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Changes in drought characteristics for Romania projected by a regional climatic model

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Abstract — Climate change will influence not only mean but also climate variability, in particular the frequency, intensity and the spatial distribution of droughts. The main objective of this paper is to project the extent to which future climate-change will induce changes in drought characteristics in Romania for the middle and the end of the 21st century. We use monthly precipitation data simulated by the regional climatic model ICTP_RegCM3 over Romania to calculate the Standardized Precipitation Index (SPI) at time scale of 1, 3 and 6 months. The simulations have been conducted at a horizontal resolution of 10 km in the framework of EU-FP6 project – CECILIA. The reference period of the control run is 1961-1990 and, the scenario runs were conducted for SRES A1B scenario for the periods 2021-2050 and 2071-2100. Considerable uncertainty in model skill in reproducing summer precipitation is observed when it is driven by ECHAM GCM. Future projections show increase in seasonal drought conditions over Romania, especially in the south and south-eastern part of the country, more pronounced for the end of the 21st century. The frequency of severe and extremely dry conditions of 3 and 6 months in duration is projected to slightly increase in comparison with severe and extremely wet conditions.

Keywords — drought, climate change, regional climate model (RegCM), Romania, SPI

1 INTRODUCTION

Large areas of Europe have been affected by drought during the 20th century. Severe and prolonged droughts observed in many countries but mostly in the Mediterranean regions have highlighted Europe's vulnerability to this natural hazard and alerted the public, governments, and operational agencies to the many socio-economic problems accompanying water shortage and to the need for drought mitigation measures [1]. In this context, Romania is likely to experience a diverse range of impacts in response to climate change, with temperature increases accompanied by a perturbed hydrological cycle. Changes in the distribution of climate extremes including the daily precipitation totals and the persistence of dry days may lead to an increased frequency of droughts in some areas and increased precipitation in others [2].

The main source of information about past climate changes comes from observation. The information about possible future climate changes is obtained through numerical climate models [3]. Different models behave differently and there is no established way to tell which model represents the most probable version of the future. The general circulation models (GCM) project diverse patterns of change in climatic variables across Europe and these have been demonstrated to vary depending on which GCM is used, with some areas showing opposite developments or different magnitudes of change [4]. Such uncertainty in the performance of climate models arises from the parameterization of small-scale physical processes as well as uncertainties in the structures used to represent large-scale climate processes. Consequently, any one model simulation of future climate may represent only one of many possible future climate states. In the framework of the EU-project CECILIA (Central and Eastern Europe Climate Change Impact and VulnerabiLIty Assessment) RegCM simulations at 10 km for climate change impacts and vulnerability assessment in target areas of Central and Eastern Europe have been conducted [5].

In this paper we use monthly precipitation data simulated by the regional climatic model ICTP_RegCM3 over Romania to calculate the Standardized Precipitation Index (SPI)[6],[7] at time scale of 1, 3 and 6 months. First, the precipitation simulated by the RCM forced at Lateral Boundary Conditions (LBC) with ERA40 reanalysis data was compared with the CRU TS2.10 land observation data set [8] for the reference period 1961-1990. Secondly, the changes in seasonal precipitation simulated by the RCM under SRES A1B emissions scenario for the periods 2021-2050 and 2071-2100 were compared with the control run (1961-1990) simulations. Thirdly, the SPI calculated in each grid

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point of the selected domain over Romania was analyzed both in terms of temporal evolution and frequency distribution for the scenario runs in comparison with the control run. Future changes in drought frequency, severity and duration are obtained and examined

2 DATA AND METHODS

2.1 Data Description

We used monthly mean precipitation simulated with the Beta version of the regional climatic model ICTP_RegCM3 at a horizontal resolution of 10 km. The ICTP_RegCM model was originally developed [9] and then augmented and used in various reference and scenario simulations [10],[11],[12].

The simulations were conducted over a domain (41.016ºN-50.175ºN; 14.095ºE-36.192ºE) centered over Romania (46ºN, 25ºE) [2], [5]. The simulations were driven by ERA40 double nested from 25 km RegCM run for the period 1961-1990 and by the ECHAM driven RegCM run at 25 km for the time slices 1961-1990 (control run) and 2021 -2050 and 2071-2100 (A1B scenario runs).

