Journal of Hydrology: Regional Studies 6 (2016) 90–111

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

A regional parameter estimation scheme for a pan-European multi-basin model

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ARTICLE INFO

Article history:
Received 21 August 2015
Received in revised form 4 April 2016
Accepted 10 April 2016
Available online 8 May 2016

Keywords:
Regionalization
HYPE
Europe
Multi-basin modeling
Calibration
Catchment classification

ABSTRACT

Study region: Europe.
Study focus: A semi-distributed continuous hydrological model, HYPE, was applied to model daily stream flows in more than 35,000 subcatchments across Europe. A stepwise regionalization approach was implemented to estimate different groups of model parameters. HRU based parameters were estimated first for each soil and landuse class, respectively. Lake and reservoir parameters were estimated separately. Catchments were grouped based on similarity of their characteristics and model parameters defined at a catchment scale were then regionalized for each group as functions of the catchment characteristics by simultaneously calibrating the model for a number of catchments to concurrently optimize the overall model performance and the functional relationships between the parameters and the catchment characteristics. Calibration was performed at 115 discharge stations and the approach was validated at 538 independent stations.
New hydrological insights for the region: Parameters could be linked to catchment descriptors with good transferability, with median NSE of 0.54 and 0.53, and median volume error of −1.6% and 1.3% in the calibration and validation stations, respectively. Although regionalizing parameters for different groups of catchments separately yielded a better performance in some groups, the overall gain in performance against regionalization using a single set of regional relationships across the entire domain was marginal. The benefits of separate regionalization were substantial in catchments with considerable proportion of agricultural landuse and higher mean annual temperature.

1. Introduction

Proper management of freshwater resources requires quantification of the spatial and temporal distribution of available freshwater in its different compartments of the earth. This is often achieved through implementation of hydrological models, which have different levels of complexity, depending on the specific purpose to which they are to be applied, input data available, and resource availability (e.g. Singh, 1995; Refsgaard et al., 2010; Pechlivanidis et al., 2011; Hrachowitz et al., 2013). Although such assessment is usually performed at a catchment or river basin level, there is an increasing need for a more integrated assessment across regions at continental and global scales as society is becoming more and more integrated and resources need to be managed in a coordinated way.

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http://dx.doi.org/10.1016/j.ejrh.2016.04.002

Continental and global scale assessment of water resources have been performed in the past using macro-scale hydrological models (eg. Yates, 1997; Vörösmarty et al., 2000; Alcamo et al., 2003; van Beek et al., 2011). Such models have a rather coarse spatial resolution and low accuracy. In recent years, however, there has been a shift towards more detailed and higher resolution models for assessment of water resources at regional and continental scales (Arnold et al., 1999; Schuol et al., 2008; Arheimer et al., 2012; Donnelly et al., 2016; Pechlivanidis and Arheimer, 2015; Rakovec et al., 2016).

Implementation of more detailed hydrological models at large scale often requires calibration of the models at a large number of subbasins across the model domain to account for the spatial variability of the model parameters (e.g. Graham, 1999; Abbaspour et al., 2015). This entails a huge computational effort and requires availability of catchment response observations, such as discharge data, with a sufficient spatial and temporal coverage, limiting prediction in ungauged subbasins. One possible solution to ease these requirements is incorporating a regionalization approach, in which model parameters estimated in carefully selected gauged donor catchments are transferred to other catchments based on their similarity with the catchments where the model has been calibrated (see Parajka et al., 2013 for a review of the different methods).

