MODEL VALIDATION AND DROUGHT ASSESSMENT WITH A REGIONAL CLIMATE MODEL OVER MOLDOVA*

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We assess the drought characteristics in the Republic of Moldova based on the Standardized Precipitation Index (SPI) calculated from monthly precipitation data simulated by the Regional Climate Model RegCM3. The RegCM simulations were conducted at a horizontal resolution of 10 km in the framework of EU-FP6 project Central and Eastern Europe Climate Change Impact and Vulnerability Assessment (CECILIA). The domain was centered over Romania at 46ºN, 25ºE and included the Republic of Moldova. We validate the model ability to simulate monthly temperature and precipitation by comparing the model simulations forced by ERA40 with the observations from CRU TS2.0 dataset and station observations for the period 1961–1990. The RegCM simulations (control and scenario runs) forced with the ECHAM5 Global Circulation Model (GCM) have been corrected against the systematic errors induced by the GCM. After the bias correction, the annual cycle of temperature and precipitation is analyzed by comparing the model simulations conducted under A1B scenario for the periods 2021–2050 and 2071–2100 with the control run for the period 1961–1990.The characteristics of the drought for the current climate were assessed based on SPI calculated for 1–24 month lags from CRU dataset and station observations. The SPI for 1, 3, 6, 12, 18, and 24-month lag was calculated and analyzed for RegCM simulations. The results show that the model underestimates the severity of droughts.

drought; Standardized Precipitation Index; RegCM; climate change; Moldova

INTRODUCTION

Drier conditions and increasing temperatures already observed in many regions of Eastern Europe could reduce agricultural production and increase crop variability. The Republic of Moldova is among the Eastern European countries affected by extreme drought (Potop, 2011). It is likely to experience a diverse range of impacts on various socio-economic sectors due to temperature increases accompanied by extreme precipitation events (dry and wet). Moldova's climate is moderately continental. Summers are warm and long, with temperatures averaging about 20.0°C and total precipitation ranging from 235 mm in the North to 175 mm in the South. Winters are relatively mild and dry, with temperatures ranging from –3.4°C in the North to –1.4°C in the South and winter total precipitation averaging 104 mm. The year 2007 was extremely hot across South-Eastern Europe, and the warmest in the history of instrumental observations in Moldova. Practically all air temperature records were broken in winter, spring, and especially in summer, with numerous heat waves and an extreme shortage of precipitation (Cazac et al., 2007). The number of heat days (Tmax ≥ 30°C) in the summer season was 45–60 (3–4 times higher than normal), the number of days with Tmax ≥ 35°C was 15–22 against reference period 1961–1990, number of days with Tmax ≥ 40°C was 5 (for the first time) (Overcenco, Potop, 2011). July 2007 was the warmest month for all the observation period (since 1887) with mean air temperature deviation more than +4.8°C from the normal (1961–1990). During 19–21st July of 2007 the absolute maximum of daily temperature was observed in Moldova (+41 and +41.5ºC). The highest daily Tmin in Moldova was recorded on 23rd July of 2007 (+26.7ºC); on the 24th of July the sum of accumulated degree-days for continuous period without precipitation (10 000–15 000ºC) was the highest out of observation period 1891–2007). On the 25th of August 2007 the

* Supported by the European Commission research funding (EU-FP6 project – CECILIA), Contract 037005 GOCE/2006, by the Ministry of Education, Youth and Sports of the Czech Republic, Projects No. MSM 6046070901 and S grant.

doi: 10.7160/sab.2012.430403

absolute temperature maximum for August in Moldova (+40.5°**C** in Tiraspol weather station) was registered. Recent research has also shown that while the summer of 2007 was unusual for the current climate, its temperature regime is very similar warm to what was projected for the second half of this century (Corobov, Overcenco, 2007).

Studies with different greenhouse gas emission scenarios show that Europe is one of the Earth's most sensitive regions to global warming (Giorgi, 1993) and Romania and Moldova are located in a transition region for changing the precipitation pattern. The projected changes of temperature and precipitation over the year show that although Moldova's baseline climate only for the end of summer and the beginning of autumn was characterized as semiarid, it is likely that in the future significantly longer and more severe dry spells will appear. In particular, according to the analysis of the results provided by six General Circulation Model experiments based on A2 and B2 SRES scenarios, Moldova will face warmer and wetter winters and hotter and drier summers and autumns. The projected annual decrease of precipitation in association with the temperature increase would likely induce strong humidity deficit generating droughts (Corobov, Overcenco, 2007).

Drought is a recurring extreme climate event over land characterized by below-normal precipitation over a period of months to years. Drought is often classified into three types (Dai, 2011): (1) meteorological drought, which is a period of months to years with below-normal precipitation often accompanied by above-normal temperatures, preceding and causing other types of droughts, (2) agricultural drought, a period with dry soils that results from below-average precipitation, intense but less frequent rain events, or above-normal evaporation, all of which leading to reduced crop production and plant growth, (3) hydrological drought occurring when river streamflow and water storages in aquifers, lakes, or reservoirs fall below long-term mean levels. Hydrological drought develops more slowly because it involves stored water that is depleted but not replenished. Severe drought conditions can profoundly impact agriculture, water resources, tourism, ecosystems, and basic human welfare.

