CLIMATE CHANGE AND ITS IMPACT ON ANNUAL MAXIMUM PRECIPITATION USING HIGH RESOLUTION REGIONAL CLIMATE SIMULATIONS FOR THE REGION OF IGOUMENITSA

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Summary: *This study analyzes high spatial resolution simulations (0.11^ox0.11^o) out of ten regional climate models (RCMs) from the EURO-CORDEX initiative, to quantify the impact of climate change on annual maximum precipitation events in the region of Igoumenitsa, Greece. The examined historical spans from 1971-2000 and the two future periods range from 2021-2050 and 2071-2100. In each future period two Representative Concentration Pathways (RCPs) are taken into consideration, the RCP4.5 and the RCP8.5. The results for the RCP4.5 and the RCP8.5 indicates that for the first future period, the annual maximum precipitation increases by 8% and 16.5%, while in the second future period it increases by 22% and 32.1% respectively. The Intensity-Duration-Frequency (IDF) curves show that in both future periods the intensity of precipitation increases. This work highlights the need of using ensemble of future climate projections from RCMs to estimate flood episodes in accordance with structure resilience under the anticipated anthropogenic future climate change.*

Key words: *Annual Maximum Precipitation, Climate Change, Regional Climate models, Floods*

Introduction

The use of RCMs for dynamical downscaling to higher resolution is necessary to assess the regional and sub-regional climate of the complex topographically area of Greece (Zanis et al., 2015) while the Mediterranean is recognized among the most responsive regions to climate change (Giorgi, 2006). Climate change may alter the climate extremes, especially at the eastern part of the Mediterranean (Tolika et al. 2008; Kioutsioukis et al. 2010). Notably, positive trends of extreme daily precipitation was estimated for Greece (Nastos and Zerefos 2008). The intensity and the potential changes of extreme precipitation due to climate change may cause flood events, which are considered as a factor for a structure resilience (EL05). Recently a new high-resolution regional climate change ensemble has been established for Europe within the World Climate Research Program Coordinated Regional Downscaling Experiment (EURO-CORDEX) initiative with a horizontal resolution of 0.11^o (Jacob et al., 2014). Thus, in this work we attempt to provide a comprehensive estimation of future climate change impact on the annual maximum precipitation over the region of Igoumenitsa, using high resolution climate simulations from EURO-CORDEX.

1. Data and Method

1.1 Observational Data

The study area is located at the northern western Greece, in the province of Igoumenitsa (Figure 1). Meteorological measurements of daily aggregated precipitation ($mm \cdot day^{-1}$) have been used from the station of Corfu for the period 1971-2000. The meteorological station of Corfu is located near the airport of the main city of the island and is a part of the Hellenic

National Meteorological Service network. Although the station of Corfu is 36km away from the study area, it is the closest coastal, low altitude station that resemblance the climate conditions of the study area.

1.2 Simulated Data

The simulations are a product of various Regional Climate Models (RCMs) driven by Global Climate Models (GCMs). Table 1 depicts the simulations that have been used on this study. The RCM simulations cover the EURO-CORDEX domain, have a high spatial resolution (0.11 degrees) and cover a time period from 1950 to 2100. The historical period of each experiment refers to 1950-2005, while the future projection period is 2006-2100 under the influence of two Representative Concentration Pathways (RCPs) adopted by the IPCC for its fifth Assessment Report (AR5); RCP4.5 and RCP8.5. For this study, the part of the historical period that was analyzed ranges from 1971-2000 and the two future periods range from 2021-2050 and 2071-2100. In order to cover the full extent of the study area, four neighboring grid cells have been selected (Figure 1). The four timeseries have been averaged to create a mean timeseries for each simulation.

Table 1. An overview of the climate simulations used on this study, along with the regional climate model, the global climate model used as driver and the total period of each experiment.

