18th February 2020

Response to peer reviewer comments
nhess-2019-270: **Summer variation of the UTCI index and Heat Waves in Serbia**
Milica M. Pecelj, Milica Z. Lukić, Dejan J. Filipović, Branko M. Protić

Dear Reviewer,

We would like to thank the you for giving us the opportunity to submit a revised draft of our manuscript titled Summer variation of the UTCI index and Heat Waves in Serbia to Journal of Natural Hazard and Earth System Science. We appreciate the time and effort that you dedicated to providing valuable feedback on our manuscript.

We have been able to incorporate changes to reflect most of the suggestions. Since you emphasized major revisions to the manuscript, significant changes have been made to the paper. The revision, based on your input, includes changed interpretation of research in all chapters.

Here are the responses to yours comments and concerns, listed step by step. To make the changes in the manuscript easier to follow, we have highlighted the modified text in green and the new added text in blue.

Reviewer Comment:

The assessment of bioclimatic conditions in Serbia has been investigated in the present research. This work seems to be interesting and can be accepted for publication after major revisions. The content of the manuscript should be deeply improved in terms of scientific (results, interpretations and discussions) and technical approaches (methodological approach). The content is deemed to be not fully satisfactory to understand the main finding of the work. Introduction According to the introduction, many studies have been carried out in Serbia. It's important to underline the original contribution of the present research. This part should be improved and some part are difficult to understand. Methodological approach Any detailed explanation has been presented in this part. I have not understood the methodology and how the results have been calculated. Then, a more recent meteorological data sets are used for the computation of the UTCI index values for the selected stations. Starting in 1998 should not be enough to calculate the long-term trends. Starting before should be more interesting to identify the trend of such extreme heat waves. Results This part should be more explained. I cannot fully understand the results since the methodology is not detailed. More analysis should be added to explain the main finding of the paper. Parts of Discussions and Conclusions Both parts should be written differently. The work should be discussed with other previous works dealing with extremes in this zone and also other works using the same methodology (if this one is not new.. I don't know exactly since it's not clearly presented).

Author response: Thank you for pointing this out. Since the major revisions to the manuscript have emphasized, significant changes were made to the manuscript. The revision, based on the review input, includes a number of following changes:

Title

We have modified the title and named in revised text as: Analysis of UTCI index during heat waves in Serbia

Abstract

According to all changes that have made in the manuscript we have modified Abstract and in revised text is provided as follows:

(lines 8-9) The objective of this paper is to assess the bioclimatic conditions in Serbia so as to identify biothermal heat hazard.

(lines 12-14) In order to identify patterns of biothermal heat stress conditions, the thresholds of daily UTCI index, refers as very strong heat stress (VSHS), are compared with the thresholds of daily maximum of air temperature which are termed as heat wave events.

(lines 16-18) Heat wave events recorded (HWE, VSHSE) in July 2007 (10 days), 2012 (9, 12 days) 2015 (7, 10 days) were of the longest duration and refer as indicators of biothermal heat hazard.

Introduction

In relation to your remarks, we have completely modified the introduction where have emphasized and explained the concept of heat budget index more clearly. We have supplemented the introduction with a new text outlining the concept of heat budget indices, their importance for bioclimatic analysis.

We agree with the reviewer statement about data set used in the study however, in the case of our study, it seems slightly out of scope because the procedure for obtaining daily hourly data from the national weather center is very slow, so it would be impossible to respect the time limit for correction. It would certainly have been interesting to explore this aspect for future research. Since many studies have been conducted in Serbia concerning the analysis of heat waves in the last 50 years, we considered their results relevant indicating an increase in heat waves especially since 2000. Starting from this fact, we used available data only from 1998-2017 and for that period we did a bioclimatic identification of thermal discomfort. We changed a part in introduction to emphasize this point.

Then, we modified the paragraph followed by detailed recent studies (lines 47-58; lines 63-74; lines 77-94) and moved it into the discussion section (lines 479-494; lines 448-462; lines 463-469). More specifically, lines 47-58 have been moved into the discussion lines 479-494, where a reference about heat wave related mortality in 2007 by Bogdanović et al. (2013) was added (lines 491-494). In addition, lines 63-74 have been moved into the discussion lines 448-462, and there is an explanation of what a tropical day is (line 455-456) in the analysis by Unkasevic and Tosic (2009b). Lastly, lines 77-94 have been moved into the discussion section (lines 466-472).

The revised text reads as follows on:

(lines 21-25) Extreme weather events such as heat waves, floods, droughts or storms have shown an increased frequency in recent decades (Brown et al., 2008; Easterling et al., 1997; IPCC, 2012; Rahmstorf and Coumou, 2011; Seneviratne and Nicholls, 2012). Not only are heat and drought events of great importance in most Mediterranean climate regions, but also in most of southern and south-eastern Europe, because of the diverse and costly impact that they have on various economic sectors and on the environment (Peña-Gallardo et al., 2019).

(lines 27-29) They have both direct effects on human health, affecting the body's physiological responses and functions and indirect effects on human health, increasing challenges to food and water safety (Lee et al., 2019).

(lines 32-35) Over the last century many models and indices have been developed for the assessment of human exposure to heat, ranging from simple physical instruments designed to imitate the human heat exchange with the environment, to complex thermophysiological models that simulate external and internal body heat transfer and allow detailed simulation of different work load, clothing, and climate scenarios (Havenith and Fiala, 2015).

(lines 36-64) Many thermal indices have been developed for the purpose of describing the complex conditions of heat exchange between the human body and its thermal environment (Fanger, 1970; Landsberg, 1972; Parsons, 2003). Those are two meteorological parameter indices – the ones used for cold environment conditions combining the air temperature and the wind velocity (Osczevski and Bluestein, 2005; Siple and Passel, 1945;), and the ones used for heat environment conditions combining the air temperature and humidity (Masterton and Richardson, 1979; Steadman, 1984; Yaglou and Minard, 1957). Considering their shortcomings, i.e. the fact that they are not universally applicable to all climatic regions, including different seasons, the dominance in the analysis of biothermal conditions and thermal stress over the last 30 years has been taken over by so-called heat budget indices (Blazejczyk, 1994; Hoppe, 1999; Jendritzky, 2012). The heat budget indices are based on the thermal exchange between humans and the environment. Methodologically, they use variables related to meteorological (air temperature, wind velocity, radiation, air humidity) and physiological processes (most commonly metabolic heat) and clothing insulation. The issue that should be emphasized during the analysis of the thermal stress is the influence that extreme temperatures have on the physiological parameters in humans. According to McGregor and Vanos (2018), generated heat load can undermine the human body's ability to hold its core temperature within the range of optimal physiological achievement.

For the purpose of estimating the thermal effect of the environment on the human body, the total effects of all the thermal components are considered by the UTCI index. The UTCI is heat budget index considering both physiological and meteorological parameters describing the physiological heat stress that the human body experiences while achieving thermal equilibrium with the surrounding outdoor environment (Błażejczyk et al., 2013). Compared to other indices, UTCI is more sensitive to changes in all of the environment parameters, particularly 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 and has a wide application in weather forecast for outdoor activities, appropriate behavior and climate therapies, and extreme thermal stress alerts. These analyses can have application in tourism, health sector, and urban and regional planning (Jendritzky et al., 2012). In the past decade, a large number of publications in Europe concern analyses of bioclimatic condition in accordance with the UTCI index (Błażejczyk et al., 2014; Błażejczyk et al., 2017; Bleta et al., 2014; Di Napoli et al., 2018; Di Napoli et al., 2019; Matzarakis et al., 2014; Milewski, 2013; Nastos and Matzarakis 2012; Nemeth, 2011; Tomczyk and Owczarek, 2019; Urban and Kyselý, 2014).