In previous studies (Potop, Soukup, 2009; Constantinov, Potop, 2010; Potop, 2011; Potop et al., 2012) we have extensively analyzed the spatial and temporal evolution of drought events in the Republic of Moldova by comparing results from the most advanced drought indices (e.g. the Standardized Precipitation Index – SPI and the Standardized Precipitation Evapotranspiration Index – SPEI), which take into account the role of antecedent conditions in quantifying drought severity. In the present study, the SPI, originally developed by McKee et al. (1993), was adopted to assess and project drought characteristics in the Republic of Moldova based on Regional Climate Model (RegCM) simulations. High resolution climate model simulations are thus needed to provide accurate climate change scenarios accounting for this complex spatial and temporal modulation of the climate change signal. It is well recognized that GCMs can reproduce reasonably well climate features on large scales (global and continental), but their accuracy decreases when proceeding from continental to regional and local scales because of the lack of resolution (Meehl et al., 2007). This is especially true for surface fields, such as precipitation and surface air temperature, which are critically affected by topography and land use. In many applications, particularly related to the assessment of climate-change impacts, the information on surface climate change at regional to local scale is fundamental.

One alternative to bridge the gap between the climate information provided by GCMs and that needed in impact studies is nesting of a fine scale limited area model (or Regional Climate Model, RegCM) within the GCM. Such an approach has been used in the framework of the EU project CECILIA. The Regional Climate Model ICTP_RegCM3 centered over Romania and including the Republic of Moldova was run at a horizontal resolution of 10 km, for the current climate (1961–1990) and under SRES A1B scenario for 2021–2050 and 2071–2100 periods. In this paper we validate the monthly temperature means and precipitation totals simulated by the ICTP_RegCM3 against CRU TS2.0 dataset and station observations, and assess the drought characteristics over the Republic of Moldova based on the Standardized Precipitation Index (SPI) (McKee et al., 1993, 1995).

MATERIAL AND METHODS

Data description

We used monthly temperature means and precipitation totals from gridded simulated data at 10 km horizontal resolution performed with the Regional Climate Model RegCM and CRU TS2.10 land observation data set at 0.5° × 0.5° horizontal resolution available at http://www.cru.uea.ac.uk/cru/data/hrg/cru_ts_2.10. The ICTP_RegCM model was originally developed (Giorgi et al., 1993) and then augmented and used in various reference and scenario simulations (Giorgi et al., 1994a, 1994b; Pal et al., 2004). The RegCM simulations conducted within the CECILIA-FP6 project covered a domain (41.016°N–50.175°N; 14.095°E–36.192°E) centered over Romania (46°N; 25°E) (Boroneant et al., 2009, 2011a,b; Halenka, 2010). For this study we selected a model domain centered over the Republic of Moldova (45.01°N–49.01°N; 26.52°E–30.48°E) (Fig. 1). 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 monthly temperature and precipitation RegCM simulations driven by ERA40 reanalysis have been validated against CRU TS2.10 land observation data and observations recorded at 15 meteorological stations of Moldova's State Hydrometeorological Service (SHS). The station distribution is given in Fig. 1. The validation period was 1961–1997. To examine spatial drought variability, three agro-climatic regions were delimited in the country: the Northern, Central, and Southern (Constantinov, Potop, 2010; Potop et al., 2011). The agro-climatic regions reflect various physico-geographical conditions (relief, slope, and elevation). The distribution of the stations within each agro-climatic region is given in Table 1.

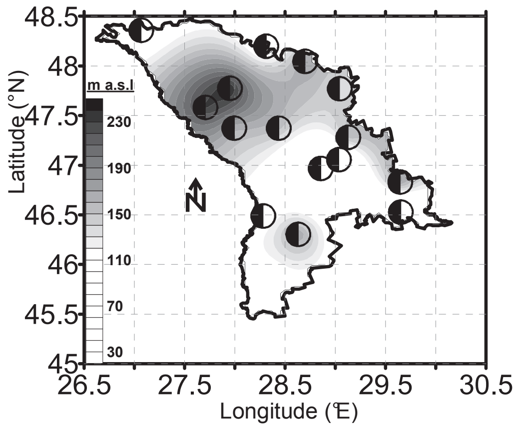


Fig. 1. Location of 15 Moldova's meteorological stations and their altitudes

The bias correction of RegCM simulations forced with ECHAM5 GCM

The RegCM simulations (control and scenario runs) forced with the ECHAM5 GCM have been corrected against the systematic errors induced by the GCM. The bias correction has been applied at monthly data using the delta method (Déqué, 2007). The bias was calculated for each month, in each grid point, as a difference (ratio) between the temperature (precipitation) mean of the control run of RegCM forced by ECHAM5 GCM and the RegCM run forced by ERA40 for the common period 1961–1990. Then this difference (ratio) was added (multiplied) to (with) each value of the time series of the control run (1961–1990) and scenario runs (2021–2050 and 2071–2100) of RegCM forced with the ECHAM5 GCM, in each grid point of Moldova domain (Boroneant et al., 2011c).

