Reply to review report 2 on the revision. The comment s are in *blue and italic*, our response in black and regular font.

The revised article including the new figure 3 has improved and is easy to read. Before publication, some technical aspects related to the hydraulic conductivity function must be clarified.

1) I tried to reproduce some of the plotted K(theta) curves for RIA and VGA model and did not get the same curves. Possibly/probably, I made a typo in the equations and because of that I have different curves. However, as a reviewer (and potential user) I must be sure how the authors computed the curves.
Specifically, for RIA, I implemented eq. (14) using eq. (8) and (9) for beta and h_d, respectively. I tried to compute K(theta) for UNSODA sample 1143 using parameters listed in Table C2. On page 17, lines 298 and 299, it is written "Mualems model for the unsaturated hydraulic conductivity curve was used …" to plot K(theta). So I'm assuming they refer to eq. (14) with gamma=2 and tau = ½. Is that correct?

Yes

Given the complexity of the equations, an excel sheet (or a few lines of codes in matlab or python) to enable the user to reproduce a specific example would be helpful (for example as supplementary information file).

If one first calculates recurring terms involving multiple variables and stores these separately, the full equations can be built with relative ease. The guidelines are not permitting the inclusion of program code as supplemental material. If an exception is granted, the first author will provide the Fortran routines for the various parameterizations used in the paper.

2) Similarly, I'm not sure how the conductivity function for the VGA curve was computed. Did the authors apply eq. (11) of Ippisch et al. (2006)? As the authors state on page 24, lines 396-399: "Near saturation, RIA's K(θ) curve often drops off sharply before leveling off, in stark contrast to that of VGA, which remains high in the wet range. Given the similarity in the θ(h) curves of VGA and RIA, the difference in their K(θ) curves is remarkable."

The paper presents only one set of equations (14a and 14b) that provide an explicit $K(h)$ function, so there is no ambiguity about the calculation of $K(h)$ - Comment (1)above correctly refers to these equations. We slightly modified the text below Fig. (1) to clarify this even further.

The authors do not explore or explain why there is a big difference in K(theta) between VGA and RIA for several cases. It must be possible to explain this from a mathematical point of view. The authors must expand on this (explain the differences between VGA and RIA close to saturation) and must provide the expression for K(theta) they used to plot VGA.

We explained above which equations were used. If one calculates θ and K for a range of h-values, the $K(\theta)$ data points are obtained as well.

We agree that the differences in the conductivity curve can be explained mathematically, and it is clear from Table 2 that α and n have interestingly different values in some cases. Finding out how exactly these affect the shape of the conductivity curve is quite laborious. In the first round, the referee criticized the limitations of the conductivity curve because it did not account for film flow and corner flow. We explained we are working on that, and prefer to focus our energy on that. It would take several days at least to develop plots of $K(h)$ for different combinations of α and n, and we may end up recommending different parameterizations in our future work anyway.

For those who are interested in exploring this, the paper provides all the information they need to get started.

3) In Appendix C, the authors show a comparison of measured and modeled conductivity data. Only in one case the conductivity values were measured in the lab, for all other cases lab-based SWRC parameters inserted into the conductivity function were compared to field measurements (see page 23/24, line 386-388). From my point of view, such a comparison is meaningless and does not help to understand which K(theta) model gives a more realistic description – the results are just dominated by different sample sizes and structures (as the authors know). A more theoretically based description of different K(theta) shapes based on the SWRC parameters would be more insightful.

This comment was raised in the first round, and we refer to our earlier reply.

Another aspect that the authors should explain in more detail is the value of h_d given in eq. (9) (matric potential at which water content reaches zero). Should this value not be universal (as the authors discuss with pF=6.8)? Is this not just the potential to withdraw the last monolayer of water around the particles? How can the authors defend a value of pF = 10.5 as in Figure 1 for clay?

See our discussion of Figure 3. When insufficient, or incorrect, data are available, physically unrealistic values of h_d will be fitted. Our point of view is that this is not a weakness of the parameterization, but rather an indication that such unrealistic results point to the need to double check the data and/or add additional data points in the dry range. The UNSODA database mostly consists of data that predate Bitelli and Flury (2009). Our work shows that there is a certain risk when these data uses uncritically. Fitted values of h_d can be used as a diagnostic.