(lines 72-83) There is a need to study the evolution of such indices regarding heat stress that affects the human thermoregulatory system as a result of heat exchange between the body and its thermal environment.

Considering extreme temperature is one of the most significant climatic parameters in the universal context of climate change, analyses of heat waves in Serbia have been performed in several different approaches and all of them show a growing trend in max temperature (Drljača et al., 2009; Unkašević and Tošić, 2009a; Unkašević and Tošić, 2009b; Unkašević and Tošić, 2013) and heat waves (Unkašević and Tošić, 2011; Unkašević and Tošić, 2015) especially since 2000.

Keeping this fact in mind, the basic idea of this study is to conduct the analysis of human bioclimatic conditions in Serbia in the last 20 years, where according to the previous studies mentioned above, warming has been perceived and recorded, especially since 2000. Determining extreme weather event from the aspect of heat budget indices allows other meteorological parameters to be taken into account because high temperatures and humidity generate a heat load more rapidly, unless the wind and direct radiation are taken into account.

(lines 86-90) The conducted human bioclimatic evaluation of UTCI thermal stress in Serbia was considered to be of great importance due to the identification of biothermal heat hazard and the study of the evolution of such indices regarding climate change. This evaluation is aimed at addressing the following topics in this study:

- providing a comprehensive assessment of the human heat stress associated with UTCI index and
- comparing it to heat waves defined by meteorological parameters.

To provide a clearer introduction we have inserted a new text. Namely, we added a heading ''Study area" where we provided a relief map of Serbia, inside Europe, with the location of the three stations studied in the paper (lines 92-105). Basic information about the climate of Serbia has been added. Thus, we switched the first paragraph (lines 105-115) from the Materials and methods section, which in the revised version takes up lines 107-121.

The revised text reads as follows on:

(lines 92-121) *Study area*

The Republic of Serbia is located in south-eastern Europe, in the area of the southern Pannonian Plain and the central Balkans. Northern Serbia is mainly flat, while its central and southern areas consist of highlands and mountains (Gocić and Trajković, 2014), as the map of the relief characteristics shows (Figure 1). The territory of Serbia is characterised by temperate continental and mountain climate and the spatial distribution of climate parameters is determined by geographical location. The research involved studying three synoptic stations located in different geographical areas of Serbia: (i) Novi Sad, (ii) Niš and (iii) Mt. Zlatibor (Figure 1).

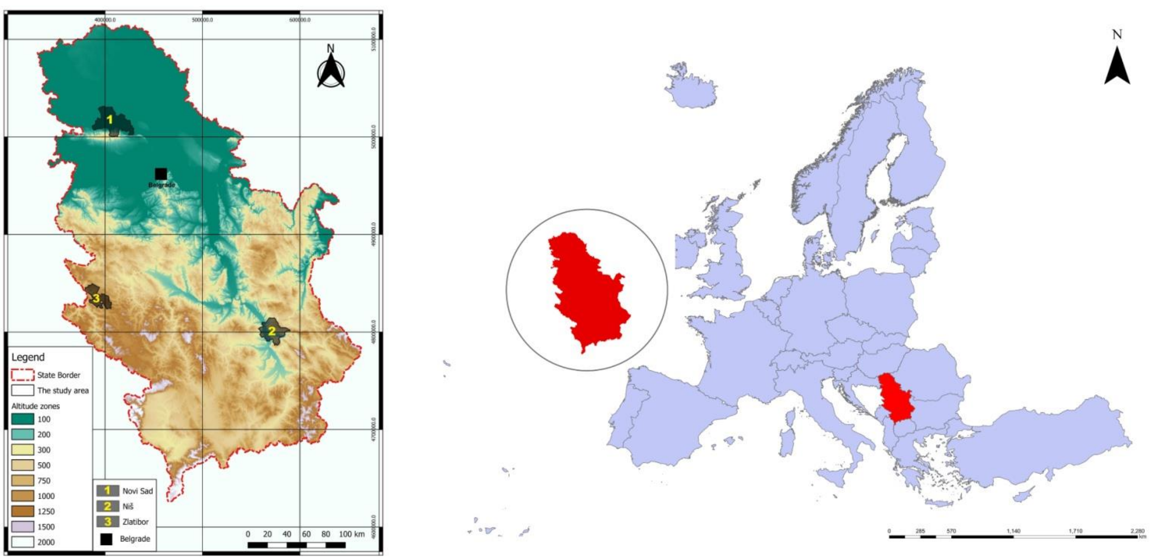

Figure 1. Relief map of Serbia with the areas studied: 1-Novi Sad, 2-Niš, 3-Zlatibor and a map of geographical location of Serbia in Europe. Maps were created using QGIS 3.8 software on the basis of the official European Commission's (Eurostat) datasets, available at https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/, (Map ratio: 1:1900000; Map projection: WGS 84/UTM, Zone 34N, the official national coordinate system)

The first weather station (at an altitude of 86 m) is located in the territory of Novi Sad, which is the administrative urban center of Vojvodina province and South Bačka District (Figure 1_1). The city is located in the southern part of the Pannonian Basin, on the Danube River bank near Mt. Fruška Gora, and the national park bearing 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). The second station is Niš (at an altitude of 202 m) and it is located in the Niš Fortress. This city is the administrative urban center of the Nišava District in southern Serbia and it is situated in the Nišava valley, located in the central part of the spacious geological depression called the Nišava Basin (Figure 1_2). 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 recorded at the beginning of the summer) and somewhat dry winters (Prokić, 2018). Compared to other cities in this valley (Dimitrovgrad, Pirot and Bela Palanka), Niš is the hottest one with an average annual temperature of 11.8°C(Prokić, 2018). The third station is Zlatibor, a mountain in western Serbia, which belongs to the mountain range of the Dinaric Alps (Figure 1_3). Zlatibor weather station lies at an altitude of 1029 m a.s.l. In the area of Zlatibor plateau mountains meet air currents from the Adriatic Sea, which, as it can be assumed, creates a favorable climate and for this reason Zlatibor has already been confirmed as a climatic resort (Pecelj et al., 2017). The mountain climate of Zlatibor involves long and cold winters, short and fresh summers, and less pronounced spring and autumn.

Materials and methods

We have, accordingly, a modified description of the model used to compute the index and we have made changes, clarifying the index analysis methodology. More specifically, we have divided the Materials and methods into two sections. In the beginning, an overview of meteorological and physiological components is given (lines 123-133), where we describe in more detail the metabolic rate as a key physiological parameter. The first section deals with the Universal Thermal Climate Index (UTCI), where we provide detailed definition, parameter inputs, and their limitations including stress classification (123-142; 147-169).