Validation of RegCM simulations

We validated the model ability to simulate monthly temperature and precipitation over the Republic of

Table 1. Distribution of climatological stations into three agro-climatic regions: Northern (N), Central (C), and Southern (S)

Stations	Latitudinal degree	Longitudinal degree	Altitudinal (m a.s.l.)	Slope degree	Aspect
I agro-climatic region – N					
1. Briceni	48.359	27.069	242	1.0	SE
2. Balti	47.775	27.952	102	0.5	S
3. Soroca	48.199	28.313	173	1.0	SE
4. Camenca	48.046	28.700	154	0.0	plain
5. Falesti	47.582	27.708	162	0.5	S
6. Ribnita	47.770	29.045	119	1.5	E
II agro-climatic region – C					
7. Bravicea	47.373	28.438	78	5.5	SW
8. Baltata	47.056	29.037	79	1.5	SE
9. Corneşti	47.373	27.995	232	5.5	SW
10. Dubasari	47.281	29.130	42	4.0	SW
11. Tiraspol	46.830	29.647	21	0.0	SW
12. Chisinau	46.967	28.856	173	0.5	plain
III agro-climatic region – S					
13. Comrat	46.303	28.632	133	0.5	SE
14. Leova	46.488	28.284	156	0.5	plain
15. Stefan-Voda	46.527	29.653	173	0.0	plain

Moldova domain. In this respect, we compared the annual cycle of temperature and precipitation based on RegCM simulations forced with ERA40 reanalysis data with the corresponding annual cycle calculated from CRU TS2.10 land observation data set and from observations at 15 representative stations from the Republic of Moldova.

The 30-year averages (1961–1990) for the monthly means of temperature and precipitation totals were calculated in each grid point of the domain both for simulated data set and CRU observations. Both simulated and CRU gridded data were downscaled at station coordinates in the sense that the closest grid point to station location was selected for comparison. To validate the RegCM data forced by ERA40 we compared the simulated annual cycle of spatially averaged 30-year monthly means of temperature and precipitation totals with the corresponding annual cycle calculated from CRU and station observations. Prior the calculation of the annual cycle of temperature and precipitation for the RegCM simulations (control and scenario runs) forced with the ECHAM5 GCM both monthly temperature means and precipitation totals have been bias corrected against the systematic errors induced by the GCM.

SPI calculation

Drought was analyzed using the SPI (McKee et al., 1993, 1995) which has been considered the most reliable index for quantifying the intensity, duration, and spatial extent of drought on multiple time scales (Lloyd-Hughes, Saunders, 2002). It is an excellent tool for research on spatial analysis, since it removes the temporal effects of various precipitation magnitudes. The SPI is computed by fitting a probability density function to the frequency distribution of precipitation summed over the time scale of interest. Each probability density function is then transformed into a standardized normal distribution and the anomaly strength is classified into 7 categories. The transformed distribution allows us to determine the intensity of precipitation deficit by reference to a mean value. This facilitates the spatial comparison of drought conditions and enables us to monitore drought at various temporal scales (McKee et al., 1995). The main advantages of the SPI is that it can be computed for different time scales, can provide early warning of drought and can help assess drought severity. The SPI is less complex than the Palmer Drought Severity Index. The main shortcoming of the SPI is that it does not provide the real magnitude of drought (precipitation differences from mean values) or the absolute differences between sites (Hayes et al., 1999).

We used the distribution version of the SPI program available at ftp://ulysses.atmos.colostate.edu which was adapted for looping over each grid point of the domain. The SPI was calculated at time scales from 1 to 24 months for CRU and station observation data, and for 1, 3, 6, 12, 18 and 24-month lags for the RegCM simulations. The drought at these time scales is relevant to describe drought conditions for a range of meteorological, agricultural, and hydrological applications and also its socio-economic impact. For example, soil moisture conditions respond to precipitation deficits occurring on a relatively short time scale, whereas groundwater, streamflow, and reservoir storage respond to precipitation deficits arising over many months.On the other hand, socio-economic drought occurs when human activities are affected by

Table 2. Monthly mean temperature and precipitation totals for observation datasets (CRU and stations) and Regional Climate Model (RegCM) simulations values after bias correction for the control run (1961–1990) and A1B scenario runs (2021–2050 and 2071–2100) for Moldova domain

Datasets, time slices	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean air temperature (°C)												
CRU, 1961–1990	–3.2	–1.8	2.7	9.6	15.6	19.2	20.9	20.7	16.2	10.4	6.2	–0.5
Stations, 1961–1990	–3.4	–1.9	2.5	9.8	15.7	19.1	20.5	20.1	15.5	9.8	4.0	–0.7
RegCM (ERA), 1961–1990	–1.8	–0.8	3.0	9.4	15.5	18.9	20.6	20.1	15.3	9.2	3.9	0.2
RegCM ctl, 1961–1990	–1.7	–0.5	3.4	9.6	15.1	18.2	19.8	19.2	15.4	9.2	4.3	0.4
RegCM sc1, 2021–2050	–0.1	2.2	5.9	11.7	17.0	19.5	20.2	19.3	16.2	11.2	4.8	1.6
RegCM sc2, 2071–2100	1.5	3.0	7.4	12.7	18.6	21.8	23.2	23.1	19.3	13.0	7.3	3.9
Monthly precipitation totals (mm)												
CRU, 1961–1990	36	34	31	42	56	72	68	50	48	27	36	40
Stations, 1961–1990	34	33	30	42	58	77	71	54	50	27	39	38
RegCM (ERA), 1961–1990	53	53	52	78	111	136	129	95	51	37	54	54
RegCM ctl, 1961–1990	53	53	52	78	111	136	129	95	51	37	54	54
RegCM sc1, 2021–2050	48	56	51	61	121	135	155	104	60	36	51	53
RegCM sc2, 2071–2100	60	56	42	87	87	102	117	88	62	42	59	50

