Editorial
Looking back on 2015 it can be safely concluded that the WG on “soilscape modelling” was successfully launched with a number of activities: a session at EGU-2015, a high-impact review paper on the state of progress in soil- and landscape modelling and a 1-day well-visited workshop at Pedometrics 2015 in Córdoba. A summary of the conclusions of that meeting can be found below, and impressions of several participants have already been reported in this Pedometrics newsletter.

In October 2016 the WG (on Arnaud’s initiative) organizes a hands-on workshop on soil and landscape modelling in Wageningen with the purpose to bring the models to the users (an audience of PhD-students) and find out what these models can (and perhaps cannot yet) do to forward their research. Advertisement elsewhere in this newsletter. There is a lot of research going on regarding man-soil-landscape interaction, as can be seen in the programs of the big conferences, like EGU2016 (below), in which several WG-members are convenors or contributors.

In this 2nd newsletter a contribution by Budiman Minasny on continuous depth functions as a new paradigm for soil evolution modelling, a contribution by Sophie Leguédois on how to move towards pedogenetic modelling of Technosols and by the undersigned on the question if pedogenetic models need to be slow. Happy readings!

Peter Finke

Looking back on Pedometrics 2015
As appetizer for the Pedometrics 2015 conference in Córdoba, a 1-day workshop was organized titled Modelling of soil and landscape evolution, state of progress. The morning session contained presentations on model instruments: MilesD (Vanwalleghem et al.), Lorica (Temme & Vanwalleghem), mAIRM3D (Willgoose et al.), Speros-C/LT (Bouchoms & Van Oost), SoilGen (Finke) and a position paper on the international soil modelling consortium ISMC by Vanderborght et al. The afternoon session started with 3 model
demonstrations (SoilGen by Opolot, mARM3D by Willgoose and Lorica by Temme, demo downloads here) and thereafter ample time was devoted to a discussion around today’s hot topics in soil-landscape modelling. An extensive summary of the discussed topics can be found here. Both the morning presentations and the afternoon demos invoked vivid and interesting discussions. The afternoon discussions were useful not only for information exchange, but also helped to identify major development issues. To mention a few:

1. **Further outreach is necessary** to make modellers meet, to work with ecosystems services experts as one important group of “ultimate consumers” of soilscape model outputs, to contribute to Earth System Models, to work with the Critical Zone people to exchange data and modelling approaches;

2. **The linkage to pedometrists needs further development** as questions exist on calibration protocols for (often slow) models, on the supportive relation between sampling and calibration/validation in spatial and temporal domains, on the usage of modern sensor technologies, etc.;

3. **The process coverage of soil-landscape models in function of their intended application range needs to be improved.**

I am sure that these items will prove an inspiration when session themes in future conferences and workshops are to be defined, and am looking back to a successful workshop. Many thanks to Tom Vanwalleghem and colleagues for making Pedometrics a smoothly organized happening!

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**Upcoming events**

**EGU 2016:** A selection of relevant sessions:
- Coevolution of soils, landforms and vegetation: patterns, feedbacks and ecosystem stability thresholds. Read [this](#).
- Human-Landscape interaction in the Anthropocene. Read [this](#).
- Soil evolution in Space and Time: From polar to tropical - from Paleogene to Anthropocene - towards sustainable management futures. Read [this](#).
- Sediment archives and landscape evolution in dryland areas: New approaches, perspectives and challenges. Read [this](#).
- Soils as Sediment: integrating soil properties into erosion modeling. Read [this](#).
- Multiscale modeling and analysis of environmental processes. Read [this](#).

**3rd conference on Hydropedology 2016.** Read [this](#).
PhD-course
The international PhD course on soil-landscape modelling will be organized from 3-7 October 2016 at Wageningen University in the Netherlands. This course presents the latest insights and techniques in the rapidly developing field of science, and introduces participants to the community’s most popular models. As such, it prepares to offer integrated answers to questions about the sustainability of land use, and the sensitivity of soils and landscapes to changes in land cover and climate.

