AIR TEMPERATURE AND PRECIPITATION VARIABILITY IN NORTHEASTERN BULGARIA ON THE BACKGROUND OF CLIMATE CHANGE

by

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The aim of the present research work is to bring to better understanding the recent climate change at regional scale. The tendencies of many-years variability of air temperature and precipitation in Northeastern Bulgaria are determined. In order to determine future tendencies in air temperature and precipitation variability the data from regional climate models are analyzed. The occurrence of extreme monthly temperature and precipitation totals are investigated by calculation of 10th and 90th percentiles of the empirical distribution in the reference period 1961-1990. The main result of present work is that there are a positive tendency in changes of air temperature and negative in precipitation. The regional climate model data show increasing of extreme hot and dry months which is considerable for the second part of 21th century.

Key word: *air temperature, precipitation, extreme temperature, extreme precipitation, observation, regional climate models*

Introduction

Knowledge about changes in temperature and precipitation is the most important information about climate changes and the air temperature and precipitation are the main elements of climate which determine various aspects of human life and activities. That is why the variability of air temperature and precipitation has been the topic of many research works. The scientific publications show that by the late 19th century until now the global air temperature increases, and the first decade of the 21st century was the warmest period of instrumental observations [1]. According to Hadley Centre for Climate Prediction and Research, the mean global air temperature in 2010 was with 0.81 °C higher than one in 1850 and in Europe the increasing was with 1.0 °C. Based on the regional climate models for Central and East Europe the results form CECILIA project [2] show statistically significant trend to increasing of mean air temperature with about 1.5 °C for the period 2012-2050 compared to the reference period 1961-1990.

The tendency for precipitation is for increasing of winter totals with about 20% and decreasing of summer values with 10% [3]. According to the results of PRUDENCE project in the

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end of 21th century there will be considerable decreasing of summer precipitation total in South and East Europe and the extreme precipitation will be more frequent and intensive [4]. Many scientific publications show increasing of extreme climate events in Europe as heat waves, drought, and intensive precipitation [5, 6].

Contemporary climate changes in Bulgaria are investigated by many authors [7-13]. Extreme precipitation is a topic of many publications [14-17]. The scientific works on regime and many-years changes in precipitation in Bulgaria showed a decreasing trend of rainfall amounts and drought in many regions of the country. Alexandrov [18] shows three periods with prolonged and intensive droughts in Bulgaria: 1902-1913, 1942-1953, and 1982-1994. In the first period the dry years are about 20%, in the second they increased to about 40%, and during the period 1982-1994 the dry years are about 50%. According to Bocheva *et al.* [19] there is considerable increasing of the average number of days with the daily precipitation totals above 100 mm. During the 1940s and 1980s the extreme dry months have been observed more often than extreme wet months but since the beginning of 21th century the increasing of extreme wet months is observed [20]. Despite of many publications on air temperature and precipitation in Bulgaria deep statistical and geographical analyses are needed in order to answer various questions related to contemporary climate change in regional scale and its impact.

The aim of present study is to provide updated information about many-years variability in air temperature and precipitation in Northeast Bulgaria and to analyze their possible future changes. The main question is if the regional climate variability is consistent with global climate change. In order to achieve this objective the following tasks are solved:
– quality control of the initial information,
– characterization of observed trend of seasonal temperature and precipitation,
– analysis of the expected changes in air temperature and precipitation in the 21st century, and
– investigation of occurrence of extreme temperature and precipitation months.

Data and methods

Northeast part of Bulgaria is one of the main agricultural areas of the country and the information about air temperature and precipitation variability is very important for this area. Monthly data for air temperature and precipitation from four meteorological stations are used for the research. The stations are situated at the regions with a various geographical conditions: station Russe is at the Danube river coast, Varna is at the Black sea coast, and other two stations Razgrad and Shumen are situated in the east part of the Danube river valley (fig. 1).The altitude of the stations varies between 4 m a. s. l. (Varna) and 216 m a. s. l. (Shumen).

Figure 1. Map of study area and location of investigated meteorological stations

The climate is moderate continental with the influence of the Black Sea on the east. Due to the effect of the Black Sea in the eastern part of the Danube valley winter is relatively mild and summer temperatures are lower than in other parts of the study area. The annual precipitation amount is less than the annual average for the country. Rainfall amounts in Dobrudja plateau reached not more than 450-500 mm per year.

