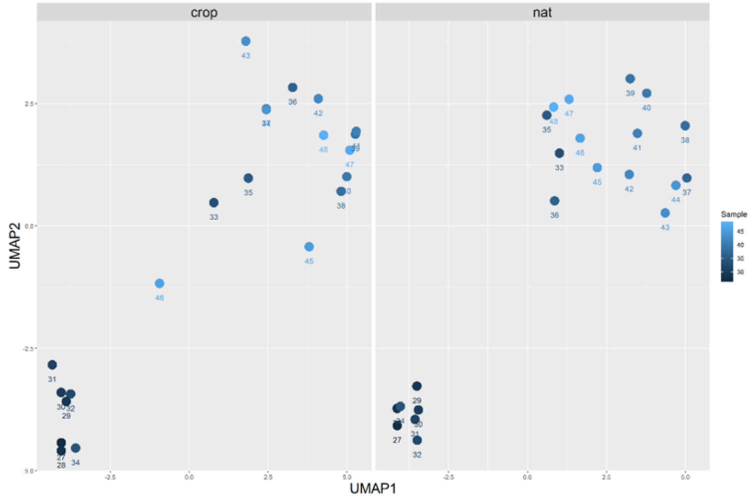


Figure 1 UMAP dimensional reduction on bacterial beta diversity.

ecology pedometrically. First, on the basis of soil DNA sequences, the diversity of soil microbes is estimated at the highest possible resolution in the soil continuum . Secondly, soil biodiversity is directly related to soil functionality to the point that both decays seem to be directly connected (Luo et al., 2018; Wall et al., 2015). This fact places soil biodiversity as a crucial parameter to be included in a digital soil assessment.

From here, we can make use of soil microbial DNA data not only for mapping soil biodiversity but also for finding how to link or infer soil biodiversity changes using other approaches to facilitate access to this kind of information and increase our expertise in working with it. Could the use of spectroscopy or the application of pedotransfer functions be an option in the future? Let's figure this out!

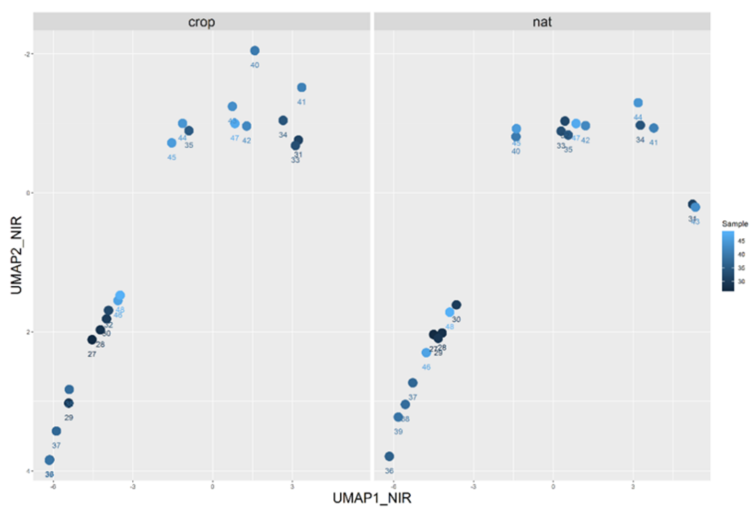


Figure 2. UMAP dimensional reduction on NIR data.

Our first case study seems to be opening a possibilty.

We analyse whether or not can be possible to infer changes of soil microbial diversity from soil NIR data. We analysed the relations between changes of soil microbial diversity based on soil DNA to changes in the soil composition based on NIR measurements. The figures below show part of our preliminary results which so far suggest that there is a relationship between soil microbial beta diversity (i.e. community dissimilarities calculated by

Unifrac distance) and the soil physicochemical attributes captured by the reflection of light in the near infrared part of the EM spectrum. This relationship is even clearer when dimensional reduction is achieved using an innovative UMAP tool (McInnes et al., 2018) is applied.

This relation might seem obvious for a soil scientist, since we study soil as the complex matrix that holds and is affected by microbes an not merely as a sum of abiotic factors that might relate to their activity. Pedometricians sense of the soil matrix is tacitly multi- or even hyper- dimensional… exactly the output that sequencing techinques are delivering and reason why new mathematical algorithms as UMAP are in high demand, exciting times for beeing a pedometrician.

Promising results aside, it is important to highlight the necessity for a deeper examination of quantitative methods that are suited to quantitative ecology and pedology. Pedometrics expertise will surely be a major contribution to such studies..

References

Luo, G., Rensing, C., Chen, H., Liu, M., Wang, M., Guo, S., Ling, N., Shen, Q., 2018. Deciphering the associations between soil microbial diversity and ecosystem multifunctionality driven by long-term fertilization management. Funct. Ecol. 32, 1103–1116.

McInnes, L., Healy, J., Melville, J., 2018. UMAP: Uniform Manifold Approximation and Projection for Dimension Reduction.

Nesme, J., Achouak, W., Agathos, S.N., Bailey, M., Baldrian, P., Heulin, T., Jansson, J.K., Jurkevitch, E., Kruus, K., Kowalchuk, G.A., Lagares, A., Lappin-scott, H., Lemanceau, P., Le, D., Mandic-mulec, I., Murrell, J.C., Myrold, D.D., Nalin, R., Nannipieri, P., Neufeld, J.D., Parnell, J.J., Pylro, V., Ramos, J.L., Roesch, F.W., Schloter, M., Schleper, C., Sczyrba, A., Sessitsch, A., Tebbe, C., Topp, E., Tsiamis, G., Elsas, J.D. Van, Keulen, G. Van, Widmer, F., Wagner, M., Zhang, T., Zhang, X., Zhao, L., Zhu, Y., Vogel, T.M., Simonet, P., Genomics, E.M., Lyon, E.C. De, Environment, N., Road, M., Science, F., Directorate, C.S., Biology, E., Plata, L., Plata, L., Science, E., Science, B., Ecological, N., Network, O., Gabriel, S., 2016. Back to the future of soil metagenomics. Front. Microbiol. doi:10.3389/fmicb.2016.00073

Ramirez, K.S., Knight, C.G., De Hollander, M., Brearley, F.Q., Constantinides, B., Cotton, A., Creer, S., Crowther, T.W., Davison, J., Delgado-Baquerizo, M., Dorrepaal, E., Elliott, D.R., Fox, G., Griffiths, R.I., Hale, C., Hartman, K., Houlden, A., Jones, D.L., Krab, E.J., Maestre, F.T., McGuire, K.L., Monteux, S., Orr, C.H., Van Der Putten, W.H., Roberts, I.S., Robinson, D.A., Rocca, J.D., Rowntree, J., Schlaeppi, K., Shepherd, M., Singh, B.K., Straathof, A.L., Bhatnagar, J.M., Thion, C., Van Der Heijden, M.G.A., De Vries, F.T., 2018. Detecting macroecological patterns in bacterial communities across independent studies of global soils. Nat. Microbiol. 3, 189–196.

Vos, M., Wolf, A.B., Jennings, S.J., Kowalchuk, G.A., 2013. Micro-scale determinants of bacterial diversity in soil. FEMS Microbiol. Rev. 37, 936–954.

Wall, D.H., Nielsen, U.N., Six, J., 2015. Soil biodiversity and human health. Nature 528, 69–76.

*Global Soil Biodiversity Initiative > https://www.globalsoilbiodiversity.org/

A poem

By DvdL

Scrutiny

Forty years of soil
Twenty years of toil
Comprehensive
Carefully crafted
Methods invented
To fill
The imagined frame
Summarily sunk
By a flood of words
Why or why?
To impress or suppress
Negolutely to depress
Incomplete?
Logically always
And forever so
Geostatistical?
It's about the soil
Crafted can-openers
For crucial secrets
Of the hidden pedoverse
Gently carefully
Peruse disabuse
Devise revise
Do it again
Be gracious
In the flak
Do not yield
To the wrath
Of this
Or any time
Until the end of soil
Be bold
Be brave
Be brilliant

spemd: a R implementation of a bi-dimensional Emprical Mode Decomposition

By Pierre Roudier

The spemd package implements a bi-dimensional Empirical Mode Decomposition (EMD). The code behind the package has been originally developed when I was a postdoc at the University of Sydney (many moons ago now!). The package is now hosted on Github (https://github.com/pierreroudier/spemd), and it can be installed directly from CRAN (install.packages('spemd')).

The spEMD algorithm

The empirical model decomposition is a data-driven method to decompose a given signal into different scales (Huang et al., 1998). The EMD decompose the original data into scale-specific components, called intrinsic mode functions (IMFs), along with a residue. Ideally, the mean of IMFs are zero, and the residue is a constant, equal to the mean of the original data. The original data can therefore be reconstructed by adding the different IMFs to the residue. The IMFs can also be studied independently (e.g. to test the levels of correlation at different spatial scales), or the original data can be filtered by excluding certain IMFs.

