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Summer variation of the UTCI index and Heat Waves in Serbia

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Abstract. The objective of this paper is the assessment of bioclimatic conditions in Sebia. A special emphasis has been given to the heat budget bioclimatic Universal Thermal Climate Index (UTCI) whose purpose is to evaluate degree of thermal stress that human body is exposed to during the last twenty years. In addition, the thresholds of daily maximum temperatures are analysed in order to identify increase and frequency of heat waves in Serbia. For this research, daily and hourly (07h and 14h) meteorological data from 3 weather station (Mt. Zlatibor, Novi Sad, Niš) are collected for the period 1998-2017. The results show that the most frequent UTCI heat stress categories are "strong heat stress" and "very strong heat stress". The most extreme heat waves events are occurred in 2007, 2012, 2015 and 2017. Moreover, there were three Heat wave events (HWE) in Niš occurred in July, 2007 lasting 3, 10 and 4 days in row. Heat wave events (HWE) In July 2007 (10 days) and July 2012 (9 days) in Niš are occurrences with maximum number of days in row recorded.

Key words: Bioclimatic conditions, Universal Thermal Climate Index (UTCI), variability, heat waves.

1. Introduction

Extreme high temperatures, especially during summer months, bring up the question of how heat could affect everyday life of humans. Heat waves as a hazard often have a negative effect causing heat stress in the man. Heat and drought events are of great importance in most Mediterranean climate regions, but also in the bigest part of Southern and South-Eastern Europe, because of the diverse and costly impacts they have in various economic sectors and on the environment (Peña-Gallardo et al., 2019). Bioclimatic condition provides a base for considering the effects of climatic conditions on humans and give special importance the social factors that mitigate or strength the consequences of environmental changes (Bleta et al., 2014).

During recent years, there is an increase in the number of articles analysing heat waves. It could be noticed it is a difficult to determine the universal definition of a heat wave that could be applied in all climate zones. The heat wave is a prolonged period of abnormally high air temperature that causes changes in everyday life and can have health effects on humans. Although a heat wave is understood as a meteorological event, its significance and influence could not be adequately presented without a clear impact on man (Robinson, 2001). The impact of weather and climate on humans could be presented by

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bioclimatic indices. According to Epstein et al. (2006) there are over 100 heat stress indices that could describe extreme bioclimatic conditions in relation to humans. Among them are the so-called heat budget indices based on the heat exchange between humans and the environment. It should be emphasized the influence of extreme temperatures on the physiological parameters in humans in the analysis of thermal stress. With objective to estimate the thermal effect of the environment on the human body, the total effects of all thermal components has been considered by UTCI index. In addition to UTCI index, extreme temperature thresholds were analysed so as to observe the biothermal stress caused by the heat wave. The UTCI is heat budget index in function of both physiological and meteorological parameters describing the physiological heat stress that human body experiences while achieving thermal equilibrium with the surrounding outdoor environment (Błażejczyk et al., 2013). In recent years, several bioclimatic analyses in accordance with the UTCI index have been presented (Błażejczyk et al., 2014; Bleta et al. 2014; Błażejczyk et al., 2017). Compared to other indexes, UTCI is more sensitive to changes in all of environment stimuli parameters in particular air temperature, solar radiation, humidity, and wind speed (Błażejczyk et al., 2012). According to Jendritzky et al. (2012) the UTCI evaluates the outdoor thermal environment for biometeorological applications by simulating the dynamic physiological response with a model of human thermoregulation together with a modern clothing model. UTCI provides a multiple opportunity for investigation. The UTCI index has a wide application in weather forecast for open-air activities, appropriate behavior and climate therapies, then alerts about extreme thermal stress. These analyzes can find application in tourism, health sector, and urban and regional planning (Jendritzky et al., 2012). Analysis of the UTCI index correlated with mortality in Europe shows the deaths occur in the southern Europe (Italy, Portugal, Greece, Spain) for the categories of moderate and strong stress. There is an impact of heat load in increasing mortality, as conditions become more thermally stressful (Di Napoli et al., 2018). The intensity of heat stress in Poland was assessed by the UTCI index based on daily mortality and weather data for 1991–2000. There is increase in mortality for the days with strong and very strong heat stress, in relation to no thermal stress days, of 12% and 47%, respectively (Błażejczyk et al., 2017). Biothermal conditions and mortality rates show that during summer in southern Europe thresholds of Physiological Subjective Temperature (PST) increase when moving from west to east. The general founding is that population of central Europe is more sensitive for thermal stimuli in summer then citizens of the south of continent (Błażejczyk and McGregor, 2008). According to the comparison of UTCI index with other thermal indices), PST index is very well correlated with UTCI index (Błażejczyk et al., 2012). Another sensitivity of extreme heat weather on biothermal condition is presented by impact of heat waves on daily mortality in Belgrade during summer where the strong correlation between heat waves and daily mortality occurred in July 2007 (Stanojević et al., 2014). The idea of the analysis in the paper is to observe the variation of UTCI index values during the summer months and to rate how much thermal stress has occurred in the past 20 years in different geographical landscapes in Serbia.

