Response to reviews of the manuscript titled "Hydro-pedotransfer functions: A roadmap for future development" - egusphere-2023-1860 - by Weber et al.

Disclaimer: changes to our text in response to the reviewer comments are given in italic font. In several instances, we have made small changes to the English language for increasing readability, which is not specifically marked in the reply.

Replies to Reviewer Comments 1 (RC1)

Thank you very much for your time and effort to dedicate yourself to this extensive manuscript. Your work is very much appreciated.

Main Comments[1]

We summarize the concerns as

1. This long manuscript needs a clearer structure to be more accessible to the reader by
    a. summary outlining the structure
    b. introducing a glossary

AGREED.
ad a: The summary at the end of the introduction now provides an overview of the sections to come and reads:
*"In **section 2**, we present the most commonly adopted SHP models and discuss potential improvements, inherently keeping PTF development in mind. Instead of giving a full review of SHP model development, it targets the most prominent aspects. In section 2.1 we discuss issues related to the dominance of the van Genuchten Mualem model, in section 2.2, the lack in consideration of non-uniform pore size density distributions, in section 2.3 problems related to the deficiency in the capillary bundle model, the non-consideration of capillary hysteresis (section 2.4) and dynamic non-equilibrium and transient SHPs (section 2.5) are addressed.*

*In **section 3** a guidance for the use of PTFs and critical limitations is given with some words auf caution in applying PTFs in land surface models (section 3.1), especially regarding the spatial appropriateness and spatial validity in the PTFs for large scale application, as well as methods of modulation to better suit the natural soil systems. The next four subsections deal with*

obvious gaps in PTFs for specific soils, substrate types, and land uses (section 3.2), transient PTFs: accounting for time-dependency of SHPs (section 3.3), regionalization and upscaling (section 3.4), and soil hydraulic property (SHP) maps (section 3.5). Section 3 closes with a call for harmonizing PTFs in model inter-comparison studies (section 3.6), acknowledging that SHPs are an important contributor to uncertainties in modelling water

[1]https://editor.copernicus.org/index.php?_mdl=msover_md&_jrl=778&_lcm=oc158lcm159n&_ms=114233&salt=21209361041319166294

fluxes in the earth system, and finally, a guidance and tools to facilitate the use of PTFs (section 3.7).

***Section 4** is dedicated to the requirements of measurements and auxiliary information when compiling and harmonizing datasets intended for PTF development (sections 4.1-4.3). Subsequently, section 4.4 and 4.5 deal with the inclusion of soil structure characterisation and new opportunities for using in situ sensing.*

*While the previous sections address limitations and data needs surrounding PTF development and use, **sections 5 and 6**, address some important considerations regarding PTF development. Both sections do not intend to give a review on the technical methods to build PTFs, but rather address that PTFs have to lead to predicted PTFs which lead to consistent and comprehensive simulations of water fluxes. As such, **section 5** presents concepts of constraint-based SHP parameterisation for plausible modelling with a list of some concrete examples to ensure how SHPs honour physical constraints. This section precedes **section 6**, which substantially discusses the evaluation of PTFs addressing the gap between the scale of derivation and scale of application in PTF development and use (section 6.1-6.3), and closes with a proposal for a standardized pedon-scale experiment to overcome the gap (**section 6.4**) in scales.*

*Lastly, the manuscript closes with **section 7**, a manifesto for future development and use which we think is a solid basis for developers and reviewers of PTFs to refer to.*

A glossary of abbreviations and variables is given in Table 1."

ad b: We introduced a *glossary* at the end of the introduction. Doing this will technically improve the manuscripts' readability. We also make more consistent use of abbreviations.

The glossary has now been introduced: which is given here, as

Table 1: Abbreviations used in the main text.

Abbreviation	Definition	Explanation
AgMIP	Agricultural Model Intercomparison and Improvement Project	An international collaborative effort to assess the state of global agricultural modeling and to understand climate impacts on the agricultural sector.
ARS	Agricultural Research Service	Principal in-house research arm of the United States Department of Agriculture responsible for conducting scientific research to find solutions to agricultural problems of high national priority.
AWC	available water capacity	The amount of water that a soil can hold and make available for plant roots to extract.
BC	Brooks and Corey	Relates to the soil hydraulic property model by Brooks and Corey (1964) which describes the relationship between capillary pressure and water saturation in soil.
BD	bulk density	The weight of a unit of dry soil..
BW	Brunswick	Relates to the soil hydraulic property model framework by Weber et al. (2019) which describes the relationship between pressure head and the volumetric water content and the unsaturated hydraulic conductivity.
CEC	cation exchange capacity	The ability of a soil to hold positively charged ions, or cations.

CoGTF	Covariate-based GeoTransfer Function	Statistical model that combines soil data with remotely sensed (RS) data to predict soil properties over large areas.
DNE	Dynamic Non-Equilibrium	A phenomenon that is emergent at the representative elementary volume (REV) scale when there is a deviation from the constitutive relationship between the water content and pressure head of the soil as described by the water retention curve.
EU-HYDI	European Hydro-pedological Data Inventory	A comprehensive non-public database with soil properties, mostly related to soil hydraulic properties, compiled from measurements on samples from all over Europe.
FAO	Food and Agricultural Organization	A specialized agency of the United Nations that leads international efforts to eliminate hunger, improve nutrition, promote sustainable agriculture, and achieve food security for all.
FC	field capacity	The amount of water content held in the soil against gravity after excess water has drained.
GCM	Global Circulation Model	A mathematical representation of the Earth's climate system.
GLOSOLAN	Global Soil Laboratory Network	A collaborative initiative established in 2017 by the Food and Agriculture Organization of the United Nations to strengthen and enhance the capacity of soil laboratories worldwide.
h	pressure head	Liquid pressure head, which is negative for unsaturated porous media.
HCC	Hydraulic Conductivity Curve	The relationship between the hydraulic conductivity of a porous material and its water content.
HYBRAS	Hydrophysical Database for Brazilian Soils	A publicly available database that contains water retention and saturated hydraulic conductivity data for a wide range of Brazilian soils.
HYPRES	Hydraulic Properties of European Soils	A publicly available database that contains water retention and hydraulic conductivity data for a wide range of European soils.
ISMC	International Soil Modelling Consortium	A global network of researchers, scientists, and practitioners dedicated to advancing soil systems modeling, data gathering, and observational capabilities
LSM	Land surface models	Quantitative methods to simulate the exchange of water and energy fluxes at the Earth's Surface.
MCMC	Markov-Chain Monte Carlo	A computational method used to generate samples from (complex) probability distributions.
MIR	mid infrared range	Allows for the measurement of the molecular composition and properties of soil samples based on their unique absorption and reflection patterns
ML	machine learning	A field of study that enables computers to learn without being explicitly programmed.
MSC	moisture supply capacity	The ability of a soil to retain and supply moisture to plants
NIR	near infrared range	Allows for the measurement of the molecular composition and properties of soil samples based the reflectance or absorbance of light patterns.
NRCS	Natural Resources Conservation Service	A United States federal agency that provides technical and financial assistance to private landowners, communities, and farmers to conserve and protect natural resources.
PSD	particle size distribution	The relative proportions of different-sized particles within a soil sample
PTF	PedoTransfer Functions	Mathematical models or equations that estimate soil hydraulic properties based on easily measurable soil properties.
PWP	permanent wilting point	The point when there is no water available to the plant.
REV	representative elementary volume	The scale at which properties and processes within a heterogeneous medium can be considered representative or effectively averaged.
RRE	Richards-Richardson equation	Represents the movement of water in unsaturated soils.
S_e	Effective saturation	The fraction of water-filled pore space that is available for water to move through.
SHP	Soil Hydraulic Property	The characteristics that describe how water is stored and moves through soil and are important for understanding and predicting water flow and retention in the soil.