The programme prominently features afternoon activities where students can use models on their own data, if desired. A one-day excursion to a famous soil-landscape research site in Belgium is included. Teachers will be dr. Arnaud Temme (Wageningen University, the Netherlands), profs Michael Sommer (ZALF, Germany), Peter Finke (Ghent University, Belgium), Garry Willgoose (University of Newcastle, Australia), and drs. Tom Vanwalleghem (University of Cordoba, Spain) and Sagy Cohen (University of Alabama, USA). Course details and registration are available at https://www.pe-rc.nl/soil-landscape-modelling. Logistical and practical requests can be directed at Arnaud Temme, arnaud.temme@wur.nl

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Soil depth functions
At the Digital Soil Morphometrics May 2015, Alfred Hartemink asked to give a presentation on soil depth functions and to present some common typologies. It was a challenge, as we often looked at depth functions presented in papers, but never thought of the possibilities of having a set of typologies. As soil is developed in situ, so there must be a pattern that is linked with the processes happening in the profile. Examining the literature, we came out with 7 possible typologies of depth functions, that illustrate how soil properties change with depth. The depth functions are uniform, gradational, duplex, exponential, wetting front, abrupt, peak/convex and minima-maxima (Figure 1).

Figure 1. General typologies of depth functions.

What is the benefit of characterising these depth functions? Each of the depth function tells us about
the processes that occurred in the profile. Knowing the processes, enable us to model them. This allows us to understand more about the process and possibly allow us to project what is going to happen in the future. Some of these depth functions have been discussed in the literature, so let us look at them.

**Pedology models**

The Great Hans Jenny wrote in the Factors of Soil Formation that “in the language of the pedologist, the anisotropism of soils is usually expressed with the words: "The soil has a profile" and thus naturally, every soil property has its own vertical distribution pattern or specific "depth function." He further suggested the use of the soil indicatrix (a laterally isotropic 3-D depth function) for clarification and refinement of soil-profile descriptions. Obviously, Jenny’s indicatrix has not been taken up, as his clorpt model.

![Figure 2. Soil Indicatrix (Jenny, 1946)](image)

In Australia, Keith Northcote’s Factual Key for the Recognition of Australian Soils grouped soil profiles based on its primary profile forms: organic, uniform, gradational, and duplex. Mineral soils are distinguished by the depth trend in texture. Uniform profiles have little or no change in texture, gradational profiles show a steady increase in clay content with depth, and duplex profiles have layers of contrasting texture within the solum. The profile forms imply the degree of soil development from minimum (uniform), to moderate development with some illuviation process (gradational), and advanced development with heavy illuviation (duplex).

**Mechanistic models**

In Mechanistic models, the depth functions arise from the modelled processes. For example in Mike Kirkby’s soil profile model, the exponential function assumes the distribution of organic matter that was added to soil via plant litter or decaying of roots. Heat transport via diffusion also produces an exponential depth function. The movement of water through a soil profile creates wetting front depth functions. The bell-shaped function assumes the distribution of water and the movement of solutes (convective-dispersion equation), and their extraction by plant roots. The bell-shaped or peak functions can also indicate compaction. Anthropogenic influences can create variations such as multiple peaks. Mixing in the surface layer can create minimum-maximum peaks. This minima-maxima (minimax) depth function can be related to mixing processes in the surface and translocation
to the subsurface, through excessive bioturbation, or textural discontinuities resulting from different parent materials within the soil profile.

**Mass-Balance Models**

Susan Brantley and Art White calculated the mass transfer coefficient based on measurement of elements and bulk density of the regolith and soil. The depth functions of these mass transfer coefficients can indicate various processes:

A) immobile, in the case of Ti or Zr, which indicated that the soil is developed in situ
B) depletion, such as Mg due to weathering
C) addition, such as enrichment of SOC
D) depletion-enrichment, such as Al, which suggests it is leached at the surface and re-precipitates at depth
E) biogenic, such as K and Ca which shows depletion at depth but enrichment at the surface. It may result from the weathering of primary minerals at depth and uplifted via plants.

**Conclusions**

We identified 7 typologies of soil depth functions: uniform, gradational, duplex, exponential, wetting front, abrupt, peak/convex and minima-maxima. These depth functions represent major soil processes. Field observations using sensors such as pXRF and NIR in digital soil morphometrics allow measurement of soil properties and elemental concentration at small depth increments, enable us to measure depth functions easily. In addition, rather than compartmentalising soil properties based on horizons or arbitrary layers used in computer models, we should model properties as a continuous function of depth.