Heat waves in Serbia were analyzed with several different approaches and all of them show an increase in the trend of max temperature, especially since 2000 (Drljača et al., 2009; Unkašević and Tošić, 2009a; Unkašević and Tošić, 2009b; Unkašević and Tošić, 2015). Based on the autoregressive-moving-average model, heat waves were examined in Belgrade, Niš and Smederevska Palanka and their connection with the circulation of the atmosphere for 1949-2007. The warmest years were

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65 observed during three periods in 1951-1952, 1987-1998 and 2000-2007. The longest heat wave was recorded in 1952 in Niš (21 day) and Smederevska Palanka (16 days). During 1994 in Belgrade is observed the heat wave of 18 days and 21 consecutive numbers of tropical days. During 2003 in Niš is observed 29 consecutive tropical days (Unkašević and Tošić, 2009b). The length and strength of heat waves in Belgrade and Niš during the summer and winter season was determined using Heat Wave Duration index (HWD). The analysis based on daily maximum values of air temperature showed Niš with greater number of
70 heat waves compared to Belgrade. Since the mid-1980s, heat waves have a higher frequency and occur on average every year. Prior to that period heat wave fluctuations have generally been reported in one of two years (Niš during summer) or even one in three years (Beograd during summer) (Drljača et al., 2009). An increase of the heat wave duration, in addition to increase of the heat wave frequency of occurrence was detected by Unkašević and Tošić (2011) during the period 1999 – 2007, studying the characteristics of the heat waves in central Serbia (1949 – 2007).

75 Recently, several articles have been published analysing bioclimate conditions in Serbia considering heat budget indices (Basarin et al., 2016; Basarin et al., 2018; Milovanović et al., 2017; Pecelj et al., 2017; Pecelj et al., 2018; Stojicević et al., 2016). As regards Heat Load index (HL) in Serbia (July) for 2000-2010 is noted that in Loznica, Belgrade, Niš, Vranje, Zlatibor and Novi Sad expired "extremely hot" in 2007 and 2000 than in other years (Milovanović et al., 2017). Referring to Physiological Equivalent Temperature PET for the period 1949–2012, the highest number of heat waves in Novi Sad was
80 observed in the last two decades and in the first decade of the investigated period (Basarin et al., 2016). As regards extreme bioclimatic events were analysed for 1961-2014, the number of the days above particular thresholds is increase along with a number of heat waves per year since 1981. The highest values of mean annual PET are mostly detected during the last 15 years. For heat waves defined as 6 and more serial days with PET over threshold, the 63 consecutive days with extreme heat stress was observed in Novi Sad during 2003 (Basarin et al., 2018). For the city of Loznica, for 1961-2014 is observed a
85 growing trend in the annual and seasonal values of PET. The increase in these trends is associated with an increase in air temperature and a decrease in relative air humidity (Stojićević et al., 2016). In the framework of the geoecological evaluation of the City of Loznica for the purpose of recreational tourism, the UTCI index in July 2000-2016 shows marked stress in 2007 (Pecelj et al., 2018). Bioclimatic conditions on Zlatibor and Belgrade referring to UTCI index and Heat Load in man (HL) in July for 2000-2010 were analyzed by Pecelj et al. (2017). Bioclimatic conditions in Belgrade have dominant HLs of the
90 "extremely hot" and "hot". The situation on Mt. Zlatibor is more favourable where the dominant category of HL is "warm". The categories "extremely hot" and "hot" are less present so in comparison to Belgrade. Furthermore, the results for the UTCI show a domination of strong heat stress and moderate heat stress in Belgrade compared to Mt. Zlatibor without heat stress. The highest heat stress expressed by HL occurs during 2000, 2007 and 2008 for both Belgrade and Mt.Zlatibor (Pecelj et al., 2017).

95 Although in recent years in Serbia it has begun publishing works with analyses the bioclimatic condition through the bioclimatic heat budget index, so far detailed bioclimatic condition has not been thoroughly analysed by the UTCI index. The idea of the analysis in the paper is to observe the variation of UTCI index values during the summer months and to rate how much thermal stress has occurred in the past 20 years in different geographical landscapes in Serbia.

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2. Materials and methods

The research covered three weather stations located in different geographical areas of Serbia (Novi Sad, Niš and Mt. Zlatibor). First is the Rimski Šancevi weather station (45° 19' N, 19° 50' E, at an altitude of 86 meters) located in the territory of Novi Sad which is the administrative urban center of Vojvodina province and South Bačka district. The city is located in the southern part of Pannonian basin, on the Danube River bank near by the mountain Fruška Gora, National Park of the same name. Novi Sad has a temperate continental climate, summers are warm and winters are cold with a small amount of snow (Lazić et al., 2006). Second is Niš weather station (43° 19' N, 21° 53' E, at an altitude of 202 meters), located in the city center of Niš, on location the Niš Fortress. This city is the administrative urban center of the Nišava district located in South Serbia and it's situated in the Nišava valley occupying the central part of the spacious geological depression called Nišava basin. According to Köppen's climate classification, the Nišava valley belongs to the Cfwax type – the Danube type of moderately warm and humid climate characterized by hot summers, the highest precipitation is recording at the beginning of summer and somewhat dry winters (Prokić, 2018). Compared to the other cities in this valley (Dimitrovgrad, Pirot and Bela Palanka) Niš is the hottest one with an average annual temperature of 11.8℃ (Prokić, 2018). The third analysed area is Zlatibor, a mountain in Western Serbia, which belongs to the mountain range of the Dinaric Alps. Zlatibor weather station (43° 44' N, 19° 43' E) lies at an altitude of 1029 meters. The mountain climate of Zlatibor is characterized by mild summers with moderately warm days and cold and snowy winters. In the area of Zlatibor plateau mountains meet sea air currents, what it could be assumed, creates a favorable climate accordingly Zlatibor is already confirmed as a climatic resort (Pecelj et al., 2017).

