MULTI-VARIABLE CALIBRATION OF A CONCEPTUAL RAINFALL-RUNOFF MODEL IN THE SELECTED ALPINE CATCHMENT

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The accurate estimation of snow is important, especially in alpine (mountainous) regions where the snow provides an important contribution to catchment runoff. In this study we assess the benefit of snow cover data in multi-variable calibration approach in terms of model performance. A lumped conceptual rainfall-runoff model (TUW model) is calibrated and validated over two periods between 1981 – 1990 and 2001 – 2010 for one selected Alpine catchment in which we illustrate the model performance by daily simulations of the flows and snow water equivalent (SWE). The results compare two different approaches used for model calibration: (a) single-variable calibration approach (termed SINGLE) using only runoff data, (b) multi-variable calibration approach (termed MULTI) taking into account runoff and snow cover data. The model performance is assessed by different metrics, such as the Nash-Sutcliffe efficiency (NSE), the volume error (VE), and the snow error (SN). The results demonstrate a benefit of using snow data in calibration in the context of the SWE modeling. We found that using MULTI approach (in comparison to SINGLE approach) leads to better simulations of SWE but slightly poorer simulations of runoff. Some of the comparisons (SINGLE vs MULTI approach) are discussed in conclusion.

Keywords: TUW model, single-variable calibration, multi-variable calibration, snow cover data

INTRODUCTION

In alpine (mountainous) regions a snow is an important runoff generation process. In these regions the correct representation of hydrological processes (e.g. snow water equivalent SWE) is crucial (because of large variability of hydrological processes, data are sparse, etc.). One of the possible approach to overcome these limitations is to use the additional data to modeling. These can be, e.g. groundwater data (Seibert 2000; Beldring 2002; Madsen, 2003; Juston et al., 2009), soil moisture data (Western and Grayson, 2000; Parajka et al., 2009), and snow cover data (Parajka et al., 2007; Udnaes et al., 2007). For example, Parajka et al. (2007) used multi-variable strategy (values from two measured processes: runoff and snow cover) for calibrating a HBV model in 320 catchments in Austria. The authors compared the results of the multi-variable approach with the results of the traditional calibration procedure involved only the values from one measured process (runoff). They concluded that that the multi-variable approach performed poorer than the traditional calibration approach in terms of runoff simulations but better in terms of snow cover simulations. This is in agreement with the results presented e.g., Madsen (2003), who showed that the use of groundwater data in model calibration leads to poorer simulation of catchment runoff but better representation of groundwater dynamics. Duethmann et al. (2014) showed that the use of satellite-derived snow cover data in multi-variable calibration can be a good way to improve representation of hydrological processes. Several studies have shown that the use of both flows and snow data (for example, snow cover, SWE, MODIS data) in modeling helped to better represent snow processes and the model performance with respect to the flows did not change much (e.g. Parajka and Blöschl, 2008, Andreadis and Lettenmaier, 2006).

The aim of this study is to assess the effects of different objective functions (single-variable approach termed SINGLE and multi-variable approach termed MULTI) on the performance of the conceptual hydrologic model. Specifically, we address two research questions: (a) What is the benefit of snow data in hydrologic model calibration? b) Does a multi-variable approach perform better than a single-variable in terms of simulations of the flows and snow water equivalent?

DATA

The study focuses on one selected Alpine (mountainous) catchment in Austria (Fig. 1). The catchment area is 40 km^2. 24% of the catchment is forested. The mean elevation is 2144 m a.s.l. The slope of the catchment is approximately 54%. The mean annual precipitation ranges from 1125 to 1583 mm. The mean annual air temperature varies from -0.7 to 2.6 °C. The mean annual runoff is from 1063 to 1550 mm.

Daily input data between 1981 – 2010 was used in this study. The input data consisted of mean daily precipitation, air temperature, potential evapotranspiration and streamflow. Data were carefully checked before gaps (e.g., plotting daily data).

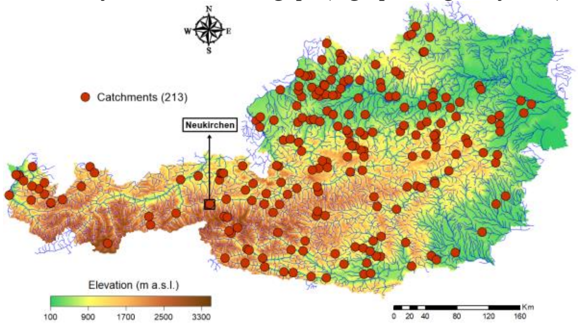

Figure 1. Map of Austria with the selected catchment.