A number of research efforts have been put on developing strategies to relate model parameters to measurable catchment properties using different approaches. One group of approaches uses an assumption that catchments that are spatially close to one another tend to be similar in their characteristics and hydrological behaviors and therefore parameters of the models employed to simulate their flows (e.g. Li et al., 2009; Gottschalk et al., 2011). Using such an assumption, model parameters are transferred from calibrated nearby catchments. Another group of approaches groups catchments based on catchment physiographic and/or hydrological similarities using different catchment properties and flow indices to transfer model parameters (e.g. Johansson, 1992; Arheimer and Brandt, 1998; Merz and Blöschl, 2004; Lee et al., 2005; Parajka et al., 2005; Lindström et al., 2005; Seibert and Beven, 2009; Bulygina et al., 2011). A third group of approaches follows a strategy in which regression based models are established between model parameters and several catchment characteristics and flow indices from a number of catchments for which the model is calibrated independently (e.g. Abdulla and Lettenmaier, 1997; Seibert, 1999; Wagener and Wheater, 2006; Pechlivanidis et al., 2010; Singh et al., 2012).

One of the problems associated with the regression based approach is that because of the problem of equifinality (Beven and Binley, 1992), it may be difficult to obtain a unique set of parameters in the individual catchments, potentially making it difficult to come up with a strong relationship between the model parameters and catchment properties. In order to address this problem, a regional calibration approach, which treats the model calibration and fitting of the relationship between the model parameters and catchment attributes simultaneously, has been pursued by some researchers (Fernandez et al., 2000; Hundecha and Bárdossy, 2004; Hundecha et al., 2008; Samaniego et al., 2010; Kumar et al., 2013; Wallner et al., 2013). In this approach, the functional form of the relationship between the model parameters and catchment characteristics is assumed a-priori and model calibration is done for a number of catchments simultaneously to estimate the parameters of the functions relating the model parameters and the catchment characteristics.

Each of the methods listed above has their own advantages and shortcomings. The proximity and similarity based methods are easier to implement in that the entire set of parameters are assumed to be the same in all ungauged catchments where the parameters are transferred to. However, they ignore the possible variability of the catchment characteristics between the different catchments. The regression based method enables estimation of a unique set of parameters for each catchment based on their catchment characteristics. However, as mentioned in the previous paragraph, the equifinality problem makes it difficult to achieve a strong relationship between model parameters and catchment characteristics. The regional calibration approach eases this problem, but at a higher computational cost. See Blöschl et al. (2013) for a review of the different methods.

In the present work, we brought together some elements from the different groups of approaches in order to exploit their advantages and achieve robust parameter regionalization. To that end, we grouped catchments into homogeneous groups using catchment classification and performed regional calibration separately for each group by simultaneously calibrating the model for multiple catchments within each group while concurrently estimating the regional relationship between the model parameters and the catchment descriptors whose form is assumed a-priori. The rationale behind combining the two approaches lies in the following:

A regional model calibration approach, in which model calibration and estimation of the relationship between model parameters and catchment characteristics is performed simultaneously, needs a prior assumption of the functional form of the relationship between the model parameters and the catchment descriptors (eg. Hundecha and Bárdossy, 2004; Samaniego et al., 2010). If this approach is implemented over a large spatial domain, where the variability of the catchment descriptors is large, the assumed function may fail to capture the inherent relationship over the full range of variability of the catchment characteristics. Reducing the variability of the catchment characteristics over which the relationship is established by grouping catchments of similar catchment characteristics would reduce this risk and could lead to a stronger relationship. On the other hand, regionalization approaches that are based on catchment similarity have usually been pursued by directly transferring parameters from calibrated catchments to other similar catchments. This has been performed either from a single catchment or from a group of catchments through averaging the parameters estimated at individual catchments (eg. Parajka et al., 2005), or by simultaneously calibrating selected catchments of a homogeneous group established through catchment classification (eg. Pagliero et al., 2014). Nevertheless, despite their homogeneity, catchments in the same group still exhibit some variability in their catchment characteristics. Therefore, estimating the model parameters as functions of the catchment characteristics within a group would improve the parameter estimation.

We tested the benefits of using this new parameter estimation scheme for the HYdrological Predictions for the Environment (HYPE) model (Lindström et al., 2010) set up for the pan-European region and referred to as E-HYPE (Donnelly