SHP2	secondary soil hydraulic properties	Parameters that describe the water flow characteristics of soils beyond the primary hydraulic properties, such as saturated hydraulic conductivity and water retention curves.
SOC	Soil Organic Carbon	Measurable component of soil organic matter.
SOM	Soil Organic Matter	The organic materials present in soil, derived from the decomposition of plant and animal residues.
SOPHIE	Soil Program on Hydro-Physics via International Engagement	A collaborative initiative that aims to harmonize, standardize, and innovate towards cost-effective measurements of soil hydro-physical properties (SHP) across Europe.
SP-MIP	Soil Parameter Model Intercomparison Project	A collaborative research initiative that aims to investigate the impact of soil parameters on the performance of Land Surface Models (LSMs)
UAV	Unmanned Aerial Vehicle	Commonly known as a drone, is an aircraft that operates without a human pilot onboard.
UNSODA	Unsaturated Soil Hydraulic Database	A database developed by the United States Department of Agriculture (USDA) that provides information on the hydraulic properties of unsaturated soils.
US	United States	A country located primarily in North America.
USDA	United States Department of Agriculture	A federal executive department responsible for overseeing and promoting agricultural and food-related industries, rural development, forestry, and natural resource conservation.
VGM	van Genuchten-Mualem	Empirical model for describing the soil water retention curve and unsaturated hydraulic conductivity of soil.
WRC	water retention curve	The relationship between the water content and the soil water potential.
α	shape parameter inversely related to the air entry value	The shape parameter of van Genuchten-Mualem equation.
ϕ	soil porosity	The amount of pores, or open space, between soil particles.
$K(h)$	hydraulic conductivity curve	The relationship between the hydraulic conductivity of a porous material and its water content, or pressure head.
K_o	matching point conductivity	The conductivity estimated/measured under slightly unsaturated conditions., often close to a pressure head of -6 cm. Often used as the saturated hydraulic conductivity of the soil matrix.
K_r	relative conductivity	The ability of a soil to transmit water.
K_s	saturated conductivity	Model parameter of the ability of soil to transmit water when it is fully saturated.
K_{sat}	measured/field saturated conductivity	Measurement of the saturated conductivity of soil, either determined through direct measurements in the field or the laboratory.
L_c	Characteristic Length of Evaporation	The maximum front depth reflecting interplay between capillarity, gravity and viscous dissipation.
T_p	ponding time	The duration of time that water remains on the surface of a soil, forming a pond.
θ	water content	The quantity of water contained in soil.
$\theta(h)$	water retention curve	The relationship between the water content and the soil water potential.
θ_{fc}	Water content at Field Capacity	The maximum amount of water the soil can hold against the force of gravity while still allowing for good aeration and root growth.
θ_f	field water content	The maximum amount of water that the soil can hold against the force of gravity.
θ_r	residual water content	Model parameter. The water that remains in the soil even under very dry conditions.

2. Manuscript presentation: trim the text down and, to the best of their ability, strive to focus on the main takeaways. For example, Fig. 9 seems to portray many (if not most)

of the points the authors are making. Fig. 9 could feature much earlier in the manuscript and be used as a vehicle for presenting or better structuring the discussion.

AGREE partly. With reference to R2, who states the paper is "*well-organized and well-written"*, we will take your valuable point and carefully go through the manuscript, streamline where feasible and ensure to make it more concise

With more clarity about the contents and an enhanced coherence with the glossary, we will seek to emphasize the takeaways of each section. Because section 6 is at the most abstract level, Fig. 9 alone would lose much of the main points of the former sections if taken as the central vehicle.

3. As *minor* comment: Explicitly mention composite soils, and how microbial activity and plants modulate soil hydraulic properties and how this relates to hyPTF.

AGREE. Although this seems to slightly contradict point 2, we now write "*Another factor that has been neglected so far is the temporal evolution of SHPs. Swelling and shrinking processes may change soil saturated and near saturated hydraulic conductivity radically within a few hours (Stewart et al., 2016). Burrowing of soil macrofauna like earthworms can increase hydraulic conductivity by orders of magnitudes in a matter of weeks (Bottinelli et al., 2017). Several studies have meanwhile provided evidence of seasonal dynamics, which may be strongly modified on a temporal scale of days to months to years (Messing and Jarvis, 1993; Horn et al., 1994; Bodner et al., 2013; Sandin et al., 2017). Droughts have also been found to alter SHPs significantly (Robinson et al., 2016; Gimbel et al., 2016).*"

This stresses the point of seasonality and temporal evolutions of SHP more clearly.

Minor Comments

Extracted from: https://doi.org/10.5194/egusphere-2023-1860-RC1

In each comment, sentences from the paper are transferred here and the highlighted words by RC1 in the pdf are shown in red color. Then, the reviewer's comments are pointed to as Reviewer comments.

1. Line 5: Hydro-pedotransfer functions (PTFs) :

   Reviewer comment: just wondering if not better to call them HPTFs?

There is no call for action, thus we do not change anything.

Detailed rationale: Using the acronym PTF might align better with the terminology employed in the literature thus far. For instance, PTF is utilized for predictions which are based on easily available soil properties, STF is employed when spectral information is the input, and co-GTFs are prediction methods that include various environmental covariates as input (encompassing not only soil but also topography, vegetation, meteorology, etc.). In this context, the acronym reflects the nature of the input used for the prediction.

2. Line 17: Most system settings are not captured by existing PTFs, which have been built mostly for agricultural soils in temperate climates:

Reviewer comment: settings is a bit unclear, could you please provide an example here? or rephrase?

