This is a review on the paper “It rains and then? Numerical challenges with the 1D Richards equation in kilometer-resolution land surface modelling” by Daniel Regenass, Linda Schlemmer, Elena Jahr and Christoph Schär, Hydrology and Earth System Science Discussions. This review was prepared as part of graduate program Earth & Environment (course Integrated Topics in Earth & Environment) at Wageningen University, and has been produced under supervision of dr Ryan Teuling. The review has been posted because of its potential usefulness to the authors and editor. Although it has the format of a regular review as was requested by the course, this review was not solicited by the journal, and should be seen as a regular comment. We leave it up to the authors and editor which points will be addressed.

This paper describes the sensitivity of the Richards equation on different temporal and spatial resolutions. Simulations of land surface models are compared to each other for different resolutions, to investigate how, and how good they converge. Different rainfall forcings are applied, to investigate its effects on infiltration and surface runoff processes, and its implications. The effects of continuous intense rainfall and realistic precipitation events are investigated for different vertical layer thicknesses, and thus different vertical resolutions, and different time-steps, and thus different temporal resolutions. The simplified one-dimensional Richards equation is used and is inserted into two land-surface models: Rijtema model (Rijtema, 1969) and the Mualem-Van Genuchten model (Mualem, 1976; Van Genuchten, 1980).

Currently, the precipitation measurements are improving, leading to increasing resolutions, which leads to insufficiently known modelling errors (Ban et al., 2021; Stephens et al., 2010). This makes this research urgent, as there is currently insufficient knowledge in the numerical subgrid-scale processes and the errors in the model parameters (Wood et al., 2011). Most land-surface models use the one-dimensional form of the Richards equation (Heise et al., 2003; Balsamo et al., 2009; Ducharne et al., 2016). Therefore, the numerical errors and implications caused by this equation will be investigated in this research for two different land-surface models.

This paper has a clear structure, and the methodology and results are clear, with understandable figures and theories or references were needed. They match the aim of the paper and correspond to existing knowledge gap in this field, as mentioned above. The methodologies are a good representation of what is done, why it is done and how it is done. Next to that, the results give a clear and brief description of the results from the performed research. The paper is currently under review for the journal HESS, which mainly publishes papers regarding hydrology and the earth system (Hess, n.d.), which matches the subject of this paper. Overall, a good and clear paper is written with interesting and innovative research. However, there are some points which I want to point out. I would say that the paper is clear and can in principle be accepted after several issues discussed below are addressed.

To start with, there might be more uncertainties within the chosen numerical technique than currently addressed, which should be elaborated within the introduction. According to a recent paper in HESS by la Follette et al (2021), most conceptual hydrological models show increasing uncertainties for increasing rainfall intensities. As the considered rainfall events are intensive, large uncertainties for the Richards equation could be expected as well, although it is not a typical conceptual hydrological model, but there are similarities between conceptual models and the Richards equation. The possible uncertainties between the numerical techniques used and their relationship with high rainfall intensities should be elaborated in the introduction. Other relevant papers regarding the numerical uncertainties are the paper by Melsen et al (2016), concerning calibration and validation of models for increasing spatial and temporal resolutions, and the

“classical” study by Clark and Kavetski (2010), concerning numerical errors in several rainfall-runoff models for different time steps, and its impacts on performance of hydrological models.

The second issue is concerning the aim and the research questions. The aim of the research is clear and a good representative of the goal of the research. It is clearly indicating what the research is about: the numerical convergence of the Richards equation within soil hydraulic models is discussed, while focussing on different spatial and temporal scales (i.e., differing vertical layer thicknesses and time-steps). The research questions on the other hand, are not corresponding to the aim of the paper. The research questions are currently focussing on how the solutions of the Richards equation converge in land-surface models, and what its implications are. Next to that, the research questions focus on the errors interacting with rainfall intensities and the implications of kilometer-scale weather modelling. However, I am missing the main subjects which come back in the whole paper, and especially in the results: the different spatial and temporal scales and the infiltration and surface runoff processes. The results are focussing on the development of infiltration, and thereby the movement of the wetting front, and surface runoff processes for different resolutions and different rainfall intensities. In my opinion, these processes need to be mentioned in the research questions, to answer how the solutions of the Richards equation converge in the models, and what implications are occurring. Next to that, I recommend to also include the spatial and temporal resolutions in the research questions, as this is what the report is all about. It is okay to also mention the kilometer-scale in the end, but the effect of the different vertical and temporal resolutions must first be clear. The reader must also know that this is what the paper focuses on, as the whole results are comparing the processes on different temporal and spatial resolutions. Why would they do this if this is not even mentioned in the research questions? Changing the research questions would also make the conclusion stronger, by concluding which spatial and temporal resolutions are best to simulate the infiltration and surface runoff processes.

