ΠΕΔΟΜΕΤΡΟΝ

Newsletter of the Pedometrics Commission of the IUSS Issue 43, January 2019

From the Chair

Happy new year, happy 2019 and welcome to the 43th issue of Pedometron!
It has been a great year for Pedometrics. We have been present at large international conferences, such as the World Congress of Soil Science in Rio de Janeiro, Brazil (August 2018) and the Soil Security and Planetary Health in Sydney, Australia (December 2018), among others. Here, great talks have been given on pedometrics, on methods and applications fitting societal demands. Moreover, linkages have been made towards large international incentives and partnerships, such as the Global Soil Partnership, and great papers have been published on upcoming methods such as deep learning!

Now, it is the beginning of a new year, students and colleagues have come back from holidays. With that, it is our great pleasure to introduce to you the newly designed Pedometron by our new guest editor Alexandre Wadoux. There are several new recurring items added for you to enjoy. In our philosophy, Pedometron should inform you about the latest updates on scientific advances and upcoming events. In addition to that, we want to inspire you with topics covering the aspect of soils and its connection to the arts and philosophy and we also want to entertain you with puzzles and comics. It is brought to you a little later than usual due to the changes in chairs and committees but we hope you experience it was worth waiting for! In this issue, you can read about the changes in some of the working groups and the new award committee.

Happy reading and be inspired for another year of Pedometrics. We are sure it is going to be a fruitful year, with many opportunities to meet you all at various interesting conferences from Pedometrics and our working groups.

Looking forward to 2019, wish you a productive and successful new year.

Titia Mulder & Nicolas Saby

In this issue

Delivered by

Chair
Titia Mulder
Vice-chair
Nicolas Saby
Editor
Alexandre Wadoux

Murray lark was awarded in 2018 with the Richard Webster medal from the Pedometrics Commission of the International Union of Soil Science. He shares with us on his career history.

The Webster Medal

By Murray Lark

It is a very great honour to have been awarded the Richard Webster Medal for 2018, and I was happy to agree to Titia's request that I write a response to this award for the current *Pedometron*. Of course I still have the responsibility of delivering the Richard Webster lecture at Pedometrics 2019, so what I write here will be more personal and less technical. If you want to hear my thoughts on big data, digital soil mapping, and the role of pedometrics in pursuit of sustainable development then come to Canada in June! The present article is mainly a set of more-or-less connected reminiscences from my career in pedometrics to date.

Figure 1: Lark and friends, c 1977.

An exploratory soil map of Zimbabwe (then called Southern Rhodesia) was published in the year I was born, and identifies the soils in the immediate vicinity of Harare as moderately deep to deep reddish-brown granular clays – fersiallitic soils with some 2:1 clay minerals and appreciable reserves of weatherable minerals. Of course this map generalized a complex pattern of soil variation for publication at a scale smaller than 1: 1M. Although the soils in the garden at home probably met this description, at school (upslope) the clay minerals were predominantly kaolinitic and the soil was a brighter red, while a few hundred metres downslope a snake-ridden vlei had black, sticky soil in which I was regularly plastered. This reader might recognize the classical central African catena, reflecting lateral movement of weathering products and differences in microclimate, both controlled by topography. On the high-ground the soils are sandier soil and on the way to school I could see a few survivors of the original tree cover: frost-sensitive *Uapaca kirkiana*. Our home, part-way down the catena, had ironstone cuirasses and pisolithic material with the iron sufficiently concentrated that one could pick it up with a magnet. This was just around the frost line.

Figure 2: Dr Philip Beckett.

It was in Zimbabwe that I cut my scientific teeth, determining the organic carbon of the soil at different locations on the catena by loss on ignition (using a lot of methylated spirit in the process and nearly causing a serious fire). I also had my first encounter with problems of sampling and statistical estimation, using airphotographs to estimate the rate at which elephants were depleting the tree cover in the large wildlife reserve in the west of the country.

Some years later I arrived in Oxford with a place to study Zoology. However, one fateful evening I attended a lecture for first-year biologists where Dr Philip Beckett, senior lecturer in soil science, described the geomorphology of the Zambezi valley, and how the topographic variation generated by successive changes in base level gave rise to the spatial distribution of different soils and vegetation communities. This, and some additional lectures and field classes convinced me to change direction. I changed to a course in Applied Biology, based on a recently-discontinued Agriculture and Forestry Degree. The Oxford system leaves it largely to the student to direct their own time, so I focussed on soil science and biometry, a sort of assemble-it-yourself degree in pedometrics. In the summer vacation after graduating I was employed by the University to map the soils of some newly-acquired farm land near the Wytham Estate, an iconic location for field ecology and long-term environmental monitoring. The soils were formed in weathering products of the underlying Jurassic rocks, redistributed during the Pleistocene in periglacial conditions. I enjoyed the field work, triangulating on local landmarks with a plane table and alidade (look it up, youngsters from the GPS era!) When the mapping was done I completed a set of profile pit descriptions, emerging from one pit to find myself surrounded by a group of curious sheep.

Figure 3: Environmetricians sampling the environment.

In due course I began a PhD (D.Phil. in Oxford parlance) under Philip Beckett's supervision. Philip was Richard Webster's supervisor back in the 1960s, and also supervised the D.Phil. studies of Peter Burrough, later to supervise Gerard Heuvelink, Marc Bierkens and others well-known to the readers of Pedometron. My thesis was on remote sensing, with particular interest in multivariate methods and spatial analysis.

After holding a University of Wales fellowship for two years, I took up a position at the Silsoe Research Insitute, a public-sector research organization focussed on engineering, physics and maths as applied to agriculture and food. My initial role was primarily to give statistical support to studies in precision agriculture, but after a while I was able to broaden the scope of my work to include soil monitoring and studies on nutrient cycling, much of the latter involving collaboration with colleagues at Rothamsted, a short distance away. The Environmetrics Group, later to transfer to Rothamsted, began to self-assemble at Silsoe, a motley crowd of mathematicians, statisticians and soil scientists. As well as developing and applying geostatistical methodology, sampling design, wavelet analysis and assorted other pedometrical techniques the Environmetrics Group's key characteristic was that all our projects involved new field work and the collection of data, mainly from the local landscape, Cretaceous rocks of very diverse lithology, and with a complex pattern of superficial deposits to add to the variability. We were visited at Silsoe by various colleagues, includ-

Figure 4: Environmetricians at Broadbalk Field, Rothamsted.

ing Prof Richard Ferguson from Nebraska and Alex McBratney from Sydney, when the first foundations of the recent Pedometrics textbook were laid.

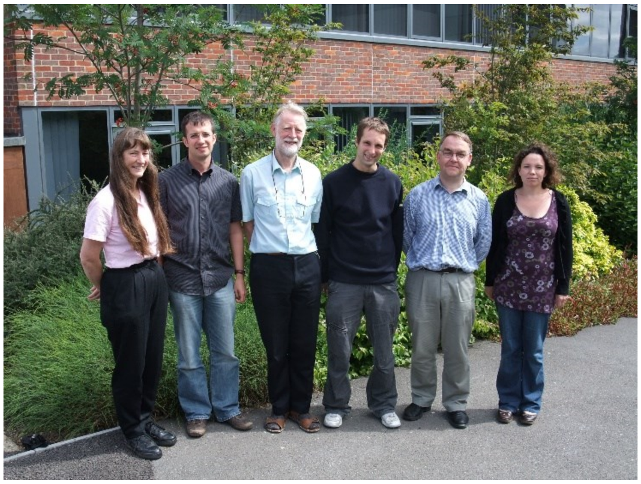


Figure 5: Environmetrics Group, Rothamsted.