A discussion on these functions can be found in our paper that is published in the Digital Soil Morphometrics book.
References

Modelling pedogenesis of Technosols
Technosols, soils subjected to a strong human influence and containing significant amounts of artefacts, are characteristic of the Anthropocene. In order to better apprehend their growing importance in our current environment, our knowledge of the evolution and fate of these soils must be improved. The aim of this article is to promote pedogenic modelling for Technosols by proposing an appropriate framework.

The paper first defines the characteristics of Technosol pedogenesis. Technosols are: (i) man-made soils, (ii) created under a relatively warm and humid climate favourable for soil evolution, (iii) surprisingly biologically active, (iv) generally developed on levelled land surfaces showing high heterogeneity in depth, (v) relatively young, and (vi) with reactive artefacts as parent materials. Pedogenic processes observed in Technosols are similar to those occurring in more natural soils; however they generally have fast kinetics and occur in unusual assemblages.

In order to evaluate how the specific features of Technosol pedogenesis are currently integrated into soil evolution modelling and to examine a diversity of modelling approaches, we then selected and analysed 18 existing quantitative models. Ultimately, we choose quantitative models of pedogenesis as well as quantitative profile scale models of soil functioning in different domains of application.

We focused on domains of application relevant for pedogenic processes (biogeochemistry, soil erosion) and integrating biological processes (crop/forest development, ecosystem functioning, root growth, and biomechanics).

From this selection, we carried out a mixed technical and conceptual analysis, whose main conclusion are presented here. As the pedogenic processes are similar, it is possible to develop a modelling framework for Technosol pedogenesis from existing models developed for more natural soils. We have therefore proposed basing the modelling framework on: (i) the already well-developed process-based approach; (ii) the coupling of the numerous existing models of soil processes; and (iii) the use of advanced coupling techniques. As processes related to water transfer and chemical reactivity are well modelled, basic conditions are already in place for initial attempts at representing the evolution of Technosols involving those mechanisms.

The requirements for the modelling of Technosol evolution aren’t radically different than the ones needed for more natural soils. Indeed, the characteristics of Technosol pedogenesis conspicuously highlight several general needs for soil evolution modelling: (i) the development of biological and physical models, key mechanisms which have been overlooked until now, in order to be able to accurately represent the diversity of observed processes; (ii) the selection of a universal energy unit in order to cover the numerous anthropic and natural control variables; (iii) the joint consideration of

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Footnote 1: The references of the 18 selected models are: Gabet et al. (2003), EPIC (Williams et al., 1983; Williams, 1995), MODHMS + EROSION-3D (Sommer et al., 2008), PASTIS (Lafolie, 1991), QPEM (Rasmussen et al., 2005), Root Bundle Model (Schwarz et al., 2010), ROOTMAP (Dunbabin et al., 2002a,b), SAFE (Sverdrup et al., 1995), SoilGen1 (Finke and Hutson, 2008), SPACSYS (Wu et al., 2007), STICS (Brisson et al., 2003), Volobuyev (1985), WaNuLCAS (Van Noordwijk and Lusiana, 1998), WITCH-ASPECT (Godéris et al., 2006), Regan (1977), HYDRUS 1-D/2-D (Šimůnek et al., 1996, 2013), MINTEQ, and Vidal-Beaudet et al. (2012)
trend changes at the decade scale and periodic changes at the seasonal scale in a dual-time scale modelling approach; (iv) a multi-scale representation of the soil profile to reproduce the spatial control of pedogenic processes. Technical developments are required for the last three items. Concerning the energy unit, we suggest adapting and testing existing metrics like entropy, exergy, energy or EEMT for soil in general and Technosols in particular. We also propose an original conceptual approach on a dual-time scale based on resilience patterns in soil changes (Illustration 1) and, a multi-scale representation adapted from the APSF (Marilleau et al., 2008). We conclude that the specific features of a modelling framework for Technosol pedogenesis are: (i) the ability to parametrise the models on a range that is representative of the unusual conditions found in Technosols, and (ii) the integration of the peculiar chemical and physical properties of technogenic materials. Regarding the data needed for development of the modelling of Technosol pedogenesis, constructed Technosols are a relevant experimental model which supply reliable data on soil evolution.

Technosols are emblematic of the issues we face for the management of the soils of the Anthropocene. The design of a modelling framework for Technosol evolution should therefore bring interesting developments for pedogenic modelling in general.