The revised text reads as follows on:

(lines 123-142) The present study implements the methodological approach of Universal Thermal Climate Index (UTCI) based on human heat budget model relying on the evaluation of human energy balance. As a thermal comfort indicator, the UTCI considers combined meteorological and physiological parameters describing thermal comfort through the evaluation of human energy balance. In terms of physiological conditions, the metabolic rate plays the most important role. Metabolic processes in the human body create heat that is constantly exchanged with the environment achieving a state of thermal equilibrium in the body for maintaining a constant body temperature. The amount of the heat that is produced and released depends on the following: physical activity, clothing, sex, age, body mass, diet, mental state, health, external conditions, acclimatization, etc. As a measure of physical activity, a unit of "MET" was defined, which corresponds to the release of human heat of 58.2 $W.m^{-2}$ for average body surface area (1.8 m^2), i.e. it is equal to the energy rate produced per unit surface area of an average person seated at rest (ANSI/ASHRAE Standard 55). According to ISO 8996 for standard applications, the metabolic heat energy is M = 135 $W.m^{-2}$ i.e. 2.3 MET, for a person moving at a speed of $1.1 m.s^{-1}$.

The Universal Thermal Climate Index (UTCI)

For valid assessment of the outdoor thermal environment in the fields of public weather services, public health systems, urban planning, tourism and recreation and climate impact research, the Universal Thermal Climate Index (UTCI) has been developed based upon the most recent scientific progress in human thermo-physiology in biophysics and heat exchange theory. The UTCI is the result of an approach which was developed in the International Society of Biometeorology (ISB) Commission 6 and was later improved by COST Action 730 (Jendritzky et al., 2012). The design of UTCI is of great importance due to the fact that it is applicable to all seasons and climates together with all spatial and temporal scales.

(lines 147-169) In other words, this model simulates the same sweat production or skin wettedness in human body response as the actual environment condition (Błażejczyk et al., 2013; Błażejczyk et al., 2014). This is derived from the multi-dimensional dynamic response of a state-of-the-art multi-node thermo-physiological model of human heat transfer and thermoregulation (Fiala et al., 2012). The UTCI can be represented in general function as bellow:

$$UTCI = f(t, f, v, t_{mrt}) \quad \text{(Eq.1)}$$

UTCI = f (air temperature, relative humidity, wind speed, mean radiant temperature)

For appropriate use, UTCI can only be approximated using a regression equation abbreviated from sample calculations performed by computing centers (Bröde et al., 2012; Jendritzky et al., 2012). It causes a narrow range of input parameters it can manage with. The regression equation supports reference environment described as: (i) air temperature (t) in the range of -50.0°C to +50.0°C, (ii) relative humidity (f) from 0 % to 100 %, (iii) wind speed (v) at 10 m from 0.5 ms^{-1} and up to 17.0 ms^{-1}, (iiii) including a difference between mean radiant temperature (t_{mrt}) and air temperature (t) of -30.0°C to +70.0°C. Physiological parameters, the metabolic rate (M) and the thermal properties of clothing (clothing insulation, permeability) are taken as universal constants in the model due to the evaluation by means of the regression equation. This implies an outdoor activity of a person walking at the speed of 4 $km.h^{-1}$ (1.1 $m.s^{-1}$), corresponding to heat production of 135 $W.m^{-2}$ (2.3 MET) of metabolic energy (Błażejczyk et al., 2013; Jendritzky et al., 2012) and the clothing insulation which is self-adapting according to the environmental conditions (Havenith et al., 2012). Clothing insulation, vapor resistance and the insulation of surface air layers, are strongly influenced by changes in wind speed and body movement and will therefore also influence physiological responses (Błażejczyk et al., 2012). Particular ranges of UTCI are categorised according to thermal stress (Table 1).

Table 1. UTCI thermal stress classification

UTCI (°C)	> 46	38 to 46	32 to 38	26 to 32	9 to 26	0 to 9	0 to -13	-13 to -27	-27 to -40	< -40
Stress	extreme heat stress	very strong heat stress	strong heat stress	moderate heat stress	no thermal stress	slight cold stress	moderate cold stress	strong cold stress	very strong cold stress	extreme cold stress
Abbr.	EHS	VSHS	SHS	MHS	NTS	SLCS	MCS	SCS	VSCS	ECS

Source: Błażejczyk et al. 2013

The second section, named *Data and indices considered in the study,* explains what kind of analysis was done in the study. The revised text reads as follows on:

(lines 170-210) *Data and indices considered in the study*

The meteorological data set from the period from 1998 to 2017 was recorded for two urban weather stations (Novi Sad and Niš) and one rural mountain station (Mt. Zlatibor). Mean daily and hourly meteorological parameters (07h, 14h, CET) of air temperature (t), air humidity (f), and wind speed (v) from the above weather stations were considered for the calculation of particular UTCI thermal heat stress in the summer months (July, August and September). The meteorological data set used in the study was retrieved from the Meteorological Yearbook for the period from 1998 to 2017 (Republic Hydrometeorological Service of Serbia) while the UTCI index was calculated by applying the BioKlima 2.6 software package (available at http://www.igipz.pan.pl/Bioklima-zgik.html).

Although extreme temperatures are one of the most effective climatic parameters in the universal case of hot days and heat waves, the influence of other parameters, especially clothing insulation and metabolic rate, can justify the thermal discomfort and the other way round. In that regard, the summer (July, August and September) daily maximum and minimum temperatures (tmax, tmin), for the same stations, were analysed in terms of particular thresholds to identify the frequency of extremely high temperatures and heat waves in the period observed to compare them with the discomfort recorded by the UTCI index.

The first stage of the study presented mean daily ($UTCI_{avg}$), morning ($UTCI_{7h}$) and midday ($UTCI_{14h}$) UTCI indices. They are presented by months (July, Aug, Sep) for each station to identify the general differences caused by the geographical origin of the stations under study. The quantification of human bioclimatic conditions in Serbia was designed for the UTCI indices on a daily basis of each defined stress categories. To obtain a better insight into the $UTCI_{14h}$ index values during the summer months, averaged monthly $UTCI_{14h}$ index was provided for each year to see how much the $UTCI_{14h}$ index fluctuated in relation to the average monthly value.

For the second stage, midday UTCI thermal stress indices were identified (strong heat stress SHS, very strong heat stress VSHS, extreme heat stress EHS) and thermal indices based on the maximum and minimum temperatures (hot day HD and hot night HN). During the midday observation (14 CET), particularly prominent are strong heat stress (SHS), which refers to UTCI range of 32°C to 38°C and very strong heat stress (VSHS), which refers to UTCI range of 38°C to 46°C (Table 2).The occurrence of thermal stress days was presented for each month (July, August and September) in the last 20 years. Extreme heat stress (EHS), which refers to UTCI range above 46°C was presented separately when it occurred. Thermal indices, hot day (HD) and hot night (HN), were identified on the basis of the threshold of the maximum and minimum temperatures. Considering the influence of extreme temperatures, as stated by Collins et al. (2000) the following indices were marked in relation to the thresholds of maximum and minimum temperature: Hot days ($HD=t_{max}\geq35$°C) and Hot nights ($HN=t_{min}\geq20$°C) (Table 2).