The CRU TS2.10 land observation data set (http://www.cru.uea.ac.uk/cru/data/hrg/cru_ts_2.10) has been used to validate the RCM simulated precipitation. The horizontal resolution of CRU TS2.10 precipitation data set is 0.5ºlat x 0.5ºlon. For this study we have selected a smaller domain (45.01ºN-49.01ºN; 26.52ºE-30.48ºE) including only the Romania's borders.

2.2 Standardized Precipitation Index (SPI)

SPI is a simple index which was developed [6],[7] to quantify precipitation deficits on multiple time scales. The SPI is calculated from the long term record of precipitation in each location (at least 30 years). It is simply the transformation of the precipitation time series into a standardized normal distribution (z-distribution). There are advantages and disadvantages when using the SPI to characterize drought severity [13]. The SPI has three main advantages. The first and primary advantage is its simplicity. The SPI is based solely on rainfall and requires only the computation of two parameters, compared with many computational terms needed to describe the Palmer Drought Severity Index (PDSI). By avoiding dependence on soil moisture conditions, the SPI can be used effectively in both summer and winter. The SPI is also not affected adversely by topography. The SPI's second advantage is its variable time scale, which allows it to describe drought conditions important for a range of meteorological, agricultural, and hydrological applications. This temporal versatility is also helpful for the analysis of drought dynamics, especially the determination of onset and cessation, which have always been difficult to track with other indices. The third advantage comes from its standardization, which ensures that the frequency of extreme events at any location and on any time scale is consistent. The SPI has three potential disadvantages, the first being the assumption that a suitable theoretical probability distribution can be found to model the raw precipitation data prior to standardization. An associated problem is the quantity and reliability of the data used to fit the distribution. It is recommended using at least 30 years of high-quality data [6], [7]. A second limitation of the SPI arises from the standardized nature of the index itself; namely that extreme droughts (or any other drought threshold) measured by the SPI, when considered over a long time period, will occur with the same frequency at all locations. Thus, the SPI is not capable of identifying regions that may be more 'drought prone' than others. A third problem may arise when applying the SPI at short time scales (1, 2, or 3 months) to regions of low seasonal precipitation. In these cases, misleadingly large positive or negative SPI values may result.

The SPI is computed by fitting a probability density function to the frequency distribution of precipitation summed over the time scale of interest. This is performed separately for each month (or whatever the temporal basis is of the raw precipitation time series) and for each location in space. Each probability density function is then transformed into the standardized normal distribution. Thus, the SPI is said to be normalized in location and time scale, sharing the benefits of standardization described for the PDSI. Once standardized, the strength of the anomaly is classified as set out in Table 1. This table also contains the corresponding probabilities of occurrence of each severity, these arising naturally from the normal probability density function. Thus, at a given location for an individual month, moderate droughts ($SPI \leq -1$) have an occurrence probability of 15.9%, whereas extreme droughts ($SPI \leq -2$) have an event probability of 2.3%. Extreme values in the SPI will, by definition, occur with the same frequency at all locations [14].

Table 1. Drought classification by SPI value and corresponding event probabilities

Class no	Category	SPI value	Probability %
1	Extremely dry	≤ -2.00	2.3
2	Severely dry	-1.50 to -1.99	4.4
3	Moderately dry	-1.00 to -1.49	9.2
4	Near Normal	-0.99 to +0.99	68.2
5	Moderately wet	+1.00 to +1.49	9.2
6	Severely wet	+1.50 to +1.99	4.4
7	Extremely wet	≥ +2.00	2.3

To calculate the SPI, the distribution version of the SPI program available via anonymous ftp on ulysses.atmos.colostate.edu have been modified to loop for each grid point of the selected domain.