Two types of data are used for the research: observation data for four meteorological stations (mentioned above) for the period 1961-2010 and, ENSEMBLES data*, with global climate models (GCM) boundary conditions for 1950-2100 and simulations with the ERA-40 re-analysis for the period 1961-2002. The data from regional climate models (RCM) MPI – Germany and ETHZ – Switzerland are used**.

The model outputs are downscaled to the stations data and the bias corrections are made by use of measured climatic data for the period 1961-1990. The temperature data are corrected as a difference and the precipitation data as a ratio between climate normal (average for the period 1961-1990) and model data for each month and year. In order to show the necessity of bias correction we show the annual cycle of air temperatures and precipitation for the period 1961-1990 at one of studied stations – Razgrad, based on data from the MPI model before (a) and after (b) bias correction (fig. 2). There is a complete coincidence in the annual cycle of air temperature based on observation and model data after correction but for precipitation data there are some uncertainties, however the annual cycle of precipitation after bias correction of model data is close to one of observed data.

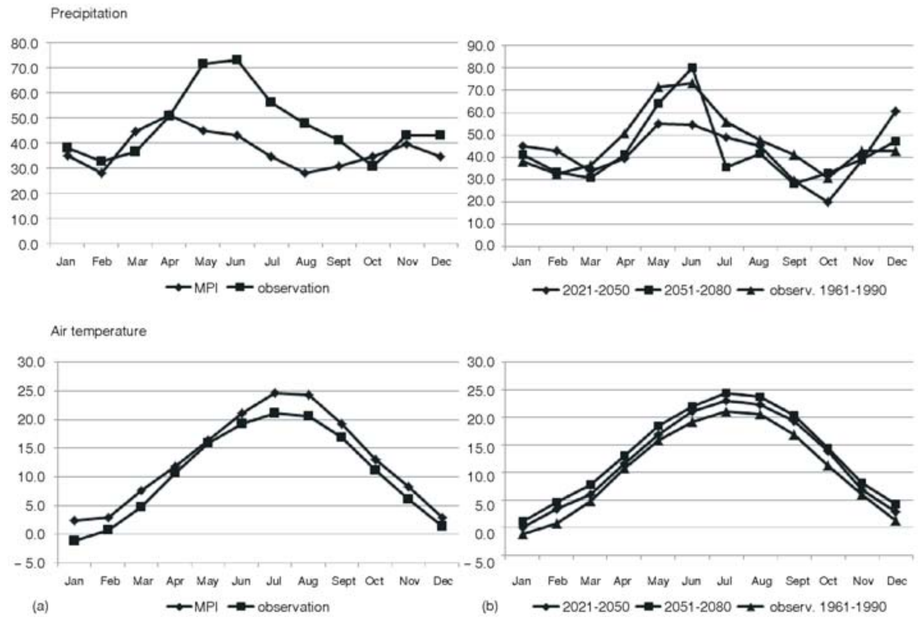

Figure 2. Annual cycle of air temperature and precipitation for the period 1961-1990 at station Razgrad on the basis of MPI regional climate model; (a) before bias correction, (b) after bias correction

On the basis of monthly data the seasons are determined as follows: winter – December, January, and February; spring – March, April, and May; summer – June, July, and August; autumn – September, October, and November.

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** Data are freely available at http://climexp.knmi.nl/start.cgi?id=someone@somewhere (accessed by June 3, 2015)

The assessment of seasonal trends in air temperatures and precipitation is made on the bases of observation data for the periods 1981-2010. The calculation of coefficients of the trend and assessment of their statistical significance are made by AnClim software [21]. The air temperature changes are determined as a difference between seasonal averages for the observed period 1981-2010 and two future 30-years periods with model data: 2021-2050 and 2051-2080. In order to investigate the changes in seasonal precipitation the precipitation totals for the periods 2021-2050 and 2051-2080 are presented as a percentage of precipitation for the observed period (1981-2010).

The analysis of extreme monthly temperature and precipitation are investigated by calculation of 10th and 90th percentiles of the empirical distribution in the reference period 1961-1990. Extremely cold and warm months were determined for every of investigated stations. An extreme temperature month is defined as a month whose mean air temperature is lower (colder) than 10th percentiles or higher (warmer) than 90th percentiles of empirical distribution of each month in the period 1961-2010. Extreme wet months are defined as months whose monthly precipitation total is higher than 90th percentile of the empirical distribution in the period 1961-2010. As extreme dry month we consider the month with precipitation total lower than 10th percentile.