Multiannual hourly (07h, 14h) data from the period 1998-2017 from three stations, Novi Sad and Niš (an urban stations) and Mt. Zlatibor (a rural mountain station below 1500 m), were used for comparison of the frequency of particular UTCI categories of heat stress. Hourly meteorological parameters of air temperature (t), air humidity (f), air pressure (p) and wind speed (v) from mentioned weather stations were considered for calculation of UTCI index in summer months (July, August and September).

The UTCI is a thermal comfort indicator based on human heat balance models. The index is design to be applicable in all seasons and climates together with all spatial and temporal scales. Human reaction was simulated by the UTCI-Fiala multi-node model of human thermoregulation, which was integrated with an adaptive clothing model. For a given combination of meteorological parameters, based on the conception of an equivalent temperature, the UTCI was defined as the air temperature of the reference environment, which according to the model produces an equivalent dynamic physiological response (Bröde et al., 2012). Therefore, the UTCI index represents the air temperature of a reference environment that would cause the same sweat production or skin wettendness in human body, response as the actual environment (Błażejczyk et al., 2013; Błażejczyk et al., 2014). Reference environment is described as the condition of calm air (v=0.5 ms^{-1} at 10 m above the ground, with no more thermal irradiation (radiant temperature is equal to air temperature) and 50% relative humidity where average person walks at 4kmh^{-1} producing metabolic rate equal 135Wm^{-2} (2.3 MET) (Błażejczyk et al., 2013; Błażejczyk et al., 2014).

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The meteorological data used in this research are taken from the Meteorological Yearbook for the period 1998-2017 (Republic Hydrometeorological Service of Serbia). The UTCI index was calculated by applying the BioKlima 2.6 software package (available at http://www.igipz.pan.pl/Bioklima-zgik.html). There is the scale of UTCI stress categories marked in Table 1.

In addition, the summer daily maximum temperatures are analysed in order to detect increase and frequency of heat waves. Considering the influence of extreme temperatures, as stated by Collins et al. (2000) the following indices were mark off in reference of the thresholds of maximum and minimum temperature: Hot days (HD=T_{max}≥35ºC), Hot nights (HN=T_{min}≥20ºC), Hot day events-analogous to Heat wave event (HWE=3-5 days T_{max} ≥35ºC) and Hot night events (HNE=3-5 days T_{min} ≥20ºC) (Table 2).

3. Results and Discussion

Based on the conducted bioclimatic analysis and by comparing biothermal conditions given in the two urban meteorological stations Novi Sad and Niš with in Mt. Zlatibor, respresenting rural and lower mountain area, there are some differences of weather situations in summer period as expected. In this section, there are results of the heat budget index UTCI calculated for mean daily data and hourly data at 07h and 14h depicted in Fig. 1. and indices marked off in reference of the thresholds of maximum and minimum temperature in particular HD, HN, HNE depicted in Fig.2, Fig.3, and Fig.4., for the period of 20 years (1998-2017). The HWEs are depicited in Table 3. Obtained results of UTCI show compatibility with previous analyses related to the occurrence of heat waves especially since 2000 (Basarin et al., 2018; Unkašević and Tošić, 2009a; Unkašević and Tošić, 2009b; Unkašević and Tošić, 2013). In particular, the physiological stress in the category of "strong heat stress" appeared quite frequently in 1998, 2000, 2004, 2007, 2011, 2012, 2015 and 2017 in Niš (July and August) and little less of its in Novi Sad where the mentioned index appeared more frequently in July and August 2000, 2002, 2006, 2007, 2009, 2013, 2015, 2016 and 2017. There is quite less of the "strong heat stress" observed in Mt. Zlatibor. There were periods with categories of "moderate" and "strong heat stress" evenly spread in the months of July and August over the investigated period. It is important to emphasize that the most frequent category of "strong heat stress" in Mt. Zlatibor was occurred in 2000, 2004, 2007, 2012, 2015 and 2017, were generally coincided with the other two stations. The results depicted in Fig. 1 shows the frequency of all UTCI categories in percentages that occurred during July, August and September during for 20 years. Bioclimatic conditions in Niš are certanly the most unpleasant with domination of "strong heat stress" and not so rare "very strong heat stress" categories. There are 5 days observed with "extreme heat stress", especially for hourly meteorological data at 14h (UTCI14h). Bioclimatic conditions are more pleasant in the morning hours (UTCI7h) where the dominant category "moderate heat stress" (July and August) and "no thermal stress" in September (Fig. 1a).

