Dynamics of hydrological model parameters: mechanisms, problems, and solution

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Introduction

This supporting information includes five sections that support the analysis. The *1 HYMOD model* and *2 SCE-UA algorithm* sections are used to support the *3.1 calibration schemes* section in the main manuscript. The *3 Violin plot* section is used to support the *5.2.1 A tool for convergence evaluation of dynamized parameters* section in the main manuscript. The *4 evaluation results of model performance in Mumahe basin and Xunhe basin* section is used to account for *4 results* section in the main manuscript. The *5 Convergence performance in Mumahe basin and Xunhe basin* section is used to supplement *5.2.2 Convergence assessment* section in the main manuscript.

1 HYMOD model

The HYMOD model (Moore, 1985; Wagener et al., 2001; Vrugt et al., 2002; Yadav et al., 2007; De Vos et al., 2010; Pathiraja et al., 2018) consists of a simple rainfall excess model based on the probability-distributed moisture store which characterizes the catchment storage as a Pareto distribution of buckets of varying depth as the soil moisture accounting component. It routes through three parallel tanks for quick flow and a tank for slow flow and required five adjustable parameters: H_{UZ} , B , α , K_q and K_s . XH_{UZ} and XC_{UZ} are state variables characterizing the upper soil moisture content; AE is actual evapotranspiration which is calculated by linear correlations between the soil moisture state and the potential evapotranspiration; $effP$ is effective precipitation; OV is excess precipitation to routing module generated from overflow of soil moisture accounting component; See (Moore, 1985) for a detailed description of the soil moisture accounting model; X_{q1} , X_{q2} , X_{q3} and X_s are the state variables of the individual tanks of the routing module; Q_q and Q_s are the flow values generated from the quick- and slow-flow tanks, respectively.

2 SCE-UA

The shuffled complex evolution approach (SCE-UA), as an effective global optimization method, is a commonly used algorithm, because it is open source and was the first algorithm aimed specifically at calibrating hydrological models (Khakbaz and Kazeminezhad, 2012; Eckhardt and Arnold, 2001; Duan et al., 1994; Sorooshian et al., 1993). The technical details about the SCE-UA can be shown in the flowchart (see Figure S1) (Duan et al., 1994). In the SCE-UA, the upper limit of the objective function evaluation is set to 10,000 times. All other settings of the SCE-UA technique are the default.

Figure S1. The flowchart of the SCE-UA algorithm (Duan et al., 1994; 1993; 1992).

3 Violin plot

A violin plot is a combination of a Box Plot and a Density Plot showing more details of data distribution. As shown in Figure S2, the thick black bar in the center represents the interquartile range. The white dot represents the median. The thin black line is extended from the thick black bar and represents the 95% confidence intervals. On each side of the thin black line is a kernel density estimation to show the distribution shape of the data. Wider sections of the violin plot represent a higher probability that members of the population will take on the given value; the skinnier sections represent a lower probability (Hintze and Nelson, 1998). The violin plots can exactly show the kernel density distribution, avoiding the overlapping traditional density plot occur to become difficult to identify. Moreover, unlike bar graphs with means and error bars, violin plots contain all data points, which makes them an excellent tool to visualize samples of small sizes. Violin plots are perfectly appropriate even if your data do not conform to normal distribution. They work well to visualize both quantitative and qualitative data.

Figure S2. Anatomy of a violin plot

4 Evaluation results of model performance in Mumahe basin and Xunhe basin

Table S1. Evaluation results of model performance for scheme 1 and scheme 5 in the Mumahe basin. The best performance is marked red.

	NSE	LNSE	RMSE_Q5	RMSE_Q20	RMSE_mid	RMSE_Q70	RMSE_Q95
Calibration							
Scheme 1	0.691	0.445	0.953	0.357	0.118	0.554	0.909
Scheme 5	0.324	0.262	0.362	0.070	0.112	0.288	0.729
Verification							
Scheme 1	0.750	0.686	1.082	0.342	0.183	0.825	1.450
Scheme 5	0.345	0.325	0.338	0.056	0.165	0.524	0.717
Calibration-verification							
Scheme 1	0.059	0.241	0.129	-0.015	0.065	0.271	0.541
Scheme 5	0.021	0.062	-0.023	-0.013	0.053	0.236	-0.013

Table S2. The parameter sets of scheme 1 and scheme 5 in the Mumahe basin.

		H_{uz}	B	alpha	K_q	K_s
Scheme 1		916.692	1.990	0.048	1.000	0.079
Scheme 5	Dry period	999.540	1.990	0.051	0.501	0.038
	Rainfall period I	999.998	1.900	0.010	0.713	0.143
	Rainfall period II	27.799	1.990	0.010	0.801	0.237
	Rainfall period III	644.639	1.990	0.010	0.501	0.090

Table S3. Evaluation results of model performance for scheme 1 and scheme 5 in the Xunhe basin. The best performance is marked red.

	NSE	LNSE	RMSE_Q5	RMSE_Q20	RMSE_mid	RMSE_Q70	RMSE_Q95
Calibration							
Scheme 1	0.617	0.334	0.495	0.164	0.304	0.192	0.573
Scheme 5	0.252	0.183	0.165	0.153	0.157	0.166	0.724
Verification							
Scheme 1	0.683	0.478	0.616	0.271	0.322	0.091	0.674
Scheme 5	0.253	0.258	0.186	0.071	0.076	0.092	0.292
Calibration-verification							
Scheme 1	0.066	0.144	0.120	0.107	0.018	-0.100	0.101
Scheme 5	0.001	0.074	0.021	-0.055	-0.081	-0.074	-0.432

Table S4. The parameter sets of scheme 1 and scheme 5 in the Xunhe basin. The best performance is marked red.

		H_{uz}	B	alpha	K_q	K_s
Scheme 1		999.991	1.259	0.342	0.894	0.024
Scheme 5	Dry period	999.943	0.391	0.565	0.506	0.011
	Rainfall period I	988.154	1.602	0.031	1.000	0.112
	Rainfall period II	353.777	0.641	0.010	0.500	0.319
	Rainfall period III	456.369	0.418	0.104	1.000	0.121

Figure S3. Fluxes assessment. All fluxes (including AE , OV , Q_q , Q_s , and Q_{sim}) for five schemes in the whole calibration period in Hanzhong basin.

Figure S4. State variables assessment. All state variables (including XH_{UZ} , XC_{UZ} , X_{q1} , X_{q2} , X_{q3} , and X_s) for five schemes in the whole calibration period in Hanzhong basin.

Figure S5. Fluxes assessment. All fluxes (including AE , OV , Q_q , Q_s , and Q_{sim}) for five schemes in the calibration period in Hanzhong basin.

Figure S6. State variables assessment. All state variables (including XH_{UZ} , XC_{UZ} , X_{q1} , X_{q2} , X_{q3} , and X_s) for five schemes in the calibration period in Hanzhong basin.

Figure S7. Fluxes assessment. All fluxes (including AE , OV , Q_q , Q_s , and Q_{sim}) for five schemes in the whole verification period in Hanzhong basin.

Figure S8. State variables assessment. All state variables (including XH_{UZ} , XC_{UZ} , X_{q1} , X_{q2} , X_{q3} , and X_s) for five schemes in the whole verification period in Hanzhong basin.

5 Convergence assessment in Mumahe basin and Xunhe basin

Figure S9. Convergence assessment. Convergence performance for scheme 1 and scheme 5 in Mumahe basin.

Figure S10. Convergence assessment. Convergence performance for scheme 1 and scheme 5 in Xunhe basin.

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