Response to comments on Manuscript egusphere-2026-4655

Title: An Open-Source Python Framework for the Flexible Deployment and Advanced Applications of the Variable Infiltration Capacity (VIC) Model

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Dear Editor and Reviewers,

Please find enclosed our responses to the manuscript assessment entitled "An Open-Source Python Framework for the Flexible Deployment and Advanced Applications of the Variable Infiltration Capacity (VIC) Model".

We would like to express our sincere gratitude to the Editor and the two anonymous reviewers for their invaluable support and constructive suggestions, as well as for the opportunity afforded to us to revise our work. We have given full attention to all comments and suggestions and made all revisions accordingly.

Concerning the revision of the manuscript, the following major changes have been made:

(1) **Introduction and Background:** The Introduction has been expanded to provide additional context for the CWARHM initiative and to better position EVB within the broader VIC model deployment ecosystem (e.g., VIC-ASSIST, TONIC, CyberWater).

(2) **Methodology Completeness:**
   a) Appendix A has been supplemented with a summary table of the transfer functions to clarify their implementation in MPR.
   b) Several methodological descriptions have been expanded or clarified, including the selection of the model warm-up period and the assessment of computational efficiency across different spatial resolutions.

(3) **Results and Discussion:** The discussion has been expanded to cover spatial parameter estimation in distributed hydrological models (Sect. 6.1) and the broader VIC model deployment ecosystem, including the relevance of the CWARHM initiative (Sect. 6.2).

(4) **Writing and Structural Refinement:** The manuscript has been streamlined to improve clarity and organization, including concise descriptions of the deployment workflow and study catchments.

(5) **Reference Verification and Correction:** We have checked all flagged references in the reference verification report, corrected the identified inconsistencies, and added DOIs for all retained references identified in the report. References that were not cited in the main text or were incorrectly cited have been removed.

We believe the paper quality has significantly improved through this review process. We are also happy to address any comments that may further strengthen the paper quality. We are uploading our point-by-point response to the comments, an updated manuscript with red highlighting indicating changes, and a clean updated manuscript without highlights.

In the point-by-point responses below, the original comments are displayed in **bold**. **EC1-n/, RC1-n/**, and **RC2-n/** correspond to the comments from the Editorial support team, Referee 1, and Referee 2, respectively. The corresponding responses begin with **R/** and the revisions is highlighted in red, while unchanged text from the original manuscript is shown in grey. The important parts are highlighted in **blue**. The quoted content is displayed in *italics*. All references cited in this response are listed at the end of the reply. Line numbers from the revised manuscript with marked-up changes are provided where relevant (i.e., tracked version).

We thank you for your consideration,

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Responses to the Editorial Support Team

EC1-1/ For now, we will proceed with your manuscript as submitted. However, please adjust your manuscript files before your next file upload (next round of revision or after acceptance) considering the following requirements:

We checked the references in your manuscript against their metadata and found some inconsistencies. In addition, we noticed that some references are missing DOIs. Please revise the affected references, add DOIs where available (this is typically the case for publications from 2010 onwards), or remove them from the manuscript. If a DOI is not available, please provide a stable URL for the referenced source instead. The report of our reference check is available at: https://editor.copernicus.org/GMD/reference-verification/egusphere-2026-4655/manuscript-version/2

R/ Thank you for providing the reference verification report. We have **checked all references flagged** in the report, corrected the identified inconsistencies, and added DOIs to all retained references concerned. We have also **removed references that were not cited in the main text or were incorrectly cited**.

One exception is Sherman (1932), "Stream Flow from Rainfall by the Unit-Graph Method." For this historical publication, we could not identify a DOI or a stable URL despite consulting related literature. We have therefore retained this reference without a DOI or URL.

Sherman, L.: Stream Flow from Rainfall by the Unit-Graph Method, Eng. News-Record., 108, 1932.

Responses to RC1

Many thanks for taking the time and effort to review our paper. All comments from Referee #1 are addressed below with point-by-point responses.