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References
Are soil formation models necessarily slow?
As a wake-up quote I like this one from Manfred Eigen (1967 Nobel Prize in Chemistry): “a theory has only the alternative of being right or wrong. A model has a third possibility: it may be right, but irrelevant”. Although the relevancy of both theory and models may be proven only years after their conception, few people would like the idea of producing a model residing permanently in the third category. On the other hand, model builders are often struggling with issues of computational expenses responding to the detail in which processes are described. This results in choices that might actually influence the usefulness of the model in certain scenario contexts: simplified models may no longer be able to detect differences between scenarios. As I have managed to build a fairly slow model because of the desire to –gradually- make it as complete as possible, I posed myself the question if this slowness is necessary to avoid the irrelevancy bugaboo.

First some thoughts on what causes slowness. This may be any combination of high process coverage, fine model discretization (e.g. compartment sizes), choice of algorithms with low computational efficiency, less smart choice of development platform. Model discretization, or resolution, is related to the question if profile information is retained during simulations with coarser compartment sizes, and if changes over time are still detected when temporal resolution decreases. Improving these retardant factors should be associated with an evaluation of alternative models versus the original model using benchmarks that include but are not just associated with runtime. Some benchmarks that come into mind are:

- functionality (does the application range change when model coverage changes);
- relevancy (in a global change context: does the adapted model respond to the forcings that represent climate change and land use change);
- scenario sensitivity (can the model distinguish between 2 scenarios);
- face validity (are results still plausible);
- runtime.

Having a question (are soil formation models necessarily slow) and the above evaluation criteria, I was tempted to set up a small simulation experiment in which part of the functionality of the SoilGen2.25 model (Opolot & Finke, 2015) was either disconnected or replaced. The basic version using the Richards’ equation and the Advection-Dispersion Equation is called RWC for brevity. As an alternative formulation for water flow I activated Addiscott’s mobile-immobile capacity model (Addiscott, 1977) in its modified implementation by Hutson (2003): model version AWC. This model takes larger (1-day) time steps and solving the equations is computationally less expensive as well. It is thus expected to be faster, but lacks the possibility for upward flow of water. Additionally, a trimmed hi-speed version of the model was produced by disconnecting the water flow and the chemical equilibration routines: model version NWNC. These 3 model versions were applied onto 2 scenarios and with 2 compartment sizes: 5 and 10 mm layers. The 2 scenarios comprise the interglacials MIS5 (about 120 kY ago, duration 22 kY) and MIS13 (about 500 kY ago, duration 30 kY), that result in different (field) soils in the Chinese loess belt. As model output parameter I took the calcite (re-)distribution in the loess soils.

The 12 model runs were evaluated for the aspects functionality, relevancy, detectability of differences between MISS and MIS13, plausibility of the model outputs and runtime as described above. The detectability of differences between scenarios was estimated by a paired t-test on the difference of means, comparing calcite contents of soil compartments at equal depths for the 2 scenarios. It is likely that better tests can be designed for this purpose (notably bootstrapped Loess regression), therefore for the sake of this experiment I did not just do the paired t-test but also did a visual inspection of time-depth diagrams (Figure 1).

Table 1 summarizes the results. The runtimes vary a factor 25 between the slowest (RWC5) and fastest (NWNC10) model version, but this is at the cost of relevancy (effects of global change on...
soils can hardly be simulated in NWNC10). As a consequence the scenario sensitivity is low for NWNC10: the difference between soils formed during MIS5 and MIS13 almost disappears and what’s left is directly related to differences in dust input: no model needed for this... The time-depth diagrams for NWNC-scenarios are featureless and less plausible. On the other hand, RWC5 detects a difference between MIS5 and MIS13 that is also observed in palaeosols on the Chinese loess plateau. Simulations with the AWC-models did not result in a high scenario sensitivity but the time-depth diagrams do show similar differences between MIS5 and MIS13 as those of the RWC-scenarios, at least in the topsoil. The deeper calcic horizon was lost, however... Finally, the choice for a lower resolution (5 cm depth intervals versus 10 cm intervals) gave a worse scenario sensitivity but the patterns in the time-depth diagrams were preserved.

