Local refinement of RCM simulations based on the theory of Copulas: An application to bias correct WRF precipitation for Germany

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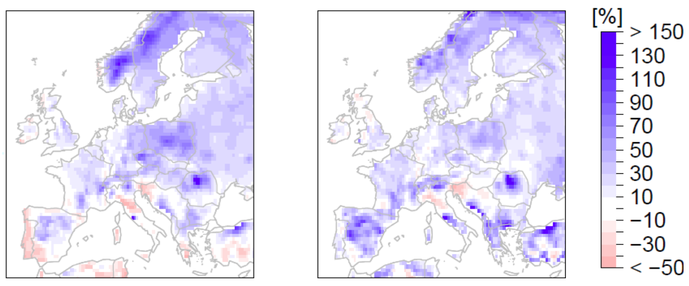
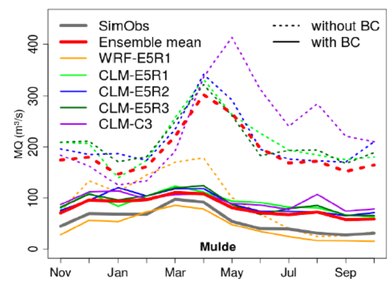
Introduction

Regional climate model (RCM) simulations often cannot be used directly for local climate change impact studies due to their inherent biases. Most of the bias correction procedures such as the quantile mapping correction employ a transfer function based on the statistical differences between RCM and observations for adjusting the RCM results. Apart from such transformation algorithms, a stochastic bias correction technique based on the concept of Copula theory is developed and applied to correct precipitation fields from the Weather Research and Forecasting (WRF) model.



Relative bias maps of annual mean precipitation for the ERA40 driven simulations with the CLM (left) and WRF (right) in comparison to the E-OBS data set from 1971 to 2000 (Berg et al., 2012)



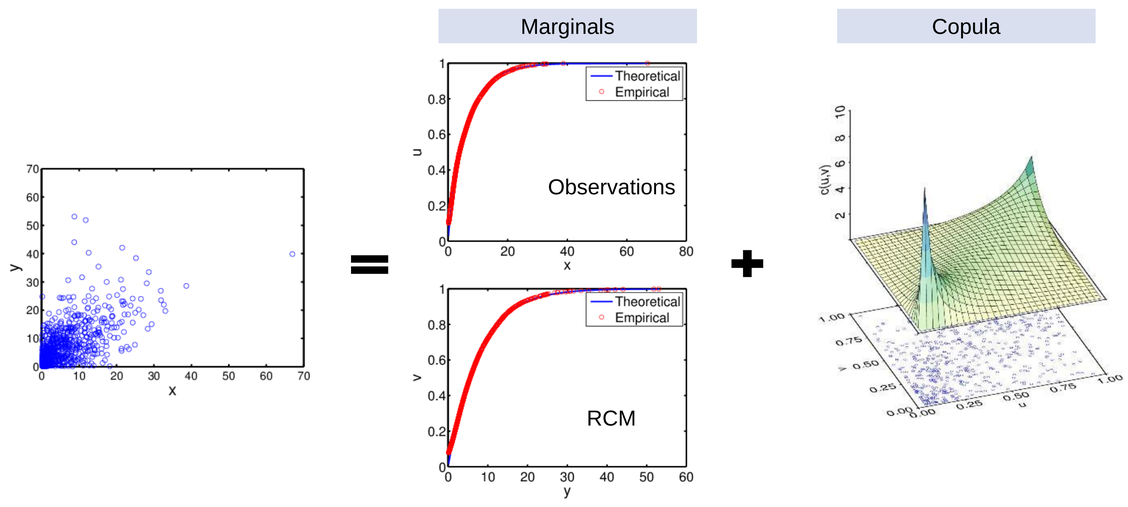
Effect of the bias corrected (BC) precipitation and temperature data to the mean monthly discharge (1971-2000) at gauge Bad Düben, Mulde. Simulations based on WaSiMETH (Ott et al., 2013)

Methodology

Copulas provide a functional link that connects multivariate probability distributions to their one-dimensional marginal distributions. The multivariate probability distribution, H, can be expressed in terms of its marginal functions F_i and the associated dependence function C (Sklar's Theorem):

$$H(x_1,\ldots,x_n) = C_\theta(F_1(x_1),\ldots,F_n(x_n)) \qquad \vec{x} \in R^n \qquad \theta = \{\Theta_1,\ldots,\Theta_k\}$$

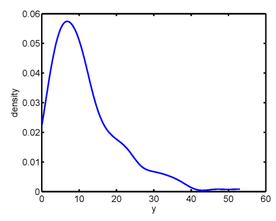
where C, called Copula, is unique if the marginal functions $F_1,\cdots,F_n$ are continuous. The Copula captures the features of dependence between the random variables. A bivariate Copula model consists of two marginal functions and a Copula function. The marginal functions describe the statistical aspects of variables and the Copula describes the dependence structure between the variables.



