EXTREME TEMPERATURES TRENDS IN EASTERN BULGARIA DURING THE PERIOD 1959-2009

***VENETA IVANOVA*[1]**

ABSTRACT. - Extreme temperatures trends in eastern Bulgaria during the period 1959-2009. The present study investigates variations of four, so called "Core" extreme temperature indices. For the period of 1959-2009 based on the STARDEX project, data from 16 weather stations located in the eastern Bulgaria were analyzed. The temperature indices include the threshold of 0°C, which is applicable for almost every type of climate: two indices refer to the degree of extrema (*txq90*-Tmax 90th percentile, *tnq10*-Tmin 10th percentile) and two - to the frequency (*tnfd*-Number of frost days Tmin<0°C, *txhwd*-Heat wave duration). Some statistical parameters for every index were also calculated. For the trends calculation and detection of significance, the Mann-Kendall and Sen's slope estimator were applied. The spatial distribution of the trends shows similar behavior for the most of stations in every season. The *Txq90* series are characterized by statistically significant increasing slopes.

Keywords: eastern Bulgaria, extreme temperature index, STARDEX, Mann-Kendall test, Sen's slope

1. INTRODUCTION

In recent years the study of extreme events increased because of their impact in various sectors (Alexander et al., 2006; Alexandrov et al., 2011; Ivanova, 2013, etc.) Describing their trend by using climatic indices calculated based on different climate scenarios and statistical methods, further contributes to a clearer understanding of changes in the climate of an area. According to data from the Centre for drought management in southeast Europe over the Balkan Peninsula (http://www.dmcsee.org) since the late 20th and early 21st century trend towards increasing droughts. That is why the main goal of this study is to investigate the spatial and temporal variation of extreme temperatures.

2. DATA AND METHODOLOGY

Data used in this study are the time series of observed daily temperature at 16 weather stations located in eastern Bulgaria (Fig.1). The data have been collected from the meteorological database of the National Institute of Meteorology and Hydrology and cover the period 1959-2009. A software package RHtestV3 (Wang et al., 2010) was used to make a quality control and

[1] National Institute of Meteorology and Hydrology – branch Varna, BAS, 10 Sveti Nikola district, Varna 9010, Bulgaria, E-mail: veneta74@abv.bg, Veneta.Ivanova@meteo.bg

homogenization of data series. Using EU research project STARDEX (*http://www.cru.uea.ac.uk/projects/stardex*) seasonal and annual values of four temperature indices (Table 1) for each station are calculated. To provide an overall picture of temperature variations, the average trend for every index is computed. To check the trends of used indices the non-parametric Mann-Kendall test and the Sean's method are implemented.

Fig. 1. ***The location of considered meteorological stations on the map of Bulgaria***

Table 1. ***STARDEX temperature indices***

Index	Definitions	Units
tnfd	Number of frost days (number of days when the minimum temperature is less than 0°C)	days
txhwd	Heat Wave Duration (The total number of days when, for at least 5 consecutive days, the maximum temperature is at least 5°C greater than the 1961-1990 climatological mean value	days
txq90	90^{th} percentile of maximum temperatures	°C
tnq10	10^{th} percentile of minimum temperatures	°C

3. RESULTS

3.1. Indices related to the frequency of extreme temperatures (tnfd, txhwd)

The mean temperature in eastern Bulgaria is rising, especially during summer and autumn (Ivanova, 2015; Alexandrov et al., 2011; Velev, 2008). The Mann-Kendall test and the Sen's slope showed statistically significant increasing trend in summer between +1.5°C and +2.0°C for the regarding period. Naturally, this increasing of mean temperature has influence to the number of days with

Tmin<0°C. The statistical parameters of *tnfd* index show that the mean values in the different seasons vary from 8 days during the autumn to 53 in winter. In annual average terms the number reaches 74.