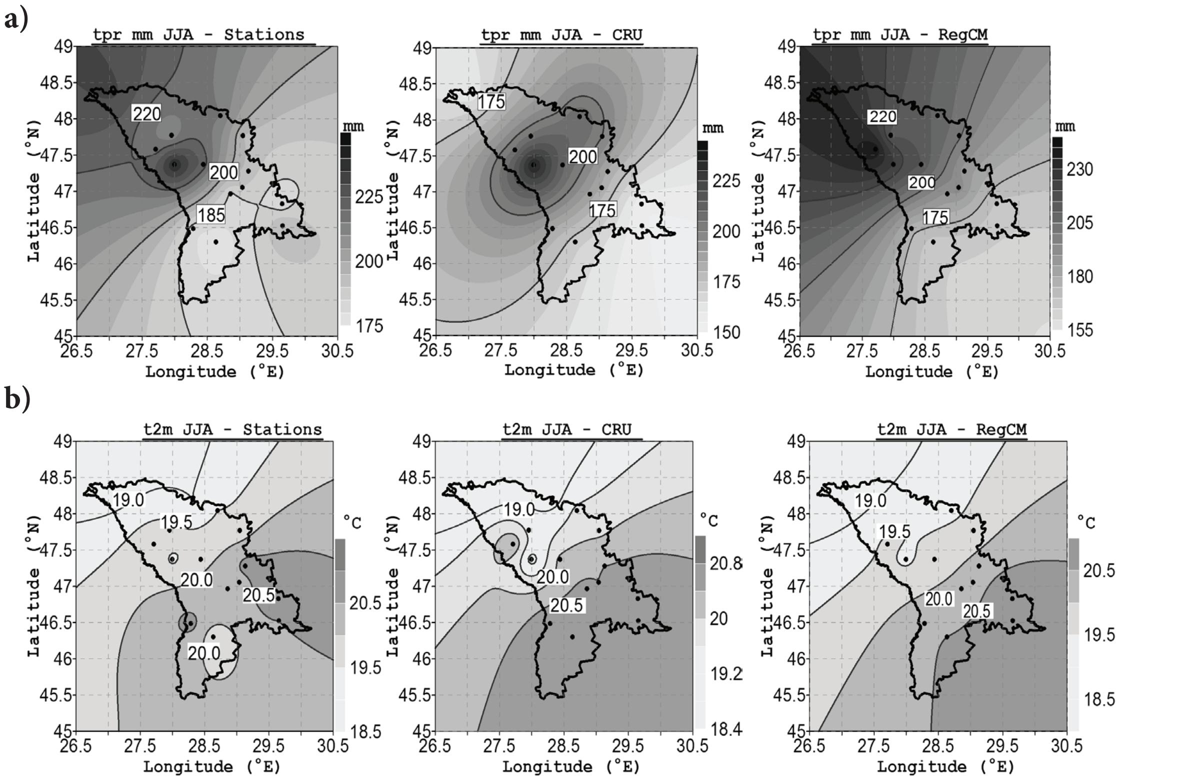


Fig. 2. Maps of mean summer precipitation totals (a) and air temperature means (b) for 15 station observations, CRU TS2.1 data and simulation (RegCM3 forced by ERA40); JJA = June, July, August, REGCM = Regional Climate Model, CRU = dataset

reduced precipitation and related water availability. In this study, a summer (June, July, and August) drought episode was defined as a continuous period of the SPI values less than –1.0 at least once during the episode. Values from –1.0 to –1.49 correspond to moderate drought, –1.50 to –1.99 to severe drought, and below –2.0 to extreme drought. Similarly, values 1.0–1.49 correspond to moderate wet, 1.50–1.99 to severe wet, and values above 2.0 correspond to extremely wet conditions. Values from –0.99 to 0.99 are qualified as normal conditions.

RESULTS AND DISCUSSION

Model validation

The 30-year monthly means of RegCM simulations (forced by ERA40), CRU observations, and station observations were calculated for the period 1961–1990 in each grid point of corresponding data set, and at station location. Then, these means were spatially averaged and compared. The results are presented in Table 2. Comparison between the simulated (RegCM forced by ERA40) and observed monthly temperature (CRU and station observations) shows that the model skillfully captures the temperature characteristics during summer months over Moldova but overestimates the winter month temperature means. The model does well representing the annual cycle of temperature but slightly overestimates winter (December, January, February) temperature means and slightly underestimates autumn (September, October, November) temperature means. Monthly precipitation totals are systematically overestimated by the model compared to station and CRU observations (Table 2). The largest magnitudes of RegCM (ERA40) precipitation errors are observed in late spring (April, May) and summer (June, July, August) months when the simulated mean precipitation totals are almost doubled the observed (station and CRU) precipitation means.

The spatial distributions of 30-year summer (JJA) temperature means and precipitation totals over Moldova domain as represented in RegCM simulation forced by ERA40, CRU TS2.1 data set and at stations were represented in Fig. 2. As the maps on the upper panel show, the RegCM overestimates precipitation totals in comparison both with CRU and station observations. Higher summer precipitation totals are simulated (observed) in the northern half of the country while lower precipitation totals are simulated (observed) in the southern half of the country. The spatial distribution of simulated and observed summer (JJA) temperature means are represented in the lower panel of Fig. 2. The model reproduces quite well the summer temperature mean and its spatial distribution over the country territory. Higher summer temperature means are simulated (observed) in the southern part of the country while lower temperatures in the northern part of the country.