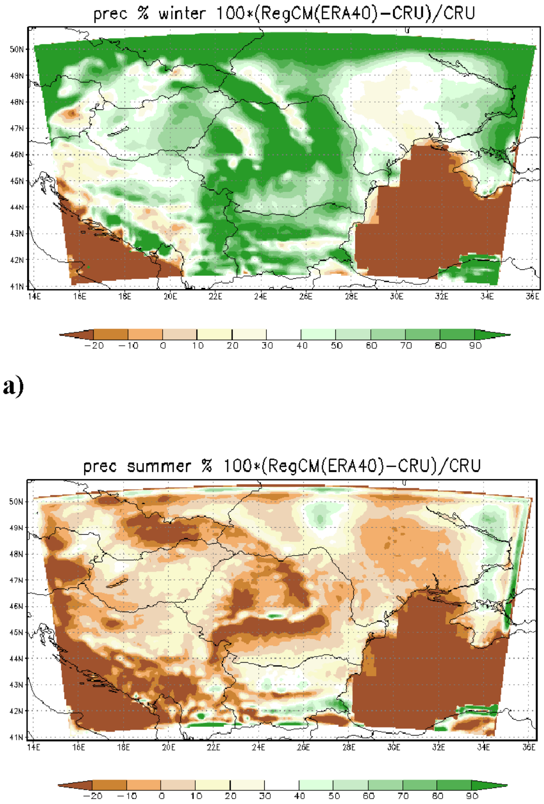
3 RESULTS

3.1 Model validation – Precipitation annual cycle

Mean daily precipitation amounts were calculated on a seasonal basis across the Romania domain for the CRU series for the period 1961–1990 and compared with the RCM integrations driven by the ERA40 reanalysis. The magnitude and spatial extent of errors varies with the season. Some generalizations may be inferred from the spatial structure of model errors across the domain centered over Romania.

Winter rainfall is overestimated over most of the region with the largest errors at higher altitudes over the Carpathians and sub-Carpathian regions. Underestimation of winter rainfall is generally observed only over the Black Sea and Adriatic Sea.

During summer, precipitation amounts are, in general, underestimated. The largest negative errors generally occur over the mountains and adjacent areas and over the seas. Slightly positive errors are confined to southern and western Romania.



a)

b)

Fig. 1. RegCM anomaly expressed as a percentage deviation from the corresponding observed grid cell mean for a) winter (DJF) and b) summer (JJA) daily precipitation for the period 1961-1990.

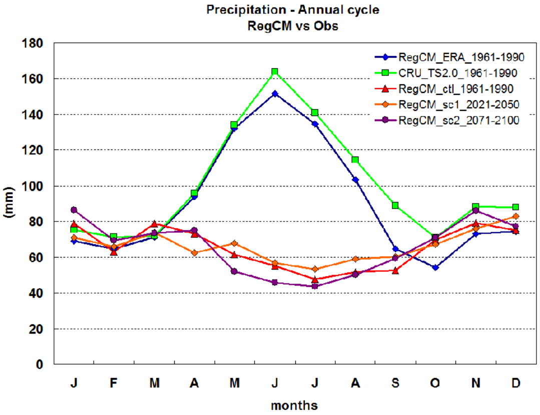


Fig. 2 Annual precipitation cycle of the RegCM simulations versus CRU observations.

For the smaller domain limited to Romania's borders, the mean precipitation amount was calculated and spatially averaged for each month both for model driven by ERA40 and CRU data to allow the examination of model skill in reproducing the annual precipitation cycle. Fig. 2 shows that, in general, the model overestimates precipitation and the largest biases are observed from June to November. The RCM reproduces the observed characteristics of the annual precipitation cycle in the region but it systematically overestimates the monthly precipitation. When the RegCM is forced with the ECHAM GCM it fails to reproduce the observed characteristics of annual precipitation cycle. This feature is obvious from April to September both in the control and scenario runs as shown in Fig. 2.

Examining the model errors on the regional scale of Romania, it is important to note that the biases are not evenly distributed throughout the year, indicating seasonal variability of the model to represent physical processes responsible for precipitation.

3.2 Future changes in seasonal precipitation

The annual cycle of precipitation shown in Fig. 2 point out on the key role of LBC in driving the RegCM simulations. Our results seem to be in line with precipitation and drought projections obtained with other ECHAM-driven RCMs under PRUDENCE project for the south-eastern Europe [15]. Taking into account the uncertainty associated with the driving GCM, the spatial distribution of the projected changes in mean seasonal precipitation over Romania is further analyzed. Fig. 3 shows an increase of winter precipitation in the north-western part of the country up to 15% for the period 2021-2050 (Fig.3a) and up to 20% for the period 2071-2100 (Fig. 3b) relative to the 1961-1990 mean. Decrease of winter precipitation is projected for the southern and eastern part of the country, up to 15% for the period 2021-2050 and up to 5% for the period 2071-2100, relative to the reference period

1961-1990. General increase of projected summer precipitation, up to 30% relative to the reference period is expected in the south-eastern part of the country for the period 2021-2050 (Fig. 4a). For the period 2071-2100 a general decrease of summer precipitation up to 35% relative to the reference period is projected for the south-eastern part of the country (Fig. 4b).