When the powers that be decided that the UK no longer needed a centre with SRI's specialisms the Environmetrics Group moved to Rothamsted's Biomathematics Department. Richard Webster was an emeritus fellow there, and he became an active member of the group, continuing our collaborations which began from Silsoe. During this time we also collaborated with colleagues in Australia, Germany and Florida, as well as the British Geological Survey, Cranfield University and the Centre for Ecology and Hydrology. During this time I also had the privilege to serve as Chair of the Pedometrics Commission. It was a very rewarding time, and I enjoyed the opportunity to engage with the IUSS. Fellow Commission chairs from that period might remember the insistent soil scientist who repeatedly emailed us with his insights into how soil K had been incorrectly measured by everyone throughout history, his missives cc'd to the President of the United States and Pope Benedict XVI.

One of Philip Beckett's principles was that everyone should change direction in their research at intervals no less than about 10 years. *In research, as in life'* he wrote, *the most seminal ideas often arise before the mind and imagination have settled into a rut*. Given that, I was excited by the opportunity in late 2010 to make a move to the British Geological Survey as environmental statistician. While continuing to work on soils I also became involved in other work at the Survey.

The geology of the UK, at least onshore, is now mapped in some detail, so the task for geologists is to extend these to 3-D models of the subsurface. This is not a particularly radical departure. Geologists never understood the geological map merely as a set of polygons, but rather as a 2-D slice from a 3-D mental model which they developed from the inspection of outcrops, cuttings and borehole records and their understanding of geological processes. The change is in the availability of computer software to capture, refine and interrogate those models. However, many questions remained about their uncertainty. I tackled the process initially by designing experiments in which geologists made models from subsets of available records, and these models were then tested against the withheld data using mixed models to examine effects of factors such as the individual geologist's experience. Later work involved the use of methods of expert elicitation to try to formalize the geologist's own intuitive sense of how reliable a model is as a prediction of the geometry of the subsurface. As well as pursuing my longstanding interests in the statistical characterization of uncertainty I became interested in how uncertain environmental information can be most effectively communicated

Figure 6: Lark in a hole in Malawi.

to different stakeholders. This resulted in a joint project with the Department of Experimental Psychology at Imperial College London in which, with a PhD student, we examined factors which influence the success or otherwise of communicating uncertain information by means of verbal scales.

Figure 7: Colleagues from Malawi, Zimbabwe, Zambia and the UK setting up a geophysical array at a long-term conservation agriculture experiment, Chitedze, Malawi.

Not long after joining BGS I became involved with collaborations including the University of Nottingham focussed on soil geochemistry and the nutrition of crops, animals and people. Much of this work remains focussed in Africa, and I became involved with statistical training, sampling design and spatial mapping. More recently I have taken the lead in developing, with colleagues in Malawi, Zambia and Zimbabwe as well as the UK, a network to examine the impacts of conservation agriculture management on soil physical properties, crop resilience and groundwater recharge. The CEPHaS network involves soil physicists, hydrogeologists and geophysicists alongside agricultural economists and farm system scientists. We are developing research capacity across a broad front and beginning to add value to established experiments.

In December 2018 I joined the University of Nottingham as Professor of Environmetrics, based in the Division of Agriculture and Environment and a member of the Future Food Research Beacon. I continue to collaborate with the British Geological Survey as well as colleagues at Rothamsted and overseas. There remain a host of interesting scientific problems to be tackled, and enormous scope to make an impact by working across disciplines. In some respects the Beckett principle of changing direction every 10 years is harder in the modern setting, with the demands that adminstrators put on academics. In other respects it is far easier because of the need to work across disciplines. In the last few years I have been able to publish in journals of statistics and of soil science, but also of haematology, geology, psychology, agronomy and environmental health.

I am very grateful to the Pedometrics Commission for maintaining an international community of committed scientists for more than 25 years. I have learned an enormous amount at the commissions meetings, and from its publications. Above all I have learned from colleagues and friends. The challenges of developing resilient and sustainable food systems remain as urgent as ever, and pedometricians can play a central role in that as long as they play to the discipline's traditional strengths: sound sampling, rigorous deployment of statistics and genuine engagement with understanding of the soil.

Announcements

Pedometrics Award Committee & Calls for Nominations

For many years, David Rossiter was chair of the Pedometrics Award Committee. He was a devoted chairman who engaged us all in the fair process of nominating and assigning awards to our colleagues. We would like to thank him and the other committee members for all the hard work they put in. Now, we are happy to announce the new committee for the Pedometrics awards. For the period 2018 to 2022, the Pedometrics Awards Committee is comprised of previous Richard Webster medal winners and early career scientist. They are chosen as to result in a fair gender balance and geographical spread. The current committee members are:

- Murray Lark, University of Nottingham, UK (Chairman)
- Sabine Grunwald, University of Florida, USA
- Gerard Heuvelink, ISRIC World Soil Information and Wageningen University, The Netherlands
- Yang Lin, Nanjing Normal University, Peoples' Republic of China
- Alessandro Samuel-Rosa, Federal University of Technology, Paraná, Brazil
- Uta Stockmann, CSIRO, Australia

We are happy that Sabine Grunwald and Yang Lin were willing to remain in the committee. The new committee is already working hard for the upcoming nominations for the Margaret Oliver Award and the Best Paper 2018 Award. See the calls below and visit the website for more information!

Margaret Oliver Award for Early-Career Pedometricians Call for Nominations, 2019 award

The Pedometrics Commission of the International Union of Soil Sciences (IUSS) makes a biennial award, which is intended to recognize up-and-coming talent in pedometrics. The next award will be at Pedometrics 2019, Guelph, Ontario, Canada, 2–6 June 2019. Nominees must have received a PhD degree or equivalent no more than six years before the nomination deadline of 1st-February-2019, have made high-quality contributions to pedometrics. Nominations should be sent **before 1 February 2019** to Murray Lark at murray.lark@nottingham.ac.uk.
Read more: https://www.iuss.org/index.php?article_id=26

Best Paper in Pedometrics, 2018

Nominations are invited for the best paper in pedometrics, 2018. The Pedometrics Commission awards committee will assess all nominations, along with their own, and prepare a shortlist for a public vote in advance of the Pedometrics 2019 meeting next June. Please send nominations **before 1st February 2019** to Murray Lark, murray.lark@nottingham.ac.uk.
Read more: https://www.iuss.org/index.php?article_id=26

Announcements

IUSS Pedometrics Working Group updates

IUSS WG GlobalSoilMap

In 2018, the IUSS WG GlobalSoilMap prepared a motion to the Global Soil Partnership (GSP) to be invited to INSII and Global Soil Partnership Pillar 4 WG meetings. Last November, at the GSP INSII meeting at FAO, we were able to defend our motion for the working group members and the International Network of Soil Information Institutions (INSII) which by voting was accepted by the INSII members. In this motion, it was described 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. The acceptance of the motion was a great step forward towards our efforts to align our research activities with the GSP. Now, the final decision will be made in June at the GSP plenary. We will keep you all posted! In order to keep up with the work related to the WG GlobalSoilMap, Zamir Libohova (NRCS Soils USDA, USA) has been appointed secretary, whereas Dominique Arrouays and Pierre Roudier remain chair and vice-chair of the WG.

IUSS WG Soil Monitoring

Currently, there is a high demand on methods and applications in Soil Monitoring and thus there is great potential for pedometricians to advance this discipline, working together. In order to do this successfully, the current chair and vice-chair, Dominique Arrouays and Ben Marchant, proposed that now is the time for a new chair and vice-chair who can bring this working group back on the map. We are happy to inform you all that Thomas Bishop (University of Sydney, Australia) and Dylan Beaudette (California Resource Lab, Davis, USA) have taken up the position of chair and vice-chair. We wish them all the best in putting this high-potential working group back on the map!