The referee appears to imply claim that we defend unrealistically high values of h_d. This is patently false. We explicitly state these values are unrealistic, explain the cause of this, and propose a potential remedy.

MINOR COMMENTS:

Page 2, line 29: Rephrase or specify "The new curve was more robust than the other two (for more simulation scenarios, convergence to numerical solution was achieved)"

The parenthesized section specifies why the new curve was more robust. We do not understand this comment.

Page 7, lines 133-134: the sentence "Madi et al. ...." is not clear to me. Could the authors specify the constraints and why (and which) usual models are ruled out?

The derivation of the criterion that helps determine these constraints, the application of this criterion to 18 different parameterizations, and the resulting mathematical definitions of the constraints are fully explained in Madi et al. (2018). The paper is open access and we recommend that the referee and anyone else interested in the analysis consult it. Complying with the referee's request would force us to repeat verbatim a sizeable piece of text from that paper without adding anything new.

Page 7, lines 141 ff: This paragraph on the hydraulic functions in the wet range is poorly connected to the previous paragraph on dry range. Please rephrase.

We changed the order of the paragraphs.

Page 8, line 144: I suggest to list the equations of Brooks and Corey and Fayer and Simmons model as well (for example in the Appendix)

Why repeat Madi et al. (2018) here? These equations are not needed in the rest of the paper.

Page 11, lines 206 ff: A main benefit of the multimodal curve is to describe the effect of macropores on SWRC; but equation (10) is only valid with the constraint that (1/alpha_i) is larger than |h_ae|. Is this constraint meaningful? Could the authors please comment on that?

From discussions about that with colleagues who strongly favor multimodal curves and reading some of their papers it appears that they consider multimodality to be an expression of particularities in the particle size distribution that lead to multimodal distribution of pore sizes below the macropore range. We prefer to simply offer the multimodal version here and let the section of the research community involved in that line of research explore the issue further.

Page 12, line 224: The authors state that the primary focus is on SWRC – from my point of view the effect of SWRC on K(theta) or K(h) is as important as well …

The referee is of course entitled to her or his view, but our focus is on the retention curve. We will probably address the conductivity in a future paper.

Page 12, line 231: define saturation S_e

Done.

Page 12, line 233: must be eq. (13), not eq. (12)

The referee is right. We corrected the number.

Page 14, line 265: what do the authors mean with "sufficient"

For several soils in UNSODA, the range of matric potentials for which retention data are provided is too small to trace the intermediate and the drying branch of the retention curve. These data were of no use for our purpose.

Page 15, line 276: for the convenience of the reader, give saturated hydraulic conductivity value as well

We do not understand this comment. Why would this be convenient to the reader? The saturated hydraulic conductivity is only relevant for the simulations, and the values are provided in the supplement that deals with the simulations.

Figure 1: Explain in the captions why you stop at pF=6.8 for VGA and VGN

Above, the referee chastised us for reporting h_d values beyond the theoretical maximum of pF 6.8, and here we are required to explain why we stop at this value. We can only generate a finite number of data points from which to make our graphs. For the curves that have a finite value for h_d, we made its absolute value the upper limit of the table with retention points. Asymptotic functions have an infinite value for h_d, and we therefore chose the cut-off at the theoretical maximum (pF 6.8). We have never come across a simulation that reached this value, so to devote a caption to the choice for a cut-off that is adequate for all reasonable scenarios seems to be a bit over the top.

Page 19, line 321: The authors write that RIA has clear advantage compared to RNA and FSB – this is a bit misleading or incomplete, because also VGN and VGA have the same advantage (and

perform slightly better than RIA)

This is a strange comment. The sentence the referee refers to is the first of a paragraph in which we compare RIA to all other parameterizations that we fitted. in the following sentences of that paragraph we compare RIA against VGN and VGA.

Page 28, Summary and conclusions: For the convenience of the reader that are not reading the entire article, explain RIA, VGA and VGN

That would be against the guidelines for authors. Furthermore, these abbreviations are explained in the list of abbreviations (Appendix A) on the next page.

Page 32, line 534: Do you refer to eq. (14a) and (14b)?

Thank you, yes. We corrected the equation numbers.

On behalf of all authors,

Gerrit de Rooij, January 2021