HYDROLOGICAL MODEL

A lumped hydrological model TUW ("Technische Universität Wien") (Viglione and Parajka, 2014) is used to simulate runoff and snow water equivalent (SWE) in this study. This model requires a daily time series of precipitation, air temperature, potential evapotranspiration, and streamflow. This model follows a structure of Swedish HBV model (Bergström, 1995). TUW model has been widely applied in various modeling studies (e.g., Sleziak et al., 2016a; Sleziak et al., 2016b; Parajka et al., 2007; Viglione et al., 2013).

The model has 15 calibrated parameters (Tab. 1). The structure of the model involves three submodels: snow, soil, and runoff submodel. Snow submodel involve parameters such as the degree-day factor DDF (mm/ °C day), the snow correction factor SCF (-), and the threshold temperatures Tr, Ts, and Tm (°C). The role of this submodel is snow accumulation and melting in a catchment.

The soil submodel represents the runoff generation in a catchment. Its role is to simulate the processes taking place under the soil. This submodel consists of parameters such as the parameter of runoff generation BETA (-), the maximum field capacity FC (mm), and the limit for potential evapotranspiration Lprat (day).

The runoff submodel is used to transform the outflow from upper and lower reservoirs. This submodel involves parameters related to surface and subsurface runoff k0, k1, and k2, the threshold storage state Lsuz (mm), the constant percolation rate Cperc (mm/day), the maximum base et low flows Bmax (day), transformation parameter Croute (runoff/day). The model and its structure is thoroughly described in Parajka et al. (2007).

Table 1. The TUW model parameters including lower and upper bounds. The parameter ranges were taken from the literature (e.g. Merz et al., 2011).

Parameter	Model part	Range
SCF (-)	Snow	0.9 – 1.5
DDF (mm/1C day)	Snow	0 – 5
Tr (°C)	Snow	1 – 3
Ts (°C)	Snow	-3 – 1
Tm (°C)	Snow	-2 – 2
Lprat (day)	Soil	0 – 1
FC (mm)	Soil	0 – 600
BETA (-)	Soil	0 – 20
k0 (day)	Runoff	0 – 2
k1 (day)	Runoff	2 – 30
k2 (day)	Runoff	30 – 250
Lsuz (mm)	Runoff	1 – 100
Cperc (mm/day)	Runoff	0 – 8
Bmax (day)	Runoff	0 – 30
Croute (runoff/day)	Runoff	0 – 50

Calibration and validation strategy

In this study we calibrated and validated TUW model over two periods between 1981 – 1990 and 2001 – 2010 for one selected mountainous catchment in Austria. The model parameters were estimated with an automatic calibration using a differential evolution algorithm Deoptim (Ardia et al., 2015). We tested two calibration approaches:

1) *Single-variable calibration on daily runoff data (termed SINGLE):*

This calibration approach involved only the values from one measured process (runoff). The SINGLE (runoff) objective function combines the Nash-Sutcliffe coefficient (NSE) (Nash and Sutcliffe, 1970) and the logarithmic Nash-Sutcliffe coefficient (logNSE) (Merz et al., 2011). The meaning of this function is to achieve a good representation of low and high flows. This objective function is used in the form of:

$$ME = \frac{(NSE + \log NSE)}{2} \tag{1}$$

2) *Multi-variable calibration on daily runoff and snow cover data (termed MULTI):*

This calibration approach enables take into account more objective criteria. In this study we involved the values from two measured processes (runoff and snow cover). Due to the fact that the measurements of the snow water equivalent (SWE) were not available we used observed snow depth data.
The snow objective function is defined as:

$$SN = \frac{SN_{under} + SN_{over}}{N_{day}} \tag{2}$$

Where, SN_{under} and SN_{over} is the number of days with poor snow cover simulation (underestimation or overestimation) and N_{day} is the total number of days in the simulation period.
Multi-variable objective function is defines as:

$$MULTI = (1 - ws) * ME + ws * SN \tag{3}$$

Where, ME is the SINGLE (runoff) objective function, SN is the snow objective function, and ws is the weighting coefficient that ranges between 0 and 1. In this case the weighting coefficient (ws = 0.9) was determined by test simulations.

The calibration results are assessed in terms of accuracy of the observed and simulated flows and SWE. The results are also evaluated by the different metrics: the Nash-Sutcliffe efficiency NSE (NSE = 1 indicate a good match measured and simulated flows), the Volume error VE (VE = 0 indicate that the calibration is unbiased, VE < 0 and VE > 0 indicate underestimated and overestimated flows), and the snow error of snow SN (the ideal case is SN = 0).

