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Committees Of Specialized Conceptual Hydrological Models: Comparative Study

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COMMITTEES OF SPECIALISED CONCEPTUAL HYDROLOGICAL MODELS: COMPARATIVE STUDY

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Single hydrological model or model calibrated on single objective function often cannot capture all components of a water motion process. One possibility is building several specialized models each of which responsible for a particular sub-process (e.g., high flows or low flows), and combining them using dynamic weights – thus forming a committee model. In this study, we test two different committee models: one uses fuzzy memberships function and another one - weights calculated from hydrological states. Specialized models are calibrated using Adaptive Cluster Covering Algorithm with different objective functions. The performances of the two different committee models are illustrated and compared.

Keywords: combination of models, fuzzy committee model, multi-models, specialized models.

INTRODUCTION

Committee modelling approach in hydrology combines different individual models specialized on distinctive hydrological regimes that are instantiated in same model structure are optimally combined. Reason of applying this approach is that a single hydrological model often cannot capture all facets of a complex process.. Single hydrological model could be either accurate for high flows or for low flows but not for both cases. Therefore instead of one, several sub models (specialized models) can be built representing sub-processes (high flows or low flows) separately and combining them using dynamic weights – thus forming a committee model. In this study, we compare two different types of committee models: (i) committee model based on fuzzy memberships function (Kayastha et *al*. [1], Fenicia et *al*. [2]) and (ii) committee model based on weights that calculated from hydrological states (Oudin *et al*. [3]). Before combining models the individual hydrological models are calibrated by Adaptive Cluster Covering Algorithm (ACCO, Solomatine [5]) for high and low flows using (different) suitable objective function. The relative performances of the two different committee models and their characteristics are illustrated using HBV hydrological models in Bagmati catchment in Nepal and Leaf catchment in USA

Fuzzy committee models

A fuzzy committee model is an integration of the specialized models to provide more comprehensive and accurate model predictions. The specialized models are built under conditions of different regimes of catchment hydrological responses and combining them using fuzzy combining scheme.

The fuzzy membership function is use to handle the compatibility at the boundaries between the two different specialized models. The contribution of each specialized model is based on using a fuzzy membership function – the so-called “fuzzy committee” (Solomatine [4]). The details of approach can be found in Fenicia *et al*. [2] and complemented by the possibilities of its further improvement in Kayastha *et al*. [1]. The committee model is defined as follows.

$$Q_{fcm,i} = (m_{LF} \cdot Q_{LF,i} + m_{HF} \cdot Q_{HF,i})/(m_{LF} + m_{HF}) \tag{1}$$

$$m_{LF} = \begin{cases} 1, & if \quad h < \gamma \\ 1-(h-\gamma)/(\delta-\gamma), & if\ \gamma \le h < \delta \\ 0, & if \quad h \ge \delta \end{cases} \tag{2}$$

$$m_{HF} = \begin{cases} 0, & if \quad h < \gamma \\ (h-\gamma)/(\delta-\gamma), & if\ \gamma \le h < \delta \\ 1, & if \quad h \ge \delta \end{cases} \tag{3}$$

where m_{LF} and m_{HF} are membership functions for the two individual models, $Q_{LF,i}$ *and* $Q_{HF,i}$ are simulated high and low flows for the time step *i*; γ and δ: threshold for high and for low flows respectively.

First two optimal specialized models that one for the low-flow ($Q_{HF,i}$) and one for the high-flow ($Q_{HF,i}$) are sought using optimization algorithm (ACCO) and then two membership function parameters δ and γ are introduced to control the transition between the specialized models. The committee model output Q_{fcm} is calculated by combination sets of δ and γ which are selected within given intervals and the performance measure is calculated by *RMSE* and *NSE*.

The two models $Q_{LF,i}$ *and* $Q_{HF,i}$ are calibrated individually using weighted objective functions, where one is stressing the model error with respect to low flow simulation, and the other stressing the model error with respect to high flows.