Example using elevation data

The data used in in this tutorial is a 100-m resolution SRTM digital elevation model (DEM) from a 10 by 10 km area located near the city of Göttingen, Germany. This data set is distributed as part of the `plotKML` package (Hengl et al., 2015).

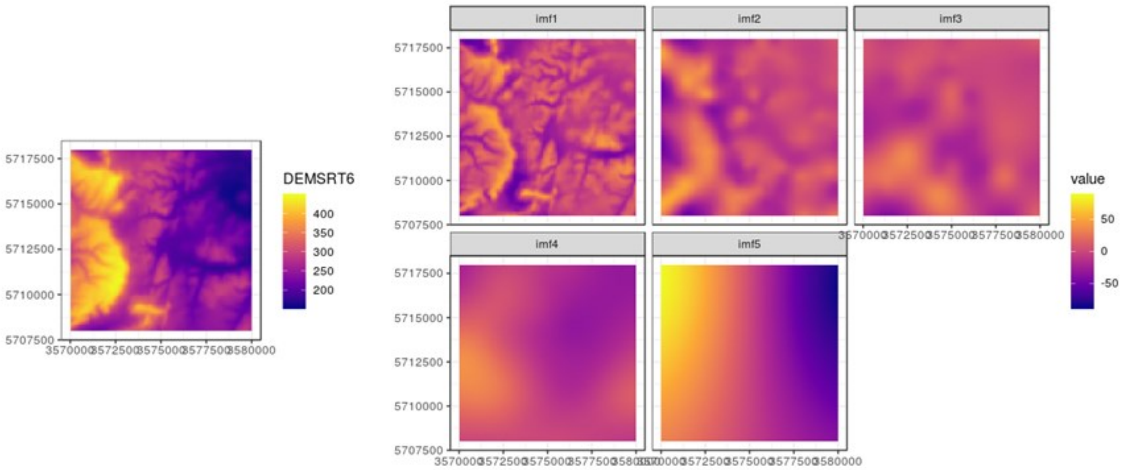
```
library(sp)
library(spemd)
data("eberg_grid", package = "plotKML")
dem <- eberg_grid[, c("x", "y", "DEMSRT6")]
coordinates(dem) <- c('x', 'y')
proj4string(dem) <- CRS("+init=epsg:31467")
gridded(dem) <- TRUE
```

The spatial EMD is run using the spEMD function. There are a range of options available, but the most important ones are data, the data set to be processed, `zcol`, the name of the column storing the relevant attribute, and `thresh.extrema`, a tolerance level for the creation of IMFs.

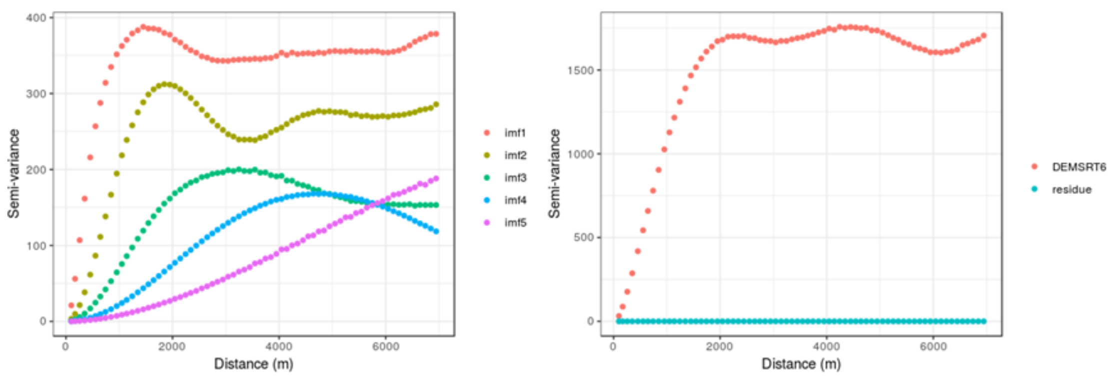
```
res <- spEMD(data = dem, zcol = "DEMSRT6", thresh.extrema = 0.1, verbose = FALSE)
```

The results of the decomposition is a suite of 5 IMFs, along with monotonic residue (composed of a single value: 284.32). This number is close to the mean of the original data (276.62), but not exactly the same due to the tolerance factor used to make the decomposition faster, and more parsimonious.

What's new in R?



IMFs 1 to 5 correspond to components of the original signal at decreasing spatial scales. This can be properly quantified by plotting the semi-variograms of the respective IMF. The semi-variogram of the original signal ("DEMSRT6") and of the residue are also presented for comparison.



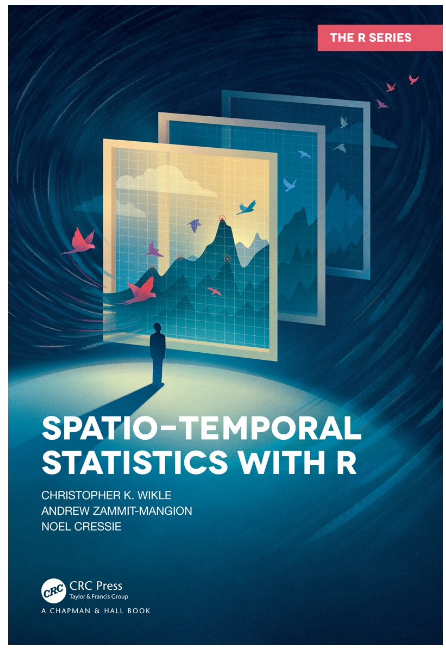
We demonstrated its capabilities on raster data, but it is worth noting that the `spemd` package also supports non-gridded/sparse data sets.

Recent publication: Spatio-Temporal Statistics with R

Wikle, C. K., Zammit-Mangion, A., & Cressie, N. (2019). *Spatio-Temporal Statistics with R*. CRC Press.

Book review by Madlene Nussbaum

Free PDF available: https://spacetimewithr.org



Alongside the omnipresent aspect of space in pedometrics research, time-structured data are gaining ground. This new book offers a timely hands-on introduction based on the previously published and more advanced "Statistics for Spatio-Temporal Data" (Wikle and Cressie, 2011; Wiley). Each chapter closes with R labs, including easy-to-implement examples. The focus on direct application is underlined by "R tips" boxes containing the R packages and functions needed to apply the methods covered in each section and by the inclusion of the "STRbook" R package along with the book. This R package has not, however, been uploaded to CRAN (most likely due to data limitations of the repository) and hence has not undergone CRAN's formal checks. Help pages for some functions and descriptions of the provided datasets are unfortunately missing from the package.

The authors take a classical approach to spatio-temporal data analysis. This is reflected in the table of contents; the book starts with descriptive visualization of data, continues by applying parametric descriptive and dynamic models, and then evaluates these. The content is mainly rooted in the hierarchical approach, which makes a clear distinction between the data and the underlying latent process of interest. Besides classical linear statistics, generalized linear and generalized additive models are also briefly touched upon.

