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Hydrology and Earth System Sciences Discussions

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Interactive comment

Interactive comment on "A Comprehensive Quasi-3D Model for Regional-Scale Unsaturated-Saturated Water Flow" *by* Wei Mao et al.

Wei Mao et al.

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Response to Review of the Manuscript

Dear Editor, We would like to thank you and the reviewers. The reviewers have raised a number of important comments which we address in this Response. Below are our point-by-point responses to the review comments.

Comments from Referee #1:

General Evaluation: The paper presents a combination of a simplified one-dimensional unsaturated flow model and a full-3D MODFLOW aquifer model to achieve regional-

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scale modelling of a system consisting of a soil and an underlying phreatic aquifer over an impermeable layer. The paper presents a logical step in the model development of the unsaturated zone model (UBMOD). I was unfamiliar with that model but I like it. Unfortunately, we have a conflict with Elsevier at the moment so I have no access to the paper that describes the model. Perhaps for that reason I would like to have the equation used for the drainage function included in the paper. Also I would like to know how the hydraulic conductivity is related to the water content, and how the water content is related to the matric potential. I agree with the way the authors established the coupling between UBMOD and MODFLOW. This coupling is the main contribution of the paper, as both models have already been published. The coupling is not trivial and appears to be well-conceived, so I have no reservations about the suitability for publication in HESS.

Response: We thank the reviewer for his positive evaluation of the manuscript. We will reorganize the description of UBMOD to make it more clearly. Moreover, we are preparing to upload the report and the code of UBMOD to Github during the revision process.

Specific comments

Comment 1:

The structure of the paper is logical and clear. The writing is mostly clear, but the English will need editing. The only sections that I really could not follow were Equation (1) and the description of the iterative procedure.

Response 1:

We will do a thorough editing to improve the English flow. The responses to the two comments are as follows.

Comment 2:

In Eq. (1), I expected the layer thickness M to have an index running between 1 and j indicating the layer number. From the description it is not clear to me if the equation applies to M1 (the top layer) or involves a summation over all layers (M1...Mj). I believe this can be easily clarified. I also would like a more thorough explanation of the way infiltration is handled. I do not understand the difference between I and Id. I also could not find anything about the partitioning of rainfall between infiltration and runoff, and about the way infiltration is added to the soil water. The paper mentions 'allocation of infiltration' but I do not understand what that means. Evapotranspiration was not discussed either. As I explained I am unable to consult the paper in which UBMOD was discussed, but I believe it is acceptable to repeat the key points of UBMOD here, with proper referencing to the earlier paper.

Response 2:

Equation (1) can be applied to all layers. The vertical soil column is divided into a cascade of "buckets" and each "bucket" corresponds to a soil layer. The "buckets" will be filled with infiltration water until saturation from top to bottom if there is infiltration. I indicates the total amount of the infiltration water per unit area, and Id indicates the consumed infiltration water by upper layers for a specific layer. The subscript will be added in Eq. (1) to indicate the specific layer. We leave out of consideration the partitioning of rainfall between infiltration and runoff by now, which will be added into our model in future. The source/sink terms are used to account for soil evaporation and crop transpiration. The Penman-Monteith formula and Beer's law (also known as Ritchie-type equation) are adopted in UBMOD to estimate the potential soil evaporation Ep and potential crop transpiration Tp. Then Ep and Tp are distributed to each layer based on the evaporation cumulative distribution function and the root density function. The actual soil evaporation and crop transpiration are obtained by discounting Ep and Tp with the soil water stress coefficient. The description of UBMOD was too simple in the current manuscript. An appendix is added as the supplementary file to introduce the major procedures of UBMOD. We will add more details of UBMOD in the revised manuscript.

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Comment 3:

Regarding the iterative solution, Figure 2 is not always helpful in supporting the text to explain the iterative process. I indicated where I got lost in the pdf file. I also make suggestions for improvements there. I was also puzzled by the three time increments (the stress time and the time steps for UMBOD and ModFlow). I cannot really see how they interact in the iterative process, where you only use one type of time step without indicating which of the three it is. You set the values of the three time steps a priori for all tests without indicating how you arrived at the chosen values, or helping the reader find the optimal values for a given problem. Also, if I am not mistaken, the time steps for UMBOD and ModFlow are constant and equal for all test cases. Is this a necessity in this model?