Results

Quality control of initial data has been performed in order to receive the most reliable results. The data have been checked for missing values and have been tested for homogeneity. There are not missing values in the investigated time series. The homogeneity of monthly air temperature and precipitation are tested by AnClim software, Alexandersson test [21, 22]. Non-homogeneities have been detected in January and March and the non-homogeneous series have been adjusted with AnClim software.

Trend of seasonal air temperature and precipitation

The analysis of seasonal temperatures and precipitation for the observed periods (1981-2010) shows positive trend of seasonal temperatures and precipitation totals (tab. 1). In most of cases the coefficients of air temperature trends are close to 0 and they are not statistically significant. The statistically significant trend is established for summer temperatures. Station Varna, situated on the Black sea coast shows positive statistically significant trend in all seasons except in winter.

The trend of seasonal precipitation totals for the period 1981-2010 is positive except in two cases (tab. 1). Despite the positive trend of precipitation the values of coefficients of the trend are quite low and they are not statistically significant. Statistically significant trend is established in two stations Shumen and Razgrad in autumn only.

The RCM data (MPI and ETZH) show increasing of air temperatures for all seasons (tab. 2). In comparison to the observed data for the period 1981-2010 the increasing of seasonal temperatures in the period 2021-2050 is with values from 1.4 ºC to 2.2 ºC. In a few cases we have to expect the increasing of seasonal temperatures with about 1 ºC.

The model data show higher thermal level in the period 2051-2080 when it is expected that in most of cases seasonal temperature will be higher than average for the period 1981-2010 with values between 2 ºC and 3.7 ºC. The results given in the tab. 3 show that the changes of temperatures will be more considerable in summer and autumn than in other two seasons. The results from the present analysis correspond with the existing research work about temperature variability [2].

Table 1. Trend of seasonal air temperature and precipitation for the period 1984-2013 (trend/10 years, values in bold are statistically significant)

Meteorological station	Meteorological parameters	Winter	Spring	Summer	Autumn
Varna	*T* [°C]	0.2	**0.6**	**0.8**	**0.4**
	P [mm]	23.0	2.3	8.2	15.3
Shumen	*T* [°C]	0.3	0.5	**0.8**	0.4
	P [mm]	1.4	–16.8	4.0	**37.2**
Razgrad	*T* [°C]	0.3	0.5	0.7	0.3
	P [mm]	10.1	-8.0	6.0	**36.4**
Ruse	*T* [°C]	0.1	0.4	**0.7**	0.3
	P [mm]	–0.4	3.2	–2.4	29.5

Table 2. Changes of seasonal air temperature in the periods 2021-2050 and 2051-2080 according to the MPI and ETZH models (in °C as a difference from the average for the observation data 1981-2010)

Meteorolog-ical station	Model	Winter		Spring		Summer		Autumn	
		2021-2050	2051-2080	2021-2050	2051-2080	2021-2050	2051-2080	2021-2050	2051-2080
Varna	MPI	1.5	2.8	0.9	2.4	0.9	2.0	2.0	3.0
	ETHZ	1.8	2.8	1.5	2.5	1.8	3.6	2.0	3.6
Shumen	MPI	1.4	2.7	0.9	2.5	1.0	2.2	2.2	3.1
	ETHZ	1.8	2.7	1.5	2.4	1.8	3.5	2.0	3.5
Razgrad	MPI	1.5	2.9	1.2	2.7	1.5	2.7	2.2	3.2
	ETHZ	2.0	2.8	1.8	2.6	2.4	4.0	2.2	3.5
Ruse	MPI	1.5	2.8	0.9	2.4	1.0	2.3	2.2	3.2
	ETHZ	1.6	2.8	1.5	2.3	1.9	3.6	2.1	3.7

The analysis of changes of air temperature for the territory of Bulgaria on the bases of RCP-scenarios, IPCC 2013, AR 5 [23] is given at [24, 25]. The investigations show the increasing of annual temperature in Bulgaria for the periods 2016-2035 and 2046-2065 with values between 1.5 ºC and 4.0 ºC in comparison to average for the period 1961-1990.

Despite of positive trend of precipitation shown by the observation data, the models data show negative trend for two future 30-years periods (2021-2050 and 2051-2080). On the background of general increasing of seasonal air temperatures the model data show decreasing of precipitation totals. Exception from this tendency is slightly increasing of precipitation in winter (tab. 3). According to the results from RCM we have to expect slightly increasing of winter precipitation totals in 21th century in Northeastern Bulgaria in comparison to the period 1981-2010 (tab. 3). Decreasing of seasonal precipitation will be higher in summer and autumn. In most of cases the decreasing for the period 2021-2051 is higher than one in the period 2051-2080.

