Interactive comment on “Improvement of hydrological model calibration by selecting multiple parameter ranges” by Qiaofeng Wu et al.

Yi Cai et al.

caiyi@tongji.edu.cn

Received and published: 28 August 2016

General comment:

We appreciate the comments from the reviewer and truly believe these comments can help us to improve our manuscript. We consider the corresponding changes can be included in the revised document to achieve publication status. We provide responses to the main and specific comments in sequential order as follows:

Responses to Referee #2

Main comment #1

"My main concern is related to the real impact of the proposed methodology. The benefit in terms of NSE is very small: see Fig. 9. Is this improvement relevant for hydrological application? If we focus exclusively on model performances I do not think this methodology shows a significant improvement. I suggest to emphasize more the physical considerations that may rise from the application, for example in terms of sensitivity of specific parameters in relation to the particular nature of the study area, or regarding the evaluation of parameters correlation. From my point of view this methodology may provide additional insights regarding the interactions among model parameters under different hydrological conditions. In other words: since the improvement in terms of NSE seems to be not relevant, what are the added values of this methodology compare to existing ones?"

Responses to main comment #1:

Notwithstanding a small increase in maximum E_{NS}, there is a significant improvement in minimum E_{NS} by using the proposed method. Comparing case 6 (using the optimal combination of ranges) with case 1 (using the initial ranges) in Fig. 9, we find that the maximum E_{NS} increases by 0.001 while the minimum E_{NS} (except outliers) increases by 0.01. The rising minimum E_{NS} with the fixed maximum contributes to the shrinkage of the range of the possible solutions. As a result, the uncertainty of the model performance can be effectively controlled. Moreover, the methodology can be used to analyze the parameter correlation and sensitivity by computing two indexes $R_{\mathrm{C\,Y,X}}$ and S_E. The paper presents the preliminary study of the proposed methodology. In the preliminary study, we adopt a Xinanjiang model with several parameters to evaluate the calibration efficiency of the methodology. Since the parameter Im having negative effect on other parameters is a little bit insensitive in a Xinanjiang model, a modest improvement in calibration efficiency is found after the application of the methodology.

In future, we will consider using other complicated hydrologic models with more parameters to further study the application of the methodology.

Main comment #2

"Continuing on the effectiveness of the methodology, the Author do not provide any information regarding the initial GA calibration. Are there benefits from the application of the methodology in terms of NSE values? What are the computational/time efforts required for the implementation of the calibration framework compared to other techniques?"

Responses to main comment #2:

Since the GA method is very common tool for parameter calibration of hydrologic models, we provide a little information about GA calibration. In the study, we carried out trial tests to determine the optimal combination of control parameters: crossover probability of 0.5, mutation probability of 0.7 for the individual, mutation probability of 0.5 for each gene, population size of 21, maximum generation number of 500 and maximum iteration number of 50. These parameters were kept constant for GA calibration in the investigation. The application of the proposed methodology results in an increase of 0.01 in minimum E_{NS}, compared with that of the pure GA method. The rising of minimum E_{NS} with little change of the maximum may shrink the range of the possible solutions. As a result, the uncertainty of the model performance can be effectively controlled.

Through a run of calibration framework, a combination of values of all parameters and the corresponding E_{NS} are obtained. Figure A shows the variation curves of maximum and minimum values of E_{NS} with number of runs by using a GA method and a proposed PRS method, respectively. It is indicated from Figure A that no mater it is maximum or minimum E_{NS}, the value calculated with a proposed method is almost the same as that with a GA method when the number of runs is less than 100. If a proposed method is used for calibration instead of a GA method, there are approximately an increase of 0.001 in maximum E_{NS} and an increase of 0.01 in minimum E_{NS} when the number of runs is greater than 100. Thus, for any particular run number, the value of E_{NS} calculated with a PRS method is not less than that with a GA method. The application of a proposed method, therefore, contributes to a more efficient calibration than that of a GA method does.