So far I have managed to avoid the topic of computational efficiency. There is surely an effect of chosen compiler (-options), chosen software platform, choice of algorithms and the programming skills of the modeller. For models that cover millennia, with potentially millions of time steps for which sets of equations need to be solved, software stability is essential, which may exclude some faster but less stable algorithms. There is thus a huge software engineering side to this issue. The substantial efforts in the Vsoil project by INRA should be mentioned, followed and appreciated in this respect, and also the International Soil Modelling Consortium has this issue on the agenda.

The above discussion bears resemblances to those on model complexity (and its trimming using Ockhams’ razor). Often, complex models can be simplified without too much loss of predictive capacity when confronted to a data set. When aiming to develop a complete model (describing the maximal range of processes that can occur in a soil, to assure maximal applicability worldwide), one might produce a complex model but that is rather because of the large number of interacting processes than because of the level of detail at which the individual processes are described. Highly detailed process descriptions may be justifiably simplified especially when they can only be parametrized with high uncertainty at the scale level at which the model operates. Reducing model coverage (to simplify its complexity) will reduce its application range as well. In short, I think model simplification is only advisable as long as its application bandwidth is either preserved or reassessed.

Conclusions

- Simplified water transport may obscure scenario sensitivity (e.g. because upward water flow is not simulated);
- Smaller compartment sizes give a higher scenario sensitivity;
- To gain speed without losing too much scenario sensitivity it may be better to increase compartment size than to simplify water transport;
- No-flow models seemed to have little relevancy in a global change context;
- Soil models may indeed be necessarily slow if sensitivity to global change scenarios is desired.

Table 1: Performance evaluation of various model versions of SoilGen in a comparison of MIS5 and MIS13

<table>
<thead>
<tr>
<th>Model version</th>
<th>Functionality</th>
<th>Runtime hr/kY</th>
<th>Relevancy</th>
<th>Scenario sensitivity 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RWC5</td>
<td>100% SoilGen (incl. Richards, Advection-Dispersion Eqs.)</td>
<td>10.2</td>
<td></td>
<td>0.003</td>
</tr>
<tr>
<td>RWC10</td>
<td>4.2</td>
<td></td>
<td>0.063</td>
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<tr>
<td>AWC5</td>
<td>Tipping bucket water flow sub-model=no upward water transport</td>
<td>3.2</td>
<td></td>
<td>0.391</td>
</tr>
<tr>
<td>AWC10</td>
<td>1.6</td>
<td></td>
<td>0.902</td>
<td></td>
</tr>
<tr>
<td>NWNC5</td>
<td>No water transport, limited weathering/C-sequestration, no chemistry (constant pH)</td>
<td>0.5</td>
<td></td>
<td>0.127</td>
</tr>
<tr>
<td>NWNC10</td>
<td>0.4</td>
<td></td>
<td>0.426</td>
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Relevancy indicates if the model version is relevant to evaluate global change scenarios. It is defined by 6 components, each of which can score fully/limited/not responsive:

- R1=responsive to changes in precipitation amounts/intensity/distribution
- R2=responsive to changes in potential evaporation
- R3=responsive to changes in temperature
- R4=responsive to vegetation change (root distribution, root water uptake, biomass production, nutrient uptake)
R5=responsive to effects of land use change (plowing, erosion, deposition)  
R6=responsive to changes in biological activity (bioturbation)

Sensitivity is defined by Probability $H_0$: \( \mu_{MIS5} - \mu_{MIS13} = 0 \), here based on simulated calcite profiles. Result of paired t-test on differences in calcite content over all (n=20 or n=10) compartments in the top 1 meter of soil in the final year of the simulation.

Figure 1: Time-depth diagrams for calcite content of various model versions of SoilGen for MIS5 and MIS13. Increasing depth (0-2100 mm) from top to bottom, increasing time (duration 22kY or 30kY) from left to right. Blue colours indicate “above soil surface” (revealing dust additions over time). White-black gradients show increasing (0-60%) calcite contents.

<table>
<thead>
<tr>
<th>Model version</th>
<th>MIS5 (22 kY)</th>
<th>MIS13 (30 kY)</th>
<th>Observations</th>
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<tbody>
<tr>
<td>RWC5</td>
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<td>RWC10</td>
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<tr>
<td>NWNC10</td>
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**Observations**
- Deeper decalcification MIS13; 2 calcic horizons. Fair comparison to field soils.
- Deeper decalcification MIS13; 1 calcic horizon. Fairly plausible for topsoil.
- Slight differences due to non-equal dust deposition. Not plausible.

References

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