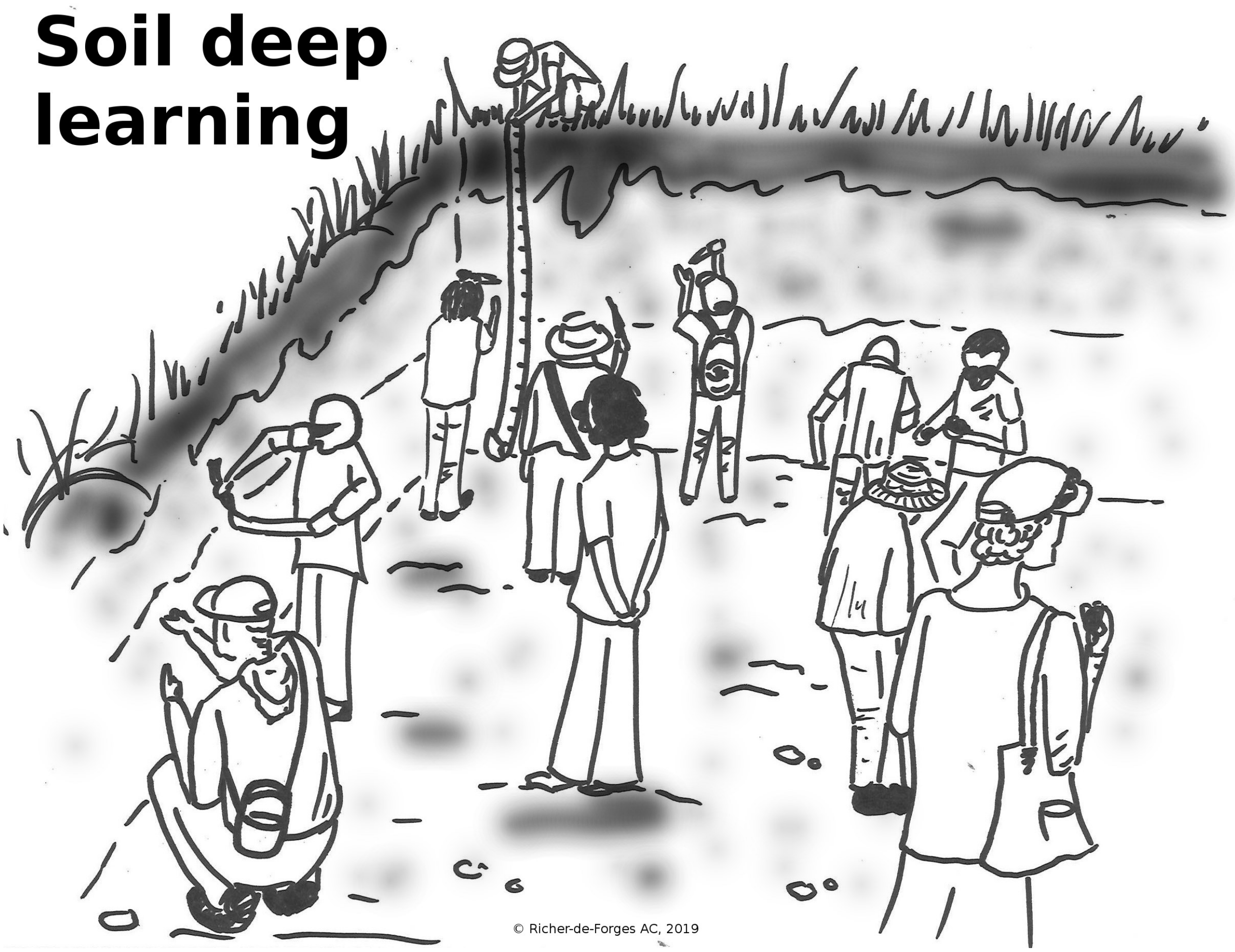
Statistical learning approaches for space-time data remain vague, being mentioned only in passing. Moreover, model selection is only very briefly discussed, despite its being a recurrent problem for most modelers nowadays, in view of the ever-increasing quantities of input data. Also absent are robust model-parameter estimation and other methods beyond the classical Gaussian framework.

That said, scoring rules to evaluate probability predictions – often neglected in Pedometrics – are outlined properly. R code is mostly up-to-date. Examples are based on the latest R features, such as "tidyverse" syntax and data types, although the authors stick to the "sp" package and have not adopted the new representation of spatial classes in the "sf" package.

In summary, this book provides a very neat introduction to classical space-time data analysis for R modelers. The presence of a freely available PDF version, step-by-step tutorials, "Technical Notes" providing a brief statistical background, and even a matrix algebra refresher in the appendices also make the book a suitable basis for teaching. However, Pedometrics readers should keep in mind that approaches exist beyond the ones presented here, which were not included by the authors "because of space and time limitations" (p. 304).

Another cartoon!

By Anne Richer de Forges and Dominique Arrouays



The PM10 challenges

We asked a few Pedometricians to give their opinion, to comment or to add to the PM10 challenges proposed by Gerard Heuvelink in the last Pedometron. We obtained a few answers, from Zamir Libohova, Philippe Lagacherie, Lin Yang and Johan Bouma. We start by the latter .

A comment or answer to the PM10 challenges (1/4)

By Johan Bouma

Johan Bouma is emeritus professor of soil science at Wageningen University. He recently received the President's Award of the SSSA, the Dukochaev medal (IUSS) and the Alexander von Hunboldt medal (EGU).

Reading PEDOMETRON 43 was a real pleasure: it radiated a genuine and adventurous scientific spirit and authentic enthousiasm for the profession. I attended part of PEDOMETRICS 2017 in Wageningen and was also at that time impressed by the presence of a large group of inspired and vocal young scientists.

In the newsletter, Gerard Heuvelink proposed to define ten guiding challenges for future PEDOMETRIC research. Gerard not only asks some key questions about our work but also sticks his neck out, defining ten challenges to start with. I believe that this is what we urgently need in our profession and, oh boy, I certainly missed this type of an initiative at IUSS 2018 in Rio, last August.

I retired, so consider my comments as coming from the sidelines or, perhaps, from the dug-out! I like to react to some of the introductory comments of Gerard and end with a proposal.

(1) Can scientific research developments be planned? True, we don't know what new internal and external methods may become available and which types of research will become "hot". But this is not something that just happens to us! An active mode is preferable. By setting goals, we can investigate whether existing methods work or not and if we have to develop new ones either by ourselves or by shopping in adjacent scientific fields. And whatever will be "hot" in the policy arena can, and should, also be the result of our convincing lobbying. See what the IPCC climatologists have achieved by making their studies one of the "hottest" items in the policy arena. Goal setting is important, I feel, because if you don't: *'any road you take is the right one".* Those of you that have followed my recent publications know that I feel we should see the UN-SDGs as our ultimate goals. They are very broad so everything fits in one way or the other. The UN-SDGs have been embraced by 193 countries in 2015 with a commitment to realize the goals by 2030. Some scientists are sceptical: they feel this is yet another bureaucratic blurp, producing a cheap and temporary "good" feeling that at least something is being planned. I don't believe this and expect that in few years time the indicators for the SDGs will be thoroughly checked and discussed. So better be involved, the more so since soils are crucial when discussing climate change, water shortages, biodiversity loss and increasing agricultural production by 40%, feeding 10 billion people in 2015. We have heard this (too) many times already, so what are we going to do? Luca Montanarella (JRC-EU) and I were invited to present a paper at SSSA-San Diego 2019 in a symposium on SDGs. Luca was very critical of the soil science community not being involved in the SDG debate and in defining targets and indicators, not only because soil input is crucial but also as it can improve communication of the soils work to the outside stakeholder and policy arenas.

(2) I strongly agree with Gerard that there is not enough reflection on what we do and why we do it. The ten

challenges of Gerard sound a bit like the ten commandments of Mozes. When he came down from the mountain his people were dancing around the "golden calf" (still a quite appropriate metaphor for today, by the way). Indeed, sometimes it seems that we, scientists, dance around the "golden h-index". Gerard is right: "we should take more control, we should define a research agenda and work towards its realisation". Back to the need for reflection: there has been a flurry recently of requests to submit abstracts for a series of meetings in the coming months. Digital Soil Mapping and Global Soil map. Chili in March; Pedometrics in June, Canada; Yearly April meetings of the EGU that has now a large soil section; Proximal Soil Sensing in May in Columbia, Missouri, USA; Eurosoil 2020 asking for ideas; Wageningen Soil Conference in August; WRB in July and that's not all. Perhaps the number of frequent-flyer miles should count for the H-factor? Seriously, is this not a bit too much, the more so since several activities fit right into what PEDOMETRICS has been working on? Enough time left to reflect? A rhetorical question. We also see that the IUSS has six Divisions, twenty-two Commissions and nineteen working groups. Don't misunderstand me: any science that does not expand its boundaries and explores new frontiers is a dead science before long. But is anyone putting the pieces together from time to time? Defining challenges, following Gerards proposal, can be a manner to organise a coordinated approach aimed at certain goals, separating major items from minor ones. . This is urgently needed now for soil science at large, in my perception.

(3) But what should be the focus of these challenges? Gerard focuses on Pedometrics and that's logical when contributing to PEDOMETRON. His ten challenges are all inward looking (no 1 mentions applications, though). I like to raise the question here why not also address soil science at large? We need that and PEDOMETRICS is in a unique position to take the lead here, as they emphasize quantitative pedology. Realizing that soil scientists by themselves cannot define approaches to realize the SDGs we need, I believe, two approaches:

1- effective inter-disciplinarily, working with hydrologists, climatologists, agronomists and ecologists, where our input is soil data in space and time. Emphasis is on the dynamic behavior of soil syst ems. Not empirical data that we provide in classical soil surveys but hard data derived from existing but also new methods (e.g. proximal sensors for one) , including its variability. Here, several of Gerards challenges apply but put in a wider context.

Challenge: Which soil data are most effective when contributed to interdisciplinary studies of the dynamic soil-water-atmosphere-plant system in space and time.

