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USING CLIMATIC SCENARIOS AS A SUPPORT FOR A SUSTAINABLE AGRICULTURE IN THE ROMANIAN PLAIN

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Abstract

The Romanian Plain, covering a surface area of about 52 600 sq.km and stretching along the Danube, is one of the largest agricultural regions in the European Union. It presents diverse ecological conditions in four major zonal units, steppe, silvo-steppe, forest zone and its large Danube floodplain. In this context, the assessments of climate change, specifically of those climatic elements like temperature and precipitation which may have an important impact on various economic sectors, represent a necessary scientific support for end-users to envisage sustainable development strategies. This paper presents 1) the evaluation of the regional climatic model RCA4 driven by the ERA-Interim reanalysis and five general climatic models under historical forcing, 2) the adjustment of the bias identified in the simulations compared to the observation data using the Delta Change method, and 3) the projected changes of seasonal mean temperature and precipitation in the Romanian Plain for the mid-term period 2021-2050 under the RCP4.5 scenario compared with the reference period 1971-2000 of ROCADA observations.

Key words*: regional climate model, climate scenarios, Romanian Plain.*

INTRODUCTION

The need for climate change information at regional-to-local scale is one of the central issues within the global change debate. The users, including policy-making communities have long sought reliable regional and local scale projections to provide a solid basis for guiding response options (Giorgi et al., 2009). Climate impact assessments and the development of regional to local-scale adaptation strategies require the availability of high-resolution climate change scenarios, including an assessment of their robustness and inherent uncertainties. The exploitation of the vast amount of available data derived from the climate models became therefore a challenge for a wide range of users. The Coordinated Regional Downscaling Experiment (CORDEX) initiative to produce improved regional climate change projections for all land regions world-wide provides a platform for a joint evaluation of model performance, along with a solid scientific basis for impact assessment and other uses of downscaled climate information (Giorgi et al., 2009). EURO-CORDEX is the European branch of the international CORDEX initiative, to produce high-resolution climate scenarios for Europe. An increasing number of studies have dealt with the evaluation of EURO-CORDEX regional climate model (RCM) performance over different regions in Europe (Jacob et al., 2014, Kotlarski et al., 2014, Smiatek et al., 2016, Dyrrdal et al. 2018).

Previous studies on climate change have shown that southern and eastern regions of Romania, including the large agricultural areas of the Romanian Plain (RP), are increasing vulnerable to different kinds of drought: meteorological, hydrological or pedological (CLAVIER, 2009; Sima et al., 2015). This is particularly relevant as the environmental constraints on agriculture are overlapping particular socioeconomic conditions. The transformations in the first decades of the transition and post-transition period in the type of land property and in the type of farms (e.g. fragmentation of farm land, the emergence of numerous individual farms of subsistence agriculture, poor agricultural infrastructure and services (degraded irrigation systems, inappropriate farming practices etc.) were profound, yielding numerous economic and social implications. Conversely, over the last decade, the trend underlined a shift from individual/family-oriented farms and highly fragmented lands towards agricultural holdings with a strong commercial focus (Balteanu et al., 2010). This situation is highly spatially different, as in many parts of the RP, the agricultural resources are still unexploited and/or impacted by drought and desertification, land degradation, water stress, confusion about property rights, etc. The effects of climate change on agriculture coupled with diverse land management practices in the area call for integrative, regionally specific land management options for a sustainable use of land resources (Balteanu et al., 2017). In this context, climate change scenarios and climate change impact assessments hold a central role, while the new generation of scenarios provide enhanced opportunities for the evaluation of the projected climatic changes relevant for the society, in general, and the agriculture, in particular.

The aim of the paper is to assess future projections of temperature and precipitation changes over the RP with the regional model RCA4 (Rossby Centre Atmosphere version 4), for improving communication of climate knowledge to end-users. To reach this objective, a number of specific objectives should first be completed: (i) evaluate the performance of RCA4 driven by „perfect boundary conditions” in terms of reproducing the annual cycle and mean seasonal temperature and precipitation features in comparison with different observational datasets; (ii) assess the overall bias in the ensemble of five GCM-driven RCA4 temperature and precipitation simulations compared to observations; (iii) bias-correction of RCA4 temperature and precipitation simulations and assessment of the seasonal mean temperature and precipitation projections and their uncertainties from different driving GCMs and emission scenarios on mid-term timescale; (iv) assess future changes of seasonal temperature and precipitation and their uncertainties over the RP.

