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Author Response on RC5

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Author comment on "Water balance model (WBM) v.1.0.0: a scalable gridded global hydrologic model with water-tracking functionality" by Danielle S. Grogan et al., Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2022-59-AC6, 2022

Reviewer #5

Overall comments:

The authors present and describe a new open-source version of the global hydrologic model WBM, emphasizing new capabilities for tracking water sources. The paper is well written, and the overview is fairly comprehensive, including theory, examples, plentiful references to earlier literature, and a discussion of how this open-source version relates to other versions of WBM that have been used over the 3 decades since the first version was created. Not only is the model now open source, but the authors have provided a Singularity container to simplify access/usage. Overall, this is a nice contribution, and I recommend publication after minor revisions.

We appreciate the reviewer's endorsement for this manuscript. We thank the reviewer for making numerous straightforward editorial suggestions that we agree with. In the absence of a direct response, please assume that the correction will be made in any subsequent revision of the manuscript.

Below are listed specific comments keyed to particular line numbers, sections, or equations:

Introduction: I appreciate the overview of applications of GHMs, which seems like a useful entry point for those new to the topic.

Though we appreciate this reviewer's comments on the introduction, any revision of the manuscript will include refinements of the introduction based on other's comments; however, we aim to maintain the general overview we present in the initial submission.

Sec 1.1: the need for water tracking is well motivated here.

69-70 typo?

It is and we will fix it.

86-88 at some point around this section it would be useful to describe how WBM handles gridding. Here an example is given of a fixed-width (120 m) grid, and later examples are noted of lat-lon based grids. Does the user have a choice between these? Does the model account for the variable size of fixed-longitude grid boxes? What happens at the poles? Or does the global configuration exclude very high latitude regions like Antarctica?

We appreciate the reviewer pointing out this important but absent consideration in our model description. We will provide an appropriately detailed description of WBM's grid cell representation in the General Overview section. To briefly address the reviewer's concern, WBM utilizes underlying raster representations using the Geospatial Data Abstraction Library (GDAL) (GDAL/OGR contributors, 2022) and can theoretically use any raster grid types (projections and resolutions) that can be represented by GDAL provided a user enters a flow direction file for those grids. Commonly we have used geographic rasters, and a layer of grid cell area is precomputed for all calculations relying on area using the Haversine formula. Therefore, for geographic rasters, errors in area estimation are most significant close to the poles, where polar projections are more appropriate.

124 and ff: thank you for listing units of each variable.

Eq 3 & 4, should this be P^e? (also, in general, instead of introducing equations with 'defined according to', it can be helpful to say something more descriptive like 'so-and-so depends on temperature T and precipitation rate P according to')

The equations are correct as written. We do not have elevation dependency of precipitation represented in the model and apply a uniform precipitation rate over each pixel. Therefore, we only identify elevation differences in the forms (frozen or rain) of precipitation. We will look to provide more descriptive introductions to variables in our equations as you suggest in any revision of the manuscript.

Eq 4 and other math: if you want text-like typesetting, e.g., the word "if" in eq 4 or a sub/super-script like "max", use \text{if}, W_i^\text{max}, etc. (requires \usepackage{amsmath})

We will make these formatting revisions as requested.

142 grammar around lapse rates

We see how the list structure of this sentence is a bit awkward, and we will revise to read more smoothly.

158 is Pt a user-defined param? A fixed fraction of P? Calculated in some other way?

P_t represents the throughfall flux calculated in the subsequent equations. We can add an additional equation showing how this variable is calculated in a revised manuscript; however, this equation is found in the technical documentation.

Eq 7 and others: consider the more traditional use of a dot (\cdot) or no symbol at all to represent multiplication, as opposed to an asterisk (which I think traditionally means convolution, even though most modern programming languages use it as a multiplication operator)

Agreed.

212 no cap

eq 13 ff: this is somewhat confusing because the phrase 'immediately moved' suggests a discontinuity but the differential equation suggests differentiability / continuity. Please clarify (maybe via a delta operator in front of R_EXC, which is 1 if volume of retention pool exceeds the threshold and 0 otherwise?)

