THERMAL STRESS IN SELECTED MOUNTAIN SYSTEMS IN CENTRAL AND EASTERN EUROPE – INITIAL RESEARCH BASED ON UTCI CHARACTERISTICS

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Abstract
Mountain areas create specific features of local climates (by modification of air circulation, insolation, air temperature, precipitation, wind regime) and greatly affect ambient weather conditions which influence different kinds of human (climbing, skiing, walking, etc.). However, till now only few studies of human bioclimate in individual mountain ridges in Europe were done. The aim of the present study is to assess thermal stress features represented by Universal Thermal Climate Index (UTCI) in nine mountain systems in Central and Eastern Europe. 37 meteorological stations located at altitudes of 237-3580 m above sea level were considered. The data represent midday observational term and cover the period 2000-2017. Mean, highest and lowest annual thermal stress values and annual frequency of cold and heat stress days are analysed. The conducted studies have demonstrated that in the examined mountain systems thermal stress conditions are dependent (though to a various extent) mostly on altitude (UTCI values and heat stress days decrease and number of cold stress days rise significantly due to increase of altitude). However, impacts of latitude and longitude is well seen only in altitude belt of 300-1000 m a.s.l.

Key words
human bioclimate • UTCI • mountain tourism potential • Central Europe • Eastern Europe
Introduction

Mountains are important elements of regional and global climate systems. On the one hand they are influenced by global climate processes and on the other they modify air circulation, insolation, air temperature, precipitation and wind regime. Mountains are key areas for different kinds of human tourist and recreational activity (climbing, skiing, walking, etc.), which are greatly affected by ambient weather conditions. During the last decades tourist activity has been increasing all over the world. According to the United Nations World Tourism Organization, international arrivals have risen from 436 million in 1990 to 1401 million in 2018 (UNWTO, 2019). International tourism involves the necessity of sudden human adaptation to changed climatic conditions (de Freitas & Grigorieva, 2009; Błażejczyk & Vinogradova, 2014).

Due to their stimulating climate and attractive landscape, mountains are target areas for various groups of visitors both in warm and in cold seasons. Mountains have an important place in climatic and bioclimatic research because they significantly influence climate, not only of their own areas but also of their surroundings. They affect all meteorological variables (Trepińska, 2002; Migala, 2005; Niedźwiecki, 2012; Cheval et al., 2014; Spinioni et al., 2014; Rubel et al., 2017; Błażejczyk, 2019). Due to their elevation above sea level, mountains are a source of several modifications of various meteorological elements such as: air temperature (Baranowski, 2003b; Żmudzka, 2009, 2011; Dąbrowska & Guzik, 2015), precipitation (Sindosi et al., 2015; Khokhlovskih & Cebulskie, 2019), cloud cover, solar radiation and insolation (Baranowski, 2003a; Matzarakis & Katsoulis, 2006; Żmudzka & Kulesza, 2019), wind speed and direction (Baranowski, 1999; Błażejczyk, 2019) and atmospheric phenomena (Niedźwiecki, 2003, 2006; Błażejczyk, 2019). Important factors that also affect the mountainous climate are geographical position and orientation of mountain ridges while they influence all meteorological elements, mostly solar radiation, air temperature and precipitation (Hess, 1965; Smith, 2015; Błażejczyk & Skrynyk, 2019).

Lower temperature and higher wind speeds, which give a ‘wind-chill’ effect, cause the human body to be exposed to stronger thermal stress in those areas (Błażejczyk & Sitek, 2003; Błażejczyk et al., 2013). Some research underline the role of continentality in creating climate features in transitional areas, both in lowland and mountain regions (Ciaranek, 2014; Viček et al., 2016). A significant impact of continentality on thermal stress intensity in the northern Carpathians has been reported by Błażejczyk et al. (2020a, 2020b). They also found a strong influence of elevation above sea level and the exposure of a location (southward vs. northward) on UTCI values and frequency of thermal stress categories.

