MULTI-MODEL APPROACH FOR PROJECTING EXTREMES RELATED TO THE LACK AND EXCESS OF PRECIPITATION IN CENTRAL/EASTERN EUROPE

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ABSTRACT

Frequent hot weather in summer and overall increasing warm regional climatic conditions are quite straightforward local-scale consequences of global warming. Regional warming induced effects on precipitation are less clear than in case of temperature because the higher spatial and temporal variabilities might hide any robust changing signal. Nevertheless, precipitation is one of the most important meteorological variables since it considerably affects natural ecosystems and cultivated vegetation as well, as most of human activities. Extreme precipitation events – both excessive, intense rainfalls and severe droughts – may result in several environmental, agricultural, and even economical disasters. The lack of precipitation for extended period and coincidental intense heat wave often lead severe drought events. In order to avoid or at least reduce the effects of these precipitation-related hazards, national and local communities need to develop regional adaptation strategies, and then, act according to them. For this purpose, analyzing future precipitation projections is essential, for which results of global climate model (GCM) simulations must be downscaled to regional and local scales, hence better serving end-users' needs. From the agricultural point of view, especially potential dry conditions induce long-term planning, for which estimation of precipitation is evidently the key element.

In order to analyze the estimated trends of precipitation- and drought-related climate indices we used a multi-model approach taking into account of 11 regional climate model (RCM) simulations from the ENSEMBLES project (van der Linden and Mitchell, 2009) with 25 km horizontal resolution using the emission scenario A1B (Nakicenovic and Swart, 2000). Validation analyses (Pongrácz et al., 2011) for the Central/Eastern European region showed that simulated precipitation values significantly underestimate the observations in summer and overestimate them in the rest of the year. Therefore, we applied quantile matching bias correction technique (Pongrácz et al., 2014) to eliminate these systematic errors. Thus, the monthly empirical distribution functions of each grid cell for each RCM simulation were fitted to the observed distributions using reference-data from E-OBS (Haylock et al., 2008) and CARPATCLIM (Szalai et al., 2013); then, the calculated multiplicative bias correcting factors are applied to the raw outputs of individual RCM experiments. After the correction, we analysed several precipitation-related climate indices for the 1961-2100 time period both on seasonal and annual scales.

According to our results, regional climate change results in more intense and more frequent precipitation extremes in Central/Eastern Europe. For instance, in case of consecutive dry days ~50% increase is estimated in summer, hence substantially drier climatic conditions are projected for the future (Pongrácz et al., 2013, 2014) - especially in the southern parts of the region. In winter and autumn more heavy precipitation days and more intense precipitation are very likely to occur in the 21st century (Bartholy et al., 2015). Overall, the Central/Eastern European region should be prepared both for more intense floods and droughts in the future.

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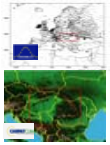
DATA: Precipitation simulations – ENSEMBLES daily outputs

The table lists the RCM experiments used in this analysis, the responsible institutes, and the driving GCMs
Horizontal resolution of all RCM experiments: 25 km (van der Linden and Mitchell, 2009)
Estimated CO_2 level according to the applied SRES A1B scenario by 2100: 717 ppm (Nakicenovic and Swart, 2000)
Driving GCMs: ECHAM (MPI-M, DE) - Roeckner et al. (2006)
HadCM3Q (UKMO, UK) - Gordon et al. (2000); Rowell (2005)
ARPEGE (CNRM, FR) - Déqué et al. (1998)

