

## Reply to Reviewer's Comments on egosphere-2025-5694

We sincerely thank the Editor, Dr. Yonggen Zhang, and the two reviewers for their careful evaluation and constructive comments on our manuscript. Their valuable suggestions have substantially improved the clarity and quality of the manuscript. Below, we provide a point-by-point response to all comments. The reviewers' comments are shown in black, our responses in blue. All changes in the revised manuscript have been highlighted in red for ease of reference.

### Reply to Editor's Comment

#### General Assessment

Thank you for submitting your manuscript to HESS. We have received the feedback from two reviewers. One reviewer recommended acceptance, and the other suggested minor revisions. After reading your manuscript, I agree with their positive assessment and would suggest a minor revision. In addition to addressing the reviewers' comments, please also attend to the following minor editorial details.

**Response:** We sincerely thank the Editor, Dr. Zhang, and the two reviewers for their careful evaluation and constructive comments on our manuscript. We are pleased that the revisions from the previous round were positively recognized.

**Comment 1:** Figure 1 panel referencing: In the main text, Figure 1c is cited first (Line 97), followed by Figure 1b (Line 101). To ensure a smooth reading flow, I suggest swapping the labels of panels (b) and (c) in Figure 1 so that they are introduced in alphabetical order (a, b, c, d) throughout the text.

**Response:** We thank the editor for this suggestion. Following the Editor's recommendation, we have swapped the labels of panels (b) and (c) in Figure 1 so that the panels are introduced sequentially in alphabetical order throughout the manuscript. The figure caption have also been updated accordingly in the manuscript.

**Comment 2:** Potential typo at Line 131: The phrase reads "suggests that estimating  $r$  EEs...". Please check if the letter "r" before "EEs" is a typo or extraneous, and delete/revise it if necessary.

**Response:** We apologize for the confusion caused by this wording. In the original text, we intended to indicate that estimating a total of  $r$  elementary effects (EEs) requires  $2rk$  model simulations. To improve clarity and avoid ambiguity, we have revised this sentence.

*"This suggests that estimating a total of  $r$  EEs requires  $2rk$  model simulations."*

## Reply to RC3's Comment

### General Assessment

I was not a reviewer of the previous submission; however, I carefully examined the revised manuscript and the comments from the last review round. Overall, the manuscript is generally well written, and it addresses an increasingly important issue in distributed hydrological modelling, namely the challenge of performing sensitivity analysis in high-dimensional parameter spaces. The authors have clearly made substantial efforts to address the earlier concerns, including significant improvements to the Discussion section. The results are interesting and potentially valuable for the hydrological modelling community.

**Response:** We sincerely thank the reviewer for the positive and encouraging comments on our manuscript. We greatly appreciate the reviewer's careful evaluation of the revised version and recognition of our efforts to address the concerns raised in the previous review round.

### Specific comments:

**Comment 1:** Line 54: The statement "Conventional SA approaches can be grouped into spatially lumped and spatially distributed methods" specifically refers to SSA frameworks. More generally, SA methods are commonly classified as local or global methods. Please clarify this distinction to avoid confusion.

**Response:** We thank the reviewer for pointing this out. We agree that the original statement may cause confusion between the general classification of sensitivity analysis methods and the classification specific to distributed hydrological models. To improve clarity, we have revised the sentence as follows:

*"Conventional SA approaches applied to distributed hydrologic models can be grouped into spatially lumped and spatially distributed methods."*

**Comment 2:** Line 70: "Recent advances in surrogate modelling have provided promising solutions." Promising solutions for what specifically? Please clarify the challenge being addressed.

**Response:** We thank the reviewer for this comment. The phrase "promising solutions" referred specifically to addressing the substantial computational demands caused by the high dimensionality of distributed models. To clarify this point, we have revised the sentence as follows:

*"Recent advances in surrogate modelling have provided promising solutions for reducing the computational demands associated with high-dimensional distributed models."*

**Comment 3:** Line 98: The sentence regarding "mean annual precipitation of 654 mm, ranging from 381 mm to 857 mm" is confusing.

