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Discussions

Interactive comment on "A new fractal-theory-based criterion for hydrological model calibration" *by* Zhixu Bai et al.

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Dear Editors and Reviewers:

Thanks for your kind comments about our manuscript. Your comments are not only helpful but also inspiring. The comments provide new perspectives to understand the application of fractal theory in hydrological modeling. We have studied the reviewers' comments carefully and made responses in the following texts. We are looking forward for further advice from you.

Kind regards, Zhixu Bai, Yao Wu, Di Ma, Zixia Wang

Responses to the reviewers' comments:

Reviewer 2#:

Specific comments

1. L20-39: The introduction starts with a paragraph about fractality without describing the (hydrological) context. Fractality is used as an additional criterion for model calibration in this paper to obtain calibrated models which perform well for better reasons than when only using traditional criteria based on for instance squared residuals. Hence, a fractality-based criterion is introduced and evaluated as a tool for a more robust model calibration. Therefore, it would be more logical to start the introduction with a description of the pros and cons of existing calibration criteria followed by the introduction of fractal theory as an additional evaluation framework for hydrological models. The last two sentences of sub-section 2.3 (L157-159) typically form (part of) the research gap and are a natural link to the research objective.

Response:

Thanks for reviewer's kind comment. We will change the sequences of our introduction as suggested in our final manuscript.

2. L23: Terms like 'self-affinity', 'periodicity', 'long-term memory' and 'irregularity' are listed without any explanation. In different contexts these terms might have different meanings. What is the meaning of these terms in this study and which of these terms are quantified by/ included in the ratio of fractal dimensions introduced in this paper?

Response:

Thanks for your kind comment. We are glad to add the explanations about "self-affinity", "periodicity", "long-term memory" and "irregularity" following the revised manuscript: "The self-affinity of time series is the similarity of fine-resolution small parts and coarse-resolution large parts of data. Hausdorff dimension is defined and calculated based on the self-affinity of data series."

"The periodicity and long-term memory of time series referred by its fractality are highly related. Long-term memory is the feature that the effect of an event in a series may persist for a relatively long time. Long-term memory of hydrological time series is usually studied with rescaled range analysis (Hurst, 1951)."

"The irregularity of a fractal series refers to the unpredictable changes in a time series, which is a feature of chaos system."

3. L82: The structure of sections 2 and 3 can be improved. Part of the discussion of the traditional criteria and their cons (and pros) and the fractal dimensions and related indices (sub-sections 2.1 and 2.2) can be included in the introduction (section 1). The description of the fractality-based criterion used in this study (sub-section 2.3) and the calibration strategy (sub-section 2.4) can be merged with section 3. As a consequence, section 2 will disappear.

Response:

Thanks for your kind comment. We have rearranged our manuscript as the reviewer suggested.

4. L190-206: The authors use data from three catchments with different sizes and different data periods (and lengths of time series). In particular, the data period for the Dong catchment is short (4 years) compared to the other two catchments. What is the influence of these differences in data periods on the results? Does it explain the relatively poor performance of the HBV model for the Dong catchment compared to the other two catchments, particularly for fast and slow flow? Did the authors test their framework with equal data periods for the three catchments (i.e. for Jinhua and Xiang also 4-year time series)? This would be a useful test to isolate the influence of difference lengths of data periods.

Response:

Thanks for your kind comment and advice. We made a comparison of the modeling performance based on 4-year time series, and the results are shown below.

Fig. R2-4 Comparison of the E-RD strategy with 4-year data and whole period in Xiang case.

Fig. R2-4 will not be put in the manuscript. According to Fig. R2-4, the E-RD strategy would not change its behavior with the lengths of data in our study. The relevant description will be:

"To get rid of the possible influence of the lengths of time series, a comparison of the multi-objective calibration with the same length of data is made. The results show that, at least in the cases of this study, the E-RD strategy would not change its behavior with the lengths of data."

We agree that the length of data may limit the performance of HBV in Dong case, but as we showed in manuscript, the E of Dong case is about 0.7, which is good enough for an integrated model.

5. L211-247: The description of the HBV model is somewhat messy and not complete. For instance, actual evapotranspiration is not described, the order of the fluxes is not logical and the description of the parameters is not consistent with the literature. Since this model has been very frequently used and described in the literature, the authors are advised to reduce the description to a small general paragraph and refer for more details to the literature.

Response:

Thanks for your kind comment and advice. Following the reviewer's advice, we have modified the description of HBV model as follows: "The HBV model is a conceptual rainfall-runoff model originally developed by Swedish Meteorological and Hydrological Institute (SMHI) (Bergström, 1976; Bergström, 1992; Lindström et al., 1997). The model has been successfully used in many cases (Seibert and Vis, 2012; Tian et al., 2015; Tian et al., 2016). The HBV model is composed of precipitation and snow accumulation routines, a soil moisture routine, a quick runoff routine, a baseflow routine and a transform function. The HBV model takes into account the effect of snow melting and accumulation, which is significant in the Dong catchment. The actual evapotranspiration is calculated with a linear function. Two conceptual runoff reservoirs, the upper reservoir and the lower reservoir are included in HBV model."