The city of Niš is located in the south part of Serbia and belongs to the areas that are most endangered by drought and extreme high temperatures in Serbia. Novi Sad is located in north part of Serbia, on the slopes of Mt. Fruška Gora wich characterized

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by a temperate continental and continental climate therefore bioclimatic conditions in Novi Sad are more pleasant then in Niš. The most frequent categories are "moderate heat stress" on the mean daily level (UTCI) and "strong heat stress" on the hourly level at 14h in the past 20 years ($UTCI_{14h}$). Days with "very strong heat stress" are observed in July and August (Fig. 1b) and one day with "extreme heat stress" happen in July 2007 ($UTCI_{14h}$=48.42°C). Mt. Zlatibor has distinctive characteristics of the sub-mountain and mountain climate. Among these three stations, bioclimatic conditions of Mt. Zlatibor are the most pleasant considering the dominant category of UTCI on the daily level is with "no thermal stress". The conditions with a morning values (7h) are similar to mean while the UTCI measured at 14h shows higher values with the prevailing categories "moderate heat stress" and little less "strong heat stress" during summer. It is important to emphasize UTCI category of ""slight cold stress" recorded several times during the three months of the observed period. The lowest value of the UTCI index is -2.84°C occurred in September 5th, 2007 (Fig. 1c). There were only few cases when the UTCI has exceeded the limit value for "extreme heat stress" in Niš. It is happened in July 5th, 2000 (UTCI=47.08°C); July 24th, 2007 (UTCI=48.26°C); August 24th, 2007 (UTCI=46.29°C); August 5th and 6th, 2017 (UTCI=46.75 and UTCI=46.76°C). The highest value of UTCI in Novi Sad was recorded in July 24th, 2007 (UTCI=48.42°C). In the area of Mt. Zlatibor, the "extreme heat stress" has not been recorded during last 20 years. The highest values of UTCI in Zlatiobor were in July 22nd and July 24th, 2007 (UTCI=38.62°C and UTCI=38.37°C). The year 2007 is rated as the most unfavourable, particularly the date of July 24th, when the highest temperature ever was recorded in Serbia (Smederevska Palanka, t_{max}=+44,9°C, source: Republic Hydrometeorological Service of Serbia RHMSS). In accordance with thresholds of maximum temperatures, there were several years in Niš with 10 days or more when the temperature was higher than 35ºC as it is shown in Fig. 2. This is observed in July in 2000, 2007, 2012, 2015, and 2017, and in total, for each year is amounted to 10, 18, 16, 11 and 11 days respectively (in July). It is worth mentioning several heat events of 3 days or more with tmax above 35ºC, marked as a heat wave events (HWE) in Niš (July). An event of 10 days in row (Niš, July 15th to 24th, 2007) is the maximum number of days in row with such high temperatures comparing all three stations. In the same month, event of 3 days in row (July 8th to 10th) and 4 days in row (July 27th to 30th) were observed (Table 3).

Altogether, the heat wave events (HWE) were occurred 3 times with 3, 10 and 4 during July 2007, which is certainly an extreme for the observed period. The events of 3 or 4 days in row appeared during 9 years in the observed period of 20 years. From that source, there were 2 times heat wave events (HWE) occurred with 3 to 4 days during July in 2004, 2007 and 2017 (Table 3). It needs to be pointed out July in 2002, 2005, 2007, 2012 and 2015 with more than five days in row with tmax above 35oC and it is amounted to 6, 6, 10, 9, 7 days respectively. In regards to the thresholds of maximum temperature in Novi Sad, there were 10 days or more with temperatures above 35ºC respectively 10 and 11 days during July in 2012 and 2015.

In August, it is observed in 2000, 2007, 2012, 2013, 2015, and 2017 and in total is amounted of 12, 13, 13, 13, 10, 10 days respectively for each year (Figure 3). During August 2 times heat wave events (HWE) with 3 to 6 days happened in 1999, 2000, 2001, 2012, 2015 and 2017. Further in August, series of heat wave events with 5 days in row or more were observed in

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1998, 2000, 2007, 2012, 2013, 2015 and 2017 and it is amounted to 5, 6, 6, 6, 7 and 6 days respectively. In regards to the thresholds in Novi Sad, there are two times heat waves events (HWE) with 3 and 4 days appeared in 2012 and 2015 in August. In 2017 occurred 3 times heat wave events (HWE) with 6, 3, and 3 days.

It is certainly important that two times HWEs have occurred during September 2015 with 3 and 5 days in row with t_{max} above 35ºC (Figure 4). This justifies the finding of Tomczyk (2016) the heat waves began to appear in September in the last decade. In August in 2015 and 2017 the t_{max} over 35ºC was amounted to 11 and 13 days in total. If we observe the number of HDs in September during 20 years, it can be noticed that the number of days with air temperatures higher than 35°C increased significantly after 2007, especially in Niš (Figure 4). During the first decade of the investigated period (1998-2007), only one HD was recorded (September 27th, 1999, when the maximum daily temperature was 35°C). In the period 2008-2017 there were 20 such days (especially during 2011 and 2015). In the second decade of the researched period stands out 2015 with two HWEs (September 1st to 5th, and 17th to 19th). The same year the highest daily temperature in September was recorded (on September 18th, t_{max}=37.5°C). A similar situation occurs in the area of Novi Sad. During the first 10 years, there was no recorded even one HD in September while after 2007 there were recorded 5 such days. For Niš and Novi Sad stands out 2015 and the hottest days, September 17th and 18th with tmax=36.7°C and 36.4°C.