**Response:** We thank the reviewer for pointing out this unclear wording. We intended to indicate that the annual precipitation ranges from 381 mm to 857 mm, with a mean annual precipitation of 654 mm. To improve clarity, we have revised the sentence accordingly:

*“Annual precipitation ranges from 381 mm to 857 mm, with a mean annual precipitation of 654 mm.”.*

**Comment 4:** Line 100: “for the same period” is unclear. Please specify the exact period being referenced.

**Response:** We thank the reviewer for this comment. The phrase “the same period” referred to the period 1962 – 1986 mentioned in the previous sentence. To avoid ambiguity and improve clarity, we have revised the sentence as follows:

*“Mean annual potential evapotranspiration during 1962 – 1986, estimated using the Penman – Monteith method, is 972 mm.” .*

**Comment 5:** Line 114: “marks” should be “mark”.

**Response:** Corrected.

**Comment 6:** Line 139: Consider replacing “important” with “sensitive” for consistency with SA terminology.

**Response:** Thank you for this comment. We have revised the text accordingly.

**Comment 7:** Equation (3): The notation  $x_{\sim i}$  represents all parameters except  $x_i$ , so the vector notation should be made explicit (e.g., bold font).

**Response:** We thank the reviewer for this careful observation. We have revised Equation (3) to clarify the notation by using bold font accordingly.

**Comment 8:** Lines 149-151: Please clarify whether the  $N \times (k+2)$  model evaluations are used to estimate all  $S_i$  and  $S_{T_i}$  indices simultaneously or for each parameter separately.

**Response:** We thank the reviewer for this helpful comment. The total of  $N \times (k+2)$  model evaluations are used to estimate all  $S_i$  and  $S_{T_i}$  indices for all parameters simultaneously, rather than separately for each parameter. To clarify this point, we have revised the text accordingly:

*“The  $S_i$  and  $S_{T_i}$  indices for all  $k$  parameters are then estimated simultaneously using  $2 \times N$  model simulations from **A** and **B**, plus  $k \times N$  model simulations from the hybrid matrices  $C_i$ , resulting in a total cost of  $N \times (k + 2)$  model runs” .*

**Comment 9:** Line 196: “sensitivity analysis” should be abbreviated as “SA”, since the abbreviation has already been introduced in the Introduction.

**Response:** Revised accordingly.

**Comment 10:** Line 229: Some information here appears repetitive and could be streamlined.

**Response:** We have removed the phrase “the magnitude of a parameter’s overall influence and the extent of interaction or nonlinearity,” which had already been explained earlier in the manuscript. The revised sentence now reads:

*“The Morris method was then used to calculate  $\mu_i^*$  and  $\sigma_i$  for each parameter, and a scatterplot of  $\mu_i^*$  versus  $\sigma_i$  was used to screen the influential parameters (Yang and Ye, 2022).”*

**Comment 11:** Line 236: “distributions” should be “distribution”.

**Response:** Revised accordingly.

**Comment 12:** Lines 275-280: Although explaining the selection of the MLP architecture is necessary, this paragraph is somewhat overly verbose. I suggest condensing this part.

**Response:** Thank you and we agree with the reviewer that the original paragraph was overly detailed. Accordingly, we condensed the description of the MLP architecture and its rationale while retaining the key methodological information. The revised text now reads:

*“Due to the computational impracticality of applying the Sobol' method to such high-dimensional parameter spaces, particularly at the HRU scale, deep learning surrogates were constructed to efficiently emulate SWAT (Razavi et al., 2012). The task was formulated as a high-dimensional vector-to-vector regression problem, where static parameter vectors were mapped to the full 180-month runoff series at the ZJS gauge. Accordingly, fully connected MLPs were adopted because they effectively approximate complex nonlinear relationships in high-dimensional spaces. Although hydrological processes exhibit temporal dependencies, these dynamics are implicitly embedded in the SWAT-generated runoff sequences used for training. The MLP therefore learns the integrated parameter–response relationship over the entire simulation period. While sequence-based models such as LSTM networks may explicitly represent temporal dependencies (Jeong et al., 2024), the MLP achieved sufficient accuracy in this study and was selected as a parsimonious and computationally efficient surrogate model for sensitivity analysis (Yang et al., 2024; Yu et al., 2024).”*

**Comment 13:** Figure 2: Please define “BN” in the figure.

**Response:** We thank the reviewer for pointing this out. “BN” refers to “batch normalization”. Although the full term was provided in the main text, the abbreviation was not explicitly defined. To improve clarity and maintain consistency with “ReLU”, which is also defined in the main text rather than in the figure, we have added the abbreviation definition where “batch normalization” first appears in the manuscript.

**Comment 14:** Line 326: The phrase “Due to the much higher input dimensionality” is incomplete or awkwardly phrased. Please revise for clarity.

