THE USE OF COPULA METHOD FOR THE BIAS CORRECTION OF MPI MODEL EXTREME PRECIPITATION IN NESTOS CATCMENT

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Summary: *Last decades, extreme climate episodes have become more frequent and intense with severe impacts in different fields such as agriculture and economy. Extreme rainfalls are one of the most severe phenomena. Consequently, scientists try to understand and analyze their characteristics in order to project their future values with climate models. Unfortunately, there are important biases between the values of climate models and observed extremes and several statistical methods are used for the reduction of these biases - bias correction techniques. The present study proposes a new bias correction method, the copula method, for correcting extreme rainfalls of the MPI regional climate model, in a Greek catchment. The results were evaluated both spatially and temporally and showed that copula is a statistical method that can satisfactorily improve the projected extreme rainfalls in the studied area.*

Key words: *copula, extremes, precipitation, bias correction, Greece*

Résumé : *Au cours des dernières décennies, les événements climatiques extrêmes, comme les pluies extrêmes, sont devenus plus fréquents et plus intenses, avec des impacts graves dans différents domaines tels que l'agriculture et l'économie. C'est la raison pour laquelle, la communauté scientifique tente de comprendre et d'analyser les caractéristiques des pluies extrêmes afin de projeter leurs valeurs futures en utilisant des modèles climatiques. Malheureusement, des biais considérables entre les valeurs des modèles climatiques et les extrêmes valeurs observés existent, subséquemment plusieurs méthodes statistiques sont utilisées pour réduire les biais. La présente étude propose une nouvelle méthode de correction de biais, la méthode copula, pour corriger les pluies extrêmes du modèle climatique régional MPI, dans un bassin versant grec. Les résultats ont été évalués aussi spatialement que temporellement et montrent que copula est une méthode statistique qui peut améliorer de manière satisfaisante les précipitations extrêmes projetées dans l'étude de cas.*

Mots clés: *copula, extrêmes, pluies, correction biais, Grèce.*

Introduction

Last decades, it is generally accepted that extreme climate events are observed with higher intensity and frequency causing severe problems in different fields such as economy, agriculture, insurances, society (Easterling et al., 2000). For example, some of the most severe drought events caused by extremely low precipitations and result in some of the most important shortfalls in many crops production (Lobell and Burke, 2008). Except of extremely low precipitations impacts, an extremely high rainfall episode is also dangerous as it can cause flood events (Frei et al., 2000). Taking into account the severe impacts of extreme rainfall episodes, scientists try to analyze and project their behavior. Climate models constitute an attractive tool for extremes projection. Unfortunately, the biases between models' projections (especially for extreme events) and observed values are important (Mearns et al. 2012; Sillmann et al. 2013). Lupo and Kininmoth (2013) prove that a serious reason why models projections diverge from the observed is the inability of models to describe of all the physical, chemical and biological procedures that observed in the atmosphere. Additionally, despite the technology evolution the computation power is still limited (Easterling et al., 2000).

In order to use climate models projections for extremes, scientists develop some statistical methods for minimizing the observed biases. The quantile mapping is one of them and it is used for the bias correction of GCM precipitations (Cannon et al., 2015). Additionally, linear correction method or the delta method (Hay et al., 2002) are also used for bias correction and their advantage is the simplicity of the procedure that they propose. Except of the linear correction methods, nonlinear methods have also been developed with improved results (Lenderink and Buishand, 2007).

In the present study, the copula method is proposed for the bias correction of extreme precipitations in a Nestos catchment, North Greece. The method was used and evaluated for its ability to improve projected extremes by climate models.

Copula is widely used statistical method in economics and insurances (Hu, 2006; Li, 2006; Goodwin, 2014; Yaoting, 2002) as well as, during the last decades in hydrology. Particularly several researchers try to model the dependence between two or more characteristics of drought episodes (Shiau, 2006; Shiau, 2009; Chen, 2012) while a general analysis of hydrological episodes and parameters had also been achieved with this method (Favre, 2004; Salvadori, 2007; Renard, 2007). The main advantage of this method - describe the correlation of the studied variables not only linearly as the correlation indices - results in its use more frequently.