For both weather stations in second decade, together with the increase of HDs, the HNs increase. In September, the daily air temperature increases, so there are more frequent days with temperatures around 30°C and higher. In this weather station 2015 stands out with the same date of the hottest day in September (September 18th, tmax=33.2°C). This is correlated with heat waves analysis in Athens where period of heat wave occurrence from mid of June to the Beginning of September (Papanastasiou et al., 2014). In the Mt. Zlatibor area there was no significant phenomenon of extreme temperatures, therefore there wasn't recorded even one HWE events (HWE=3-5 days $t_{max} \geq$35°C).

Considering standardized indices found on thresholds of maximum temperatures and bioclimatic index UTCI could improve understanding of biothermal conditions relative to heat wave. The investigated indices for three weather stations go along with trend of general warming. These trends indicate that occurrences of warm heat events and temperature extreme events have generally increased over investigation period (Collins et al., 2000). In the light of climatic changes and other negative factors resulting from this global phenomenon, it is becoming a true challenge to minimize their effects and improve living conditions in urban and rural areas (Stevović et al., 2017).

According to earlier studies of the air temperature extremes in Serbia for 15 weather stations, climate tended to be warmer especially during summer (Unkašević and Tošić, 2013). The analysis expands 2007, 2012, 2015 and 2017 with the most heat waves registered as heat wave events (HWE), with special attention on Niš where HWE lasted for 10 days in July, 2007 (Fig. 2). According to Unkašević and Tošić (2011) there are record values of the maximum temperatures observed over almost the whole territory of Serbia in 2007. As reported by Unkašević and Tošić (2009a) heat wave during July 2007 was associated with a system of low pressure located east from Britain and a weak gradient pressure field over southeastern Europe. Further, the summer 2007 was the warmest summer in Athens in the last century (Papanastasiou et al., 2014). Found on the investigation

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of heat waves (a sequence of at least 5 days with maximum temperature above the 95th annual percentile) in southeastern Europe for 21 stations from the period 1973–2010 there is increase in the number of hot days. In southeastern Europe, heat waves occurred from May to September, mostly, the highest number of HWs was recorded in July and August. In the last decades, heat waves begin to occur in May and September (Tomczyk, 2016). July is the hottest summer month in Serbia, when the health disorders, caused by weather conditions, are more frequent. In certain cases, heat waves cause certain problems, especially to children, elderly people, chronic patients and workers. The urban areas have a high-risk of heat absorption of buildings and asphalt, resulting the formation of high temperatures during the night (Giannopoulou et al., 2014). Rural and mountainous areas enriched in forests as Mt. Zlatibor are less exposed to these phenomena, but during the hottest summer months, days with high temperatures and tropical nights can occur (Fig. 1c).

Bioclimatic conditions analyzed using the UTCI index show that calculated data observed at 14h are related to marked heat wave events (HWE). If the $UTCI_{14h}$ category of "very strong heat stress" is compared with heat wave events (HWE) it could be stated a special category (sub-index) of $UTCI_{14h}$ called very strong heat stress event ($UTCI_{14h}$VSHSE). The sub-index is defined if 6 days in row appears in the category of "very strong heat stress" by month ($UTCI_{14h}$VSHSE $\geq$ 6 days). The sub-index corresponding with heat wave event and it could be an indicator of extremely unfavorable bio-climatic conditions. Along these lines, $UTCI_{14h}$VSHSE in Niš appeared during July in 1998, 2005, 2007, 2012 and 2015 when there were 6, 6, 10, 12 and 10 days respectively and appeared during August in 2000, 2012, 2013, 2015 and 2017 when there were 6, 6, 8, 7 and 6 days respectively. These results are depicted in Fig 2 and Fig 3. Covering the data period from 1948–2007 for Niš it is recorded the highest temperatures ever during the summer 2007 (44.2°C) and summer 2000 (42.5°C) (Unkašević and Tošić, 2009b). $UTCI_{14h}$VSHSE appeared in Novi Sad during July in 2007 (7 days), 2012 (7 days) and 2015 (8 days) and during August in 2000 (7 days), 2013 (8 days), 2015 (6 days) and 2017 (6 days). As reported by Basarin et al. (2018) the periods of extreme warm bioclimate conditions in Vojvodina are more lasting indicating future bioclimate conditions will be more stressful for people's health and wellbeing. It is detectible in the last two decades the summers are warmer, the indices increase including September and even a heat waves. It highlights the increase in the length of heat waves, marked as Heat wave events (HWE). The sub-index $UTCI_{14h}$VSHSE was no recorded in Zlatibor.

4. Concluson

The assessment of biothermal conditions during the summer was analyzed based on the variability of UTCI index and indices based on thresholds of t_{max} for two cities (Niš and Novi Sad) and a mountain (Zlatibor) up to 1500 m located in different geographical regions in Serbia. It was found that most frequent heat stress categories are "strong heat stress" and "very strong heat stress", occur in all three locations with the tendency of increasing the number of days in the last decade. "Extreme heat stress" category describing an alarming biothermal state and appeared several times in Niš. The most extreme heat waves events are occurred in 2007, 2012, 2015 and 2017. Heat wave event (HWE) of 10 days in row in July 2007 and 9 days in row in July 2012, occurred in Nis, is the maximum number of days in row comparing all three stations. Together with HWEs of 3

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and 4 days in row, HWE of 10 days occurred in July makes 2007 the most extreme. Appearance of HWE with more than 5 days in row in July and August increases in the last decade. It is certainly important finding that two times HWEs have occurred during September 2015 with 3 and 5 days in row. Considering these facts, it can be deduced that HWEs are becoming more frequent, stronger and longer. The outcome of the study is separation of $UTCI_{14h}$ sub-index called "very strong heat stress event" ($UTCI_{14h}$VSHSE) corresponding with heat wave event as an indicator of extremely unfavorable bioclimatic conditions.

