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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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We thank the referee for their time in reviewing our manuscript and providing feedback. We were about to post this first reply (which addresses many of your comments) exactly when the review of the second referees came in. While we go through their review, we thought it could still be useful to post this in case it can generate some addition discussion. Also, we hoped that the referee can clarify: (1) in Specific Comment 1, what do you mean by "dynamic (e.g. in-situ visualization) inspection" and (2) in Technical Correction 3, do the blue precipitation lines not show up at all in your figures? See our responses below for more details related to these two questions

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of clarification. We will post a complete response after going through all reviews and completing a full revision of the manuscript.

General comments: The manuscript presents the development of a suite of tools for preparing the input, submitting the simulation runs, and visualizing the output of the groundwater–surface-water coupled GSFLOW model. The proposed suite of tools is developed exploiting the functionalities of the open-source GIS software GRASS and ad-hoc Python scripting. Authors tested the developed toolkit presenting test cases based on three catchments having different physiographic features. The manuscript is generally well written and with a logical and easy-to-follow structure. While I concur with the authors on the potential of such kind of efforts to encourage the use of complex surface-subsurface coupled hydrological models, I question the actual novelty and technical advancements presented in their work. Besides a suite of GIS extensions and scripts, the manuscript does not propose new technical solutions for the problem at-hand. For this reason, and for those elaborated below, I consider this contribution not suitable for GMD standard.

We are glad the manuscript was found to be generally well-written and well-structured, but we are obviously very disappointed that the referee did not consider it to be suitable for GMD standard. Overall, we believe our practical, new utility toolbox for the USGS's GSFLOW model fits very well within GMD's solicitation for Model Description Papers: *"this type of paper may also describe model components and modules, as well as frameworks and utility tools used to build practical modelling systems."* However, this review brings to our attention that the current manuscript version fails to adequately explain the novel aspects and technical advances provided by our toolbox. We will clarify these points here and revise the manuscript accordingly.

While some of the individual scripting components within the toolbox may appear straightforward, our work's innovation is the entire bundled package. This includes fully automated, integrated, robust, and open-source codes that cover everything from building topologically linked and robust hydrologic sub-basin domains and assembling model input parameters to visualizing model outputs within a self-consistent and efficient framework. The USGS's GSFLOW model couples two already-complex hydrologic models in a way that retains distinct structures of each, resulting in an integrated model of even greater complexity that presents new obstacles to the user. Our toolbox offers a solution that seamlessly handles the heterogeneity of this coupled model, thus tackling the grand challenge of accessibility plaguing many integrated modeling systems. As an important additional feature of accessibility, our toolbox is written using entirely free and open-source programming languages and software.

Within the toolbox, the major technical advancement is the development of a toolkit of streamlined GRASS-GIS extensions for building stream networks and sub-basins. While overland flow routing and the calculation of drainage basins from topography are standard GIS capabilities, their implementation is typically only semi-automated: systemic issues in most flow-routing algorithms require users to manually perform error-checks and corrections, which add a source of subjectivity and laborious processing time. Even more significantly, we know of no standard GIS tool predating ours that automatically builds topologically structured vectorized drainage networks that include information on adjacency and routing pathways through the network. We have now developed robust and automated algorithms that address these issues and have been tested with diverse DEMs as part of our model implementation examples. Furthermore, we have developed tools to link the irregular fluvial network to the regular grid used for the groundwater model component, permitting water to appropriately flow between the surface and subsurface. These advances now enable rapid, automated delineation of surface-water drainage networks across any generalized topography and any practical resolution, and this is conveniently done within a framework that readily links to implementation in a coupled hydrologic model.

We recognize that these new advances with our toolbox were not adequately expressed in the current manuscript version. They will be more fully described and clearly emphasized in our revision.

Specific comments:

1. In presenting/justifying their work, I think authors overlooked a bit too much the key technical issues preventing the widespread use of complex, physically based surface-subsurface coupled hydrological models in a decision-making framework. Here, I would argue that preparing the input is certainly a necessary and important step in the modeling exercise but not the most challenging one. In fact, if we agree that computationally efficient and numerically stable codes are needed to "promote science-driven decision making" then ad-hoc tools allowing a dynamic (e.g. in-situ visualization) inspection of such physical and numerical model response are probably much more needed, especially when we approach big-data problems. Saying that, I do not see the positioning of the effort presented in this manuscript with respect to these grand challenging tasks.

