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Improving the temporal transposability of lumped hydrological models on twenty diversified U.S. watersheds

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ABSTRACT

Study region: Twenty diversified U.S. watersheds.
Study focus: Identifying optimal parameter sets for hydrological modeling on a specific catchment remains an important challenge for numerous applied and research projects. This is particularly the case when working under contrasted climate conditions that question the temporal transposability of the parameters. Methodologies exist, mainly based on Differential Split Sample Tests, to examine this concern. This work assesses the improved temporal transposability of a multimodel implementation, based on twenty dissimilar lumped conceptual structures and on twenty U.S. watersheds, over the performance of the individual models.
New hydrological insights for the region: Individual and collective temporal transposabilities are analyzed and compared on the twenty studied watersheds. Results show that individual models performances on contrasted climate conditions are very dissimilar depending on test period and watershed, without the possibility to identify a best solution in all circumstances. They also confirm that performance and robustness are clearly enhanced using an ensemble of rainfall-runoff models instead of individual ones. The use of (calibrated) weight averaged multimodels further improves temporal transposability over simple averaged ensemble, in most instances, confirming added-value of this approach but also the need to evaluate how individual models compensate each other errors.

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1. Introduction

As pointed out by Wilby (2005), there is a growing need to investigate uncertainty in hydrological modeling, because it may have a substantial influence on the identification of climate change adaptation strategies for water resources management. For example, Prudhomme and Davies (2009) studied four British catchments and showed that the uncertainty of the hydrological model cannot be ignored in changing climate conditions. Bae et al. (2011) studied the effects of climate change using three semi-distributed hydrological models and found that they lead to substantially different changes under similar climate forcing. Bastola et al. (2011) also reported high hydrological uncertainty in a survey over four Irish watersheds.

Obviously, the use of a model in conditions different from those it was developed raises the question of transposability of its structure and parameters. Indeed, it is a common implicit assumption that hydrological models calibrated on a specific period remain valid over other periods. This assumption generally holds till conditions do not differ much from those of the calibration. However, in a context of climate change, contrasted climate conditions between calibration and projection periods are often substantial, challenging the assumption of stationarity. As mentioned by Salathé et al. (2007), transposability of a hydrological model into the future is a fundamental uncertainty. Rosero et al. (2010) revealed the strong influence of the climatic conditions on the parameters of Noah model. A similar dependence has been reported by Vaze et al. (2010) and Merz et al. (2011). For example, Vaze et al. (2010) found that the transposability to a dry climate was particularly problematic for three parameters and concluded that such transfer should be avoided for changes in rainfall superior to 15%. Coron et al. (2012) also showed that the transposition of model parameters over time may introduce large bias in hydrological simulations.

Much less studies have been devoted to the structural uncertainties of hydrologic models. Panagoulia and Dimou (1997) compared simulations of two hydrological models and obtained large disparities under dissimilar climates. Jiang et al. (2007) submitted six conceptual rainfall-runoff models to fifteen random climate change scenarios and came to the conclusion that models with similar behavior under past climate may behave differently under future climate. Minville (2008) applied two very different models and found that the structure of the hydrological model generated lots of uncertainty for summer flows. Ludwig et al. (2009) compared two physically-based models and of a conceptual one in the context of climate change and concluded that differences in the complexity of model structure can play an important role in resulting simulations. Poulin et al. (2011) demonstrated that the structure of the hydrological model is more influential than their parameter identification. Finally, Bae et al. (2011) and Velázquez et al. (2013) showed that the structure of their hydrological models has a substantial impact on planned changes, especially on projected low flows.

Consequently, a growing number of studies opted for a combination of models with dissimilar structures to quantify their inner sensitivity (Shamseldin et al., 1997) and to improve overall performance. As highlighted by Butts et al. (2004), the combination of different model structures through a multimodel approach is of vital interest for structural uncertainty.

1.1. Multimodel approach

Many hydrologists have developed new models or improve existing ones in order to capture real-world processes as much as possible. However, the identification of the best model in all circumstances is a difficult if not an impossible task, because if some models are on average more efficient than others, none are systematically. Based on this statement, several comparative studies have been performed on a large number of hydrological models (for example Perrin, 2000 or Georgakakos et al., 2004). They confirmed a high diversity in performance and the difficulty to identify a model systematically superior to the others, but in return they found the existence of potential complementarities between them. For example, Perrin (2000) analyzed 38 hydrological models on 429 catchments and observed that a pair of complementary models outperforms all single ones. Therefore, a number of hydrologists expressed interest in multimodeling for increasing performance and allowing uncertainty analysis. The multimodel approach essentially aims to extract as much information as possible from existing models. The reasoning behind a multimodel combination lies in the fact that each output model