Response 3:

The Fig. (2) will be reorganized. The fonts of the figure will be enlarged. We will replot Fig. 2(b) to make it more clearly. The stress time step (ΔT) is used in the iterative process and it is constant during the calculation. The time steps for UBMOD (Δtu) and MODFLOW (Δts) are the calculating time step for the unsaturated flow and groundwater flow respectively. It is not necessary to set the Δtu and Δts to be equal. The time step for UBMOD (Δtu) is a priori value and cannot be changed during the calculation. The UBMOD can give acceptable results when the time step (Δtu) is less than 10 d for an assumed case and 1 d for a real-world case (Mao et al., 2018). The specific time step for MODFLOW (Δts) is not constant and can be adjusted during the calculation. A time step multiplier is set priori to adjust the time step (Harbaugh, 2005). As also recommended by Reviewer 2, a sensitivity analysis about the stress time step (ΔT) will be added in the revised manuscript, which will be helpful to find the optimal values.

Comment 4:

The test cases are limited in scope and very much non-regional. I suggest to reduce the overselling of the test case based on data from the Hupselse Beek, since it is really only a single profile that is being considered. The second test case is a 2D problem of a system of only a few meters. I do not consider the limited scale to the test cases a serious drawback because they do the job of providing a test of various model components. And the demonstration case that follows the test cases truly aims at the scale for which the model is intended.

Response 4:

Thanks for the suggestion. In the revised manuscript, we will declare that we only simulated a single field soil profile with the data provided by HYDRUS-1D technical manual. The purpose of case 2 is to discuss the limitations of our model which ignores the lateral flow in the unsaturated zone. We agree that the soil water movement at a laboratory scale is different with that at the regional scale. But this case can help us to understand the model performance under extreme situations. Therefore, we would like to keep case 2. In the revised manuscript, we would clarify the purpose of it more clearly.

Comment 5:

In a few locations the grammar was such that I could not discern the meaning of a sentence (see detailed comments in the manuscript).

Response 5:

The language of the manuscript has been checked. Thank the reviewer again for the comments.

Comment 6:

I printed out the figures so I could consult them while working on the pdf file to do the review, but the fonts were so small that I had a hard time reading the texts. I suggest redesigning Figure 2. It cannot be read stand-alone, and I found that it not always helped me understand the iterative process.

Response 6:

The Fig. (2) will be reorganized. The fonts of the figure are enlarged. We replot Fig. 2(b) to make it more clearly. The presentation of the iterative process will be reorganized accordingly in the revised manuscript.

Comment 7:

In Eq. (2) I believe the minus sign should only be there is the vertical coordinate is defined positive downward, but the text indicates otherwise.

Response 7:

The referee is right. The vertical coordinate is defined positive downward. The ground surface is used as the base level. This will be added in the revised version.

Comment 8:

All in all I consider this a good paper that deserves publication in HESS after moderate revisions. To help with the revisions I made some remarks directly on the manuscript. Please also note the supplement to this comment: https://www.hydrol-earth-syst-sci-discuss.net/hess-2019-87/hess-2019-87-RC1- supplement.pdf

Response 8:

Thank the reviewer again for the comments. Most comments in the supplement are listed above. Two more comments are responded below.

Comment 9:

Don’t you need an average water content as well to do so? How did you determine this average water content? I suspect that most of the downward water movement take place when the soil is relatively wet. Therefore, a simple time-averaged water content probably underestimates the amount of groundwater recharge.

Response 9:

It is a thoughtful comment. The tracer is injected at a specified depth from the soil surface. Changes in tracer concentration as a function of time and the water content are determined from soil samples collected along depth profiles. The average water content used to calculate the downward velocity is the average value from the initial position of the tracer to the final position of the tracer. According to the measurements of Peng (2015), the soil water content at the depth of 1 m was relatively stable in temporal with small variations in this area (See attached Fig.1). So, the simple averaged water content would not greatly affect the results. We will add more details of tracer experiment and evaluate the measured recharge rate by the tracer experiment in the revised manuscript.

