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UNCERTAINTY OF LOW FLOW PROJECTIONS IN AUSTRIA

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ABSTRACT

The main aim of this contribution is to evaluate the overall uncertainty in low flow projections resulting from hydrological model uncertainty and climate projection uncertainty. Hydrological model uncertainty is represented by simulations obtained by different parameterizations of a conceptual semi-distributed hydrologic model (TUW model) in three different decades (1976-86, 1987-97, 1998-08). Climate projection uncertainty is quantified by four future climate scenarios (ECHAM5-A1B, A2, B1 and HADCM3-A1B) using a delta change approach. The evaluation of uncertainty is tested for 262 basins in Austria.

The results indicate that the most important factor affecting the performance of model calibration is the seasonality of the low-flow regime. In Austria, the range of simulated low-flow discharge (Q95) in the reference period is larger in basins with summer low-flow regime than in basins with winter low-flow regime. The simulated Q95 varies in a range of up to 60% depending on the decade used for calibration.

The low-flow projections of Q95 for future period 2021 – 2050 show a 10 – 30% increase of low flows in the Alps. Decrease (5 to -20%) in low flows is simulated in the south-eastern part of Austria. The change in seasonality varies between climate scenarios, but there is

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a tendency for earlier winter low flows in the Alps and later summer low flows in flatland. The relative contribution of the three main variance components (i.e. climate scenario, decade used for model calibration and calibration variant representing different objective function) to the low-flow projection uncertainty shows that while in basins with summer low-flows the climate scenarios contribute more than 75% to the total projection uncertainty, in basins with winter low flow regime, the median contribution of climate scenario, decade and objective function is 29%, 13% and 13%, respectively.

1. Introduction

Assessment of climate impacts on hydrologic cycle is important for a wide range of practical applications, including estimation of environmental flows, effluent water quality, hydropower operations, water supply or navigation. Future projections of low flows are hence important for planning and development of adaptation strategies in water resources management. A typical way of evaluating future runoff changes is using hydrologic models calibrated in historical periods and applying for simulation of future flows by using climate projections.

The research question and objective of this study is to analyze how sensitive and uncertain the future low flow predictions are if the hydrologic model is calibrated in climatically different time periods and by using different objective functions. Austria is an ideal test bed for such analysis, because there are two regions with distinct summer and winter low-flow regimes.

2. Methodology

Hydrologic model used for low-flow simulations is a conceptual semi-distributed rainfall-runoff model (TUW model). The model simulates water balance components on a daily time step by using precipitation, air temperature and potential evapotranspiration data as an input. The model consists of three modules which allow simulating changes in snow, soil storages and groundwater storages. TUW model is calibrated by using compound objective function (ZQ) consisting of two parts, i.e. a part emphasizing the high flows (HQ) and a part weighting more the low flows (LQ). High and low flow parts are described by the Nash–Sutcliffe model efficiency of normal and logarithmic transformed flow values, respectively:

$$ZQ = wHQ + (1 - w)LQ.$$

Model calibration is tested by using eleven weights w (0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0) and each calibration variant is repeated in three different calibration periods (976-86, 1987-97 and 1998-08). The low-flow projections are analysed by comparing future to past flows by using a hydrologic model forcing from a delta change approach. This concept allows to remove biases resulted from simulations when regional climate model (RCM) outputs are used as an input in hydrologic modelling. In the first step, hydrologic model is calibrated by using observed climate characteristics in three different reference periods (1976-86, 1987-97 and 1998-08). In a next step, RCM outputs are used to estimate monthly differences between simulations in the reference (control) and future periods. These differences (delta changes) are then added to the observed model inputs and used for simulating future projections of low flows.

The future low-flow changes are quantified by the Q_{95} low-flow quantile and seasonality index SI. The Q_{95} represents river flow that is exceeded on 95% of the days of the entire reference or future period. The seasonality index is estimated for observed and simulated low flows. The differences between model simulations (i.e. Q_{95} and seasonality index) in the reference and future periods are then used to quantify potential impacts of climate change on low flows. More details about the model structure and examples of application in the past are given e.g. in [1] and [2].

