ARTICLES

# HORIZONTAL AIR TEMPERATURE CHANGES AS A BASIS FOR THE REGIONAL CLIMATE DIFFERENTIATION OF BOSNIA AND HERZEGOVINA

*AUTHORS*

***Nusret Drešković, Ranko Mirić***
*Department of Geography, Faculty of Science, University of Sarajevo,*
*Zmaja od Bosne 35, 71 000 Sarajevo, Bosnia and Herzegovina,*
*e-mail:nusret2109@gmail.com; rmiric@gmail.com*

*UDK: 913:551.585(497.6)*

*ABSTRACT*
***Horizontal air temperature changes as a basis for the regional climate differentiation of Bosnia and Herzegovina***
*General natural environmental characteristics of Bosnia and Herzegovina and of some of its regions are defined on a full annual level primarily by the influences of different physical and geographical elements and factors whose modifying influence is defined by highly complex mutual relationships existing within a number of various spatial and temporal scales. This paper presents the basic quantitative and qualitative characteristics of horizontal and altitudinal changes of air temperature as the basis for the spatial thermo-climatic differentiation of Bosnia and Herzegovina into its continental and Mediterranean regions. The conducted analyzes and the interpretation of general physical-conditions determining the spatial position of the aforementioned thermic limit have used a GIS spatial thermic model and the longitudinal and transverse thermic profiles as a basis for defining the horizontal temperature changes.*

*KEY WORDS*
*air temperature, Bosnia and Herzegovina, horizontal change, altitudinal change, spatio-temporal dynamics, climatic and thermic limits, GIS thermic spatial model*

## 1. Introduction

Air temperature is a basic meteorological element in the climatological spatial explorations whose intensity suggests the fluctuation in the overall heat balance across different geographical areas or regions, and thus defines the basic environmental characteristics of these areas and regions. For the purpose of studying the climate within the operating range of this paper, we have analyzed the annual flow of air temperature in the horizontal and vertical directions based on a number of average mean monthly and extreme values.

In order to define the qualitative and qualitative thermic characteristics, the use of GIS kriging spatial interpolation analyzer has helped us develop the spatial thermic models for Bosnia and Herzegovina for the mid-January and mid-July monthly air temperatures and the mean annual temperature.

These spatial models have been developed by using the temperature data collected at a network of the main and supporting (hypothetical) temperature stations with the validation of the analyzed data done by using the Digital Elevation Model (DEM) for Bosnia and Herzegovina with 20-meter resolution (Figure 1).

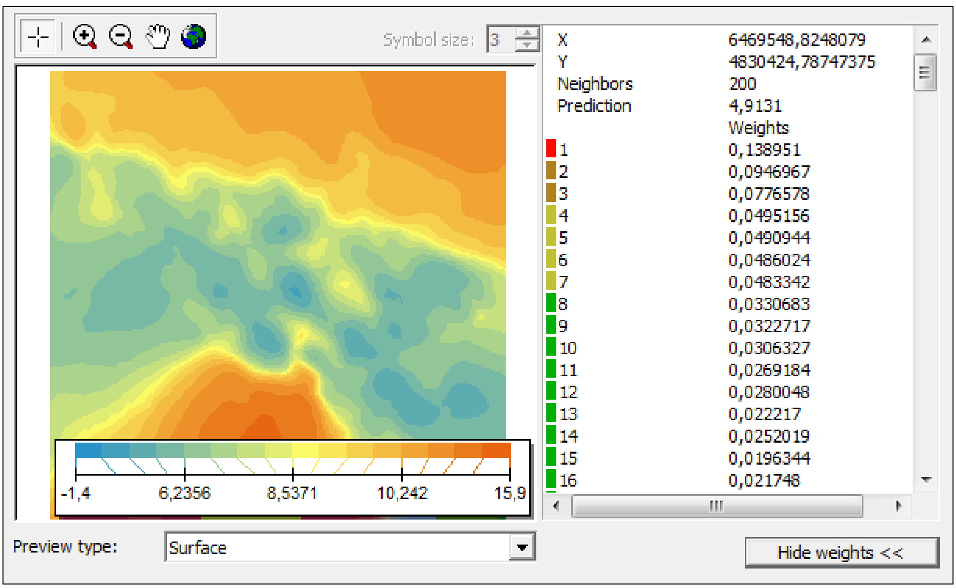


***Figure 1.*** *Kriging search of interpolation neighbourhood is based on a maximum of 200 neighbouring locations including: the values of the weighted means in the neighbouring locations; the constructed surface of the thermic models by using the data collected about the mean annual temperatures at the main and supporting networks of temperature stations in Bosnia and Herzegovina.*

