



EGUsphere, author comment AC1
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Reply on RC1

Simon Cazaurang et al.

Author comment on "Numerical assessment of morphological and hydraulic properties of moss, lichen and peat from a permafrost peatland" by Simon Cazaurang et al.,
EGUsphere, <https://doi.org/10.5194/egusphere-2022-475-AC1>, 2022

Dear Xiaoying Zhang,

On behalf of all the co-authors, I would like to thank you for reviewing this manuscript. Please find below the answers to the questions raised in your review report. In order to make the answers to the questions accessible to everyone, we have chosen to answer each question individually.

Sincerely yours,

Simon Cazaurang

General comment:

[XZ]: This manuscript mainly presents a numerical assessment approach for the morphological and hydraulic properties of Western Siberian Lowland ground vegetation samples (Sphagnum moss, lichens, peat) by tomography scans. The numerical method based on digital X-CT recombination of samples can obtain the porosity and hydraulic conductivity. It provides a way to quantify hydrological properties of the bryophytic cover in permafrost-dominated peatland catchments. Overall, the contents of the manuscript are interesting. The logic of the paper is clear, and the results are well discussed and explained. However, there were some issues I was concerned about after I had read through the paper.

[Authors]: The authors want to thank the reviewer for the appreciation of our work. One can find below our detailed answers to the raised concerns. Each question is answered under the form of a paragraph regarding the raised question.

Questions/Remarks:

[XZ]: It seems quite complicated to obtain the porosity with the method the authors proposed compared to the traditional experimental method. In general, the advantage of using a non-destructive test is its coverage for large areas like remote sensing. However, with the method you proposed, you just measure the properties of samples as the traditional one and even more complicated. Thus, why does this method have superiority?

[Authors]: In this work, we wanted to prove that using a numerical scheme could provide us with data of the same stiffness and quality as traditional methods, which are here field percolation and constant-head permeameter. These methods have one major disadvantage: they can only be performed a few times on a given sample. Using such methods is complicated when field study sites and quantification facilities are far from each other. Often, studies already available in the literature are only dealing with one property at a time for a given sample batch. Thus, experimental methods lead to a result, but they rely on a strong calibration in order to be statistically representative. Intercomparing experimental results is also intricate because experimental devices are different between studies.

Our samples are fragile, requiring extra care during sampling, transportation and analysis. Using non-destructive methods is interesting, even though our measurements heavily rely on samples' pre-processing after scanning, which is non-deterministic.

Beyond retrieving some values, we want to show through our study that numerical methods are elements of an innovative methodology that only relies on the input tomography. Indeed, numerical methods allow retrieving all usual properties at once using the sample batch, facilitating intercomparisons between them.

[XZ]: The authors stated that they confirmed the REV theory, but in the paper, I only see a schematic representation in Fig.2. Where is the data from the experiments?

[Authors]: A schematic representation of the REV theory is indeed available in Fig.2. Applying our method leads to computation of around 1.5 million of intermediate porosity values, with variable cube length. This process is done for each sample, creating 12 different graphs. Due to the numerous graphs and for the sake of clarity, we decided to put the data of the numerical experiments in Supplement B1 for porosity and in Supplement B2 for hydraulic conductivity. For each sample, the statistic spread as well as the mean porosity value is shown. The black point indicates the minimum REV identified, along with the property variability associated. We will add a sentence to emphasize the presence of the results in Supplement B1 for porosity and in Supplement B2 for hydraulic conductivity.

[XZ]: A schematic figure should be given to show the detailed methodology and technologies of PNM.

[Authors]: In our work, we used some specifically designed Pore Network Model libraries such as PoreSpy (<https://porespy.org/>) and OpenPNM (<https://openpnm.org/>) which are open-source and free. Both packages are relying on a dedicated algorithm named SNOW (Sub-Network of the Oversegmented Watershed). Some precision about the construction of such algorithm based on image processing is available in Gostick, 2017 (<https://doi.org/10.1103/PhysRevE.96.023307>). One can also refer to the following Python tutorial showing the construction of a pore network (https://porespy.org/examples/networks/tutorials/snow_basic.html). Other pore network model generation algorithms are also existing in the literature (such as the "Maximal Ball"

algorithm, Silin & Patzek, 2006). However, we decided to give a try to PoreSpy and OpenPNM because of their easy integration to the already existing workflow developed during the implementation of image processing. Many other pore network generators require extensive home-made codes, which makes it difficult to intercompare to other results from different materials.

[XZ]: The author stated the computation of K is represented in Fig.9, but what I see is a pressure field. What is the connection? And what is the relationship between a and b in Fig.9.