2- facing up to the transdisciplinary challenges in a "post-truth" world. We rightly say that 30% of the soils of the world are degraded but at the same time we know what to do about degradation. Many successful studies are available. Why don't too many land users adopt soil protection measures that have been successful in research programs? And how can land-use policies be more effective? There is an increasingly wide gap between science and society. How to close it? I feel that the soil science profession has an edge in trying to be effective here because deep down people have a intuitive affinity with soils. I like to mention here the propositions of the Soil Security concept in which not only the more common elements of soil condition, capa bility and capital are distinguished but also connectivity, describing links with stakeholders, and codification, describing links with the policy arena.

Challenge: how can soil science make a contribution to close the gap between science and society as evidenced by non adaptation of convincing research results.

This, obviously, is only a first quicky crack. My main point is my feeling that the PEDOMETRICS group can make a crucial contribution to the soil science society at this particular point in time by (following Gerard Heuvelink's proposal), proposing a number of challenges not only relating to soil studies but also reaching out to colleagues in other disciplines and to the stakeholder and policy arena. Think about it.

A comment or answer to the PM10 challenges (2/4)

By Zamir Libohova

Gerard opens "10PM challenges" with a very challenging question: "Can scientific research developments be planned?" My first response: "yes and no" and "it depends". It is the preferred escape by many and would earn me an unwanted pontification medal while unleashing a fury of arguments and speculations with perhaps no end in sight. A scientific debate, right? The 10PM challenges laid out so eloquently by Gerard evolve around fundamental and applied research. From the null hypothesis viewpoint, I often ask myself, can the "discovery" and its "expectations" be planned? Should we, and to what extent? NO, I would say, otherwise research models could be poor mirrors of business models, where certain investments would yield certain benefits. The use of "benefit" is vague on purpose, as it could be anything, including profits for a capital venture or stature for a scientist. I am not advocating for or against them, but it goes to the heart of Gerard's observation "Quantity is more important than quality". Unfortunately, it is not an exaggeration. It has become a "modus operandi", except for me. Kidding. How did we get here? Better leave it to the historians, I guess. However, the question of how to overcome this brings me to the 10PM challenges. If I may, for the sake of the argument, group the 10PM challenges, they lend themselves to two major classes: (i) fundamental research questions related to scale, variability and uncertainty (Challenges 1, 2, 3, 4, 7 and 9) and (ii) applied research questions (Challenges 5, 6, 8 and 10). Regarding the fundamental research challenges, soil systems are complex and dynamic and more observations and measurements may help us to better understand them but not necessarily simplify them. Thus, the main challenge remains how to map the uncertainty at every level (point to area, measured to estimated, "wet" sensors to "remote" sensors) and relate it to scale. It is the Holy Grail for just about any science discipline, even for religious ones when it comes to human systems of beliefs and behavior. No shortage of job security. For a more practical aspect, how do we as soil scientists navigate in today's research environment and discovery without losing the perspectives of the fundamental research questions? I would be lying if I claimed to have the answers. I hope, however, that my observations would contribute somehow. Everybody is enamored with machine learning - the technology trap. For obvious reasons, it is fast, "sexy" and capable of feeding the appetite of publishing. At the same time, it has exposed vulnerabilities, especially in measurement support or data support in general, as Gerard has stated previously. Our capabilities to process huge chunks of data at the speed of light have increased exponentially, yet our predictive models are not keeping pace and are only improving incrementally, if at all. I recall a question Alex McBratney once asked, "Why can't R^2 on average be greater than 0.75?" It made me think a lot and I still don't have a good answer. Maybe there is not supposed to be one. Whatever the case, the quest for the answer is humbling and it has made me realize that perhaps increasing the data support would get us there in iterative fashion (i.e. we teach the machines and learn from them) in the long run, hopefully. But how can we do this in the world of competing resources? Gerard touches upon it in Challenge 2 when he talks about uncertainty, decision making and risk analysis. So, my question/challenge is: *Can we translate uncertainty at every scale to cost-benefit and risk assessment analysis capable of supporting any decision*? "Show me the money" is a movie quote that somehow drives my point. I am not suggesting following the money literally, but to make the case to the decision makers for the need for more accurate predictions of soil properties and functions. If we can quantify in monetary values the impact that poor predictive soil maps have on the society, then maybe decisions makers would open their pockets. Maybe, because at the end of the day more accurate maps may not make a difference. However, it should not stop us from trying. I tried to stay afloat and did not dive to the bottom of these challenges for fear of drowning in my own indulgence. Gerard, thank you for sharing these challenges. You have certainly stirred up the pot. I look forward to the debate.

A comment or answer to the PM10 challenges (3/4)

By Philippe Lagacherie

Challenge 1: *Can we better understand proximal soil sensing signals and link these directly to soil functions and applications?*
How well do we understand the physics that causes variation in proximal soil sensing signals and can we model the underlying mechanisms? And if we can, may we then discover that these signals reflect highly relevant soil properties, perhaps more relevant than traditional wet chemistry soil properties? Why do we still link proximal soil sensing signals first to traditional soil properties and only in a second stage to soil functions? For example, why don't we link proximal soil sensing signals directly to soil fertility and soil degradation?

Soil sensing (not only proximal sensing but also remote sensing) is probably our best chance to produce accurate soil maps in the future. This is why I fully support this challenge. The dream is to use the soil sensing without any expensive local measurements that serve for re-calibrating the soil prediction functions. Using radiative models developed by our colleagues involved in remote sensing research for representing the underlying mechanisms of the signal and of its perturbations should be attempted. Using advanced machine learning algorithm, using big datasets that associate measurements of soil properties, soil sensing signal and assessments of potential perturbation factor is another way.

About the two last Gerard's questions: My first opinion was that I did not believe that skipping the step "prediction of traditional soil properties" would emerge as a better solution. These good old soil properties have two advantages over soil function assessments: 1) their measurements are well known with clear and harmonized protocols, 2) they are closer to the physic of the signal (for example Vis-SWIR spectral signature of clay can be related to well-known chromophores). But recent discussions with my colleagues Cécile Gomez and Mogen Greve led me to a more balanced opinion. Successful attempts of linking directly soil sensing signal with functional soil properties exist in the literature. This is probably because soil sensing can capture some hidden soil properties that are more closely linked to the soil function than the traditional soil properties that are involved in the pedotransfer function.

Challenge 2: *Can we develop communicable measures of uncertainty?*
One of the things that pedometricians can be proud of is that as a rule we always quantify the accuracy of our products, typically by probability distributions, although sometimes limited to an RMSE or concordance correlation. Among others, we quantify uncertainties because it tells users of our products whether a product is accurate enough for the intended use. But somehow this is where it goes wrong: many users do not seem to care or are not able to comprehend our measures of uncertainty. We have not made a good job of showing why quantified uncertainty is important and how it can be used. For instance, it may be essential for decision making and risk analyses. If we can communicate uncertainty better then we might be more successful in getting users to appreciate and use our measures of uncertainty.

Actually, the uncertainty of our map has the same status as the special clauses that are written in small letters at the bottom of a selling contract or as the Personal Data Protection protocols that you should read before using any web tool: They are theoretically accessible but nobody cares. Obviously, when setting the GlobalSoilMap specifications, we naively overestimated the ability of the users to get to grips the uncertainty information, yet clearly provided by prediction intervals. My personal experience is that most of them simply dislike any uncertainty and the others do not know how to use it. We should force the users to open their eyes, even if the price to paid is to produce less attractive maps. The solution would be to degrade the map resolution at locations where uncertainty is higher than a given RMSE value or confidence interval width or simply not to provide predictions at these locations (like "terra incognita" of the old maps). I even suggest that the user provides him/herself the error threshold from his/her knowledge of his/her requirement so that the final map could be more acceptable for him (her).

Challenge 3: *Can we develop sound scaling methodologies?*
We are still struggling with the concept of scale. We too often make it vague and obscure because we use poor definitions. In the meantime, there are burning issues. For instance, soil physicists model water infiltration using models based on the Richards equation. Such models are meant for the pedon scale but are also applied (by 'scaling' the model parameters) at the scale of regional Land Surface Models. Should not the model structure change as well when upscaling? If yes, how? How does a non-linear partial differential equation interact with spatial variation? Similar issues arise when modelling soil-landscape evolution. We also haven't really solved the problem of how to statistically validate a model that makes predictions at a support much greater than the support of validation measurements.

Another very relevant challenge. I let the soil physicists react about the right model at the right scale. Our job, as Digital Soil Mappers, is to provide estimations of soil properties and of the associated uncertainties for any required geographical support whereas we stick at working at the horizon or pedon level. My experience is that most of the users do not ask for such a fine support for making decisions. Delivering soil prediction at larger support is not only relevant for users but also would avoid discouraging the users with the large uncertainties that are often obtained when working at the pedon level. Spatial aggregation techniques exist, including those provided by geostatistics. As often, the main limiting factor for applying these techniques is the input data, in particular a minimum knowledge of the short-range soil spatial variabilities. Ad-hoc spatial sampling, collection of legacy proximal and high-resolution remote sensing data, or meta-analysis of the literature should be explored as possible solutions for obtaining this information.