3. Data

Austria represents diverse climate and physiographic conditions of Central Europe, and different hydrologic regimes of low flows are observed there. The topography has the range from 115 m a.s.l. in the lowlands to more than 3700 m a.s.l. in the Alps. Austria is situated in a temperate climate zone affected by the Atlantic, meridional south circulation and the continental weather systems of Europe. Mean annual air temperature is the smallest in the Alps (-8 °C) and the highest in lowlands, where it can exceed 10 °C. The smallest and largest mean annual precipitation (550 mm/year – 3000 mm/year) is observed in the Danube lowlands and on the windward slopes of the Alps, respectively.

The evaluation of low-flow projections is based on daily river flow measurements at 262 gauges (Fig. 1). Low flows have different seasonality in Austria (Fig. 2). While in the Alps there is a typical winter low-flow regime, lowlands are characterised by summer low-flow regime. The winter flow minima in the mountains are controlled by freezing processes and snow storage, summer low flows occur during long-term persistent dry periods when evapotranspiration exceeds precipitation. The different low-flow generating processes, together with the hydro-climatic variety of the study area, gives rise to an enormous spatial complexity of low flows in Austria. The largest values occur in the Alps, with typical values ranging from 6 to 20 l s^{-1} km^{-2}. The lowest values occur in the east ranging from 0.02 to 8 l s^{-1} km^{-2}, although the spatial pattern is much more intricate.

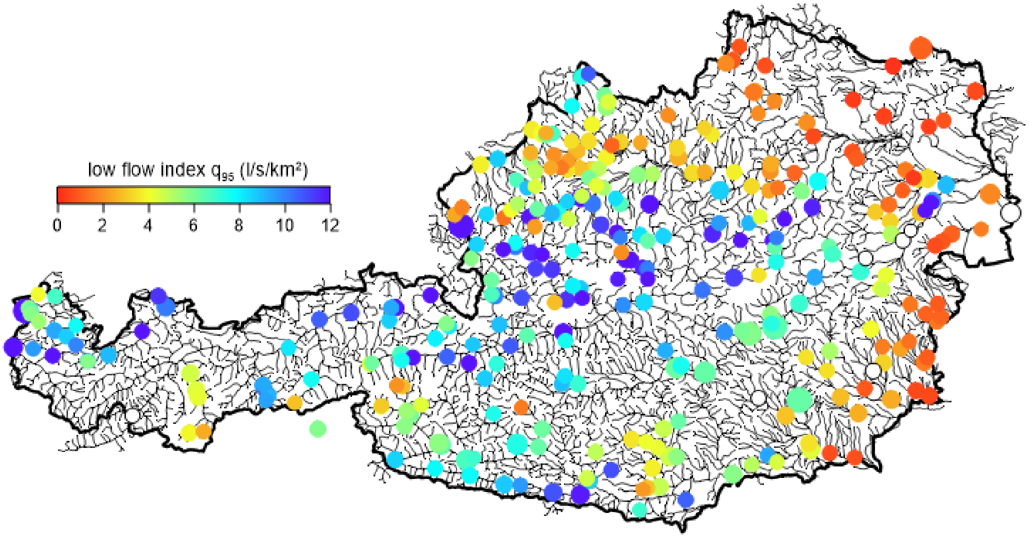

Figure 1. Low-flow Q_{95} values (in l/s/km^2) in Austria in the period 1976 – 2008