MATERIALS AND METHODS

Study area

The Romanian Plain, also known as the Lower Danube Plain, with 10 m to 200 m altitudes extends from west to east over 500 km, with the municipality of Bucharest, Romania’s capital, located in its central part. It is bordered by the Danube in the south and east and the Getic Piedmont, the Bend Subcarpathians and the Moldavian Plateau in the north. The Romanian Plain is divided into four subdivisions (Figure 1): the Oltenia Plain situated to the west of the Olt River, the Central Romanian Plain, between Olt and Arges rivers, the East Muntenia Plain with large loess covered non-fragmented tabular plains, and the Danube floodplain of 1-4 km width in the west and up to 15-20 km in the east (Balteanu, 2006). Each subdivision comprises different geomorphological subunits, shaping the land use particularities.

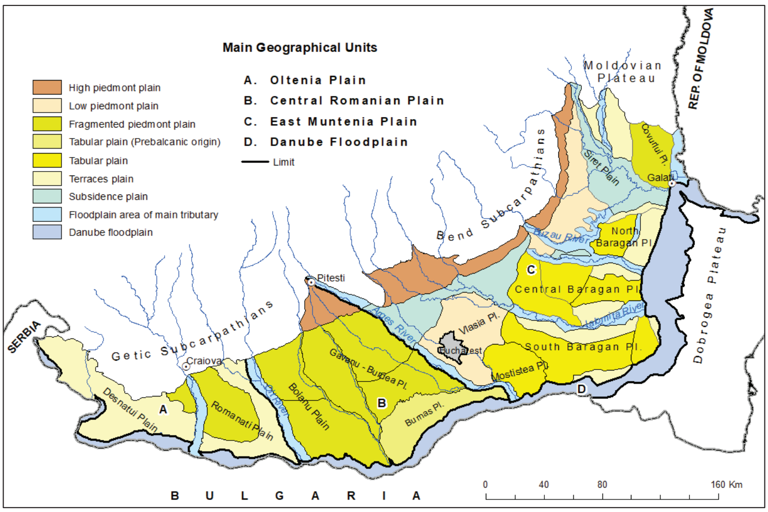

Figure 1. The geomorphological units of the Romanian Plain

Datasets

The simulations of the regional climate model RCA4 available from the EURO-CORDEX framework have been used in this study. The RCM is based on the numerical weather prediction model HIRLAM (Undén et al., 2002). The choice of RCA4 is supported by the good validation results of the RCA3 (Samuelsson et al., 2011) and RCA4 (Kotlarski et al., 2014; Strandberg et al., 2014) in different regions of Europe and, particularly, in a pilot study in the south-eastern RP (Sima et al., 2015). In the high resolution experiment design carried out in the EURO-CORDEX framework, RCA4 was setup on a rotated latitude-longitude grid over Europe with a horizontal resolution of 0.11°, corresponding to approx. 12.5 km. The integration domain includes all Europe, and for this study, the RP (22.3˚E– 28.3˚E, 43.5˚N– 46.2°N) was extracted as study region.

For the evaluation run, the RCA4 model was driven by „perfect boundary conditions" provided by the ERA-Interim reanalysis (Dee et al., 2011) covering the period 1981-2010. To evaluate the RCM performance over the RP, the RCA4 driven by ERA-Interim was compared to three observations datasets presented in Table 2.

As a next step of evaluation, the RCA4 has been given boundary conditions from five different GCMs: CNRM-CM5, EC-EARTH, HadGEM2-ES, IPSL-CM5A-MR, MPI-ESM-LR. All of them are fully coupled atmosphere–ocean General Circulation Models forced by different emission scenarios. The list of the GCMs and the RCM references is presented in Table 1.

The simulations have been performed for i) 1971–2005 period with historical forcing, and ii) 2006–2100 period under different Representative Concentration Pathway (RCP) scenarios (Moss et al., 2010).

GCMs may simulate quite different responses to the same forcing, simply because of the way certain processes and feedbacks are modeled. For this reason, it is important to evaluate the performance of different GCMs under historical forcing. In these simulations (historical runs) time-varying external forcing such as GHG and aerosol concentrations, solar inputs applied based on historic records from a given year up to the present. As these forcing elements change over time, the GCM simulates the evolution of the climate over this period in these historical runs.

For the future (scenario runs) the external forcing varies according to one of the future scenarios, e.g. the Representative Concentration Pathways (RCP) applied in the latest IPCC report (AR5). The RCP scenarios are expressed as changes in equivalent carbon dioxide concentrations (Kotlarski et al., 2014). In this study only the RCP4.5 pathway is used, assuming GHG peak by 2040.

Methods

Regridding

Before starting the analysis, the gridded datasets and model outputs were transformed from their native grids to a common regular grid of 0.1° (ROCADA grid) using the bilinear interpolation (Nikulin et al., 2012).The RCM simulations (driven by the ERA-Interim and by GCMs with historical forcing) were compared to three observation datasets listed in Table 2.