1. Data and Method

1.1 DATA

In the present research, daily precipitation values over the Nestos Catchment in the North-East part of Greece, are used (Figure 1). The values cover a period of 20 years starting from 1981 to 2000 and they are coming from two sources: i) The re-analysis dataset of the European Climate Assessment & Dataset (ECA&D) (Haylock et al, 2008) with spatial resolution of 0.25° x 0.25° and ii) the Regional Climate Model dataset of the Max Plank Institute (MPI model) with spatial analysis 0.5° x 0.5°.

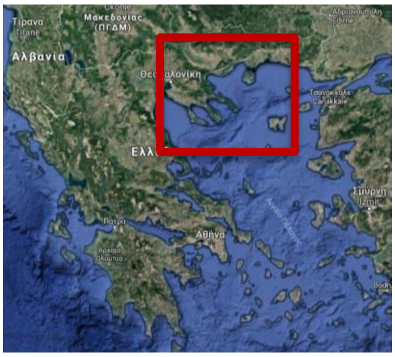

Figure 1. The studied area – Nestos catchment.

1.2 METHODOLOGY

Copula is a multivariate function which have normally distributed marginals between [0,1] (Nelsen, 1999). According to Sklar (1959) when the marginal distributions of the studied parameters are continues, then the copula function is unique. This is the most important theorem of the copula method, as it means that every joint distribution of two or more variables can uniquely be decomposed into continues distributions of the variables and to a copula function. The general mathematical explanation of copula for n variables is: Assuming that X= (x_1, x_2,…x_n) is a vector of n random variables and F_i is the marginal distributions - cumulative function - of each variable respectively, then the mathematical type of the joint distribution of these variables is a copula family C: $[0,1]^n \rightarrow [0,1]$ for all $x=(x_1,x_2,\ldots x_n) \in R^n$, and is equal to $F(y)=C\{F_1(x_1),\ldots F_n(x_n)\}$. According to the above analysis, copula C, of two or more random variables X, is a mathematical function that models the marginals $F_1,\ldots F_n$ to the joint distribution F ($X \sim F=C(F_1,..F_n)$). (Patton, 2009; Patton, 2012)

In the present study for the bias correction of MPI model's extreme precipitations, some sequel steps have been followed. Firstly, for every MPI grid point the closer E-OBS grid was chosen as default, for the correction and the evaluation of the proposed method. After that, the copula family which describes more satisfactorily the dependence between mean and extreme monthly precipitations of each E-OBS grid point was chosen. It should be mentioned that for the selection of the best copula family, more than 10 copula families have been tested from both Elliptical and Archimedean categories. The tested families are: Clayton, Frank, Gaussian, Student, Joe, BB1, BB6, BB7, Tawn type 1 and 2. Following the selection of the appropriate family in every grid, the MPI's extreme precipitation combined with the selected copula family and the bias corrected extremes were simulated. Finally, the bias corrected values were compared with the corresponding E-OBS extremes with different statistical methods in order to evaluate the copula method for extremes bias correction.

2. Results

The dependence between E-OBS mean and extreme rainfalls was described with the selected copula family in each grid point. Using MPI extremes in combination with the copula function, the MPI's bias corrected extremes were found. The bias corrected extremes were compared with both MPI and E-OBS extremes for the evaluation of the copula method. The evaluation was made in both spatially and temporally base.

A comparison between the E-OBS extreme precipitations and MPI's extreme rainfalls before and after the bias correction was accomplished for all the 45 grid points that cover the studied area. The results were similar for most of grid points. Consequently, the line plots for one grid are presented in Figure 2. It should be mentioned that the selection of the one grid was random and the behavior of extremes for almost all the other girds was the same with small differences in extreme precipitation amounts.