The figure above shows a Kriging method of default surface interpolation of data about the mean annual air temperatures, which is based on two subprocessing methods. The first sub-processing method is the **basic** subprocessing method, which is based on searching through the vicinity of 200 (maximum defined) locations of the temperature stations and the use of data about air temperatures. The second subprocessing model is the **validation** subprocessing model. In the climate modelling, the latter model is used for a series of interpolation searches that define the vertical thermic gradient, or in other words, it assigns to each grid cell the temperature value based on the ratio defining the relation between the air temperature and altitude of the basic and neighbouring temperature stations.

By using the above mentioned GIS-based concept of modelling we have obtained the spatial thermic models of high precision for the mean annual, or January and July, average monthly air temperatures in the GRID format. Having in mind that the validation analysis (as already mentioned above) has used the DEM of 20-meter resolution, the output thermic models for Bosnia and Herzegovina have thus been developed in the same resolution. This methodological approach has been implemented by using ArcGIS software and with the appropriate hardware support (of very high performance level), considering that the said subprocessing methods have been applied on practically a multi-million item database.

Through an analysis of the entire geodatabase of the thermic model for annual temperature, we have obtained the information that the mean annual air temperature for the territory of Bosnia and Herzegovina is about 10.9 °C, although there are significant differences at the level of two existing climate zones. More specifically, in the area of the northern temperate climate zone, the value of the average annual temperature is about 9.7 °C, while in the Mediterranean climate zone this value amounts to 12.1 °C. Thermic contrasts are very sharp, considering that the average annual temperature in the zones of the highest mountain peaks in the highlands of South-eastern Bosnia are negative and amount to -1.4 °C (top of Mount Maglić), while in the zone of the coastal belt of Neum it is about 15.9 °C. It should be noted that the above temperature difference of nearly 18.0 °C has been observed at a horizontal distance of only 85.5 km *as the crow flies* (top of Mount Maglić – Župa Bay), i.e. about 0.21 °C/km, which is more than 30 times higher compared with the average horizontal temperature change in the Northern Hemisphere (Spahić, 2002). The above climatological peculiarity is the result of morphological and morphometrical relationships, since the average slope gradient in the above-mentioned profile is approximately 30 m/km.

Compared with the Mediterranean climate zone, the thermic contrasts in the continental climate zone are somewhat less striking, since the temperature difference at the level of average annual temperatures is a bit lower – about 16 °C. The horizontal temperature decrease is about 0.07 °C/km, with the average slope gradient that is less pronounced – about 12.9 m/km

## 2. Horizontal and vertical temperature change in Bosnia and Herzegovina

A very illustrative indicator of horizontal temperature change in Bosnia and Herzegovina are its changes throughout the transversal and longitudinal profile. For this purpose, the lines have been designed for two temperature profiles in the thermic model for the mean annual air temperatures (see Figure 3):

- Mali Ston channel – the estuary of the Drina River into the Sava River – a transversal profile (Figure 1);
- Mount Maglic – the river Glina (Ponikva village) – a longitudinal profile (Figure 2).

Both profile lines have been designed (as already mentioned) on the basis of the thermic model of very high resolution (a 20-meter GRID) which is why these profiles are very detailed and present all the changes of temperature on the cell size of 20m x 20m.

This fact explains the very strong thermic fluctuations on the diagram lines, which have not been further levelled out statistically for the reasons of achieving a genuine representativeness. The transversal thermic profile has been outlined from the centre of the Mali Ston channel and it continues throughout to the Neum Bay and the hinterland (Mount Žaba), Hutovo Blato, Dubrava plateau, Mount Velež, the north-western slopes of Mount Crvanj, Mount Visočica, the western slopes of Mount Bjelašnica and Mount Igman, Mount Trebević, Sarajevo, Mount Ozren and Mount Bukovik, the western slopes of Mount Šljemenska Kosa and Mounts Javor and Javornik, the Spreča River Valley, Mount Majevica, the Sapna Valley, the highlands of Visoka Glava, Bijeljina and Brodac all the way up to the Drina River estuary into the Sava River. The total length of air line profile is about 262.5 kilometres, with the length of the topographic profile much higher. (Figure 2).