For the last stage of the study, for the purpose of identifying thermal discomfort during the period observed, as an illustration of a threshold based on the duration of hot days (HD) and hot nights (HN) a hot day event is determined (HWE =3 HD days of $t_{max}\geq35$°C). In addition, as an illustration of a threshold based on the duration of very strong heat stress (VSHS), a very strong heat stress event (VSHSE) is determined and it is caused by the occurrence of 5 consecutive VSHS days (Table 2).

As a result of comparing UTCI thermal stress to the selected thresholds of maximum and minimum temperatures, biothermal discomfort was identified during extremely high temperatures for the geographical area of Serbia. The recorded number of days with VSHS stress was compared to the number of days when the maximum air temperature was above 35°C.

Table 2. Definition of indices used in the study

Abbrevations	UTCI Indices	Definition
$UTCI_{avg}$	Universal Thermal Climate Index	$UTCI_{avg} = f(t, f, v, t_{mrt})$
$UTCI_{07h}$	Universal Thermal Climate $Index_{07h}$	$UTCI_{07h} = f(t_{7h}, f_{7h}, v_{7h}, t_{mrt})$
$UTCI_{14h}$	Universal Thermal Climate $Index_{14h}$	$UTCI_{14h} = f(t_{14h}, f_{14h}, v_{14h}, t_{mrt})$
Abbrevations	UTCI heat stress indices	Definition
SHS	Strong Heat Stress	SHS= UTCI (32°C to 38°C)
VSHS	Very Strong Heat Stress	VSHS = UTCI (38°C to 46°C)
VSHSE	Very Strong Heat Stress Event	minimum 5 VSHS days in a row
EHS	Extreme Strong Stress	EHS= UTCI >46°C
Abbrevations	Thermal indices	Definition
HD	Hot days	$t_{max}\geq35$°C
HN	Hot nights	$t_{min}\geq20$°C
HWE	Heat waves event	minimum 3 HD days in a row

t-air temperature; f-relative humidity; v-wind speed; tmrt-mean radiant temperature; tmax-maximum air temperature, tmin-minimum air temperature

Results

We have divided the section Results and discussion in two separate sections. According to the 3 stages of the study, described in revised Methodology (Data and indices considered in the study), the results are presented in three sections: (i) UTCI indices ($UTCI_{avg,}$ $UTCI_{7h}$, $UTCI_{14h}$), (ii) UTCI heat stress indices (strong heat stress SHS, very strong heat stress VSHS, extreme heat stress EHS) and thermal indices (hot day HD, hot night HN), (ii) Heat waves (HWE and VSHSE). In all three sections the results are explained in more detail along with the modified and new added figures. Alongside the trend of UTCI index, the correlation between UTCI and maximum air temperature, is provided, too.

We have improved the figures and tables. Figures 2,3 and 4 have been changed and merged to form one, which became Figure 4 in the revised manuscript. Furthermore, one new figure (Figure 3 in the revised version) has been added in the first section of Results to represent the trend of the $UTCI_{14h}$ index. Table 3 has been supplemented with VSHSE index compared with HWE. In the revised manuscript it became Table 4.

The revised text reads as follows:

(lines 213-222) On the basis of the conducted bioclimatic analysis and comparison of biothermal conditions given in the two urban meteorological stations Novi Sad, Niš and Mt. Zlatibor, which represents a rural and lower mountain area, some differences in weather conditions were perceived in the summer period, as was expected. The results are presented in three sections: (i) UTCI indices ($UTCI_{avg,}$ $UTCI_{7h}$, $UTCI_{14h}$), (ii) UTCI heat stress indices (strong heat stress SHS, very strong heat stress VSHS, extreme heat stress EHS) and thermal indices (hot day HD, hot night HN), (iii) Heat waves (HWE and VSHSE).

UTCI indices ($UTCI_{avg,}$ $UTCI_{7h}$, $UTCI_{14h}$)

This section presents the results of the heat budget index UTCI calculated for mean daily data ($UTCI_{avg}$) morning ($UTCI_{7h}$) and midday ($UTCI_{14h}$) for the period of 20 years.

(lines 228-235) These are the years when significant heat waves were recorded. The results depicted in Fig. 2 show the frequency (in percentages) of all stress categories for each index ($UTCI_{avg,}$ $UTCI_{7h}$, $UTCI_{14h}$) that occurred in July, August and September for the period that was observed.

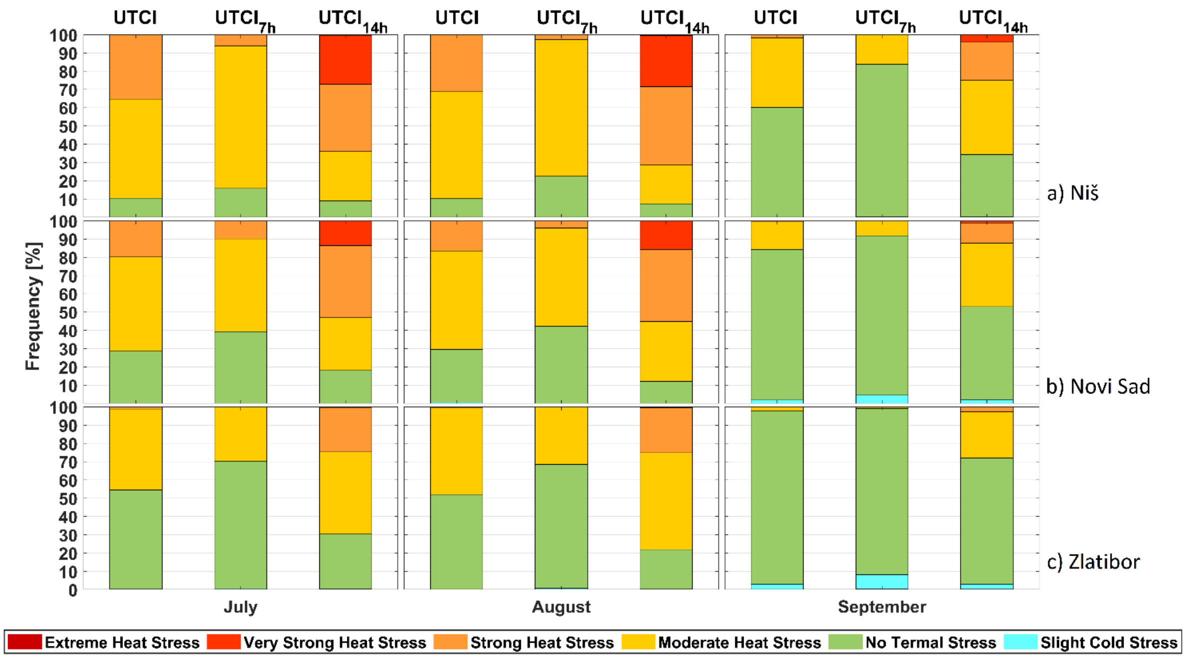

Figure 2. Frequency of the days with different UTCI thermal stress categories for mean daily ($UTCI_{avg}$), morning ($UTCI_{7h}$) and midday ($UTCI_{14h}$) index during the period from July to September, 1998-2017: a) Niš, b) Novi Sad, c) Zlatibor. X-axis: time (months), y-axis: frequency (number of days)

(lines 241-244) This is confirmed by Tošic and Unkasević (2014) in the study of dry periods in Serbia during the period between 1949 and 2011. It was found that the frequency of droughts in the southern part of Serbia was higher than in the other parts of the country. The most severe drought occurred in Niš and lasted from July 2006 to March 2008 (with a duration of 21 months and severity of 63.0).