Next to that, the dimensionality of the paper should be reconsidered. The whole paper is focused on the one-dimensional Richards equation. Currently, there is already quite a lot known about this form of the Richards equation: many papers have already explained the 1D Richards equation, its behaviour in models and the errors. You already mentioned some papers in your paper, and you explained what we already know from these papers. This might question whether the one-dimensional form is indeed the innovative aspect you are aiming to investigate, or if multi-dimensionality needs much more attention in further research: multi-dimensionality is much more unknown (Basha, 1999; Tracy, 2006), and it might even be a more interesting research topic. Especially because lateral water flow and other assumptions related to multi-dimensionality can then be included too**.** The first experiment is indeed completely one-dimensional, due to assumptions made for the Richards equation, and lateral water flow is excluded. However, the surface slopes are considered for surface runoff, indicating that it is at least dependent on two-dimensionality. The second experiment uses precipitation convection data with a horizontal resolution of several kilometres, which is in my opinion no one-dimensional input.

In fact, the focus on the implications at kilometre-scale, addresses the third issue. The research is mainly focused on the one-dimensionality. However, as mentioned in the title and introduction, the research focusses on the kilometer-resolution of land surface modelling too, which is the resolution of the precipitation data in the models. For the first experiment, the precipitation input data is a constant precipitation rate of 20 mm/h, not related to any actual precipitation data. This experiment investigates the processes of surface runoff and infiltration, and thereby the movement of the wetting front on different spatial and temporal resolutions. The spatial resolutions are in this case vertical, i.e., the depth. This already shows that the kilometer-scale is not present in the first

experiment. The second experiment on the other hand, uses a realistic precipitation forcing from actual precipitation timeseries. These simulations have a horizontal resolution of either 2.2 or 12 kilometres extracted from simulations carried out by Zeman et al. (2021). This is indeed a resolution on kilometer-scale, but this is just used as input for the models, to investigate the effect of actual precipitation on infiltration and surface runoff for different spatial and temporal resolutions. This contradicts the kilometre-resolution, which is mentioned in the report.

Even though the effect of the different horizontal resolutions is considered and compared to each other, the whole report mentions to be one-dimensional. In my opinion, it is good that the different horizontal resolutions are compared and distinguished, but it might be better to change the main focus on dimensionality of the paper. The vertical spatial resolution and the temporal resolution is something which comes back in the whole report, and the whole research is focused on this, but it is not necessarily one-dimensional, as the kilometer-aspect shows. Therefore, I would recommend to focus less on the specific one-dimensional part of the Richard question, and reconsider if the research is indeed completely one-dimensional, taking into account the kilometre-scaled horizontal resolution and the assumptions made.

In addition to these main arguments, I have some minor suggestions which the authors might want to take into account as well:

- In the methods, some assumptions are done regarding the input parameters for the model. I would like to see how seepage and root water uptake are considered or neglected in this research. These processes are not mentioned yet in the methods.
- The analysis is based on the saturated form of the Richards equation (p7, line 14-150), but soils are not always saturated, especially for the second experiment I do not expect this. Next to that, the saturation form is not suitable for infiltration close to saturation. I recommend explaining how this could affect the outcome of the research.
    - (Farthing and Ogden,2017)
- In this study is chosen for a loam soil (p7, line 159) but I would like to see an explanation why loam soil is chosen.
- The second experiment is only simulated for a geometric grid, and not for an equidistant grid (page 8, table 2). I would like to read why the equidistant grid is neglected for the second experiment.
- The reference run is using an equidistant grid (p13, line 279). It is not mentioned which grid is used as reference run for the non-regular grid, therefore I recommend elaborating this for the non-regular grid (p14, line 306).

Finally, I found some minor (detailed) issues which can be easily fixed.

- p2, line 30: paper Pichelli et al., 2021 should be Ban et al., 2021 (Ban is the first author).
- p3, line 86: missing space between Recently,some.
- p4,18,19,21, figure 1,6,7,8: add sub-numbering for figures: a-f or a-b.
- p6, figure 2: subscription is too large, I would mention ‘Note the sharp … on the surface’ in the text itself, instead of in the subscription.
- p7, line 151: you mention that the E=0 for all further derivations and experiments, but in the following equations (8), (10) and (11), you still mention the evapotranspiration which was already set to zero. You can either remove the evapotranspiration term in the equations or adapt line 151.
- p11, line 224: equation (5) should be equation (4).
- p13, line 281: add (NRMSD) after normalized root mean squared differences.

- p14, table 4: change the location of the table, such that the text below is above the table.
- p18, figure 6: the x-axis mentions number of vertical layers, whereas the caption mentions delta_z. The number of layer and depth difference is confusing in multiple parts of the report, please look into this.
- p18,19, figure 5,6: I would change the title RIJTEMA to RT (MVG is also an abbreviation)

Now my personal opinion about the paper is clear. Overall, it was a interesting and well-written paper. I would recommend to accept and publish the paper after considering the above-mentioned arguments and issues.

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