Author's response for a revision

In order not to extend this text too much, we do not copy the entire reviewers' comments, but only refer to them. For example, for a comment number one of reviewer RC1 we refer to **RC1_comment1**. Moreover, we do not repeat our answers here because these are already included in point to point responses to reviewers. We changed the manuscript according to the proposed changes in these point to point responses.

In the revised manuscript, the new text is highlighted in blue and the text we removed is highlighted in red. In this document we list all the changes made in the revised manuscript.

Reviewer RC1

Our point to point response to reviewer RC1 can be found here:
https://doi.org/10.5194/egusphere-2022-673-AC1
Based on this response, we implemented the following changes in the revised manuscript.

- **RC1_comment1**. Third reviewer's comment (**RC1_comment3**) addresses the same issue, please see below.
- **RC1_comment2**.
  - We replaced the first paragraph as suggested in our response to RC1, hence the proposed text in response to RC1 was copied into the revised manuscript. See lines 9-23 (p. 1–2). The proposed text was slightly modified to avoid repetition in the second paragraph. Moreover, the first sentence from the second paragraph was removed (lines 24–25, p. 2).
  - Other parts of this comment are related to **RC1_comment3**, please see below.
- **RC1_comment3**.
  - As we suggested in response to RC1, we added a new subsection 2.3, in which we discuss a concept of the semi-continuum model and its limit in spatial variable (lines 198–237, p. 7–9). The proposed text in response to RC1 was therefore copied into this new section.
  - The corresponding text referring to the new subsection was added (lines 178–182).
  - The paragraph on REV (lines 51–60, p. 2–3) was slightly changed and moved to subsection 2.3, which describes the role of the REV in more detail.
  - Finally, we stressed that we use the previously developed semi-continuum model to describe the Bauters' paradox (line 94, p. 4).
- **RC1_comment4**. For clarity, we added a new sentence to the description of the Bauters' paradox. See lines 100–101 (p. 4).

Reviewer RC2

Our point to point response to reviewer RC2 can be found here:
https://doi.org/10.5194/egusphere-2022-673-AC2
Based on this response, we implemented the following changes in the revised manuscript.

- **RC2_comment1**. Note that this reviewer's comment is similar to **RC1_comment3**. Please, see our changes in the revised manuscript described in **RC1_comment3**.
- **RC2_comment2**. Sensitivity analysis was included in the revised manuscript as we suggested in response to RC2. Some parts of the sensitivity analysis were included in the main part of the revised manuscript and some parts in Appendix B. We copied the proposed text in response to RC2 as follows:

  - A part of the sensitivity analysis was included in Appendix B, specifically the effect of intrinsic permeability and dynamic viscosity, relative permeability and retention curve on the flow regime. We decided to include this part in the appendix so that the main part of the revised manuscript would not expand too much. Therefore, a new section Appendix B was created for the purpose of sensitivity analysis. See lines 455–516 (p. 23–28) and corresponding figures Fig. B1–B6 (p. 23–28).
  - We believe that the effect of the boundary flux on the flow regime is relevant to the continuity of the manuscript and therefore this part of the sensitivity analysis was added in the main part of the revised manuscript. For this reason, a new subsection 3.5 was created. See lines 319–347 (p. 14–15) and new Figure 8 (p. 15).
  - Moreover, one sentence was added to the discussion regarding sensitivity analysis (lines 374–375, p. 16).
  - All simulation data related to the sensitivity analysis were uploaded to the Zenodo repository. The reference was changed in the revised manuscript to refer to the new version of the dataset.

- **RC2_comment3**.
  - As suggested in response to RC2, we included simulations without distribution of the intrinsic permeability in Appendix A; see lines 448–454 (p. 20) and Figure A1 (p. 20). The corresponding text in the revised manuscript was changed (line 272, p. 11).
  - Simulation data were uploaded to the Zenodo repository. The reference was changed in the revised manuscript to refer to the new version of the dataset.

- **RC2_comment4**. The proposed text in response to RC2 was copied into the revised manuscript (lines 354–367, p. 16).

- **RC2 minor comments**. Minor issues were fixed.
  - Figures Fig. 5 and Fig. 6 were fixed (p. 13).
  - Units were specified for figures Fig. 3 (p. 11) and Fig. A2 (p. 20).

Reviewer RC3

Our point to point response to reviewer RC3 can be found here:
https://doi.org/10.5194/egusphere-2022-673-AC3
Based on this response, we implemented the following changes in the revised manuscript.

- **RC3_comment1**. Many changes were made related to this comment. All the implemented changes were already suggested in response to RC3. For the sake of clarity, we summarise the changes here.
  - A new subsection 2.3 was added, please see **RC1_comment3** for details.
  - We stressed that in the case of boundary influx, the Richards' Equation is unconditionally stable regardless of whether the hysteresis is included (lines 64–65, p. 3).
  - The proposed text in response to RC3 was slightly modified and copied into the revised manuscript (lines 394–399, p. 17).
  - We modified the part of the discussion related to the Richards' Equation (see changes in lines 399–421, p. 17–18). Moreover, the caption of Fig. 9 was changed accordingly (p. 18).

- **RC3_comment2**. The text discussing the role of geometric mean was modified in the revised manuscript to reflect our response to RC3 (lines 399–414, p. 17). This comment is partly related to the previous comment **RC3_comment1**.

- **RC3_comment3**. The proposed text in response to RC3 was copied into the revised manuscript (lines 383–384, p. 17).

- **RC3_comment4**.
  - We stressed in the revised manuscript that the non-monotonic behavior of the finger width and velocity is counterintuitive (lines 44–45, p. 2).

- We also updated the number of citations in the Scopus database for the manuscript Bauters et al. (2000). See lines 116–117 (p. 4).

- **RC3_comment5**.
  - As we mentioned in response to RC3, the sensitivity analysis was performed. Please, see **RC2_comment2** for more details.
  - Moreover, we also added a new paragraph explaining that the semi-continuum model is predictive (lines 394–399, p. 17).

- **RC3_comment6**. This reviewer's comment is already addressed in **RC1_comment3**: The paragraph on REV (lines 51–60, p. 2–3) was slightly changed and moved to subsection 2.3, which describes the role of the REV in more detail.

- **RC3_comment7**. A misleading text in the revised manuscript was changed (lines 66–67, p. 3). Both references (Wilkinson 1986 and Lenormand 1983) were removed (lines 69–70, p. 3) and a new reference (Hunt and Sahimi 2017) was added (lines 77–78, p. 3).

- **RC3_comment8**. We removed the inappropriate sentence on lines 92–93 (p. 4).

- **RC3_comment9**. As we explained in response to RC3, wetting profiles for some values of initial saturation are not included in Fig. 4 to make this figure more readable. For clarity, we stressed this in the revised manuscript (line 287, p. 12). All simulation data can of course be downloaded from Zenodo repository.

- **RC3_comment10**. As suggested in response to RC3, we changed *classical Richards' Equation* to more general *classical theory as the Richards' Equation* (line 299, p. 12).

Changes not related to reviewers' comments

- The affiliation of the two authors was slightly modified (p. 1).

- We use the geometric mean of the hydraulic conductivity for computing the flux between neighboring blocks. However, in some cases we wrote about the geometric mean of the relative permeability, which was incorrect. This was corrected in the revised manuscript.