The Conditional distribution that derived from Copula model allows us to predict the value of one variable when the value of the other variable is given.

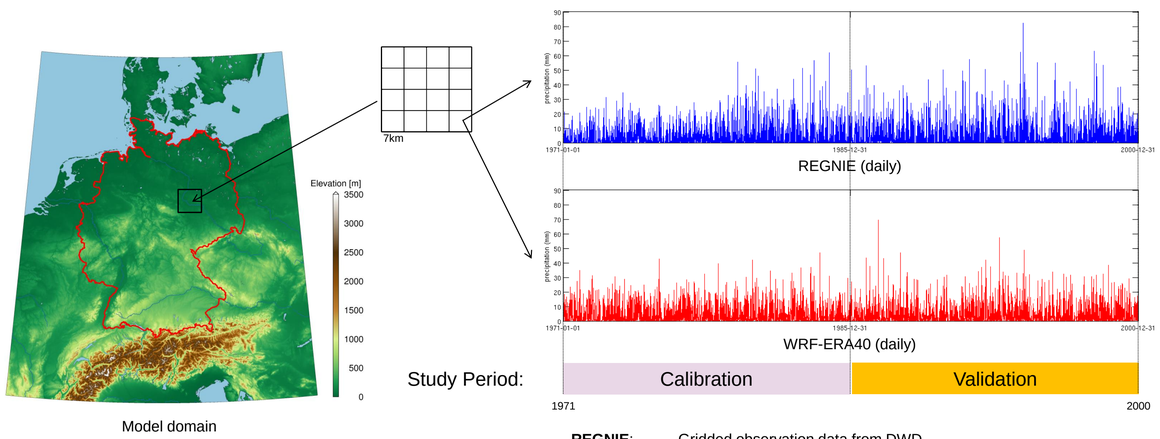
$$c_u(v) = P[V \le v \mid U = u] = \frac{\partial C(u,v)}{\partial u}$$

To assess the uncertainty associated with this prediction, the prediction process must be repeated for a large number of times. This leads to an empirical predictive distribution.



Predicted probability density function for *y, under the condition x=7.4*

Application



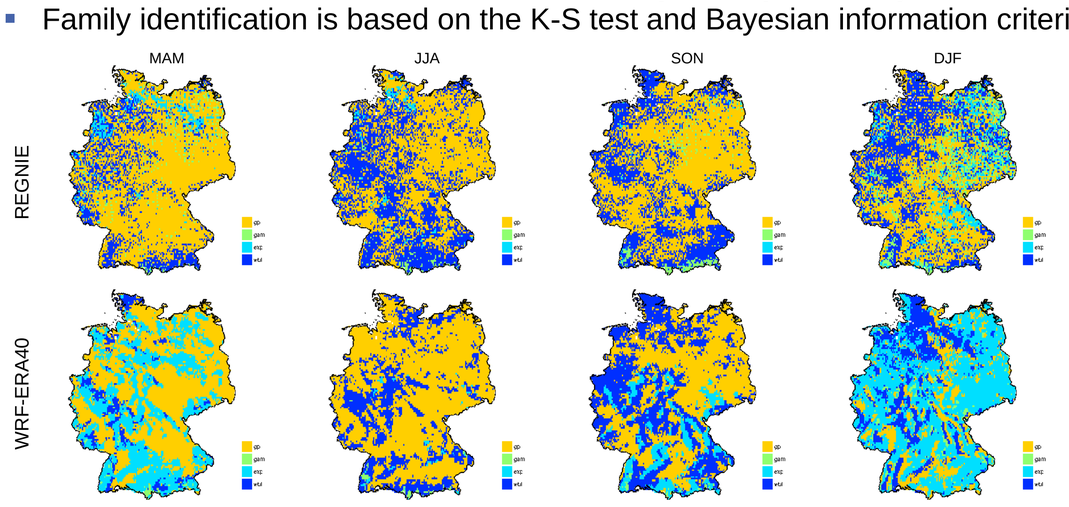
Model domain

REGNIE: Gridded observation data from DWD
WRF-ERA40: WRF simulation driven by ERA40 reanalysis data from ECMWF
Only positive pairs are considered

Results

Fitted marginal distributions from calibration period (seasonal)