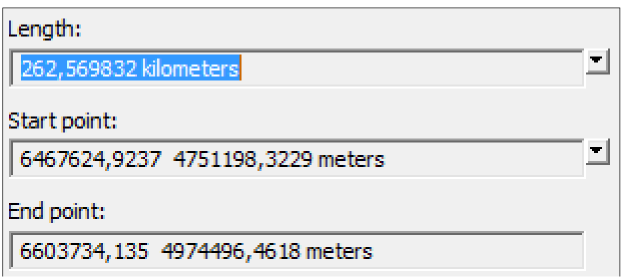


***Figure 2.*** *Mathematical-cartographic indicators for temperature profile 1.*

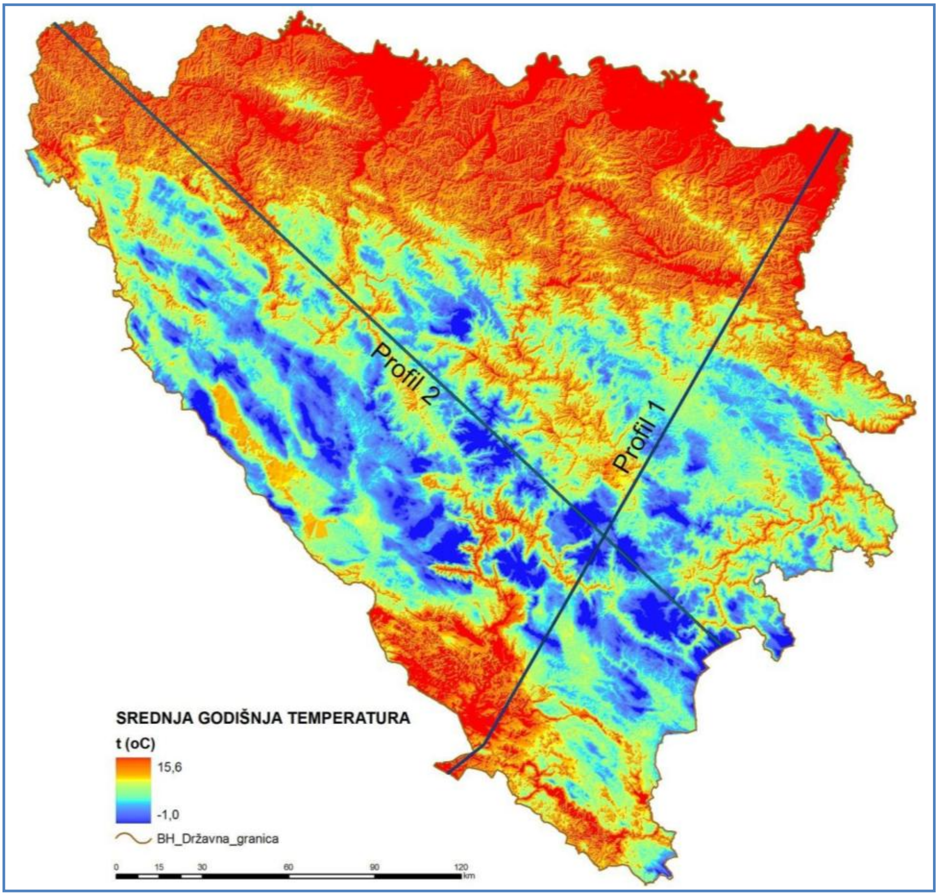


*Figure 3. Horizontal change of mean annual air temperatures in Bosnia and Herzegovina in the transversal (profile 1) and longitudinal (profile 2) temperature profiles.*

The enclosed diagram for the transversal profile can be used to determine the average variation of air temperature across the profile zone within the range from 3,0 °C to 15,5 °C, which is quite representative, considering that the profile line has been laid to the west of the zone of the Southeast Bosnian Highlands (Figure 4.). One of the main conclusions that can be drawn from the analyzed diagram is that the profile line generally takes the opposite form compared with the morphological and morphometric changes in the relief of the area through which the profile zone is passing. More specifically, the already presented theoretical views cab be fully validated with regard to the profile concerning the drop in the mean annual temperatures that occurs with the increase of the altitude in the whole territory of Bosnia and Herzegovina by an average of about 0.55 °C/100m, so that the higher hypsometric levels correspond to the lower temperatures and vice versa.