Projected changes of temperature and precipitation

Table 2, among other, shows also the annual variation of bias corrected monthly temperature means and precipitation totals calculated for 30 years, corresponding to the RegCM forced by ECHAM5 GCM in the control run (1961–1990) and A1B scenario runs (2021–2050 and 2071–2100), respectively. The results show that the projected temperature means for all months in the A1B scenario runs will increase compared to the control run. The temperatures are projected to a higher increase by the end of the 21st century compared to the mid-21st century and reference period 1961–1990, respectively. The highest increase of monthly temperature mean is expected during the summer months (JJA). The monthly precipitation totals are projected to slightly decrease in late autumn (ON), winter (DJF) and spring (MA) and highly increase in summer months (JJA) during the period 2021–2050. The A1B scenario projects significant decrease of precipitation totals in summer months (JJA) during the period 2071–2100. The 30-year summer temperature means for Moldova domain vary between 18.0 to 20.0°C for the current climate (1961–1990), between 19.0–21.0°C for the A1B scenario (2021–2050), and 22.0–24.0°C, respectively, for the A1B scenario (2071–2100). The projected changes of summer temperature mean under the A1B scenario varies between 0.3–0.7°C for the period 2021–2050 and between 3.2–4.0°C for the period 2071–2100 (Boroneant et al., 2011c). According to the A1B scenario the summer precipitation totals are projected to slightly increase (20%) in the northern part of the country during 2021–2050 compared with the control run (1961–1990) while significant decrease of precipitation is projected for summer during the period 2071–2100 (–10% to –30%).

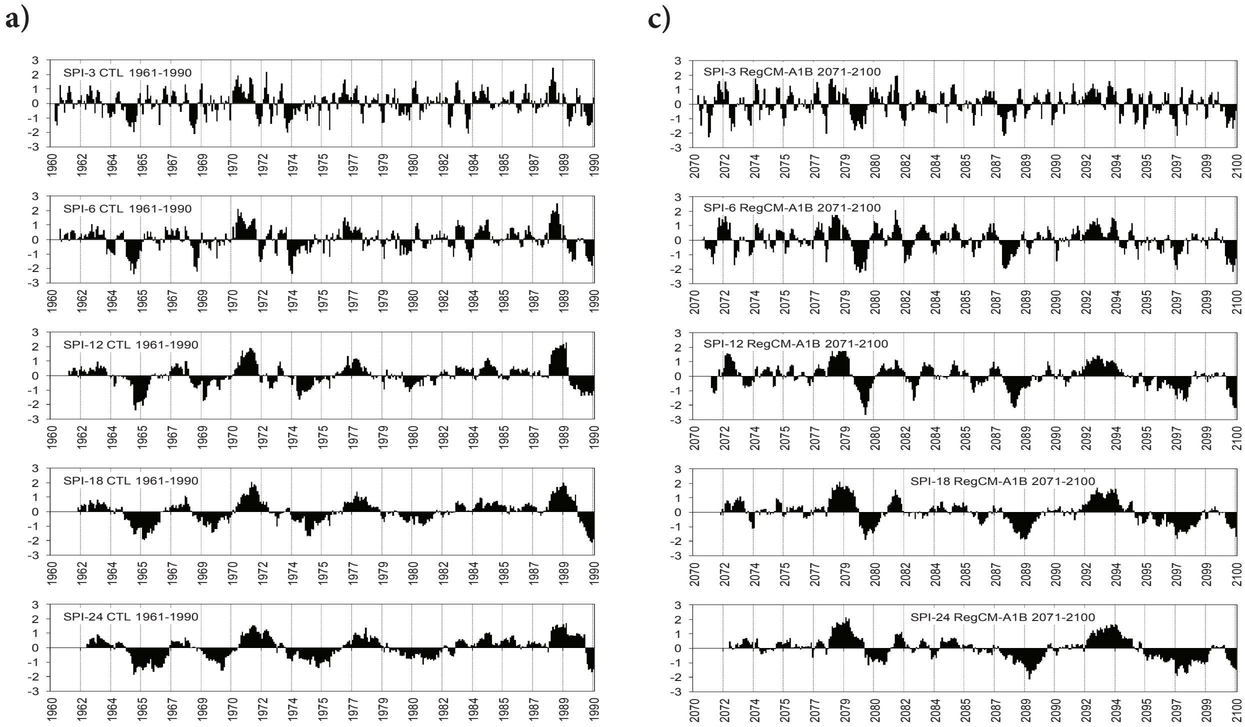
Observed characteristics of drought for the current climate