Challenge 4: *Can we incorporate mechanistic pedological knowledge in digital soil mapping?*
Most digital soil mapping algorithms are to a high degree empirical. And this is only increasing, now that we entered the data science era and rely heavily on machine learning algorithms. Pedological knowledge only creeps in when we adopt the CLORPT model to identify relevant covariates. Structural equation modelling makes an attempt to move away from purely data-driven approaches and Bayesian networks may be useful too, but ideally we would make use of dynamic, mechanistic models of soil forming processes. Can we do that? This is a huge challenge because the input variables and parameters of these models are often poorly known, and also the model structure (and 'optimal' degree of complexity) is far from obvious. Hydrologists are much further than we are with methods to deal with parameter and structural uncertainties, such as through Bayesian calibration and Bayesian model averaging. Is this the way forward? Or should we be looking for ways to incorporate expert knowledge that is in the heads of soil surveyors and pedologists?

Having begun my career as a soil surveyor, I appreciate well the loss of information from the soil surveyor's mental model to any empirical DSM model, however sophisticated it is. Most of this loss lays in the story of soil cover genesis that a soil surveyor builds along his (her) prospection and uses as a powerful way for extrapolating the observations. Rather than searching the Holly Grail, i.e. the mechanistic model of soil forming process that would predict any soil properties at any locations that have little chance to become operational for the reason mentioned by Gerard, I prefer looking to less ambitious solutions e.g. considering in our models the old idea stating that the soil cover is made up of nested systems or completing the quantitative evaluation of DSM models by assessing the plausibility of the predicted soil patterns considering our knowledge of soil forming processes.

Challenge 5: *Can we make sufficiently accurate global soil maps?*
The GlobalSoilMap project (which, actually, is a perfect example of setting a long-term PM challenge that we jointly work on, and guess what: it worked!) had as its aim to map the soil on a global scale at 90 m resolution. We are very close to reaching this goal. But resolution is easier reached than accuracy, and we now need to set a new aim of making global soil maps that not only satisfy the resolution requirements but that in addition meet pre-defined accuracy standards. Part of the solution may be to develop optimal sampling schemes that meet the requirement (like OSSFIM, but then for the modern DSM world). And when we get down to this, maybe at the

same time we should also solve the problem of how to ensure that country borders do not show in a global soil map that is a stitch of bottom-up country-based maps.

The main driver of the map accuracy is the density of locations with known soil properties. For anyone that went once in the field for studying the soil variations, it is easy to understand that these soil variations cannot be captured with a density of one observation for several tens or hundreds of square kilometers, however good the covariates are. We should therefore densify our soil observations. This means first of all fighting for conserving, sometimes restoring and developing across the world teams of experienced soil surveyors able to collect good soil data. This means also developing optimal sampling schemes and feeding our models with less expensive soil data such as soil sensing data or qualitative soil characterizations, both legacy or participative ones.
However, could these data be collected for the global level? Even, must we make a significantly more accurate Global Soil Map? (see Challenge 12)

Challenge 6: *Can we quantify the information content of a soil map?*
Which soil class map is more informative? A map with a detailed legend and low purity or a map with a coarse legend and high purity? Can we characterise the information content of a soil map with the Shannon entropy or differential entropy and if yes, what does this tell us? Can the economic value of a soil map be assessed and is this then a proper measure of its information content? How about the fitness-for-use of soil maps? Can we use the concept of soil map information content to help guide and improve our soil mapping activities?

We cannot answer yet to these (good) questions because we do not have enough experience of real uses of our DSM products. We must not limit our effort to only delivering these products. We should be involved in projects with real users of soil data, as diverse as possible. Anyway, a prerequisite to this challenge is to produce accurate and communicable measures of uncertainty of the DSM products (see Challenge 2) so that all the information, i.e. the legend and the purity in the example of a soil map, is on the table.

Challenge 7: *Can we quantify uncertainty in soil observations and analyse how this affects soil mapping?*
Measurement errors in soil observations can be large, but unfortunately they are often ignored. We need to work together with soil physicists, chemists and biologists to develop statistical methods that help characterise and quantify soil measurement error and make sure that measurement uncertainty is routinely stored in soil databases. We need to make sure that soil mapping algorithms take measurement uncertainty into account. All this is ever more important because we will get more of proximal soil sensing data and crowd-sourced and volunteered soil information, which all have substantial uncertainty. Measurement uncertainty also influences map validation strategies and sampling design optimization.

I fully support this challenge since I advocated before (Challenge 5) the extensive use of soil sensing and volunteered soil information.

Challenge 8: *How to map soil functions?*
We have spent a lot of effort on modelling and mapping soil type and (basic) soil properties. This was time well spent because soil type and soil properties are useful for many purposes, but many end-users require maps of soil functions. As yet we have not paid enough attention to establishing rules and models that derive soil functions from soil properties and other land characteristics. We must work on this with much greater effort and make sure that we also quantify the associated uncertainties. Among others, it requires that pedometricians help define soil functions or measures of soil functions in an unambiguous way.

Mapping soil functions is effectively the way forward. This means moving from monovariate DSM to multivariate DSM, which carries some methodological issues that should be thoroughly addressed in the near future. In the following, I cite three of them, among others: how to find the best inference trajectory between "mapping first the soil properties then combine them" or the reverse (and all the intermediates)? How to account for correlations between soil properties in the DSM models for not creating pedo-chimera that could lead to mistaken estimations of soil functions? How to propagate the uncertainties in mapping soil properties toward the function map? Some of these questions have been already worked out, including recently, but this does not end the story.

Challenge 9: *How to map the soil in 3D (and 3D+T) while accounting for huge lateral-vertical and space-time anisotropies and huge differences in measurement support?*

The PM10 challenges

We have made tremendous progress in modelling and mapping lateral spatial variation but we have not made nearly as much progress in modelling vertical variation. We are still using fixed depth intervals while we know that soil vertical variation is driven by the development of horizons. We should learn to predict horizon thicknesses and characteristics and how these develop over time. We also have a measurement support problem: in the vertical our measurements are not points but averages over fairly large intervals. Do we take this sufficiently into account when we build and calibrate models of soil variation? Have we ever considered over what depth intervals we should be taking our samples? Should these be 1, 2, 5 or 10 cm thick? Is the answer case-specific? There is still so much to discover in modelling soil vertical variation.

I am not sure it is a first-order challenge. If we remember the soil surveyor's practices, the values of soil properties per horizons are already averaged since they are measured on composite soil samples constituted by soil samples taken at different depths within the horizon. Most often, the legacy measured profiles we have provide no more than three of these averaged soil properties. It is a much too poor dataset for expecting any improvement in the representation of the soil vertical variations brought by more sophisticated models than our good old spline function. I will advise investing time on this subject when I will see substantial progresses in inexpensive methods for producing better data on soil vertical variations.
However, another challenge related to soil vertical variation is to be cited: we are not good in predicting the soil properties of the deepest soil layers, especially the saprolite (between the bottom of the pedogenic horizons and the bedrock). Yet, these soil properties are required by many users dealing with forest or vineyard or with superficial aquifers. We should improve this in the future.

Challenge 10: *What can we learn about soil processes from calibrated machine learning models?*
We make use a lot of machine learning methods to build models that predict soil classes and soil properties. We almost only use these models to make predictions. Have we forgotten that the purpose of modelling is usually twofold: 1) to improve understanding; and 2) to make predictions? So can we use calibrated machine learning models to help us understand why soil varies the way it does? Can we open the black box? If yes, what will we learn? Will it confirm pedological knowledge or will it reveal new insights?

I do not expect getting new insights on the soil cover by using machine learning methods at the scale they are usually applied. Machine learning methods make only predictions, often more accurate than those of other models when dealing with large areas that include a lot of soil systems with many drivers acting differently from a place to another. Yes, we need to open the black box, but it is more for checking that the soil predictions match well our current pedological knowledge. If they do, it is enough for making me happy. Any so-called new insight has more chances to be an overfit than anything else. If we want to learn something about soil variations, we should work differently: delineating first well-identified soil systems, collect enough data and use statistical or mechanistic models that are easier to interpret.