***Figure 4.*** *Transversal thermic profile: Mali Ston channel – Drina River Estuary into Sava River*


***Figure 5.*** *Longitudinal thermic profile: Maglić – Ponikve (Glina River)*

The longitudinal thermic profile position covers the area northwest of the top of Mount Maglić, through Mount Trebova, Mount Lelija, Mount Treskavica, Mount Bjelašnica, Zujevina River valley, the north-west slopes of Mount Bitovnja, Mount Pogorelica, Mount Zec and Mount Vranica, Mount Radovan, Mount Komar, the south-western slopes of Mount Radalj, the town of Jajce, Pliva Lakes, the town of Mrkonjić Grad, Mount Manjača, the valley of the Sana River (near the village of Donje Sokolovo) and further down southwest of the town of Sanski Most, Mount Majdan, the valley of the Una River (near the village of Ivanjska), Mašena Glavica, the Bužimica River valley (near the village of Čaglić), Gladno Brdo down to the valley of the Glina River (near the village of Ponikve). Since this profile line extends towards the direction of the Dinarid mountain range across Bosnia and Herzegovina, its air length is longer and amounts to about 317km (Figure 6). The general characteristics of the temperature profile are conceptually fully in line with the views presented with regard to the previous profile. The only difference is in the amplitude of temperature variation considering that it is somewhat higher with regard to the longitudinal profile zone and ranges from 1.5 °C to 14.5 °C. Indeed it should be noted that this is partly due to the fact that the profile line of this profile is not connected with the very top of Mount Maglić but is positioned northwest of it, which has resulted in a variation that has been reduced by about 1.0 °C. It is also important to stress that there are some differences when it comes to the trend of spatial air temperature change from one to another part of Bosnia and Herzegovina. More specifically, On the profile stretching from Neum towards Brcko the air temperature first follows a general declining trend from 15.6 °C to about 3.0 °C (first 95 km), where the general temperature change trend tends to increase to about 14.0 °C. On the longitudinal profile we can identify a continuing general trend of air temperature rise of about 2.0 °C (within the zone of Mount Maglic) to about 14.5 °C in the wider area around the town of Velika Kladuša (Figure 5).

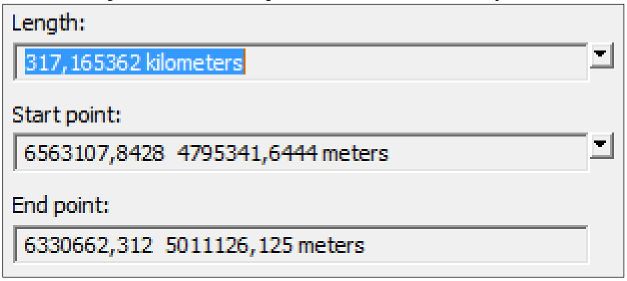


***Figure 6.*** *Matemathical-cartographic indicators for temperature profile 2.*

The basic thermic characteristic that can be seen in the annual flow of air temperatures in the entire territory of Bosnia and Herzegovina is the existence of only one extreme maximum and minimum temperature, which occur on average one month after the Sun reaches its solstice positions.

More specifically, the maximum air temperatures are present during the climatological summer period of the year (June – August) with the peak in July. The exception to this rule are the zones of the highest mountain peaks, since at the altitudes higher than 1,900m above the sea level, the temperature maximums are positioned temporally to reach yet another month – August. These temperature relationships are a result of the reduced heat surfaces at the highest hypsometrical levels, as a result of which the time required to warm up the contact surface and accumulate heat in the soil is somewhat longer. Indeed we should emphasize that the established intermonthly temperature differences in these zones are quite small and range from 0.2 °C to 0.5 °C.

A similar situation also exists with regard to the minimum temperature extremes, considering that their time schedule is associated with the winter climatological period, i.e. the period from December to February. Minimum air temperatures occur in January, while in the highest mountain zones (above the mentioned altitudinal limit) they also have a slight shift to the month of February. Intermonthly temperature difference between the extreme months within these hypsometrical ranges are also quite insignificant and range from 0.1 °C to 0.3 °C.

