Analysis of Climatological Drivers of Low-Flow Events in Hydrological Bavaria Using Large Ensemble Climate Projections

Theresa Meier[1], Nikita Paschan[1], Andrea Böhnisch[2], Henri Funk[12], Alexander Sasse[2], Helmut Küchenhoff[1]

[1] Department of Statistics, LMU Munich, Germany
[2] Department of Geography, LMU Munich, Germany

E-mail for correspondence: `Theresa.Meier@campus.lmu.de`

Abstract: As the world faces the dire reality of climate change, hydrological droughts have become a major concern, with devastating consequences for nature and humans. In Bavarian rivers, low-flow events have become more frequent. Therefore, this research project aims to quantify the primary drivers for these events. In climatology, large ensemble climate projections of meteorological and hydrological variables are commonly used to understand the effects of climate change and to make possible predictions. Using ten different realizations, a logistic regression is applied to analyse the data, evaluate the effect sizes and predict low-flow scenarios under changing climate conditions. The analysis reveals large regional differences between the effects and significance of drivers such as precipitation, soil water, snow storage and temperature on the occurrence of low-flow in "hydrological Bavaria" and a partially severe increase of low-flow events for more extreme climate conditions.

Keywords: Climate Modelling; Applied Statistics; Scenario Analysis.

1 Introduction

Changing climate is not only inducing extreme weather patterns but also affects hydrology. In recent years, Bavaria faced more frequent and intense low-flow events. Those events change nature and animal habitats, cause damage to infrastructure and economy and impact the water supply (Marx et. al. 2018). This project contributes to a better understanding of the climatological and hydrological drivers of low-flows in different catchments of "hydrological Bavaria" and their assessment of future climate change.

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2 Data

The data are composed of ten hydrological simulations of the WaSiM model, each of which is driven by a member of the single model initial condition large ensemble CRCM5-LE (Leduc et al. (2019)). The differences in the corresponding realizations between members are induced by perturbations of the initial conditions of the members, yet they are homogeneous in their distributional characteristics. This approach allows natural variability to be taken into account. The resulting time series data covers three-hourly data from 1990 until 2020 which is aggregated into daily data for this analysis.

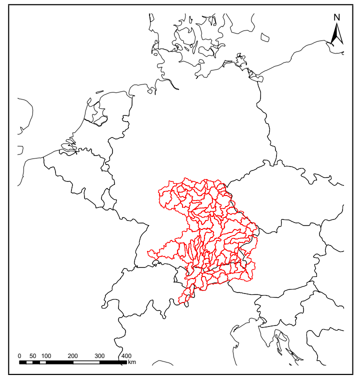

FIGURE 1. Map of hydrological Bavaria.

Hydrological Bavaria (see Figure 1) is divided into 98 catchments with virtual gauges that act as measuring stations. The data set provides regional catchment averages of hydrological and meteorological variables such as precipitation, temperature, snow storage and soil water. A day is classified as a low-flow event when drainage falls below the season-, catchment- and member-specific NM7Q for at least 3 days in a row. The seasons refer to the hydrological half-year, with summer covering the months from May to October and winter the months from November to March.

3 Methods

The occurrence of low-flow events is explained by logistic regressions with drivers such as precipitation, temperature, soil water and snow storage as covariates, as well as interaction terms. Due to the data situation at hand, some challenges arise. To account for a time lag in the drainage-driver relationship, each covariate is included as a simple moving average, the length of which is determined by the inertia of the driver on the drainage. Since the effects of drivers differ between hydrological half-years, separate models are fitted for each season. The members are taken into account by means of individual logit models and in order to make the effects comparable, the coefficients are averaged over the 10 members. The Bonferroni correction is therefore applied to the assessment of the significance of the effects. Since the catchment "Altmühl-Aha" is not subject to any low-flow events in 9 out of 10 members in summer, this catchment is excluded from the modelling process. Altogether, fitting one model for each combination of catchment, member and season leads to a total of 1959 logistic models.

