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Geoscientific Model Development Discussions

Interactive comment on "Simulating Coupled Surface-Subsurface Flows with ParFlow v3.5.0: Capabilities, applications, and ongoing developmentof an open-source, massively parallel, integrated hydrologic model" *by* Benjamin N. O. Kuffour et al.

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Response to Anonymous Referee #1 Comments for "Simulating Coupled Surface-Subsurface Flows with ParFlow v3.5.0: Capabilities, applications, and ongoing development of an open-source, massively parallel, integrated hydrologic model" We would like to extend our profound gratitude to the Editor and the Anonymous Referee #1 for the comments and suggestions intended toward improving our manuscript. The orig-

inal text of the Anonymous Referee's comments is below in plain face font and our responses are given with heading "RESPONSE" under each comment.

Anonymous Referee #1 Authors have summarized major advances in development of an integrated hydrologic – atmospheric model (ParFlow.*) for simulating terrestrial hydrologic processes. The paper is a nice summary of authors' effort in the past 3 decades on ParFlow development, and its coupling with land surface, atmospheric and reactive transport models. As authors state, the information presented here has been previously published as part of software manuals and papers published by the developers. Therefore, this manuscript provides a valuable resource for the users to learn about the model functionality

However, it would be more useful if authors consider adding the following information: 1.The paper falls short in describing capabilities of ParFlow in comparison to other integrated hydrologic models such as CATHY, HydroGeosphere, etc. This will help users with model selection for a particular application. RESPONSE We agree with the Referee #1 that it is important to understand how one integrated model compares to others but our main goal in this manuscript was to primarily focus on the functionality of ParFlow, not a cross-comparison of the various models. However, quite germane to this comment, we note that, some of the co-authors have organized and participated in comprehensive inter-comparison studies to compare ParFlow with the Referee's suggested models and these exercises were specifically designed to investigate similarities and differences. For example, Kollet et al. 2017 and Koch et al. 2016 did great job in that aspect. Since these are recently published works, it would be redundant to include a formal comparison, but the manuscript has been revised to clearly refer readers to those inter-comparison papers of the various contemporary integrated models.

2.It would be very useful if authors could describe future model development. What is next? RESPONSE We concur that including further description of future model development would be useful to ParFlow users. We made mention of the availability of a software development and sustainability plan to improve the capabilities of ParFlow in the last paragraph of the manuscript, so it'll be best to elaborate on those developmental plans. We have added text concerning the code developers next plan in improving the code such as new formulations of both kinematic and diffusive wave approximations, and advanced parallelization support (GPU'S and heterogeneous compute architectures).

3.Despite improved parallel efficiency for large scale application, model application for large domains is computationally intensive. Can authors provide further guidelines for model set-up (table of inputs), initialization and calibration? Are there any efforts underway to improve computational time? RESPONSE Large and/or complex problems (which are not necessarily synonymous) will always take time to solve directly, but the approach for setting up a particular problem depends on the specific problem being modeled. Even for one specific kind of model there are multiple workflows that can be used, so this could not be one table but would be more like a tangled spider web. How to model is ultimately the responsibility of the modeler and our goal with this manuscript is to describe the functionality available to the modeler within the ParFlow system. We absolutely agree that guidance is useful in these areas but disagree that this is an appropriate venue for such guidance. However, we have added clarifying text nothing that the studies involving ParFlow outlined in Table 1 provide a wealth of knowledge regarding domain setup. Since these are all specific applications, their information will likely be very useful to modelers trying to build a new domain during the setup and planning phases. As for efforts to improve efficiency, ParFlow is already the most scalable integrated model available today because of its robust library of nonlinear solvers. Barring new advances in nonlinear solvers, the main focus is on increasing efficiency on heterogenous compute architectures, as noted above in our response to comment 2.

4.While authors summarized various application of the model in Table 2, it would be great if they can present a simple case study that compares computational time as different components are added from land surface to the atmosphere, and show how

simulated outputs have been improved compared to observations. RESPONSE If the reviewer has a specific problem in mind and would be willing to discuss it, we would be glad to explore adding such an example but note that this would not be possible across the full spectrum of ParFlow variants because they have different functionality. Furthermore, the computational cost of any integrated model is extremely difficult to predict because of the nonlinear nature of the system. Any results we could show for this would be entirely conditional to the problem selected and could not be considered general in any way. The solution time for the solver depends on the number of degrees of freedom, the heterogeneity of the parameters, which processes are active (e.g. snow accumulation vs snow melt), and how rapidly the problem is changing. The discretization of each equation carries a floating-point cost and for parallelized components, but this depends on whether it is a coupled distributed model (WRF) or a column model (CLM). In a situation where ParFlow works in conjunction with or coupled to other land surface or atmospheric models i.e. increased computational complexity by adding different components or processes improved computational time may not only depend on ParFlow. Many of the studies presented in Table 1 include computational times for problems with different complexities where ParFlow was used. So, while we agree that this could be informative to some extent, the only way to know how fast a specific problem will run is to try that problem, and we have added some notes to this affect.

Minor Comments Lines 82-85- The differences between the integrated approach and indirect approach is not clear. Please explain. RESPONSE This is a good point, and modifications have been done according to referee's suggestions. For example, further descriptions on how ParFlow employ these approaches pertaining simulation of flows in surface and subsurface domains.

Line 94 – Kollet et al. (2010) does not seem to be a suitable reference here as the focus of the paper is on parallel efficiency. Please refer to Kollet and Maxwell (2008), Water Resources Research instead. RESPONSE Correction made.

Line 139 – Is the variable vertical discretization only possible with the terrain following grid option in ParFlow? RESPONSE Variable vertical discretization can be used with any domain/grid; however, it usually makes the most sense to do so with a terrain following grid since this is commonly used to increase the resolution of the shallow soil layers.

Line 155 – Remove “of” from “relative of saturation” RESPONSE The suggested correction has been done.

Line 171- According to equation 4, units of Darcy flux should be LT-1. RESPONSE The change has been affected accordingly

Section 2.3. Add information regarding flow routing approach. For example, does the new version support D8 flow direction? RESPONSE D4 flow direction is implemented in ParFlow

Line 194 – Move “slope” before the “(gravity forcing term)” RESPONSE “Slope” has been moved before the “gravity forcing term”

Line 254 – Add “relative” to Si RESPONSE “Relative” has been added

Line 742- To main consistency, write units. RESPONSE The units are provided to all variables presented

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