We agree that equation 13 could be presented more clearly. The reviewer is correct in that a dirac delta would be more appropriate in equation 13 to make it consistent with the conditional formulation of equation 18. The delta would yield an impulse at times when the upper limit of the surface runoff retention pool is exceeded, and the magnitude of the impulse would be equal to the volume in excess of the pool's limit times the time-step length.

250ff isn't there a unit mis-match between W and R in eqs 14-18? And between R and T in 18?

There is indeed a unit mismatch. Each R value in these equations is a flux that is integrated over the timestep and should thus be multiplied by dt. We will make this correction in any revision of the manuscript.

286 unclear what 'stock' means here (it seems to be a standard term with WBM, so please define it before using)

We use the term stock interchangeably with the term pool to denote a control volume. The term stock is widely used in ecological modeling.

Sec 2.2.3: I appreciate the references to papers that describe the routing methods, but it would still be helpful to have a bit more information on linear reservoir routing. For example, does it mean that each grid cell's river discharge output to its neighbor is calculated as a linear reservoir, that is, as a function of river water within the cell? What, briefly, is the basis for assigning a reservoir coefficient? Are these constant or do they depend, for instance, on channel geometry?

Yes, the linear reservoir scheme calculates reach outflow as a function of water within each pixel, and the release coefficient is a function of estimated celerity and reach length. These details are described in the technical documentation accompanying the model code on our GitHub repository, which can be added as a supplement to the manuscript.

418 does 'scaler' mean 'scaling factor' or 'scalar' or something else?

We will revise the term to scaling factor in any revision of the manuscript.

429-437 Can you elaborate a bit on this treatment and why it is needed?

Because WBM calculates a uniform soil water balance over potentially large pixels, water can be withdrawn in larger pulses when soil moisture falls below the crop depletion factor than is typical in practice. This formulation provides an alternative to more closely approximate the practice of irrigating a rotating subset of crops continuously. We plan to revise the manuscript with an explanation of the utility of this option.

473 capitalization consistency

Sec 2.2.7 source tracking: this section is a bit confusing, partly (I think) because of the wide variety of sources that could be tracked. If I understand right, a user would not normally track ALL of these sources in any given model run, but rather would pick a type of source to track - is that right? Actually, reading forward in section 4, we learn that there are 3 options. It would be helpful to list these options up here in section 2. In addition, a couple of examples would potentially help a lot. They need not be very elaborate, but could be as simple as something like: 'a user interested in X might choose to track sources Y and Z'.

545 again, are these 3 mutually exclusive (i.e., one chooses from among them), or are all 3 tracked simultaneously? (later text suggests the former, but at this point in the text it is not clear)

In any revision of the manuscript, we can provide greater detail in Section 2.2.7 detailing the inter-relationship between the tracking components. First, none of the components (primary, return flow, or land attribute) are mutually exclusive, and a user could implement all three simultaneously if desired. We agree that providing simple examples in this section would help clarify the intended use of this functionality. For example:

A user interested in understanding the role of snowmelt as a component of streamflow downstream of a mountainous region would use primary source component tracking, whereas a user interested in understanding the potential for anthropogenic contaminants to be present in streamflow would use return flow component tracking. Finally, if a user was interested in runoff generated within any political boundary, land attribute tracking could be used. Any combination of the three components could be included in a model initialization and calculated simultaneously. However, the intersection of the three components is not calculated in this circumstance. Therefore, by initializing the model with primary source and return flow component tracking, WBM will not calculate the fraction of (for example) irrigation return flow composed of snowmelt.

557 daily time step: helpful to mention this much earlier.

We concur. A mention of the timestep will be made in the General Overview section in any revision of the manuscript.

Sec 3: helpful to define what you mean by validation (I'm not personally a stickler for semantics, but some would consider the term problematic, and better described by confirmation, testing, or evaluation).

We think the reviewer makes a good point that we will clarify in any manuscript revision. We use the term validation as used in common practice throughout modeling of natural systems, which is better described as corroboration (Oreskes et al. 1994). We will decide to either use an alternative term, or more clearly define our meaning and use of validation in any revision of the manuscript. To remain consistent throughout our responses to reviewer's comments and the draft of the manuscript we have continued our use of the term validation, with an implied meaning more closely aligned with corroboration.