Table 1. Overview on the models used in this study.

Climate model	**Acronym in EURO-CORDEX**	**Institute (country)**	**Acronym in thisstudy**	**Website**
RCM	RCA4	Swedish Meteorological and Hydrological Institute (Sweden)	RCA4	www.smhi.se
	ICHEC-EC-EARTH	Irish Centre for High-End Computing and EC-Earth consortium of weather services and universities in Europe	ICHEC	www.ec-earth.org
	MOHC-HadGEM2-ES	Met Office Hadley Centre (UK)	HADGEM2	www.metoffice.gov.uk
	IPSL-IPSL-CM5A-MR	Institute Pierre Simon Laplace (France)	IPSL	www. icmc.ipsl.fr
	MPI-MPI-ESM-LR	Max-Planck-InstitutfürMeteorologie (Germany)	MPI	www.mpimet.mpg.de

Table 2. Reference datasets for the evaluation of the model simulations

Dataset	Description	Time resolution	Space resolution	Reference
ROCADA	Romanian daily gridded climatic dataset (version 1.0)	daily	0.1°	Dumitrescu & Birsan (2015) https://doi.pangaea.de/10.1594/PANGAEA.833627
E-OBS	European, gridded from observations (version 17.0)	daily	0.25°	Haylock et al. (2008) www.ecad.eu
CRU	Climate Research Unit, gridded from observations (version CRU TS v. 4.01)	monthly	0.5°	Harris et al.(2014) https://crudata.uea.ac.uk/cru/data/hrg/

Validation

To quantify the bias originating from different sources, the validation of the RCM was carried out in three phases: 1) RCM driven by reanalysis („perfect boundary conditions”) vs. observations, 2) RCM driven by GCMs vs. observations, and 3) ensemble mean of five GCM-driven RCA4 vs. observations. Phase 1 estimates the bias of RCM, i.e. to what extend the RCA4 distort the large-scale flow imposed by the „perfect boundary conditions” compared to observations. Phase 2 estimates the additional contribution of GCMs to the overall bias structure and, the Phase 3, the overall bias of the ensemble mean of five GCM driven RCA4 simulations compared to selected observation dataset. Through the RCM experiments assessed here it is not possible to separately quantify the uncertainty originating from different sources like the imperfection of reanalysis data or the internal climate variability inherent in model simulations, thus present results on the model biases are interpreted and discussed accordingly. To study the annual cycle and spatial patterns in the temperature and precipitation simulations monthly and seasonal mean values were calculated in every grid point and compared to reference datasets. The climatologies of air temperature and precipitation for the evaluation period 1981-2010, historical period 1971-2000 and mid-term future 2021-2050, for winter and summer were calculated and analyzed.

Metrics and bias assessment

To compare the model outputs against gridded observational data (i.e., reference) the bias was defined as the difference for temperature and ratio for precipitation of spatially averaged climatological seasonal mean values for the domain. In the case of five GCMs driven RCM, after evaluating the mean seasonal biases of each GCM-driven run, seasonal means of the ensemble were also calculated.

Bias correction

The bias correction (BC) techniques are needed to ensure a better agreement between models and observations. For this study the delta-change approach has been used (Teutschbein and Seibert, 2012) and, it was done on a monthly basis. This approach uses observations as a basis and, thus, it is a stable and robust method that produces future time series with dynamics similar to current conditions. The base-line climatology corresponds to the observed climate. An additive correction was used to adjust temperature whereas multiplicative correction was used for precipitation.

RESULTS AND DISCUSSIONS

Evaluation of RCM reanalysis-driven simulation vs. observations

First, the evaluation was carried out on the RCM simulation driven by the ERA-Interim reanalysis data (so-called evaluation run) against three observational datasets, using the 0.1° regular grid of ROCADA for the comparisons. The annual cycle of both simulated mean temperature and precipitation totals averaged over the RP were compared to the ROCADA, CRU and E-OBS observations datasets. The spatially averaged values of mean monthly temperature over the RP during the evaluation period 1981-2010 and the corresponding mean biases calculated as RCA4 – obs are shown in Figures 2 a) and b), respectively. Compared to the observations, the RCA4 model tends to underestimate the temperature with a cold bias during February to June (between -0.5˚ and -1.2˚, depending on the reference data set) and to overestimate the observations with a warm bias from July to December (between 0.1˚ and 2.1, depending on the reference data set).