ID	*Regional Climate Model*	*Global Climate Model (Driver)*	*Period*
M1	CLMcom-CCLM4-8-17	CNRM-CERFACS-CNRM-CM5	1950 Jan – 2100 Dec
M2	CNRM-ALADIN53	CNRM-CERFACS-CNRM-CM5	1950 Jan – 2100 Dec
M3	SMHI-RCA4	CNRM-CERFACS-CNRM-CM5	1970 Jan – 2100 Dec
M4	KNMI-RACMO22E	ICHEC-EC-EARTH	1950 Jan – 2100 Dec
M5	IPSL-INERIS-WRF331F	IPSL-IPSL-CM5A-MR	1951 Jan – 2100 Dec
M6	SMHI-RCA4	IPSL-IPSL-CM5A-MR	1970 Jan – 2100 Dec
M7	CLMcom-CCLM4-8-17	MOHC-HadGEM2-ES	1949 Dec – 2099 Nov
M8	SMHI-RCA4	MOHC-HadGEM2-ES	1970 Jan – 2099 Nov
M9	CLMcom-CCLM4-8-17	MPI-M-MPI-ESM-LR	1949 Dec – 2100 Dec
M10	MPI-CSC-REMO2009	MPI-M-MPI-ESM-LR	1950 Jan – 2100 Dec

1.3 Methods

1.3.1 Calibration of the simulated annual maximum precipitation

The IDF curves are highly dependent on the distribution of annual maximum precipitation (30years=30values for each period) and not on the low/mid values of daily precipitation. The IDF is not affected by the year to year changes of the annual max precipitation timeseries that is used for its creation. Thus, the Ensemble (ENS), which is the average outcome of all experiments, was created after sorting the annual max precipitation in ascending order.

Although ENS distribution is pretty close to the OBS distribution, there is still a combination of models (Best Ensemble; BENS), that can match better the annual maximum precipitation of OBS. Thus, all the available combinations between the ten regional climate simulations (1023 combinations) were estimated. Each combination is generated by averaging the sorted in ascending order annual maximum precipitation timeseries of two to ten climate models in each case. The Root Mean Square Error (RMSE) was one of the metrics used in order to identify the BENS. RMSE can be interpreted as the standard deviation around zero and is a performance metric that takes into account both bias and variance. Mathematically is a sequence of the mean difference (m_{diff}) to the standard deviation difference (sd_{diff}) between two datasets:

$$m_{diff} = mean(\sum_{i=1}^{n} mod_i - obs_i) \qquad sd_{diff} = sd(\sum_{i=1}^{n} mod_i - obs_i) \qquad RMSE = \sqrt{m_{diff}^2 + sd_{diff}^2}$$

where mod is the combination of the models, obs is the OBS dataset, n is the length (timesteps) of the datasets. Additionally the standard deviation and the 95% confidence interval of the mean for each combination, which indicates the range of annual maximum precipitation for each combination, was taken into account for the selection of BENS. The BENS is derived by a combination of 8 out of 10 models (M1,M4,M5,M6,M7,M8,M9,M10) with RMSE, StDev and CI equal to 0.131, 0.9 and 0.75 respectively. Indicatively it is noted that the RMSE of ENS is 0.277 and it underestimates the higher values of OBS distribution.