Upcoming Conferences and call for abstracts

In 2019, we will have plenty of interesting IUSS Pedometrics conferences to attend:

⇒ 12-16 March, Santiago, Chili: 2019 Joint workshop for Digital Soil Mapping and GlobalSoilMap - Soil information supporting environmental modelling and management at multiple scales. Abstract submission will remain **open until 15 January 2019,** more details can be found on the conference website, https://sites.google.com/view/mapsoil2019/home.

⇒ 7-12 April, Vienna, Austria: EGU General Assembly, various interesting sessions, including SSS11.3 Variability in Landscape Processes: Digital Soil Mapping for Sustainability (Convener: Laura Poggio, Co-Conveners: Eric C. Brevik, V.L. (Titia) Mulder, Paulo Pereira, László Pásztor). Abstract submission will remain **open until 10 January 2019**.

⇒ 28-31 May, Columbia (Missouri), USA: 5th Global workshop on Proximal Soil Sensing, PSS 2019 - Linking Soil Sensing to Management Decisions. Abstract submission will remain **open until 7 January 2019**, more details can be found on the conference website, https://www.pss2019.org/

⇒ 2-6 June, Guelph (Ontario), Canada: Pedometrics 2019, more details can be found on the conference website, www.pedometrics2019.com. Abstract submission will remain **open until 15 January 2019**.

Announcements

Please submit your abstract and give your research the widest visibility.
27-30 August, Wageningen, The Netherlands: Wageningen Soil Conference 2019 – Understanding soil functions. Abstract submission will remain **open until 10 May 2019**, more details can be found on the conference website, www.wur.eu/wageningensoilconference2019

Special Issues

Soil System Special Issue "Digital Soil Mapping of Soil Functions", edited by Dominique Arrouays and Titia Mulder. Submission deadline has been postponed until **30 April 2019**. More details can be found here: https://www.mdpi.com/journal/soilsystems/special_issues/digital_soil

A cartoon

By Anne Richer-de-Forges & Dominique Arrouays

Christmas pedometricians' gifts

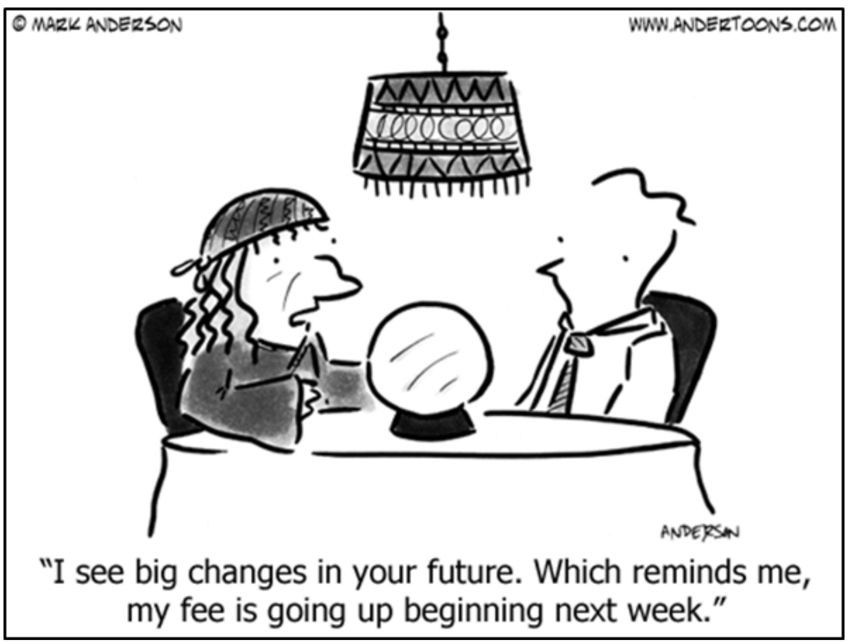
In conversation with Gerard Heuvelink

Gerard Heuvelink has been appointed special Professor in Pedometrics and Digital Soil Mapping at ISRIC - World Soil Information and Wageningen University. Based on his inaugural lecture in September 2018, we asked him to share with us his vision on the future of Pedometrics.

The '10PM Challenges'

By Gerard Heuvelink

Can scientific research developments be planned? I am not sure how you feel about this question but my experience over the past 30 years is that this is true only to a very small degree. The main reasons for not being able to plan how a scientific field will develop over time are that we cannot tell in advance which methods work and which not, that we have little idea what external technological and methodological developments the future will bring and that we often do not know which type of research will become 'hot' and amenable to external funding.



Is the future of Pedometrics research truly unknown? Can we control it?

This also applies to pedometrics. How could we have anticipated 30 years ago that pedometrics would become so heavily involved in proximal soil sensing, machine learning and the mapping and monitoring of global soil organic carbon stocks? Did we plan this? No, we did not. It just happened, so it seems.

But it is not only the outside world that makes that we have little control over the direction of our future research. The truth is that we ourselves also rarely take the time to take a step back and ask ourselves what are the main fundamental scientific challenges that need to be solved in our field. We just move from one research project to the next, constantly look for short-term opportunities, are too busy with our next publications and with increasing our h-index, we prefer quick results over achieving long-term goals that have a high risk of failure, and constantly feel the pressure (usually from within) to produce and publish. Quantity is more important than quality. Perhaps I am exaggerating here and of course it does not apply to all, but surely you agree that it is not an uncommon phenomenon, also not within pedometrics.

Is this not very unsatisfactory? Should we not take more control? Should we not define a research agenda and jointly work towards its realisation? Inspired by Murray Lark's invited talk at Pedometrics 2017, in which he presented three important pedometrics questions for the next 25 years, I have come up with the idea of having the pedometrics community jointly define a list of ten key pedometrics problems that we should try and solve. I propose that we call this list the **'10PM Challenges'**.

Each of the 10PM challenges is a pedometric holy grail.

We would not be the first to define such list. For example, mathematics has the Millenium Prize Problems (http://www.claymath.org/millennium-problems). In fact there are many more disciplines that have a list of unsolved problems (https://en.wikipedia.org/wiki/Lists_of_unsolved_problems). It may be difficult to find a donor willing to pay US$1 million for solving a 10PM Challenge (as is the case for the Millenium Prize Problems), but then again eternal fame among fellow-pedometricians for solving one of the 10PM challenges is of course priceless. What are the ten pedometric holy grails that are on the 10PM list? Well, that is something we must jointly define, but to make a swing start I have compiled a first list. **I am calling upon a young pedometrician**, handy in web-programming, to set-up a webpage where all pedometricians can add their challenges, where all pedometricians can vote items on the list up or down, and where we might even start a discussion on why some challenges are more important than others. Who knows, perhaps in a year's time we have a decent list. We might even organise a discussion session during Pedometrics 2019 on the 10PM Challenges (Asim are you listening)?

I propose that each item on the list is characterised by one title sentence and described by a short text.

In conversation with Gerard Heuvelink

Here is my list, in alphabetical order, including the three problems identified by Murray, and obviously biased by my personal interests:

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?

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.

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.

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?

In conversation with Gerard Heuvelink

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.

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?

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 optimisation.

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.

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?*

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.

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?