Similarly, the spatially averaged monthly precipitation totals and the corresponding mean biases calculated as ratios RCA4/obs are shown in Figures 2 c) and d). Compared to the observations, the RCA4 model tends to systematically overestimate the observed precipitation (January to May and October to December) except during summer (July to September) when precipitation is underestimated. The ratios RCA4/obs ranges from 1.1 to 2.1 showing that the model overestimates the simulated precipitation by 10% to 110%, depending the reference data set, whereas the ratios 0.6 to 0.9 means that the simulated precipitation represents 60% to 90% of observation, respectively, depending on the reference data set.

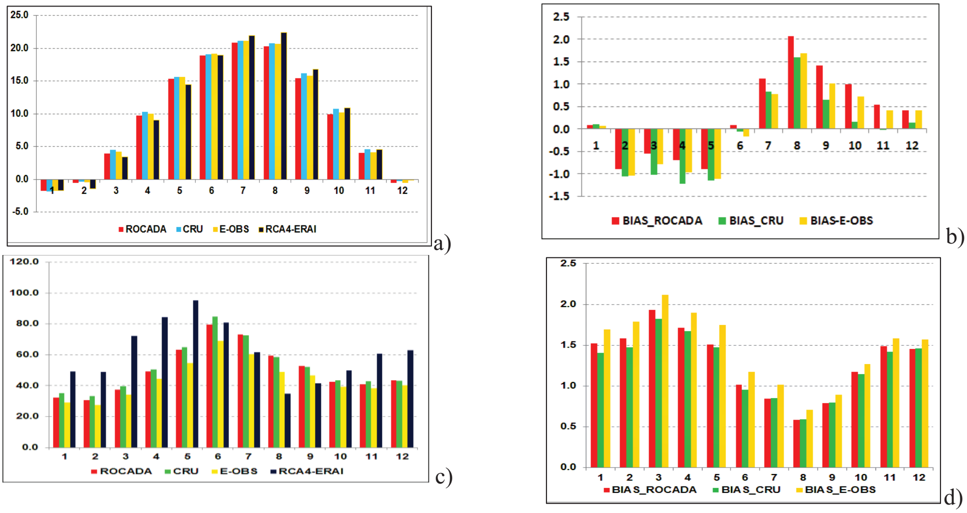

Figure 2. Mean annual cycle of the RCA4 evaluation run (1981-2010) compared with three observation data sets (ROCADA, CRU and E-OBS). Spatially averaged monthly mean temperature: a) the corresponding mean biases; b) the same for precipitation in c) and d) the mean biases were calculated as RCA4/ obs. for temperature and, RCA4/obs. for precipitation, respectively

Evaluation of GCM-driven RCM simulations vs. observations

Because the ROCADA observations dataset (Birsanand Dumitrescu, 2014) provides the highest available resolution (0.1°) of homogenized series over Romanian territory, based on 150 stations for temperature and 188 stations for precipitation, further on, this data set will be used as reference for comparison in this study.

The historical runs (RCA4 simulations driven by five GCMs with historical forcing) were compared with the ROCADA data set over the period 1971-2000. In this way, the bias introduced by the GCM in the RCM model output could be estimated.

First, the annual cycle was analyzed, in order to gain an overview on the model bias averaged over the RP for each month. Then, the seasonal spatial patterns of mean temperature and precipitation biases (GCM-RCM historical runs vs. ROCADA obs) were described in the form of difference and ratio maps, respectively. The comparison was carried out on the native high-resolution grid (0.1°) of the ROCADA data set, after regrinding the RCA4 model simulations from their native resolution of 0.11° to 0.1°.

The monthly means of air temperature spatially averaged over the RP domain compared with the ROCADA observations and, the corresponding mean biases calculated as RCA4/ obs. are shown in Figures 3 a) and b), respectively, for the five historical runs of the GCM-driven RCA4 model for the period 1971-2000.

During July to November all the models overestimate the mean temperature with 0.7°C (HadGEM2) in October up to 3.1°C (HadGEM2) in July. Zero bias comparing to observations shows EC-EARTH model in September and November, MPI model in April and June and IPSL model in June. Negative biases of all five GCM-driven RCA4 are evident in May with values ranging from -0.6°C (MPI) and - 2.5°C (EC-EARTH). During the months of the cold season (December to March) three models overestimate temperature with values ranging from 0.1°C (HadGEM2) to 2.2°C (MPI) whereas the others underestimate the mean temperature with values ranging from -0.1°C to - 1.5°C (CNRM).

Likewise in the evaluation run, in the historical runs most of the GCMs-driven RCA4 tends to systematically overestimate the observed precipitation (January to May and October to December) except during summer (July to September) when precipitation is underestimated. The ratios (GCM-RCA4)/obs. ranges from 1.1 to 1.9 showing that the model overestimates the observed precipitation by 10% to 90%, depending on the driving GCM, whereas the ratios 0.4 to 0.9 means that the simulated precipitation represents 40% to 90% of observation, respectively, depending on the driving GCM.

