Public justification (visible to the public if the article is accepted and published):

Both reviewers have recognized the significant potential of your work in advancing the theoretical understanding and practical implications of hydrological modeling. I fully concur with their positive assessments. While reading the manuscript, I have developed a few additional thoughts that may help you sharpen and contextualize your work in the new era of hydrology.

Response: We thank the Editor for the positive and encouraging assessment of our work. Point-by-point responses to the editor's comments are listed below. For clarity, our responses are color-coded as follows: editor's comments are in black, our responses are in light blue, the line numbers (corresponding to the clean version) are in red, and the texts excerpted from the manuscript are in brown.

The role of vegetation and topography in your framework: Your current modeling framework centers on the spatial distribution of soil water storage, infiltration capacity and their dynamic link to infiltration and saturation excess runoff. I would encourage you to reflect more explicitly on the roles of vegetation and topography within this framework, as both exert strong controls on runoff generation processes. I trust you are already familiar with the relevant literatures.

Response: Thank you for your suggestion, we revised the sentence in line 338-340 to explicitly express the linkage between vegetation, topography and our model:

"the linkages between landscape conditions (e.g., vegetation dynamics and topographic controls) and the parameterization of infiltration capacity and storage capacity distribution in URSSIE warrant further investigation"

In this context, I would like to draw your attention to an ongoing debate regarding the centrality of soil in hydrological modeling. Recent studies (e.g., Addor et al., 2018; Gao et al., 2023) have questioned the adequacy of soil-centric indicators for capturing hydrological behavior, with growing recognition that ecosystem functioning—including vegetation dynamics and land-atmosphere feedbacks—plays an essential role in shaping land surface hydrology.

Response: Thank you for your suggestion and we revised the sentence in line 44-49 as follows:

"The spatial organizations of saturation and infiltration excess occurrences and their interconnections are underpinned directly by the spatial organization of soil moisture (Rodriguez-Iturbe et al., 1995; Western et al., 1999) and indirectly by the spatial organizations of soil (Lin, 2003; Targulian and Krasilnikov, 2007), topography (Rodriguez-Iturbe and Valdes, 1979; Rodriguez-Iturbe and Rinaldo, 2000), and vegetation (Rodríguez-Iturbe et al., 1999; Franklin et al., 2020), with emerging evidence highlighting the role of ecosystem functioning and land–atmosphere interactions in shaping hydrological behavior (Addor et al., 2018; Gao et al., 2023) at the catchment and larger scales."

I would suggest positioning your work more explicitly within an ecosystem-centered perspective (see Savenije, 2024; Gao et al., 2024). This does not require altering your model structure, but rather acknowledging how vegetation and topography may implicitly influence the parameters or distributions used in your framework (e.g., through the shape parameter *a*, the infiltration exponent n, or the spatial organization of storage capacity). A brief discussion of how your soilbased scheme could be extended or coupled with vegetation and topographic controls would greatly enhance the conceptual richness and relevance of your paper.

Response: Thank you for your suggestion, we revised the sentence introducing the parameters in line 91-93:

"Introducing the shape parameter allows for flexibility in representing various forms of spatial distributions of soil water storage capacity, ensuring that the CDF can represent a range of catchment types with different topographic organizations and associated soil storage capacity distributions."

and in line 172-174:

"The dimensionless exponent, n, reflects the spatial heterogeneity of landscape conditions within a catchment, such as vegetation cover and soil properties, which can be interpreted as a simplified representation of root-zone and ecosystem controls on infiltration behavior (Savenije, 2024; Gao et al., 2024)."

Detailed evaluation of model performance: While you have provided summary statistics (e.g., KGE > 0.5 for 90% of catchments), the manuscript would benefit from a more detailed and illustrative presentation of the model's performance. I recommend including additional figures that highlight in which basins and under which conditions the new model outperforms traditional approaches (e.g., saturation-excess-only or infiltration-excess-only models). This could be done through:

Side-by-side comparisons of hydrographs for selected catchments representing different climate regimes.

Maps or scatter plots showing performance gains (e.g., ΔKGE) relative to benchmarks.

Event-scale analyses demonstrating how the dynamic transition between runoff mechanisms is better captured by URSSIE.

Response: Thank you for your suggestion. We revised the description of the comparison in line 288-291 as follows:

"The two models show comparable performance in humid catchments, while URSSIE achieves noticeably higher KGEs (ΔKGE > 0.05) in 20 of the 66 arid basins for flood peaks, and 15 of the 66 arid basins for daily streamflow (see Fig. S8 and Supplementary Information for details)."

We added a map of ΔKGE in Supplementary line 280-281 and line 290-291:

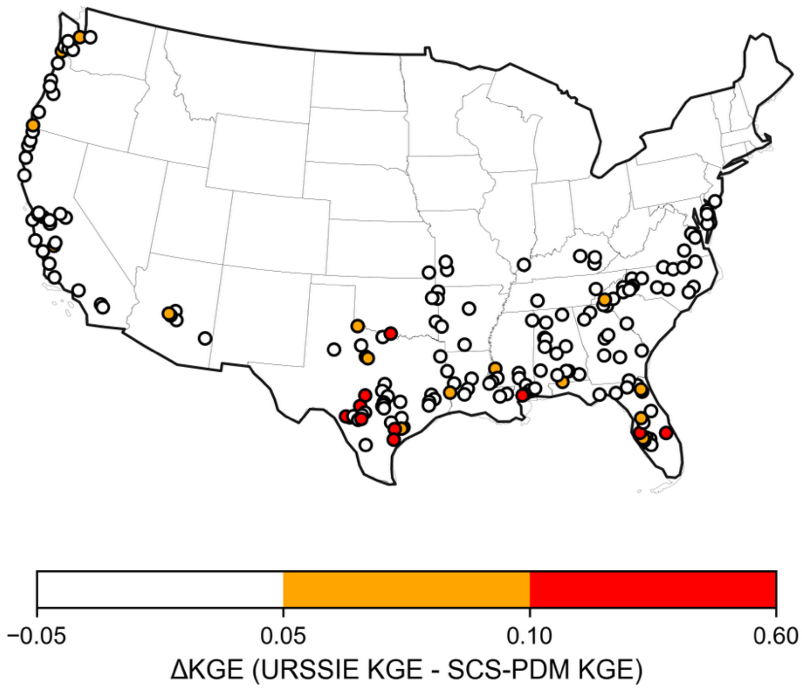

Figure S9. Spatial distribution of daily streamflow ΔKGE (URSSIE KGE − SCS-PDM KGE) across the 181 catchments.

Figure S9 shows that URSSIE achieves comparable performance to SCS-PDM in daily streamflow, with improvements mainly observed in arid catchments in Texas.

We also added a 1-year observed and simulated daily streamflow timeseries plot in a humid and two arid catchments in Supplementary line 282-283 and line 292-295:

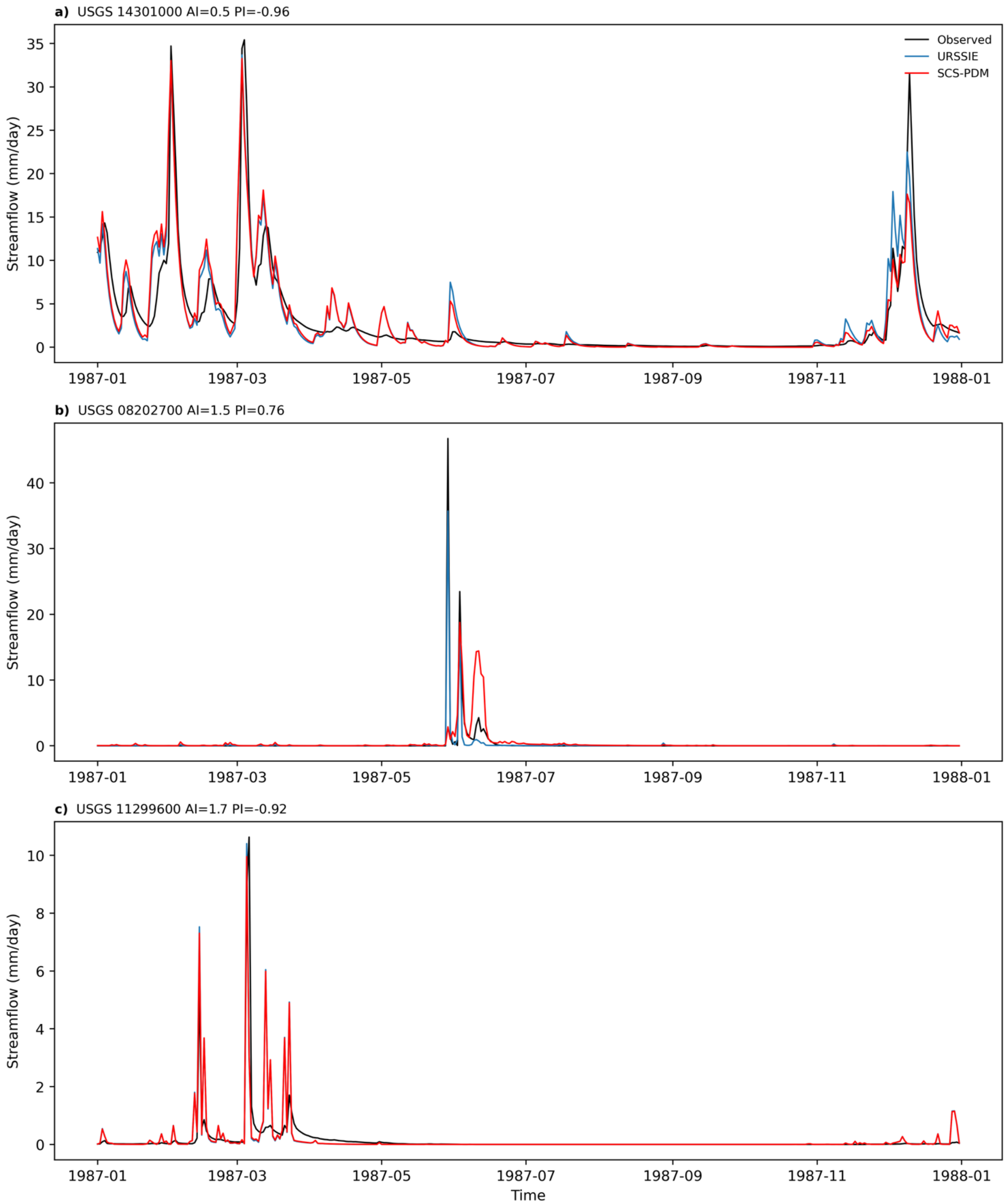

Figure S10. Daily timeseries of observed and simulated streamflow at the representative catchments.

Figure S10 presents examples of one-year daily streamflow in a humid catchment (Fig. S10a) and two arid catchments (Figs. S10b and S10c). In the humid catchment and in the arid catchment where precipitation and PET are out of phase, the two runoff schemes show similar performance (Figs. S10a and S10c). In contrast, for the arid catchment where precipitation and PET are in phase, URSSIE better captures the flood peaks (Fig. S10b).

I hope these points help you situate your work more clearly within contemporary hydrological discourse and further demonstrate its practical utility. I look forward to seeing your revised version.

Yes indeed. We greatly appreciate the editor's insightful comments.