AGREE. We delete the words *settings* and made changes to the text. This is then sufficiently clear. (changes in italics)

"Most soil *systems are not represented* in PTFs, which have been built mostly for agricultural soils in temperate climates"

3. Line 17: Thus.

   Reviewer comment: replace dot with comma

AGREE. Done.

4. Line 18: existing PTFs largely ignorie how parent material, vegetation, land use, and climate affect processes that shape soil hydraulic properties:

   Reviewer comment: revise ignorie

AGREE. Corrected.

5. Line 23: These aspects are addressed here in a joint effort by the members of the International Soil Modelling Consortium (ISMC) Pedotransfer Functions Working Group with the aim to systematise PTF research and provide a roadmap guiding both PTF development and use.

   Reviewer comments: the aim, and how the study strives to achieve it, is a bit unclear. Given the relevance of this study, i suggest the authors provide a more concise and clearer aim statement followed by the application/impact of the study. It is also unclear whether the study focuses on reviewing existing evidence or if the latter was verified with new research.

AGREE. Also in reference to Major comment #1 of RC1, we will structure the manuscript more clearly, by giving an overview of what is to come at the end of the introduction.

   Though I still need to read the following sections, i missed a reference to soil composites . One can assume that PTFs were developed for soil materials alone but did not consider reinforced soil, vegetated soil, or soils with high microbial biomass, thus presenting totally different properties.

AGREE. Also in reference to Major comment #3 of RC1, we include a list of further porous media/soils and forces for temporal variations which are unaddressed in section 3.3.

6. Line 26 (Introduction section):

   Reviewer comment: a list/table containing abbreviations and their meaning would be useful if provided after the abstract

AGREE. We have added a glossary (Table 1).

7. Line 42: (capacity models)

   Reviewer comment: replace with i.e.

AGREE. Done.

8. Line 42: Water flow in soils is also described by simple models based on basic mass balance calculations (capacity models) (Gilding, 1992)

   Reviewer comment: full stop

AGREE. Done.

9. Line 50: PTFs refer to a linear or non-linear regression relationships between explanatory and predictor variables that allow the estimation of SHPs from data available in soil maps or easy-to-measure soil properties.

   Reviewer comment: full stop

AGREE. Done.

10. Line 50: Thus, provided the spatiotemporal states of soils are known (Gerke et al., 2022).

    Reviewer comments: but this is something very hard to know accurately for some soil attributes, as the soil is a very heterogeneous compartment. I suggest the authors make a point in relation to this issue here.

AGREE. This now reads

"Thus, provided the spatio-temporal states of soils are known (Gerke et al., 2022), *which is still a great challenge*, PTFs can be used to relate information contained in soil maps or easy-to-measure soil properties to the SHP of interest for use in numerical models "

   Change full stop with comma.

AGREE. Done.

11. Line 56: Predictors generally include sand, silt, clay content, soil texture classes, bulk density (BD), and soil organic carbon (SOC), although some attempts have been made to include additional chemical and morphological properties and soil structure information (see Van Looy et al., 2017) or water retention properties such as water content at field capacity and at wilting point (Schaap et al., 2001).

    Reviewer comment: this clarifies my point above, but it is a very long sentence. Please, split it into two.

AGREE. Will do to read:.

*"*Predictors generally include sand, silt, clay content, soil texture classes, bulk density (BD), and soil organic carbon (SOC). *S*ome attempts have been made to include additional chemical and morphological properties and soil structure information (see Van Looy et al., 2017) or water retention properties such as water content at field capacity and at wilting point (Schaap et al., 2001).*"*

12. Line 60: The majority of PTFs predict parameters of the Brooks-Corey or van Genuchten (Brooks and Corey, 1964; van Genuchten, 1980) and capillary conductivity functions (Mualem, 1976).

    Reviewer comment: perhaps a reference to the value of this equation could be made here? e.g., estimation of matric suction under unsaturated conditions (which is very hard to predict and measure) using soil moisture as predictor (which is relatively easy to measure and estimate).

AGREE. We added (L40):

"These continuous soil hydraulic properties (SHPs) are described using hydraulic functions or SHP models over the entire pressure head range*, where the often easy to measure WRC is used to predict the HCC.*"

13. Line 64: However, the scale of application typically ranges from field or pedon scale of several meters (Vogel, 2019) to regional or global scales where application is done on grids >> 1 km resolution by PTF users, typically modelers interested in the representation of different Earth System processes (e.g., Pinnington et al., 2021).

    Reviewer comment: please revise this - i would suggest to use text instead of a symbol.

AGREE. Now to use "much larger than" instead of ">>"

14. Line 85: research directions for the definition of a more robust and versatile next generation of PTFs.

    Reviewer comment: A short paragraph outlining the paper's structure could follow the aims section, so it is easier to follow by the reader. Also, it is unclear how these aims are going to be achieved. a brief reference to the methodology employed throughout would also help the reader follow and understand better the message.

AGREE to some extent. The manuscript will receive a brief outline summary at the end of the introduction. This manuscript is something between a review manuscript, a perspectives paper and an opinion and as such does not require a methods section. This was included see at the top.

15. Line 86: Soil hydraulic property models and egregious shortcomings

    Reviewer comment: i love the word choice :D

Thanks! So do we.

16. Line 109: Based on regression with data from 45 soils, Mualem found tau=0.5 as the best value.

    Reviewer comment: revise

AGREE.

We now write: "*Based on regression with data from 45 soils, Mualem (1976) found that a value of 0.5 for the so-called tortuosity parameter (often tau or lambda) is a suitable choice value and has been used in the predominant cases.*"

17. Line 110: This model has become so widely used because

    Reviewer comment: which model?

AGREE. Now reads "*The VGM* model has become [...]"

18. Line 120: In spite of its wide adoption, the use of the VGM model to represent SHPs is challenged

    Reviewer comment: this is great stuff

AGREE. Thanks!

19. Line 130: Also, authors have excluded the conductivity data > -6 cm pressure head, and estimated the VGM parameters, but then used the matching point conductivity ($K0$ [LT-1]; (Weynants et al., 2009; Zhang and Schaap, 2017a; Zhang and Schaap, 2017b) to describe datasets of WRC and HCC.

    Reviewer comment: this is hard to follow, please, rephrase

AGREE. We now rewrite this sentence as:

"A number of approaches exist, in which all conductivity measured at pressure heads larger than -6cm were excluded. The motivation is that the remaining data is related to the soil matrix, only, discarding the data describing the conductivity of the macropores. The subsequent model fitting still requires a conductivity parameter, which is termed the matching point conductivity ($K0$ [LT-1]; (Weynants et al. 2009; Zhang and Schaap, 2017a; Zhang and Schaap, 2017b). This matching point conductivity is the saturated hydraulic conductivity of the soil matrix."