**Response:** We thank the reviewer for this comment. To improve clarity, we have revised the sentence as follows:

*“Due to the substantially higher dimensionality of the HRU-scale parameter space ...”.*

**Comment 15:** Line 340: The notation “Si/STi” is visually misleading because it resembles a ratio. It would be clearer to write “Si and STi”.

**Response:** We thank the reviewer for pointing this out and we have revised it accordingly.

**Comment 16:** Line 359: Again, “sensitivity analysis” should be abbreviated as “SA”.

**Response:** Revised accordingly.

**Comment 17:** Line 362: “small” may be more appropriate than “limited”.

**Response:** Revised accordingly.

**Comment 18:** Lines 362-364: The sentence beginning with “SSA was performed with both the original SWAT model...” is difficult to follow and should be rewritten for clarity.

**Response:** We thank the reviewer for this comment. To improve clarity, we have revised the text as follows:

*“SSA was conducted using the same parameter samples for both the original SWAT model and the corresponding MLP surrogate model. This produced two sets of sensitivity indices, allowing direct comparison between the SWAT-based and MLP-based sensitivity results.”.*

**Comment 19:** Line 368: “numerical values” may be clearer than “absolute values”.

**Response:** Revised accordingly.

**Comment 20:** Line 403: Consider replacing “demonstrate” with “indicate”.

**Response:** Revised accordingly.

**Comment 21:** Line 408: “analysis focuses” should be revised to “analyses focus”.

**Response:** Revised accordingly.

**Comment 22:** Line 487: “metric” should be “metrics”.

**Response:** Revised accordingly.

**Comment 23:** Line 510: “watershed outlet” is misleading. I believe the authors mean the ZJS gauge station rather than the actual watershed outlet.

**Response:** We thank the reviewer for this comment. The reviewer’s understanding is correct. In this context, we intended to refer to the ZJS gauge station rather than the actual watershed outlet. Accordingly, we have replaced “watershed outlet” with “gauge station”.

**Comment 24:** Line 540: “parameter constraints” may be better expressed as “performance constraints” depending on the intended meaning.

**Response:** Revised accordingly.

**Comment 25:** Line 545:  $C_i$  should not be italicized differently from other matrices. Also, please clarify whether the MLP surrogate was re-trained using posterior parameter distributions.

**Response:** We thank the reviewer for pointing this out. We have corrected the formatting of  $C_i$  to ensure mathematical consistency.

The MLP surrogate models were not re-trained using the posterior parameter distributions. This is because the posterior parameter samples remained within the same parameter bounds as the prior distributions used for surrogate training. Therefore, the original surrogate models remained applicable for the posterior-based sensitivity analysis without additional retraining. To clarify this point, we have added the following explanation to the revised manuscript:

*“The trained MLP surrogate models were then used to generate the corresponding model outputs. Note the MLP surrogate models were not re-trained for the posterior-based SSA because the posterior parameter samples remained within the same parameter bounds used during surrogate training, although their probability distributions changed from uniform prior distributions to empirical posterior distributions.”*

**Comment 26:** Line 549: “outlet response” should be clarified. Does this refer specifically to runoff at the ZJS gauge station?

**Response:** We apologize for the confusion caused by this wording. Here, the term “outlet response” refers to the NSE performance metric calculated between the observed and simulated monthly runoff at the ZJS gauge station. To improve clarity, we have revised the text accordingly in the manuscript.

*“At both scales, the principal sensitivity hotspots are preserved, and the same key regions continue to exert dominant control on the runoff at the ZJS gauge station.”*

**Comment 27:** Line 592: There appears to be an error in Equation (5). The last term should be mean of YJP not ZJS. Please check.

**Response:** Thank you for pointing this out. The reviewer is correct. We have corrected the last term in Equation (5) from the mean of ZJS to the mean of YJP. The revised equation is shown below:

$$\text{NSE}_{agg} = 1 - \frac{\sum_{i=1}^n (Q_{o,i}^{ZJS} - Q_{s,i}^{ZJS})^2 + \sum_{i=1}^n (Q_{o,i}^{YJP} - Q_{s,i}^{YJP})^2}{\sum_{i=1}^n (Q_{o,i}^{ZJS} - \overline{Q_o^{ZJS}})^2 + \sum_{i=1}^n (Q_{o,i}^{YJP} - \overline{Q_o^{YJP}})^2}, \quad (1)$$

**Comment 28:** Line 683: Delete “explicitly”.

**Response:** Deleted.