For spring precipitation, a general decrease, more enhance in the south and south-eastern part of the country is projected for the period 2071-2100 (not shown). For autumn precipitation, slightly decrease in the south-western part of the country is projected for the period 2021-2050. A general increase of autumn precipitation, more enhanced in the eastern and north-eastern part of the country, up to 35% relative to the reference period is projected for the period 2071-2100 (not shown).

The projections of drought expressed in SPI which is based only on precipitation will depend on model performance to simulate precipitation characteristics in the region.

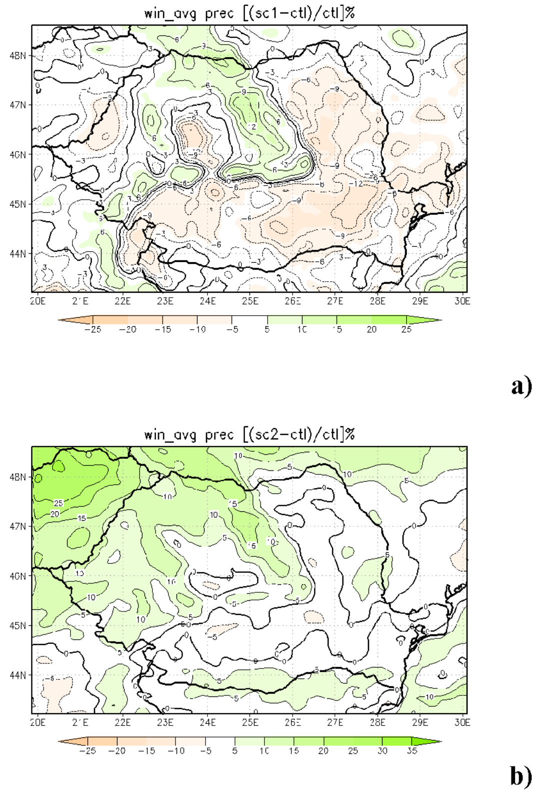


Fig. 3. Projected changes in winter precipitation a) for the period 2021-2050 and b) for the period 2071-2100 expressed as a percentage of the 1961-1990 mean

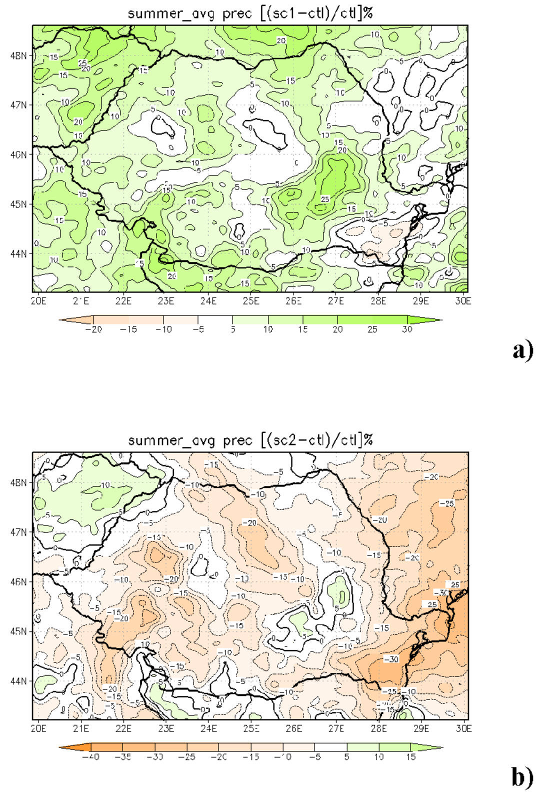


Fig. 4. Projected changes in summer precipitation a) for the period 2021-2050 and b) for the period 2071-2100 expressed as a percentage of the 1961-1990 mean

3.3 SPI – Temporal evolution

Drought appears first in the short time scales and if dry conditions persist, the drought develops at longer time scales. The use of several time scales of SPI take into account the role of antecedent conditions in quantifying drought severity, allowing a better understanding of time scales of water supplies. The SPI was calculated at short time scales of 1, 3 and 6 months for each grid point of the RegCM both for the control and scenario runs. The temporal evolution of the averaged SPI over Romania's domain for the control run for the period 1961-1990 is represented in Fig. 5.