The two objective functions are defined as follows.

$$RMSE_{LF} = \sqrt{\frac{1}{n}\left(\sum_{i=1}^{n}(Q_{s,i} - Q_{o,i})^2 \cdot W_{LF,i}\right)}, \tag{4}$$

$$RMSE_{HF} = \sqrt{\frac{1}{n}\left(\sum_{i=1}^{n}(Q_{s,i} - Q_{o,i})^2 \cdot W_{HF,i}\right)}, \tag{5}$$

$$W_{LF} = \frac{Q_{o,\max} - Q_{o,i}}{Q_{o,\max}} \qquad W_{HF} = \frac{Q_{o,i}}{Q_{o,\max}} \tag{6}$$

where *n* is total number of time steps, $Q_{s,i}$ is simulated flow for the time step *i*, $Q_{o,i}$ is observed flow for the time step *i*. The two weighting functions W_{LF} and W_{HF} allow for placing the stronger weight on the low or on the high portions of the hydrograph. As a result, $RMSE_{LF}$ places stronger weight on low flows errors and weaker weight on high flows.

State-based committee models

State-based committee models are composed by two individual models that calibrated on single objective functions under the conditions of high-low and low-flow regimes and combined individual models using weights which are based on internal model variables. Oudin et al. [3] proposed the various dynamic weights to combine two models. One of the dynamic weights is computed from rate of the soil moisture accounting (SMA) store of the rainfall runoff models. These weights represent the average of the water content (between 0 and 1) of the two SMA stores from the models calibrated on objective function *RMSE* and objective function $RMSE_{ln}$. When the moisture rate is close to 1, the combined streamflow tends to be equal to the streamflow obtained with the objective function *RMSE* and when the moisture rate is close to 0, the combined streamflow tends to be equal to the streamflow obtained with the objective function $RMSE_{ln}$. In addition, the cubic function is used in shape of weighting scheme (see eq. 8) to increase the influence of the variations of these weights because the SMA store is rarely completely full or empty and vary slowly over time. The combination models obtained with SMA weights are called "state-based committee model" and this is expressed as follows:

$$Q_{csma,i} = W_{sma} \cdot Q_{R,i} + (1 - W_{sma}) \cdot Q_{R\ln,i} \quad (7)$$

$$W_{sma} = \frac{s^3}{s^3 + (1 - s^3)} \quad (8)$$

where $Q_{R,i}$ *and* $Q_{R\ln,i}$are simulated high and low flows for the time step *i* which calibrated on objective function *RMSE* and $RMSE_{ln}$ respectively. *s* is internal variable of HBV models and W_{sma} is weighting function which allow for placing the stronger weight on the low or on the high flows. Oudin *et al*. [3] proposed the objective function based on the logarithms for transformations on low flows and *RMSE* on high flows simulation. The logarithmic transformed root square given below:

$$RMSE_{\ln} = \sqrt{\frac{1}{n}\left(\sum_{i=1}^{n} (\ln Q_{s,i} - \ln Q_{o,i})^2\right)}, \quad (9)$$

Results discussion and conclusion

A lumped conceptual hydrological model HBV (Lindström et al. [5]) is used for this study. The model effectively uses nine parameters since there is no snowfall. The performances of single hydrological model and committee models are presented Table 1. Noticeably committee models improved their performances in both calibration and verification in comparison to single hydrological model. Experiment shows that the performance of the fuzzy committee model is higher than that of any other model.

Table 1. The performances of single hydrological model (optimized based on *RMSE*) and committee models (assembled by fuzzy membership function and weights based on SMA)

		Bagmati catchment				Leaf catchment			
		RMSE		NSE		RMSE		NSE	
SN.	Models	Cal.	Ver.	Cal.	Ver.	Cal.	Ver.	Cal.	Ver.
1	Q_{sin}	101.26	112.42	0.87	0.82	17.56	26.76	0.87	0.90

2	Q_{fcm}	95.66	109.38	0.89	0.83	15.63	25.23	0.89	0.91
3	Q_{csma}	100.53	111.20	0.87	0.82	16.55	26.08	0.87	0.90

Cal. - calibration; Ver. -verification;