(lines 247-291) Nevertheless, this does not rule out the occurrence of high temperatures and severe dry periods during the warm part of the year. This idea is based on the findings of Leščešen et al. (2018), when they analyzed drought periods in Vojvodina for over 60 years (1956-2016). All the regions of Vojvodina that were investigated experienced at least one extreme drought event over the reference period, in particular in 2000, 2001-2002, and 2011-2012. Moreover, the same results were obtained in other similar studies (Gocic and Trajković, 2013; 2014; Milanović, et al., 2014). On the mean daily level ($UTCI_{avg}$) the most frequent category is "moderate heat stress" while on the hourly level $UTCI_{14h}$ the most frequent category is "strong heat stress". Days with "very strong heat stress" were observed in July and August (Fig. 2b) and there was one day with "extreme heat stress" in July 2007. Mt. Zlatibor has distinctive characteristics of the sub-mountain and mountain climate. Among these three stations, the bioclimatic conditions of Mt. Zlatibor are the most pleasant ones considering the dominant category of "no thermal stress" on the daily level of $UTCI_{avg}$. The thermal conditions with a morning $UTCI_{7h}$ are similar to $UTCI_{avg}$ while the $UTCI_{14h}$ shows the prevailing categories of "moderate heat stress" and slightly less "strong heat stress" and "very strong heat stress". It is important to emphasize the UTCI category of "slight cold stress" for all the indices ($UTCI_{avg,}$, $UTCI_{7h}$, $UTCI_{14h}$) was recorded several times during the three months of the period which was observed. The lowest value of the UTCI index was -2.84°C and it occurred on September 5th, 2007 in Mt. Zlatibor as "moderate cold stress" (Fig. 2c).

Of all the calculated UTCI indices, mean daily data ($UTCI_{avg}$), morning data ($UTCI_{7h}$) and midday ($UTCI_{14h}$) data, the midday $UTCI_{14h}$ index shows the most extreme values for identifying heat waves. In this regard, for the further data analysis in this study, the $UTCI_{14h}$ is used. To gain better insight into the $UTCI_{14h}$ index values during the summer months, for the investigated period, averaged monthly $UTCI_{14h}$ index for each year was provided for all three stations. The mean monthly values are presented in Fig. 3, together with the trends in $UTCI_{14h}$ and mean absolute deviation of $UTCI_{14h}$ in order to see how much the $UTCI_{14h}$ index fluctuated in relation to the mean monthly value. The results show a significant increase in the extreme values of the $UTCI_{14h}$ index over the last ten years, presented mainly as "very strong heat stress category" (VSHS). A series of peaks can be observed in the years that have been marked as extremely warm. In addition, there is a growing trend of the $UTCI_{14h}$ index in all the summer months and all the weather stations, i.e. a series of peaks with successively higher values during the investigated period (1998-2017). The highest growing trend can be seen in September in Nis and Mt. Zlatibor, while the lowest growing trend can be observed in August on Zlatibor.

As regards the severity of daily UTCI index, there were 5 days recorded in Niš when the $UTCI_{14h}$ exceeded the limit value for "extreme heat stress" (EHS). This happened on July 5th, 2000 ($UTCI_{14h}$=47.08°C); July 24th, 2007 ($UTCI_{14h}$ =48.26°C); August 24th, 2007 ($UTCI_{14h}$ =46.29°C); August 5th and 6th, 2017 ($UTCI_{14h}$ =46.75 and $UTCI_{14h}$ =46.76°C). The maximum value of UTCI in Novi Sad was recorded on July 24th, 2007 (UTCI=48.42°C). In the area of Mt. Zlatibor, the "extreme heat stress" has not been recorded in the last 20 years. The highest values of UTCI in Zlatibor occurred on July 22nd and July 24th, 2007 ($UTCI_{14h}$ =38.62°C and $UTCI_{14h}$ =38.37°C). The year 2007 is rated as the most unfavourable one, particularly the date of July 24th, when the highest temperature ever was recorded in Serbia (Smederevska Palanka, t_{max} = 44,9°C, source: Republic Hydro-meteorological Service of Serbia, RHMSS).

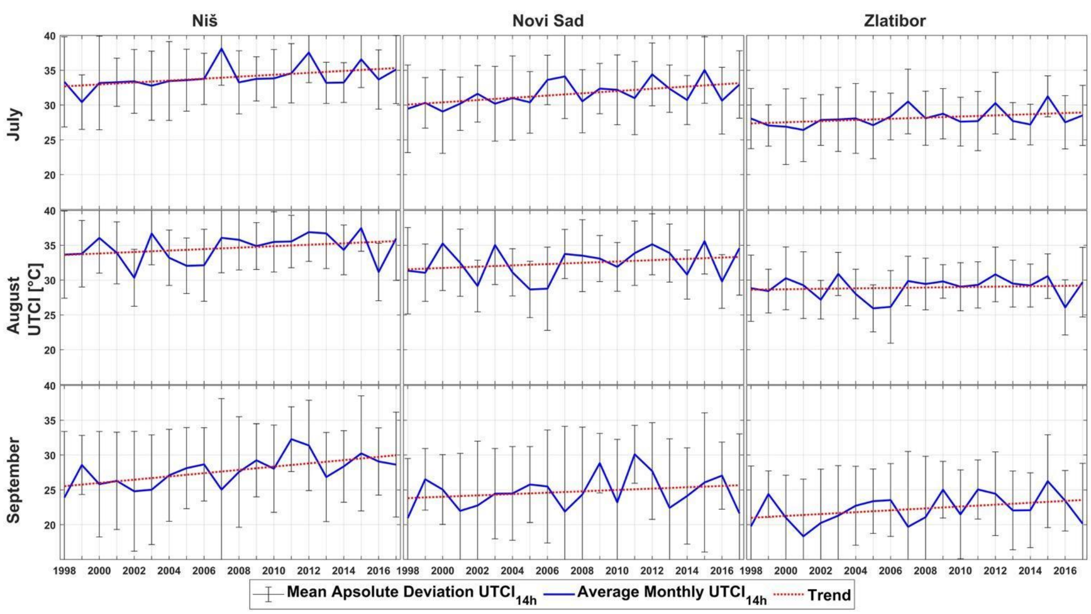

Figure 3. The mean monthly $UTCI_{14h}$ index during the period which is investigated (1998-2017). x-axis: time (years), y-axis: UTCI (°C)

Thermal indices and UTCI heat stress indices

This section identifies midday $UTCI_{14h}$ heat stress indices (strong heat stress SHS, very strong heat stress VSHS) and thermal indices marked in relation to the thresholds of the maximum and minimum temperatures in particular (hot day HD and hot night HN). Fig. 4 presents frequency (number of days) of hot days (HD), hot nights (HN), strong heat stress (SHS) and very strong heat stress (VSHS) for each month (July, August and September) in the last 20 years. The results of UTCI that were obtained show compatibility with previous analyses in relation 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).

