BIOCLIMATIC STRESS DUE TO OVERHEATING IN ROMANIA

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By analyzing the time and space distribution of some relevant heat-related bioclimatic indices, such as the Equivalent Effective Temperatures (EET), the Summer Scharlau Index (SI), the Relative Strain Index (RSI) and the Summer Simmer Index (SSI), the present bioclimatic study aims at providing a representative image of not only the intensity of heat stress, but also of the extent of the risk areas due to overheating in Romania. The results we obtained, fully concordant with the unanimously accepted global approaches, clearly show that the heat-related bioclimatic stress in Romania is mostly connected to the main air-circulation pattern over the country's territory in summer. An interesting finding is that under specific topoclimatic conditions, the intensity and spatial pattern of heat-stress changes according to the nature and extent area of the particular factors of influence.

Keywords: bioclimatic indices; bioclimatic stress due to overheating; Romania.

1. Introduction

Out of all environmental factors of influence on human health and efficiency, the climatic ones are the most important because their continuous space and time variation require the permanent adaptation of all human physiological systems of control and integration. Human comfort and wellbeing is, therefore, directly connected to the state of local weather and bioclimatic conditions, especially under conditions of overexposure to extreme values. In this respect, special attention should be given both to their range of variation and to their specific time and space distribution. Consequently, by analyzing the time and space distribution of some relevant heat-related bioclimatic indices, such as the *Equivalent Effective Temperatures* (EET), the *Summer Scharlau Index* (ISE), the *Relative Strain Index* (RSI) and the *Summer Simmer Index* (SSI), the present bioclimatic study aims at providing a representative image of the intensity of heat stress and of the extent of the risk areas due to overheating in Romania. By using the monthly maximum values of air-temperature (^{0}C) and air-humidity values (%), obtained from 114 weather stations from all over the country, for a period of 30 years (1961-1990), we have calculated, by means of formulas which are currently being used worldwide but have been adapted

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to the set of weather parameters and system of units which are used in Romania, the above-mentioned bioclimatic indices which, in the absence of wind, but in certain conditions of air-humidity, best describe the bioclimatic state of heat-stress. This is due mainly to the fact that, during the hot, humid summer days, the heat loss of the human body is greatly increased not only by the intense evaporation of the sweat water from the human skin, but also by the evaporation of watery humours in the lungs and the upper ways of the respiratory system. From this point of view, evaporation and, consequently, the heat loss/cooling of the human body primarily depend on the water-vapour content of the air, that is of air's relative humidity, so that the greater the air humidity is, the more difficult the human body eliminates the inner heat surplus, due to the physiological failure of the cooling processes, so that the inner body's temperature increases, thus creating discomfortable overheating sensations. In this respect, special attention had to be given to the limits within formulas could be applied, so that the input data, especially air-temperatures maintain higher than certain specified thresholds. The software calculation methods we applied, have originally been derived from the mathematical formulas which are currently being used worldwide for each bioclimatic index of interest in the present study. The results we obtained, fully concordant with the unanimously accepted global approaches, clearly show that the heat-related bioclimatic stress in Romania is mostly connected to the main air-circulation pattern over the country's territory in summer, but under specific topo-climatic conditions, the intensity and spatial pattern of heat-stress changes according to the nature and extent area of the particular factors of influence.

2. The Equivalent Effective Temperature (EET)

The Equivalent Effective Temperature (EET), expressed in ^{0}C, is the internal temperature of a given air volume, which could be reached if all water vapours inside it condensed, thus releasing their latent heat of vaporization or, more simply, the EET values reflect the air-temperatures actually perceived by the human body during the hot, humid summer days, when the heat loss of the human body is greatly increased by the intense evaporation of the sweat water on the human skin. Provided that air-pressure ranges between 800 and 1,100 hPa, The EET Index could best be computed for air-temperature values ranging from +20^{0}C to +45^{0}C, according to the *Bründl W. & Höppe P.* [1] equation:

$$TEE\ (^0C) = T_d + w \times (r - 2.326 \times T_d) / (c_p + w \times c_w) \quad (1)$$

in which: T_d = dry-bulb air-temperature (°C);

r = latent heat of vaporization (cal·g^{-1});

w = effective mixing ratio (g / Kg^{-1});

c_p = specific heat of air (cal ·°C ·g^{-1}) ;

c_w = specific heat of water (cal·°C·g^{-1}).