The evolution of the SPI calculated for 1 month shown in Fig. 5a presents a high variability of the index between -1 and +1. It is difficult to identify the persistence of drought conditions from the SPI at time scale of 1 month. As the time scale for calculation the SPI increases (Fig. 5b and 5c) the wet and dry conditions can be clearly identified as well as their persistence. The antecedent conditions in SPI calculated for 6 months point out on persistence of dry and wet conditions for time lengths of some years (Fig. 5c).

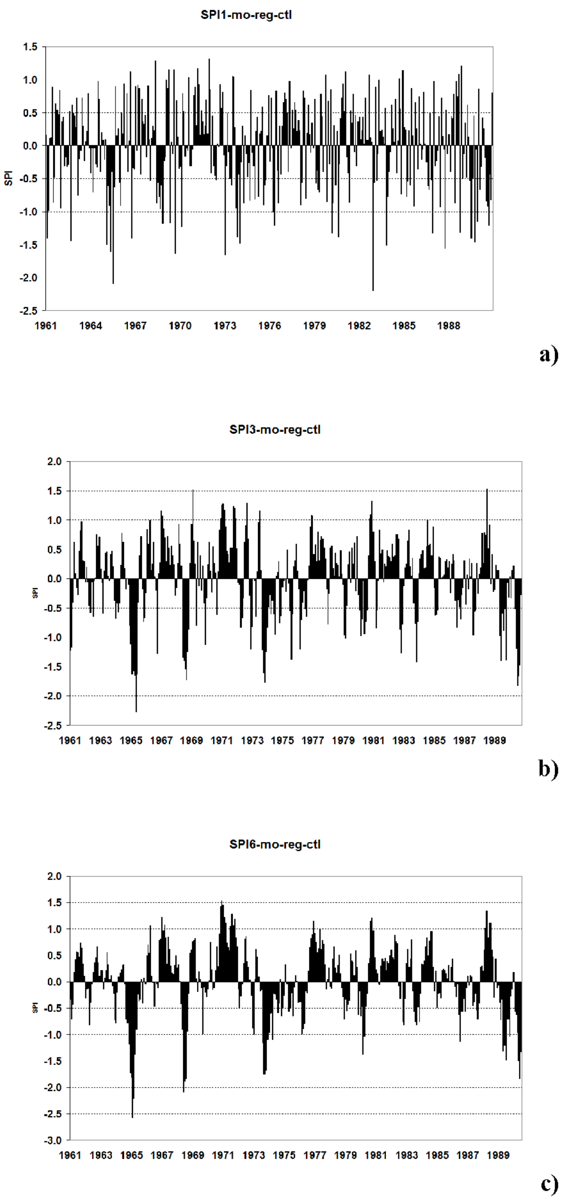


Fig. 5 SPI series at time scales of 1, 3 and 6 months based on monthly precipitation totals simulated by the RegCM control run, averaged for all the grid points of the domain

3.4 SPI – Frequency distribution

Frequency distributions of SPI calculated from RegCM simulations driven by ERA40 at LBC and from CRU observations for 1, 3 and 6 months are represented in Fig. 6 a), b) and c), respectively. All these three frequency distributions of SPI show that the model over estimates the near normal humidity conditions. The frequency distribution of moderate dry and moderate wet conditions is well simulated by the model at 1, 3 and 6 months time scales. The frequency distribution of severely dry and extremely dry conditions increases as the time scale for calculation of SPI increases but it remains under estimated by the model comparing to CRU observations. Fig. 6 shows that the RegCM has difficulties in simulating extreme precipitation that give rise to extreme dry or extreme wet conditions.