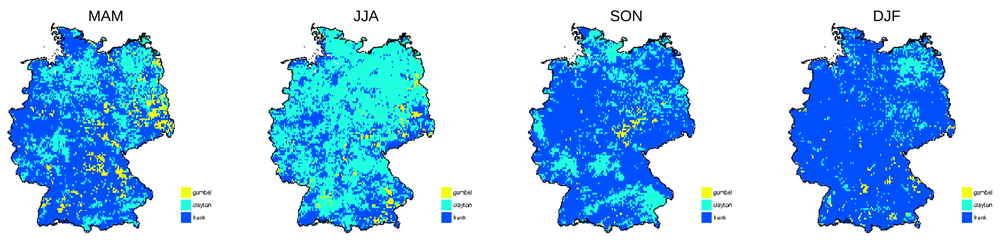
- Family identification is based on the K-S test and Bayesian information criteria



Fitted marginal distributions of REGNIE and WRF-ERA40 in different seasons

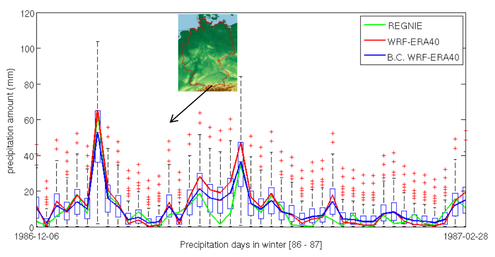
Identified Copula families from calibration period (seasonal)

- Family identification is based on the Cramér-von Mises statistic

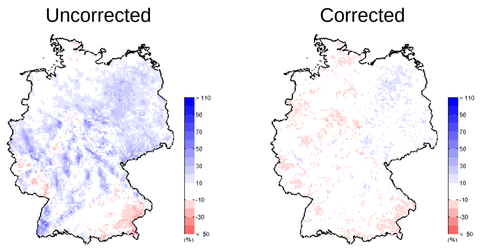


Identified Copula families in different seasons

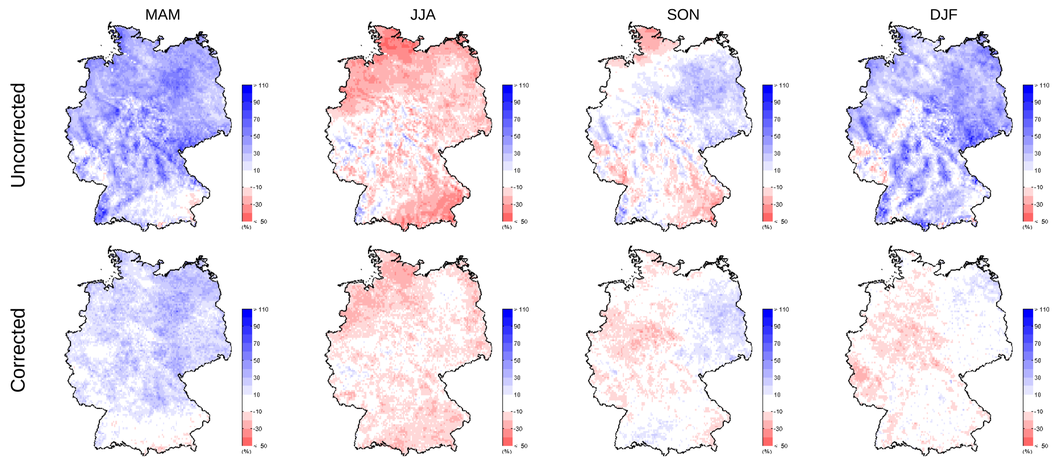
Validation of Copula-based bias correction



Comparison of bias-corrected WRF-ERA40 data (blue) with the original WRF-ERA40 data (red) and REGNIE (green) in winter 1986-1987 (positive pairs only) in Garmisch-Partenkirchen. For each time step 100 random samples are drawn from the conditional distribution. The blue line indicates the median of random samples.



Relative bias of mean daily precipitation for uncorrected (left) and corrected WRF-ERA40 precipitation field (right). The results are based on the validation period 1986-2000.



Relative bias between uncorrected and corrected WRF-ERA40 mean daily precipitation and the REGNIE data set for the different seasons

Conclusions and Outlook

- Copula based approach inherently allows for uncertainty estimation via stochastic sampling from the conditional Copula function
- Copula models are flexible as marginal distributions are independent from the Copula
- Fitted marginal distributions of REGNIE and WRF-ERA40 are different which indicates deficiencies of WRF-ERA40 simulations to reproduce the statistics of precipitation properly
- Copula based correction efficiently corrects most of the errors in WRF-ERA40 while it performs better for wet bias correction than dry bias correction
- The errors that WRF does not detect rainfall event correctly are not be able to correct by this method, and has to be investigated additionally

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