According to RCP-scenarios, IPCC AR 5 [24, 25] the changes of annual precipitation in Bulgaria will be with different sign for the periods 2016-2035 and 2045-2065 and will vary with ± 10% from the average for the period 1961-1990.

Table 3. Changes of seasonal precipitation in the periods 2021-2050 and 2051-2080 according to the MPI and ETZH models (in % from the average seasonal precipitation for the observation period 1981-2010)

Meteorolog-ical station	Model	Winter		Spring		Summer		Autumn	
		2021-2050	2051-2080	2021-2050	2051-2080	2021-2050	2051-2080	2021-2050	2051-2080
Varna	MPI	122	116	88	80	82	78	69	80
	ETHZ	103	109	92	87	62	35	91	89
Shumen	MPI	124	102	82	83	80	91	63	75
	ETHZ	100	102	97	100	69	56	79	75
Razgrad	MPI	133	107	85	90	83	98	60	68
	ETHZ	106	110	99	104	75	57	78	65
Ruse	MPI	137	112	102	106	101	106	64	77
	ETHZ	105	116	98	104	90	63	79	64

Extreme monthly temperatures and precipitation

In order to analyze the occurrence of extreme monthly temperature we consider the number of stations with three and more extreme cold and extreme hot months (fig. 3). Three and more extreme cold months are observed in 15 years during the period 1961-2010 *vs.* 11 years with three and more extreme hot months. As coldest years for the period 1961-2010 we can distinguish the years 1996 and 1997 when between three and fife extreme cold months are observed in different investigated stations. The results of analysis show those extreme cold months are observed mainly in 70-es, 80-es, and late 90-es. From other side there is well established period with extreme hot months since 2001. Six of ten years in the beginning of 21^{th} century have between 3 and 6 extreme hot month and the hottest years are 2001 and 2007.

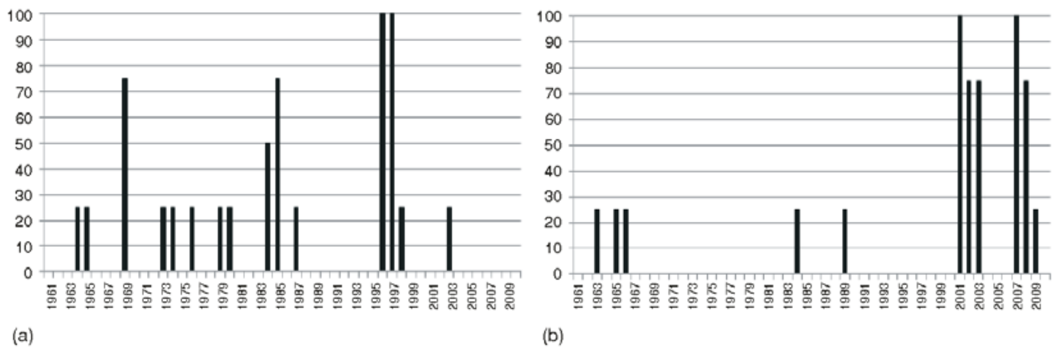

Figure 3. Percentage of investigated stations with three and more extreme temperature months; (a) extreme cold, (b) extreme hot

The years with three and more extreme dry months are observed a little more often than those one with extreme wet months – 16 and 13, respectively (fig. 4).

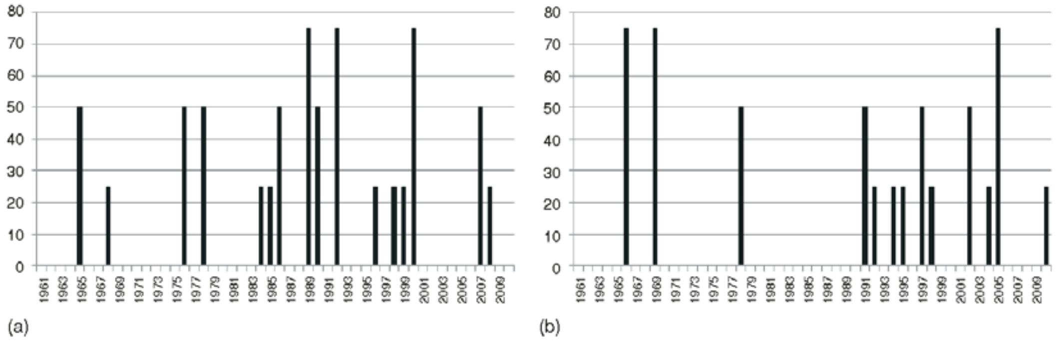

Figure 4. Percentage of investigated stations with three and more extreme precipitation months; (a) extreme dry, (b) extreme wet

The dryest years are 1989, 1992, and 2000 with three extreme dry months in 75% of investigated stations.The year 2000 makes impression with the highest number of extreme dry months (Varna – 2, Shumen – 4, Razgrad – 5, and Russe – 10).

