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Geoscientific Model Development Discussions

Interactive comment on "GSFLOW-GRASS v1.0.0: GIS-enabled hydrologic modeling of coupled groundwater–surface-water systems" *by* G.-H. Crystal Ng et al.

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RESPONSE TO REVIEWER 3

<u>Boldface:</u> Reviewer 3's original comments

<u>Italics:</u> Our response

We thank the referee for their time in reviewing our manuscript and providing feedback.

This article presents a user interface for the community hydrologic model GS-

Flow using the community GIS package GRASS. This manuscript is well written and clearly presented. The interface is well documented. However, I am having trouble seeing the primary goal or take-home message for the readership of GMD. Is there a science or educational motivation for this work that allows users to do something they can't already do with the existing PRMS / Modflow approach? I like this manuscript and think it's well written but as currently framed, for me, misses this key point and reads much more like a user manual than a scientific article. I think revisions are needed to bring this critical point forward.

We are glad that the reviewer liked our manuscript and found it to be well-written. We also appreciate the reviewer bringing to our attention that we needed to clarify the scientific merit of the work, which we realize was very inadequately described in the original manuscript. Scientific understanding of integrated hydrologic processes has been stymied by the inaccessibility of complex models for many researchers and resource managers; the major advancement of our work is to provide a robust and flexible software for implementing the USGS's groundwater and surface-water flow model - GSFLOW - across diverse hydro(geo)logic settings; importantly, this required the development of new GRASS GIS extensions that overcome common obstacles in creating automated and reproducible surface and subsurface model domains for integrated hydrologic models. We now realize that many of these points were almost entirely missing from the original manuscript version, and we have substantially revised the manuscript to address this major shortcoming.

Our edited Introduction now emphasizes that existing software for integrated hydrologic models do not provide freely accessible toolkits that fully cover pre- to post-processing steps (p. 2, lines 22-30), and that GSFLOW-GRASS addresses that gap (p.2 lines 31-34, p. 3 lines 1-6). The original manuscript version documented the new GRASS GIS extensions, but admittedly, it did so much like a manual and provided almost no background on the challenges of creating robust and automated tools – which have led to a general unavailability of such solutions predating our toolbox. A new *paragraph has been added to the Introduction to present the technical advancements with these GRASS GIS extensions (p. 3 Lines 7-21). Further, we have entirely re-written Section 3.2 on the GRASS GIS domain builder (p. 10-12), so that it now explicitly describes what was implemented to solve specific known problems with stream network delineation. Finally, we also made major changes to Section 4 on the Examples, in order to explain how each model implementation demonstrates a different capability of the domain builder (specifically, p. 21 Lines 3-10 for Shullcas, p. 21 Line 32- p. 22 Line 4 for Santa Rosa, and p. 23 Line 10- p. 24 Line 4 for Cannon River). In particular, these examples demonstrate how GSFLOW-GRASS handles known challenges with various degrees of drainage integration, landscape relief, and grid resolution, as well as the presence of irregular coastal boundaries.*

<u>minor comments</u> p1. lines 1-6. I think a better firs paragraph can help motivate this work's main takeaway point more clearly.

We have entirely rewritten the first paragraph (as well as most of the rest of the Introduction section) to highlight key motivations for "streamlined access to models that integrate surface and subsurface processes," which includes tools that address "challenges of of generating computationally robust surface and sub-surface model domains" (p. 1 Lines 1-8).

p1. line 9. GS-flow isn't an integrated model, it is coupled. Integrated models are defined to solve 3D richards' equation and the shallow water equations in an implicit framework to capture these coupled, nonlinear processes. This should be clarified in the revised manuscript.