Conference report

21st Word Congress of Soil Science

By Yakun Zhang

The 21st World Congress of Soil Science was held in Rio de Janeiro, Brazil, on the August 12-17, 2018. The event theme was "*Soil Science: beyond food and fuel*". There were 8 keynote speakers, 16 Interdivisional Symposia, 5 Technical & Innovation Symposia, 75 Divisional Symposia, 15 Working Groups, and 3 Poster Sessions. A total of 4,234 registered participants from more than 140 countries have contributed 648 oral and 1608 poster presentations. The Soil Judging Contest took place on the three days before the congress with a tough competition between 12 teams and 48 individuals. This was the biggest international soil science conference I've ever attended and my first time at the World Congress of Soil Science. It was a great experience in the beautiful city – Rio. It provided me a good opportunity to meet with old and new friends and colleagues and discuss a lot of soil science.

From left to right: Jingyi Huang, Birl Lowery, Alfred Hartemink, Ekrem Ozlu, Hans Klopp, Yakun Zhang

There were lots of inspiring presentations during the conference. In general, I was impressed by the applications of science and technologies in the agricultural industry of Brazil and their development of sustainable soil management. I saw people from different disciplines in soil science were working together and pushing the boundaries of our understanding of soils, and the various methods and technologies in agriculture and beyond. I enjoyed a talk given by Thomas J. Sauer (USDA) with the title "From Soil Properties to Soil Functions and Beyond: Paradigm Change in Soil Science". He discussed the evolution of soil science as a scientific discipline within the context of Thomas Kuhn's "The Structure of Scientific Revolutions" and the paradigm change in soil science. His talk inspired me to think what could happen in the future with soil science and what the opportunities are.

Contributions from Pedometricians:

Pedometricians were holding oral and poster sessions. There were three Divisional Symposia under Pedometrics Commission and four Working Groups:

- C1.5.1 - Global soil carbon modeling
- C1.5.2 - Crucial techniques for the critical zone: Soil morphometrics, monitoring & modeling
- C1.5.3 - Reconciling pedometrics and pedology
- WG02 Digital Soil Mapping: Progress in digital soil mapping
- WG03 Digital Soil Morphometrics: Soil imaging and image analysis at multiple scales
- WG05 Proximal Soil Sensing (PSS)
- WG06 Soil Monitoring
- WG07 Universal Soil Classification: Progress for the development of a Universal Soil Classification System

I enjoyed the talks given by Alfred Hartemink (University of Wisconsin-Madison) and Alex McBratney (University of Sydney) on the first day of the conference. Prof Hartemink mentioned how the latest technologies can be applied to improve our ability of measuring soil properties and classifying soil types and suggested that more work need to be done to translate these technologies for improved fundamental understanding of the soil. Prof McBratney summarized the latest development in global soil classification and suggested that soil scientists from different countries can work together to build a universal soil classification - not by starting everything from scratch - but by combining knowledge from existing soil classification system.

In addition, I found the talks given by Dr Jacqueline Hannam very interesting as she introduced pedometrics techniques into urban soils and argued that we may collect data from various sources including citizens to fit the gap of soil maps in urban areas. I very much liked Budiman Minasny's talk as he extended the boundary of digital soil mapping to understand the dynamics of soil carbon across the world by combining empirical with mechanistic models. There was so much to like.

I was impressed by the award given to many senior and young soil scientists. The Dokuchaev Medal was awarded to Professor Johan Bouma. The Richard Webster Medal was awarded to Professor Richard Murray Lark. Professor Lark is a great pedometrician and he has developed and applied advanced statistical techniques to understand and quantify the complexity of soil distribution in the landscape. The Dan Yaalon Medal was awarded to two young soil scientists: Fei Yang and Bradley Miller.

It was a great pleasure to attend the 21st World Congress of Soil Science, a big and comprehensive conference in soil science. The next World Congress of Soil Science will be held in Glasgow, Scotland, UK in 2022. The Soil Science Society of China (SSSC) was announced to host the 23rd World congress of Soil Science (2026) in Nanjing, China.

Conference report

Soil Security and Planetary Health 2018

Wartini Ng & Yuxin Ma

After Texas (2015) and Paris (2016), the 3rd global soil security conference on ‘Soil Security and Planetary Health‘ was held in Sydney (New South Wales, Australia) from 4th – 6th December 2018 and was organized by the Sydney Institute of Agriculture and the Planetary Health Platform. The participation of the conference was successful, with the contributions of 82 talks from 17 countries.

Celebration of World Soil Day at the University of Sydney’s farm in Narrabri.

The organising committee consisted of Alex McBratney (Chair), Damien Field, Tony Capon, Milena Kalinina and Martin King. The range and quality of discussions and oral presentations was simply unprecedented. We learnt about how various framework was developed to assess soil security across the globe, how contamination affects soil condition, how soil security can be valued in terms of economy, why continuous monitoring soil conditions are necessary, how climate and human intervention affects soil security, how proper management could improve soil security, how soil security also impacts human health, various management methods the farmers apply to promote soil security, how to educate the public regarding soil security through art and science, how soil capability promote soil security, and much, much more…

Conference report

Some of the highlights include:

- The dimensions of soil security, 5Cs (capability, condition, capital, connectivity and codification), can be the basis of innovative development in soil science in terms of pedometrics and digital soil mapping.
- Various frameworks have been developed to assess soil security across the globe, e.g. Republic of Korea, China, New Zealand, USA, and Scotland.
- Economics plays a key role in soil science for achieving soil security. The value of Korean soil was calculated to be $1,190 billion by Prof. Jae Yang (Kangwon National University). Mark Brady (Swedish University of Agricultural Sciences) talked about the value of soil ecosystem services.
- Soil biota is essential for planetary health, as soil microbes are moved around the globe at an unparalleled scale according to Yong-Guan Zhu (Chinese Academy of Sciences). Craig Liddicoat (University of Adelaide) showed that soil with high microbial diversity are linked to reduced infectious and parasitic disease risk.
- Safeguard soil and planetary health should move scientific knowledge and technology from laboratory to farm field by bringing together scientists and all stakeholders, e.g. consumers, ranchers, farmers, government agencies.
- Ensure soil security in sustainable development with the evidence-based information, such as digital mapping of peatlands by Budiman Minasny (University of Sydney) and global distribution of biochar soil amendment by Sanjai Parikh (University of California, Davis).

On 5th December, commemorating United Nations World Soil Day 2018, Sydney Ideas discussion has been hosted. A panel of world-renowned experts: Damien Field (University of Sydney), Cristine Morgan (Texas A&M University), Yong-Guan Zhu (Chinese Academy of Sciences, China), Catherine Allan (Soil CRC/Charles Sturt University), Johan Bouma (Wageningen University) and Patrick Holden (Sustainable Food Trust UK), has clarified the current state of soil security and put forward solutions for securing our soils into the future.

After three days of intensive discussion, the conference dinner at L'Aqua provided yet another chance to mingle with other conference attendees while enjoying food, drinks, music and dance.

Altogether, the scientific program was generally interesting and well presented in addressing the dimensions of the soil security. Conference proceedings which will be published in a special Issue by *Soil Systems* journal. Attendees are encouraged to submit papers which will be reviewed for publication in the special issue. The next conference of this series is proposed to be held in 2020 in Seoul, South Korea. Great news is that Prof. Jae Yang assure that the conference will be held in great venue with the experience of authentic Korean food with conference registration fees of <$500!! In short, this conference a great success. Many thanks to the organizers and the participants and looking forward to the upcoming conference.

As noted by one of the speakers, To Save the Planet, First Save the Soil

Cheers :D

Pedomathemagica

Gerard Heuvelink & Luc Steinbuch

Recent Pedometrons did not have pedomathemagica puzzles but in response to an overwhelming number of requests (two, to be precise, one from the Commission Chair and one from the Editor of this newsletter) we decided to start this (in)famous column again. So please find three new puzzles for all pedometricians to solve. Answers in the next Pedometron. You have about half a year to solve them. Feel free to send us your solutions and rise in our esteem!