Comment 10:

I suspect the model also does not perform too well if there is a substantial transfer of water between soil profiles through the groundwater: recharge in one location is wetting up the soil elsewhere. This can occur in areas with slopes and in areas with bare soils at one place and thriving vegetation elsewhere. Although your model should be able to handle this if the soil columns are well chosen and placed correctly. I am not so familiar with Modflow, but I believe it can handle slopes. This implies that you need to know beforehand that the problem may occur so you can set up your model accordingly. If you are not aware of the problem and choose too few subunits, the model will probably not simulate the true extent of the lateral transfer of water.

Response 10:

The developed model can simulate the lateral flow through the groundwater since MODFLOW is a three-dimensional model, while the model cannot simulate the lateral flow in the unsaturated zone because UBMOD is a one-dimensional model ignoring the lateral unsaturated flow. So, the model can be applied with slopes with lateral groundwater flow. However, the model will fail to capture the soil water and groundwater movement with obvious lateral flow in the unsaturated zone. Indeed, the land usage

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type, the climate condition and topography condition should be considered to set the soil columns when setting up the model. The declaration of choosing soil columns will be added in the revised manuscript.

Harbaugh, A.W.: MODFLOW-2005, The U.S. Geological Survey modular ground-water model — the Ground-Water Flow Process. U.S. Geological Survey Techniques and Methods 6-A16, variously p, Chapter 4, 2005. Mao, W., Yang, J. Zhu, Y., Ye, M., Liu, Z. and Wu, J.: An efficient soil water balance model based on hybrid numerical and statistical methods, J. Hydrol., 559, 721-735, doi:10.1016/j.jhydrol.2018.02.074, 2018. Peng, Z.Y., 2015, Mechanism and modeling of coupled water-heat-solute movement in unidirectional freezing soils, Doctor thesis, School of Water Resources and Hydropower Engineering, Wuhan University, China, 2018.

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2019-87/hess-2019-87-AC1-supplement.pdf

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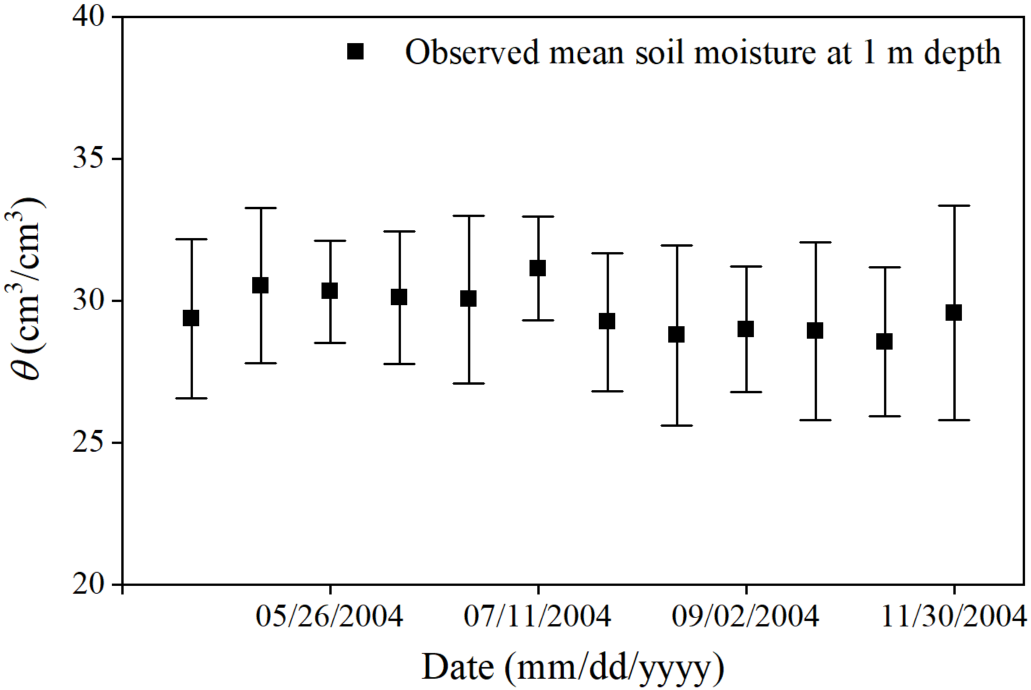
40
35
30
25
20
θ (cm³/cm³)
Observed mean soil moisture at 1 m depth
05/26/2004
07/11/2004
09/02/2004
11/30/2004
Date (mm/dd/yyyy)

Fig. 1.