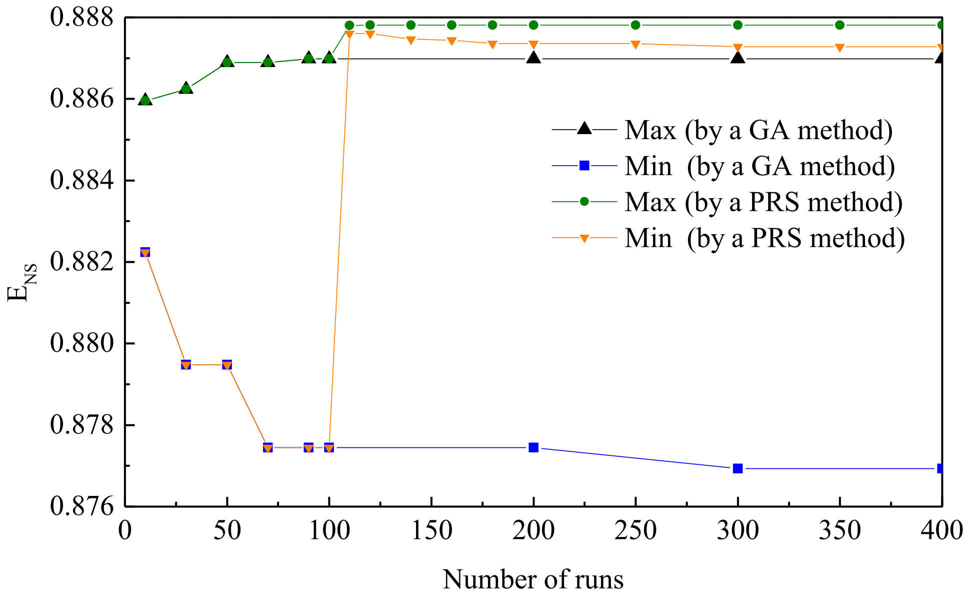

Figure A. the variation curves of maximum and minimum E_{NS} with number of runs by using a GA method and a proposed PRS method

Main comment #3

"Is there a specific reason for considering the MAXR range interval in addition to MINR (see Figure 3). Why a modeler should consider the range of minimum probability density of the parameter values? If it is not necessary I suggest to consider its removal from the analysis."

Responses to main comment #3:

In order to figure out how the selections of two typical ranges, MINR and MAXR, affect respectively the calibration efficiency under different distribution types, we considered the MAXR range internal in Figure 3. From the results shown in Figures 6-7 (referring to parameter CI of a normal distribution and parameter KI of an exponential distribution), it is indicated that MINR is better than MAXR for improving calibration whichever distribution is specified. We removed, therefore, the MAXR range interval from the later analysis presented in Figure 8. As it is one of the main results of the study that MINR is better than MAXR for improving calibration, we would like to keep the MAXR range interval in Figures 3/6/7.

Main comment #4

"At P7, line 25. Why this is obvious? Looking at Fig. 5 this is not. Do the Authors apply statistical tests to evaluate the statistical distribution of the parameters?"

Responses to main comment #4:

There are three types of distribution discussed in the investigation. In order to distinguish them, a simple method in section 3.2.2 was used based on shapes of the cumulative frequency curve and the histogram as well as the sizes of whiskers and box in the box-plot. Despite simplicity, it is subjective and unintelligible to readerships. For avoiding the confusion as described in this comment, a Kolmogorov-Smirnov (K-S) test will be employed to objectively identify each distribution type in the revised paper. Indeed, we carried out K-S tests to evaluate statistical distributions of all parameters in the hydrologic model. The results of K-S tests for parameters CI, Kc, and SM are listed in the following Table A. It is shown that both exponential and uniform distributions are rejected for the three parameters while normal distribution is not. It implies that the three parameters follow normal distributions. Therefore, the simple method used earlier does not change the results of the study, although it is subjective.

Table A. The results of K-S tests for parameters CI, Kc, and SM

	CI			Kc			SM		
	Normal	Exponential（2P）	Uniform	Normal	Exponential（2P）	Uniform	Normal	Exponential（2P）	Uniform
Statistic	0.0623	0.32805	0.1151	0.09199	0.37961	0.10694	0.05983	0.30392	0.10982
P-Value	0.80925	5.40E-10	0.1306	0.34466	3.08E-13	0.18882	0.84521	1.23E-08	0.16628
α	0.2	0.01	0.2	0.2	0.01	0.2	0.2	0.01	0.2
Reject?	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes

Main comment #5

"Concerning the 7 scenarios reported in table 5, how have you defined them? Are there specific reasons behind the use of initial or optimal ranges for cases 5, 6 and 7? In addition, I suggest to keep the same column order for parameters, it’s easier to read table 5 in relation to the values of table 4."