RESULTS

This section summarizes the results obtained by single-variable (SINGLE) and multi-variable (MULTI) calibration approach. This can be seen in Figs. 2 – 5, which give information about the plotting the observed and simulated flows (Figs. 2, 3) or observed snow depth and simulated snow water equivalent (SWE) (Figs. 4, 5). This is also documented in Tabs. 2 and 3, which provide information about the different metrics of the quality of the simulations (NSE, VE, and SN).

Fig. 2 (top and bottom) gives information about the observed and simulated flows for one year averaged over the periods 1981 – 1990 (top) and 2001 – 2010 (bottom) for SINGLE calibration approach. From Fig. 2, it is clear that using SINGLE approach we are able to obtain good simulations of the flows (better in calibration period). The similar results are presented also by MULTI calibration approach (Fig. 3, top and bottom).We can see that the model quite well captured the size and shape of the hydrogram (underestimation of the runoff volume is visible mainly in the validation periods). Also, there is a slight shift in advance over the measured flows. From Tabs. 2 and 3, we can see that the MULTI approach performs better in terms of SN (values of snow error SN are lower in comparison to SINGLE approach).

Fig. 4 (top and bottom) provides information about the observed snow depth and simulated snow water equivalent (SWE) for one year averaged over period 1981 – 1990 (top) and period 2001 – 2010 (bottom) for SINGLE calibration approach). By visual interpretation of results, it is clear that using SINGLE approach, the simulations of SWE are rather poor. There are also large differences between observed and simulated values. The better results are presented by MULTI calibration approach (Fig. 5, top and bottom). We can see that the use of snow cover data in the calibration (the MULTI calibration approach) is beneficial in the simulations of the SWE. In other words, using MULTI approach leads to better simulation of the SWE (Fig. 5) as compared to SINGLE approach (Fig. 4). According to the results the following conclusions can be made. We found that the use of snow cover data in the calibration (the MULTI approach) improved the model performance in terms of simulating snow water equivalent SWE (the model performance in terms of simulating runoff is slightly poorer) as compare to SINGLE approach.

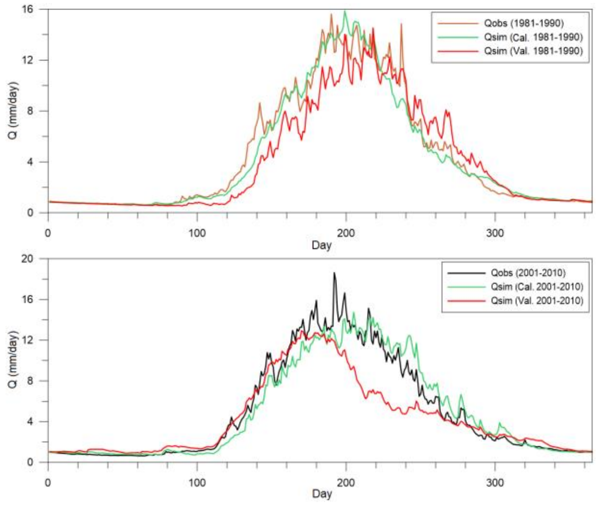

Figure 2. Comparison of observed (Qobs) and simulated flows (Qsim) for one year averaged over period 1981-1990 and period 2001-2010 (SINGLE approach).

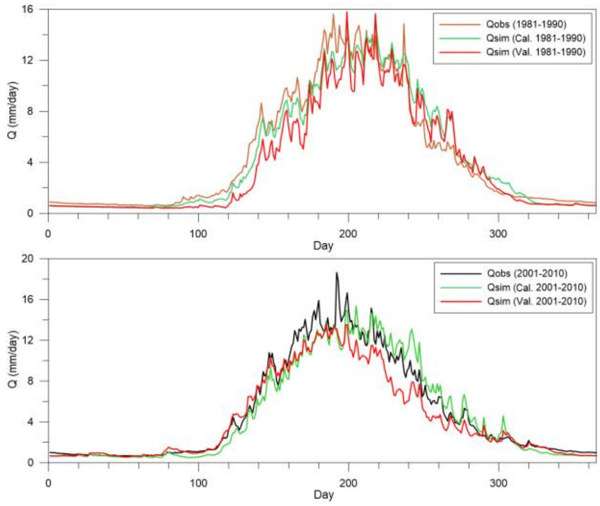

Figure 3. Comparison of observed (Qobs) and simulated flows (Qsim) for one year averaged over period 1981-1990 and period 2001-2010 (MULTI approach).