The intensity of the heat-stress and the extent of the heat-risk area as described by the EET values obviously change from one place to another, for the same moment of time, and from one month to another, for the same place. The analysis of the summer EET values in Romania (Fig. 1a-c) shows that all through the warm season (June-August), most of the country's territory is largely characterized by highly-uncomfortable values (EET>51^{0}C), mostly because of the increasing evaporation rates, due to high air-temperature and low air-pressure values, which prevent the human body from efficiently eliminating the inner heat surplus, so that the internal temperature of the body increases, thus creating stressful overheating sensations. The EET values in the highest mountain peaks from the Southern Carpathians (namely the Făgăraş and Bucegi Mts.) are obviously lower as air-temperatures largely decrease with altitude, so that the bioclimatic stress due to overheating is less severe, although it is, nevertheless, present, even if the areas of moderate risk gradually shrink from the beginning to the end of the summer season.

3. The Summer Scharlau Index (ISE)

The Summer Scharlau Index (ISE), experimentally derived by K. Scharlau [4] clearly reflects that, in the absence of wind, the hot-humid climatic conditions may be harmful to the non-acclimatized human body, by greatly increasing the radiation and evaporation exchange rates, thus affecting the efficiency of the thermoregulatory system. Scharlau's formula must first be applied to calculate the critical temperatures, which correspond to the air-temperature values **above** which, depending on the actual values of air-humidity, the human body feels physiologically uncomfortable because of the overheating processes, according to the formula: $Tc = (- 17.089 \times Ln (RH)) + 94.979$ (2)
in which: $R^2 = 0.9985$; RH = relative humidity (%); Tc = critical temperature (^{0}C).

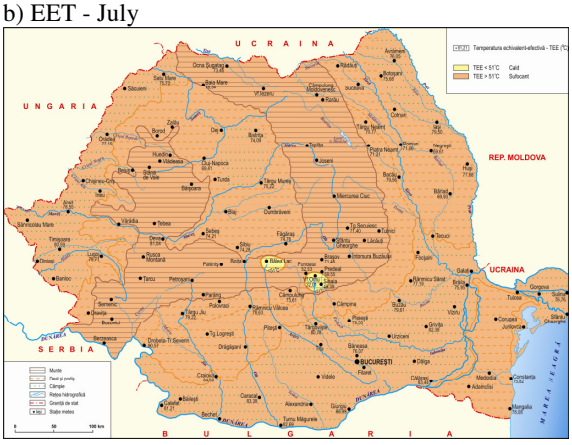
The resulting values of the Summer Scharlau Index– ISE (units), actually representing the difference between the critical temperature (Tc) and the local dry-bulb air-temperature (Ta), according to the formula: ISE = Tc – Ta, may be relevant only if applied for air-temperature values ranging from +17^{0}C to +39^{0}C and relative humidity values higher than 30%. They describe a state of bioclimatic comfort whenever they maintain above 0 and the lower they decrease, the more intense the heat-stress becomes, according to a scale of bioclimatic sensations associated to hot-humid environments.

The analysis of the summer ISE values in Romania (Fig. 2 a-c) shows that most of the country's territory is characterized by a pretty high risk due to overheating. For example, at the beginning of the warm season (June), the ISE "comfortable" values (ISE>0) are specific only of the mountainous regions with altitudes higher than 1,500 m above sea level, such as the Maramureş-Rodna Mts. in the Eastern Carpathians, the Făgăraş-Bucegi Mts. in the Southern Carpathians and the Western Carpathians, while their extensive slope surrounding areas, as well as a centrally-located higher portion of the Moldavian Plateau, are characterized by slightly uncomfortable ISE values (-1<ISE<0).