Up to now there have been only few papers presenting the biometeorological specificity of individual mountain areas in Europe (e.g. Gajc-Čapka & Zaninović, 1997; Głowicki, 2000; Harlinger et al., 2004; Zaninović et al., 2006; Miszuk, 2008; Endler et al., 2010; Endler & Matzarakis, 2011a, 2011b; Matzarakis et al., 2012; Błażejczyk et al., 2013, 2020a, 2020b; Milewski, 2013; Pecelj et al., 2017; Bokwa et al., 2019). Throughout the last century a large number of indices have been proposed to define bioclimatic conditions, which are (or were) in use worldwide. The most frequently used indices (e.g. PT, PET, SET, WCI, WCT, Humidex, HI, PST and many others) have been listed and discussed by Epstein and Moran (2006), Błażejczyk et al. (2012) and de Freitas and Grigorieva (2017). Temporal and spatial variability is one of the essential features of mountainous climate while people experience frequent changes of weather during a stay in mountains as reported by Zeng et al. (2020) for mountain regions of China-Pakistan border. Humans must adapt to changing weather stimuli. In general, an increase in differences in climate stimuli intensifies weather variability and the magnitude of adaptation processes in an organism (Jendritzky & de Dear, 2008).
These require to be prepared for changing weather stimuli during staying in any mountain (Miszuk et al., 2016; Acs et al., 2020).

There have been only few comparative studies of bioclimatic conditions in Europe (Błażejczyk & McGregor, 2007; Błażejczyk et al., 2010, 2015; Błażejczyk & Kunert, 2010; Błażejczyk & Błażejczyk, 2014; Acs et al., 2020). The authors have reported an influence of geographical location (longitude and latitude) on bioclimatic features of studied cities. Recently, Błażejczyk et al. (2020) have compared the suitability of bioclimatic weather features for outdoor tourism in three European countries: Poland, Serbia and Ukraine. While general features of climate (e.g. air temperature, precipitation, cloudiness) in different mountain systems are compared in many research (e.g. Trepínska, 2002; Migala, 2005; Spinoni et al., 2014; Błażejczyk & Skrynyk, 2019) then, there are no direct comparisons of the bioclimatic conditions in different mountain systems in Europe.

Therefore, the aim of the study is to present initial research dealing with the assessment of human bioclimate in different mountain systems in Central and Eastern Europe. While thermal features are of great importance of climate-tourism research the present paper concentrates on thermal stress in humans depending on elevation above sea level. The possible impact of geographical factors (latitude, longitude) is also discussed.

Materials and methods

The objects under study are nine mountain systems in Central and Eastern Europe (Fig. 1), namely: the Black Forest, northern Alps, central Alps, Sudetes, Western Carpathians, Eastern Carpathians, Dinaric Alps, Caucasus and southern Ural. In every area, depending on data availability, 3-7 meteorological stations were chosen. In total, 37 stations located at altitudes of 237-3580 m above sea level (m a.s.l.) were considered.

Figure 1. Mountain systems of Central and Eastern Europe considered in the research; explanations of abbreviations in Table 1

Source: own elaboration using map by San Jose – own map, based on the Generic Mapping Tools and ETOPO2, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=676986
### Table 1. Meteorological stations used in the study