20. Line 133: This also indicates the presence of bimodality, something which has been corroborated by a systematic analyses of some data bases by Zhang et al. (2022).

    Reviewer comment: revise

AGREE. Done.

21. Line 152: This PTF translates any set of VGM parameters to the BW parameters and it was shown that it was possible to outperform the VGM model, even if the model was not directly fitted to training data.

    Reviewer comment: this is quite interesting

AGREE.

22. Line 157: Capillary hysteresis results from pore scale processes, mainly due to the irregular shapes of pores (ink bottle effect, (Haines, 1930)), the hysteresis of contact angles

    Reviewer comment: between which elements these contact angles form? water film and soil particles? please specify

AGREE. We now write:

"Capillary hysteresis results from pore scale processes, mainly due to the irregular shapes of pores (ink bottle effect, (Haines, 1930)), *inducing hysteresis of contact angles between the soil water and the soil particle*."

23. Line 161: as hysteresis has been shown to impact the simulation of water fluxes and storage in the soil.

    Reviewer comment: is that hysteresis impacts the simulation, or that it actually impacts on soil hydrological processes? and so the simulation without hysteresis can not realistically predict water retention and flux. please, clarify

AGREE. deleted "*the simulation of*"

24. Line 170: The reason is that it requires extensive laboratory measurements to determine the boundary curves (drying and wetting curves; the solid red and blue lines in Fig. 1

    Reviewer comment: i guess this could be delted. as it clear from Fig.1 which are the wetting and drying curves, and Fig.1 has a caption for reader interpretation

AGREE. Done.

25. Line 172: model parameterization is mainly based on the use of "effective properties", whereby effective WRC and HCC models are calibrated to match observed average state variables

    Reviewer comment: please, provide examples

DISAGREE. The very fact of averaging over a soil sample makes the properties effective. This does not require examples, but is the mere nature.

26. Line 181: Dynamic non-equilibrium and transient SHPs

    Reviewer comment: please, spell out here

AGREE. Done

27. Line 184: In other words, under transient conditions, the water phase is not instantaneously in equilibrium with the pressure head, so that the water content may lag behind

    Reviewer comment: please, clarify behind

AGREE. We rewrite:

"*In other words, under transient conditions, the water phase is not instantaneously equilibrated with the pressure head and water content in soil which is continuously drained (wetting), attaining the equilibrium curve described by the WRC.*"

28. Line 204: An example for this time-dependence is considering information about soil tillage operations and post-tillage pedogenic processes leading to transient SHPs.

    Reviewer comment: what about natural soils subjected to other changes? e.g., forest soil subjected to biomass decay, changes in soil microbial communities, etc. I think the the application of SHPS is beyond agricultural soil, and this should be acknowledged here somewhow.

    In any case, i find the idea of time-dependent PTFs very interesting

AGREE. It now reads:

"Examples for the time-dependence are soil tillage operations, cryo- and bio-turbation, root growth, microbial activity, and post-event pedogenic processes which lead to transient SHPs, a desired feature in many current policy incentives in agriculture.

29. Line 206: This section is intended to assist the reader in the choice of PTFs for modelling applications while presenting the numerous limitations surrounding PTFs.

    Reviewer comment: this opening text for each section could be moved, or outlined, in the introduction, so it is easier to follow

AGREE. Outline included at end of introduction and remove it in all instances at the beginning of a section.

30. Line 221: 3.1.1 Spatial Appropriateness

    Reviewer comment: i find this section very interesting, but it also feels very long. I suggest the authors condense it and focus on the key message(s) or main takeaways from the review

AGREE somewhat. While the main point cannot be made rapidly, since it is a multi-faceted .

31. Line 228: "In a review on PTFs, Pachepsky and Rawls (1999) and Pachepsky and Rawls (2004) recommended the use of PTFs for regions or soil types similar to those in which they were developed".

    Reviewer comment: why this in italics?

AGREE. Well spotted. We now mark this as direct citation from Barros et al. (2013) by adding "*Barros et al. (2013) state in their review on PTFs. [...]*"

32. Line 248: They found that it is similarities in the correlation of the data, rather than climate

    Reviewer comment: please, revise

AGREE. Done.

33. Line 250: More studies are required to substantiate and verify this transfer learning which is used in soil mapping (Malone et al., 2016) or lean on meta-models

    Reviewer comment: this is a bit unclear, please, rephrase

AGREE. Language improved.

34. Line 255: An alternative approach to tackle this lack of site-specific data is to develop PTFs that explicitly incorporate soil taxonomic classes and/or diagnostic horizons

    Reviewer comment: I understand the authors are referring here to FAO/USDA classifications, but what about other more quantitative classifications such as that used in soil mechanics? i.e., using a combination of soil attributes such as particle size distribution, porosity, bulk density, % organic matter, ettc

DISAGREE. This must be a misunderstanding, since the idea is to precisely include more than the standard repertoire. This is exactly what the manuscript is about.

35. Line 273: While this is never included, a meta-PTF has been developed

    Reviewer comment: please, clarify

Agree. We now write: "*While this has thus far never been included directly, a PTF was developed which first predicts the standard model parameters of VGM and then extends them to a model variant, which includes water stored and conducted explained by forces other than capillary theory*".

36. Line 276: For simplicity and due to a lack in knowledge, these LSMs apply the same soil hydraulic parameterization as used for the rest of the terrestrial surface, even though sediments and unsaturated rocks may show substantial differences in SHPs compared to the soils located close to the surface.

    Reviewer comment: please, clarify, some rocks are impervious

AGREE somewhat. Yes, some rocks are impervious, but we are discussing soils, here, which are porous as a result of pedogenesis. No changes to the text required.

37. Line 291: As stated, parent material, climatology, and land use are important drivers that determine SHPs.

    Reviewer comment: this paragraph is redundant

AGREE. Deleted.

38. Line 319: SHPs are controlled considerably by plant root processes shaping soil structure.

    Reviewer comment: this and the impact of soil microbial communities (related to the vegetation) should be acknowledged in the abstract and introduction

AGREE somewhat. It is not important enough to be mentioned in the abstract, but, as stated in a reply to an earlier comment, here, microbial acitvitiy as a soil morphological forming process will be included.

39. Line 332: Most Earth System models also do not explicitly represent the litter layer (the so-called 'O horizon')

    Reviewer comment: organic matter may be very hydrophobic, so i guess here is where the difficulty of deriving PTFs might lie.? that O horizons simply do not like water.? could the auhtors comment on this?

DISAGREE. We do not want to speculate about the reasons, here.