Institute	Driving global model	Regional model
HC (Hadley Centre, United Kingdom Met Office)	HadCM3Q0	HadRM3Q0
ETHZ (Swiss Federal Institute of Technology Zurich)	HadCM3Q0	CLM
C4I (Community Climate Change Consortium)	HadCM3Q16 (high sensitivity version)	RCA3
SMHI (Swedish Meteorological and Hydrological Institute)	HadCM3Q3 (low sensitivity version)	RCA3
	ECHAM-r1	RCA3
ICTP (International Centre of Theoretical Physics)	ECHAM5-r3	RegCM
KNMI (Royal Netherlands Meteorological institute)	ECHAM5-r3	RACMO
MPI (Max-Planck-Institut für Meteorologie)	ECHAM-r3	REMO
DMI	ECHAM5-r3	HIRHAM5
(Danish Meteorological Institute)	ARPEGE	HIRHAM5
CNRM (Centre National de la Recherche Scientifique)	ARPEGE_RM.1	ALADIN

DATA: Reference databases

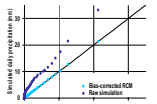
	E-OBS	CarpatClim
Reference	Haylock et al., 2008	Szalai et al., 2013
Time period used for correction	1961–2000	1961–2010
Area	Europe (land): 43.625° – 50.625° N 13.875° – 26.375° E	Carpathian Region: 44° – 50° N 17° – 27° E
Horizontal resolution	0.25°	0.1°
Subregions defined in our analysis	SE-CZ, E-AT, SK, SW-UK, SI, HU, RO, CR, N-SR	**SK/C**: UA/C, **HU/C**, **RO/C**, SR/C



The applied bias-correction method

Percentile-based quantile matching bias correction (Formayer and Haas, 2010):
The monthly distribution function is fitted to the reference (E-OBS/CarpatClim) distribution function using multiplicative factors.

$$\varepsilon_{mo}(y) = F_o^{-1}(y)/F_m^{-1}(y) = x_o/x_m$$
$$x_c = x_m \cdot \varepsilon_{mo} = x_m \cdot x_o/x_m = x_o$$

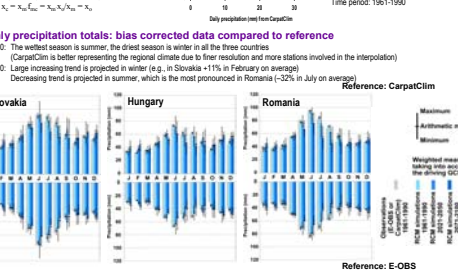


Example:
January daily precipitation data
Simulation:
RACMO RCM driven by ECHAM GCM
Grid cell location:
47.625°N, 19.125°E;
Reference: CarpatClim
Time period: 1961-1990

Monthly precipitation totals: bias corrected data compared to reference

1961–1990: The wettest season is summer, the driest season is winter in all the three countries
(CarpatClim is better representing the regional climate due to finer resolution and more stations involved in the interpolation)

2071–2100: Large increasing trend is projected in winter (e.g., in Slovakia +11% in February on average)
Decreasing trend is projected in summer, which is the most pronounced in Romania (–32% in July on average)



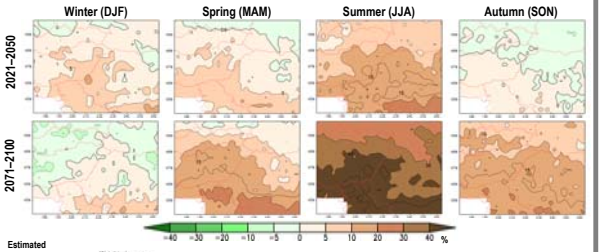
Precipitation indices

Several types of extreme indices can be defined (e.g., Karl et al., 1999) for describing extreme meteorological/climatological events related to precipitation:
(i) based on exceeding various threshold values, which can be an absolute value or a given percentile of long climatological time series
(ii) more complex indices consider duration, intensity, and/or persistence of the events