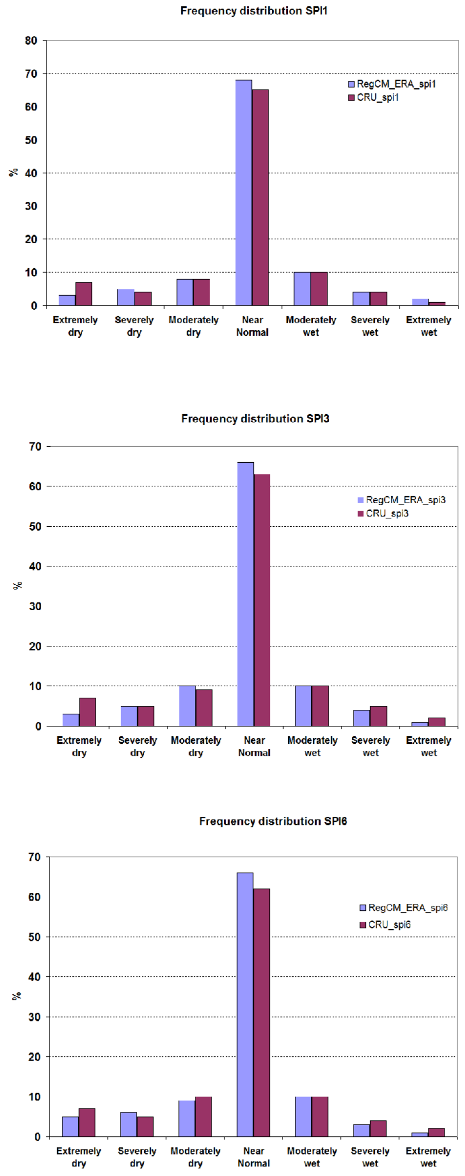


Fig. 6. Frequency distribution of monthly SPI values calculated from RegCM simulations and CRU observation for a) 1 month, b) 3 month and, c) 6 month time scale averaged over all grid points of the Romania domain

The frequency distribution of SPI values calculated for the control run (1961-1990) and A1B scenario runs for the periods 2021-2050 and 2071-2100, respectively for 1, 3 and 6 months presents similar characteristics as in the case of RegCM driven by ERA40. Fig. 7 shows that there are not significant differences between frequency distribution of SPI values calculated for 6 months in the control run and the two A1B scenario runs. Slightly increase in extremely dry conditions compared to extremely wet conditions is observed both for the control and scenario runs.

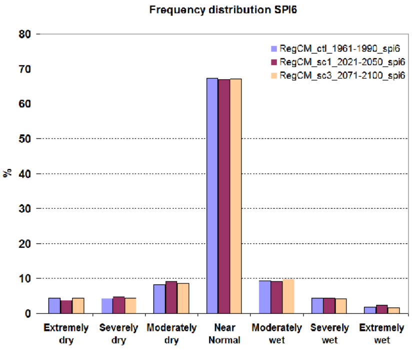


Fig. 7. Frequency distribution of monthly SPI values calculated from RegCM simulations of the control run (1961-1990) and for the A1B scenario runs (2021-2050 and 271-2100, respectively) for 6 month time scale. The SPI were averaged over all grid points of the Romania domain

4 FINAL REMARKS

Monthly precipitation data simulated by the regional climatic model RegCM over Romania were used to calculate the Standardized Precipitation Index (SPI) at time scale of 1, 3 and 6 months. First, the model skill in reproducing the annual cycle of precipitation was demonstrated by comparing the RegCM simulation driven by ERA40 reanalysis with CRU observations. When the RegCM is driven by the ECHAM GCM, the control run underestimates the summer precipitation. Winter drier conditions are projected in the southern and eastern part of the country for the period 2021-2050 and, in general, summer drier conditions are projected for the end of the 21st century. Changes in the seasonal distribution of precipitation and the occurrence of drought will have significant implications for the management of water resources in Romania. The evolution of SPI time series calculated from monthly precipitation simulated by the RegCM driven by the ECHAM GCM at time scales of 6 months better emphasizes the persistence of dry and wet conditions. There are not significant differences between the frequency distribution of SPI values calculated for 6 months in the control run and the two A1B scenario runs. However, slightly increase in extremely dry conditions compared to extremely wet conditions is observed both for the control and scenario runs.

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