| Mountain system (and abbreviation) | Name of station (and abbreviation) | Latitude (North) | Longitude (East) | Elevation (m a.s.l.) |
|-----------------------------------|------------------------------------|------------------|------------------|---------------------|
| Black Forest (Bf)                 | Freiburg (FRB)                     | 48°01'           | 7°48'            | 237                 |
|                                   | Freudenstadt (FRE)                 | 48°27'           | 8°24'            | 797                 |
|                                   | Feldberg (FEL)                     | 48°00'           | 8°00'            | 1490                |
| Northern Alps (A-N)               | Obersdorf (OBE)                    | 47°27'           | 10°18'           | 806                 |
|                                   | Garmisch-Partenkirchen (GAP)       | 47°29'           | 11°04'           | 719                 |
|                                   | Zugspitze (ZUG)                    | 47°24'           | 11°00'           | 2964                |
| Central Alps (A-C)                | Interlaken (INT)                   | 46°40'           | 7°52'            | 580                 |
|                                   | Jungfraujoch (JUN)                 | 46°33'           | 7°59'            | 3580                |
|                                   | Chur (CHU)                         | 46°52'           | 9°32'            | 556                 |
|                                   | Weissfluhjoch (WFJ)                | 46°50'           | 9°48'            | 2691                |
|                                   | Engelberg (ENG)                    | 46°49'           | 8°25'            | 1035                |
| Sudetes (S)                       | Kłodzko (KLO)                      | 50°27'           | 16°15'           | 356                 |
|                                   | Jelenia Góra (JEG)                 | 50°54'           | 15°48'           | 345                 |
|                                   | Śnieżka (SNI)                      | 50°44'           | 15°44'           | 1603                |
| Western Carpathians (W-C)         | Zawoja (ZAW)                       | 49°37'           | 19°31'           | 720                 |
|                                   | Krynica (KRY)                      | 49°25'           | 20°58'           | 595                 |
|                                   | Zakopane (ZAK)                     | 49°17'           | 19°57'           | 857                 |
|                                   | Hala Gąsienicowa (HAG)             | 49°14'           | 20°00'           | 1520                |
|                                   | Lomnicky Stit (LOS)                | 49°12'           | 20°13'           | 2635                |
| Eastern Carpathians (E-C)         | Lviv (LVI)                         | 49°48'           | 23°58'           | 319                 |
|                                   | Kolomya (KOL)                      | 48°32'           | 25°03'           | 298                 |
|                                   | Pozhyzhevska (POZ)                 | 48°09'           | 24°32'           | 1451                |
|                                   | Rakhip (RAK)                       | 48°02'           | 24°11'           | 431                 |
| Dinaric Alps (Da)                 | Bugoyno (BUG)                      | 44°03'           | 17°27'           | 562                 |
|                                   | Sarayevo (SAR)                     | 43°52'           | 18°25'           | 630                 |
|                                   | Livno (LIV)                        | 43°42'           | 17°00'           | 724                 |
|                                   | Ivan-Sedlo (IVS)                   | 43°45'           | 18°02'           | 967                 |
|                                   | Byaleshnica (BYA)                  | 43°42'           | 18°15'           | 2067                |
|                                   | Vranje (VRA)                       | 42°33'           | 21°55'           | 435                 |
|                                   | Zlatibor (ZLA)                     | 43°44'           | 19°43'           | 1030                |
| Caucasus (C)                      | Kislovodsk (KIS)                   | 43°54'           | 42°43'           | 943                 |
|                                   | Zelenchukskaya (ZEL)               | 43°52'           | 41°34'           | 928                 |
|                                   | Krasnaya Poljana (KRP)             | 43°41'           | 40°12'           | 566                 |
|                                   | Kluchovski Pereval (KLP)           | 43°15'           | 41°50'           | 2037                |
| Southern Ural (U-S)               | Ekaterinburg (EKA)                 | 56°50'           | 60°38'           | 281                 |
|                                   | Tukan (TUK)                        | 53°52'           | 57°25'           | 551                 |
|                                   | Verhneuralsk (VER)                 | 53°53'           | 59°12'           | 401                 |

Sources of meteorological data:
1 https://opendata.dwd.de/climate_environment/CDC/
2 www.meteo.ch
3 https://dane.imgw.pl/data/dane_pomiarowo_obserwacyjne/
4 Slovak Hydrometeorological Institute (not available on-line)
5 Ukrainian Hydrometeorological Institute (not available on-line)
6 Federal Hydrometeorological Institute of Bosnia and Herzegovina (not available on-line)
7 http://www.hidmet.gov.rs/latin/meteorologija/klimatologija_godisnjaci.php
8 http://meteo.ru/english/climate/thmo.php
In every mountain system the used stations show changes in thermal stress from their foothill up to the most elevated locations (Tab. 1). For every station daily meteorological data for the midday observational term were taken to calculate the Universal Thermal Climate Index. The data represent: air temperature, relative humidity, total cloud cover and wind speed at 10 m above ground. The data cover the period 2000-2017. While meteorological data were taken from meteorological services (Tab. 1) with different observational systems the common time for midday term occurs at 1 p.m. of local time.