Among the said extreme periods in the annual flow of air temperature in Bosnia and Herzegovina we can single out also the transitional climatological seasons, spring and autumn, with the considerably similar thermic characteristics. The only specificity that can be particularly highlighted is that the temperatures present during the spring season (March – May), in line with the astronomical factor, still rise continuingly towards the summer period – by an average of about 4.5 °C to 5.0 °C, while in the autumn the flow of temperatures is reversed, or in other words the air temperatures decrease from the beginning of autumn to the beginning of winter, with an average intermonthly variation by about 5.0 °C. Analyses made on numerous examples also show that the spring season is characterized by a somewhat lower seasonal average compared with the autumn seasons, or that at the level of the entire Bosnia and Herzegovina the autumn season is warmer by about 1.0 °C compared with the spring season.

## 3. Results and discussion

Based on the above distribution of extremes in the annual flow of air temperatures we can come to the conclusion that, in Bosnia and Herzegovina but also in the wider region, there is a dominant presence of **the type of climate that is otherwise present in the moderate latitudes**. Furthermore, since its position is located practically in the central part of the northern temperate climate zone, with four clearly differentiated climatic periods, the said climate type could be further identified as **the proper climate type of the moderate latitudes**. It has to be highlighted that, according to the macro-relief elements, the said climate type in Bosnia and Herzegovina appears in two varieties: **continental and maritime**, which spread across the areas of dominant continental and maritime influences.

However, it has to be mentioned that, considering the general scheme of annual thermic regime in Bosnia and Herzegovina, there is a very commonplace phenomenon of time shifts in terms of the respective maximum or minimum temperatures. Based on the data measured at the main network or those recalculated data that is derived from the data collected at the supporting network of temperature stations in Bosnia and Herzegovina, it is possible to determine the horizontal and altitudinal temperature amplitudes, in terms of both the overall air temperature changes and the changes featured by 100-meter hypsometrical grades. Determination of the above indicator is the basis for defining the position of a particular area in relation to the prevailing maritime and/or continental influences. For the specific analyses that are used in determining whether there is a more prevailing degree of continental or maritime influences a great number of climate scientists have suggested a variety of methods. Most of them are based on the previously mentioned analyses of quantitative and qualitative indicators of spatial-temporal dynamics of temperature extremes. More specifically, in order to determine whether there is a more prevailing degree of continental or maritime influences this paper has used the method by which the boundary that separates the continental from the maritime influences is determined by annual isotalantosys of 20.0 °C. The results of spatial interpolation of the main and supporting networks of temperature stations are presented on Figure 8.

The overall variation of air temperatures on an annual level has been defined by an average annual temperature in Bosnia and Hercegovina's coastal belt amounting to 15.9 °C and in the zone of the highest peaks of Mount Maglić amounting to -1.4 °C, or in other words the overall air temperature difference between the warmest and coldest areas in Bosnia and Herzegovina amounts to 17.3 °C. The said areas are characterized by similar features in terms of both the maximum and the minimum average monthly temperatures. More specifically, the highest median monthly mean temperature is 24.9 °C and it belongs specifically the coastal part of the BiH Littoral. An opposite temperature extreme analogue that characterizes the thermic conditions of the wider zone in the peaks of Mount Maglic reaches the value of -9.3 °C. By using this information we have determined the absolute average annual temperature amplitude which for the entire area of Bosnia and Herzegovina amounts to 34.1 °C. The said value can be characterized as a very high value and it best illustrates all thermic contrasts of Bosnia and Herzegovina.

The data collected at the temperature stations of the main and supporting networks also provide a very detailed and representative analysis of the temperature fluctuations also by main (100-meter) hypsometrical grades for the entire Bosnia and Herzegovina (Figure 7). It is evident from the attached curve of the altitudinal changes in the mean annual temperature amplitudes that the average annual temperature amplitudes are dropping rather evenly with the rise of altitude, except in the last three hypsometric grades where the decline is somewhat more pronounced.

