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Discussions

Interactive comment on "Hydrologic system complexity and nonlinear dynamic concepts for a catchment classification framework" *by* B. Sivakumar and V. P. Singh

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Response to Referee Comment – B. Selle (RC – C2189)

We thank B. Selle for his positive and constructive comments on our work. Overall, we agree with B. Selle on his comments and suggested improvements. As we have discussed in detail in our "General Response to Guest Editor Comment (EC), Referees' Comments (RCs), and Short Comment (SC)," we have substantially revised our manuscript in light of the various comments and concerns raised by the RCs, SC, and EC. As discussed therein, we have now focused on the essential first step in the classification proposal (i.e. identification of complexity), with analysis of streamflow data from a large network of 117 gaging stations in the western United States. We have also incorporated all the relevant review comments (both technical and presentation), including removing certain sections/significant portions of the text. Some of the comments by B. Selle are more relevant in the context of the overall proposal we presented earlier, including those associated with Step 2 and Step 3. We will investigate these aspects in great detail in the future, as we proceed with further implementation of our ideas. Here, we briefly respond to some of the comments.

Referee Comment – B. Selle (RC – C2189): The third step in their proposal, namely the verification of the framework, i.e. to relate different levels of complexity to catchment properties and processes, is probably a very important one. This step would also test the underlying assumption of this framework, i.e. complexity in observed catchment response is related to the number of contributing processes. It would be an innovative aspect of this paper that was not previously published. The third step in their proposal could readily be demonstrated by applying models of different complexity to e.g. the Mississippi and Kentucky river flow records presented in their paper. Adequate models will produce streamflow simulations that have a similar complexity as observed ones. Note that criteria such as Nash-Sutcliffe efficiency or Root mean square error may not be sufficient here.

Author Response: We completely agree with these suggestions. As may be appreciated, study of a large number of catchments/relevant time series would provide a better way to identify the system complexity and grouping and subsequently test different model complexities. With our new analysis of 117 streamflow time series, we have gained more confidence in interpreting the complexity and forming the groups. Therefore, we believe it would be more appropriate and helpful to incorporate the above suggestions on these 117 streamflow series. We will do this in our subsequent stages of the implementation of our proposal.

Referee Comment – B. Selle (RC – C2189): Study by Jakeman and Hornberger (1993)

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shows that for a range of scales and climatic conditions, a model with two storages in parallel representing a slow and a quick run-off component were sufficient to reproduce observed stream flow from rainfall. In the context of the proposed framework, it may therefore be expected that most of the catchments would fall into one single category of complexity.

Author Response: We thank B. Selle for appropriately mentioning the study by Jakeman and Hornberger (1993) regarding (streamflow) complexity and number of dominant processes. Although not cited in the current manuscript, the study by Jakeman and Hornberger (1993) is certainly relevant in the context of hydrologic model complexity, which we have pointed out in our earlier publications, including Sivakumar et al. (2007) and Sivakumar (2008a, 2008b). While it may be the situation in some cases that streamflow is influenced by only one dominant variable (e.g. at very fine temporal scales and for fully-developed urban catchments, streamflow is basically influenced by rainfall intensity), this may not always be the situation in every case. As the correlation dimension results for the 117 streamflow time series suggest, monthly streamflow dynamics in different catchments in the western United States are dominantly influenced by varying number of variables, ranging from very few to very large. The results also allow grouping of these catchments into four different categories of complexity (Low-dimensional, medium-dimensional, high-dimensional, and unidentifiable), instead of just one single category.

Referee Comment – B. Selle (RC – C2189): For the example presented (Figures 1 and 2), correlation dimension seems to be related to autoregression at short time scales. Phase space diagram reveals higher autocorrelation of streamflow for Mississippi than for Kentucky river at lag of one day. This, however, is also obvious from autocorrelation function. Consequently also correlation dimension is higher for Mississippi than for Kentucky river.

Author Response: In general, higher correlation between successive values in the time series means less complexity and thus a smaller correlation dimension value. This is why deterministic time series (i.e. highly correlated valeus) yield very low dimensionality, while stochastic time series (with very low correlation or none at all) yield very high (or infinite) dimensionality. The Mississippi River time series and Kentucky River time series are not part of the revised manuscript. However, in response to B. Selle, we would like to clarify that the correlation dimension value for the Mississippi River time series is lower (not higher) than that for the Kentucky River time series; the phase space results also support this, as the attractor for the Mississippi River is much more structured and well-defined in a very narrow region of the phase space when compared that for the Kentucky River (see Figure 2 of the earlier version). It must be noted, however, that the autocorrelation function is not always a reliable indicator of the correlation of the system dynamics, especially when nonlinearity is involved. A perfect example of this situation can be seen from the analysis of the low-dimensional chaotic Henon time series and high-dimensional stochastic time series. For both time series, the autocorrelation function suddenly falls to zero at a lag time of 1, wrongly indicating that both time series are stochastic in nature. This was clearly presented in Sivakumar et al. (2007), and also in the earlier version of this manuscript.

Referee Comment – B. Selle (RC – C2189): Complexity of observed discharge probably also depends on the temporal scale of observation. Hourly time series have different complexity compared to daily data. Different model purposes require different time scales.

Author Response: B. Selle is absolutely correct. We have discussed the role of temporal scale on system complexity in many of our earlier studies. For instancec, Sivakumar (2008a) discusses the important role of 'scale' in the fundamental definition of a 'system.' Sivakumar et al. (2007) discuss the change in the level of streamflow system complexity with change in temporal scale, based on analysis of streamflow at daily, 2-day, 4-day, and 8-day from the Mississippi River using correlation dimension method. Relevant details are also extensively discussed in Sivakumar (2001), Sivakumar et al. (2001, 2004), among others.

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