The frequency of occurrence of extreme dry months is higher in 80-es and 90-es and occurrence of extreme wet months is more often since 1991. The wettest years are 1966, 1969, and 2005 with three dry months in 75 % of investigated stations.

Future peculiarities in occurrence of extreme monthly temperatures and precipitation are analyzed on the bases of comparison monthly data from MPI and ETHZ models with 10th and 90th percentile for the period 1961-2010. The results for two future 30-years periods show that extreme cold months are observed in a few cases. Practically in regards to observed data there are not extreme cold months for the period 2051-2080. Unlike extremely cold months there is a significant increasing of the number of extreme hot months (tab. 4). According to the comparison with the values of 90th percentile of empirical distribution for the period 1961-2010 we have to expect considerable increasing in the thermal level in the future.

Table 4. Number of years with extreme hot temperature in all of investigated stations period 3 and more extreme hot months more than 6 extreme hot months

Period	Three and more extreme hot months		More than six extreme hot months	
	MPI	ETHZ	MPI	ETHZ
2021-2050	22	24	3	7
2051-2080	28	30	22	21

The MPI data show that in 22 years during the period 2051-2080 in all of the investigated stations the monthly air temperature will be higher than 90th percentile for the period 1961-2010 in more than six months during each year *vs.* three years in the period 2021-2050.

On the background of increasing the cases with extremely high monthly air temperature the model data show that in two future 30-years periods (2021-2050 and 2051-2080) there will be an increasing also of cases with extreme dry months in all of the investigated stations (fig. 5). This fact is well expressed by the data from ETHZ model. From other side only a few cases with extreme wet months will be observed in the future.

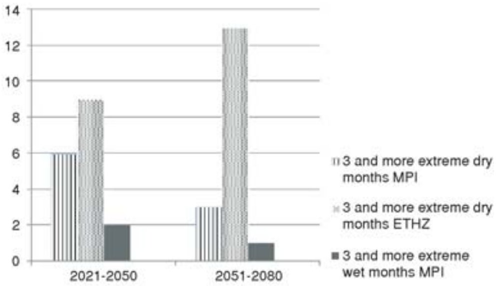

Figure 5. Number of years with extreme precipitation months in all of investigated stations

According to MPI data three and more extreme wet months will be observed in all of the investigated stations only in two years during the period 2021-2050 and in one year in the period 2051-2080. ETHZ model do not show occurrence of extreme wet months in two 30-years future periods.

The results from the present investigation are in coincidence with the studies from other authors for the territory of Bulgaria. Nikolova [25] points out that according to RCP-scenarios, IPCC AR 5 there will be increasing of temperature and precipitation extremes in 21th century, as well as the increasing of duration of dry periods.

Conclusions

The following conclusion could be made on the base of the results from the present investigation.

- The trend of seasonal air temperature and precipitation for the period 1984-2010 is positive (exception is spring precipitation with the negative trend). Statistical significant positive trend of summer temperatures with the values 0.7 ºC to 0.8 ºC per 10 years makes impression.
- The models data (MPI and ETHZ) show that the tendencies in air temperature and precipitation variability in Northeast Bulgaria for two future 30-years period (2021-2050 and 2051-2080) are in accordance with the regional trends for South Europe and Bulgaria: increasing of temperature and decreasing of precipitation (exception is winter precipitation).
- The investigation of extreme monthly temperature shows that extreme cold months are observed mainly up to 2000 as extreme hot months are more characteristic for the period 2001-2010.
- There is increasing of frequency of occurrence of three and more extreme wet months since 1990s however the frequency of occurrence of extreme dry months in 80-es and 90-es is higher than one for extreme wet months.
- The regional climate models (MPI and ETHZ) show considerable increasing of number of years with extreme hot months for the period 2051-2080 in comparison to 2021-2050.
- The number of years with three and more extreme dry months could reach 13 in 2051-2080 and from other side there will be not more two years with extreme wet months.

The general conclusion from the present paper is that there is a risk of increasing drought events in Northeast Bulgaria in the future (2051-2080) due to increasing of air temperature and decreasing of precipitation.

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