(lines 302-350)

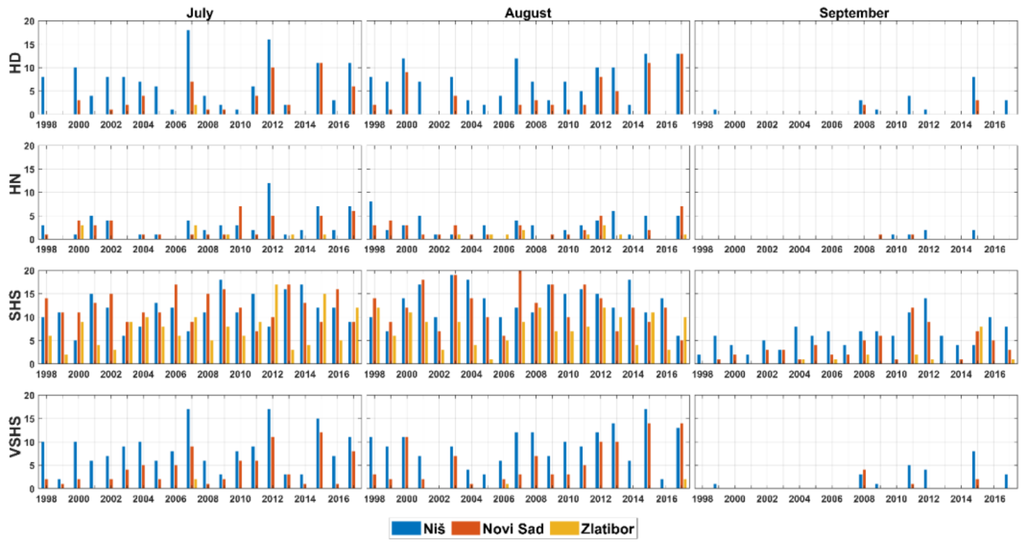

Figure 4. Number of hot days (HD), hot nights (HN), strong heat stress (SHS) and very strong heat stress (VSHS) in Niš, Novi Sad and Zlatibor (July, Aug, Sep) 1998-2017. x-axis: time (years), y-axis: number of days

For the period investigated (1998-2017), the total number of hot days recorded in July, August and September in Niš was 126, 133 and 21 HDs, respectively, while Novi Sad saw about a half of the said number of hot days, namely 52, 63 and 3 HDs, respectively. In Mt. Zlatibor 2 HD days were recoreded in July.

As regards hot nights (HN), there is generally a lower intensity of HNs compared to HDs. Generally, during the observed period up to 4 HNs were recorded, although an increase in the HNs has been observed in the last ten years. For example, in Niš during 2012, 2015 and 2017 the number of HNs recorded in July was 12, 7 and 7 respectively and during 2000, 2013, 2015, and 2017 the number of HNs recorded in August was 8, 6, 5 and 5 respectively. Since 2010 up to 2 HNs have been recorded in September. In Novi Sad, during 2010, 2012, 2015 and 2017 there were 7, 5, 5 and 6 HNs respectively recorded in July, while in August during 2012 and 2017 there were 5 and 7 HNs respectively. In September, one HN was recorded during 2009 and 2011 (Figure 4). The total number of hot nights recorded in July, August and September for the investigated period in Niš was 60, 56 and 6 HNs, respectively, while in Novi Sad there was a significantly lower number of hot nights – 41, 38 and 2 HNs, respectively. In Mt. Zlatibor 9 HN days were recorded in July and 11 HN days were recorded in August for the period which was investigated.

Midday $UTCI_{14h}$ "strong heat stress" (SHS) occurs most commonly in all three stations. For example, SHS is particularly important to Mt. Zlatibor, located at an altitude above 1000 m since there has been an increase in the number of days with SHS in Zlatibor over the last decade. The best indicator is the increase in SHS in September. Similarly, the indicator of biothermal discomfort, "very strong heat stress" (VSHS) has been occurring more frequently in the last decade, reaching a maximum of 17 days in July 2007 and 2012 and in August 2015 in Niš. The number of VSHS days in Novi Sad reached a maximum of 12 days in July 2015 and 14 days in August 2015 and 2017. The total number of VSHS days recorded in July, August and September for the investigated period in Nis was 167, 174 and 25 VSHS days, respectively, while in Novi Sad there was a significantly lower number of VSHS days – 83, 97 and 7 VSHS days, respectively. In Mt. Zlatibor 2 VSHS days were recorded in July and 3 VSHS days were recorded in August. The recorded numbers of VSHS days indicate slightly greater biothermal discomfort duration in relation to the number of HD days. The HD and VSHS indices are significantly correlated during the summer months as they are directly derived from the maximum air temperatures and $UTCI_{14h}$ indiex (Table 3). $UTCI_{14h}$ and t_{max} for the Niš and Novi Sad urban stations have a significantly high linear correlation.

Table 3. Linear correlation of $UTCI_{14h}$ and t_{max}

$UTCI_{14h}$ ~ t_{max}	Niš	Novi Sad	Zlatibor
July	0.88	0.97	0.85
August	0.92	0.95	0.77
September	0.89	0.92	0.41

For Zlatibor the correlation is slightly lower, and in September it is weak compared to the urban stations, but neither HD nor VSHS indices occurred on Zlatibor. Similar results of the linear relationship between the air temperature and the UTCI index (r = 83; r = 0.98) were shown in the studies of Urban and Kysely (2014) for summer in the urban areas of South Bohemia in Czech Republic and in the studies of Nassiri et al. (2017) for Iran.

Heat waves (HWE and VSHSE)

After UTCI thermal stress was compared to the selected thresholds of maximum temperature, biothermal discomfort was identified during extremely high temperatures for the geographical area of Serbia. During the observed period, a heat wave event (HWE) was determined, caused by 3 consecutive HD days and very strong heat stress event (VSHSE), caused by the occurrence of 5 consecutive VSHS days.

Table 4 lists the identified heat waves that refer to $UTCI_{14h\ VSHS}$ index (VSHSE) and HD index (HWE). It has a very similar layout. However, shadowed differences can be observed, especially in the duration of the heat wave event. The results are presented for Niš and Novi Sad since there were no recorded heat waves in Mt. Zlatibor. More heat waves, both HWEs and VSHSEs, have been identified in the last ten years.

A heat wave event (HWE) of 10 days in a row (Niš, July from 15th to 24th, 2007) is the maximum number of consecutive days with such high temperatures when all the three stations are compared. In the same month, HWE of 3 days in a row (July 8th to 10th) and 4 days in a row (July 27th to 30th) were observed (Table 4, HWE). Altogether, the heat wave events (HWEs) occurred 3 times and they lasted 3, 10 and 4 days in July 2007, which is certainly an extreme for the observed period.