RC1-1/ This manuscript addresses practical challenges in deploying the VIC model, particularly the tedious preparation of input data and model parameters. The authors present Easy VIC Build (EVB), an open-source Python package that integrates these procedures into a unified workflow, and demonstrate its applicability in two real-world basins with different modeling settings. The integration of MPR further enhances the potential of EVB to support accessible spatially distributed parameterization. Overall, the manuscript is of high quality, fits well within the scope of the journal, and should be of interest to an international readership. In addition, the manuscript examines the relationship between the spatial distribution of model parameters and runoff generation from the perspective of physical plausibility, providing an indirect assessment of the rationality of the MPR approach. Although such an analysis is not commonly adopted, I find this aspect particularly interesting and believe that it deserves further discussion. I therefore minor revision, with several points regarding the presentation and wording to be addressed, as outlined below.

R/ We appreciate your positive feedback and recognition of our work. Your comments are valuable for revising and improving our paper. We fully agree that examining the **physical plausibility** of the estimated parameter from different perspectives **is important**. Following your suggestion, we **further discuss this aspect** based on our existing findings and relevant findings reported in the literature. Below, we provide detailed responses to each of your concerns.

RC1-2/ 1. As noted above, the authors examine the physical plausibility of the spatial patterns of model parameters, which is an important advantage facilitated by the application of the MPR technique. However, the manuscript does not appear to provide sufficient discussion of the estimation of spatially distributed parameters, and thus this advantage is not fully highlighted. I therefore suggest that the authors expand the discussion of spatial parameter estimation, including (1) what alternative approaches, besides MPR, can be used to estimate spatially distributed parameters, (2) what are the major challenges and difficulties associated with spatial parameter estimation, and (3) what are the specific advantages of MPR in addressing these challenges. Such a discussion would help better contextualize the contribution of MPR and further highlight the significance of the spatial parameter patterns obtained in this study.

R/ Thank you for this valuable suggestion. We fully agree that the spatial parameter estimation enabled by MPR is one of the key components that allows EVB to effectively support distributed modelling and distinguishes it from existing model deployment frameworks. We also acknowledge that a more comprehensive discussion of spatial parameter estimation would help better highlight the significance of this advantage and strengthen the broader implications of our work.

In response to this comment, we have added **a new Section 6.1 entitled "Opportunities and challenges of spatial parameter estimation in distributed hydrological models"** to provide a more systematic discussion. This discussion addresses your concerns by highlighting (1) the necessity and opportunities of spatial parameter estimation, (2) the challenges associated with this process, (3) the available approaches for estimating spatially distributed parameters, and (4) the unique advantages of MPR

compared with other approaches. These aspects are substantiated, to some extent, by a synthesis of previous studies and relevant literature, providing a broader context for understanding the contribution of MPR. For ease of review, the newly added discussion is provided below.

Please refer to **Lines 716-773** in the tracked version of the manuscript for the newly added discussion.

RC1-3/ 2. A key aspect that is currently missing from the manuscript is a clear description of the transfer functions, particularly which predictor variables are used to estimate each model parameter. I suggest that the authors provide a summary table in Section 3.1 specifying the predictor-parameter relationships. The corresponding transfer functions could also be presented explicitly, similar to those given in Eqs. (2)–(4). Providing this information would make the parameter estimation procedure more transparent and help readers better understand the implementation of the proposed approach.

R/ Thank you for pointing out this important omission. In the previous version, the transfer functions were primarily encapsulated in the code implementation, which we now recognize could make the parameter estimation procedure less transparent and potentially cause confusion for readers. Following your suggestion, we have **added a summary table of the transfer functions in the Appendix A**, explicitly specifying the predictor–parameter relationships for all model parameters.

In addition, we have **standardized the notation** of all model parameters and predictor variables and carefully revised the corresponding descriptions throughout the manuscript to ensure consistency and clarity.

The revised Appendix A, which includes the newly added summary table, can be found in **Lines 871-879** of the tracked-changes version of the manuscript. A corresponding description has also been added to the main text in Lines **253–254**.

RC1-4/ 3. Given the length of the manuscript, I suggest that the authors consider reducing or streamlining some of the less essential content to improve the overall readability and focus of the manuscript. The space saved through these revisions could instead be used to further strengthen several aspects that are more closely related to the scientific contribution of the study. Specifically:

Section 2.1.3: This subsection could be removed from the main text or reduced to a brief description and incorporated elsewhere, as the current level of detail does not appear essential to understanding the main contribution of the study.