Puzzle 1: Soil profile description

If three soil surveyors can describe three soil pits in three hours, how many soil surveyors are needed to describe 100 soil pits in 100 hours?

Puzzle 2: Organic matter (de)composition

While investigating a peat soil, we ended up with a 1 kg sample of pure organic matter. The sample consists of two distinctive types of organic matter:

Type A, which loses 50% of its mass over 180 days when exposed to air (half-life of 180 days);
Type B, which has a half-life of 45 days.

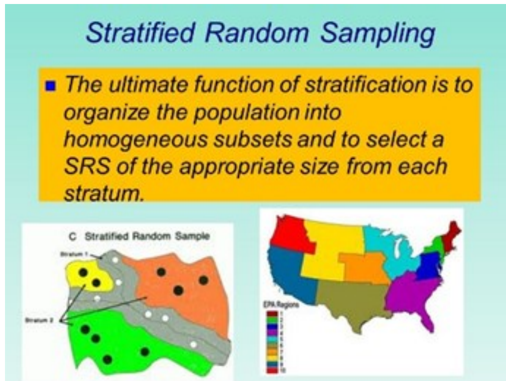
We exposed our sample to air (while keeping it moist) for 180 days, to find out that the mass had decreased to 0.4125 kg. Question 1: Calculate the fractions of A and B in the initial sample.

Sampling at another location, we took again 1 kg of pure organic matter, this time composed of three different types of organic matter:

Type C, half-life of 300 days;
Type D, half-life of 150 days;
Type E, half-life of 75 days.

After 300 days, the remaining mass of this sample was 0.28125 kg, and after 600 days it was 0.094140625 kg (yes, we measured *very* precisely and accurately). Question 2: Reconstruct the fractions of C, D and E.

Question 3: There is something special about the resulting fractions (each multiplied by ten) when you put them in the order C, D, E, A, B. What is it?



Puzzle 3: Cutting a circular study area into as many parts as possible

Some of us love to divide a study area into mutually exclusive and jointly exhaustive subareas so that they can apply their favourite stratified sampling statistical inference. With one straight cut you can divide a circular study area into two parts. A second cut that crosses the first will produce four parts, and a third cut (see illustration) can produce as many as seven parts. What is the largest number of parts that you can get with six straight cuts?

Deep learning for soil mapping

Alexandre Wadoux & José Padarian

Deep learning is a branch of machine learning, where a neural network learns hierarchical representations of the data. A simple example could be an application in computer vision, where the model learns to recognize lines → shapes → objects → composition. There are many types of deep learning architectures, but we will focus on convolutional neural networks (CNNs).

Neural networks are structured in layers, each layer containing several neurons. CNNs have at least one convolutional layer, which acts as a window that moves along the input image. The best example of what a convolutional layer does is to think about a high-pass filter to detect edges. Figure 1 shows the original image and the result of convolving a Sobel filter. A Sobel filter is not more that 2 matrices with some weights (Equation 1). A convolutional layer is formed by many of those filters, and the weights are learned via optimization when training the model. The more layers we add, the higher the complexity of the learned features

Figure 1: Example of a convolution with a Sobel filter.

CNNs have been used in many fields, but just recently in soil sciences. We introduced them for DSM this year (Padarian et al., 2018), and we hope to see many more applications during the coming years.

$$S_{horizontal} = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}; \; S_{vertical} = \begin{bmatrix} -1 & 0 & 1 \\ 2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad (1)$$

Why using CNNs for DSM?

The theoretical background of DSM is based on the relationship between a soil attribute and soil forming factors. In practice, a single soil observation is usually described as a point p with coordinates *(x, y)* and the corresponding soil forming factors are represented by a vector of pixel values of multiple covariate rasters ($a_1, a_2, ..., a_n$) at the same location, where *n* is the total number of covariate rasters.

This point representation is definitely useful but it is the equivalent to a soil scientist just looking at the soil profile without considering the surrounding landscape. To complete the picture, we can expose the model to the spatial context of each observation... the equivalent of stepping out of the soil pit and looking around.

With the help of CNNs, we can expand the classic DSM approach by including information about the vicinity of *(x,y)* and fully leverage the spatial context of a soil observation. We can replace the covariates vector with a 3D matrix (basically a stack of images) with shape $(w \times h \times n)$, where *w* and *h* are the width and height in pixels of a window centred at point *p*.

Multi-task learning (multi-depths, multiple soil properties)

Thanks to the flexibility of CNNs, they have the capacity to predict multiple outputs in a single network and training process. This has obvious implications in simplicity and computing time, but also the capacity to achieve synergy, usually improving the predictions compared with predicting a single output.

In DSM, there are two main approaches to deal with the vertical variation of a soil property. You can make prediction layer by layer (depth is implicit), or you include depth in your model (depth is explicit). Both approaches show a decrease in the variance explained by the model as the prediction depth increases. This is expected since the information used as covariates usually represents surface conditions.

In Padarian et al., (2018) we can see the synergistic effect of using a multi-task CNN. As shown in Figure 2, the variance explained by the model actually increased with depth. Absolute values of R^2 should not be compared between models and datasets, but it is absolutely possible to compare the trends.

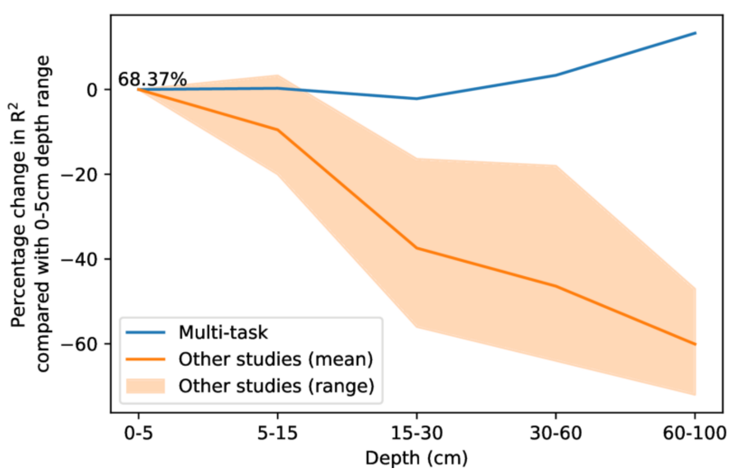


Figure 2. Percentage change in model R^2 in function of depth (Padarian et al. 2018).

This is also confirmed in Wadoux et al., (2018) for mapping total carbon at two soil depths. Deeper soil layer prediction error decreased, while preserving the interrelation between soil property and depths. When compared to predicting each depth separately using random forest, CNN model reduced the mean squared error by 15 and 25% for topsoil and subsoil, respectively.

As for predicting multiple depths, a single CNN model can be trained to predict multiple soil properties simultaneously. In a paper currently under review, Wadoux (2019) tests the use of CNN on a potential application scenario, mapping topsoil clay, silt, sand, organic carbon, total nitrogen and pH in CaCI2 solution over France. The estimation of the model parameter is constrained to produce maps of soil texture summing to 100%. For this country-extent mapping with a large number of observation, there is a large benefit in processing time by building a single model for all soil properties.

Measurement error

With the advent of new technology, soil measurements are often inferred using sensors such as spectrometers. The result is the creation of databases of soil properties measured or inferred using several sensors which predicted soil properties with different accuracy levels. This can be taken into account when calibrating a CNN model.

In Wadoux et al., (2018) we show how to calibrate a CNN model, while accounting for values of total carbon measured in the laboratory, or inferred using a near- or mid-infrared spectroscopic model. A weight is given to each measurement of the soil carbon, depending of its measurement error. The weights are then used to give less importance to measurements that are more uncertain when calibrating the deep learning model.