(lines 364-371) **Table 4.** Number of Heat waves events (HWE) and Very strong heat stress event (VSHSE) in Niš, Novi Sad - July, Aug and Sep, 1998-2017

HWE	July		Aug		Sep	VSHSE	July		Aug		Sep
	Niš	Novi Sad	Niš	Novi Sad	Niš		Niš	Novi Sad	Niš	Novi Sad	Niš
1998	4	/	5	/	/	1998	7	/	5	/	/
1999	/	/	3, 4	/	/	1999	/	/	5	/	/
2000	3	/	4, 6	6	/	2000	/	/	6	7	/
2001	3	/	3, 3	/	/	2001	/	/	/	/	/
2002	6	/	/	/	/	2002	/	/	/	/	/
2003	4	/	/	/	/	2003	/	/	/	/	/
2004	3, 4	3	/	/	/	2004	5,5	/	/	/	/
2005	6	/	/	/	/	2005	6	/	/	/	/
2006	/	/	3	/	/	2006	/	/	/	/	/
2007	3, 10,4	6	6	/	/	2007	10	7	/	/	/
2008	/	/	4	3	3	2008	/	/	5	/	/
2009	/	/	3	/	/	2009	/	/	/	/	/
2010	/	/	4	/	/	2010	/	/	5	/	/
2011	3	4	3	/	/	2011	/	/	/	/	/
2012	9	6	4, 6	3, 5	/	2012	12	6	5,6	5,5	/
2013	/	/	7	4	/	2013	/	/	8	8	/
2014	/	/	/	/	/	2014	/	/	/	/	/

2015	7	9	6, 4	4, 5	5, 3	2015	10	8	7	6	5
2016	3	/	/	/	/	2016	/	/	/	/	/
2017	4, 4	/	6, 4	6, 3, 3	/	2017	/	/	6,5	6	/

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

Of the total number of hot days, it amounts to 21 HDs in September in Niš, only one HD was recorded in the first decade (1998-2007) of the investigated period, while the remaining HDs were recorded over the last decade (2008-2017), especially in 2011 and 2015. In the second decade of the investigated period the year 2015 stands out with two HWEs (September 1st to 5th, and 17th to 19th). In the same year the highest daily temperature was recorded in September (on September 18th, t_{max}=37.5°C).

(lines 381-396) Bioclimatic conditions analyzed by means of the UTCI index show that the calculated data observed at 14 CET are related to the marked heat wave events (HWE). When $UTCI_{14h}$ thermal stress category of “very strong heat stress” (VSHS) is compared to the selected heat wave events (HWE,) a sub-index is defined. It is called very strong heat stress event (VSHSE) and it is caused by the occurrence of 5 consecutive VSHS days. The VSHSE corresponds to heat wave event and provokes a severe biothermal discomfort, so it was used as an indicator of extremely unfavorable bioclimatic conditions (biothermal heat hazard). Along these lines, the VSHSE in Niš occurred during July in 1998, 2004, 2005, 2007, 2012 and 2015 where 7, 5 (on two occasions), 6, 10, 12 and 10 VSHS days in a row were recorded respectively (Table 4, VSHSE). In August, VSHSE was recorded on 5 VSHS days in a row in 1998, 1999, 2008, 2010, 2012 and 2017, while in 2000, 2012, 2013, 2015 and 2017 6, 6, 8, 7 and 6 VSHS days in a row were recorded respectively. It should be emphasized that there were two VSHSE events in 2012 and 2017, for each year 5 and 6 VSHS days in a row. September 2015 saw a VSHSE with 5 VSHS days in a row. According to Unkašević and Tošić (2009b) the highest temperatures in Niš ever were recorded during the summer of 2007 (44.2°C) and the summer of 2000 (42.5°C), covering the data period from 1948 to 2007. The VSHSE occurred in Novi Sad in July 2007 (7 VSHS days in a row), 2012 (6 VSHS days in a row) and 2015 (8 VSHS days in a row) and in August 2000 (7 VSHS days in a row), 2013 (8 VSHS days in a row), 2015 (6 VSHS days in a row) and 2017 (6 VSHS days in a row). In August 2012 VSHSE occurred twice and each time 5 VSHS days in a row were recorded. There was no sub-index VSHSE recorded in Zlatibor.

Discussion

Considering that the revised version has separated the results and the discussions, we need to point out the changes in the discussion section. According to the mention changes regarding Introduction chapter, we modified the paragraph followed by detailed recent studies (lines 47-58; lines 63-74; lines 77-94) and moved it into the discussion section (lines 479-494; lines 448-462; lines 463-469). More specifically, lines 47-58 have been moved into the discussion lines 479-494. In addition, lines 63-74 have been moved into the discussion lines 448-462, and there is an explanation of what a tropical day is (line 456-457) in the analysis by Unkasevic and Tosic (2009b). Lastly, lines 77-94 have been moved into the discussion section (lines 463-469).

The revised text is provided as follows:

Discussion

(lines 398-430) The assessment of human biothermal conditions during the summer made it possible to identify biothermal discomfort related to heat waves in Serbia. The results obtained in the study for the investigated period from 1998 to 2017, indicates the general increase in biothermal discomfort associated with heat waves defined by maximum air temperature above 35°C and UTCI “very strong heat stress” above 38°C.

The results obtained for morning, midday and average UTCI show significant occurrence of thermal heat stress during the summer months and increase in biothermal discomfort especially for $UTCI_{14h}$. This is confirmed by obtained distribution of the average monthly $UTCI_{14h}$ showing a significant increase in the extreme values of the

$UTCI_{14h}$ index in the last ten years, presented mainly as "very strong heat stress category" (VSHS) together with a growing trend of the $UTCI_{14h}$ index in all the summer months (especially September) for all three investigated weather stations (primarily in Niš). According to Di Napoli et al. (2018), there are two thermal climates in Europe. One of them is associated with heat stress condition and it is predominant in the southern part of Europe (including the Balkans) when moderate and strong heat stress occurs at central day time hours, which reflects the general relationship between heat load and insolation.

The increase in extreme biothermal conditions is the most evident in the number of days with maximum air temperature thresholds above 35°C, defined in the study as hot days (HD) and in the number of days with UTCI index thresholds between 38°C and 46°C, defined in the study as "very strong heat stress" (VSHS). Thus, most HDs (18 days) occurred in 2007 and then in 2012 (16 days), which means that more than half of July in these years was characterised by extremely high temperatures. Similar results about increase in daily maximum air temperature were obtained by Unkašević and Tošić (2011), when the record values of the maximum temperatures were observed for almost the whole territory of Serbia in 2007. As reported by Papanastasiou et al. (2014), the summer of 2007 was the warmest summer in Athens in the last hundred years. Besides, Spinoni et al. (2015) in their study compiled a list of the most severe drought events which occurred in Europe from 1950 to 2012. They singled out the Balkan countries as extreme weather and drought-prone areas (particularly Serbia) with the longest drought registered in 2007, and the most severe drought event in 2011. Moreover, in 2012 the Balkan Peninsula and the south-eastern Europe faced the hottest summer and one of the worst droughts in nearly 40 years (Unkašević and Tošić, 2015). This is in relation with the investigation of heat waves (a sequence of at least 5 days with maximum temperature above the 95th annual percentile) in south-eastern Europe, where there was an increase in the number of hot days for the period from 1973 to 2010. The $UTCI_{14h}$ category of "very strong heat stress" (VSHS) correlates with the maximum air temperatures and there has been an increase in the number of such days over the last ten years. Particularly severe biothermal discomfort occurred in 2007 (18 VSHS days) and 2012 (17 VSHS days). This is in agreement with the statement of Di Napoli et al. (2018) about UTCI reference value from the period between 1979 and 2016, when the UTCI at 12:00 (UTC) was about 0.5°C colder in the period between 1980 and 1999, while it was 0.5°C warmer in the period between 2000 and 2009 and 1°C warmer in the period between 2010 and 2016.

