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The impact of bias correcting regional climate model results on hydrological indicators for Bavarian catchments

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ABSTRACT

Study region: The Mindel river catchment, gauge Offingen, Bavaria, Germany.
Study focus: The study investigates the potential interference of climate change signals (CCS) in hydrological indicators due to the application of bias correction (BC) of regional climate models (RCM). A validated setup of the hydrological model WaSiM was used for runoff modeling. The CCS, gained by the application of three RCMs (CCLM, REMO-UBA, RACMO2) for a reference period (1971–2000) and a scenario period (2021–2050), are evaluated according to eight hydrological indicators derived from modeled runoff. Three different BC techniques (linear scaling, quantile mapping, local intensity scaling) are applied.

New hydrological insights for the region: Runoff indicators are calculated for the investigated catchment using bias corrected RCM data. The quantile mapping approach proves superior to linear scaling and local intensity scaling and is recommended as the bias correction method of choice when assessing climate change impacts on catchment hydrology. Extreme flow indicators (high flows), however, are poorly represented by any bias corrected model results, as current approaches fail to properly capture extreme value statistics. The CCS of mean hydrological indicator values (e.g. mean flow) is well preserved by almost every BC technique. For extreme indicator values (e.g. high flows), the CCS shows distinct differences between the original RCM and BC data.

1. Introduction

In recent years, large efforts have been made in climate research to improve process understanding and advance computation power to allow for higher resolution dynamical regional climate models (RCM) (Kotlarski et al., 2014). Meanwhile, a large number of RCM results have been made available to a growing user community, showing a broad range of variability and bias (Christensen et al., 2008; Giorgi et al., 2009; Kotlarski et al., 2014; van der Linden and Mitchell, 2009). Reasons for deviations from observations are manifold and encounter various sources of uncertainty, such as errors in reference data sets (Ehret et al., 2012), the spatio-temporal scale gap between RCMs and observations, differences in model parameterizations (e.g. for convection) (Maraun et al.,

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2010). The selection of SRES emission scenarios (SRES, Nakicenovic (2000)) or recently developed representative concentration pathways (RCP, van Vuuren et al. (2011)), however, affects the climate change signal for the future period. RCM data is made freely available through various data bases (ENSEMBLES (SRES) (van der Linden and Mitchell, 2009), CORDEX (RCP) (Giorgi et al., 2009)) and evermore climate change impact studies apply these data to assess the effects of potential alterations in climate on various physical, ecological and/or socio-economic aspects (e.g. runoff regimes, extreme discharge, biodiversity, water management) (Hattermann et al., 2014; Lenderink et al., 2007; Majone et al., 2012; Stagl and Hattermann, 2015). However, the increasing resolution of RCMs is mostly still too coarse for smaller scale investigations in hydrology, so additional downscaling techniques must be applied (Cloke et al., 2013). Besides this scale issue, RCMs often exhibit pronounced systematic deviations from any given reference period which are considered as bias (Ehret et al., 2012; Kotlarski et al., 2014; Maraun, 2016). If large enough, these biases can result in significantly and often non-linearly different outputs from subsequent models (e.g. for hydrological models) (Chen et al., 2011) which are usually calibrated against observations. Thus, the bias between the observations and the models has to be removed before the data is applicable for impact models. Several methods have been developed for this purpose and are often critically discussed (Ehret et al., 2012; Maraun et al., 2010). Recent studies indicate, that bias correction (BC) methods can have different effects on the distribution of any given parameter (e.g. precipitation), and can thus particularly impact its extreme values (Hagemann et al., 2011; Mudelsee et al., 2010). The underlying principle and thus the most crucial assumption is that the bias correction factors retrieved by any such methods must necessarily be considered valid for the future, assuming a temporal stationarity and thus introducing another, yet often neglected source of uncertainty (Teutschbein and Seibert, 2012). Hence, it must be argued that BC methods might falsify the original climate change signal (CCS) of RCMs with extreme values being stronger affected than means (Themeßl et al., 2012). Regarding the influence of the use of bias corrected data on hydrological modeling, Muerth et al. (2012) point out that individual simulations with a strong inherent bias visibly affect the CCS of hydrological indicators. The overall mean CCS of large RCM ensembles (i.e. multiple member of a RCM driven by the same GCM with changing initial conditions) however seem to be less sensitive to BC.