The patterns of seasonal temperature and precipitation biases are analyzed over the RP based on seasonal gridded data averaged over the historical period 1971–2000. The main focus was to assess the ability of the regional model to simulate the surface climate in response to large-scale forcing imposed by the GCMs-driving RCA4 model and by local topographical features. In this study, the cold and warm season of the year were analyzed. To quantify the average bias over the whole domain, evaluation metrics were calculated in each grid point as the difference (GCM-RCA4) – ROCADA obs., for temperature and, as the ratio (GCM-RCA4)/ROCADA obs., for precipitation, respectively. Figures 4 and 5 show the seasonal mean temperature bias for winter and summer, respectively, for the five GCM-driven RCM historical runs and for the ensemble mean of these models.

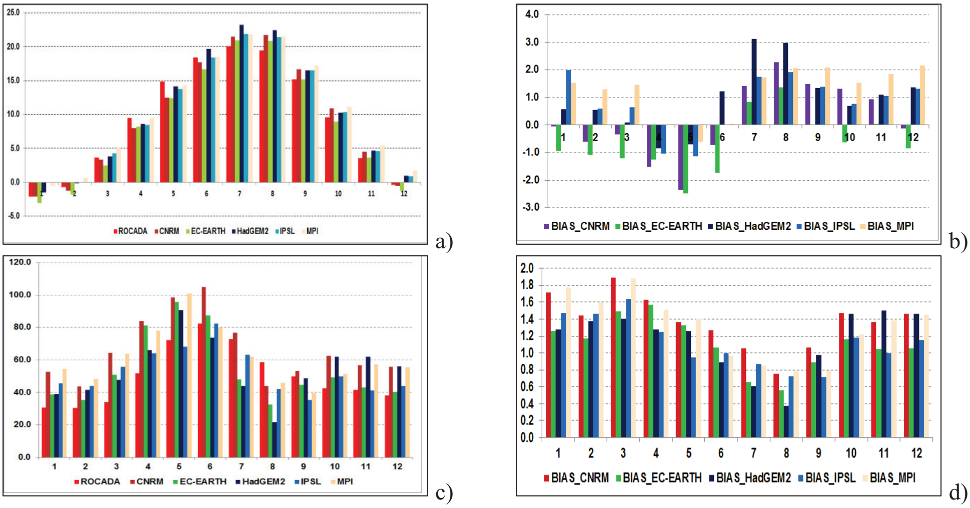

Figure 3. Mean annual cycle of five GCM-driven RCA4 historical runs (1971-2000) compared with ROCADA data set. Spatially averaged monthly mean temperature: a) and the corresponding mean biases; b) the same for precipitation in c) and d). the mean biases were calculated as RCA4/obs. for temperature and, RCA4/obs. for precipitation, respectively

In winter (Fig. 4), most of the GCM-driven RCA4 runs show warm biases in the region with low altitude (RP) and cold biases in the region with higher altitudes (Sub Carpathians and Carpathians).

In the RP, the lowest positive bias ranges between 0°C and 2°C (CNRM and EC-EARTH) and the highest positive bias ranges between 2°C and 3°C (IPSL and MPI).

In the Carpathian and Subcarpathian region the values of negative biases range between -1°C and - 6°C (CNRM and EC-EARTH) and -1°C and -4°C (HadGEM2, IPSl and MPI). The ensemble mean shows warm biases of 1°C to 2.5°C in the RP and cold biases of -1°C to -4°C in the Carpathian and Sub-carpathians.

For summer, likewise for winter, the sign of the bias depends on the altitude. The highest warm bias, up to 3°C in the RP and Sub-Carpathians is shown in the HadGEM2-RCA4 simulation whereas the lowest warm bias up to 1.5°C in the RP is shown in the EC-EARTH-RCA4 simulation. At high altitudes, the cold biases are less than -2°C.

The maps of spatial distribution of seasonal precipitation bias based on the ratios of five GCM-driven RCA4 historical runs and ROCADA observations reveal that, in general, the models overestimate precipitation at higher altitude and underestimate precipitation in the plain region. The maps of monthly biases between each GCM-driven RCA4 and ROCADA observations for the reference period 1971-2000 for both temperature and precipitation have been used to adjust both historical and scenario runs using the delta-change approach (Teutschbein and Seibert, 2012).