We appreciate the reviewer's rigor in distinguishing between the use of the terms "integrated" and "coupled." Indeed, GSFLOW is a "coupled" model in that it that employs an iterative method to link the base codes of PRMS and MODFLOW. We chose to also

refer to GSFLOW as an "integrated" model following the USGS's use of that term. The GSFLOW manual (Markstrom et al., 2008) distinguishes between two types of "integrated" models - "fully integrated" models that simultaneously solve surface and subsurface domain equations (what the reviewer calls "integrated") and "coupled regions" models that iterate between solutions for each set of equations (what the reviewer calls "coupled"). Thus, the USGS presents GSFLOW as an "integrated" model of the "coupled regions" type.

In order not to confuse model users, who will likely also be looking at the GSFLOW manual, we elected to adopt the same terminology as the USGS. However, we do now clarify that GSFLOW is not "fully integrated" but is instead "coupled" on p. 2 Lines 18-20. In fact, as a coupled model, GSFLOW still requires all the individual input files of both underlying models, which accounts for much of the laborious and time-consuming process of implementing GSFLOW. This motivation for a bundled toolkit solution for coupled models is now highlighted on p. 2 Lines 20-22.

p3. lines 7-11. Is this platform run in parallel? My understanding is not, nor is GS-flow parallel. I'm confused by this statement.

We realize from this comment that our original wording was confusing. No, GSFLOW-GRASS is not set up to run in parallel. The statement referenced by the reviewer was simply referring to the general advantages of using gridded domains, one of which is easier porting to parallel systems if desired. We edited the text to now read: "In general, gridded domains are easier to construct and extend to parallelized computational systems, and they allow flexible spatial specification of soil and land-cover heterogeneity." (p. 4 Lines 11-13).

p3. line 10. I think the comment about triangulated grids providing better water balance is unsubstantiated and perhaps false. Most triangulated formulations

are not even locally mass conservative which leads to local water balance error. GS-flow also uses structured grinding, which seems contradictory to these statements.

We realized that we left out a critical detail - we meant to specify that TINs show better water balance performance IF they are implemented with the finite volume method (because the finite volume method is mass-conserving). We edited the text to clarify the water balance advantage with finite volume on p. 4 Line 15-16. GSFLOW-GRASS uses rectangular grid cells for the MODFLOW subsurface component, but it uses irregular sub-basin HRUs for the PRMS surface component. We consolidated all the information about the GSFLOW-GRASS domain discretization in the first paragraph of our Methods section to make this clearer (p. 9 Lines 2-7).

p3. line 24. again, GS-flow isn't integrated (or "integrated") and I don't know what 'integrated-coupled' even means.

See our above explanation of our use of "integrated," "fully integrated," and "coupled." However, we do realize that the wording mentioned by the reviewer was awkward and removed it on p. 3 Line 26.

p4. line 26+. This paragraph is short and confusing. Please reword.

We believe the reviewer was confused by the vagueness of "different modes" and the ambiguous "they" in the original text ("Table 1 in the GSFLOW manual (Markstrom et al., 2008) lists all PRMS modules, MODFLOW stress packages, and GSFLOW modules used by GSFLOW in the different modes. This section includes a brief description of the main processes they represent."). We re-wrote the paragraph more clearly as follows: "This section includes a brief description of the main hydrologic processes represented in GSFLOW, with select parameters listed in Table 1. Full details can be found in the GSFLOW manual (Markstrom et al., 2008). In particular,

Table 1 from Markstrom et al. (2008) summarizes all the surface-water processes captured by PRMS modules, groundwater processes captured by MODFLOW stress packages, and model coupling procedures captured by GSFLOW." (p. 5 Lines 2-5).

p22. lines 7+. These don't strike me as conclusions and read a bit like an advertisement. To my central point, what is the scientific motivation and conclusions reached by this work. Reworking this paragraph would help that substantially.

After reading this review, we agree that the Conclusion should be re-written and have now done so. The new Conclusions section emphasizes the technical advances provided by the GRASS GIS domain builder tools, the capabilities of GSFLOW-GRASS across diverse settings demonstrated by the model examples, and the value of this new toolkit for making integrated hydrologic modeling more accessible; we also end with a list of potential future extensions of this toolbox.

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