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Table 1. The scale of UTCI and the degree of comfort

UTCI (°C)	Stress category
UTCI > 46	extreme heat stress
38 < UTCI < 46	very strong heat stress
32 < UTCI < 38	strong heat stress
26 < UTCI < 32	moderate heat stress
9 < UTCI < 26	no thermal stress
0 < UTCI < 9	slight cold stress
-13 < UTCI < 0	moderate cold stress
-27 < UTCI < -13	strong cold stress
-40 < UTCI < -27	very strong cold stress
UTCI < -40	extreme cold stress

Source: Blazejczyk et. al 2014

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410 **Table 2.** Definition of indices used in the study

Abbrevations	Indices	Definition
HD	Hot days	$t_{max} \geq 35°C$
HWE	Heat waves event	3-5 days in row days $t_{max} \geq 35°C$
HN	Hot nights	$t_{min} \geq 20°C$
HNE	Hot nights event	3-5 nights in row $t_{min} \geq 20°C$
UTCI	Universal Thermal Climate Index	$UTCI = f(t, f, v, t_{mrt})$
$UTCI_{07h}$	Universal Thermal Climate $Index_{07h}$	$UTCI_{07h} = f(t_{7h}, f_{7h}, v_{7h}, t_{mrt})$
$UTCI_{14h}$	Universal Thermal Climate $Index_{14h}$	$UTCI_{14h} = f(t_{14h}, f_{14h}, v_{14h}, t_{mrt})$
$UTCI_{14hVSHSE}$	$UTCI_{14h}$ Very Strong Heat Stress	$UTCI_{14hVSHSE} \geq 6_{VSHS}$ days in row by month

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Table 3. Number of Heat waves events (HWE) in Niš, Novi Sad, July, Aug and Sep, 1998-2017

Month	Year/ HWE	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
July	Niš	4	/	3	3	6	4	3, 4	6	/	3, 10,4	/	/	/	3	9	/	/	7	3	4, 4
	NS	/	/	/	/	/	/	3	/	/	6	/	/	/	4	6	/	/	9	/	/
Aug	Niš	5	3, 4	4, 6	3, 3	/	/	/	/	3	6	4	3	4	3	4, 6	7	/	6, 4	/	6, 4
	NS	/	/	6	/	/	/	/	/	/	/	3	/	/	/	3, 5	4	/	4, 5	/	6, 3, 3
Sep	Niš	/	/	/	/	/	/	/	/	/	/	3	/	/	/	/	/	/	5, 3	/	/
	NS	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/

Note: pink cells have more than one HWE/duration defined by numbers of the days

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Figure 1. Frequency of the UTCI heat stress categories during July-September, 1998-2017: a) Niš, b) Novi Sad, c) Zlatibor