To analyse thermal stress the Universal Thermal Climate Index (UTCI, Bröde et al., 2012; Fiala et al., 2012) was used. The UTCI is derived from the UTCI-Fiala model and is defined as the air temperature of the reference condition causing the same model response (understood as sweat production, shivering, skin wettedness, skin blood flow and rectal, face and mean skin temperatures) as the actual conditions. The model response is indicative of the physiological and thermoregulatory processes which are characteristic of the human reaction to neutral, moderate and extreme thermal conditions. The UTCI values are categorised in 10 classes (Tab. 2). To calculate UTCI, the BioKlima 2.6 software package was used (www.igipz.pan.pl/geoeoklimat/blaz/bioklima.htm). The present research analyses the average (UTClavg), lowest (UTCImin) and highest (UTCImax) annual UTCI values and the frequencies of days with cold stress (CS_days, UTCI < -13°C) and heat stress (HS_days, UTCI > 32°C). The analysis concerns spatial distribution of thermal stress characteristics as well as their relationships to altitude.

![Table 2. UTCI equivalent temperature categorized in terms of thermal stress](image)

| UTCI [°C] range | Thermal stress category | Physiological responses |
|-----------------|-------------------------|-------------------------|
| > 46.0          | extreme heat stress     | Increase in rectal temperature (Tre) time gradient. Steep decrease in total net heat loss. Averaged sweat rate > 650 g/h, steep increase. |
| 38.1 to 46.0    | very strong heat stress | Core to skin temperature gradient < 1K (at 30 min). Increase in Tre at 30 min. |
| 32.1 to 38.0    | strong heat stress      | Dynamic Thermal Sensation (DTS) at 120 min > +2. Averaged sweat rate > 200 g/h. Increase in Tre. Instantaneous change in skin temperature > 0 K/min. |
| 26.1 to 32.0    | moderate heat stress    | Moderate increase in sweat rate, Tre and skin temperature: mean (Tskm), face (Tskfc), hand (Tskhn). Occurrence of sweating. Steep increase in skin wettedness. |
| 9.1 to 26.0     | no thermal stress       | DTS between -0.5 and +0.5 (averaged value). Latent heat loss > 40 W. Plateau in Tre time gradient. |
| 0.1 to 9.0      | slight cold stress      | DTS < -1. Local minimum of Tskhn (use gloves). |
| -13.0 to 0.0    | moderate cold stress    | DTS < -2. Vasoconstriction. Averaged Tskfc < 15°C (pain). Decrease in Tskhn. Tre time gradient < 0 K/h. Face skin temperature < 15°C (pain). Tmsk time gradient < -1 K/h. |
| -27.0 to -13.1  | strong cold stress      | Averaged Tskfc < 7°C (numbness). Tre time gradient < -0.1 K/h. Increase in core to skin temperature gradient. |
| -40.0 to -27.1  | very strong cold stress | Tskfc < 0°C (frostbite). Steeper decrease in Tre. Tskfc < 7°C (numbness). Occurrence of shivering. Tre time gradient < -0.2 K/h. |
| < -40.0         | extreme cold stress     | Tre time gradient < -0.3 K/h. Tskfc < 0°C (frostbite). |

Source: adapted from Błazejczyk et al. (2010) and Bröde et al. (2012)
longitude and latitude of a station. Altitudinal gradients of UTCI characteristics were calculated for individual mountain systems.

Results of previous research (e.g. Hess, 1965; Rubel et al., 2017; Błajejczyk et al., 2020a) suggest that air temperature strongly depends on altitude. Thus, the UTCI changes due to longitude and latitude were analysed for the groups of stations located in relatively narrow altitudinal belts, namely: 300-500, 600-750, 800-1000, 1450-1600 and 2650-2950 m a.s.l. The correlation coefficients of analysed relations were classified as follows: < 0.2 – very weak, 0.2-0.39 – weak, 0.4-0.59 – moderate, 0.6-0.79 – strong and ≥ 0.8 – very strong. The STATGRAPHICS Centurion XVI software package was used to verify statistical significance of relationships between altitude and UTCI characteristics.