[Authors]: The authors warmly thank the reviewer for the careful reading of our manuscript. Unfortunately, this is a typo error in the figure call itself. Indeed, Figure 9 shows pressure fields resulting from a single-phase flow simulation, either through a Representative Elementary Volume of Sphagnum sample using Direct Numerical Simulation for the rightmost figure, or on a Pore Network for the leftmost figure. For both methods, we used a steady-state solver for Navier-Stokes equations. The pressure field was used to verify the flow equilibrium prior to permeability computations. Then, we used Darcy's law to compute intrinsic permeability, and then extensively hydraulic conductivity. In our work, we initially represented the velocity field instead of the pressure field. However, this choice was not optimal because velocity field visualization would require vector components. Our figures were then unreadable, as we wanted to show the sample's morphology.

[XZ]: As we all know, the porosity does not represent the condition of K . In the method, how did you distinguish the effective pores for the estimation of K ? and decrease the impact or uncertainty that is caused by dead pores, as you are only counting the size of the pores?

[Authors]: In our method, we implement our simulation on pores' numerical representation, and not on a continuous medium. During morphological analysis, we showed that almost all pores are open and connected to each other. As the proportion of dead pores was often less than 0.1%, we made the assumption that all pores are effectively participating in flow dynamics, as we showed in Table 3.

[XZ]: For all the bar plots, I suggest you use different patterns instead of colors, as these colors are really hard to distinguish, especially in black and white print. Meanwhile, In Fig. 4 - Fig.8, one color represents different sample types, such as Lichen2.1, Hollow2.8, and Mound2.6. This can easily cause confusion. The same problem also appears in Fig. 5-Fig. 8. It is more appropriate to use one color to represent the same type of sample. Please modify the color of the samples again and add the description of types I- III in Fig. 4.

[Authors]: A new color and symbol scheme will be developed in the revised manuscript. Indeed, in the submitted version, we wanted to emphasize on the sample porosity types and not on the sample nature. Here, we will add some symbols to cope with black and white prints.

[XZ]: A flowchart is better added to show how you estimate the n and K .

[Authors]: The authors would like to thank the reviewer for this suggestion. We will add a flowchart describing the method to estimate porosity Representative Elementary Volume. An analogous method is used for the quantification of the hydraulic conductivity K.

[XZ]: Line 110: "a thorough analysis of sample homogeneity is carried out, based on porosity...." and Line 245: "in the case of a homogeneous porous medium "and Line 25: "the most homogeneous samples" and "more heterogeneous samples", what is the criteria for judging whether the sample is "homogeneous"? Is there a mathematical relationship between the homogeneity of the sample and the porosity? And why do you have to emphasize the homogeneity. Does it mean the method is going to fail if the sample is "heterogeneous"? Is there a condition that the method is valid?

[Authors]: In our study, we assume that samples' variability is conditioned upon porosity spatially varying or not. This condition is a prerequisite, especially in the presence of natural samples, potentially very heterogeneous. Homogeneity criterion is based on the existence of a Representative Elementary Volume. Property homogeneity is required to find a Representative Elementary Volume. Consecutively, if a sample admits no significant variation for a given direction, then we can consider the sample homogeneous for that given axis (i.e., 1D-homogeneous). In the same way, if this low variability is observed on the three axes, then this sample is considered as homogeneous on the whole sample (i.e., 3D-homogeneous). Otherwise, convergence cannot be reached, and therefore the method using Representative Elementary Volumes will fail. To illustrate this, it is possible to take the example of samples Peat2.2 and Hollow1.2 that do not satisfy sufficient homogeneity to converge to a Representative Elementary Volume. In this case, apart from doing a computation on the entire sample (which is prohibitive in terms of computational costs), choices are reduced. For both samples, and more widely for the Type II and III samples that are 2D-homogeneous, Pore Network Modeling is more suitable in the absence of another efficient volume averaging method.

To enhance the classification, we added average and standard deviation values for each sample class in Table 3. This will confirm that X and Y values have very low variability (under 1% for Type I samples, around 1% for Type III and less than 4% for Type II). In terms of vertical porosity, Type I have a low variability as Type III and Type II concentrates the variability.

[XZ]: In Fig. 2: the hydrological characteristics of lichen, Sphagnum moss, and peat are studied in this paper. However, Table 2 only collects references and hydraulic conductivity data for sphagnum and peat.