The spatial distribution of the trends of *tnfd* during the all seasons illustrates the great diversity in its sign (Fig.3). Excluding autumn (not shown), during the other seasons and in annual terms for the most stations located in Northeastern Bulgaria as well as for stations Shabla and cape Kaliakra on the Black sea coast, prevails statistically insignificant decreasing trend. Analysis of the data showed the fastest reduced number of "frost days" in stations General Toshevo, Krushari and Tsarev Brod, located in flat to slightly hilly areas. A similar result for Northeastern Bulgaria was found in Ivanova (2013) when the period 1970-2009 was examined. For the last three stations the decadal changes vary between 1 and 3 days in winter and between 2 and 5 days for the annual value. For Southeastern Bulgaria there was no clear trend of *tnfd* changes.

Results show that in Eastern Bulgaria *tnfd* has slight statistically insignificant increasing trend in autumn, and statistically insignificant decreasing trend in other seasons. Only station Rezovo, situated on the outflow of river Rezovo, has statistically significant increasing trend in every season.

The results shown here are in accordance to those in Milošević et al. (2013) for Slovenia for the period 1961-2011 but they are opposite to results for Greece for the period 1958-2000 obtained during the contract No. EVK2-CT-2001-00115 of STARDEX project, 2005.

For the region as a whole the trends of *tnfd* for each season are shown in Fig.4. Although some stations with increasing of "frost days" are seen, it should be noted that the slope has weakly negative sign. *Tnfd* has lowest value during 1966, while in 1993 the number of "frost days" reached the maximum of 101 days.

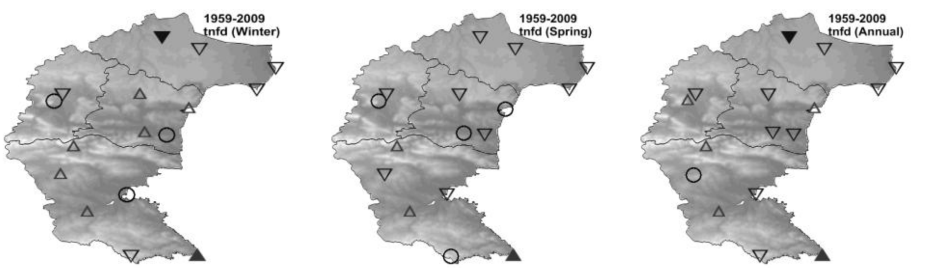

Fig. 3. ***Spatial distribution of seasonal and annual tnfd trends in Eastern Bulgaria (1959-2009) by applying the Mann-Kendall and Sen's slope tests ($\alpha \leq 0.05$). Triangles upward - increasing trend; triangles downward - decreasing trend; circles - no trend. Statistically significant trends were marked with a filled sign***

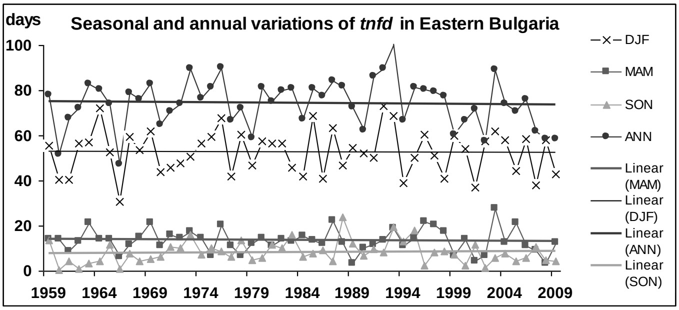

Fig. 4. ***Tnfd seasonal and annual variations in eastern Bulgaria, 1959-2009. The values are obtained as arithmetic average of the indices values at all stations.***

Another examined temperature index related to the frequency and based on fixed thresholds (except for *tnfd*) is the Heat Wave Index, *txhwd*. The basis of heat waves is a combination of high temperature with relatively low or high moisture. The study of their occurrence and their trend is essential, as they have a direct impact on the health and life of humans (Robinson, 2001). Because there are many definitions of this extreme event (Gocheva et al., 2006; Croitoru, 2014; Dragota and Havris, 2015; Keggenhoff et al., 2015), in the present work the definition based on Frich et al.(2002) and applied in STARDEX project is used (Table 1).

Statistical parameters of the distribution show that in 75% from the cases in Eastern Bulgaria we have 8 heat waves during the winter and 6 in spring. The average number of *txhwd* is highest in winter (5 days), and the reason for this can be changes on the atmospheric circulation, definition of index, etc.