We believe that the need to create long model input files does present a major impediment to many potential users who may lack the necessary software skills or who might wish to carry out initial model tests before committing time to its use. Our toolbox offers a solution for this, which can greatly expand the reach of integrated hydrologic modeling. We think "dynamic (e.g. in-situ visualization) inspection" refers to run-time visualization of model results, but if this is incorrect, we ask that the referee please clarify. We acknowledge that run-time model visualization tools could help users decide whether to terminate a simulation early. However, given that there are currently no GSFLOW visualization modules available, our post-processing visualization scripts are already filling a key gap. Further, run-time plotting would slow down simulations and are typically difficult to implement on remotely accessed computer clusters. As such, while dynamic inspection is an unresolved challenge, our toolbox first addresses a more immediate need with this model.

2. The outcome of the presented developments is clearly reflected in the results section. Here, authors describe three test cases illustrating the physical settings of each study area and discussing the potential outcome of a surface-subsurface coupled modeling approach. However, these results appear the repetition of the same exercise without much insight on the novelty of the proposed approach. For instance one could argue that such kind of plots can be simply obtained with some visualization scripts developed from scratch.

A user can indeed develop from scratch similar visualization scripts, but we believe that the need to do so presents a major impediment to many potential users who may lack the necessary software skills or who might wish to carry out initial model tests before committing time to its use. Our toolbox includes pre- and post-processing capabilities that make the GSFLOW model widely accessible.

Further, we would like to clarify that the examples we present are not simply meant to showcase plotting capabilities, but they are also to demonstrate the robustness of our toolbox for diverse watershed settings. In particular, we show that the GIS extensions work out-of-the-box for a wide range of topographies. Each of the three test cases demonstrates particular technical challenges that our toolbox overcame.

The steep topography and narrow canyons of the Shullcas case would require an impractically high resolution to model using a regular gridded surface domain, leading to lengthy compute times. Our irregular HRU-based surface-water representation allows us to compute flow paths using high-resolution topography but reduce this into its fundamental surface-water hydrologic units, stream segments and subcatchments, for the model computations. While MODFLOW is run using a regular grid, this example case also tests our method of integrating the vectorized drainage network into the MODFLOW grid cell elevations in order to accurately simulate groundwater flow at lower (and more computationally-efficient) spatial resolutions. Assigning grid cell elevations averaged over steep gradients produces spurious dams and lakes. Our toolbox's use of irregular drainage networks solved this problem by linking coarse-resolution subsurface grid cells to surface sub-basin units that give those cells a continuous downstream elevation gradient.

The Santa Rosa Island example represents another numerically challenging steep watershed. It also provided an opportunity to test our toolbox with small drainages covering just a few DEM grid cells and with irregular boundary geometries created by the coastline. This test case ensures that we can appropriately handle NULL values (for the ocean) while providing validation of the same methods required for the Shullcas watershed.

Finally, the Cannon River watershed in Minnesota includes deglacial topography that rivers have not yet organized into a linked valley network. Simple downslope flow-routing algorithms would typically fail for such settings, and "pit filling" can produce spurious results by inappropriately modifying the real topography. Our toolbox routes surface-water flow using the GRASS GIS "r.watershed" least-cost path algorithm, which is designed for such complex topography; we demonstrate that we are able to extend its capabilities to creating an automated topologically-correct and linked drainage network.

With these three distinct test scenarios, we therefore ensured that our toolbox passes stress tests in both very steep and very flat landscapes. In addition, the examples illustrate the range of hydrological processes that can be readily assessed with GSFLOW when facilitated by our toolbox, including tightly-coupled groundwater–surface-water interactions (Shullcas), episodic runoff driven by climate (Santa Rosa Island), and low-relief controls on water table depths (Cannon River). The reasons for the test case examples, and the toolbox capabilities that they highlight, were not made clear in the manuscript, and we will update it to ensure that readers recognize the purpose and extent of our testing.

3. In a similar vein to the previous point, at the end of the introduction authors argue that the developments of such automated toolkit will enable rigorous testing. Absolutely true but a concrete path forward and tangible results are not presented in this context. Wouldn't it be an interesting way to demonstrate the utility of such kind of tools?

We believe that once we clarify the novel aspects and technical contributions of the current work, it can be seen that this toolbox incorporates significant development work that constitutes a first, stand-alone manuscript. However, we agree with reviewer that a concrete path forward is key, and so we will revise the manuscript to provide greater detail on the types of rigorous model implementations and testing now possible with our toolbox.