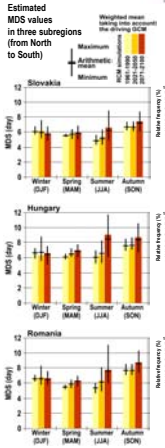
Index	Definition	Unit	
DD	Number of dry days (R_{day} < 1 mm)	day	Drought and non-extreme precipitation
CDD	Maximum number of consecutive dry days (Max (R_{day} <1 mm))	day	
MDS	Mean length of dry spell (Mean (R_{day} <1 mm))	day	
MWS	Mean length of wet spell (Mean (R_{day} ≥ 1 mm))	day	
RR1	Number of precipitation days exceeding 1 mm (R_{day} ≥ 1 mm)	day	
RR5	Number of precipitation days exceeding 5 mm (R_{day} ≥ 5 mm)	day	
RR10	Number of precipitation days exceeding 10 mm (R_{day} ≥ 10 mm)	day	Extreme precipitation
RR20	Number of precipitation days exceeding 20 mm (R_{day} ≥ 20 mm)	day	
CWD5	Maximum number of consecutive precipitation days exceeding 5 mm (Max (R_{day} ≥ 5 mm))	day	
R90p	The 90th percentile value of daily precipitation time series	mm	
R95p	The 95th percentile value of daily precipitation time series	mm	
R99p	The 99th percentile value of daily precipitation time series	mm	
R90pGT	$\sum R_{2071-2100} > R90p_{1961-1990}) / \sum R_{2071-2100}$	%	
R95pGT	$\sum R_{2071-2100} > R95p_{1961-1990}) / \sum R_{2071-2100}$	%	
R99pGT	$\sum R_{2071-2100} > R99p_{1961-1990}) / \sum R_{2071-2100}$	%	
RX1	Highest 1-day precipitation total ($R_{max,1day}$)	mm	Precipitation intensity
RX5	Highest 5-day precipitation total ($R_{max,5day}$)	mm	
SDII	Simple daily intensity index ($\sum$R/RR1)	mm/day	

RESULTS: MEAN DRY SPELL (MDS)

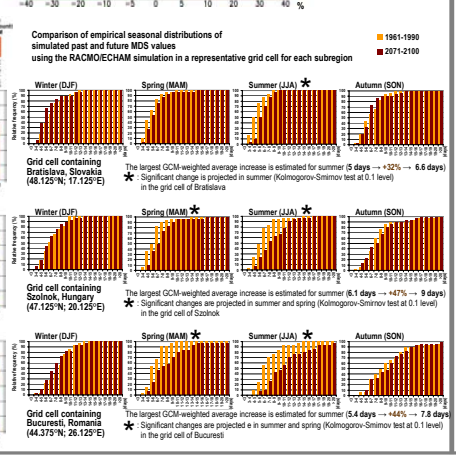
Composite maps showing the projected seasonal mean changes relative to the reference period, 1961–1990



Estimated MDS values in three subregions (from North to South)



Comparison of empirical seasonal distributions of simulated past and future MDS values using the RACMO/ECHAM simulation in a representative grid cell for each subregion



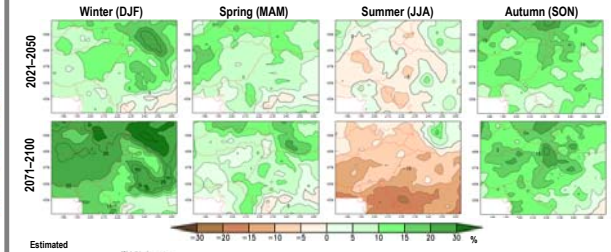
Grid cell containing Bratislava, Slovakia (48.125°N; 17.125°E)
The largest GCM-weighted average increase is estimated for summer (**5 days → +32% → 6.6 days**)
★ : Significant change is projected in summer (Kolmogorov-Smirnov test at 0.1 level) in the grid cell of Bratislava

Grid cell containing Szolnok, Hungary (47.125°N; 20.125°E)
The largest GCM-weighted average increase is estimated for summer (**6.1 days → +47% → 9 days**)
★ : Significant changes are projected in summer and spring (Kolmogorov-Smirnov test at 0.1 level) in the grid cell of Szolnok