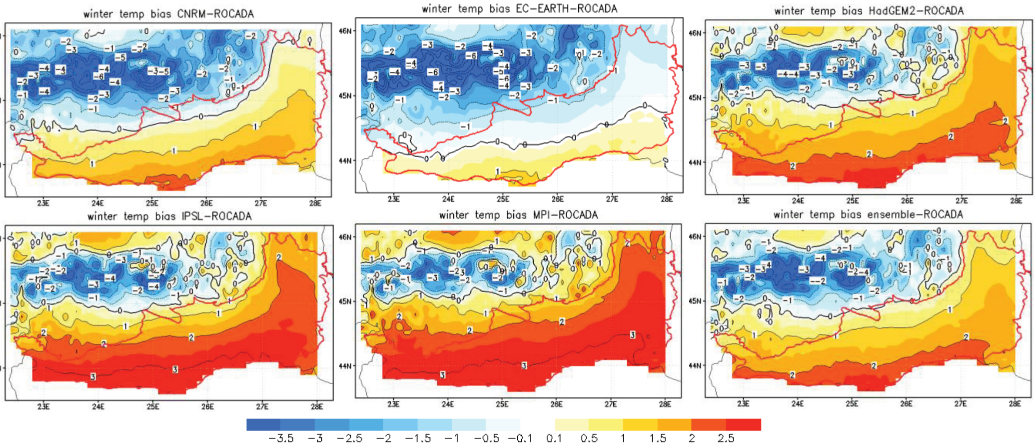

Figure 4. Winter mean temperature bias of the five GCM-driven RCA4 historical runs (1971-2000) versus ROCADA observations. The bias map of the ensemble mean is also added. Unit: °C

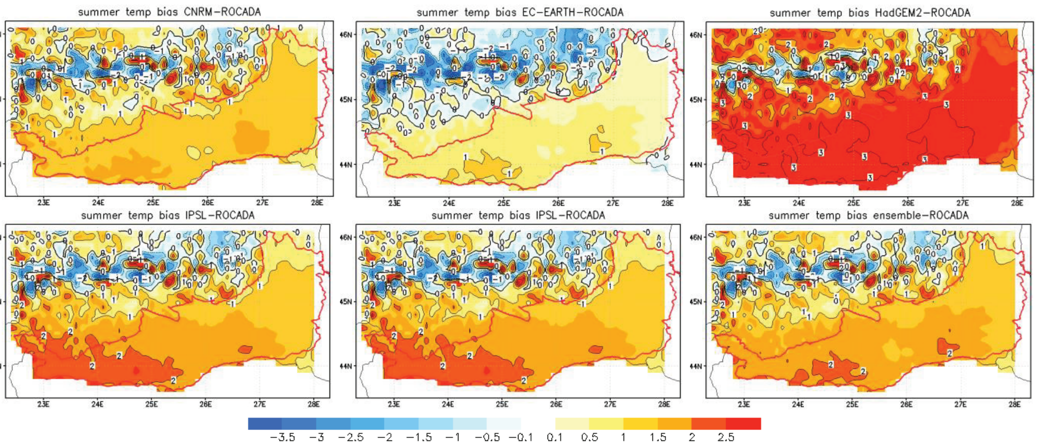

Figure 5. The same as Figure 4 but for summer

Projected changes under RCP4.5 scenario

After the bias correction of both temperature and precipitation simulations, the projected changes of seasonal temperature and precipitation for the RP have been assessed for the RCP4.5 pathway for the mid-term future 2021-2050 using as reference the ROCADA observations for the period 1971-2000. Figures 6-7 and Figures 8-9 present the spatial patterns of winter and summer temperature and precipitation changes, respectively, for the RP. The five GCMs project quite similar patterns of temperature changes for the RP. The spatial differentiation of each model depends on the altitude. Therefore, in general, the models project higher positive winter temperature changes in the Carpathians and Sub-Carpathians than in the whole RP where the winter temperature is expected to increase with 1°C to 2.5°C compared to the ROCADA reference. The highest winter temperature increases (+2°C to +2.5°C) for the RP are projected by the EC-EARTH and IPSL models while the lowest (+1°C to +1.5°C) are projected by the CNRM and MPI models. The ensemble mean projects winter temperature increase with 1.5°C - 2°C for the RP and with 2°C - 2.5°C in the higher altitudes (Figure 6). For summer, the projected temperature changes in the ensemble mean range between +1.5°C and +2.0°C in the RP and up to +2.5°C at higher altitudes. The highest summer temperature increase (>2.5°C) is projected by the HadGEM2 model over the whole domain, MPI model in the western half of the domain and IPSL in the south-western RP and higher altitudes (Figure 7).