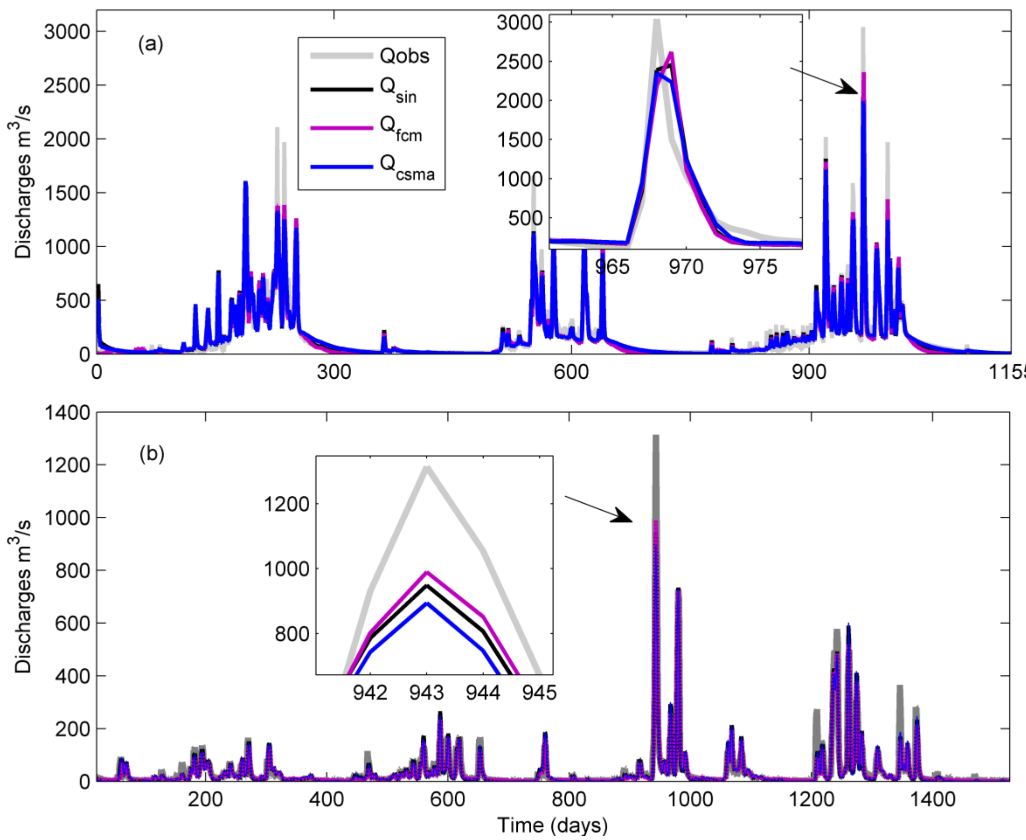

Figure 1. Hydrograph generated from various models in verification period: Q_{obs}- observed discharge, Q_{sin}-Single hydrological model identified by single-objective optimization (ACCO), Q_{fcm}- fuzzy committee model, Q_{csma}- state-based committee model (a) Bagmati (01/01/1988 - 28/02/1991), and (b) Leaf (26/07/1957 - 21/09/1967)

The fuzzy committee model resulted in the *RMSE* of 95.66 in calibration and 109.38 in verification in Bagmati catchment, and 15.63 in calibration and 25.23 in verification in leaf catchment. However state-based committee model obtained *RMSE* of 100.53 and 111.38 in calibration and verification respectively in Bagmati catchment, and 16.55 and 26.08 respectively in leaf catchment. State-based committee model performs better than single model in term of *RMSE*. It can be seen that the committee models are performing better than the other models in both catchment in calibration. During calibration of specialized models of fuzzy committee model, the objective function $RMSE_{LF}$ values obtained higher than that of $RMSE_{HF}$ – the reason is that the number of low flows is much higher than of high flows, and the denominator (total number of observations) in both formulas is the same. However, values $RMSE_{LF}$ and $RMSE_{HF}$ cannot be compared to each other and to the values of *RMSE* because of difference in weighting.

The visual plots of the committee models which are built from the combination of the two specialized models for high and low flows with respect to the hydrograph simulations are represented in Figure 1 It can be observed that the committee model combines the best features of the specialized models.

State-based committee models can be composed by the weights which are acquired not only from SMA store value but also from other internal model variables (e.g., upper zone, lower zone). Weights are implying for switch between specialized models at different time steps.

In fuzzy committee models, fuzzy membership function switches smooth transition between boundaries of specialized models which does not allow additional water into system (preserves water balance) however there is no guarantee for this in the case of state-based committee model.

Acknowledgments, appendices, and references

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