40. Line 338: A common solution to account for litter layers is to parameterize them as a 'pseudo-litter' layer by reducing the BD and estimating the SHP from given PTFs

    Reviewer comment: please spell out, this does not appear as often as SHP and PTFs. The same for other acronyms which appear for the first time in a section

DISAGREE. With reference to the now available glossary, and since BD has been introduced at this stage, we kindly disagree.

41. Line 368: In this context, the accuracy of ML-based maps of soil properties such as those provided by SoilGrids

    Reviewer comment: ML?

AGREE. ML now spelt out as machine learning.

42. Line 378: These effects cannot be modelled with the current approaches that assume a rigid porous medium.

    Reviewer comment: very good

AGREE :)

43. Line 405: For soil textural information this kind of approach is generally unsuitable.

    Reviewer comment: very good

AGREE

44. Line 426: Then, they fitted a soil hydraulic property model to all synthetic data points; this can be considered a suitable averaging procedure and has also been used by Weber et al. (2017a).

    Reviewer comment: this claim is arguable - as the SHP are as heterogeneous as the soil classes - though the spatial interpolation process is more complex, it may not be better, as it may simply add noise and uncertainty to the outputs. Could the authors comment on this?

DISAGREE. In fact this is not a correct assessment,

45. Line 505: From EU-HYDI, we selected those records that included information on soil texture, BD, and organic matter.

    Reviewer comment: did these records included SHPs, too?

AGREE. We write (changes in italics) “From EU-HYDI, we selected those *soil hydraulic property measurements* that included information on soil texture, BD, and organic matter.”

46. Line 508: Figure 6 and Figure 7 show the results for water retention at a suction of -100 cm, and $Ksat$, respectively.

    Reviewer comment: a comment on the differences between sand and clay regressions is missing here

This comment does not fit here. We checked, and could not reconstruct what is meant, while the text of the manuscript remains very clear.

47. Line 515: 4.2 Harmonization and standardization of methods

    Reviewer comment: this section is very interesting and needs to feature in this manuscript, as it is essential that more validation is carried out following standard approaches. However, i am finding it too long and sometimes it is hard to make an instant connection with PTFs. I suggest the authors trim this Section down and stick to the key message(s). Overall, this section contains detail that sometimes does not fully add to the study or key message and which in any case can be written is a more direct and brief style.

AGREE. Section will be streamlined in language and structure, but kept.

48. Line 526: In Figure 8, we present a comparison of BD on a dry mass basis determined on soil clods that were equilibrated at -33 kPa water content and oven dried with the volumes determined separately.

Reviewer comment: above, matric suction was expressed as hydraulic head and here as pressure, which makes it hard to follow. Please, use the same units throughout the manuscript.

AGREE. Changed as required.

49. Line 566: Furthermore, the X-ray tomography is also sometimes used to infer water retention curves, it is unlikely that these data are directly comparable with, for example, data from pressure plate experiments.

    Reviewer comment: please, revise. the meaning of the sentence is not clear

AGREE. (changes in italics) “Furthermore, the X-ray tomography is also sometimes used to infer water retention curves. *However, to date far, it appears unlikely that these data are directly* comparable with, for example, data from pressure plate experiments”.

50. Line 580: (see section Fehler! Verweisquelle konnte nicht gefunden werden.)

    Reviewer comment: please, delete

AGREE. Silly old MS Word. Done

51. Line 619: Harmonization and standardization significantly increase the possibilities for data (re-) use.

    Reviewer comment: this seems redundant with the previous sections - the point has been made sufficiently clear above

AGREE. Deleted

52. Line 651: Careful consideration of the use of hydraulic conductivity in models is warranted though, as it is impacted by the scale of observation (Roth 2008), and possibly by the atmospheric conditions (Oosterwoud et al., 2017), or by easonal effects

    Reviewer comment: please, revise

AGREE. Now to read seasonal

53. Line 690: Deriving a PTF for bimodal models requires robust measurements of near saturation unsaturated hydraulic conductivity.

    Reviewer comment: please, revise. it is not clear how this is connected to soil structure characterisation. the same goes for the subsequent points. it may be worth starting the section with a brief sentence introducing how soil structure emerges (given that it is an emerging property of the soil ecosystem)

AGREE. This will be achieved by making the link more clearly between macropores/inter-aggregate pores and the problem of high quality measurements in the pressure head range (typically > -6cm) which governs water storage and flow, due to the fact

that very small uncertainties in the boundary conditions lead to vast differences in the estimated effective SHP.

54. Line 752: While advancement to the quantification of soil structure is expected to enhance our ability to better characterize the wet end of the water retention curve and especially saturated and near-saturated conductivity, other opportunities have emerged that may help infer the dry range of soil water retention – whether in one step or two steps.

    Reviewer comment: i suggest the authors make a clearer connection to PTFs. one thing is understanding and characterising better water retention and hysteresis, another modelling them with simple analytical models

AGREE. This is not a useful sentence. We think this is not needed and is deleted from the text.

55. Line 764: For example, the near infrared sensor can be mounted in a penetrometer to measure soil spectra with depth. Some infrared hyperspectral sensors can be attached to satellite, aircraft or unmanned aerial vehicles, offering detailed soil surface spectra reflectance (e.g., (Lagacherie et al., 2020).

    Reviewer comment: what about other wavelengths that can penetrate in the soil?

Point well taken, however, we refrain from making the manuscript longer at this stage and keep it as is.

56. Line 766: by relating the spectra to the measured soil properties by (multivariate) regression functions.

    Reviewer comment: this seems redundant - it is already mentioned above?

AGREE. moved "*by relating the spectra to the measured soil properties by (multivariate) regression functions*" to the beginning of the paragraph. The rest of the sentence is deleted.

57. Line 783: They can open new directions in inferring soil (hydraulic) properties at the volume of soil surveys.

    Reviewer comment: this is unclear, please revise

AGREE. Deleted

58. Line 801: Bayesian inference can identify the maximum a posteriori estimate of the model parameters.

    Reviewer comment: this is unclear, please explain

AGREE The used term was incomplete, we corrected the text and refer now to the well-established statistical quantity "maximum a posteriori *probability* estimate", often abbreviated as MAP, which can be readily checked in a statistics textbook.

59. Line 805: According to Bayes' theorem,

    Reviewer comment: this can be checked in a statistics textbook (as indicated by the authors below), so i would suggest the authors are more focused and direct in this section and throughout, as the MS is very long already.

DISAGREE. We explicitly incorporate this slightly technical, but thought provoking part, here, since we think this is an essential novelty in deriving PTFs.

60. Line 826: This model-based evaluation of the prior predictive may provide a method to bridge the gap between the laboratory-based measurements commonly used in PTF building and field scale functional evaluation (section 6).