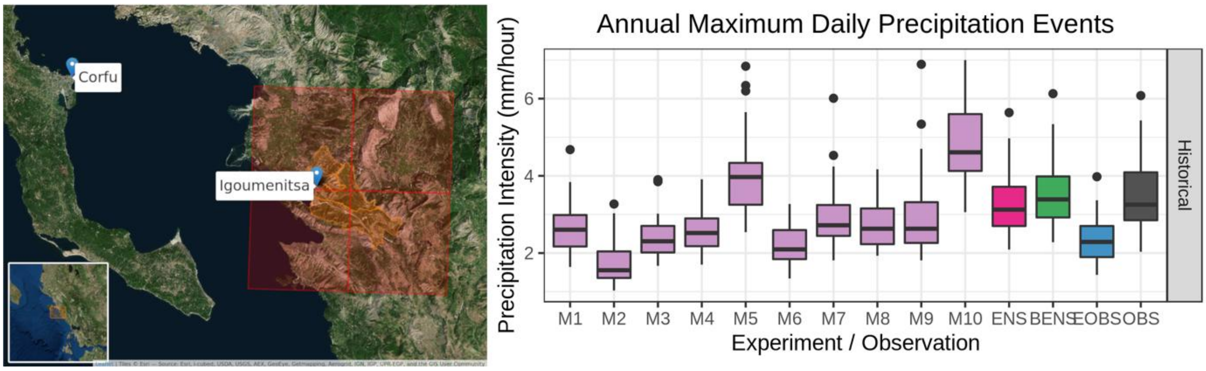

Figure 1. On the left, the study area (orange polygons) and the four selected grid cells (red boxes) of the regional climate model simulations. On the right, the annual maximum precipitation intensity ($mm \cdot hour^{-1}$) derived from daily data for the 10 regional climate simulations (M1 to M10), their Ensemble (ENS), the Best Ensemble (BENS) and the station at Corfu (OBS) regarding the period 1971-2000.

1.3.2 Intensity-Duration-Frequency (IDF) curves

The IDF curves are a statistical method of estimating the extreme precipitation of a region. Essentially its curve represents the return period of an extreme precipitation event (years), while the horizontal and the vertical axis depict its intensity ($mm \cdot hour^{-1}$) and duration (hours). In order to estimate the IDF curves, the maximum annual precipitation has to be calculated for at least two durations, which may be ranging from 5 minutes, up to 2 days. Since the original temporal resolution of our meteorological measurements is daily, annual maximum precipitation was computed for 24 and 48 hours according to the hydrological year, which starts at the 1^{st} of October. This values have been multiplied with the typical coefficients, 1.13 and 1.04 respectively, which accounts for the correction of aggregated daily measurements from rain gauge (Linsley et al., 1975).

The IDF curves were created using the Hydrognomon software (http://hydrognomon.org/). The input data were consisted by annual maximum precipitation intensity (mm/hour) in two duration (24h and 48h). The 50% highest intensity of precipitation for every duration was used as a sample to calculate the IDF using the statistical distribution function GEV-Max (kappa specified – L Moments). The GEV-Max (kappa specified - L Moments) statistical distribution function is associated with five parameters that define the shape (κ), the scale (λ), the location (ψ), the curvature (θ) and the slope (η) of the IDF curves, for specific duration (D in hours) and return periods (F in years):

$$I_{(d,T)} = \frac{\lambda \cdot \psi + \frac{\lambda}{\kappa}\left[\left(-ln\left(1 - \frac{1}{F}\right)\right)^{-\kappa} - 1\right]}{(D + \theta)^{\eta}} (mm \cdot hour^{-1})$$

It is noted that for the accurate estimation of the slope (η), curvature (θ) and shape (κ) parameters requires data from multiple stations with high frequency precipitation measurements (up to 5 minutes). Thus, this values were acquired from a prior study (EL05) and kept constant though out the data sets used in this study (η=0.667, θ=0.334, κ0.108). Furthermore the analysis of this study is focused on duration higher than 12 hours.

2. Results

2.1 Historical period (1970-2000)

The IDF curves of ENS and BENS along with the OBS in the background are depicted in Figure 2 for the historical period (1970-2000). Both of the simulated IDF are quite close to the values of the observation, although ENS underestimates precipitation especially on events with return period 50, 500 and 5000 years. The standard deviation of the mean for BENS, which was derived by combining eight climate models, is ±29%. Which means for example that a 24hours precipitation event with return period 100 years will have mean intensity 7.3mm·hour^{-1} that ranges between a low 5.2mm·hour^{-1} and a high 9.4mm·hour^{-1} value.