Responses to main comment #5:

Case 1 was defined as the initial case using all initial ranges. Cases 2-4 were defined as the single parameter range selection (S-SPR) cases. Cases 5-7 were defined as the multiple parameters ranges selections (M-SPR) cases.

The seven cases were set to demonstrate three primary results. Firstly, the M-SPR method is superior to the S-SPR one for calibrating hydrologic models with multiple parameters. It can be deduced from higher E_{NS} values of Cases 5-7 than those of Cases 1-4. Secondly, merely using the optimal range of the parameter of relatively higher sensitivity contributes to more efficient calibration when the two parameters have negative effect on each other. It can be concluded by comparing the E_{NS} values of Cases 2-4 referring to the two parameters EX and Im. Thirdly, the combination of optimal ranges of all parameters is not the optimum inasmuch as some parameters like Im have negative effects on other parameters. It can be inferred through analyzing the E_{NS} values of Cases 5-7. The analysis of sensitivity and correlation between parameters is, therefore, very important to determine the optimum ranges combination of all parameters for model calibration.

As for the column order of tables, we will modify Table 2, 5 so that the parameters are ordered in the same way as they do in Table 4.

Main comment #6

"The writing in some part of the manuscript should be improved. I suggest to carefully go through the overall manuscript and check verbs and syntax (here some example: P5, L3; P5, L23; P6, L5, P9, L25-26; ...; P10, L17)."

Responses to main comment #6:

We will revise the manuscript as the suggestion:
Page 5, line 3: "which representing agreement between observed and simulated data" >> "which represents the agreement between observed and simulated data"
Page 5, line 23: "…, the initial range of parameter is required adjusting properly" >> "…, the initial range of parameter requires adjusting properly"
Page 6, line 5: "... values can transform and finally convert into..." >> "... values can be converted into..."
Page 9, line25-26: "...when Case 4 compared with Case 1, Case 2 and Case 3 It can be explained..." >> "... when Case 4 is compared with Case 1, Case 2 and Case 3. It can be explained..."
Page 10, line 17: "to adopted" >> "to be adopted"

Moreover, we will continue to make the language of the manuscript better. For example:
Page 1, line 3: "Qiaofeng." >> "Qiaofeng"
Page 1, line 14: "characteristics of single parameter value was analysed" >> "of single parameter value was analysed"
Page 1, line 17: "corresponding to the distribution" >> "corresponding to the distribution type"
Page 2, line 4: "mechanism of water cycle" >> "mechanism of the water cycle"
Page 2, line 9: "the streamflow at catchment outlet" >> "the streamflow at the catchment outlet"
Page 3, line 23-24: "single parameter is selected" >> "single parameter was selected"
Page 3, line 30: "in flood reason" >> "in flood season"
Page 4, line 18: "from observed streamflow" >> "from the observed streamflow"
Page 5, line 11: "whisker to the box" >> "the whisker to the box"
Page 5, line 28: "represents the ranges" >> "represent the ranges"
Page 6, line 4: "in case of larger percentage" >> "in case of a larger percentage"
Page 6, line 11: "may more and less effect" >> "may affect"
Page 6, line 13: "contributes" >> "contribute"
Page 6, line 15: "The index Rc were quantified" >> "The index Rc was quantified"
Page 6, line 17: "the greater positive influence" >> "greater positive influence"
Page 7, line 2: "The statistic analysis" >> "The statistical analysis"
Page 7, line 6: "ranges is substituted" >> "ranges are substituted"
Page 7, line 8: "the selected one is adopted for calibration of multiple parameters." >> "the selected ones are adopted for multi-parameters model calibration."
Page 7, line 16: "In stage 3 the ... " >> "In stage 3, the ..."
Page 7, line 26: "direction of Y axis" >> "direction of the Y axis"
Page 7, line 30-31: "The ratio of calibrated parameter range to initial one is less than 30% for parameters CI, SM, and Kc" >> "The ratios of the calibrated parameter range