    Reviewer comment: for example, this is the key takeaway of this Section, but given the amount of text and detail, the message is not sufficiently clear. in reference to my comment above, the paper's flow and message could improve by focusing on the main points the authors want to make, reducing the extent of the context set to explain or take the reader to the key point.

DISAGREE. The intention here is clearly link the previous sections with a methodological approach, which also relates to a method of how to honor physical constraints (5.2.) and the functional evaluation (section 6)

61. Line 852: Class PTFs are typically not impacted by unphysical parameters estimated as the selected WRC and HCC models are directly fitted to all measured θ-h and (if available) K-h data for each combination of texture class (Wösten et al., 1999; Schaap et al., 2001; Tóth et al., 2015).

    Reviewer comments: what is class PTFs? what do the auhtors mean by unphysical parameters?

AGREE. This section hinders the flow and can be safely deleted.

62. Line 901: Rectifying such biases in current PTF estimates of SHPs requires a paradigm shift to build PTFs which are not purely the result of minimizing a cost-function but should be further anchored to a physically based framework (cf. section 5.1. for the methodological framework).

    Reviewer comments: physically-based. section 5.1 illustrated a methodological framework based on Bayesian statistics but, as i understand it, this is not a physically-based framework. could the authors explain and revise?

AGREE we now correct these lines by: Section 5.1 introduced a framework for parameter estimation of physically-based models based on Bayesian statistics. We corrected the text to clarify as follows:
"*Rectifying such biases in current PTF estimates of SHPs requires a paradigm shift to build PTFs that are not purely the result of minimizing a cost-function but should be anchored in a modeling framework to obtain physically consistent PTFs using Bayesian inference (cf. section 5.1. for the methodological framework).*"

63. Line 906: Box 1. Constraints for the determination of soil hydraulic properties

    Reviewer comment: could this box in feature in supplementary material? the constraints are introduced and discussed in Section 5.2, and this box only expands on it but it is not essential for the adequate understanding of the paper's message

AGREE somewhat. We think this is a typesetting question and will address it then.

64. Box 1: To provide reasonable results at larger scales, the determination of the parameter values must honour various constraints as discussed in this box.

    Reviewer comments:where are the constrains shown? a list here would make it easier to follow.

    I understand that the constraints discussed in the box are water content, n, Lc, and Tp? is so, water content and n need to be formated in bold

DISAGREE. The box gives the constraints in equation B.1-B.5. Also, we added constraints in the Glossary. The title of the Box states these are the constraints

Equation B.1 had the wrong exponent. Previously 3, now ⅓. This was now corrected.

65. Box 1: Methods how to include the constraints were discussed in subsection 5.1.

    Reviewer comment: please, revise

DISAGREE. We changed the sentence to (changes in italics): “Methods *on how* to include the constraints *during the PTF building process* were discussed in subsection 5.1.”

66. Line 921: However, when evaluating a result of regression or machine learning with general mean statistics, the performance of the resulting PTF remains opaque since the distribution and auto-correlation of residuals, non-unique variable combinations, or non-linear characteristics are not assessed.

    Reviewer comment: it may be worth indicating that machine learning outputs can be cross-validated following similar, yet simple, approaches to linear regression.

DISAGREE. Cross-validation does not solve the problem stated, here.

67. Line 937: Building on the scale triplet (Blöschl and Sivapalan, 1995), potential reference data and PTF applications can be positioned along a scale axis (Fig. 9, x-axis).

    Reviewer comments: please, define triplet.

AGREE. We now write (changes in italics) “Building on the scale triplet (*spacing, extend, and support*; Blöschl and Sivapalan, 1995)”

    fig. 9 is very good and seems to portray the key message of this paper (thus being one of the main deliverables from this study) - i would suggest that the authors use this figure as a vehicle to illustrate current practice and knowledge and future

direction in the context of PTFs. The figure could appear much earlier in the manuscript, and this could potentially help merge different subsection in which the message is similar - for example, problems with PTF upscaling are discussed in different parts of the MS and perhaps could just be assessed in one section only, thus helping with reducing the length of the text.

DISAGREE. Moving this figure as suggested would mean we have to completely reorganize the manuscript, which will be an unfathomable endeavor.

68. Line 1029: As a manifesto, we advocate ten points:

    Reviewer comment: a summary of this could be provided in the abstract?

AGREE. We now add "*We close with a ten-point catalogue for funders and researchers to guide review processes and research.*" at the end of the abstract to point at the very important part.

69. Figure 1:

    Reviewer comment: perhaps something on the scanning curves could be mentioned here?

DISAGREE. Revisiting the figure we think this is fine, in particular with reference to the legend, which is complete.

70. Figure 2:

    Reviewer comment: it may be worth mentioning in the main body text that this was tested as part of the study?

AGREE. We added a sentence to the end of section 2.4 "Figure 2 shows the retention curves from the laboratory with fully saturated samples and the field retention curve, analysed in this study. "

71. Figure 3: Total porosity and water content at -33 kPa for A-horizons (a, b), B-horizons (b, d) of selected soil orders, and diagnostic horizons (e, f) as defined by US Soil Taxonomy. Data are from the Pedogenic and Environmental Data Set (PEDS).

    Reviewer comments:this figure is very interesting, and great to improve modelling. c? citation?

AGREE. *a, b* was changed to *a, c*.

72. Figure 6: PTF fitting of the water retention data obtained from the EU-HYDI database at soil suction of -100 cm. (a) Comparison between measured soil moisture and PTF derived soil moisture by multiple linear regression (adjusted R2: 0.64), colour is related to percentage of sand in sample, data point size is related to organic matter content, (b) same as (a) colour related to method number, data point size is related to organic matter content, (c) residuals plotted per method. Method 604: unknown; Sand/kaolin box method with undisturbed soil core, method 610: 100 cm3, 613: 222

cm3; Pressure plate method with undisturbed soil core, method 620: 100 cm3, 621: 200 cm3, 622: 250 cm3; 642: Pressure membrane method on undisturbed soil clods method 642 3-5 cm3 with estimation of soil volume on undisturbed soil core (500 cm3), 643: 3-5 cm3; Hanging water column method with undisturbed soil core, method 650: 250 cm3; Evaporation method on undisturbed soil core, method 672:630 cm3, with tensiometers at four depths (1, 3, 5 and 7 cm).

Reviewer comments: a legend for the organic matter would be useful for better interpretation.

AGREE. Added the following text to the end of the caption. *Further details on methods and data are to be found in EU-HYDI; Weynants et al., 2013)*

some of the methods are hard to follow - i would suggest to revise the text provided or present it in a different manner.