In almost all seasons heat waves index presents statistically insignificant increasing trend, reaching a value of 1-2 days/decade (Fig.5). For 14 of the 16 stations during autumn and for 7 stations during spring (not shown), the variations have statistically insignificant decreasing trend which is less intense compared with positive trends. The results are similar with these of Kostopoulou and Jones (2005) for the Eastern Mediterranean. Data analyzes from Fig.6 demonstrate evidence that extreme events of such kind increase during recent years. In 1967 heat waves in Eastern Bulgaria practically were not observed, while the maximum number of 37 was recorded in 2007.

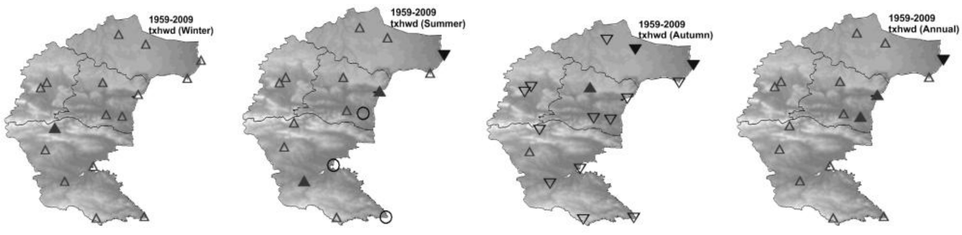

Fig. 5. ***As for Fig. 3 but for txhwd trends.***

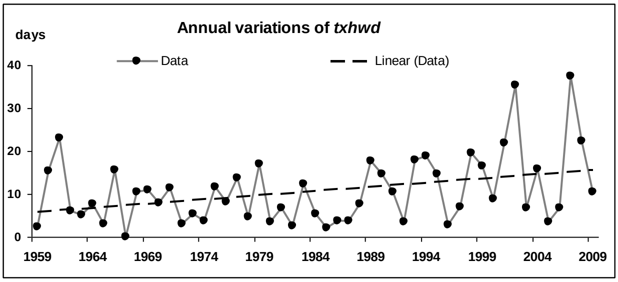

Fig. 6. ***Txhwd annual variations in eastern Bulgaria, 1959-2009. The values are obtained as arithmetic average of the indices values at all stations.***

3.2. Indices related to the degree of extreme temperatures (txq90, tnq10)

The *txq90* index gives us information for extremely high temperature and is indicative of Heat waves. The mean value is highest in summer (31.0°C) and for 50% of the cases during this season it varies between 29.6°C and 32.4°C. The lowest value is in winter when for 75% of cases it is less 15°C (Table 2).

Table 2. ***Parameters of the distribution of the 90th percentile of Tmax (txq90 index)***

STARDEX Core index		Mean	Median	Minimum	Maximum	25%, Lower quartile	75%, Upper quartile
txq90	DJF	13.3	13.3	6.5	18.6	11.8	15.0
	MAM	23.8	24.0	13.0	30.6	22.3	25.5
	JJA	31.0	31.0	25.6	37.7	29.6	32.4
	SON	26.0	26.0	20.5	32.0	24.8	27.0
	ANN	28.4	28.4	23.0	33.3	27.5	29.5

The 90th percentile of Tmax increases for all seasons, significant results for almost all stations observed in spring, summer and in annual terms (Fig.7). The rate of increase for annual values for the most of stations is low (as well as for the seasonal values) and ranging from +0.03°C to +0.06°C per year. Relatively higher coefficient of linear regression have summer values and annual values of the regional data series (Fig.8).