to the initial one are less than 30% of parameters CI, SM, and Kc"
Page 7, line 31: "It suggest that" >> "It suggests that"
Page 8, line 6: "To normal distribution" >> "For normal distribution"
Page 8, line 7: "different parameter range are selected" >> "different parameter ranges are selected"
Page 8, line 13: "concentrates at larger value zone" >> "concentrates at a higher value range"
Page 8, lien 24: "Because the parameter values in MINR indicate a high probability to be picked out to achieve high E_{NS}, vice versa." >> "It is because that the parameter values that may achieve a higher E_{NS} can be easily picked out from the MINR of higher probability density."
Page 8, line 33: "box-plot chart of E_{NS} for different ranges are shown in Fig. 8e" >> "box-plots for different ranges are shown in Fig. 8e"
Page 9, line 6: "value in columns" >> "values in columns".
Page 9, line 15: "… and CG are of high sensitive to E_{NS}" >> "... and CG are highly sensitive to E_{NS}"
Page 9, line 20: "penetrate" >> "penetrability"
Page 9, line 23: "there is contradiction owing to it" >> "there is a contradiction owing to it"
Page 9, line 25: "pf" >> "of"
Page 10, line 13: "the extension range followed by" >> "the extended range followed by"

Specific comment #1

"Abstract: in the last part of the abstract, roughly from line 20 on, the Authors report some specific methodological considerations that may not be really clear to one who has not already read the paper. I suggest to focus more on the scope and aims of the analysis, reporting also that the methodology proposes indexes for the evaluation of parameter sensitivity and correlations, as well as a summary of the main outcomes."

Responses to specific comment #1:

According to the comments of the referee, we will rewrite the abstract as follows:
The parameters are usually calibrated to achieve good performance of hydrological models, owing to the highly non-linear problem of hydrology process modelling. However, parameter calibration efficiency has a direct relation with parameter range. Furthermore, parameter range selection is affected by probability distribution of parameter values, parameter sensitivity and correlation. A newly proposed method is employed to determine the optimal combination of multi-parameter ranges for improving the calibration of hydrological models. At first, single-parameter probability distributions were analyzed based on 100 samples obtained from independent Genetic Algorithms (GA) calibration performed on a Xinganjiang model with a corresponding initial parameter range and, the distribution type (i.e. normal, exponential and uniform distributions) was specified for each parameter of the model. Then, the optimal range for each parameter was determined by comparing E_{NS} values calculated separately with the initial range, the minimum and maximum ranges of a given cumulative frequency

of 50% (i.e. MINR and MAXR) and the extended range. Next, parameter correlation and sensibility were evaluated by quantifying two indexes $R_{\mathrm{C\,Y,X}}$ and S_E which can be used to coordinate with the negatively correlated parameters to specify the optimal combination of ranges of all parameters for calibrating models. It is shown from the investigation that the probability distribution of calibrated values of any particular parameter in a Xinanjiang model is closely approximated by a normal or exponential distribution. The multi-parameter optimal range selection method is superior to the single-parameter one for calibrating hydrologic models with multiple parameters. The combination of optimal ranges of all parameters is not the optimum inasmuch as some parameters like Im have negative effects on other parameters. The application of the proposed methodology gives a rise to an increase of 0.01 in minimum E_{NS} compared with that of the pure GA method. The rising of minimum E_{NS} with little change of the maximum may shrink the range of the possible solutions, which can effectively reduce uncertainty of the model performance.

Specific comment #2

"P1, L29: is “method” appropriate to indicate hydrological process modelling? I would suggest something like “tools” or similar."

Responses to specific comment #2:

We will replace “method” with “tool” in the first sentence of “Introduction”.

Specific comment #3

"P4, L28: On which base you say that 100 samples are enough? Have you adopted some statistical texts to verify the statistical distribution of the considered parameters."

Responses to specific comment #3:

Before defining sampling size value, we performed a lot of trial tests. Figure B shows the variation curves of maximum and minimum E_{NS} with sample size. It is indicated that both maximum and minimum E_{NS} keep stable when sampling size is greater than 100. Avoiding the time-consuming computation, we assigned sampling size for the study as 100.

With regard to the statistical distribution of the parameters, we performed the K-S tests to define the distribution type for each parameter. The results of some K-S tests are given in the response to main comment #4.

