Egusphere-2023-666 “Towards Interpretable LSTM-based Modelling of Hydrological Systems” LA. De la Fuente, MR. Ehsani, HV. Gupta and LE. Condon

This article is really well written and constructed, making it an easy manuscript to read. I find little to critique about the presentation, but will talk in generalities from a hydrological modellers perspective.

Response: Thanks for your compliment. We appreciate your contribution and comment.

Temporal weighting of lagged events is highly reminiscent of unit hydrograph theory and is potentially another interpretation of the weights obtained (e.g., Sherman 1932; Lienhard 1964; Rodriguez-Iturbe and Valdes 1979). Similarly, the number of cell states may be broadly associated with the number of linear reservoirs in series that produce these unit hydrographs (e.g., Ocak and Bayazit 2003). Clearly a unit hydrograph that partitions daily total runoff into an hourly signal (for estimating peak flow for example) is not the same, but the concepts are equivalent when representing inputs as a temporal output distributed with the memory of prior inputs.

Response: We agree. The unit hydrograph and its convolution effect evoke many aspects of what we found in the weight distribution. This similarity helps differentiate the short-term effect of the forcing (unit hydrograph behavior) without a state variable, from the long-term effect produced by the water stored in the catchment (baseflow). As a result of both effects, a non-linear behavior emerges in the input-output response of the streamflow. This explanation will help us to understand why these patterns emerged in the gates. We will add this additional explanation about the interpretability of the weights.

The titles of Sections 5 and 6 should be more descriptive than “Experiment 1” and “Experiment 2”, maybe “Comparison of LSTM and HydroLSTM across hydrological regime” and “HydroLSTM performance with a single cell state”.

Response: We will make the titles of sections 5 and 6 more specific to their respective topics.

These suggestions are very rough, but the opening paragraph of each section should follow logically from the section title and expand upon it. It is unclear how the 10 catchments in Section 5 were selected, but it interesting to observe that in each of the five hydro-climate regimes that LSTM had one low cell state result, and one much higher. Was this deliberate or simply to support the later message regarding spatial variability of lag, that definitive patterns of number of cell states or lag are difficult to establish based on hydro-climate for multiple cell state representations?

Response: We will enhance the introduction of this section. Regarding the selection of the catchments, they were chosen randomly from each of the regions defined in the reference study (Jiang et al.,2022). This random selection illustrates the difficulty of determining the optimal lag solely based on performance metrics. It further emphasizes the necessity of additional regularization to draw more robust conclusions about hydrological features.

Please be careful in your equations that the hyperbolic tangent function "tanh" stays a single word and not split to "tan‸h" with a space, as I notice the language of tangent hyperbolic in the text.

Response: We will check the correct writing of the tangent hyperbolic.

Figure 6a has four clearly inferior lag times (4, 8, 16 and 32 days) with the other three (64, 128 and 256 days) being the same for all practical purposes for KGE>0.4. It is hard to reconcile in the text (S6.2) that the graph has "saturated" at lag=256 if very similar results are obtained with lag=64 and 128, and there are no lag values >256 to confirm it.

Response: We agree. The saturation region is between 64 and 256 days for catchments with KGE > 0.4. For KGE < 0.4, the curve of 256 days is the best option, which is why this one is used in the text. However, the main point of this figure is to demonstrate that a fixed memory might not be the optimal choice when dealing with a large number of catchments, considering the local dependency of that hyperparameter.

With Figure 6b it is not surprising that modelling with a single cell state is more difficult with increased aridity, as this is well known in the standard hydrologic modelling literature (e.g., Pilgrim et al. 1988).

Response: We agree; however, this behavior is present in lumped and ML models, as explored previously (De la Fuente et al., 2023), suggesting that the issues are not in the architecture used. For that reason, presenting this figure should reinforce that idea. We will add some comments about that.

It also seems that the general success of HydroLSTM with a single cell state alludes to the usefulness (success?) of simple lumped hydrologic models such as GR4J or SIMHYD with few parameters that may be physically interpretable.

Response: This is the inspiration for the paper: a parsimonious representation should be preferred if additional complexity cannot improve performance.

The Discussion is very interesting and points to useful future endeavours, with multiple output criteria to make the possible solution space smaller and get the right answer (outputs) for the right reason (see Kirchner 2006). As far as groundwater characterisation for rainfall-runoff modelling, the lag times may be very different for a “land” cell state and a “groundwater” cell state and potentially exceed one calendar year. Statistical correlation methods for groundwater variation with lag measured in months to years such as HARTT (e.g., Ferdowsian et al. 2001; Goodarzi 2020) are abstract methods that rely on variability of the assumed controlling mechanism, and have also been compared with neural network implementations. Whether these might provide some information or inspiration for additional work is unknown.

Response: Splitting the regularization into short and long-term behavior is part of our inspiration for the next steps because it allows us to gain insight into the groundwater system using streamflow data, which has more abundant and consistent data.

Reviewer references

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