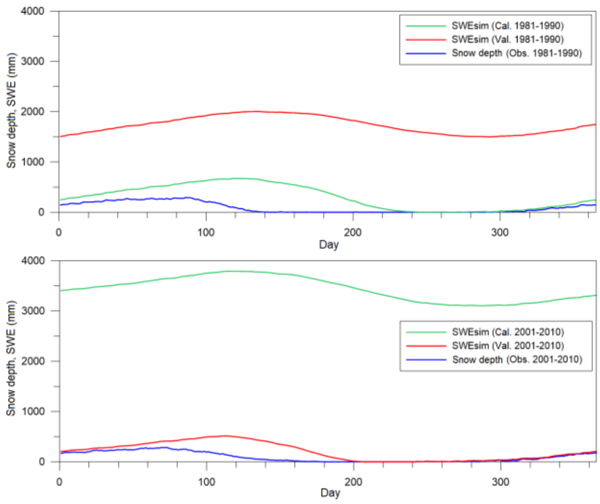

Figure 4. Comparison of observed snow depth and simulated snow water equivalent (SWE) for one year averaged over period 1981-1990 and period 2001-2010 (SINGLE approach).

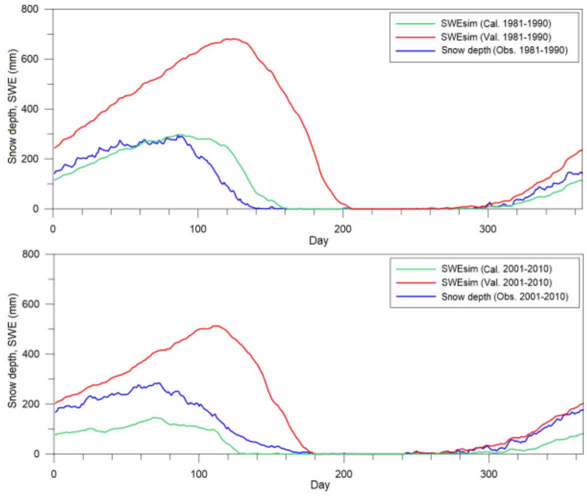

Figure 5. Comparison of observed snow depth and simulated snow water equivalent (SWE) for one year averaged over period 1981-1990 and period 2001-2010 (MULTI approach).

Table 2. Values of the NSE, VE, and SN in the specified calibration and validation periods (SINGLE approach).

	NSE (-)	VE (%)	SN (%)
C 1981-1990	0.79	-3	24
V 1981-1990	0.70	-9	44
C 2001-2010	0.72	-8	53
V 2001-2010	0.67	-15	11

Table 3. Values of the NSE, VE, and SN in the specified calibration and validation periods (MULTI approach).

	NSE (-)	VE (%)	SN (%)
C 1981-1990	0.65	-10	3
V 1981-1990	0.53	-11	16
C 2001-2010	0.59	-9	7
V 2001-2010	0.51	-12	14

CONCLUSION

In this study we have assessed the effects of different objective functions (single-variable approach SINGLE and multi-variable approach MULTI) on the performance of the conceptual hydrologic model. For the modeling we have used the hydrological model TUW. Model runs were conducted for one selected Alpine catchment in Austria in which we illustrated the model performance by daily simulations of the flows and snow water equivalent (SWE). The quality of the simulations of the flows and SWE was assessed by (a) by visual comparison, (b) by three different metrics (the Nash-Sutcliffe efficiency NSE, the volume error VE, and the snow error SN).

The results indicate that the use of snow cover data in the calibration (the MULTI approach) was beneficial in the simulations of the SWE. The MULTI approach performed better than the SINGLE approach in terms of SWE simulations (SWE) slightly poorer in terms of runoff simulations. Similar results have been reported by Parajka et al. (2007), who showed that that the multi-variable approach performed poorer than the traditional calibration approach in terms of runoff simulations but better in terms of snow cover simulations. The results are also consistent with Madsen (2003), who showed that the use of groundwater data in model calibration leads to poorer simulation of catchment runoff but better representation of groundwater dynamics. This is also in line with Seibert (2000), who confirmed these findings. These results highlighted the use of various data (e.g. SWE, snow cover, etc.) in multi-variable calibration can be a good way to improve representation of hydrological (e.g. in Alpine regions, where data are sparse).

Acknowledgement

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