6. L257-263: Although the authors mention that most settings of the calibration algorithm are default ones, it is not completely clear what the meaning of these numbers is and why mostly default settings have been used. Moreover, which 14 HBV parameters need to be calibrated? This is a large number of parameters making the calibration cumbersome. Why not firstly carrying out a sensitivity analysis to select the most dominant parameters?

Response:

Thanks for the reviewer's kind comment. The settings are determined to make sure the calibration can find the Pareto's optimal. And the default settings, as shown by the results, successfully helped us achieve our goals. We would add the reference of the meaning of the parameters in the revised manuscript:

"The meanings of settings can be found in Deb (2001)."

The 14 calibrated parameters of HBV model will be listed and added to Section 3.2. We didn't select the most dominant parameters for calibration for two reasons: 1. Three catchments used in our study are located in different climatic regions and thus have different dominant processes and corresponding dominant parameters. It is not convenient for parameter comparison if different parameters are used in model calibration 2. As an integrated conceptual model, HBV has the advantage of time saving. For example, in the Xiang case, it costs 2160 seconds to run 106 generations (63600 individuals). It's a durable time cost for the calibration of hydrological models.

7. L268: Although the authors compared different observed and simulated signatures (and separated flow components, see next comment), a validation in time and/ or space

has not been carried out. It would be very interesting to see how well the HBV model performs for another time period in the three catchments. This would enable a more independent and robust evaluation of the E-RD strategy proposed by the authors.

Response:

Thanks for the reviewer's kind comment. Since we have used all data of these three catchments in our study, it's hard to make a validation of time with another time period. One reason is that there is only 4 years' data in the Dong catchment. However, we believe the comparison made with different periods (with the length of 4 years) could help doing this.

The comparison lays in the response to comment 4#.

8. L283-285: The authors compare observed and simulated fast flow and baseflow. Observed components have been obtained using the WETSPRO tool. However, it is unclear how well the division into streamflow components is done by this tool (also mentioned by the authors in sub-section 4.3). It might well be that observed and simulated components describe a (totally) different flow mechanism. For the Dong catchment, this results in a poor performance for streamflow components and for the other two catchments in a good performance. What is the principle used by WETSPRO to separate flow components and to what extent is that principle related to the concepts of the HBV model? This needs more discussion by the authors.

Response:

Thanks for the reviewer's kind comment. We believe that the poor performance for streamflow components for the Dong catchment is determined by the moderate performance for total streamflow for the Dong catchment. However, the metrics (E and r^2) of fast and slow flow show evident improved trends when RD increases.

The WETSPRO could separate the streamflow into fast flow and slow flow first, and then separate the fast flow into overland flow and interflow. In our study, only the first step is applied and only the first-step-related parameters of WETSPRO are listed in the table below. We selected the parameters by following the procedure. In WETSPRO's procedure, the parameters are selected one by one. For each parameter/step, there is a corresponding criterion. Thus, the separated streamflow components are relatively comparatively objective. Fig. R1-5 is an example of the objective procedure of selection. In this step, the user selects the w-parameter filter, which represents the case-specific average fraction of the quick flow volumes over the total flow volumes. According to the literature, the filtered baseflow should be close to the total streamflow in dry periods (Willems, 2009). The selection can be considered relatively objective.

Fig. R2-8 An example of the objective procedure of selection. The methodology uses multiple and non-commensurable measures of information derived from the river flow series by means of a number of sequential time series processing tasks. It's derived from the recursive digital filter(Willems, 2009). To briefly introduce the characteristics of WETSPRO to our readers, we would add the following description in Section 3.4:

"WETSPRO separates fast flow and slow flow on the basis of filter theory, using several filter parameters including recession constant, average fraction of fast flow volumes over the total flow volumes, etc." We applied the WETSPRO tool to observed and simulated streamflow series. In this way, the standard of separating streamflow into components could be the same for observation and simulation. We added the following sentence to explain this in sub-section 4.3:

"The simulated total flow is also separated with the WETSPRO tool to make the principle of separation of simulation and observation same."

9. L358: Section 4.2: the selection of parameters for further analysis is not completely clear and straightforward. The authors mention a threshold for the distance correlation (is this a correlation value of a squared correlation value), but they do not consequently apply this threshold. Furthermore, the (unexpected) high correlation between RD and the degree-day factor for the (mainly) rainfed Xiang catchment needs more discussion.

Response:

Thanks for the reviewer's kind comment.