Results
Spatial variability of thermal stress characteristics

Due to the broad geographical and altitudinal scope of the mountain stations studied, distinct spatial differentiation may be observed in the thermal stress characteristics. The lowest UTCIavg and UTCImin values are seen in stations located high above sea level (ZUG, JUN, SNI, LOS, BYA). The lowest thermal stress is recorded in stations at the feet of the mountain ranges in question (Tab. 3). Considering all studied stations a distinct decrease in UTCI values may be observed with the increase in altitude (Fig. 2). For average UTCI values, altitudinal gradient (dUTCIAvg) is -1.03°C per 100 m of elevation (the correlation coefficient r between altitude and UTCIAvg is -0.78 and is statistically significant at significance level, SL = 99%). For UTCImin, altitudinal gradient (dUTCImin) is equal to -1.23°C/100 m (r = -0.68, SL = 99%), and for UTCImax, -0.72°C/100 m (r = -0.89, SL = 99%). In the Caucasus, UTCI values are distinctly higher than in the remaining systems (Tab. 3) what can be caused by very south-eastern location opened to frequent advection of dry subtropical air masses. While altitudinal gradient of UTCImin is higher than gradients for UTCIAvg and UTCImax the correlation coefficient is the lowest. This is mostly seen at elevations < 1000 m a.s.l. Inside this altitudinal belt coline relief dominates (Rubel et al., 2017) and stations are situated in very different locations (bottoms of valleys, slopes with various elevation above bottoms). It cause great vulnerability to orographical cooling of air which affect also thermal stress conditions.

With height above sea level, the number of cold stress days increases (Fig. 2) on average by 6.6 days/100 m (r = 0.77, SL = 99%). In the summit areas of the Alps, Carpathians and Dinaric Alps, there are over 185 such days per year. In the Caucasus cold stress days are rare, even at elevated stations. The number of heat stress days decreases on average by 0.53/100 m (r = -0.46, SL = 99).

Figure 2. UTCI annual values (left panel) and frequency of different thermal stress categories: CS – cold stress days, HS – heat stress days (right panel) in Central and Eastern European mountain systems as a function of altitude
Table 3. Annual characteristics of UTCI, 2000-2017