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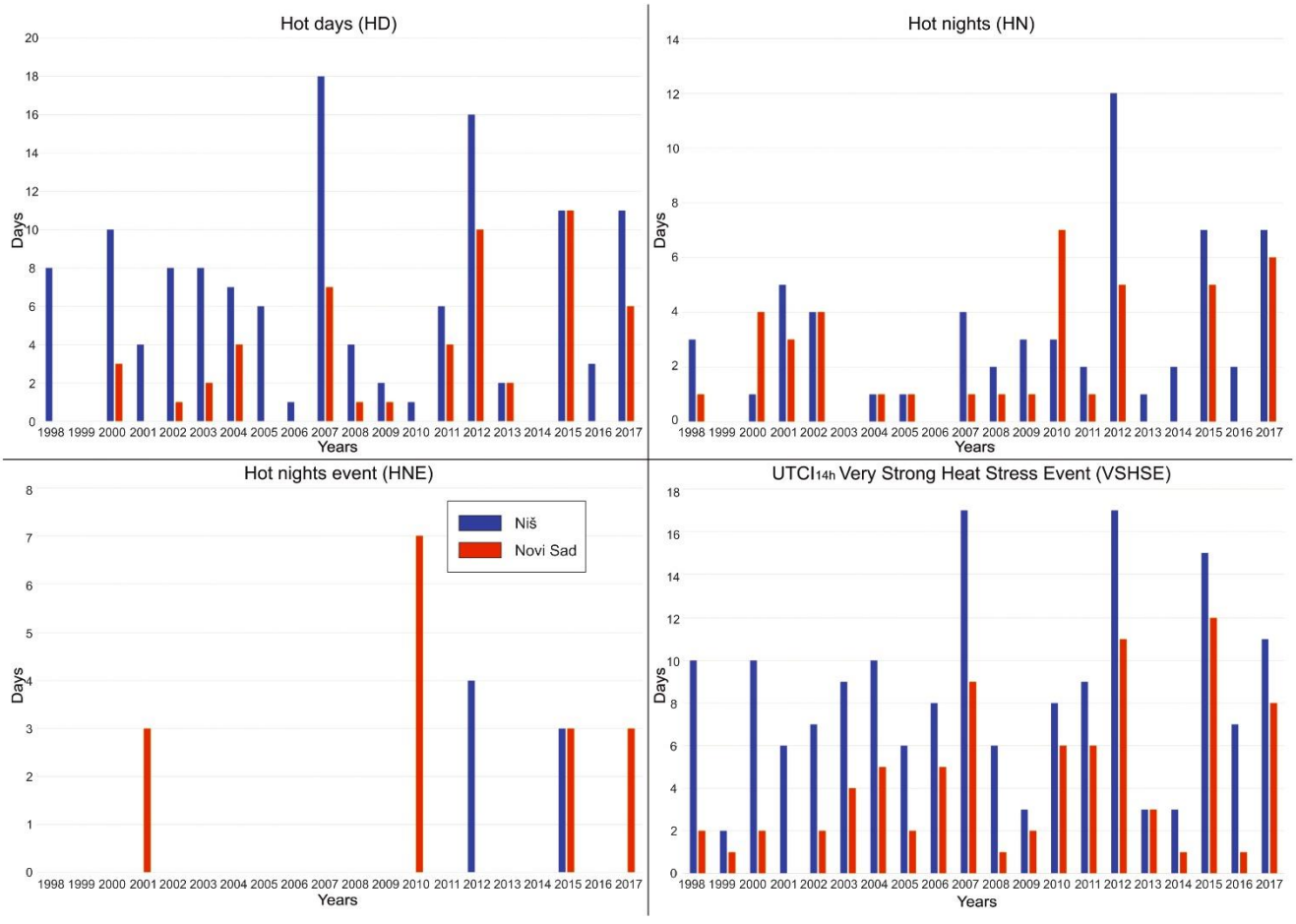

Figure 2. Number of Hot days (HD), Heat waves events (HWE), Hot nights (HN), Hot night events (HNE) and number of days with $UTCI_{14h}$ Very Strong Heat Stress (VSHS), Niš, Novi Sad, July 1998-2017.

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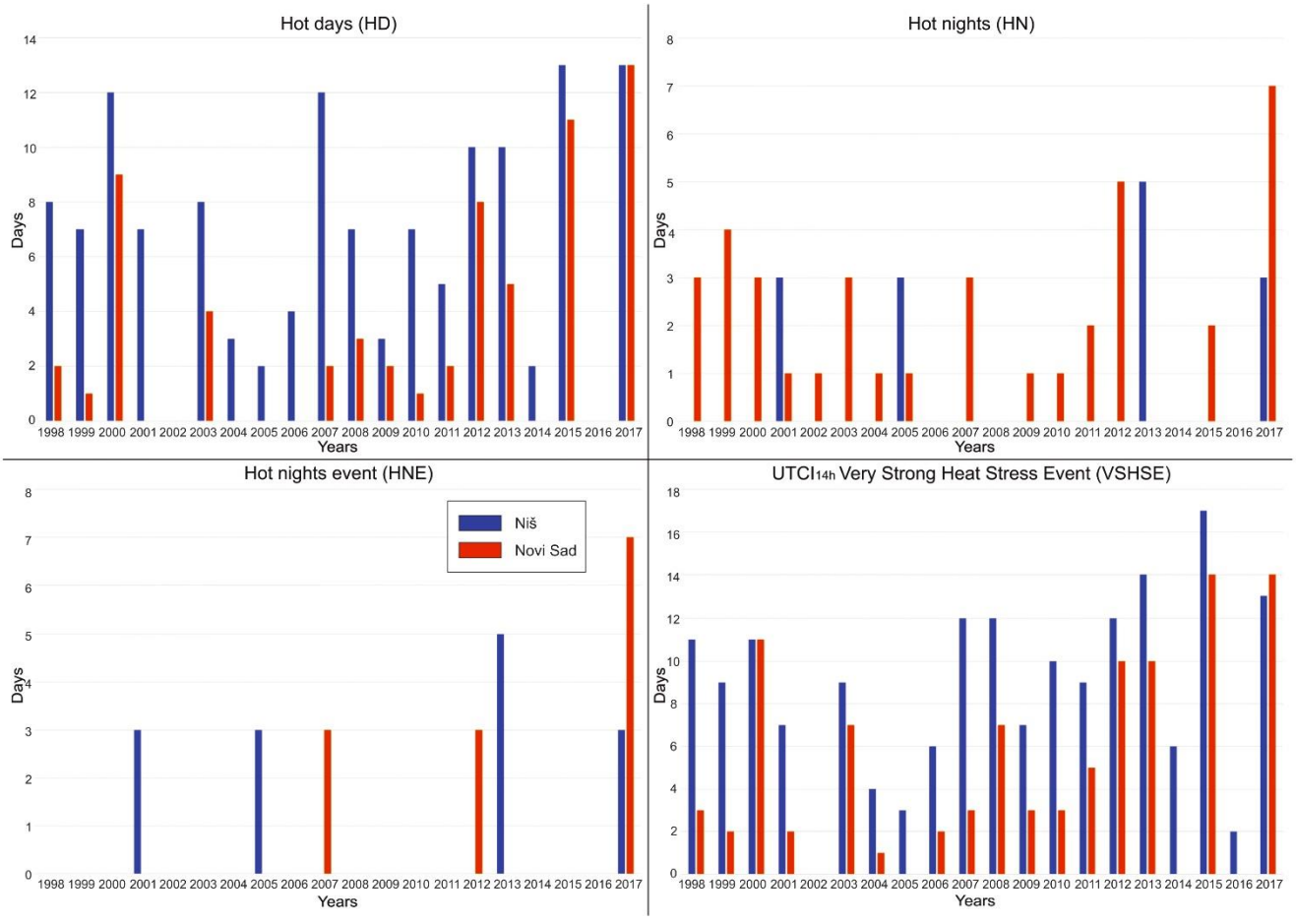