We decided to replace the sentence "The parameters with r_dˆ2<0.8 in all cases are not listed in Table 3." with "distance correlation (r_dˆ2) is used to illustrate the non-linear relationship between E and RD in the Pareto's optimal."

We will add the description of distance correlation in Section 3.4 as follows:

"The distance correlation, as a multivariate measure of dependence, calculates the correlation of distances between points to means. The distance correlation is believed to have better performance when solving problems with non-linear data or extreme values (Székely, Rizzo and Bakirov, 2007)."

We would add the discussion about the high correlation between RD and the degree-day factor for the (mainly) rainfed Xiang catchment as following:

"By checking the temperature series in the Xiang catchment, we find there are 61 days (out of 27 years) when the average temperature is below 0°C. Actually, since the Xiang catchment is large, there are snow events somewhere in the catchment almost every year. The low temperature may be covered by the averaging, but the E-RD strategy captured it and illustrate this by noticeable value of degree-day factor."

10. L413-416: Would it be possible to relate the different parameter values for different catchments to differences in characteristics of these catchments (e.g. slope, soil types, size)? See also e.g. lines 451-454.

Response:

Thanks for the reviewer's kind comment. We used to focus on the differences between different parameter sets of each catchment. We would add the discussion about the different values of the same parameters in different catchments as follows: "The KS of best-E in the three cases follows the sequence of catchment area. This agrees with the regular pattern that the concentration time of slow flow is highly related with the area of catchment." (Section 4.2) "The percolation in Dong case is larger than the others, which is the reflection of Dong catchment's arid climate. The percolation in Jinhua case is larger than the percolation in Xiang case, because the slope in Jinhua catchment is larger." (Section 4.2)

Technical corrections:

Response:

Thanks for the reviewer's careful work. We will correct as suggested in our final manuscript.

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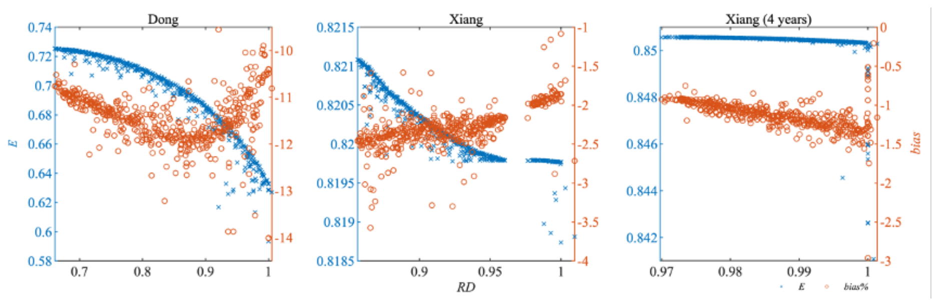
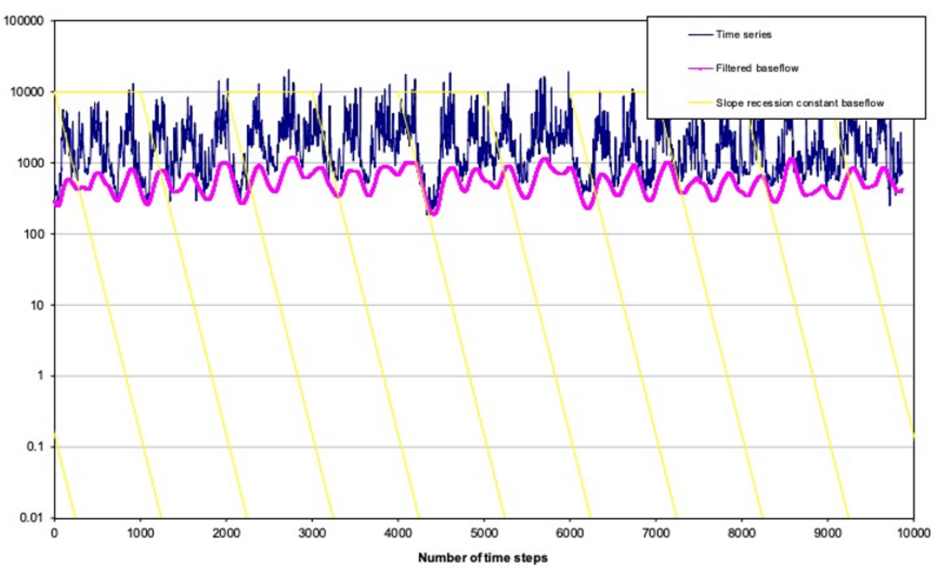


Fig. 1. Fig. R2-4



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10000
1000
100
10
1
0.1
0.01
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Number of time steps
Time series
Filtered baseflow
Slope recession constant baseflow

Fig. 2. Fig. R2-8