| Mountain system     | Station | Annual UTCI values | Annual frequency of selected UTCI categories |
|---------------------|---------|--------------------|----------------------------------------------|
|                     |         | average (UTCavg)   | lowest (UTCImin)    | highest (UTCImax) | cold stress (CS_days) | heat stress (HS_days) |
| Black Forest        | FRB     | 12.3               | -28.9             | 43.0             | 6.2                   | 19.2                 |
|                     | FRE     | 5.3                | -36.7             | 36.1             | 40.3                  | 2.7                  |
|                     | FEL     | -8.8               | -61.1             | 30.6             | 144.6                 | .                    |
| Northern Alps       | OBE     | 11.5               | -25.9             | 37.7             | 4.1                   | 6.7                  |
|                     | GAP     | 12.1               | -25.8             | 38.9             | 2.6                   | 6.3                  |
|                     | ZUG     | -18.8              | -65.1             | 22.7             | 223.5                 | .                    |
| Central Alps        | INT     | 12.8               | -23.3             | 35.8             | 2.9                   | 2.7                  |
|                     | JUN     | -19.3              | -68.7             | 17.5             | 216.7                 | .                    |
|                     | CHU     | 11.5               | -26.3             | 38.7             | 7.5                   | 5.2                  |
|                     | WJF     | -7.7               | -60.3             | 24.2             | 127.1                 | .                    |
|                     | ENG     | 9.9                | -30.6             | 32.3             | 5.7                   | 0.1                  |
| Sudetes             | KLO     | 6.8                | -42.3             | 38.2             | 35.3                  | 5.4                  |
|                     | JEG     | 7.7                | -30.9             | 39.1             | 23.0                  | 5.2                  |
|                     | SNI     | -18.3              | -64.3             | 26.1             | 210.6                 | .                    |
| Western Carpathians | ZAW     | 10.9               | -32.0             | 40.1             | 12.2                  | 7.9                  |
|                     | KRY     | 9.2                | -49.9             | 36.8             | 20.7                  | 6.2                  |
|                     | ZAK     | 8.6                | -27.8             | 37.2             | 13.2                  | 2.2                  |
|                     | HAG     | 0.4                | -52.1             | 30.1             | 64.0                  | .                    |
|                     | LOS     | -15.6              | -66.4             | 23.3             | 191.3                 | .                    |
| Eastern Carpathians | LVI     | 7.6                | -38.9             | 39.2             | 38.7                  | 9.8                  |
|                     | KOL     | 10.2               | -45.0             | 40.8             | 21.2                  | 17.8                 |
|                     | POZ     | -1.5               | -61.1             | 33.6             | 90.6                  | 0.2                  |
|                     | RAK     | 12.4               | -36.4             | 41.6             | 9.6                   | 21.9                 |
| Dinaric Alps        | BUG     | 16.0               | -26.4             | 43.8             | 4.1                   | 41.8                 |
|                     | SAR     | 15.7               | -24.1             | 43.9             | 2.2                   | 37.5                 |
|                     | LIV     | 15.5               | -33.1             | 44.3             | 5.1                   | 38.9                 |
|                     | IVS     | 12.3               | -36.3             | 40.0             | 10.8                  | 19.7                 |
|                     | BYA     | -14.7              | -65.4             | 30.4             | 185.1                 | .                    |
|                     | VRA     | 14.6               | -44.7             | 45.6             | 15.8                  | 42.6                 |
|                     | ZLA     | 12.8               | -27.8             | 39.0             | 7.4                   | 16.6                 |
| Caucasus            | KIS     | 13.4               | -40.5             | 40.2             | 6.5                   | 14.4                 |
|                     | ZEL     | 15.2               | -30.9             | 42.4             | 2.8                   | 23.6                 |
|                     | KRP     | 16.2               | -13.9             | 41.3             | 0.1                   | 26.5                 |
|                     | KLP     | 10.1               | -35.5             | 34.6             | 9.7                   | 0.9                  |
| Southern Ural       | EKA     | -0.2               | -48.9             | 38.1             | 101.3                 | 5.2                  |
|                     | TUK     | 4.9                | -39.5             | 38.7             | 59.4                  | 8.7                  |
|                     | VER     | 1.6                | -52.2             | 38.0             | 91.4                  | 6.5                  |

Dot (.) indicate that heat stress days are not observed.
It should however be noted that in most stations above 1400 m a.s.l. such days practically do not occur. The exception is the Caucasus, the most south-eastern mountain system, where HS_days are recorded on average on 1 day per year (Tab. 3).

**Altitudinal gradients in individual mountain systems**

Altitudinal gradients of UTCI in the mountain systems studied differ. In the case of UTCI_avg values, the altitudinal gradient varies from -0.4°C/100 m in the northern Caucasus (r = -0.96, SL = 99%) to -1.9°C/100 m in the Dinaric Alps (r = -0.95, SL = 99%) and -2.0°C/100 m in the Sudetes (r = -0.99, SL = 95%). These gradients have statistical significance of at least 95%. In the area of Alpine and northern Carpathian ranges, UTCI_avg altitudinal gradients are similar to each other and vary from -1.0 in the eastern Carpathians (r = -0.92, SL = 90%) to 1.4°C/100 m in the northern Alps (r = -0.99, SL 95%) (Fig. 3).

Lowest UTCI values decrease with altitude more distinctly than average values: from -1.5°C/100 m in the Western Carpathians and in central Alps to -2.0°C/100 m in the Dinaric Alps. Higher values of dUTCI_min were calculated for the Sudetes (-2.2°C/100 m) and the Black Forest (-2.6°C/100 m), and lower ones, for the Caucasus (-1.0°C/100 m); however, they are not statistically significant. The smallest altitudinal gradients were seen for UTCI_max and in each mountain system they are statistically significant. They varied from -0.5 in the Caucasus to -1.0°C/100 m in the Sudetes and Black Forest (Fig. 3).