What about uncertainty?

In DSM, we are not only interested to obtain a map of the prediction but also a map of the associated prediction error variance. It is possible to obtain such map when mapping using any neural network model. Wadoux (2019) develops a 2-step procedure to estimate the prediction error variance. The first step consists estimating the model error variance term by training a large number of neural network models based on bootstrapped samples of the input data. The second step consists in estimating the data noise variance term by assuming normally distributed error around the predicted mean. In this case, we use a neural network which outputs two values in the final layer, and optimizes a negative log-likelihood criterion instead of the commonly used mean squared error.

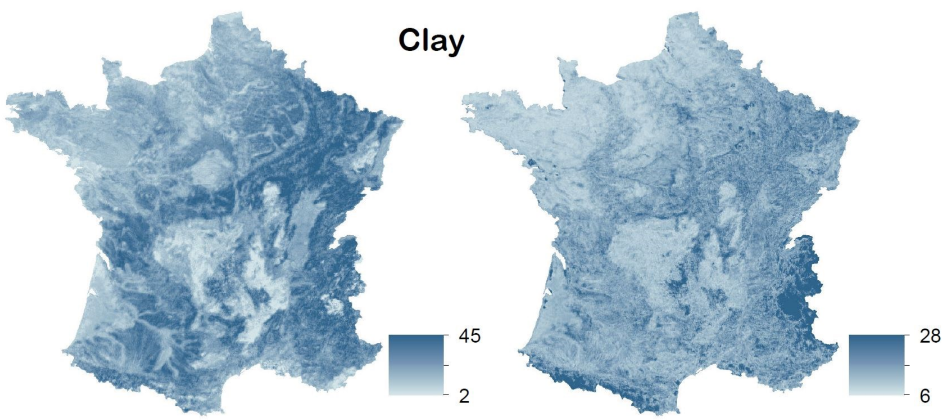


Figure 3. Maps of predicted topsoil clay content in % (left) and prediction standard deviation (right), from Wadoux (2019).

An illustration of the output is provided in Figure 3 for mapping topsoil clay content in percent using the LUCAS data over France. The uncertainty of the topsoil clay map is larger in the Alps and in the Pyrenees, where the LUCAS data have not been sampled. The validation of the uncertainty quantification shows that the 2-step procedure quantifies accurately the uncertainty.

An interesting feature: the window size of input images

In CNNs it is possible to vary the amount of contextual information we supply to the model. This is done by calibrating the model with different window size of input image. In our regional scale case study of total organic carbon (TOC) mapping, a window size of 21 × 21 and 29 × 29 pixels provided the lowest prediction error, but larger window size worsened the prediction accuracy. (Wadoux et al. 2018). This is equivalent to including spatial information in a radius from the sampling location of about 262 to 362 m. Thus, it can be assumed that the window size relates to the range of spatial auto-correlation of TOC.

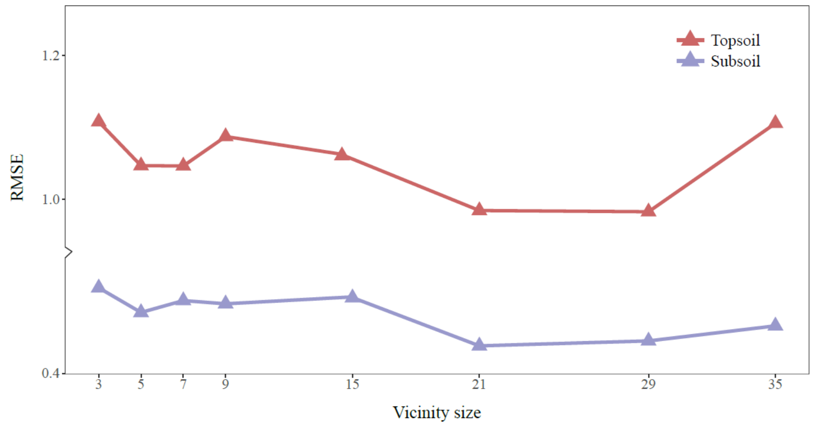


Figure 4. Effect of the vicinity size of input images on the prediction

This is curiously similar to the range of autocorrelation found is similar studies. By fitting a spherical variogram to the experimental variogram of TOC, the estimated value of range was 329 m for the topsoil and 275 m for the subsoil. This is close to the actual radius of the window size that we found optimal. A similar pattern is observed in Wadoux (2018) and Padarian et al. (2018). The actual correlation between auto-correlation range of a soil property and window size is an interesting feature observed by using CNN for soil mapping, but it deserves further investigation so as to generate rules.

Conclusion

We must however say that we need further research to interpret CNN models. We, as soil scientists, are interested to scientifically understand the soil. Despite its predictive power, CNN models are difficult to interpret, but solution exists and deserve to be tested...

To be continued...

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By DvdL

Soil and the machine

For billennia
We were left alone
To get on with
Our own evolution
We were violated of course
A bit of give and take
Here and there
And then they came
The two-legged ones
And they stayed
Made devices
To cut our skin
And spill our blood
To the rivers and skies
The machines became bigger
And bigger
All but suffocating us
Then they made a machine
To learn about us
To understand us
It crunched and gargled
Spluttered and crepitated
Finally a conclusion
Far too complex
Consequences unknowable
Best we leave you alone

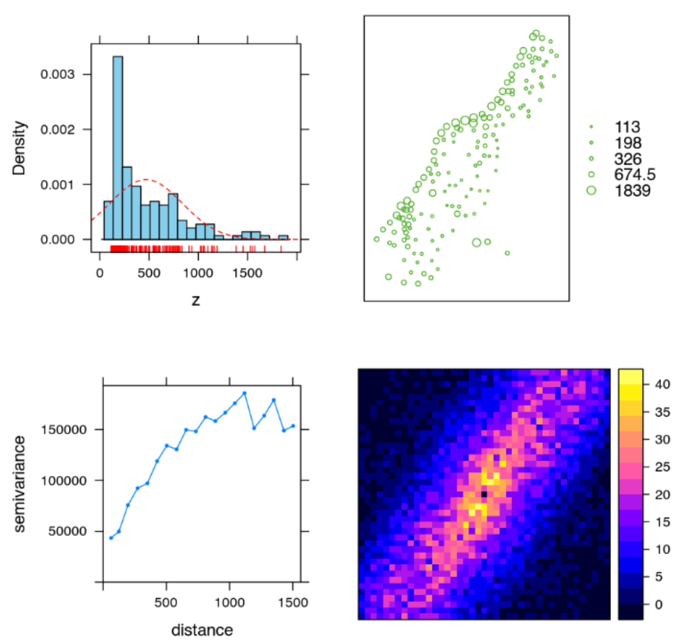
What’s new in R?

R-package pedometrics: Miscellaneous Pedometric Tools

By Alessandro Samuel-Rosa

The **pedometrics** package for R was originally created to share the developments of my PhD research project carried out at the Federal Rural University of Rio de Janeiro, Brazil (2012–2016). The idea came from an observation that was bothering me for some time: several of the pedometric methods that I saw on published scientific papers were not being broadly employed as I would expect. But why? The answer seemed straightforward: because they were not available as a computer program ready to be used. This was also making it difficult to reproduce the analyses carried out by others. Creating a generic package for R – a popular programing language among pedometricians – could be a solution. For example, the analyses described in our [2015 Geoderma paper] can be reproduced using the functions `buildMS()`, `statsMS()` and `plotMS()`.