Sec 3.1: are the summarized validation studies performed in conjunction with some kind of calibration / parameter optimization? Or is calibration only used in regional applications? You kind of answer this question around 635-640 but it would be helpful to clarify near the start of this section.

Several reviewers expressed an interest in seeing greater detail presented

regarding calibration and parameterization strategies, and we would like to provide this general response. Any revision to our manuscript will provide additional detail needed to form a baseline understanding of the parameterization strategy for the model; however, we acknowledge at the outset of this response that there is to date untapped potential for more rigorous evaluation of uncertainty quantification using WBM.

First, following comments from Reviewers 2 and 5, we think that building out Table 2 to include a greater cross-section of parameters commonly adjusted in regional studies is appropriate. We note that this table will be redundant to the WBM_Usage_and_Input_Reference.xlsx spreadsheet on the WBM GitHub page; however, we agree that providing a subset of this reference within the manuscript will improve the readability. Any revision to this table will include default values, reasonable ranges, parameter description, and important citations where applicable. We note that to the extent possible, we have relied on structuring the model consistent with empirically meaningful parameters. As such, values presented in Table 2 will often reflect syntheses of field observations and uncertainty as characterized therein. Other model parameters are more synthetic and have less direct connection to field observation. Many of these parameters have been evaluated through calibration exercises over the years in studies summarized in Section (3.1). The reasonable ranges to be included in any revision to Table 2 will be based on what the authors consider as appropriate starting points for parametric uncertainty analyses based on a combination of prior experience and physical meaning.

Previous work to calibrate WBM has generally leveraged manual calibration, with several instances of more rigorous calibration attempts. Parameterization of core WBM components evolved through iterative attempts to capture response in both global and regional contexts. Generally, it has been found that parameterization schemes as represented by the default parameter values in WBM_Usage_and_Input_Reference.xlsx reflect reasonable compromises that adequately represent discharge time-series in global simulations. We plan to highlight that uniform parameterizations can be applied to unique watersheds to capture non-default response (Samal et al. 2017, Zuidema et al. 2018), or that spatially varying parameterizations can capture more finely resolved nuance in watershed properties (Zuidema et al. 2020).

Validation generally: it would be interesting to summarize some of the lessons from testing and validation, it terms of what might be behind systematic under- or over-prediction of discharge. For example, have past validation exercises revealed certain gaps in knowledge, and/or mathematical approximations that would need to be refined in order to improve model performance? This might fit well under Results or Discussion.

This is an important point; however, we feel this would be better treated in a separate paper with a dedicated focus. We currently are working on a project centered around uncertainty quantification and with respect to on-going work focused on the conterminous United States; however, broader evaluations that include WBM should be considered for future work. We would also like to note that in response to other reviewers, we expect to add additional text that contextualizes results from model intercomparison projects that identify common constraints of macro-scale modeling and the importance of including human components into large-scale hydrologic models (Nazemi and Wheater, 2015, Veldkamp et al. 2018, Zaherpour et al. 2018).

Sec 3.2: thanks for differentiating between validation of different versions, and including this section devoted to the open-source version. It's a nice reminder (and demonstration) that testing of models should ideally include the specific code implementation alongside the theory and numerical algorithms.

Eq 31: the first time I read this, my mind immediately went to cancellation of errors -- but then realized that this is actually desirable for a bias metric. You might consider reversing the order of 32 and 31, and introducing the MBE with a phrase like 'in order to measure systematic bias' or something to that effect, so readers don't get hung up on it.

Thank you, we will follow your suggestion.

711 observations per year, or total?

We will clarify that we identify stations with total observations at each station equal to the values cited. These are very loose criteria to maximize spatial coverage of data used.

753 tense

Sec 5: I appreciate the code history and summary of different versions

943 uniformly spaced... in geographic coords? (again, helpful to explain grid set up early in the paper)

Agreed, we use uniformly spaced gridded data, typically in geographic coordinates, but the model does work with any projection recognized by GDAL.

1039 typo

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