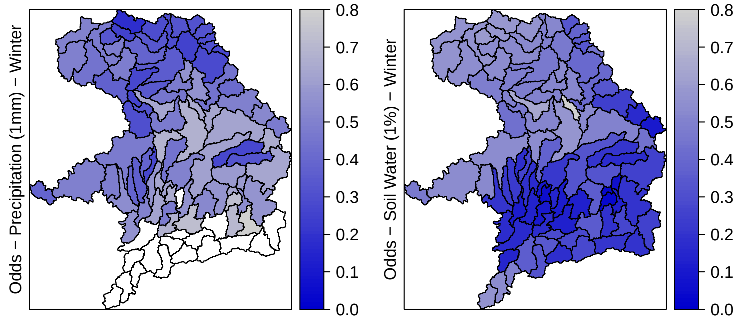

FIGURE 2. Effects for a 1 mm increase of precipitation in winter (left) and for a 1 % increase of soil water in winter (right) on the odds of low-flow events per catchment. Non-significant effects are displayed in white.

4 Result

To assess the goodness of fit, the AUC is determined for each model using test sets consisting of members not used for training. This mostly yields values greater than 0.9, indicating a very good fit. The member-averaged effect sizes are interpreted in terms of odds. Despite natural variability, a comparison of member-specific coefficients leads to very similar results.

4.1 Effects

Analysing the effects of drivers on low-flow events reveals striking regional differences in magnitude and significance. For instance, Figure 2 indicates that in each catchment, an increase in precipitation or soil water decreases the odds of low-flow in winter. Due to a large fraction of snow fall on precipitation in the Alpine regions, no significant effects at a corrected significance level are observable. The north of hydrological Bavaria is strongly influenced by precipitation, while the south is more affected by soil water. These effects are significant, whereas temperature and snow storage show hardly any significant effects. Different combinations of effect sizes and directions between north and south indicate regional differences in the driving dynamics of low-flows.

4.2 Climate Scenario

In order to analyse the impacts of potential changes of the current climate, e.g. a 3 °C rise in temperature, a 50 % reduction in precipitation and the absence of snow storage, the fitted models are now utilized to predict the number of low-flow events for the original and climate scenario data in summer as an example. Due to substantial considerations including a ROC analysis, the threshold for predictions in Figure 3 is set to 0.4. While fewer low-flow

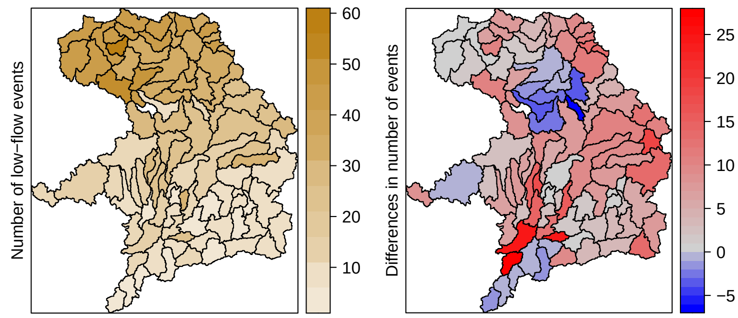

FIGURE 3. Number of predicted low-flows in summer 2010 for unmodified data (left) and differences in number of days for the climate scenario (right).

events are observed in central and south-western catchments compared to predictions for unmodified data, the expected number of events increases in large parts of hydrological Bavaria, in some catchments even drastically to up to 27 days more. Overall, these hypothetical climate changes result in an additional 519 low-flow days in the summer season across all catchments.

5 Conclusion and Outlook

By using logistic regression, including rolling averages and interactions in the drivers, a framework can be created that facilitates understanding of the process of low-flow emergence in hydrological Bavaria and allows comparison between catchments. The analysis exhibits differences in effect size and direction of the drivers by region and season. A comparison of predictions for original and more extreme climate data shows a partly drastic increase in low-flow. This analysis compares the 10 members separately, however, a mixed model including members as random effects could be applied to the whole data set. Ongoing research is extending the presented approach by introducing non-linear effects and more flexible time lag structures for a more detailed modelling of drivers in individual catchments.

References

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