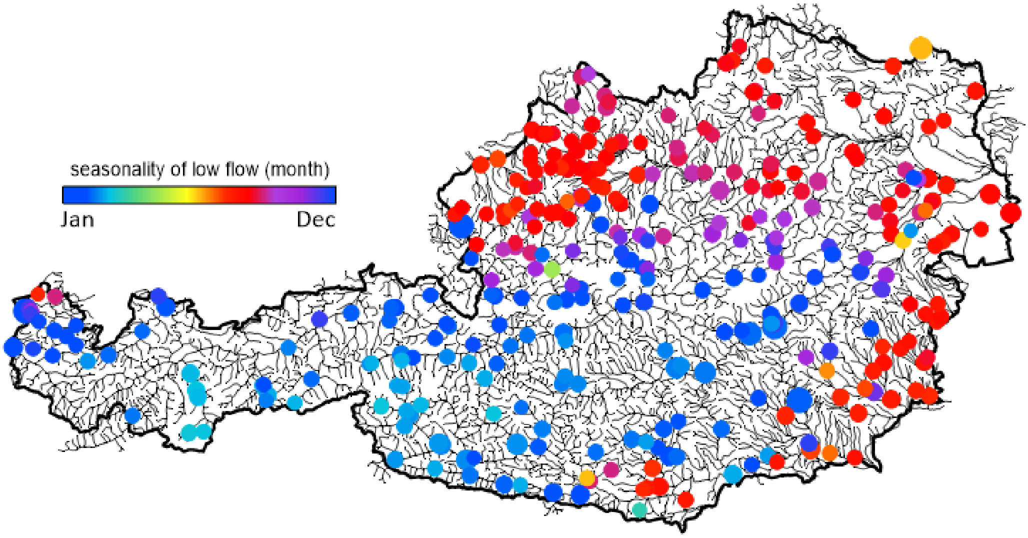

Figure 2. Seasonality of low flow in Austria in the period 1976 – 2008

The regional climate model (RCM) scenarios used in this study are generated in reclip.century project [3]. The ensemble climate projections are represented by COSMO-CLM RCM runs forced by the ECHAM5 and HADCM3 global circulation models for three different IPCC emission scenarios (A1B, B1 and A2). These represent a large spread of different emission pathways from a "business as usual" scenario with prolonged greenhouse gas emissions (A2), a scenario with moderate decline of emissions after 2050 (A1B) and a scenario indicating considerably reduced emissions from now on (B1).

4. Results

The results of model calibration are presented in Fig. 3. It shows how model calibrated to different periods into low-flow 95%-quantile Q_{95} estimated for the entire reference period 1976 – 2008. The results show that the model calibrated in the period 1976 – 1986 significantly overestimates Q_{95} of the reference period particularly in basins with summer low-flow regime. The period 1976 – 1986 is colder with less evapotranspiration and relatively higher runoff generation rates which translates into different soil moisture storage (FC model parameter) and runoff generation (BETA) model parameters. Such effects are consistent with findings of [4]. The hydrologic model applied to the entire reference period hence produces larger runoff contribution which tends to overestimate Q_{95} particularly in the warmer and drier parts of the reference period and drier and warmer parts of Austria. The overestimation is consistent for large range of w_Q (w_Q in the range 0.0 – 0.9) and the median of Q_{95} difference exceeds 20%. Also the scatter around the median is rather large, where 25% of the basins with the summer low-flow regime have Q_{95} differences larger than 35%. The simulated Q_{95} in basins with winter low flows fit closer to the observed estimates. The median is less than 10% for variants $w_Q < 1$. Interestingly, the model simulations based on calibration periods 1987 – 1997 and 1998 – 2008 are much closer to the observed values. The results for both groups of basins are very similar and essentially unbiased in terms of 95% low-flow quantile. The exception is the calibration variant $w_Q = 1$ that tends to underestimate Q_{95}. There are not any significant differences between calibration to low-flow only (w_Q = 0.0) and other weights, with exception of w_Q = 1, which represents a typical calibration of using classical Nash-Sutcliffe coefficient.