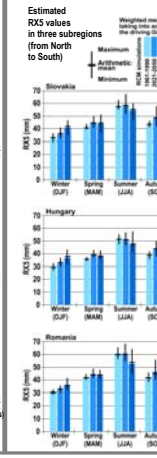
Grid cell containing Bucuresti, Romania (44.375°N; 26.125°E)
The largest GCM-weighted average increase is estimated for summer (**5.4 days → +44% → 7.8 days**)
★ : Significant changes are projected e in summer and spring (Kolmogorov-Smirnov test at 0.1 level) in the grid cell of Bucuresti

RESULTS: THE HIGHEST 5-DAY PRECIPITATION AMOUNT (RX5)

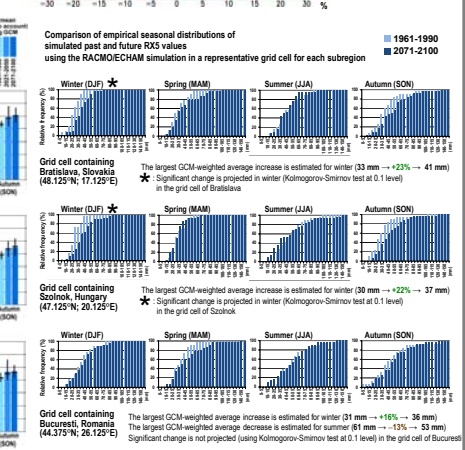
Composite maps showing the projected seasonal mean changes relative to the reference period, 1961–1990



Estimated RX5 values in three subregions (from North to South)



Comparison of empirical seasonal distributions of simulated past and future RX5 values using the RACMO/ECHAM simulation in a representative grid cell for each subregion



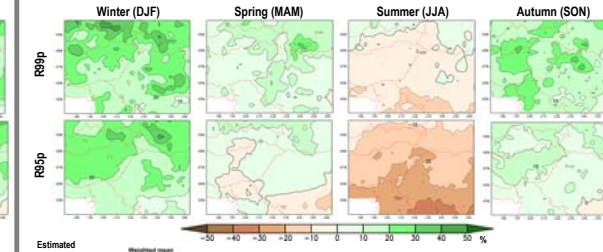
Grid cell containing Bratislava, Slovakia (48.125°N; 17.125°E)
The largest GCM-weighted average increase is estimated for winter (**33 mm → +23% → 41 mm**)
★ : Significant change is projected in winter (Kolmogorov-Smirnov test at 0.1 level) in the grid cell of Bratislava

Grid cell containing Szolnok, Hungary (47.125°N; 20.125°E)
The largest GCM-weighted average increase is estimated for winter (**30 mm → +22% → 37 mm**)
★ : Significant change is projected in winter (Kolmogorov-Smirnov test at 0.1 level) in the grid cell of Szolnok

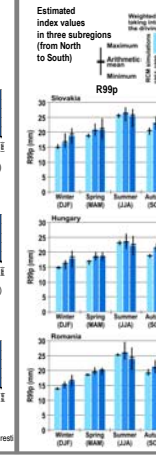
Grid cell containing Bucuresti, Romania (44.375°N; 26.125°E)
The largest GCM-weighted average increase is estimated for winter (**31 mm → +16% → 36 mm**)
The largest GCM-weighted average decrease is estimated for summer (**61 mm → –13% → 53 mm**)
Significant change is not projected (using Kolmogorov-Smirnov test at 0.1 level) in the grid cell of Bucuresti

RESULTS: HIGH PERCENTILE VALUES OF DAILY PRECIPITATION TIME SERIES (R99p, R95p)

Composite maps showing the projected seasonal mean changes for 2071–2100 relative to the reference period, 1961–1990



Estimated index values in three subregions (from North to South)



R99p and R95p:
Increasing trend in all seasons, except in summer
The largest increase (26%): R99p, Slovakia for 2071–2100
The largest decrease (23%): R95p, Romania for 2071–2100

R99pGT and R95pGT:
Increasing trend in all seasons, especially in winter and autumn