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Figure 3. Number of Hot days (HD), Heat waves events (HWE), Hot nights (HN), Hot night events (HNE) and number of days with $UTCI_{14h}$ Very Strong Heat Stress (VSHS), Niš, Novi Sad, Aug 1998-2017.

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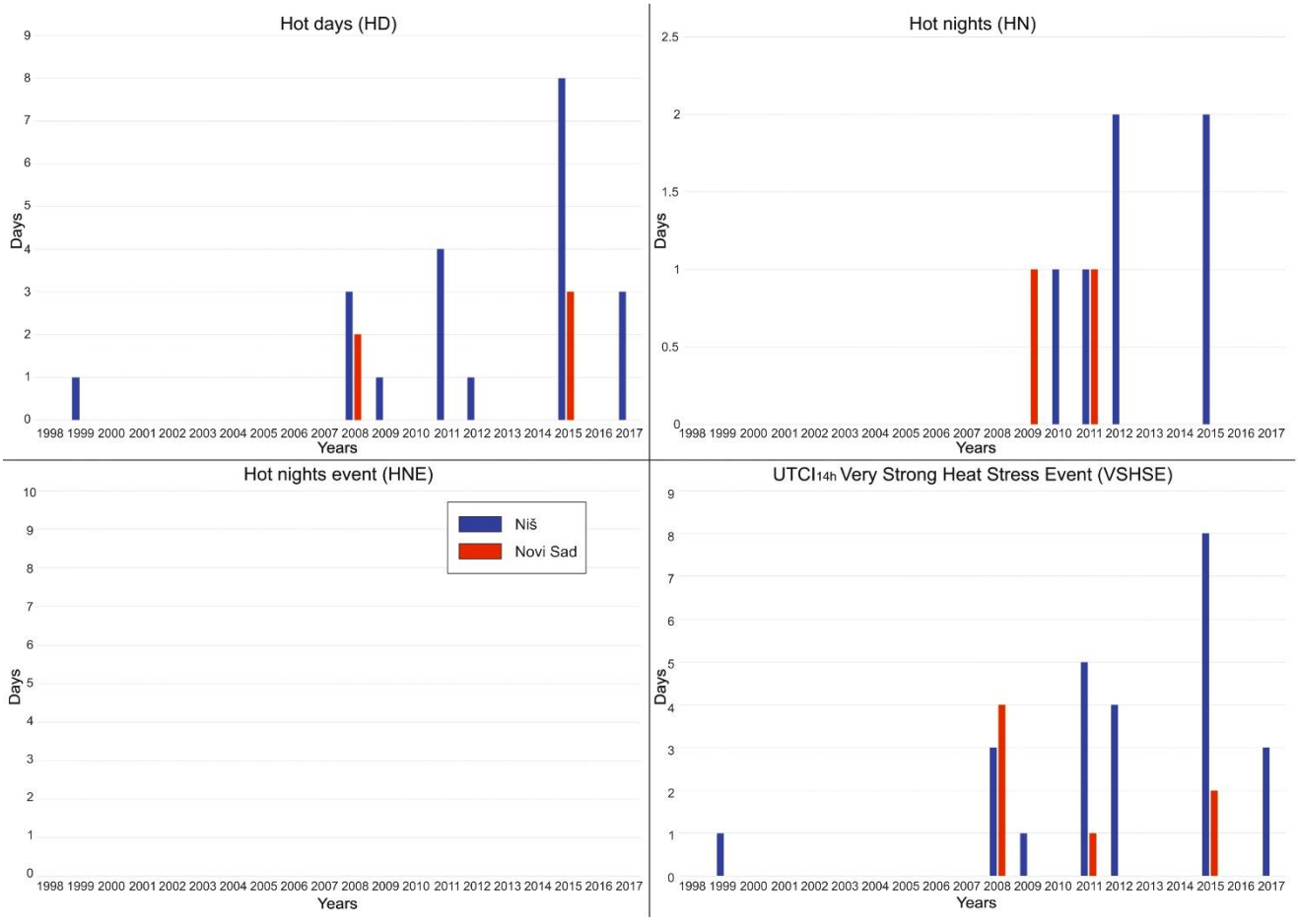

Figure 4. Number of Hot days (HD), Heat waves events (HWE), Hot nights (HN), Hot night events (HNE) and number of days with $UTCI_{14h}$ Very Strong Heat Stress (VSHS), Niš, Novi Sad, Sep 1998-2017.