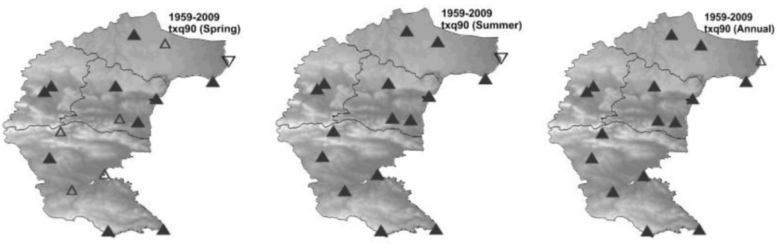

Fig.7. ***As for Fig. 3 but for txq90 trends.***

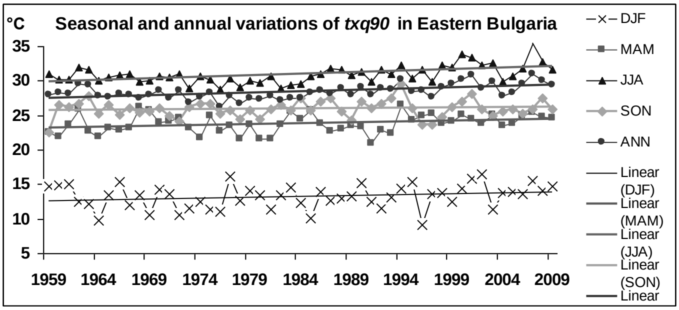

Fig.8. ***Txq90 seasonal and annual variations in eastern Bulgaria, 1959-2009. The values are obtained as arithmetic average of the indices values at all stations.***

The fourth extreme temperature index (*tnq10*) is associated with the lowest minimum temperature for the season or the year and it is often named "cold night". As it should be expected, the lowest values are in winter and the highest values in summer. The most important statistical parameters are shown in Table 3.

Table 3. ***Parameters of the distribution of the 10th percentile of Tmin (tnq10 index)***

STARDEX Core index		Mean	Median	Minimum	Maximum	25%, Lower quartile	75%, Upper quartile
tnq10	DJF	-7.3	-7.2	-16.0	0.2	-9.0	-5.3
	MAM	-0.8	-0.7	-12.7	4.8	-1.9	0.5
	JJA	12.1	11.8	6.8	18.3	10.9	13.1
	SON	0.9	0.8	-7.0	9.2	-0.6	2.5
	ANN	-2.9	-3.0	-9.2	1.5	-4.0	-1.7

Comparison of trend in spatial distribution reveals that the positive trends extend to the most of stations in spring and summer, while the negative trends extend to the whole region during autumn only. Statistically significant are trends for the 2/3 of the stations in summer (Fig.9) (approximately +0.02°C per season for the regarding period).

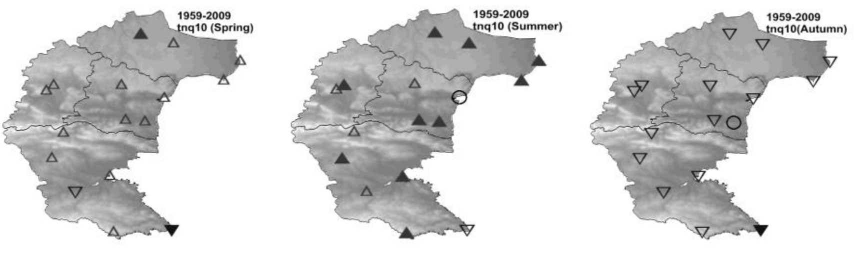

Fig.9. ***As for Fig. 3 but for tnq10 trends.***

The regional data series show slightly increasing trend of *tnq10* in summer and slightly decreasing trend in autumn, while sudden changes are observed in winter data (Fig.10).

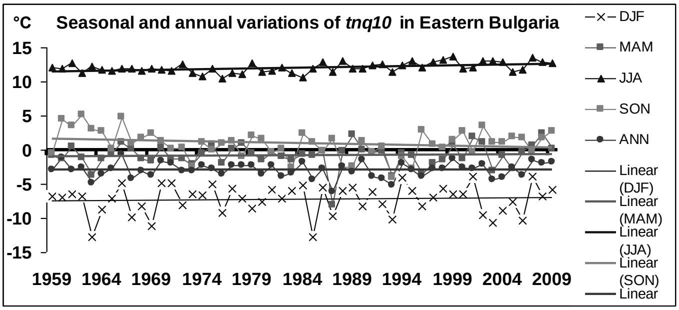

Fig. 10. ***Tnq10 seasonal and annual variations in eastern Bulgaria, 1959-2009. The values are obtained as arithmetic average of the indices values at all stations.***