DISAGREE. It is all there. The reference to the EU-HYDI document is now included.

the residuals violin plots is not commented in the legend, some brief text would help with the interpretation

DISAGREE. It is there.

73. Figure 7:

Reviewer comment: same as for Fig. 6

AGREE. Added the following text to the end of the caption. *Further details on methods and data are to be found in EU-HYDI; Weynants et al., 2013)*

74. Figure 9:

Reviewer comment: this figure is very good

THANKS

Response to reviews of the manuscript titled "Hydro-pedotransfer functions: A roadmap for future development" - egusphere-2023-1860 - by Weber et al.

Replies to Reviewer Comments 2 (RC2)

General comments: This article describes the state of the development of pedotransfer functions (PTF) development, including traditional methods of creating such models, limitations, and proposed improvements in their development. The article is well-organized, well-written, and relevant to the journal. I found the paper, especially the first half, to be thought-provoking and an easy read. The ease in readability decreased after section 3, but the remainder of the paper is still accessible to those who wish to learn more about this topic. I have only some moderate suggestions (listed below), and believe the article should be acceptable for publication once these are addressed.

Thank you very much for your time and effort to dedicate yourself to this extensive manuscript. Your work is very much appreciated.

Minor Comments

4. Line 34: revise to "spatial scales"

AGREE. Done

5. Line 42: Add period after Gilding et al. reference.

AGREE. Done

6. Line 51: Change period after Gerke et al (2002) to a comma

AGREE. Done

7. Line 52 and 212: "Land" should not be capitalized

AGREE. Done

8. Line 137: Revise to read: "…or by coupling RRE variations of the RRE…"

AGREE. Done

9. Line 145: change to "…as the point at which water loses…"

AGREE. Done

10. Line 164: Change to "… the significance of…"

AGREE. Done

11. Line 166 and many places from this point forward: There are often extra parentheses when in-text citations are given. Double-check that there are the proper number of parentheses throughout.

AGREE. Done

12. Line 210: Add period at end of sentence

AGREE. Done

13. Lines 253-264: The authors address the issue of varying taxonomic systems later in the paper, but this may be a good place to at least mention it.

DISAGREE. It is mentioned.

14. Line 266: Change to "…models applied in spatially explicit modeling…"

AGREE. Done

15. Line 303: Change to "…hydraulic properties in many tropical soils…"

AGREE. Done

16. Lines 344-346: If most models to not consider the litter/humus layer (as stated in the first sentence of this section), does it need to be modeled using the RRE, or would another method be more suitable? It seems the authors have limited themselves to a discussion of the RRE, which they admit themselves is likely not suitable for litter layers.

AGREE. We deleted the second but last sentence. Now it makes more sense. We now write at the end of this section. (Changes in italics):

"*We think this is mostly related to the lack of experimental data as a consequence of highly demanding experimental methodology for materials with such little structural cohesion and temporal dynamics.* A concerted effort is required to establish methods which can be applied to litter and humus layers and test if the theory underlying RRE is applicable in such contexts*, which includes testing if other approaches than simulating with the RRE are more suitable.*"

17. Line 449: Something weird happening with Paschalis citation; also, change to "…PTF found that uncertainties…"

AGREE. Done

18. Line 451: "artifact" is misspelled

AGREE. Done

19. Line 509: While I applaud the authors for attempting to show some analysis of their own in this study, the provided figures do not necessarily support their statements made in this section. No explanation is given as to how the residual distributions explicitly show dependency on soil texture or sample size. There is variability shown across these categories, but that does not empirically prove dependence in the way the authors are implying. I recommend that the authors re-think their arguments here.

AGREE. We have slightly rephrased this part.
"The distribution of residuals indicate that there is a dependency on methodology as well as on sample sizes used to obtain the WRCs and HCCs in the laboratory. *We do note, however, that potential effects of soil texture have not been disentangled, here*. Noise introduced by

the different measurement methods or protocols may impose a ceiling to the prediction quality of PTFs"

20. Line 540: Remove "allowing"

AGREE. Done

21. Line 541: Change to "…sequence, allowing…"

AGREE. Done

22. Line 548: Change to "…obtained data from these methods are not directly compatible with one another,…"

AGREE. Done

23. Line 549: This is the first use of "quasi-continuous data" and it would be helpful if a definition or example was given.

AGREE. Added ", *i.e. data with a high measurement resolution within minutes*"

24. Line 552: End sentence after "…quasi-continuous data." And begin the next sentence with "While it is based on…"

AGREE. Done

25. Line 566: Change to "Furthermore, while x-ray tomography…"

AGREE. Done

26. Line 569-570: remove "who illustrated the huge sensitivity in image thresholding"- this was already stated.

AGREE. Done

27. Line 580: Some random non-English text here.

AGREE. Deleted

28. Line 584: Change "effect" to "affect"

AGREE. Done

29. Line 585: I recommend that the authors change all instances of "height" to "length," because not all samples are collected vertically. Often, samples are collected horizontally by driving a sampling core into the wall of a soil pit. This assumption of vertical sampling also affects the authors' interpretation of pore characteristics, so the authors should take care here.

DISAGREE. The reason we use the ubiquitously used "height" is not related to vertical/horizontal sampling but to the height of the cylindrical sample. We will leave this as is.

30. Line 610: What did Vanclooster find, exactly?

AGREE. This was misleading. The sentence now reads: "*With regard to the hydraulic conductivity of soils, the considerations regarding sample saturation remain valid. Javaux*

and Vanclooster (2006) demonstrated hydraulic conductivity estimates may be influenced by sample size."

31. Line 633-645: I applaud the authors for their ambitious goals, but these standards are unrealistic in practice. It would be good for the authors to better discuss the reality of the costs, including money and time, needed to meet their recommended strategy, especially given that in many cases funding for such projects is very difficult to get.

We DISAGREE that cost here is an important point to be made. On a different note, we reorganised the section by moving the paragraph "*Although the scale of measurement [...], and subsequently hydrologic fluxes.*" to the end of the paragraph.

32. Section 4.4: There seems to be a shift in the writing here, and "field soil surveys" are mentioned several times in this section, where previously the discussion was centered on samples collected. The authors of this section seem to be assuming that soil samples are collected primarily during these types of pedogenic surveys, which is often not the case. Many times samples are collected without any pedogenic data or profile descriptions.

AGREE. This is very pointed. Thanks!