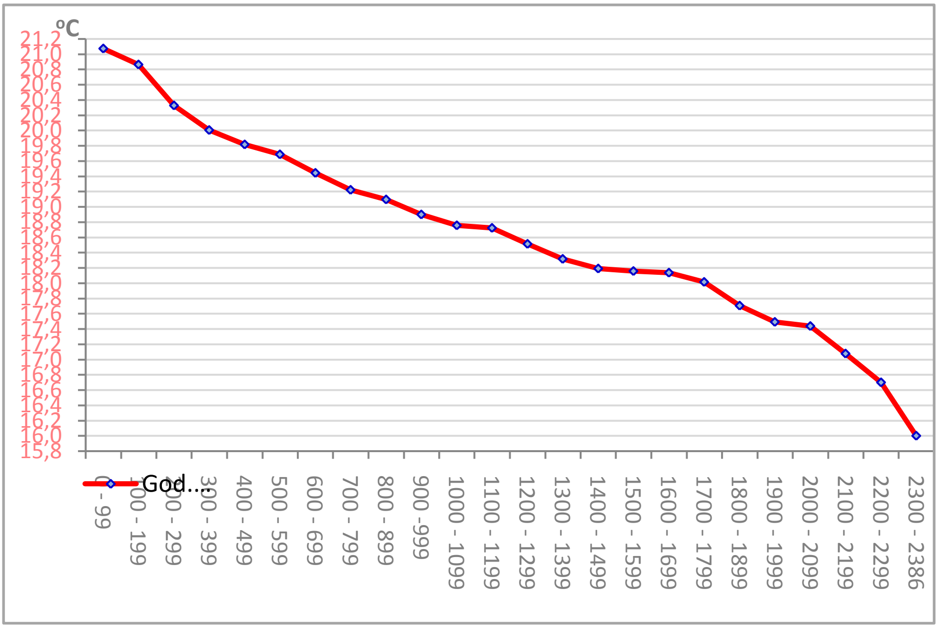


***Figure 7.*** *Mean annual amplitudes of air temperatures by 100-meter hypsometric grades*

The identified decrease in the temperature amplitudes that occurs with the increase of altitude, as it is already mentioned, is a consequence of the decrease in the size of the area of the soil that is exposed to daily insolation and night radiation, as a result of which the thermic contrasts have also been mitigated. It is interesting to note that the zone of the first 300m of altitude above the sea level in Bosnia and Herzegovina is characterized by the features of thermic continentality, knowing that the average annual temperature amplitudes amount to about 21.0 °C. The presented findings can be explained by the fact that within the said hypsometric range there is about 2/3 of the total area of Bosnia and Herzegovina that is under the direct influences of continental air masses, which are directly causing an increase in the thermic contrasts or in the temperature fluctuations.

The hypsometric classes above the specified height limits have the prevailing characteristics of thermic maritimity, considering that the average annual temperature amplitudes are below 20.0 °C. By approximation of the said values we have obtained, for the level of the entire Bosnia and Herzegovina, the value of the average annual temperature amplitude that amounts to 18.7 °C, which indicates the dominant maritime influences. More specifically, in the Mediterranean part of Bosnia and Herzegovina and generally in the hypsometrically higher parts of the mountain basin morphological regions of Bosnia and Herzegovina, we have established that the average annual temperature amplitude ranges below the threshold value of 20 °C, so it can be concluded that in these areas there are more dominant influences of the Adriatic Sea compared with the continental parts of the European continent (Figure 8). In the region of Northern Bosnia, up to the hypsometric levels of about 1,500m of altitude above the sea level, the mean annual temperature fluctuations are above 20 °C, or in other words, in this region we can identify the continental climatic influences as the dominant influences.

## 4. Conclusion

Based on the presented data we can conclude that the threshold isotalantosys of 20.0°C, which separates the areas with the standard continental climate characteristics from the area with the altered maritime influences, spreads much further north than it was indicated in the previous climatological research. More specifically, isotalantosys of 20.0 °C covers a wider zone stretching regionally and geographically along the area of Tržačka Raštela, across the top of Straža (347m), Čemernica (378m), north of the Una River basin (between Ostrožac and Velika Gomila (798 m)), from where it sways towards the southeast (south of Bosanska Krupa), towards the zone of Mount Majdanska and continues to the northeast. The defined border zone of thermic continentality continues further across the area south of Prijedor where it enters the wider area of Mount Kozara peaks (Lisina peak – 976m), from where it sways back to the south or enters the area of Mount Uzlomac (peaks: Prdeljica (1,002m , Jelovka (1,002m) and Mount Borja (peaks:. Velika Runjavica – 1.078m, the Veliki Tajan – 1,008 m) south of Banja Luka.