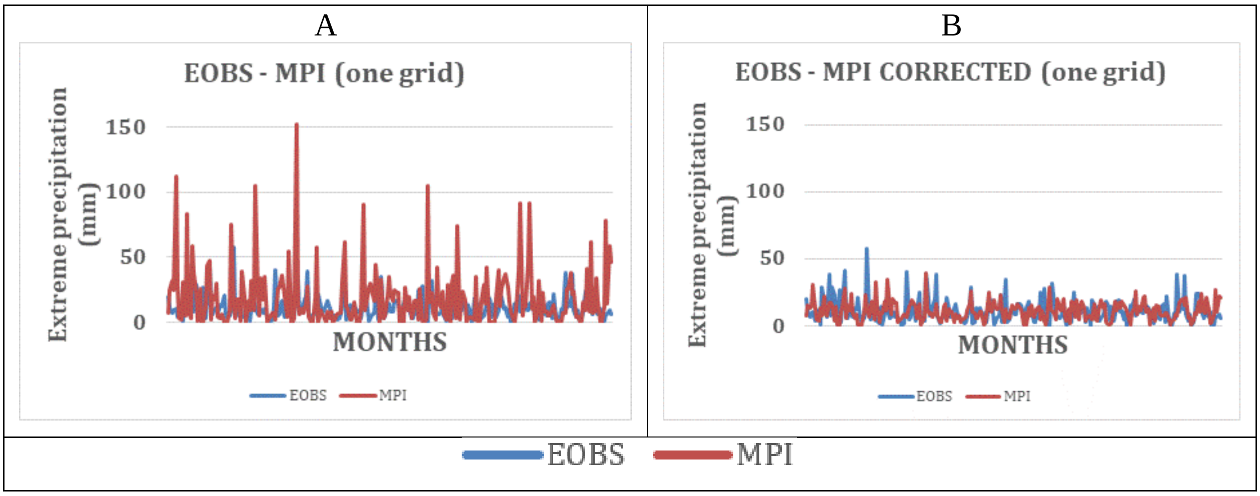

Figure 2. Extreme precipitations during the 20 studied years for one random grid of the studied area. A) presents the extremes' time series for E-OBS and MPI data and B) for E-OBS and bias corrected MPI data.

According to Figure 2A, MPI model overestimate the extreme monthly rainfalls for the majority of the studied months (from 1981 to 2000). The studied grid presents extreme precipitations that do not exceed the 60 mm, while according to MPI during several months the recorded extreme rainfall exceeds the 100 mm. Moreover, in some cases the overestimation of the MPI is greater than 100 mm. On the other hand (Figure 2B), after the bias correction, the new data set is much closer to the E-OBS extremes and as Figure 2B shows in some months there is an underestimation of the E-OBS extremes.

2.1 Temporal evaluation for the whole region (mean grid)

The results for one grid have been presented and analyzed. In the present session an average of the results from the 45 grids that cover the studied region were analyzed. Figure 3 presents the average of the monthly extreme rainfalls for the 45 grids according to the EOBS, MPI and MPI bias corrected data set. As it can be seen in Figure 3 the MPI model, overestimate the extreme precipitation of the area during the whole studied period, while after the bias correction the results are closer to the E-OBS. Additionally it is shown that there are some months when the MPI extremes before the correction were greater than 50mm, while the E-OBS values for the same months were almost 25 mm. After the bias correction, extremes are closer to the E-OBS data set as it is equal to 20 mm.

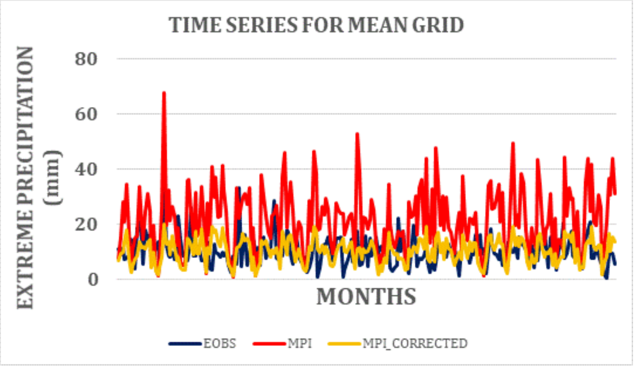

Figure 3. The average of extreme precipitations of the 45 grids, covering the studied area. With the blue color E-OBS values were described, with the red the MPI values and with yellow the MPI bias corrected.