33. Line 690: bimodal model of what? A specific parameter or something else? Please clarify.

AGREE. Added "SHP models"

34. Lines 693-699: This was already addressed in Section 3.3

AGREE. Moved to section 3.3

35. Line 702: change to "…soil pore structure…"

AGREE. Done

36. Section 4.5: This section is lacking a description of several keys methods of larger-scale in situ sensing that may provide very useful data for inclusion in PTFs. A few that come to mind are the use of electromagnetic induction (EMI) surveys for determination of clay content (e.g., Hedley et al., 2004), gamma ray spectroscopy for determination of field-scale bulk density (e.g., Reinhardt and Herrmann, 2019), and the novel use of cosmic ray neutron detectors for estimating fieldscale hydraulic properties using inverse modeling within the HYDRUS COSMIC module (e.g., Brunetti et al., 2019).
    Hedley paper: https://www.publish.csiro.au/SR/SR03149
    Reinhardt: https://onlinelibrary.wiley.com/doi/full/10.1002/jpln.201700447
    Brunetti: https://acsess.onlinelibrary.wiley.com/doi/full/10.2136/vzj2018.06.0123
    Note: None of these are my papers

AGREE: We agree that geophysical or hydrogeophysical methods applied at larger scale might be an important tool for PTF validation and development. We therefore added the following paragraph to the manuscript:

"At the landscape level one can also think about sensor technologies to estimate either soil properties such as soil texture by electromagnetic induction (EMI) (e.g., Hedley et al., 2004;

Heil and Schmidhalter, 2012; Mertens et al., 2008), gamma ray spectroscopy or EMI for determination of field-scale bulk density (e.g., Reinhardt and Herrmann, 2019, Schmäck et al., 2021), or the use of either stationary or mobile cosmic ray neutron detectors for estimating field scale water content dynamics and hydraulic properties using inverse modeling within the HYDRUS COSMIC module (e.g., Brunetti et al., 2019). While these are promising methods, they are still far from operational requiring still some fundamental research to integrate them into field-derived PTF development."

References:

Brunetti, G., Šimůnek, J., Bogena, H., Baatz, R., Huisman, J.A., Dahlke, H. and Vereecken, H. (2019), On the Information Content of Cosmic-Ray Neutron Data in the Inverse Estimation of Soil Hydraulic Properties. Vadose Zone Journal, 18: 1-24 180123. https://doi.org/10.2136/vzj2018.06.0123

Hedley C. B. , Yule I. J. , Eastwood C. R. , Shepherd T. G. Arnold G. (2004) Rapid identification of soil textural and management zones using electromagnetic induction sensing of soils. Soil Research 42, 389-400. https://doi.org/10.1071/SR03149,

Heil, K., and Schmidhalter, U. (2012). Characterisation of soil texture variability using the apparent soil electrical conductivity at a highly variable site. Computers & Geosciences, 39, 98–110.https://doi.org/10.1016/j.cageo.2011.06.017

Mertens, F. M., Pätzold, S., and Welp, G. (2008). Spatial heterogeneity of soil properties and its mapping with apparent electrical conductivity. Journal of Plant Nutrition and Soil Science, 171(2), 146–154. https://doi.org/10.1002/jpln.200625130

Reinhardt, N. and Herrmann, L. (2019), Gamma-ray spectrometry as versatile tool in soil science: A critical review . J. Plant Nutr. Soil Sci., 182: 9-27. https://doi.org/10.1002/jpln.201700447

Schmäck, J., Weihermüller, L., Klotzsche, A., von Hebel, C., Pätzold, S., Welp, G., and Vereecken, H. 2021. Large-scale detection and quantification of harmful soil compaction in a post-mining landscape using multi-configuration electromagnetic induction." Soil Use and Management. https://doi.org/10.1111/sum.12763

37. Line 785: First mention of "parametric PTF." Use consistent terminology.
Done.

AGREE: We now added "Before building a parametric PTF, *i.e. a PTF to predict SHP model parameters*, the parameters of [...]". We think this is necessary to enunciate.

38. Line 803: "We explicitly introduce it here…" What is "it" referring to? Be specific.
AGREE. replaced "it" with "the Bayesian inference scheme".

39. Line 814: What is meant by “This is mostly done…”? Do you mean that this is the most common method, or that the work is nearly completed?

AGREE. changed to “Most commonly…”

40. Line 833: Could the authors provide an example of the “clear empirical evidence” that they refer to here?

AGREE. Added from *“measurements, calculations, and physical theory*”.

41. Section 5.2/Line 803: Both sections describe physical constraints. Consider reorganizing to be more clear.

DISAGREE. The sections introduce a method (5.1.) and some physical constraints (5.3.). We carefully seek to identify and reduce redundancies.

42. Line 888: Change to “…loamy soils must have a higher length of evaporation Lc than sandier soils...”

AGREE. Done.

43. Figure 9: I really like this figure and think it provides a clear understanding of what the authors are describing.

Thanks! :D So does Reviewer 1.

44. Section 6.4: I found the vague description given of a standardized measurement method to be disappointing. I was expecting a detailed explanation that would allow for replication of the described methodology, but that description given here is very ethereal and non-specific.

PARTLY AGREE. As a roadmap paper, the suggestion for further experimentation has to remain at a higher level and provide direction. We think we are doing this. We are currently building such experiments and to thoroughly evaluate them in the described context. We have discussed a lot how far we can go in this paper and we would impose a heavy imbalance to the other aspects raised if we would give a detailed explanation. We actually hope that the proposed shift of the attention towards a) the pedon scale and b) experiments to measure a large proportion of the functional state-space can be understood.

PARTLY DISAGREE. Our suggested transfer of procedures from the lab into the field as standardized in-situ experiment is not a detailed explanation but it points out novel approaches which have high potential to advance the field. So far, no such experiments and no such sets of highly controlled boundary conditions exist. Hence we would not see the suggestion as “ethereal”.

Based on the comment, we will add the following sentence at the end of the paragraph: “*So far, controlled boundary conditions (irrigation/wetting and drying cycles) and sensors for state dynamics in the soil profile (at least soil water content, matric potential and temperature) only exist as experimental setups without any standardization and with rare links to SHPs and PTFs. Similar to recent advances in lab standardization, the development of such a device has high potential to further the data foundation of PTF development, in particular, and soil system understanding, in general.*”

45. Line 1038: How do the authors propose to actually carry out point #7? “Tackle the discrepancy” is very vague.

AGREE. it is vague. Therefore, we have added: “tackle the discrepancy between the scale of derivation and the scale of application, *by considering functional evaluation at the scale of application and using physical and functional constraint-based simulation during the building and evaluation of PTFs*”

46. Line 1040: Change to “…evaluate PTFs functionally…”

AGREE. Done.

47. Lines 1041-1042: Point #10 contains a typographical error and does not currently make sense.

AGREE. This sentence is gibberish, but was rescued and now reads: “ *rethink field experiments with the aim to gain data with a high information content and use easy to set up, standardisable, and ideally low-cost methods.*”

Göttingen, d. 14.04.2024

Tobias Weber, in behalf of the team.