(lines 437-443) In this sense, there is a difference between the definition of biothermal heat stress and potential heat stress, defined on the basis of the interpretation of maximum temperatures. Determining extreme weather event from the aspect of human heat budget indices allows other meteorological parameters to be taken into account. Apart from temperature and humidity, wind and direct solar radiation, have been considered together with physiological metabolic rate.

The identified heat waves based on the threshold of the UTCI index correspond to the identified heat waves based on the threshold of maximum air temperatures. Furthermore, there is a significant increase in heat waves (HWE and VSHSE) plus duration of such events over the last ten years in Niš and Novi Sad, especially in Niš.

(lines 449-470) This agrees with the findings of Unkašević and Tošić (2011, 2015) that there has been a growing trend of heat waves in Serbia, especially since 2000. In order to justify the present research for the last 20 years, the earlier results related to the increase in heat waves will be discussed in more detail. In that regard, previous research into heat waves in Niš for the period from 1949 and 2007, based on the autoregressive-moving-average model, observed the warmest years during three periods, 1951-1952, 1987-1998 and 2000-2007 (Unkašević and Tošić, 2009b). According to this research, the longest heat wave was recorded in Niš in 1952, with 21 days, while in 2003, 29 consecutive tropical days were observed. It should be taken into account that according to the Serbian National Weather Service, tropical days are days with a maximum temperature over 30°C. Furthermore, based on Heat Wave Duration index (HWD) i.e. daily maximum values of air temperature, Drljača et al. (2009) determined the duration and strength of heat waves in Niš during the summer season. The analysis showed Niš with a greater number of heat waves compared to the larger urban area of Belgrade. As stated in the research, since the mid-1980s, heat waves have had a higher frequency and on average they have occurred every year. Prior to that period heat wave fluctuations were generally reported in one of two years (Niš during the summer) (Drljača et al., 2009). While studying the characteristics of the heat waves in central Serbia (1949-2007), Unkašević and Tošić (2011) detected an increase in heat wave duration, in addition to an increase in heat wave frequency of occurrence during the period from 1999 to 2007.

As regards the heat budget index of Heat Load (HL) in Serbia (July) for the period from 2000 to 2010, it was noticed that in, Niš, Zlatibor and Novi Sad the category of "extremely hot" occurred in 2000 and 2007 (Milovanović et al., 2017). As for the heat budget index Physiological Equivalent Temperature PET for the period from 1949 to 2012, the highest number of heat waves in Novi Sad was observed in the last two decades and in the first decade of the investigated period (Basarin et al., 2016), while the number of the days above particular thresholds for the period 1961-2014 shows an increase along with the number of heat waves per year since 1981. The highest values of mean annual PET were mostly detected during the last 15 years (Basarin et al., 2018).

(lines 477-505) The biothermal discomfort identified in July and August as the hottest summer months in Serbia, could provoke health disorders more frequently. Specific HWs characteristics such as intensity and duration have been found to have devastating effects on human health and wellbeing. In certain cases heat waves cause problems and children, elderly people, chronic patients and workers are particularly susceptible to them. The analysis of the UTCI index correlating with mortality in Europe shows that deaths occur in the southern Europe (Italy, Portugal, Greece, Spain) for the categories of moderate and strong stress. Heat load has an impact on increasing mortality as conditions become more thermally stressful (Di Napoli et al., 2018). The intensity of heat stress in Poland was assessed by means of the UTCI index on the basis of daily mortality and the weather data for the period from 1991 to 2000. There is an increase in mortality on 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 in southern Europe during the summer thresholds of Physiological Subjective Temperature (PST) increase when moving from the west to the east. The general finding is that the population of central Europe is more sensitive to thermal stimuli in the summer than the citizens in the south of the continent (Błażejczyk and McGregor, 2008). The statement about the PST index is in support of the comparison of UTCI index with other thermal indices, including PST index, which correlates very well with UTCI index (Błażejczyk et al., 2012). Human sensitivity to extreme heat weather can also be seen in the impact of heat waves on daily mortality in Belgrade during the summer, when the strong correlation between heat waves and daily mortality can be observed in July 2007 (Stanojević et al., 2014). Similarly, Bogdanović et al. (2013) reported a significant short-term excess mortality on 16th July in Belgrade, when the maximum daily temperature exceeded 35°C, leading to 167 excess deaths (38% increase compared to the number of expected deaths) for nine consecutive days of heat, with a progressive return to almost normal mortality as the maximum temperature dropped below 35°C on 25th July.

The application of the standardized bioclimatic heat budget index UTCI could help improve the understanding of biothermal conditions relative to heat wave. The daily $UTCI_{14h}$ heat stress becomes more extreme in terms of severity and heat wave duration up to very strong heat stress (VSHS). The biothermal indices investigated for the three weather stations follow the trend of general warming. 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). However, the human heat budget indices are increasingly serving as a determinant of extreme weather condition (Di Napoli et al., 2018; Matzarakis et al., 2018; Theoharatos et al., 2010; Urban and Kyselý, 2014). UTCI index improves the understanding of extreme thermal stress, serving as one of the criteria for initiating heat alerts about extreme thermal stress in Serbia.

Conclusion

We have made improvement in conclusion and revised text is provided as follows:

(lines 507-519) The present research of the human bioclimatic evaluation of UTCI thermal stress in Serbia is considered to be of great importance due to the identification of biothermal heat hazard and the study of the evolution of such indices regarding climate change. This evaluation aims at providing a comprehensive assessment of the human heat stress associated with UTCI index and heat waves defined by UTCI very strong heat stress and maximum air temperature.

The assessment of human biothermal conditions for the investigated period from 1998 to 2017 was provided for three synoptic stations – two urban (Niš and Novi Sad) and one station representing mountain areas of an altitude up to 1500 m (Zlatibor). All of them are located in different geographical areas in Serbia. The results obtained during the study indicate the significant increase in biothermal discomfort associated with heat waves defined by UTCI "very strong heat stress". It was found that the most frequent heat stress categories are "strong heat stress" (SHS) and "very strong heat stress" (VSHS) and they have occurred in all three locations with the tendency of increase in the number of days in the last decade. The VSHS describes an alarming biothermal state and has occurred frequently in the last ten years, particularly in Niš and Novi Sad. The outcome of the study is $UTCI_{14h}$ sub-index "very strong heat stress event" (VSHSE) as an indicator of biothermal heat hazard. Undoubtedly, heat waves (HWs) are one of the natural hazards with increasing impact in urban areas related to higher population density.

(lines 523-527) Considering these facts, it can be deduced that heat waves are becoming more frequent, stronger and longer. Thus, frequent heat waves since 2007 certainly indicate biothermal heat hazard. The more lasting events of bioclimatic discomfort will indicate more stressful bioclimatic conditions for human health and wellbeing. However, the results of the study highlight the importance of UTCI index as a bioclimatic indicator of biothermal hazard in Serbia particularly if it can serve as one of the criteria for initiating heat warnings in Serbia.

Reference

Considering that the revised version has significant changes the supplemented reference in the revised version is added as follows:

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English

With regard to English, all the spelling and grammatical errors have been corrected.

We look forward to hearing from you in due time regarding our submission and responding to any further questions and comments you may have.

Yours faithfully,

Milica Pecelj