2.2 Spatial evaluation

Except of the temporal evaluation of the copula method for bias correction, a spatial analysis is also occurred for the studied area. Particularly, the average of the extremes in every grid were calculated for the three studied data sets (E-OBS, MPI, MPI bias corrected). After that, the differences between the MPI and E-OBS data sets and the bias corrected MPI and E-OBS data were estimated and plotted in Figure 4A. According to the results (Figure 4A), the MPI model, present important differences from the E-OBS data set. In almost whole studied area (except a small part in the sea), the MPI extremes are greater than E-OBS and in some continental regions (as Thrace), the overestimation is greater than 20mm. On the other hand, the bias corrected MPI extremes (Figure 4B) approach satisfactorily E-OBS extremes in the studied area and the differences range between -1 to 1 mm. A more detailed analysis of Figure 4B is presented in Figure 4C where the color scale describes the differences with a range of 0.25mm. According to Figure 4C the bias corrected MPI extremes underestimate the E-OBS extreme values almost for 1mm while in some continental areas the underestimation is less than 0.5mm.

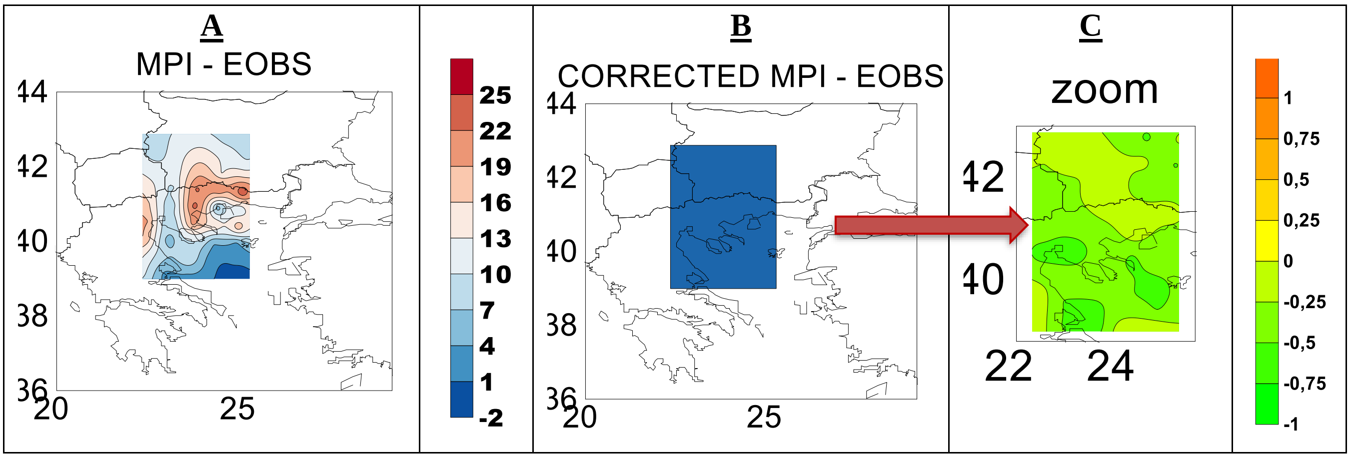

Figure 4. Spatial analysis of differences between A) MPI and E-OBS extreme rainfalls and B) bias corrected MPI and E-OBS extreme rainfalls. 4C presents a more detailed analysis of the map between bias corrected MPI and E-OBS extremes as the differences are lower and they are not distinguished with the color scale of the first maps.

Conclusions and Discussion

The present study aims to present a new statistical method - the copula method - for the bias correction of extreme precipitations in the region of Nestos catchment. Daily rainfall records from both E-OBS and MPI model were used. The E-OBS values were the default values and the bias correction method was applied in MPI extremes. Both a spatial and temporal analysis occurred for the evaluation of copula method. Previous studied have tested the copula method for the bias correction of mean not extremes temperatures (Mao, 2015) and precipitation data (Alidoost et al, 2017). The results of these studies are in accordance with the present study as the copula method is appropriate for the bias correction of the studied data sets. Specifically, copula method is proposed for the correction of extreme rainfalls in the studied area, as the MPI model overestimates sifnifically the E-OBS values while after the bias correction, the differences are lower. Despite the good results of studies using copula, most of researchers agree that copula method is a useful tool, but further investigation is needed in the future for its use (Mao et al,2015; Alidoost et al. 2017).

Acknowledgments

This research is co-financed by Greece and the European Union (European Social Fund-ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project "Strengthening Human Resources Research Potential via Doctorate Research" (MIS-5000432), implemented by the State Scholarships Foundation (IKY)».

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