Challenge 11: *How to perform multi-source Digital Soil Mapping?*

I call "multi-source Digital Soil Mapping" a DSM approach that would use together different soil inputs (laboratory analysis, qualitative soil observations, soil sensing data, soil maps, farmers expert saying, existing DSM products, etc.), each of them having different and possibly uncomplete spatial coverages of the study area. This soil data configuration fits better to the real life than the simplified soil data configuration that is most often considered in the literature, i.e. a spatial sampling of measured soil profiles covering more or less evenly the study area with sometimes an exhaustive soil map. Co-kriging could be envisaged as a solution for dealing with multi-source input data but it is hard to use with more than two sources and cannot address efficiently the uncompletedness of the spatial coverages. We already evoked this challenge in the first DSM Global Workshop held in Montpellier in 2004, suggesting that "Spatial Soil Inference Systems" could be the way forward. As nothing has happened since this event, I try to put again this challenge on the agenda. We should revisit it fifteen years after with our increasing experience in DSM … and computing power.

Challenge 12: *How to make emerge a local Digital Soil Mapping activity?*

The PM10 challenges

Will the future of operational DSM be to endlessly refine highly centralized soil database (e.g. Global, continental or national) managed by a small group of happy fews? To my opinion, this scenario is neither philosophically acceptable nor efficient. Digital Soil mapping must go down progressively at more local levels which will ensure an easier access to the input data (including the local knowledges on soil variations), a better proximity to the user needs and, finally, a better appropriation of the produced maps by the local people. The challenge is to make emerge a viable DSM activity populated by DSM-trained soil surveyors that could answer with agility to the needs in soil information expressed by the users and formalized through local specifications compatible with the higher levels ones. The methodological limitations to this scenario are not the greatest ones. We must increase our effort in capacity building and also act for overcoming the legal and economical obstacles that could hamper the growing of such DSM activity. Developing local DSM is far to be antagonist to the development of national and Global soil databases. A fruitful collaboration including data exchanges can be set between the different levels, each of them having its own utility for solving soil-related problems.

A comment or answer to the PM10 challenges (4/4)

By Lin Yang

Response to Challenge 4: *Can we incorporate mechanistic pedological knowledge in digital soil mapping?*

Soil is the result of the interaction of environmental factors including climate, parent material, topography, and organisms over millions of years. Environmental factors differ across years and locations. The forming processes of soil are very complicated. Knowledge on those processes relevant for soil formation is limited, thus it is not easy to build mechanistic pedological models.

Despite the difficulty of building mechanistic models, there are still some efforts on this topic. For example, Finke and Hutson (2008) developed a SoilGen1 model to simulate soil development in calcareous loess at Holocene (15, 000 BP-present) temporal extent. The core of this model is the LEACHM model for water and solute transport. Several functions (such as cycling of C) were added to the core model to cover the wider range of pedogenetical processes. Vanwalleghem et al. (2013) presents a model, named Model for Integrated Landscape Evolution and Soil Development (MILESD), which describes the interaction between pedogenetic and geomorphic processes. They believed that soil formation is closely related to Landscape evolution. Their model included soil formation processes including weathering and clay translocation, and the lateral redistribution of soil particles through erosion and deposition was combined. The model also simulated the vertical variation in soil horizon depth, soil texture and organic matter content.

Due to the key role of soil in critical zone, mechanistic mathematical models have been developed considering soil functions and processes. We can borrow experiences from critical zone research. For example, Giannakis et al. (2017) developed the 1D Integrated Critical Zone (1D-ICZ) mode. This model simulated the coupled processes that underpin major soil functions including water flow and storage, biomass production, carbon and nutrient sequestration, pollutant transformation, and supporting biological processes. It coupled with pedotransfer functions to predict bulk soil properties, thus dynamically links soil structure characteristics and hydraulic soil properties. Furthermore, the model can simulate and quantify four main soil ecosystem functions.

Mechanistic models for soil genesis are not easily operationalized because the temporal variation of boundary conditions is not easy to reconstruct, calibration is difficult and computational demands may be high. Some “compromise” approaches between mechanistic models and machine learning methods have been applied for soil mapping . Structural equation modelling (SEM) is one of those, which draws people's attention recently. SEM has its roots in social sciences, and integrates empirical information with mechanistic knowledge by deriving the model equations from known causal relationships (Angelini et al., 2016). It also includes a graphical form. Besides, it uses knowledge about interrelationships between soil properties and predicts these properties simultaneously. SEM cannot reproduce the true physical, chemical and biological processes. Instead, the model structure in SEM is based on hypotheses of the functioning of a soil-landscape system that is formalized in a conceptual model. SEM thus can be used as a tool to understand the interactions of the soil-landscape system, its genesis and functioning.

SoLIM (Soil Land Inference Model) (Zhu et al., 2001) is also a framework to incorporate pedological knowledge into soil mapping. In SoLIM, expert knowledge is converted and formalized as membership functions (curves) based on fuzzy logic. The success of SoLIM first depends on whether the knowledge of soil experts is comprehensive. Extensive field work is usually needed to obtain the understanding of relationships on soil and its environmental factors.

Although pedological knowledge is not used as input for machine learning approaches, those approaches could generate knowledge that is helpful to understand the relationships between soil and its environment factors. The generated decision trees and partial dependence plots based on training samples could indicate those relationships. However, the reliability of those relationships relies on the representativeness of training samples.

In my opinion, to incorporate pedological knowledge is a promising direction of digital soil mapping. However, we need to have pedological knowledge at first. Experiences of the previous studies on existing models could be a good start. Go to the field to know soil is the direct way to understand the soil-landscape system. Also, machine learning is useful as it helps to generate knowledge.

References:

Angelini, M.E., Heuvelink, G.B.M , Kempen, B , Morrás, H.J.M., 2016. Mapping the soils of an Argentine Pampas region using structural equation modelling. Geoderma 281, 102-118.

Finke, P.A., Hutson, J.L., 2008. Modelling soil genesis in calcareous loess. Geoderma 145, 462–479.

Giannakis, G.V., Nikolaidis, N.P., Valstar, J., Rowe, E.C., Banwart, S.A., 2017. Chapter Ten: Integrated Critical Zone Model (1D-ICZ): A Tool for Dynamic Simulation of Soil Functions and Soil Structure. Advances in Agronomy 142, 277-314.

Vanwalleghem, T., Stockmann, U., Minasny, B., McBratney, A.B., 2013. A quantitative model for integrating landscape evolution and soil formation. Journal of Geophysical Research Atmospheres 118(2).

Zhu, A.X., Hudson, B., Burt, J.E., Lubich, K., 2001. Soil mapping using GIS, expert knowledge, and fuzzy logic. Soil Science Society of America Journal 65, 1463-1472.

Capacity buidling in Pedometrics

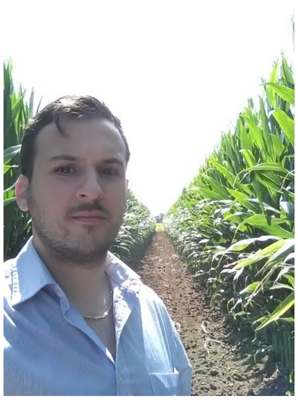
From earlier conferences, it became clear that we have to improve the capacity building of Pedometrics and that it may has to begin at the university level prior to extending our focus to NGO's, GO's and other international initiatives. From the discussion it was concluded that, despite the large amount of young researchers that are working within the field of Pedometrics, digital soil mapping, soil sensing and geostatistics, these are not often part of the University's curriculum followed by our young researchers.

We asked a few young scientists how they were trained in Pedometrics during their University courses and PhD program. They answered the following questions:

1. *What is your current research topic?*
2. *How were you trained in soil sciences?*
3. *How many credits/courses were devoted to Pedometrics topics (DSM, soil sensing, geostatistics, spatial data handling, programming)*
4. *What was the most inspiring course you followed which made you decide to continue in soil science and specifically Pedometric?*
5. *What was lacking in your university's curriculum with respect to your current required set of skills and knowledge, e.g. DSM, soil sensing, geostatistics, spatial data handling, programming?*

Answers from young scientists (1/4)

By Calogero Schillaci (Italy)



1. What is your current research topic?

My research topic is Soil organic carbon mapping in agro-ecosystem, soil organic carbon dynamics in agricultural land, applied remote sensing to field crop research, advanced literature search (systematic map, review and meta-analysis).

2. How were you trained in soil sciences?

I had one bachelor subject (pedology 6 cfu, University of Palermo), one Master subject (applied agronomy, University of Palermo) and three Master subjects during my period abroad (University of Tubingen Soil science, soil mapping, soil analysis). I've recently defended my PhD thesis entitled: Mapping Soil Organic Carbon dynamics over the last decades in Mediterranean agro-ecosystems with legacy data, supervised by professor Marco Acutis (full professor in agronomy, University of Milan). During the PhD I spent four months at the University of Tubingen (supervised by. Prof. Volker Hochschild, Remote sensing expert), four months at the Harper Adams University (Supervised by Dr. Fabio Veronesi, R and DSM), and six months at the James Hutton Institute (Supervised by Laura Poggio, Remote sensing R and DSM).