The frequency of cold stress days and heat stress days also change with altitude. In the case of cold stress, altitudinal gradient (dCS) increases from around 5.9 days/100 m in the

**Figure 3.** Altitudinal gradients (°C/100 m) of various UTCI values in studied mountain systems; circles filled in orange indicate insignificant values

**Figure 4.** Altitudinal gradients of cold stress (CS) and heat stress (HS) frequency; circles filled in orange indicate insignificant values
Eastern Carpathians to 12.7 days/100 m in the Sudetes. Only in the Caucasus is dCS statistically insignificant. As mentioned before, the number of heat stress days’ decreases with altitude (from -0.12 in the central Alps to -1.71 days/100 m in the Caucasus), but in most of the studied mountain ranges dHS are statistically insignificant or weakly significant (Fig. 4).

**Changes of UTCI due to latitude and longitude**

Latitude is geographical factor that impacts thermal and radiative features of climate and longitude influence mainly frequency of oceanic and continental air masses with different features of temperature and humidity. Relatively narrow extent of latitude and longitude of examined mountain systems allowed only for initial analysis of possible impacts of geographical location of stations on UTCI characteristics. Thus, to eliminate evident influence of elevation a.s.l. such impacts were studied separately within 5 narrow altitudinal belts (Tab. 4).

Within altitudinal belt of 300-500 m a.s.l. 7 stations quite well represent wide spectrum of latitude (42.6-53.9°N) and longitude (15.8-59.2°E). There is very distinct (indicated by strong and very strong correlation coefficients) decrease in UTCImax, UTCIavg and frequency of HS_days from southern to northern locations. On the other hand number of CS_days increase when moving from south to north. Considering longitudinal changes of UTCI the strong decrease in UTCImax and very strong increase in CS_days is observed when moving from west to east. Weak or very weak correlation was found for latitude vs. UTCImin and longitude vs UTCImax and HS_days. While in this belt meteorological stations are situated mainly in valleys’ bottoms and lower parts of slopes weak correlation is perhaps caused by impacts of another factors like slope exposure or occurrence of cold air lakes in valleys.

6 stations within belt of 600-750 m a.s.l. cover latitudes from 43.7 to 49.6°N and longitudes from 7.9 to 21.0°E. Increase in latitude caused strong and very strong decrease in UTCImax, UTCIavg and HS_days.

| Altitudinal belt [m a.s.l.] | Number of stations | UTCImin | UTCIavg | UTCImax | CS_days | HS_days |
|----------------------------|--------------------|---------|---------|---------|---------|---------|
| Latitude vs. UTCI characteristics |
| 300-500                    | 7                  | -0.311  | -0.935  | -0.959  | +0.723  | -0.935  |
| 600-750                    | 6                  | -0.491  | -0.971  | -0.720  | +0.707  | -0.860  |
| 800-1000                   | 8                  | +0.324  | -0.837  | -0.656  | +0.501  | -0.890  |
| 1450-1600                  | 4                  | -0.179  | -0.644  | -0.887  | +0.469  | .        |
| 2650-2950                  | 3                  | -0.816  | -0.454  | -0.331  | +0.409  | .        |

| Longitude vs. UTCI characteristics |
| 300-500                    | 7                  | -0.744  | -0.632  | -0.281  | +0.869  | -0.172  |
| 600-750                    | 6                  | -0.663  | -0.167  | +0.416  | +0.667  | +0.356  |
| 800-1000                   | 8                  | -0.362  | +0.713  | +0.777  | -0.417  | +0.689  |
| 1450-1600                  | 4                  | +0.279  | +0.528  | +0.423  | -0.532  | .        |
| 2650-2950                  | 3                  | -0.738  | -0.339  | -0.210  | +0.291  | .        |

Correlation coefficient:
- very weak
- weak
- moderate
- strong
- very strong

**Table 4. Correlation coefficients between latitude and longitude and various UTCI characteristics**

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Strong correlation is also noted for increased trend in CS_days due to latitude increase. Impact of longitude on UTCI characteristics is weak or very weak. Only for UTCImin and CS_days correlation is moderate.

8 stations characterise changes in UTCI within altitudinal belt of 800-1000 m a.s.l. They are located within latitude of 43.7-49.3°N and longitude of 8.4-42.7°E. Strong and very strong correlation is observed for majority of UTCI characteristics: decrease of UTCI\text{max}, UTCI\text{avg} and HS days due to rise of latitude as well as increase of the same measures due to longitude. Correlation for UTCI\text{min} and CS_days is rather weak.