Section 3.3: I suggest merging and substantially condensing the subsections under this section to provide a more concise description of the workflow and improve readability.

Section 4.1: This section could also be shortened, as the detailed description of the case-basin setup does not appear to be central to the main findings of the manuscript.

Section 5.3.2: I suggest expanding the discussion of spatially distributed parameter estimation as mentioned above, particularly the challenges associated with this process and the advantages of the MPR approach.

Abstract and Conclusion: I recommend further strengthening these sections by incorporating more quantitative results, such as specific model performance metrics and the accuracy achieved through cross-scale parameter transfer. Including these quantitative findings would allow readers to more readily assess the effectiveness and broader applicability of the proposed approach.

R/ Thank you for your constructive comments and valuable suggestions on improving the writing and organization of the manuscript. Following your recommendations, we have revised the manuscript accordingly and addressed each point as follows:

(1) Section 2.1.3: Following your suggestion, we have **removed this subsection** and moved the necessary information to the relevant sections (see Lines **202-206, 291-294, 556-561** in the tracked manuscript).

(2) Section 3.3: We have **merged and substantially condensed the subsections within this section** to provide a more concise description of the workflow and improve the overall readability. (see Lines **288-398** in the tracked manuscript).

(3) Section 4.1: We have **shortened the description of the case-basin setup** by retaining only the essential information required for understanding the modelling experiments. (see Lines **407-421** in the tracked manuscript).

(4) Section 5.3.2: In response to your suggestion, we have **added a new discussion section** of spatially distributed parameter estimation, which covers its necessity, major challenges, alternative approaches, and the specific advantages of MPR. Further details regarding this revision are provided in our response to **RC1-2**. (also see Lines **716-773** in the tracked manuscript).

(5) Abstract and Conclusion: We have strengthened these sections by **incorporating additional quantitative results** to better demonstrate the effectiveness of the proposed framework. (see Lines **14-30, 840-870** in the tracked manuscript).

RC1-5/ 4. The manuscript also contains several minor formatting and writing issues that should be addressed. For example:

Line 417: A line break appears to be missing. Please check and correct the formatting accordingly.

Appendix C: The title appears to be identical to that of Appendix B. Please verify the correct title and revise it accordingly.

R/ Thank you for your careful and thorough review. In accordance with your suggestions, we have carefully checked the entire manuscript and **revised the identified writing and formatting issues** throughout the text to improve its overall clarity and consistency. We have also **corrected the duplicated title of Appendix C** and verified the formatting, including the missing line break noted in the comments.

The corrected title of Appendix C found in **Lines 890-891** of the tracked-changes version of the manuscript.

Responses to RC2

Many thanks for taking the time and effort to review our paper. All comments from Referee #2 are addressed below with point-by-point responses.

RC2-1/ The EVB framework addresses a real and important bottleneck in VIC-5 deployment. Its Python-based, object-oriented design with integrated MPR is well conceived, and the two case studies cover both large-sample and site-specific application scenarios. The main weaknesses lie in lack of comparison with existing tools and insufficient methodological transparency.

R/ We sincerely thank you for your careful and constructive review, and for recognizing the importance and relevance of our EVB framework for VIC-5 deployment. We also **acknowledge the limitations** you pointed out and greatly appreciate these valuable suggestions for improving our manuscript. We provide point-by-point responses to your comments below and have made every effort to address them through corresponding revisions.

RC2-2/ Detailed Comments 1. There is no quantitative comparison with existing tools. The introduction criticizes VIC-ASSIST at some length, yet no functional or performance comparison is provided. A tool paper should address: How much faster is EVB than VIC-ASSIST? How much more flexible? What can EVB do that VIC-ASSIST cannot? A feature comparison matrix (model versions supported, data formats, calibration algorithms, parameter regionalization, parallel computing, etc.) is recommended. The positioning of EVB relative to alternatives such as the VIC Python driver ecosystem and SUMMA+mizuRoute also deserves brief discussion.