3. How many credits/courses were devoted to Pedometrics topics?

Hard to say, few before the PhD (<60), then, almost the whole program.

4. What was the most inspiring course you followed?

I have got involved with pedometrics since I had my internship in Tuebingen in 2013.

5. What was lacking in your university's curriculum with respect to your current required set of skills and knowledge

Before the PhD, there was a lack of advanced statistical and programming courses. During the PhD, I have tailored the study program to overcome these gaps and to be able to carry out valuable scientific research.

Answers from young scientists (2/4)

By Reyes Rojas (Chile)

1. What is your current research topic?

My research is about the use of digital soil mapping approach to estimate current soil organic carbon (SOC) and compare it to future simulations under climate change using legacy data of Chile.

2. How were you trained in soil sciences?

My background in Soil Science started as an undergrad in Agricultural Sciences, followed by a master's in soil and water management at the Soils Department of the University of Chile and now as a PhD in Soil Science at the University of Wisconsin-Madison.

3. How many credits/courses were devoted to Pedometrics topics?

I had three master's and two PhD program's courses (in addition to research credits) that were related to pedometrics.

4. What was the most inspiring course you followed?

The most inspiring course was "Nature and Properties of Soils" in my master's because it pushed me to think further about the philosophy of Soil Science, discussing papers and deriving to a higher level of questions and concepts than just the description of soil itself. Also, in "Modelling of Water Requirements" and "Crop Fertilization", where coding and database management was required, I developed my interest in open source software like Qgis, R, SagaGis, LaTex and Python which later were useful for my PhD.

5. What was lacking in your university's curriculum with respect to your current required set of skills and knowledge

UW Madison's Soil Science PhD Curriculum is lacking collaborative learning tools. During my PhD, I taught myself digital soil mapping (DSM) with codes and examples in R from the book "Using R for Digital Soil Mapping" by Malone et al. (2017) together with the guidance of Dr. Adhikari and Dr. Zhu, who have a broad experience and publications in DSM. Unfortunately, no formative courses on DSM were taught at UW Madison Soils.

Answers from young scientists (3/4)

By Mirriam Makungwe (Zambia)

My name is Mirriam Makungwe i have a BSc in Agriculture Sciences and MSc in Integrated Soil Fertility Management from University of Zambia and currently pursuing my PhD in Soil Science at University of Zambia. My research is focused on evaluating the performance of Best Unbiased Linear Predictor (BLUP) with Random Forest and Artificial Neural Network for spatial interpolation of soils in land suitability mapping.

Some of the soil science courses I was trained in during MSc include Applied Soil Chemistry, Soil Microbiology, Applied Soil Physics, Soil Amendments and Fertilizer technology, Soil Survey and Mapping, Applied Soil and Water Management, Soil classification and land evaluation. Of all these courses I was trained in, my inspiration to continue in soil science was from Soil classification, survey and mapping it is very interesting how it has evolved. During my BSc, we were being trained on the conventional way of classifying and mapping soils. I remember then we were using stereo-scopes to interpret aerial photographs. Two years later when I was doing my MSc, remote sensing was introduced in classification and mapping, we were now using satellite images. Three years later for my PhD, not only was geostatistical spatial interpolation with the best unbiased linear predictors being used, but machine learning is now being used for classification and mapping soils. In order to carry out my research, I realised I was lacking in R programming, geostatistics and GIS modelling, skills that I needed to complete my study but I was lucky that the my university had an exchange programme with the Norwegian University of Life Sciences (NMBU) where I have been trained in R programming, GIS modelling and other statistical courses.

Answers from young scientists (4/4)

By Sanaz Zare (Iran)

1. What is your current research topic?
Digital Soil Mapping Using Radar Images

2. How were you trained in soil sciences?
In our core curriculum, most of the concepts are taught and some ways to develop skills are training at the right time, using appropriate educational aids and resources, teaching and learning from reflection and its implementation, developing educational brochures and pamphlets and separating educational as well as field studies.

3. How many credits/courses were devoted to Pedometrics topics?
Geostatistics (Credits:3), Interpretation and usage of satellite and aerial photos (Credits:3), Soils Surveying (Credits:3), Processing of soil and land information (Credits:3), Identification and preparation of soil maps (Credits:3), Remote Sensing (Credits:3), Surveying and Topograpghy (Credits:3), and Geographic Information System (Credits:3). GS+, ENVI, ArcGIS are the software that is taught in these core courses.

4. What was the most inspiring course you followed?
Remote Sensing.

5. What was lacking in your university's curriculum with respect to your current required set of skills and knowledge
According to the rapid development in the spatial information system, I think Advanced Data Processing, Programming, and Fuzzy Logic and Neural Networks in Photogrammetry and Remote Sensing which are taught in workshops can be taught in our core curriculum.

Pedometrics is soil data science +++
+ human understanding
+ soil science
+ a lot more

By Alex McBratney & Budiman Minasny
The University of Sydney, Australia

We have shied away from bandying about terms like 'data science' and 'machine learning' but as they become the modern parlance we guess we shall have to use them to communicate with our colleagues and stakeholders but all of us need to think what they mean precisely and their implications for pedometrics and soil science.

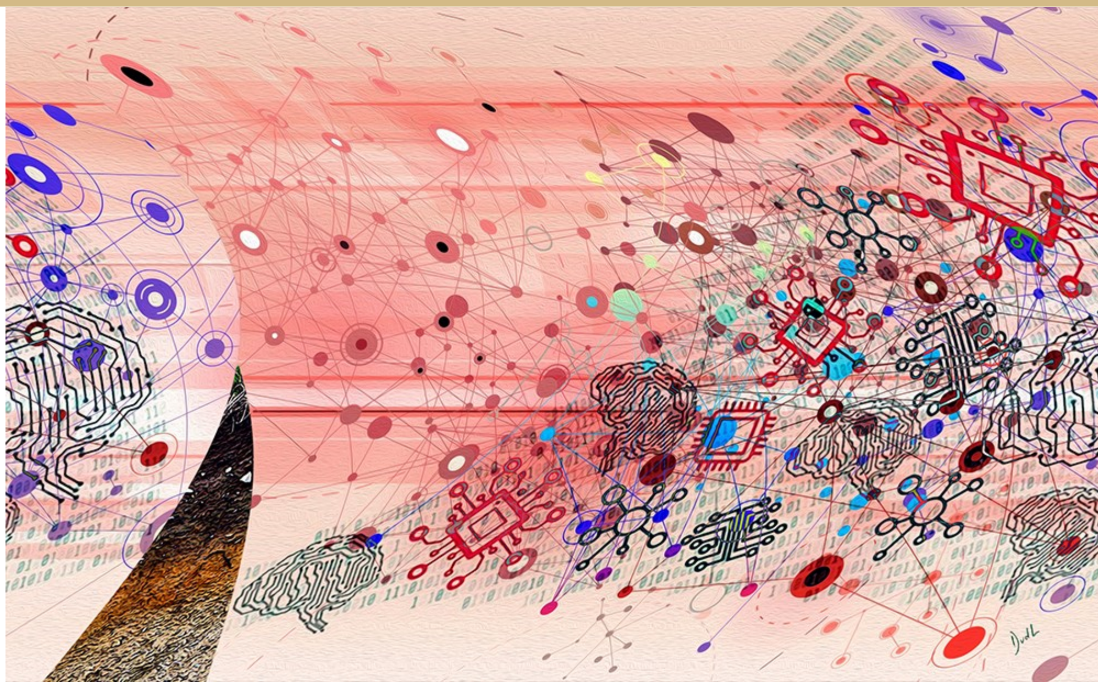
First of all, why have we shied away from using these terms widely? Largely because we haven't thought that they added much. Data science hasn't been so different from statistics, and machine learning once again hasn't been so different from statistical modelling. At least that's what we have thought. We think part of the motivation for the newer terms comes from their disciplinary background. Disciplines like biology, agriculture, earth science, psychology, economics and medicine are used to dealing with the variation of nature and have evolved quantitative ways of capturing and expressing that variation. Statistical estimation methods and sampling and experimental design methods have been devised to provide inferences under such uncertainty. More recently the engineers and computer scientists and the finance and business sectors have become interested in such estimation and prediction methods, but the approach does not necessarily arise out of the tradition of statistics but more from optimisation. It is from that set of disciplines that 'data science' and 'machine learning' has developed.