The current CRAN version of the R-package **pedometrics** – 0.6.6 – is an implementation of miscellaneous functions for various pedometric purposes. This includes the calibration of multiple linear regression models, computation of summary validation statistics, generation of plots, evaluation of the local quality of a geostatistical model of uncertainty, and so on. Other functions simply extend the functionalities of or facilitate the usage of functions from other packages that are commonly used for the analysis of pedometric data. Among these, one of the functions that I find very useful is `plotESDA()`. This function creates four plots for exploratory spatial data analysis (ESDA): a histogram + density plot, a bubble plot, a variogram plot, and a variogram map. The figure below shows the result for the zinc concentration in the Meuse river data set.



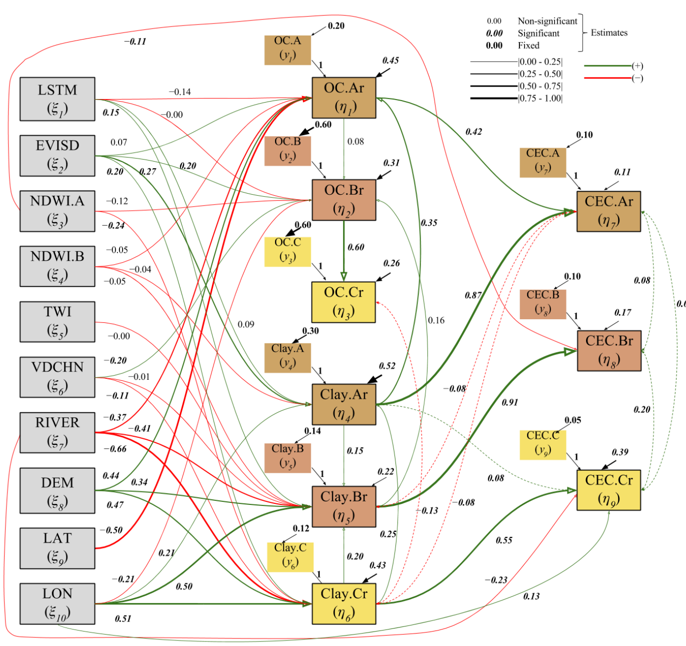
The latest developments of the **pedometrics** package can be installed from GitHub using `devtools::install_github(“samuel-rosa/pedometrics”)`. Contributions to the package are welcome and can be made via pull requests.

On winning the best paper award

By Marcos E. Angelini

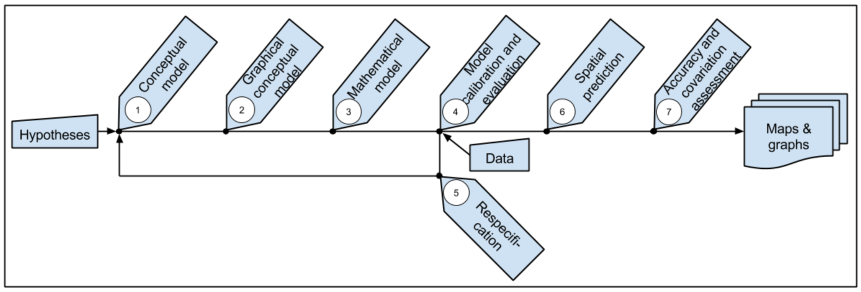
Thank you very much for voting for our paper. Having won this award represented one of the happiest moment on my professional career. I think that everybody should have such kind of acknowledgement once, at least, to be stimulated to continue working for the excellence. This achievement would not have been possible without the contribution of the co-authors, Bas Kempen and Gerard Heuvelink, as well as the thorough work of the anonymous reviewers and the editor of the journal, Margaret Oliver. I have to admit that I felt very proud of this paper yet before this award.

In this paper we remarked that even though we are very good at predicting the spatial variability of soil (properties and types) in DSM, we still need to improve our models to understand the soil-landscape system. We do not usually take into account the interrelations among soil properties, nor test we whether the single predictions of several soil properties keep coherent covariation. Also, we frequently have some knowledge about the soil-landscape system that is difficult to include in the modelling process without using mechanistic models. We proposed, therefore, to use structural equation modelling (SEM).

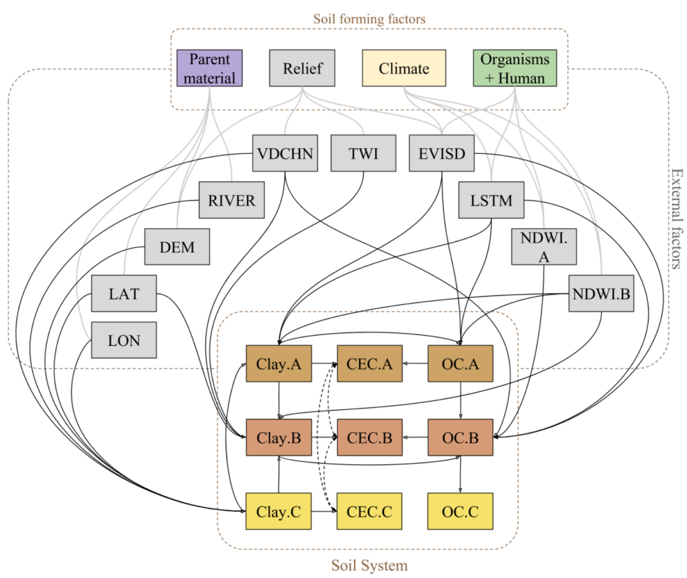


Structural equation modelling has been used in econometry, sociology and more recently in ecology, being Sewall Wright (1921) who provided the foundations of this approach. It is based on graphical modelling, path analysis and multivariate linear regression, and is generally used to study cause--effect relations in a system. Even though it does not prove causation, it has been successfully applied to test models that have been based on causal relations.

In my view, one of the most appealing features of SEM is that the modelling process starts with a development of a conceptual model,where one has to connect variables with arrows to describe the system interrelations. Those arrows represent coefficients to be estimated by empirical approaches using observations, that resulting in a system of equations. A soil property that is a dependent variable in one equation may be independent in another equation. After calibration, the graphical model will show the magnitude and sign of the relations. When the model does not fit the data well, we can modify its structure by using suggestions given by the model. This process is known as 'model respecification' and it is the way to learn from data. It means that the modeller has to thoroughly analyse the overall goodness of fit, as well as every single arrow (coefficient) to check whether it agrees with their assumptions. The model respecification step has been revealing for me, because I became conscious of the degree of knowledge about the system that I really had. Those relations that I could not explain may be subject of future studies.



To illustrate the use of SEM for DSM we applied it in the Argentinian Pampas to model soil organic carbon (OC), clay content and cation exchange capacity (CEC) at three soil horizons, A, B and C (which is the most common sequence of soil horizons in the study area). The relations between these three soil properties are very well known (clay content does affect positively OC and CEC, and OC affects positively CEC), so it did not imply a great effort to design this part of the graphical model. Environmental covariates were used to represent soil-forming factors (DEM, and its derivatives, and other remote sensing data). Since the available data were only partial proxies of the real soil-forming processes, it has been much more challenging to build the relations between covariates and soil properties at different horizons. In the paper we explained the process of model respecification and the progressive impact in the model fit. After the model was fitted, we used it to spatially predict the three soil properties at the three horizons simultaneously.



We showed that the model was slightly better than multivariate linear regression in term of prediction accuracy and in term of reproducing the covariation among soil properties. Another advantage of SEM was that we obtained a final graphical model that showed how the system variables are connected. It allowed us to discover, for example, that the links of soil properties of A horizons were weaker than expected, which might be caused by a change in the parent material, as it was suggested by Kröhling and Iriondo (2003). So I think that SEM still have a great potential of development in pedometrics, not to compete with machine learning techniques, but as alternative way to understand how the soil system works and to develop a more *conscious* DSM.