Based on monthly precipitation totals at 15 meteorological stations and in each grid point of CRU data set over Moldova domain the SPI at 1 to 24-month lags was calculated for the period 1960–1997. To assess the time evolution of drought conditions in the country, the SPI was calculated for short- (1–2 months), medium- (3–12 months), and long-term (13–24 months) droughts. As a result, the largest number of summer drought events during the early 1960s' (1961, 1963, 1967), mid 1970s' (1973–1976) to early 1980s' (1981, 1986–1987) and 1990s' (1990, 1994, 1995, 1996, 1997) was observed. Additionally, the summer drought episodes have increased in frequency and intensity since the early 1980s'. However, the longest extreme summer droughts were recorded during 1973–1976 and 1990–1997. In contrast, extreme and moderate wet summers have been recorded during the years 1965, 1970, and 1985. We also found out that according to the summer medium-term droughts which impact on agricultural production, all stations were affected by severe or extreme drought episodes during the summers of 1976 (June–July), 1986 (August), 1990 (July–August), and 1994 (June–July–August). Out of these years, the summer drought episode of 1961 was only recorded in the northern and central part of the country. Throughout the whole period of this study, the most extensive and extreme drought covering the whole territory was recorded in 1994. That year, the maximum drought duration was 6 months divided into 2 episodes (March–April and June–September) with the longest duration in summer months.

In this study, a drought episode was defined as at least one continuous period of SPI values less than –1.0 during the summer months (JJA). We computed the consecutive number of months in each drought episode for SPI at time scales from 1 to 24 months. Table 3 provides a summary of the average duration and number of summer drought episodes for short-, mid-, and long-term droughts for the three agro-climatic regions: Northern, Central, and Southern calculated from CRU dataset and station observations for the period 1960–1997. The mean number of drought episodes decreased with increasing time scales. As the timescale increased, the drought episodes appeared with a longer duration. The number of short-term summer drought events is higher than that of long-term droughts. It is worth to note that the number of summer drought events with short-term drought ranges 14–15 for CRU dataset and 15–16 for station observations while for the long-term drought the number of years ranges

Table 3. Number of summer drought events and their average duration (in months) at short-term (1–2 months), medium-term (3–12 months), and long-term (13–24 months) timescale for 3 agro-climatic regions of the Republic of Moldova: Northern (N), Central (C), and Southern (S) (1960–1997)

Time scales	CRU dataset			Station observations		
	N	C	S	N	C	S
short-term	14 (0.9)	13 (1.2)	15 (1.2)	16 (1.1)	15 (1.4)	15 (1.4)
medium-term	13 (1.1)	12 (1.8)	11 (2.0)	11 (1.3)	11 (2.0)	11 (2.2)
long-term	10 (1.3)	11 (2.1)	10 (2.8)	7 (1.5)	7 (2.3)	9 (2.9)



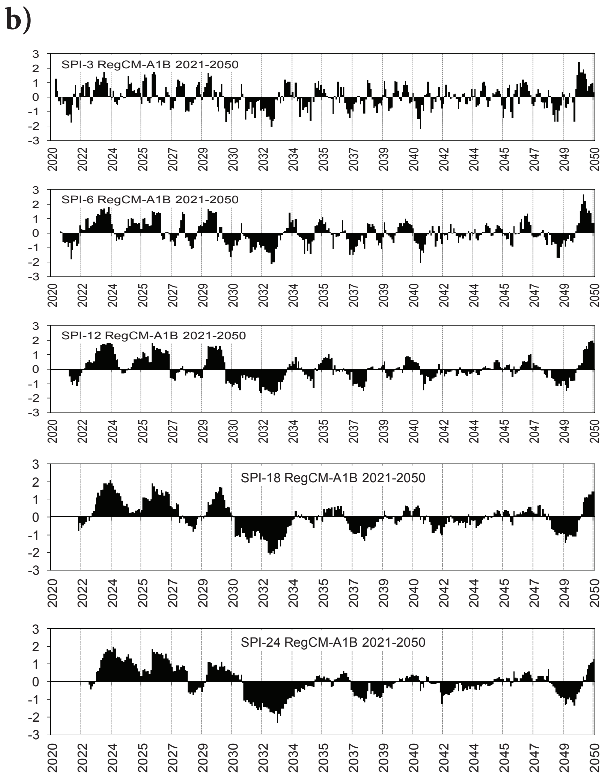


Fig. 3. SPI series at time scales of 3, 6, 12, 18, and 24 months based on monthly precipitation totals simulated by the RegCM control run (a) (1961–1990) and A1B scenario runs (b) (2021–2050) and (c) (2071–2100), averaged for all grid points of the domain; SPI = Standardized precipitation Index; RegCM = Regional Climate Model; the vertical axis is for the SPI values.

10–11 according to CRU data and 7–9 according to station observations. According to CRU and station observations, the averaged duration of short-term summer drought is 0.9–1.2 and 1.1–1.4 months, respectively, that of mid-term summer drought 1.1– 2.0 and 1.3–2.2 months, respectively, and the averaged duration of long-term summer drought is 1.3–2.8 and 1.5–2.9 months, respectively. The results show that the Southern region is more affected by moderate and extreme droughts than the Northern region and that the former is likely more vulnerable to drought (Potop, Soukup, 2009; Potop, 2011).

Changes projected in drought characteristics

SPI – temporal evolution. Drought appears first in the short time scales and if dry conditions persist, drought develops at longer time scales. The use of several time scales of SPI takes into account the role of antecedent conditions in quantifying drought severity. Based on monthly precipitation totals simulated by the RegCM for the control run (1961–1990) and A1B scenario runs (2021–2050 and 2071–2100), the SPI at 1, 3, 6, 12, 18, and 24 month lags have been calculated in each grid point of the domain and then spatially averaged.