Geographical extent of 4 stations situated within altitudinal belt of 1450-1600 m a.s.l. is very narrow (48.0-50.7°N in latitude and 8.0-24.5°E in longitude). Thus UTCI trends observed in this belt are only initial. Strong and very strong negative correlation was found for relations between latitude and UTCI\text{max} and UTCI\text{avg}. For longitude correlations are mostly weak and very weak.

Small number of station within belt of 2650-2950 m a.s.l. (only 2 in Alps and 1 in Western Carpathians) allows for very preliminary analysis. Only UTCI\text{min} shows strong and very strong negative dependence from increasing values of latitude and longitude. This suggests that lowest values of UTCI decrease when moving to north and to west.

**Discussion**

Research of mountain climate provide important information about specific spatial changes of particular meteorological elements. Many research refer decrease of air temperature due increase of elevation above sea level (Głowicki, 2000; Trepínska, 2002; Migala, 2005; Cheval et al., 2014; Błażejczyk, 2019; Łupikasza & Szy pulp, 2019). However, such decrease has different intensity in concave and convex forms of relief and in dependence of slope exposure (Hess, 1965). While UTCI strongly depend on air temperature the vertical differentiation of thermal stress is also evident. For northern Carpathians Błażejczyk et al. (2020a) have found significant changes of UTCI due to elevation a.s.l. However, the changes have different intensity at northward and southward slopes. They also reported great influence of air circulation on thermal stress in Carpathians (Błażejczyk et al., 2020b). It seems that exposure of mountain systems to different air circulation patterns can be one of causes of different altitudinal UTCI gradients in regions considered in this paper.

However, the common feature of mountain systems is acceleration of cold stress or cold thermal sensation according to increase of altitude (Harlfinger et al., 2004; Zaninović et al., 2006; Miszuk, 2008; Endler et al., 2010; Pecelj et al., 2017). This feature is of great importance in assessing touristic and recreational potential of mountain areas (Miszuk et al., 2016; Acs et al., 2020). The increasing cold stress in elevated locations is a handicap for active tourism (climbing, jogging etc.) with reduced risk of organism overheating involved by great metabolism. On the other hand cold stress at elevated locations, accelerated by strong winds, is unsuitable for passive recreation forms like sun and air bathing (Błażejczyk & Sitek, 2003; Błażejczyk & Kunert, 2010; Miszuk et al., 2016; Błażejczyk et al., 2020).

In present research we have found different patterns of latitudinal and longitudinal changes of various thermal stress characteristics. While in lower altitudes UTCI gradients have similar directions as those observed by Błażejczyk and Błażejczyk (2014) than in elevated locations such changes are less visible. It seems, that thermal stress at high summits is mostly affected by elevation and not by geographical location. However, this point needs detail research in the future with the using of extended number of summit stations located in different locations.

Altitudinal changes in thermal stress referred in present paper are in accordance with research of climate zonation of mountain areas done by Hess (1965) for Western Carpathians, Niedźwiedź (2012) for Eastern Carpathians and by Rubel et al. (2017) for Alps.
Conclusions

This paper presents initial results of research on bioclimatic conditions in the mountains of Europe. We considered here only one feature of bioclimate, i.e. thermal stress. The picture of altitudinal impacts on thermal stress is clear (decreasing of UTCI values and heat stress frequency as well as rise of cold stress days due to increase of altitude) but differs between mountain systems.

Impact of latitude and longitude on thermal stress in elevated parts of mountains is not so evident as altitude. To solve this problem there is necessary to broaden the data base, particularly for elevated locations (high ridges and summits).

Our research shows significant differences in thermal stress characteristics between various mountain systems. To explain them the detail analysis of seasonal features of bioclimate are necessary, including air circulation variability.

The paper presents only the average annual thermal stress characteristics. Future studies should also cover seasonal and daily variability of bioclimatic conditions. This will allow for complex assessment of mountainous areas with respect to various practical human needs, chiefly tourism and recreation.

Editors’ note:
Unless otherwise stated, the sources of tables and figures are the authors’, on the basis of their own research.

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