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A critical look at soil science epistemology

Alexandre Wadoux worked on the epistemology of soil science during the last two years. The conclusions of his work have been summarized in a Master thesis, realized at the Francois Viète Centre for History and Philosophy of Sciences in Nantes (France), which he defended in September 2018.

A critical view on history and epistemology of soil science

By Alexandre Wadoux

In my first year of university, I learned the factors of soil formation. I have been taught that V. V. Dokouchaev (1846-1903) proposed a new theory of soil formation and its spatial distribution, and that it marked a paradigm shift with the creation of a new and independent soil science. I also learned that the historical roots of soil science lie in geology. Let's question that.

Does soil science have its historical roots in geology?

Contemporary historiography attributes to geologists the paternity of soil science. Dokouchaev was a geologist by training, as well as (among others) N. Shaler (1841-1906) in the United-States or E. Risler (1828-1905) in France. It is thought that, since geologists were involved in various soil research, and geological societies coordinated the first soil surveys, the historical roots of soil science was inevitably established in geology (Landa & Brevik, 2015). This claim may not be as it seems.

To begin with, the example of humus theory at the end of the nineteenth century and its use in the work of the Russian soil science school is a striking example. The theory of humus was partly expanded by the experiments of the French chemist L. Grandeau (1834-1911) in a book published in 1878. Grandeau argues, based on his laboratory deductions, that the assimilable elements of the soil are inside the black matter, elements on which the fertility of the soil depends. He reconciles the humus and mineral theory, proving experimentally that humus does not nourish the plant but makes assimilable mineral nutrients.

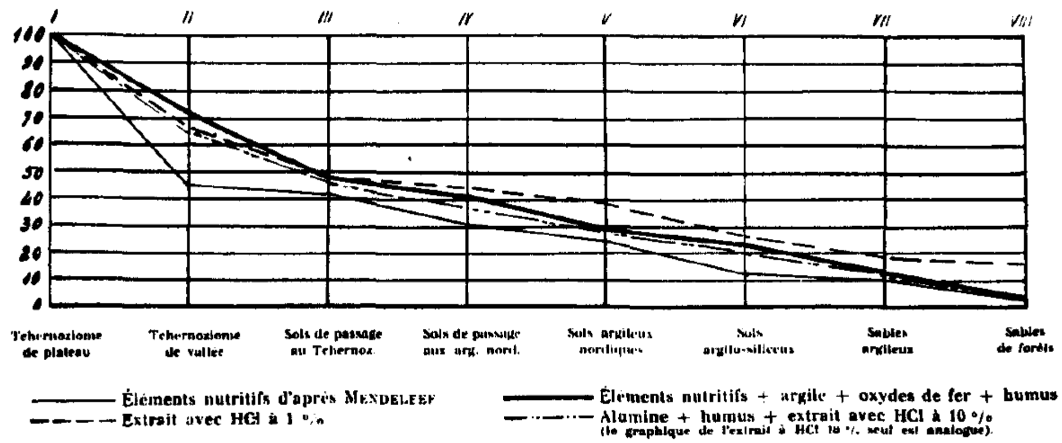

Figure 1: Chemical average of seven soils compared to a base 100 for a plateau chernozem soil.

Dokouchaev cites the works of Grandeau in many occasions. These serve as a methodological basis for the analysis of Russian Chernozems and Dokouchaev's resulting theory. Dokouchaev proposes to evaluate a soil by a number of geological, chemical, mechanical and physical factors that interact and merge into a quantitative analysis. He summarizes these properties by graphs classifying the soils by their fertility. For example, Figure 1 shows the 'chemical average' of the soil (reported by Margulis (1954)), compared to a base 100 for a chernozem positioned on a plateau (the most fertile chernozems). It responds to the practical needs of assessing farmland for tax first, and later for improving yield. To do this, Dokouchaev uses methods inherited from agricultural chemistry and agronomy, instead of geology.

Dokouchaev work on black soils are the subject of numerous frictions. H. Hitier, student of Grandeau, publishes a report in the *Journal d'agriculture pratique* describing the Russian Pavilion of the World Exhibition of 1900 in Paris. The author neither refers to the word "pedology", nor to the work of Dokouchaev, but reminds us that: "It is to him [Grandeau] that we owe the most beautiful and complete researches on the true cause of fertility of these black lands of Russia" (Grandeau, 1900, p. 44).

Did Dokouchaev's theory introduce a paradigm shift ?

The term paradigm is strong, it refers to a (scientific) revolution after finding a persistent anomaly in the existing theory. The term paradigm is very often used to characterize the change induced by the work of Dokouchaev. Personally, in Dokouchaev's new theory, I do not find in any case a paradigm shift as described by the famous theory of the philosopher T. Kuhn (1963).

The methodological basis of Dokouchaev's work is close to that of agricultural chemists (see above with the theory of humus). Some notions are borrowed from the methods of geology, for example the mechanisms of scales. The methods employed by Dokouchaev do not offer much novelty. The conclusions are, but they are fully included in the evolutions of the natural sciences of the late nineteenth century. We, in particular, find a diffusion of the ideas of C. Darwin and D. Mendéléev, which show the predictive power of a theory. C. Lyell showed on his theory of uniformitarianism that the processes that formed rocks still occur. Dokouchaev's works are perfectly part of a normal science showing a strong rationalist tendency that contradicts the positivist positions of French and English sciences, among others.

The opposition rationalism / positivism is particularly marked in soil science of the late nineteenth century. Rationalism deals with classifications, studying a system and establishing the great laws of nature. In contrast, the positivist spirit is interested in the edaphological aspects of soils with great importance given to experiments. Little room is left for a subjective interpretation. Dokouchaev's in his theory is opposed to many existing conceptions in soil formation precisely because it shows a strong rationalist vision and not because it proposes a paradigm shift.

We need historians, not pedologists

We have literature on the history and epistemology of soil science. This literature is mainly produced by pedologists working on the history of their area of interest. These publications pose a serious methodological problem and lack a necessary critical analysis; building the historical tale is not simply narrating the past, seeking the fathers of a discipline or explaining who was right, using the knowledge of the present. We must rather try to explain the complexity of past events in a context, based on a critical view of primary sources. With rare exceptions, I did not find this type of publication.

Let's take a concrete and recent example. In Rodrigo-Comino et al., 2018, the origins of soil geography are investigated. The authors search the fathers of a discipline, a discipline with a direction that leads to the current knowledge. The publication makes a list of contributors. It does not place their contributions in a context, and in fact misses much of the necessary critical analysis. It combines the methodological bias that any historian must avoid. Moreover, looking for the origins of a discipline redirects us *de facto* to the origins of humanity. Almost no primary source is used, but secondary sources. This publication is, in this sense, of no value whatsoever for historical research.

I would also like to draw attention to another bias which consists in seeking the approval of epistemological theories and their application to fields of soil science. We have previously seen the use of the term paradigm shift. It is attractive to rely on functional theories for other disciplines. I have yet not often found the rationale for using these terms and the actual understanding of their meaning. The same applies to other epistemological notions from the theories of Lakatos, Kuhn, Bachelard and others that may at first sight be easily applicable to soil science. We must use these notions with caution and understanding of their meaning.

Conclusion

In conclusion, this text emphasises the necessity of using a historical and methodological approach for the investigation of the history of soil science. Biased opinions are inevitable, yet examining them objectively is a key aspect. Moreover, being critical on historical references, authors, their ideology and scientific background, and what century and era they are from is crucial, if we want objective and reliable information on the history of science. Only then, we will be able to build a necessary critical history of our discipline.

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