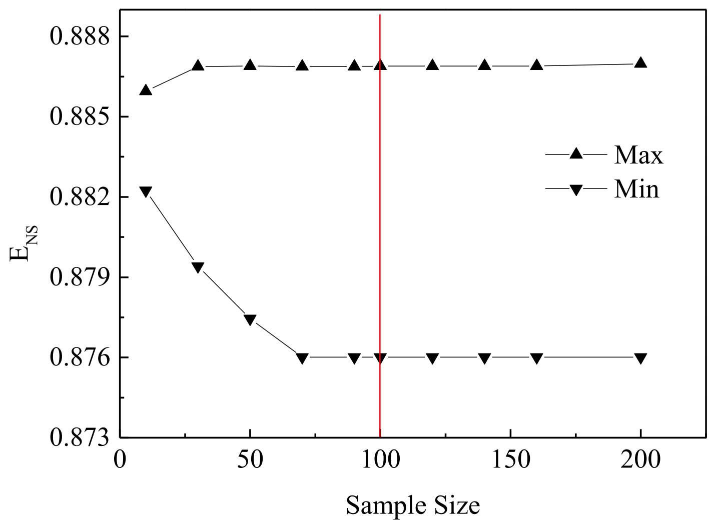

Figure B. Variation curves of maximum and minimum E_{NS} with sample size

Specific comment #4

"P4, L3: “A Genetic Algorithm (GA) was selected”"

Responses to specific comment #4:

Actually, the sentence mentioned above appears in P4, L30. We will modify it as it is suggested.

Specific comment #5

"P9, L6: why do you say that it is obvious?"

Responses to specific comment #5:

According to the values in Table 4, *R*C value in columns of parameters CI and WM are positive, most *R*C values in column of parameter Im are negative. In order to make it easy to read, we will change it to “It is obvious from Table 4 that […]”.

Specific comment #6

"P10, L7: please remove the colon;"

Responses to specific comment #6:

We will remove the colon in Line 7 of Page 10.

Specific comment #7

"Fig. 2: check “curve”; I also suggest to re-word the caption as: [...]; Cumulative frequency and [...] distribution for normal (b), exponential (c) and uniform (d) distributions."

Responses to specific comment #7:

We will replace "cure" with "curve" in the caption of Figure 2. In addition, we will modify the caption of Figure 2 as suggested: “…; Cumulative frequency curve and histogram for normal (b), exponential (c) and uniform (d) distributions”.

Specific comment #8

"Fig. 6, 7 and 8: is it necessary to report the label "schema"?"

Responses to specific comment #8:

We will remove the label "schema" in Figs. 6a, 6b, 6c, 7a, 7b, 7c, 8a, 8b, 8c and 8d.

Specific comment #9

"Table 1: is P the average or the max?"

Responses to specific comment #9:

We will modify the note on Table 1 as follows: "Q_{Max}, Q_{Min} and Q_{Avg} mean the maximum, minimum and average value of daily streamflow, respectively, and P_{Max} means the maximum value of daily precipitation.". Meanwhile, we will modify the corresponding description in section 2 to avoid the misunderstanding.

Specific comment #10

"Table 2: the definition of parameter B seems not complete. Also, the column "range" of Table 2 is reported twice (see Table 3)."

Responses to specific comment #10:

We will complete the definition of parameter B in the modified Table 2 presented below. The column "range" of Table 2 will be changed as column "units" because the ranges of parameters are reported in Table 3.

Table 2. Parameters of Xinanjiang model

Parameter	Definition	Units
CI	Recession constants of the lower interflow storage	dimensionless
Kc	Ratio of potential evapotranspiration to pan evaporation	dimensionless
KI	Outflow coefficients of the free water storage to interflow	dimensionless
SM	Areal mean free water capacity of the surface soil layer, which represents the maximum possible deficit of free water storage	mm
B	Exponential parameter with a single parabolic curve, which represents the non-uniformity of the spatial	dimensionless
WM	Averaged soil moisture storage capacity of the whole layer	mm
C	Coefficient of the deep layer, that depends on the proportion of the basin area covered by vegetation with deep roots	dimensionless
EX	Exponent of the free water capacity curve influencing the development of the saturated area	dimensionless
CG	Recession constants of the groundwater storage relationships	dimensionless
KG*	Outflow coefficients of the free water storage to groundwater relationships	dimensionless
Im	Percentage of impervious and saturated areas in the catchment	dimensionless

* the value of KG is calculated by the function 0.7-KI

Specific comment #11

"Table 3: the main legend is not really clear, I suggest to re-word it. ** “ratio of calibrated parameter ...”"

Responses to specific comment #11:

The definition of “Ratio” in Table 3 will be modified as follows: “** the ratio is calculated by dividing the parameter range derived from 100 GA calibration by the initial parameter range”.