R/ Thank you for your valuable suggestion. We agree that a systematic comparison with existing VIC deployment tools, such as VIC-ASSIST, is helpful for clarifying the scope and contributions of the EVB framework within the current VIC modeling ecosystem.

However, we would like to clarify that **a direct quantitative comparison** of computational efficiency (i.e., "how much faster") between EVB and VIC-ASSIST **may not provide a meaningful assessment**. This is because the two tools were developed for **different VIC versions, data structures, and computational workflows**, which can substantially influence the overall deployment efficiency. Specifically, (1) VIC-ASSIST was primarily designed for VIC-4 deployment, whereas EVB targets the latest VIC-5 framework; (2) VIC-ASSIST mainly relies on text-based input/output interfaces, while EVB adopts a NetCDF-based data interfaces; (3) the two tools employ different spatial data preprocessing and parameter estimation procedures (i.e., spatially uniform parameters in VIC-ASSIST versus MPR-based spatial parameters in EVB); (4) VIC-ASSIST relies on MATLAB and ArcGIS for Desktop, whereas EVB is developed as a Python-based open-source framework built upon publicly available Python packages without requiring third-party software dependencies. Therefore, a runtime comparison between them would inevitably be influenced by multiple aspects of the modeling workflow, making it difficult to isolate the efficiency of the deployment framework itself.

On the other hand, we would like to emphasize that **our intention is not to undermine VIC-ASSIST** or highlight its limitations. We highly appreciate its contribution to facilitating VIC deployment through a user-friendly GUI environment. The two tools address different needs within the VIC modeling ecosystem: VIC-ASSIST primarily emphasizes user-friendly GUI-assisted deployment, whereas EVB focuses on reproducibility, flexibility, and extensibility for advanced modeling workflows.

For these reasons, we do not perform a direct efficiency comparison between the two tools. Instead, following your suggestion, we **have added a feature comparison matrix** to the new Discussion section (Sect. 6.2) to clarify the differences between EVB and existing VIC deployment tools. To provide a more comprehensive overview of the current VIC deployment ecosystem, we also include **TONIC** and **CyberWater** in the comparison. Meanwhile, to maintain consistency and better clarify our intended message while avoiding potential misunderstandings, we have further revised the Introduction by **refining the description of VIC-ASSIST**, reducing the use of potentially critical wording.

Following your suggestion, we have also acknowledged the **workflow blueprint for coupled SUMMA and mizuRoute modelling** proposed by **Knoben et al. (2022)** and the **CWARHM initiative**. Their emphasis on reproducibility, separation of concerns, modular design, layered organization, and deployment traceability **provides useful context for the design of EVB**. We have therefore expanded the discussion of these related efforts in the Introduction and Discussion (Section 6.2) sections, emphasizing their relevance to the design philosophy of the EVB framework. We also briefly discuss the VIC Python driver ecosystem as a related development with implications for the future compatibility and development of EVB.

We believe these revisions help address your concerns regarding the positioning of EVB and provide a more balanced description of related VIC deployment efforts.

Please refer to **Lines 45-147** in the tracked version of the manuscript for the revised Introduction and **Lines 774-839** for the newly added Discussion (Section 6.2).

RC2-3/ 2. MPR transfer functions are not specified; methodological transparency is insufficient. MPR is presented as a core EVB feature, yet the mathematical form of the transfer functions is entirely absent — how soil properties map to Ks via g-parameters, how topography influences binfilt, whether vegetation parameters go through MPR or direct resampling, etc. Open-source code does not substitute for methodological transparency in the paper. Additionally, the selection of the 15-parameter reduced calibration set rests on two literature citations without an independent sensitivity analysis in this study.

R/ We thank you for identifying shortcomings in our methodological description, particularly the lack of explicit MPR transfer functions. This omission reduced the transparency of the MPR implementation and could potentially confuse readers. To address this issue, we have **added a summary table of the transfer functions in Appendix A**, explicitly specifying the predictor–parameter relationships for all model parameters.

In addition, we have **standardized the notation** of all model parameters and predictor variables and carefully revised the corresponding descriptions throughout the manuscript to ensure consistency and clarity.