We think because of a concept of optimisation rather one of estimation with minimum uncertainty and minimal parameters – the statistical paradigm – a much wider range of techniques is admissible. Data science and machine learning are the names for the discipline and the methods of this wider range of techniques. Quite a while ago, we did look at some of the emerging techniques around knowledge and its structuring (Dale et al., 1989). At that stage interrogating expert knowledge and structuring that seemed one way forward. We also discussed the main data-based alternative, i.e., 'induction' and 'inference systems'. Machine learning is data-based induction, going from specific cases to general statements. Some of the early work by Quinlan (the developer of Cubist) and on classification and regression tress was recognised.

We have always thought that pedometrics was not about techniques but about improved understanding of soil. In this sense all quantitative techniques are potentially useful. Domingos (2015) outlines five approaches to machine learning (1) the symbolic approach based on inverse logic (2) the connectionist approach based on neural networks (3) the evolutionary approach based on genetic programming (4) the Bayesian approach based on Bayesian statistics and networks – this is the statistical paradigm (5) the analogy approach based on support vectors and other identification algorithms including k-means. All except perhaps (1) have been used in pedometrics. Dynamic simulation models of soil processes are good ways of learning about the soil world, but they do not seem to be embraced in the 'machine learning' framework. For example, they may facilitate meta-modelling. The 2003 DSM paper (McBratney et al., 2003) talks about machine learning and discusses several of the categories and methods discussed by Domingos (2015). While machine learning is mentioned terms such as 'deep learning' and 'big data' had not emerged at that time however.

We have seen methods such as multiple linear regression or principal components being referred to as 'machine-learning' methods and partial least squares regression being used as a machine learning method for a limited

Pedometrics is soil data science



number of covariates. There is still confusion around methods and terminology. Perhaps the biggest problem at the moment is the misuse of existing techniques particularly the use of sophisticated techniques with too few data , e.g., ANN on 100 data points. When we move to large data sets or 'big data', and for us in soil science that means a million or more observations, clearly hierarchical or tree-like models start to make a lot more sense.

However to what degree should we embrace methods that have no principle of parsimony and do not explicitly attempt to model uncertainty? We should at least try to steer the ML methods in these directions.

One of the triumphs of recent years in digital soil mapping has been the explicit modelling and statement of uncertainty. (There are those who wish to move way from this because of potential user confusion; simply, we think we should embed the uncertainty in down-the-line products.)

Should we follow the practice in machine learning, of just getting the most accurate prediction? In some applications (such as how Facebook recognises your friend's picture), probably it doesn't really matter how the algorithm works. The greatest immediate danger we see for soil science is from private (startup) Agtech and Envtech companies selling proprietary machine-learned products to predict a range of soil properties with no estimate of uncertainty. Because of their proprietary nature of the training sets, models and calibration functions are not made known. There is no associated uncertainty. We see the beginning of this phenomenon with products for soil carbon and other soil properties using spectrometric techniques. As soil scientists and pedometricians, we simply can't tell what is being marketed. Without a degree of openness we, and the user community, cannot be confident in these approaches. The danger is they don't work properly and wrong decisions are made based on poor estimates, undermining confidence in our hard-won and carefully crafted science.

Within soil science itself there is a huge potential for data science and machine-learning techniques but once again, we should like to have at least estimates of uncertainty, and some observance of parsimony and intimate links with the science. The biggest problems with machine learning in soil science, at least with current approaches, are (1) suitable understanding and training to know when and where the various techniques may be applicable, and (2) the lack of interpretability of the models in order that our human understanding can be improved. Machine learning does not seem to have a principle of improved human learning and understanding, but without that what do we gain in our science by using such tools?

Perhaps we have missed the point completely, and there will be no need for pedometrics, soil science or soil scientists – all knowledge will be machine generatable and usable. Mais plus ça change, plus c'est la même chose.

References:

Dale, MB, McBratney, AB, Russell, JS. 1989. On the role of expert systems and numerical taxonomy in soil classification. Journal of Soil Science 40, 223-234.

Domingos, P. 2015. The Master Algorithm. Basic Books. NY.

McBratney, AB, Minasny, B, Mendonca Santos, ML. 2003. On digital soil mapping. Geoderma 117, 3-52.

Soil Genesis on Canvas

By Thomas Scholten

Art and Science are two domains that share a large portion of creativity. New findings, perspectives and theories less develop in everyday life. In fact, new and sparkling ideas and the irrepressible will to pursue them and make them understandable to others are born in curious, creative and unusual environments. So seen, artists and scientists are twins in their approach to discover the world. And they have the chance to impregnate each other.

In my case it was Alex Toland* who came across with dialogues on Soil and Art. She introduced me to Ulrike Arnold who is a German artist and studied fine arts at the Düsseldorf academy in Professor Klaus Rinke's class. She specialized in earth paintings and uses soil, minerals and sediments as resources for her paintings. In recent years, she integrated a cosmic component to her painting adding material from meteorites like nickel, iron and chondrules.

Figure 1. Soil Genesis on Canvas – a great experience. Ulrike Arnold and Thomas Scholten in dialogue with Bettina Dornberg, journalist, and Christoph Berdi, photographer, both from Cologne, Germany (Photo: Christoph Berdi).

Those of you who are familiar with soil genesis and the everlasting discussion about soil formation in space and time know that sometimes lively debates on soil forming processes can reach cosmological dimensions. And you realize it’s obvious that soil genesis on canvas can synthesize both cosmos and nature and Art and Soil science in a wonderful way. Another aspect that interestingly is at the crossroads of art and soil is dedicated to extraterrestrial material. Said that, Ulrike helped me to discover new perspectives and strengthen conceptual approaches for a better understanding of nature and humans.

Soil Genesis on Canvas

Figure 2. Can you hear the fine sand, mica...? Finger test of soil texture, an intuitively and naivety way to explore soils (Photo: Christoph Berdi).

An obvious link between Art and Soil is color. In science, soil color is something that can often be deceptive. It's the thing our eyes recognize, as a reflection. That makes it dangerous. Sometimes the color reflects the soil's content, but sometimes it doesn't. For example, the grey could be a mineral, but it isn't necessarily. If you have strong reddish colors in the soils, then those soils have typically undergone a lot of weathering, and have been eroded very intensively and/or for a very long time. That is, the color in the soil, if it is very strong, is in some ways a description of the amount of energy that has gone into it. But what about the absence of color? In cave paintings, there is no green. Did the green rot away, or was it perhaps not used for religious reasons?

Figure 3. Red from Australia and gray from Brazil, what do colors reflect (Photo: Christoph Berdi)?

Soil Genesis on Canvas

Figure 4. Weathering, erosion, sedimentation and the formation of soil horizons, which perspective fits best math and stats or searching, looking, watching (Photo: Christoph Berdi)?

We human beings do a lot of things intuitively, but I think that there are often very pragmatic and simple reasons behind what we do. The same is true for soil genesis where it often seems difficult to understand the system and the reasons behind the formation of the beautiful soil profiles we have around the world. A simple example is the ubiquitous element iron. Iron is bound in the rock. It is released through weathering and combines with oxygen, resulting in wonderful iron oxides. Going back in time, many rocks that are this color are nothing less than soils which might have formed millions of years ago, were then eroded, then solidified again to form rock. In general,

Figure 5. Beyond our world of experience - extra-terrestrial material from black meteorites (Photo: Christoph Berdi)?

a simple story with bedrock as a function of soil. Does it hold when we go deeper into chemistry? The main elements that we have in the Earth's crust are silicon, oxygen, iron, aluminum and then a bit of calcium, magnesium, potassium and sodium. The remaining elements of the periodic table account for less than one percent of the total volume. Making soil from the major elements is like when you used to play with Lego pieces and tended to have an abundance of primary colors: most soils are made up of these main elements, which are abundant across the planet.

This is still a very generic view on soil genesis. One thing missing alongside earth pigments as a proxy for soil formation and a connective element of Art and Soil is some meteorite dust, something unearthly. What is it with meteorites? They fall to earth, after all. Shall we add that as a compositional element to soil genesis, now? Elements from other planets and cosmic bodies? These are just iron too? The cosmic place of our planet is important, isn't it? The Earth and its neighbors are connected though similar origins. This material is extra-terrestrial and beyond our world of experience. However, if we put our painting containing iron-rich black meteorite dust in the open air, in 10,000 years these swaths of black meteorite dust will turn red.
Well you can see, there are many crossroads of Soil science and Art and public outreach and I hope you enjoy to see soil scientific findings from another perspective and let it impregnate one's soul.

* Toland, A., Noller, J. S., Wessolek, G. (eds.): Field to Palette: Dialogues on Soil and Art in the Anthropocene, 137-148 (2018). CRC Press, ISBN 978-1-138-58509-6.