[Authors]: Indeed, there are only values for Sphagnum and peat in this table. As far as our literature review on lichen hydraulic properties went, we were only able to find one study about macroscale properties of lichens (Voortmann et al., 2014). The authors of this study found a value between $1.8 \cdot 10^{-9} \text{ m.s}^{-1}$ to $3.7 \cdot 10^{-9} \text{ m.s}^{-1}$ using an evaporation experiment and inverse modelling. We will add this value to Table 2 among the other values for Sphagnum moss and peat. However, we express reservations about the representativeness of the obtained value. Indeed, the morphology of the presented samples seems close to those we are studying. The hydraulic conductivity remains nevertheless weak with regard to the observed structure. It would be interesting to apply the numerical scheme developed in the present manuscript in order to compare the results.

[XZ]: Line 403-405: Specific surface area of the sample obtained using the PNM method is always larger than those obtained by image processing. Besides the explanation from the perspective of porosity, are there any other reasons to prove this phenomenon? Is it true? What is the reason? And how does the specific surface area affect the estimation of K ?

[Authors]: Even though Pore Network Models are computationally more efficient than Direct Numerical Simulations, they rely on a unidimensional reconstruction of a tridimensional structure. This reconstruction causes structural simplifications and potentially errors.

Specific surface area is important for chemical and thermal reaction studies. They require in essence the most high-fidelity surface representation. Finding a specific surface area from a simplified model does not have much sense for comparison. Indeed, the authors will remove the comparison between specific surface obtained by image processing and pore network models in the main text for the revised manuscript.

[XZ]: Is the application promising like what I proposed in the beginning? Why is this hard work worthy if your only goal is to get the same values ?

[Authors]: In our point of view, even though the implementation of such numerical schemes are indeed complex and time-consuming, we believe that using numerical methods enables a better comparison between samples of different locations. Morphological and hydraulic properties assessments based on field or laboratory experiments have each one their own biases. For these methods, we can identify some possible biases :

- 1. Date and time of the sampling;
- 2. Experimenter and his/her skills or knowledge;
- 3. Transport conditions;
- 4. Physical and biological degradation;
- 5. Used laboratory hardware to achieve these measurements;
- 6. Data post-processing.

Field experiments also have some limitations. For example, a double-ring infiltrometer test was conducted during the sampling field trip next to each sample plot. In this case, the experiment was impossible to conduct for some samples due to a high conductivity. This links well with our results that show high hydraulic conductivity.

When using a numerical scheme, computations can be virtually done as many times as needed. Each computation attempt will produce the same result for a given input dataset. We can also eliminate biases #4 and #5 as the tomography gives us a steady-shot of a given sample, allowing us to study these samples thoroughly, only relying on the minimal resolution of the X-ray scanner of 88 μm .voxel-1.

We found that using numerical schemes enables classifying samples along their homogeneity or heterogeneity, which is not easy if based on experiments only. Our method is valid even for heterogeneous samples, on the condition that sampling and scanning have been conducted thoroughly. A small paragraph will be added in the conclusion to emphasize these points.

Our method allowed to pinpoint the importance of microscale characterization in order to understand macroscale phenomena. We showed that applying an analogous method is potentially valid for all kinds of porous media, even heterogeneous. Such kind of study has not been done so far to our knowledge.

Finally, we assume that the implemented numerical scheme is efficient compared to field and laboratory experiments because such work would require a statistically strong amount of samples. We compensate the low number of samples by the REV survey that validates sufficient statistical representativity of our samples. Collecting such numerous samples is difficult, both for transportation and preservation of this sensitive interface.

Minor remarks:

[XZ]: In Table C1, please add the specific surface area and porosity data of samples obtained from image processing.

[Authors]: We acknowledge this remark. We will include these values in the revised version of our manuscript.

[XZ]: In Table C4, Please check whether the symbols are correct, such as $dSph$, $\sigma S-T$, and $dThr$.

[Authors]: We acknowledge this remark. The labels of Table C4 will be modified accordingly.

[XZ]: In the abstract, summary and conclusions, the authors should add supplement contents about the limitations of this proposed model method, as well as the scientific importance of this study.

[Authors]: The authors thank the reviewer for this suggestion. Indeed, we will give some details about the limitations of the proposed model method. Indeed, the main limitation observed in our method is the input data (which is here the tomographic scans). This study highlights the need of a quantitative and reproducible microscale properties' assessment in order to implement values in a macroscale model. Our combined method enable to study any type of sample, even heterogeneous ones. Such inclusive method has not been seen elsewhere by the authors. We will modify the essence of the abstract with a dedicated paragraph. We will also add some information in the conclusion.