The revised Appendix A, which includes the newly added summary table, can be found in **Lines 871-879** of the tracked-changes version of the manuscript. A corresponding description has also been added to the main text in Lines **253–254**.

Regarding the selection of the 15 free parameters, we clarify that this decision was not based solely on

the two cited studies. Rather, **it was informed by a broader body of research and modelling practice**, including work by the VIC model developers and sensitivity analyses conducted for VIC applications in different regions worldwide. To make the basis for this selection transparent, we reproduce several relevant passages from the original studies below.

Liang et al. (1994; one of the foundational VIC papers, cited over 3,900 times):

"Among the hydrological parameters, only three (b_i, D_s, W_s) would best be estimated using streamflow data if they are available…The other hydrological parameters can be estimated using, for instance, soil characteristics."

Gao et al. (2010; a representative book on the principles and implementation of the VIC model):

*"**6.5 Calibration** …The usual implementation approach (see e.g. Nijssen et al. 1997) involves calibration of six parameters: a) the infiltration parameter (bi), which controls the partitioning of rainfall (or snowmelt) into infiltration and direct runoff (a higher value of bi gives lower infiltration and yields higher surface runoff); b) D2 and D3, which are the second and third soil layer thicknesses (D1, the top soil layer depth, is usually specified a priori) and affect the water available for transpiration and baseflow respectively (thicker soil depths have slower runoff response — baseflow dominated — with higher evapotranspiration, but result in longer retention of soil moisture and higher baseflow in wet seasons); c) Dsmax, Ds, and Ws, which are baseflow parameters and also are estimated via calibration. Dsmax is the maximum baseflow velocity, Ds is the fraction of maximum baseflow velocity, and Ws is the fraction of maximum soil moisture content of the third soil layer at which non-linear baseflow occurs. These three baseflow parameters determine how quickly the water stored in the third soil layer is evacuated as baseflow (Liang et al. 1994). The three baseflow parameters and the third soil layer depth (d3) (Nijssen et al., 2001a, Su et al., 2005) are used with only minor adjustment during the calibration, while the infiltration parameter (bi) and the second soil depth (d2) are targeted for intensive calibration. Parameters bi and d2 are calibrated independently."*

Gou et al. (2020; sensitivity-analysis-based VIC calibration in China):

"Even though the VIC model has 46 or more tunable parameters (Bennett et al., 2018), we chose only 13 parameters for this study, because the values of these 13 parameters are typically subject to calibration rather than direct measurement."

"We found that three parameters—the infiltration parameter (B) and two of the soil depth parameters (D1, D2)—are highly sensitive in most basins, while other parameter sensitivities are strongly related to the dynamic environment of the basin."

Gu et al. (2021; multi-objective calibration of the VIC model using a stepwise surrogate model):

"Generally, the parameters selected for calibration are the thickness of the second and third soil moisture layers (d2, d3), the fraction of maximum soil moisture where nonlinear baseflow occurs (W_s), the maximum velocity of baseflow (D_{smax}), the fraction of D_{smax} where nonlinear baseflow begins (D_s), and the variable infiltration curve parameter (b_{inf})(Lohmann et al. 1996; Xie et al. 2007; Mishra et al. 2010; Voisin et al. 2011; Lu et al. 2013; Zhao et al. 2013; Kang et al. 2014; Hengade & Eldho 2016; Liu et al. 2017)."

The studies use different notation but identify **a broadly consistent set of sensitive VIC parameters**. This agreement reflects the model's underlying formulations, particularly the variable infiltration capacity curve, the Xinanjiang saturation excess runoff formulation, and the ARNO baseflow function. We selected 15 MPR g-parameters to define transfer functions for the runoff parameters listed in Table A2 (unrevised manuscript). Calibration adjusts these g-parameters, while the transfer functions use them to estimate the same sensitive VIC parameters identified in previous studies.

We agree that a sensitivity analysis of the g-parameters could provide additional insight. However, it would involve a higher-dimensional parameter space and could make parameter identifiability more difficult to assess. Because the sensitivity of the underlying VIC parameters has already been examined in the studies cited above, we consider a further sensitivity analysis unnecessary and beyond the scope of this study. In addition, **our earlier EVB-based modelling study** assessed the adequacy of the selected 15 parameters for VIC calibration and **achieved good simulation performance**, providing further support for their selection (Zheng et al., 2026). Given EVB's flexible and extensible design, any VIC parameters can be adjusted and freely combined through the parameter_set module, allowing this question to be examined in future studies.