4. CONCLUSIONS

In the study analyses of variations of four temperature extreme indices for the period 1959-2009 in eastern Bulgaria was made. It was found that changes in frequency exist, but for most of station they have not large values. However, during the winter an increasing of number of Heat waves was found. The positive trends of the 90th percentile of Tmax prevail with statistical significance ($\alpha \leq 0.05$**)** for most of stations in spring, summer and in annual terms. The 10th percentile of Tmin has negative trend extend to the whole region during autumn only. The results can be very important for the authorities in Bulgaria to take some decisions, but it is needed to continue the monitoring and the updating of data.

REFERENCES

1. Alexander, L. V. et al. (2006), *Global observed changes in daily climate extremes of temperature and precipitation*, J.Geophys. Res., *111*, D05109, DOI:10.1029/2005JD006290.
2. Alexandrov V., J.Eitzinger, G. Hoogenboom (2011), *Climate variability and change and related impacts on agroecosystems in southeast and central Europe as well as southeast USA*. Publishing house Bolid, Sofia, pp 232, ISBN 978-954-394-055-4.
3. Croitoru A.-E. (2014), *Heat waves. Concept, definition and methods used to detect*, Riscuri şi catastrofe, An XIII, *15*(*2*), 25-32.
4. Dragota C.-S., and L.-E. Havris (2015), *Changes in frequency, persistence and intensity of extreme high-temperature events in the Romanian plain*, International conference ”Air and Water Components of the environment”, Cluj-Napoca, Romania, 20-22 March 2015, 17-24, DOI: 10.17378/AWC2015_03.

5. Frich P., L. V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A. M. G. Klein Tank, T. Peterson (2002), *Observed coherent changes in climatic extremes during the second half of the twentieth century*, Clim Res, *19*, 193–212
6. Gocheva, A., L. Trifonova, T. Marinova, and L. Bocheva (2006), *Extreme Hot Spells and Heat Waves on the Territory of Bulgaria*. Final Proc. of BALWOIS, Ohrid, Republic of Macedonia, 23 - 26 May 2006.
7. Ivanova V. (2013), *Climatic indices and their trends in Northeastern and Southeastern Bulgaria - a comparative analyses*, Secondary National Congress of Physical Sciences, Faculty of Physics, Sofia University, Sofia, Bulgaria, 25-29 September 2013, ISBN 978-954-580-333-8 (in Bulgarian).
8. Ivanova V. (2015), *Climate characteristics on the Bulgarian Black sea coast and relationships with atmospheric circulation in the Atlantic-European region*, PhD Thesis, Climatology and Agrometeorology Department, National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences, Sofia, Bulgaria (in Bulgarian).
9. Keggenhoff I., M.Elizbarashvili, L.King (2015), *Heat Wave Events over Georgia Since 1961: Climatology, Changes and Severity*, Climate 2015, *3*(*2*), 308-328, DOI:10.3390/cli3020308.
10. Kostopoulou, E., and P. D. Jones (2005), *Assessment of climate extremes in the Eastern Mediterranean*, Meteorol Atmos Phys *89*, 69–85, DOI: 10.1007/s00703-005-0122-2
11. Milošević D., S.Savić, I. Žiberna (2013), *Analysis of the climate change in Slovenia: fluctuations of meteorological parameters for the period 1961-2011* (Part I), Glasnik Srpskog geografskog drustva 2013, *93*(*1*), 1-14, DOI:10.2298/GSGD1301001M.
12. Velev, S. (2008), *Climat Change in Bulgaria during the 20th Century,* Global Environmental Change: Challenges to Science and Society in Southeastern Europe. Selected Papers Presented in the International Conference, 19-21 May 2008, Sofia, Bulgaria.
13. Wang, X. L., H. Chen, Y. Wu, Y. Feng, and Q. Pu (2010), *New techniques for detection and adjustment of shifts in daily precipitation data series*. J. Appl. Meteor. Climatol. *49* (*No. 12*), 2416-2436, DOI: 10.1175/2010JAMC2376.1.