The temporal evolution of the averaged SPI calculated for 3, 6, 12, 18, and 24 months over Moldova's domain for the period 1961–1990 (control run) is presented in Fig. 3a. The evolution of the SPI calculated for 3 months presented in the upper panel shows a high variability of the index between –1 and +1. The persistence of drought conditions can be easily identified from the SPI at time scales of 6 and 24 months. As the time scale for calculation the SPI increases (6 and 24 months), the wet and dry conditions as well as their persistence can be clearly identified. The antecedent moisture conditions in SPI calculated from 6 to 24 months point to the persistence of dry and wet conditions lasting for several years (central and bottom panel of Fig. 3a). The plots show that the period in which dry conditions were identified tended to increase by some months as the time scale became longer. This is a result of the calculation procedure of the multi-scalar drought index, because longer time scales generated smoother fluctuations and thus a larger sequence of anomalies with the same sign.

These characteristics are also true for the temporal evolution of SPI calculated for the scenario runs for the periods 2021–2050 and 2071–2100, respectively (Fig. 3b, c) at time scales of 3, 6, 12, 18, and 24 months. In terms of intensity and persistence of dry and wet spells, Fig. 3b shows that the first part of the period 2021–2050 is characterized by intense and persistent wet spells which are projected to be followed by some years with severe drought. The variability of SPI is projected to increase at the end of this period. The temporal evolution of SPI for the period 2071–2100 for 3, 6, 12, 18, and 24 months is presented in Fig. 3c. The time series are characterized by a higher variability and longer persistence of both wet and dry periods as compared with the control run and scenario run for the period 2021–2050.

The projected changes in summer drought characteristics based on the SPI calculated from RegCM simulations are presented in Table 4. It shows the absolute numbers of summer drought events simulated by the RegCM for the time slices 1961–1990 (control run) and under SRES A1B scenario for 2021–2050 and 2071–2100 periods. The number of summer events was calculated by averaged SPI values over the three months (JJA) of the summer season for all grid points of the domain for 3, 6, 12, 18 and 24 months (Table 4). For the control run, the summer SPI at 3-, 6-, 12- and 24-month lags show 5 years. The largest number of summer drought events was projected at the end of the 21th century (2071–2100) at timescale of SPI-18 and SPI-24 months (7 years). The RegCM simulation produced fewer drought events at timescales of 3 and 6 months during the period 2021–2150 (3 years). Therefore, during the mid-21st century (2021–2050) less dry events are projected for almost all timescales of SPI series. The projections suggest that by the end of the 21st century long-term droughts could thus become more important than it is observed during the present climate. Increases in drought severity are also projected for the end of the 21st century. The consequences of drought impact on agriculture and environment systems are expected to be severe in terms of progressive scarcity of surface water due to high demand for irrigation and of erosion and desertification processes intensification. Summer drying may also be attributed to a combination of both increased temperature and potential evaporation not balanced by the changes in precipitation. The use of SPI, being just a precipitation-based index, does not take into account the changes in evapotranspiration, which are likely to be a consequence of the projected changes in temperature (Blenkinsop, Fowler, 2007). The use of the Standardized Precipitation Evapotranspiration Index (SPEI), which is more complex and takes into consideration both temperature and precipitation, revealed new aspects of drought characteristics over the Republic of Moldova (Potop et al., 2012). According to the SPEI, the water deficit during the last three decades is to a large extent affected mainly by the increase of the maximum (+0.7°C decade^{-1}) and minimum (+0.5°C decade^{-1}) temperature associated with decreased precipitation (20 mm decade^{-1}). The increasing trend in extreme temperatures in the Republic of Moldova has particularly affected the highest positive deviation of Tmin (from 1.5 to 3.5°C) during warm season of the year and the increasing water deficit in this season. Although lack of precipitation is the principal driving factor for drought conditions, the rapid increasing of minimum temperature in this region could also play a notable role in drought through increasing its severity as a consequence of water loss by evapotranspiration (Potop et al., 2012).

SPI – frequency distribution. The frequency distribution was calculated as the ratio between the number of occurrences in each SPI category and the total number of events counted for all grid points of the domain and for a given SPI calculated for various lags (1, 3, 6, 12, 18, and 24 months). In the Table 5, percentage of drought and wet occurrences is expressed in 7 classes of moisture category (%) based on the SPI series calculated at 1, 3, 6, 12, 18, and 24 months for the time slices 1961–1990 (control run) and 2021–2050 and 2071–2100 (A1B scenario runs). As can be seen from Table 5, the frequency of extreme and severe droughts propagates from short-term (1 month, meteorological drought) and medium-term (3 and 6 months, agricultural drought) to long-term droughts (12, 18, and 24 months, hydrological drought). According to the time scale for calculating the SPI, the normal condition

Table 4. Number of summer drought events at timescales 3, 6, 12, 18, and 24 months simulated by the RegCM for the control run (1961–1990) and A1B scenario runs (2021–2050 and 2071–2100)

Model	Time slices	SPI-3	SPI-6	SPI-12	SPI-18	SPI-24
RegCM ctl	1961–1990	5	5	5	7	5
RegCM sc1	2021–2050	3	3	5	6	4
RegCM sc2	2071–2100	4	6	5	7	7

SPI = Standardized Precipitation Index; RegCM = Regional Climate Model varies between 46–78% out of the total values of SPI in all grid points of the domain. Moderate drought and moderate wet are almost equally distributed around 9% while severe drought and severe wet are equally distributed around 5%. Differences in extremely dry conditions (5%) compared to extremely wet conditions (3%) were observed when increasing the SPI lags for the control and scenario runs. The occurrence of extreme moisture conditions has a tendency toward dry conditions, especially for the SPI calculated with longer lags (12, 18, and 24 months) for the period 2071–2100. The extreme drought conditions (SPI ≤ –2) are projected to the increase (9–15%) of long-term drought (SPI at 12–24 month lags).