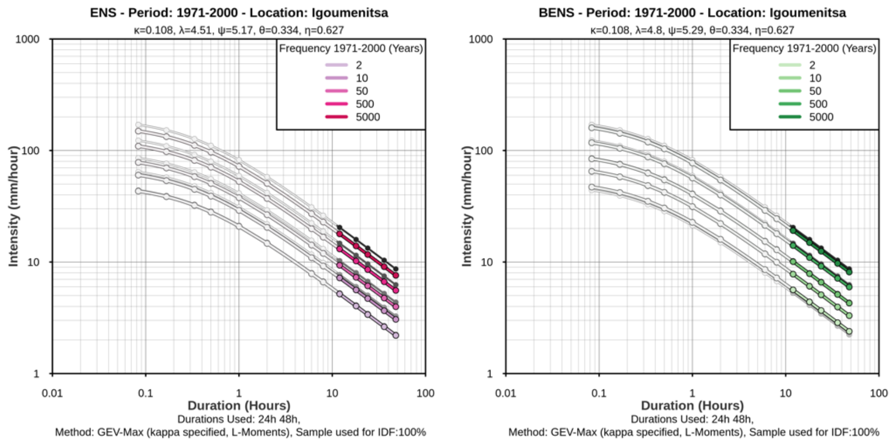

Figure 2. IDF curves with return period 2, 5, 50, 500, 5000 years regarding the period 1971-2000 and the study area over Igoumenitsa for (a) ENS and (b) BENS. In both cases OBS IDF is depicted for comparison.

2.2 First future period (2021-2050)

For the first future climate period the annual maximum precipitation for the scenarios RCP4.5 and RCP8.5 increased by 8% and 16.5% respectively. This increase is linearly growing from low to high values, with low values having an almost zero change in comparison to the historical period. Since future annual maximum precipitation is increased, future IDF curves values are increased too (not shown). For example, in the historical period, a 24 hour precipitation event with return period 50 years is estimated to have 6.6mm·hour^{-1}, while at the first future period a similar event is estimated to have 7.8mm·hour^{-1} (+18%) 8.5mm·hour^{-1} (29%) for the RCP4.5 and RCP8.5 climate scenarios respectively.

2.3 Second future period (2071-2100)

In the second future climate period (2071-2100) the increase of the intensity of annual maximum precipitation due to climate change is even more evident. Under the scenario RCP4.5 the intensity increase by 22% while for the RCP8.5 by 32.1%. It is noted, that although under the scenario RCP4.5 the emission of greenhouse gases were constrained by the year 2040 and the radiative forcing was kept under 4.5W·m^{-2} throughout the century, the intensity of annual maximum precipitation kept growing during 2071-2100 in comparison to the previous 2021-2050 period. IDF precipitation intensity grows even more in the second future period in comparison to the historical period (Figure 3). A 24hour precipitation event with return period 50 years is estimated to have intensity 8.5mm·hour^{-1} and 9.1mm·hour^{-1} for the scenario RCP4.5 and RCP8.5 respectively, which is +29% and +38% higher from what was estimated during the historical period.

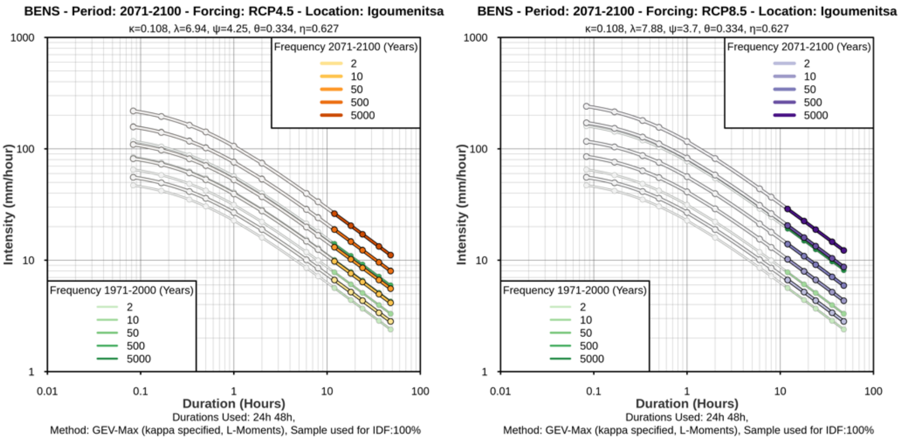

Figure 3. IDF curves with return period 2, 5, 50, 500, 5000 years regarding the period 2071-2100 and the study area over Igoumenitsa for the BENS under the climate scenario (a) RCP4.5 and (b) RCP8.5. In both cases BENS IDF of the historical period is depicted for comparison.