The analyzed isotalantosys continues to the southeast and wedges deeply into the wider area adjacent to the top of Mount Great Smolin (1,148 m), and it wedges deeply along the valley of the Bosnia River towards the south. Along the line that stretches northeast, the border zone spreads into the wider area of the mountains of Udrin (799 m) and Velež (top: Borik 915 m) and the valleys of the rivers Seone and Turia, from where it stretches to the area south of Lake Modrac and reaches the slopes of Mount Majevica. In the valley surrounding the Drina River, the area of isotalantosys 20,0 °C, wedges deeply towards the south and practically reaches the area of the upper stream (upstream part) of the river valley. South of the described border zone there are prevailing maritime influences reflected in the value of the annual isotalantosys of less than 20.0°C.

However, it is worth noting that these influences in Bosnia and Herzegovina can be characterized as the altered maritime influences, because the values of isotalantoses are not below 15.0 °C, which is a boundary for differentiation of the proper maritime influences. This is a result of deep wedging of the Adriatic Sea into the mainland, as a result of which the thermic influences of the continental hinterland largely mitigate or even annul the maritime influences. In addition, in the region of Central Bosnia, the values of annual isotalantoses are very close to 20.0 °C; so, this zone can be more properly characterized as an area where the continental and maritime influences are mixing. The area north of the threshold line (which about 1/3 of Bosnia and Herzegovina) there is an area that is completely under the influences of continental climate, considering that that the annual isotalantoses exceed the threshold line by 1.0 °C

Regarding the described zone of continuous distribution the threshold isotalantosys, it is indeed worth noting that there are a number of isolated areas of varying sizes that spread south of this line. One such area is, for example, the area south of the Vranduk Gorge which covers the area along the River Bosna basin valleys (along the stretch from the towns of Zenica to Ilijaš), including the valley of the Lašva River (downstream of Travnik), which is obviously a spatial continuity of the continental influences in the Bosna River valley coming from the north, briefly discontinued by the said Vranduk Gorge. For this and other similar reasons, it may be noted that the continental influences in the valleys of the large right tributaries of the Sava River in Bosnia-Herzegovina (Una with Sana, Vrbas, Bosna and Drina) penetrate deeper to the south, almost to the footholds and slopes of the highest mountains in BiH (in the relevant literature designated as “the roof of the Bosnian Dinarids”): Vranica, Bjelašnica, Romanija, Volujak and Maglić.