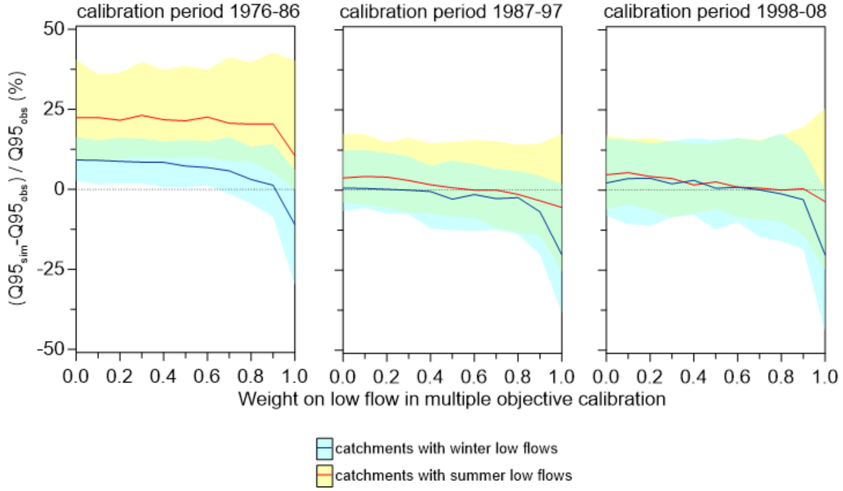

Figure 3. Difference between simulated and observed low-flow index (Q_{95}) for different calibration variants in three calibration periods. Lines represent the median, scatter (i.e. 75 – 25% percentiles) show the variability over catchments with dominant winter (blue) and summer (orange) low-flow regime

The example of low flow changes projections are presented in Fig. 4. The results indicate an increase of low flows in the Alps, typically in the range of 10 – 30%. A decrease is simulated in south-eastern part of Austria (Styria) mostly in the range of -5 – -20%. The most spatially different projection is provided by the HADCM3 A1B climate scenario which simulates the strongest gradient between an increase of Q_{95} in the Alps in winter and a decrease in south-eastern part in summer.

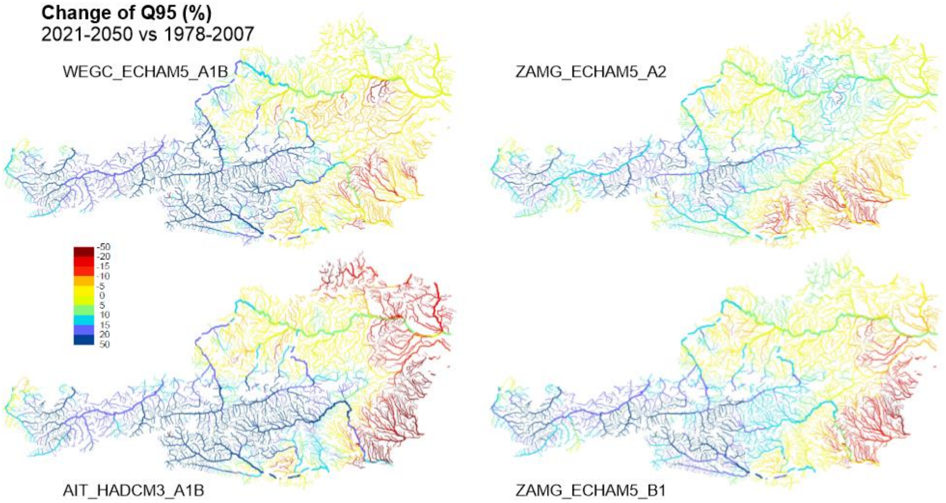

Figure 4. Projection of low-flow index Q_{95} change for four climate scenarios. Model simulations are based on variant w = 0:5 calibrated in the period 1998 – 2008