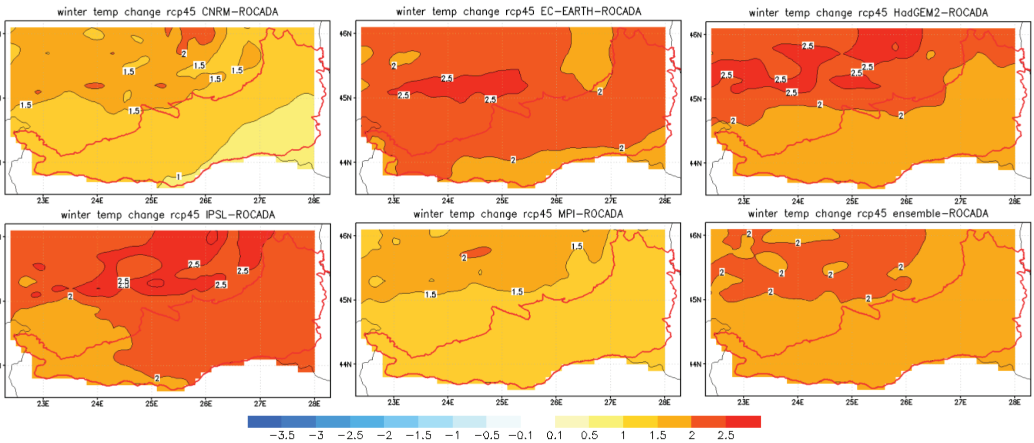

Figure 6. Projected temperature changes for winter with five GCM-driven RCA4 for the mid-term future (2021-2050) under rcp 4.5 scenario compared to the reference period 1971-2000 of the ROCADA observation dataset. Unit: °C

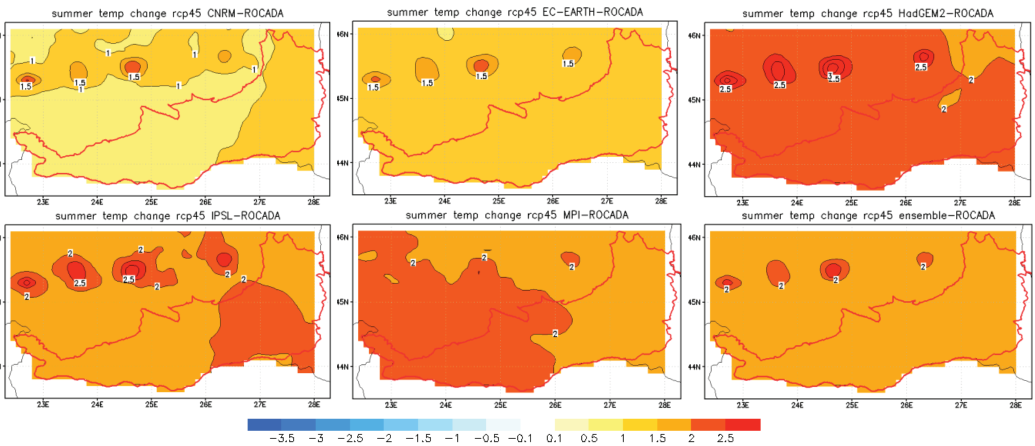

Figure 7. The same as Figure 6 but for summer

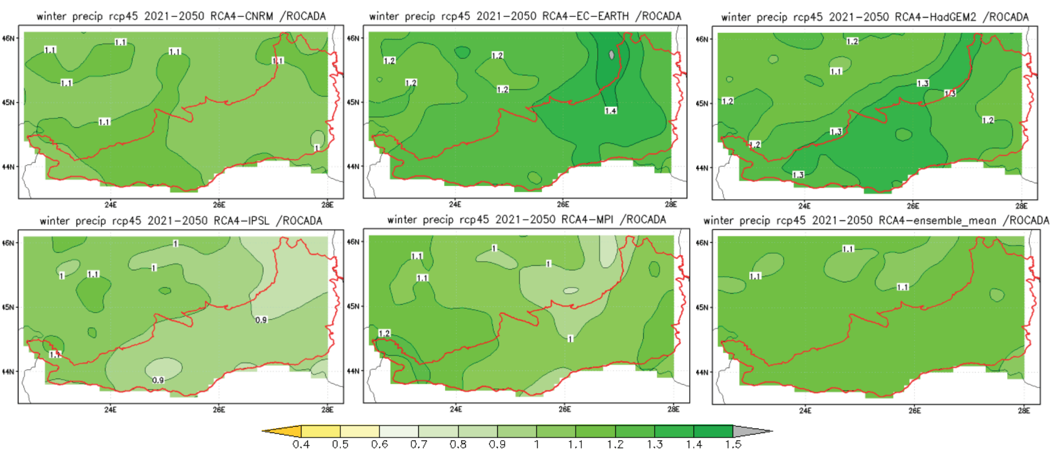

Figure 8. Projected precipitation changes for winter with five GCM-driven RCA4 for the mid-term future (2021-2050) under rcp 4.5 scenario compared to the reference period 1971-2000 of the ROCADA observation dataset