To clarify the basis for our parameter selection, we have revised the explanation in the Methods section and added further references, as detailed in **Lines 540-543** of the tracked manuscript.

RC2-4/ 3. Two-year warm-up periods may be short for a distributed model with deep soil storage and baseflow reservoirs. More discussion of this choice would be helpful.

R/ Thank you for your suggestion. Accordingly, we have **added a discussion in Sect. 5.1** to explain the choice of the two-year warm-up period. The discussion considers evidence from previous studies, established modelling practice, practical constraints related to data availability, and the the observed stability of simulated runoff during the early simulation period.

For your reference, the newly added text can be found in in **Lines 526-533** of the tracked manuscript.

RC2-5/ 4. The synthetic-rainfall parameter validation is somewhat circular: under homogeneous forcing and initial conditions, spatial variability is purely parameter-driven.

R/ We understand the concern raised by this point and agree that, because the synthetic rainfall and initial conditions are spatially uniform, the spatial variation in simulation is generated entirely by the parameter fields. Thus, this experiment cannot independently validate the parameter estimates themselves.

Our purpose, however, **was not** to demonstrate a **direct runoff–parameter correspondence**, which is inherent in the experimental design, but to examine **whether the parameter driven runoff patterns** are **consistent with general hydrological process understanding (expectations)** and therefore provide an indirect check of their plausibility.

For example, general understanding of hillslope runoff generation suggests that relatively flat areas may produce less surface runoff than steeper areas. We therefore examined whether this contrast could emerge in simulations driven entirely by the parameter fields (Fig. 8a).

Viewed in this way, the experiment highlights **the advantage of MPR in integrating land surface**

characteristics to spatially varying model parameters. This information would be lost under a spatially uniform parameterization, a common strategy in previous VIC modelling studies, because the same parameter values are applied across all terrain conditions and therefore cannot represent terrain related differences independently of spatial variations in the forcing data.

Thus, we consider this assessment meaningful within its intended scope. To clarify this point, we revised the relevant explanation in Sect. 5.3.2 (see **Lines 662-665, 673-674** in the tracked manuscript) and added a dedicated discussion of spatial parameter estimation in Sect. 6.1 (see **Lines 716-773**). For ease of review, the revised text is provided below.

RC2-6/ 5. Computational efficiency is reported for only one JRB configuration; multi-resolution comparisons would be informative.

R/ Following your suggestion, we **now report runtime measurements for the GRB setup at three spatial resolutions**, replacing the original single-resolution results for the JRB setup. These results are presented at the end of Sect. 5.1 and in Table 3, providing a more informative assessment of EVB's computational efficiency across modelling resolutions.

Please refer to **Lines 556-568** in the tracked version of the manuscript for the revised text and table.

RC2-7/ 6. A brief discussion of EVB vs. SUMMA+mizuRoute positioning would help readers understand use cases.

R/ Thank you for this helpful suggestion. We agree that a brief comparison with the SUMMA–mizuRoute framework would help clarify EVB's positioning and scopes. We have therefore added this discussion to the **Introduction** and the **new Discussion section (Sect. 6.2)**. The comparison highlights the main advantages and intended scope of EVB. Further details can be found in our response to **RC2-2**.

Reference

Gao, H., Tang, Q., Shi, J. X., Zhu, C., Bohn, T., Su, F., Sheffield, J., Pan, M., Lettenmaier, D., and Wood, E.: Water Budget Record from Variable Infiltration Capacity (VIC) Model, 2010.

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Liang, X., Lettenmaier, D., Wood, E., and Burges, S.: A Simple hydrologically Based Model of Land Surface Water and Energy Fluxes for GSMs, J. Geophys. Res., 99, 10.1029/94JD00483, 1994.

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Finally, we would like to once again thank the Editor and all Reviewers for their thorough review of our paper. If there are any questions, suggestions, or discussions, please feel free to contact us.