CONCLUSIONS

Various economic sectors, notably agriculture, are sensitive to changes in the characteristics of drought episodes. This article presents the results on drought characteristics over Moldova in a multi-scalar way based on SPI calculated for RegCM simulated data at high resolution (10 km) for the current (1961–1990) and two future climates (2021–2050 and 2071–2100). The results can be summarized as follows:

(1) RegCM simulations forced by ERA40 data were compared with station observations and CRU data downscaled at station coordinates. The results show that the model does quite well in representing the annual cycle of temperature but precipitation totals are systematically overestimated compared both with stations and CRU data. This feature is transferred to SPI which is based only on precipitation. Consequently, the model projections underestimate the severity of droughts when compared with the characteristics of current climate assessed on observation basis.

(2) The temperatures projected by the A1B scenario runs will increase compared to the control run. The temperatures are projected to increase by the end of the 21st century compared to the mid-21st century and to the reference period 1961–1990. The precipitation totals are projected to slightly decrease in autumn, winter, and spring and increase in summer during the period 2021–2050. Significant decrease of precipitation is projected for summer during the period 2071–2100.

(3) The evolution of the SPI series calculated for short- time lags (1–3 months) presents a high variability of the index around normal conditions. As the time scale for calculation the SPI increases (6 and 24 months), the wet and dry conditions as well as their persistence can be better identified.

Table 5. Projects of frequency distribution (%) of summer SPI (1, 3, 6, 12, 18, and 24 month lags) in 7 classes of moisture category (%) for RegCM control run (1961–1990) and SRES A1B scenario runs (2021–2050 and 2071–2100)

Time scales	Extreme drought	Severe drought	Moderate drought	Near normal	Moderate wet	Severe wet	Extreme wet
1961–1990 (control run)							
1-month	1	4	9	77	8	2	0
3-month	7	7	9	54	11	8	4
6-month	7	7	9	54	11	8	4
12-month	11	5	8	54	11	7	5
18-month	13	6	9	45	10	8	8
24-month	15	7	8	46	11	7	6
2021–2050 (A1B scenario run)							
1-month	0	3	8	78	8	3	1
3-month	4	6	12	55	9	7	6
6-month	6	6	11	54	8	6	8
12-month	9	6	11	51	10	6	7
18-month	11	7	9	50	8	5	9
24-month	14	4	8	53	8	6	8
2071–2100 (A1B scenario run)							
1-month	1	3	9	77	7	3	1
3-month	5	6	10	56	10	6	6
6-month	8	6	10	51	11	7	6
12-month	12	5	7	54	10	6	6
18-month	12	7	9	47	10	7	8
24-month	15	7	8	48	9	5	8

SPI = Standardized Precipitation Index; RegCM = Regional Climate Model

Acknowledgements

The RegCM simulations have been produced in the National Meterological Administration-Romania in the framework of CECILIA EU-FP6 Project.

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Received for publication on September 21, 2011
Accepted for publication on October 12, 2012

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Ověření a využití regionálního klimatického modelu při sledování změn výskytu sucha v letním období v Moldavské republice

Scientia Agric. Bohem., *43,* 2012: 134–144.

Cílem studie bylo sledovat změny výskytu sucha a suchých období v Moldavské republice, a to pomocí indexu SPI (standardizovaný srážkový index) vypočteného z měsíčních úhrnů srážek simulovaných regionálním klimatickým modelem RegCM3. Modelové simulace byly provedeny v horizontálním rozlišení 10 km v rámci projektu EU-FP6 – CECILIA (41.016ºN–50.175ºN; 14.095ºE–36.192ºE). Sledovaná oblast se středem nad Rumunskem 46°N 25°E zahrnovala i území Moldavské republiky (45.01ºN–49.01ºN; 26.52ºE–30.48ºE). Prvním krokem bylo ověřit schopnost modelu simulovat měsíční teplotu vzduchu a měsíční úhrn srážek porovnáním modelové simulace s databází CRU TS2.0 a s daty staničního pozorování. Změny v ročním chodu teploty vzduchu a srážkových úhrnů byly analyzovány na základě porovnání modelových simulací prováděných podle scénáře A1B pro období 2021–2050, resp. 2071–2100 s referenčním obdobím 1961–1990. Vypočtený index SPI (1–24 měsíců) pomocí simulace modelem RegCM pro každý gridový bod na území Moldávie byl prostorově průměrný, v porovnání s indexem SPI vypočteným z databáze CRU. Výsledky ukazují zvýšení nebezpečí výskytu sucha v letním období na území Moldávie v důsledku nižších úhrnů srážek a celkového oteplování. Ve střednědobém a dlouhodobém časovém horizontu by měla sucha přetrvávat a frekvence jejich výskytu stoupat.

sucho; standardizovaný srážkový index; RegCM; klimatická změna

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