4. In several parts of the manuscript, authors refer to a similar work, i.e., Gardner et al., which is currently under review for another journal. As the content of the cited work cannot be evaluated, these statements are unverifiable by the reader/reviewer, which is obviously not acceptable. Moreover, considering the potential overlap between the two contributions, as also acknowledged by the authors, it is not possible to weight the actual contribution of this work. For instance, one may ask if moving from ArcGis to GRASS or using ungridded versus gridded data would be enough to motivate an additional publication.

One of our co-authors, Rich Niswonger, is also a co-author of the Gardner et al. submitted manuscript and is also one of the GSFLOW developers at USGS. The Gardner et al. manuscript received encouraging reviews and is currently in revision. It may become available during the review of this current manuscript; otherwise, we may share it with permission from the first author. Our toolbox was created independently from the Gardner et al. work and can be distinguished in three important ways: 1) it creates a topography and stream network-based (ungridded) domain, offering alternative conceptual and computational implementations; 2) it fully automates all aspects of the model pre- and post-processing, from building ALL model inputs to plotting model inputs and results; and 3) it utilizes entirely free and open-source tools, which significantly extends its reach to resource-limited users. As a developer of GSFLOW at the USGS, Niswonger views our GRASS-GSFLOW toolbox as a highly valuable complement to the alternative utilities by Gardner et al., which uses proprietary software to generate gridded domains for a subset of required model inputs. Having multiple approaches for developing models helps to serve a broader community of users, and future work using these different toolboxes will allow the community to evaluate different approaches (irregular vs. gridded domains, GRASS vs. ArcGIS algorithms, different stream network development methods, etc.).

5. It appears that for some of the most critical parameters (e.g., Manning's parameter) authors present their approach referring to homogeneous values. In so doing, they advocate that field data on channel geometries come in a variety of forms difficult to accommodate in a generalized approach. Wouldn't it be the motivating reason for such geoscientific developments as the one presented here? Data fusion tools are in my opinion the key for facilitating the coherent ingestion of large source of information into a distributed model input data structure. An example along this line is represented by the work of Leonard and Duffy, 2013.

Heterogeneous hydraulic conductivity is implemented in the Santa Rosa Island example. We agree with the reviewer that a heterogeneous Manning's n parameter would also be important to include, and in response, we will develop a method to easily incorporate field data into a model for Manning's n values in our revision. We intend to use a set of point measurements of Manning's n values and assign values in the model domain units (HRU's) based on the nearest data point. This simple approach will provide the framework for more complex data integration procedures that could be developed later.

References: Lorne Leonard, Christopher J. Duffy, Essential Terrestrial Variable data workflows for distributed water resources modeling, Environmental Modelling & Software,50, 85-96, 10.1016/j.envsoft.2013.09.003, 2013.

Technical corrections:

1. Authors argue that models using triangulated irregular networks show better water balance performance over steep catchments. This is a quite interesting statement but ad-hoc citation is needed to substantiate this.

Triangulated irregular networks are often implemented with finite volume methods, which are guaranteed to conserve mass (Leveque et al. 2002). We intend to add references to the sentence as follows: “Models such as tRIBS (Vivoni et al., 2004) and PIHM (Qu and Duffy, 2007) utilize triangulated irregular networks for more computationally efficient representation of complex terrain (Goodrich et al., 1991) and for better water balance performance through the mass-conserving finite volume method (Leveque et al. 2002).”

New references:

Leveque, R. J. (2002), Finite Volume Methods for Hyperbolic Problems, Cambridge Univ. Press, New York.

Goodrich D.C., Woolhiser D.A., Keefer T.O. (1991). Kinematic routing using finite elements on a triangular irregular network. Water Resources Research 27(6): 995–1003.

2. According to the author’s opinion, PRMS does not implement Richards equation but instead applies an ‘efficient’ calculation to determine input and output for HRU. What’s the meaning of ‘efficient’ here?

By “efficient,” we mean computationally more efficient. We will clarify this in our revision.

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3. I do not see the precipitation lines in Figure 5-6-7.

We see the blue precipitation lines clearly in these figures. We are unsure why they do not appear for the referee and wonder if there is an issue with the file conversion. Could the referee please clarify whether the blue lines fail to appear at all, or whether they do but the referee does not find them to be clear enough?

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