Many studies investigated the removal of bias in RCMs, resulting in a myriad of methods and various performances for specific purposes (e.g. Maraun et al. (2010); Themeßl et al. (2012)). The study by Muerth et al. (2012) investigated the influence of BC on the representation of observed runoff, the impact of CC on the runoff regime and the effect of BC on the future change in hydrological indicators over a single catchment in Bavaria. Hagemann et al. (2011) state that the hydrological CCS at certain locations and for specific seasons might be affected by the BC of raw GCM data. This impact of BC on the CCS of hydrological indicators is also significant if outputs from corrected RCMs are applied as a meteorological driver of hydrological models (Muerth et al., 2012). Cloke et al. (2013) investigated the impact of BC on the CCS of extreme discharges for the Upper Severn catchment, England, and found that it is even stronger than for mean flows.

To further investigate this specific topic in the course of its routine operations in water resources management (e.g. design of flood detention basins based on a threshold for extreme high flows), the Bavarian Environment Agency (Bayerisches Landesamt für Umwelt (LfU)) requested to analyze the performance of three bias correction methods (local intensity scaling, quantile mapping, linear scaling) for multiple Bavarian catchments in the framework of the BI-KLIM[1] project. These specific BC approaches are chosen for being considered state-of-the-art methods to adjust the systematic differences between RCM data and observations (Ehret et al., 2012). Hence, the purpose of this study was:

a) to determine the most sufficiently performing bias correction method as a standard approach for the Bavarian domain (see Fig. 1, upper left) and
b) to quantify and evaluate the effects of bias correction on the CCS of specific hydrological indicators for river catchments located in Bavaria, Germany.

This paper focuses on the effects of bias correction on the CCS of hydrological indicators. The climate simulations ensemble for this study includes three different RCMs: the COSMO-CLM (CCLM 4.8, Berg et al. (2013); Wagner et al. (2013)) of the Karlsruhe Institute of Technology (KIT)[2], the REMO-UBA[3], and RACMO (v2.1) of the KNMI (van Meijgaard et al., 2008), all driven by the same global circulation model (GCM, ECHAM5, Roeckner et al. (2003)) (further referred to as: CCLM, REMO, RACMO). The hydrological model WaSiM (Schulla, 2012) was applied to determine the impacts of BC to the CCS in the hydrology of several selected Bavarian catchments.

The performance of BC methods is evaluated by comparing long term flow regimes as well as specific flow indicators resulting from the hydrological modeling. A reference data set of observed data was set up at the beginning of the project. This dataset is further used as the observational reference for hydrological modeling and bias correction. The effects of BC on the CCS of the catchment's hydrology are investigated using the same hydrological indicators.

[1] Einfluss der Biaskorrektur dynamischer regionaler Klimamodelldaten auf die Wasserhaushaltsmodellierung und Klimafolgenabschätzung in Bayerischen Flussgebieten (BI-KLIM) (Impact of bias correction of dynamic regional climate model data on water balance modeling and assessment of climate impacts for Bavarian catchments).

[2] Institute of Meteorology and Climate Research, Department Troposphere Research (IMK-TRO) of the KIT, 2011. Provision of CCLM forcing data, version 4.8, calculated by the KIT for runoff models for KLIWA. Unpublished report on behalf of the Bavarian Environment Agency (LfU), Measurements and Environmental Protection Baden-Württemberg, and Water Management and Factory Department Rheinland-Pfalz.

[3] Max-Planck-Institute (MPI) under contract to the German Federal Environment Agency, 2006.