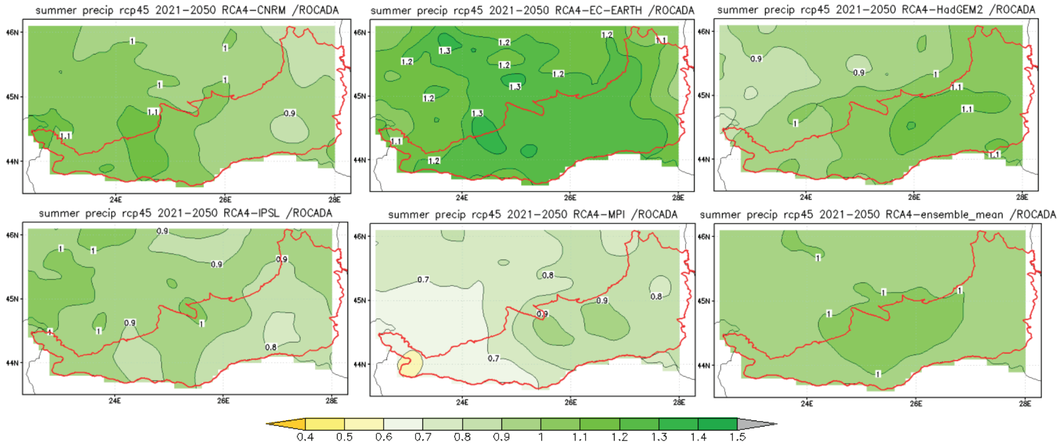

Figure 9. The same as Figure 8 but for summer

The changes in winter and summer precipitation regime for the RP are represented as ratios between simulated seasonal precipitation under the RCP4.5 scenario for the mid-term future 2021-2050 and the observed seasonal precipitation for the reference period 1971-2000, in Figures 8 and 9, respectively. For winter, two models (EC-EARTH and HadGEM2) project an increase of winter precipitation over the whole RP domain with 20% to 40% compared with the observed reference period, whereas the CNRM and MPI models project precipitation increase up to 10% in western an eastern RP. In the ensemble mean, an increase up to 10% of winter precipitation is projected over the whole domain. For summer, two models (IPSL and MPI) project the decrease of seasonal precipitation in the RP with 20% to 40%, in the western RP (MPI) and eastern half (IPSL). The other three models (CNRM, EC-EARTH and HadGEM2) project relatively slight increase, up to 10% in the western (CNRM) and eastern RP (HadGEM2). The EC-EARTH model projects increase of summer precipitation up to 30% in most of the RP domain. The ensemble mean projects the decrease of summer precipitation up to 10% in most of the RP whereas any change in the center of RP is projected.

CONCLUSIONS

The assessment of RCM performance and the bias correction are necessary before using the simulations for climatic projections and impact studies.

The assessment of the annual cycle for temperature and precipitation totals simulated by the RCA4 model in the „perfect boundary condition" experiment against three observation datasets, shows that the model systematically underestimates the mean temperature during February to May and overestimates the mean temperature during July to November, while the precipitation is overestimated during January to May and underestimated during July to September.

The annual cycle of mean temperature and total precipitation simulated by the RCA4 model forced by five GCMs with historical forcing compared to ROCADA observations show that the models underestimate temperature during April to June and overestimate temperature during July to September, while the precipitation is overestimated during January to June and October to December, and underestimated during June to September as compared to observations.

The patterns of the GCMs-driven RCA4 biases depend on the orography: the models underestimate the winter temperature over the Carpathians and sub-Carpathian region and overestimate the winter temperature with 1°C - 3°C over the RP. This bias characteristic appears, also, for summer temperature.

The RCP4.5 scenario projects increasing winter and summer temperature with 1-2°C comparing with the ROCADA observations for the reference period 2071-2000, in the RP.

The projected precipitation during winter will increase with 10% to 30% according to four GCM-driven RCA4 and will decrease with 10% according to IPSL-driven RCA4 comparing to the ROCADA observations for the reference period 1971-2000.

The projected precipitation during summer will decrease with 10% to 30% according to three GCM-driven RCA4 and will increase with 10% to 20% according to two GCM-driven RCA4, comparing to the ROCADA observations for the reference period 1971-2000. The ensemble mean does not indicate any change.

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