2.4 Climate change and IDF uncertainty

In previous studies (EL05), climate change impact on IDF has been quantified statistically, since it was based only on historical measurements of precipitation, using the 80% confidence interval of the mean around the IDF curves with return period 50, 100 and 1000 for several regions. For the region of Igoumenitsa, the lower boundary of this statistical estimation of climate impact is derived by multiplying 0.876, 0.843 and 0.723 with the actual values of IDF curves with return period 50, 100 and 1000 years. Respectively for the upper boundary these values are 1.109, 1.148 and 1.330.

In the present study, climate change impact is quantified using future projections of regional climate models under specific two RCP scenario. The error of this methodology is accounted using the standard deviation of the mean of those models. For the first future period and for both RCP4.5 and RCP8.5, the range of uncertainty estimated with the prior statistical methods lies between the lower boundary and the mean that was calculated with the current method that make use of the climate models (not shown). For the second future period, and especially for the intense RCP8.5 scenario, the range of values estimated by the prior statistical method are even lower than the lower boundary that was estimated with the current method (Figure 4), which indicates that the impact of climate change on annual maximum precipitation may be higher than previously unanticipated.

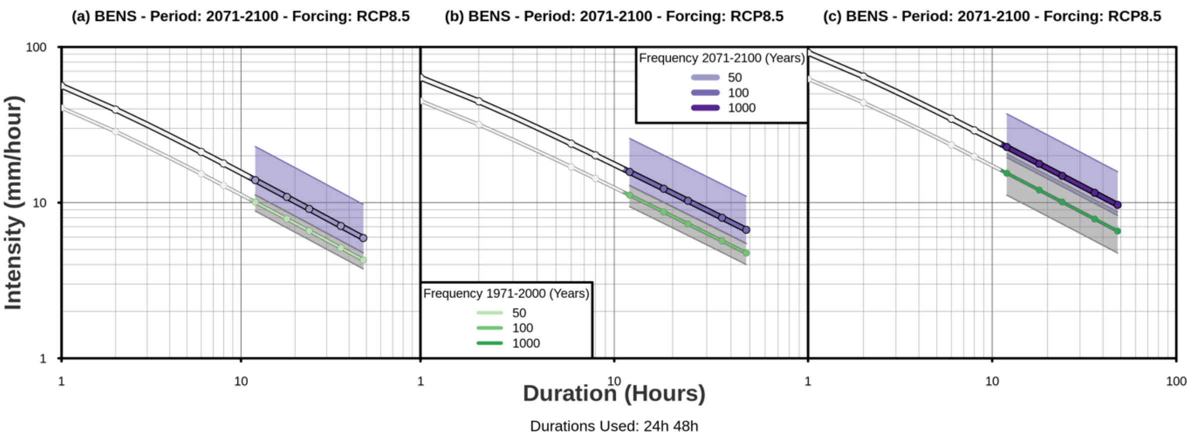

Figure 4. IDF curves with return period 2, 100, 1000 years regarding the period 2071-2100 and the study area

over Igoumenitsa for the BENS under the climate scenario RCP8.5. In both cases BENS IDF of the historical period is depicted for comparison. The shaded areas depicts the climate change uncertainty as it was previously estimated (reference; grey) and how it is estimated by the present study with the use of climate models (purple).

Conclusions and Discussion

The current study aims to provide a comprehensive approach on the impact of climate change on the annual maximum precipitation and the IDF curves over the region of Igoumenitsa, Greece. This is achieved by using data from high resolution climate simulations that were conducted in the framework of EURO-CORDEX. The simulated data were evaluated and calibrated based on daily precipitation measurements from the nearby meteorological station of Corfu. The analysis focused on the historical (1971-2000) period and two future periods (2021-2051 and 2071-2100) under RCP4.5 and RCP8.5 scenarios. Annual precipitation increased for both the first future period by 8% and 16.5% as well as the second future period by 22% and 32.1% under the RCP4.5 and RCP8.5 scenarios respectively. Equivalent rise was observed for the precipitation intensity given by the Intensity-Duration-Frequency (IDF) curves for the future periods/scenario. Furthermore, it is noted that previous studies may have significantly underestimated the impact of climate change on annual maximum precipitation events and IDF.

Acknowledgments

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