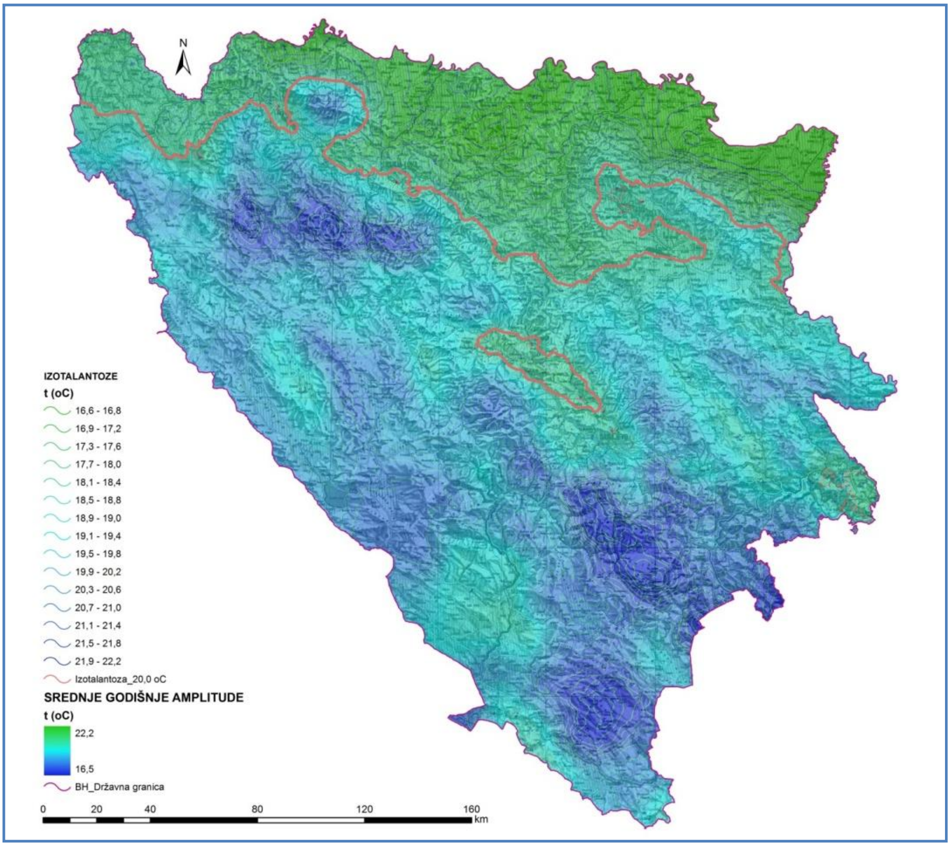


***Figure 8.*** *Temperature amplitudes in Bosnia and Herzegovina with the spatial distribution of the threshold isotalantosys of 20 °C*

## 6. References

Antonić, O., Križan, J., Marki, A., Bukovec, D.: Prostorno-vremenska interpolacija klimatskih varijabli velikog regiona složenog terena pomoću neuralnih mreža. Istitut za ekologiju i zaštitu okoline „OIKON“. Zagreb, 2008.

Bakaršić, S.: Prevoj Ivan. Geografski pregled, 1: 66-84, Sarajevo, 1957.

Ballif, M.P.: Organisation du Service Meteorologique en Bosni-Herzegovine. Resultats des observations relatives a la pluie. Imprimerie de la Cour D’Apel. L. Maretheux, directuer, Rue Cassette 1. Pariz, 1900.

Bašić, M.: Klima Vrbasko-plivskog prostora kao faktor njegove turističke valorizacije. Geografski pregled, 24: 37–44, Sarajevo, 1980.

Borilović, D.: Visinsko strujanje iznad Jugoslavije i prizemni karakteristični vetrovi. Rasprave, Sveska 3, Prirodno-matematički fakultet Univerziteta u Beogradu – Meteorološki zavod. Beograd, 1960.

Davidović, R.: Klima petrovačkog kraja. Zbornik radova Prirodno-matematičkog fakulteta u Novom Sadu, Sveska 11, p.: 5-23. Novi Sad, 1982.

Drešković, N.: Klima Sarajeva. Magistarski rad. Prirodno-matematički fakultet Univerziteta u Sarajevu, Sarajevo, 2004.

Drešković, N.: Klimatski tipovi u Bosni i Hercegovini. Doktorska disertacija. Prirodno-matematički fakultet Univerziteta u Sarajevu, Sarajevo, 2011.

Đug, S., Drešković, N., Hamzić, A.: Prirodno naslijeđe Kantona Sarajevo. Monografija. ArchDesign, Sarajevo, 2008.

Fan Y. and Huug, D.: A global monthly land surface air temperature analysis for 1948 - present. NOAA/NWS/NCEP Climate Prediction Center & RS Information System, Inc. McLean, Virginia. 2007.

Filipčić A.: Neke osobine klime delte Neretve. Geografski glasnik, 51/1989: 179–188, Zagreb, 1989.

Golubić, S.: Prilog poznavanju klime primorske regije Jugoslavije. Geografski glasnik, broj XX, P.: 139-148. Zagreb, 1958.

Kanaet, T.: Klima NR Bosne i Hercegovine. III kongres geografa FNRJ, Geografsko društvo SR Bosne i Hercegovine, Sarajevo, 1954,10–15.

Mihailović, D.T., Lalić, B., Arsenić, I.: Praktikum iz Meteorologije. Poljoprivredni fakultet, Univerzitet Novi Sad, 2008.

Rakita, R.: Klima sliva Pleve (Plive). Geografski pregled, 30: 5-24, Sarajevo, 1987.

Vemić, M.: O klimi Bosne i Hercegovine. III kongres geografa Jugoslavije, p.: 30–35. Geografsko društvo SR Bosne i Hercegovine, Sarajevo, 1954,.

Vujević, P.: Prodiranje morskih uticaja u unutrašnjost Jugoslavije. III kongres geografa Jugoslavije, p.: 36–39. Geografsko društvo SR Bosne i Hercegovine, Sarajevo, 1954.