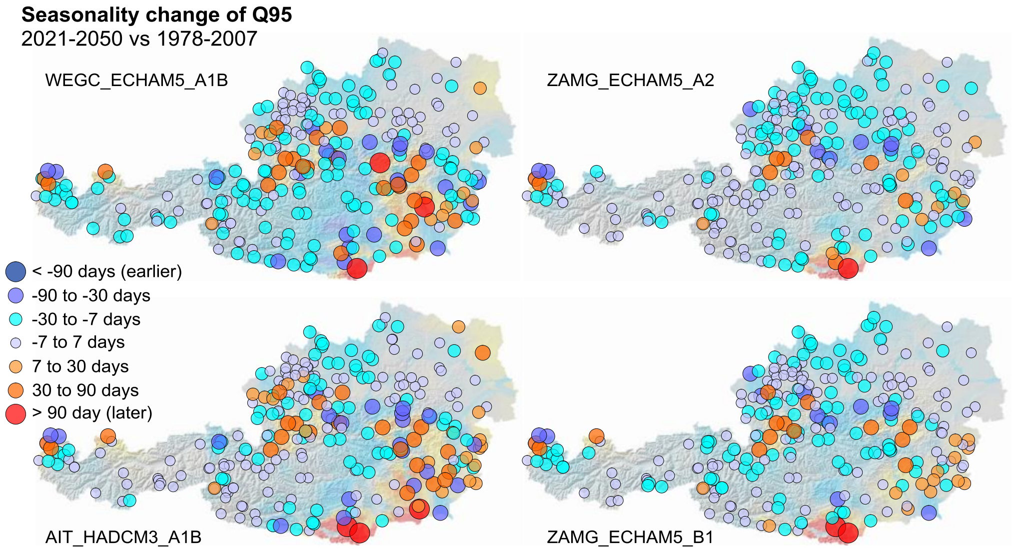

Figure 5. Projections of changes in low-flow seasonality for four climate scenarios in 262 Austrian basins. Model simulations are based on variant *w* = 0:5 calibrated in the period 1998 – 2008. Colour patterns in the background show the interpolated projections by using top-kriging

The change in the seasonality is presented in Fig. 5. The results demonstrate that change in seasonality varies between the scenarios, but there is a tendency for earlier low flows in the Northern Alps and a shift to later occurrence of low flows in the Eastern Austria. The shift in seasonality is generally small and larger than one month only in a few basins.

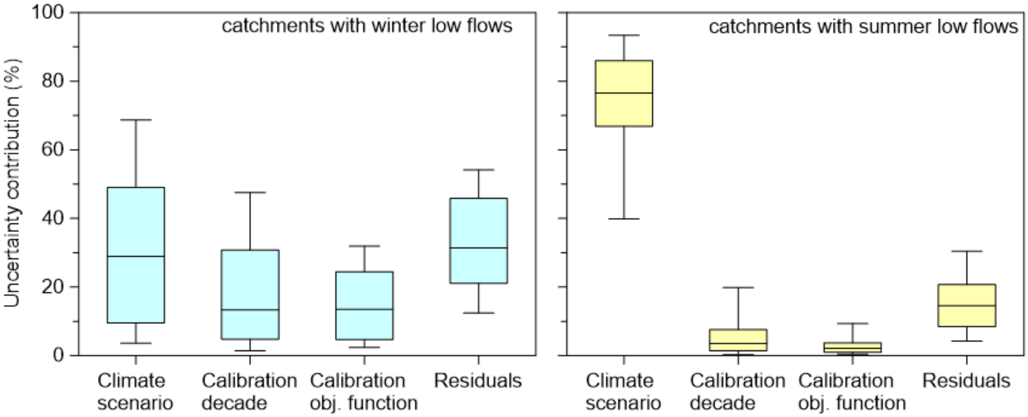

Figure 6. Relative contribution of the three variance components (i.e. climate scenario, calibration decade and objective function) to the overall uncertainty of future low-flow projection in basins with winter (left panel) and summer (right panel) low-flow regime. The boxes and whiskers show 25 and 75% percentiles and 5 and 95% percentiles of the uncertainty contributions in 130 (summer low-flow regime) and 132 (winter low-flow regime) basins, respectively

The relative contribution of the three main variance components (i.e. climate scenario, decade used for model calibration and calibration variant representing different objective function) to the overall uncertainty of future low-flow projections is evaluated in Fig. 6. Left and right panels show the distribution of ANOVA variance components for basins with winter (left panel) and summer (right panel) low-flow regime, respectively. The results indicate that the variability from climate scenarios has a dominant contribution to the overall projection uncertainty in basins with summer low-flow regime. While in basins with winter low flows the median contribution of the three variance components is 29% (climate scenario), 13% (calibration decade) and 13% (objective function), in basins with summer low-flow regime is the median contribution from climate scenario larger than 76%.

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