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Hydrology and Earth System Sciences 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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We thank the referee for his/her positive and constructive comments on our work as well as for his/her careful scrutiny of the presentation. We are pleased with the referee's positive evaluation of our work that it is scientifically plausible and worth-testing. Overall, we agree with the referee on his/her 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, as suggested particularly by this referee. Some of the comments by this referee 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 – Anonymous (RC – C2302): The manuscript could be improved by shortening the review material in sections 3-5, and showing phase space results in section 6 from enough river flow records to demonstrate that sites do cluster in a way that can be interpreted in terms of other hydrological knowledge.

Author Response: As we have discussed in our General Response, we have substantially modified Section 3 (Complexity and hydrologic systems) and Section 4 (Nonlinear dynamic concepts and relevance to hydrology). All of previous Section 3 (Sections 3.1 and 3.2) and Sub-section 4.1 have now been combined together and significantly shortened and presented as Section 3. For the benefit of the readers, it is important to review some basic information on complexity and nonlinearity in hydrologic systems, and this is what we have presented in the revised manuscript. Also, Sub-section 4.2 has now been revised (and condensed) and presented as Section 4, focusing on Correlation dimension method (with Phase space reconstruction described as an initial step of the correlation dimension method).

The previous Section 5 (Identification of complexity of hydrologic time series) has now been completely removed. Consequently, previous Table 1 and Figures 1 and 2 have also been removed. The new Section 5 (Data, analysis, and results), presenting the analysis of the streamflow time series from 117 stations in the western United States,

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has now been added. The section includes: Sub-section 5.1 (Data), 5.2 (Analysis and results), and 5.3 (Discussion). Also added are: new Table 1 (streamflow stations/data statistics/results) and new Figure 1(a) to 1(h) (Phase space diagrams) and new Figure 2(a) to (h) (Correlation dimension – Local slopes) – results for two sample time series from each of the four streamflow groups identified.

Referee Comment – Anonymous (RC – C2302): Section 2 reviews some previous approaches to catchment classification. I would contest the author's claim that "these studies and their different forms do not adequately account for some inherent properties of hydrologic systems and processes (e.g. nonlinearity and chaos) and, thus, are largely insufficient for a generic classification framework." While it may be true that catchments do possess nonlinearity and chaos, it has not been demonstrated that these features are a necessary part of a coherent, workable classification system. However, I do agree with the author's immediately following sentence: "At the least, a coherent effort to bring these disparate forms together for a workable classification framework is missing."

Author Response: We agree. We have re-worded this part as follows: "Although useful in their own ways, these studies are largely inadequate for a generic classification framework. In addition to limitations that exist in each of the different forms, a coherent effort to bring these disparate forms together for a workable classification framework is also missing."

Referee Comment – Anonymous (RC – C2302): Sections 3-5: The majority of the content in the paper (Sections 3, 4, 5) is review of previous studies on complexity, nonlinearity and chaos. The author has previously published reviews on these topics (e.g. Sivakumar 2009), and I don't feel that this review adds significantly to those previously published.

Author Response: As mentioned earlier, we have significantly modified/condensed these sections.

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Referee Comment – Anonymous (RC – C2302): Section 6 contains some new material, but is currently too brief to stand alone, and its value to science remains untested. Ideas on new ways to classify catchments are a welcome development (though these ideas are closely related to those of Sivakumar, 2004 and Sivakumar, 2008), but I do not see that the brief proposal in Section 6 for a new method is sufficient for publication.

Author Response: As mentioned in our General Response and also above, we have now focused on implementing only the first essential step (Identification of complexity) through analysis of 117 streamflow time series in the western United States. Consequently, the previous Section 6 has now been removed. We will discuss the implementation the other aspects of our full proposal in future publications.

Referee Comment – Anonymous (RC – C2302): The idea of using phase space reconstruction and/or embedding dimension as a means of classifying catchments remains untested because it has been applied to too small a sample of catchments. In my opinion, what has been shown so far is that four daily river flow records (Mississippi, Kentucky, Chao Phraya and Stillaguamish – see Sivakumar et al 2007) produce four relatively distinct phase space diagrams, two of which are reproduced in this paper. What is required is that the phase space reconstructions (or embedding dimensions) will provide useful clustering and separation of catchments. No information has yet been presented showing that clustering occurs, nor that the clustering groups are hydrologically meaningful or useful (that is, members of a cluster have some commonality of hydrological processes). My preference for the clusters to have an interpretation in terms of hydrological processes is perhaps a matter of opinion, but if no meaning can be assigned to the clusters, then it is unclear to me what is the purpose of the classification.

Author Response: We agree with the referee. We have now applied the correlation dimension method on a very large number of streamflow time series (117). The reconstruction of phase space is a first step in the correlation dimension method, and we have also presented the phase space diagrams. Based on careful exami-

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nation of phase space diagrams and correlation dimension results, we have identified four reasonably distinct groups: low-dimensional (L), medium-dimensional (M), high-dimensional (H), and unidentifiable (U). What these clusters (of phase space diagrams and correlation dimensions) represent in terms of hydrologic processes remains to be seen. This is indeed the second step of our proposal, where we will investigate the relations between the phase diagrams/dimensions and catchment physical/process properties. However, the dimensionality is a representation of the number of dominant variables influencing the dynamics, and our aim will be to connect the dimensionality to identifying the actual physical/process properties dominantly govering the dynamics.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 4427, 2011.