Fig. 1. Equivalent Effective Temperatures (EET) in Romania (1960-1990)

a) EET - June

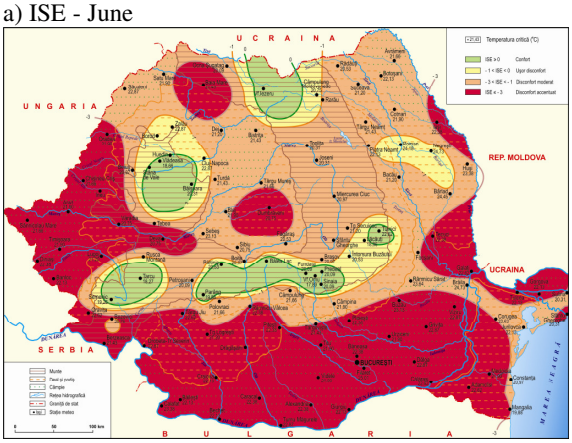
b) EET - July



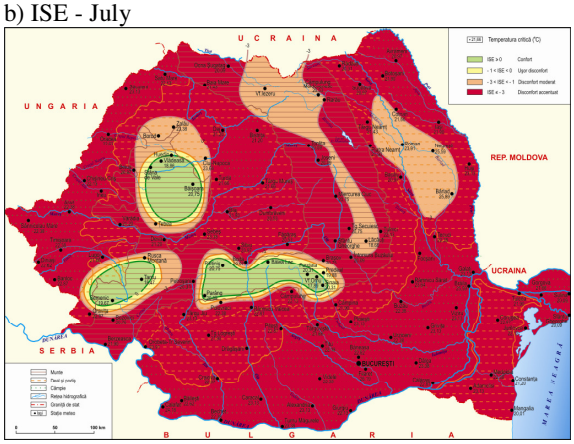
c) EET - August

Fig. 2. Summer Scharlau Index (ISE) in Romania (1960-1990)

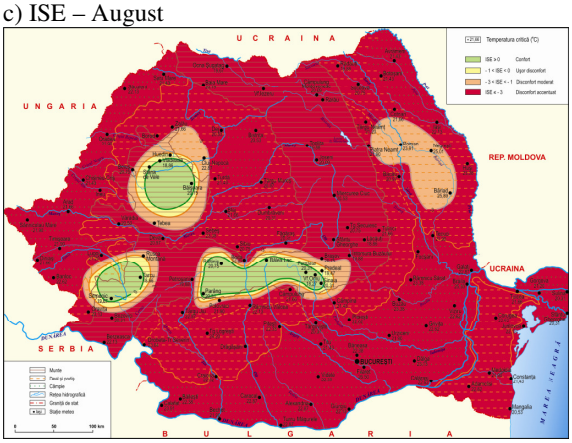
a) ISE - June



b) ISE - July



c) ISE – August



The bioclimatic stress due to overheating (-3<ISE≤-1) gradually increases all over the Western Hills, the Transylvanian and the Moldavian Plateaus, as well as the northern part of the continental Dobrudja, mainly because of the continentalized effects of the hot E air-masses and tropical SW Asian advections which largely increase the evaporation rates. However, the ISE values get even lower (ISE<-3) in most of the Western and Romanian Plains or the low-lying areas of the Transylvanian Plain and the southern peripheries of the Moldavian Plateau, so that the risk of heat-stroke must be taken into account as a potential risk to human health in these areas. In July, the initially comfortable areas (with ISE values >0) in the mountains shrink toward the highest peaks and all the remaining territory of the country is characterized by hazardous ISE values, meaning that the intensity of the bioclimatic stress due to overheating increases from two large portions in the heartland of the Moldavian Plateau and the Eastern Carpathians, where ISE values range from -1 to -3, to the remaining hilly and plain areas in the country, where ISE values decrease to extremes (ISE<-3). In August, the ISE values get even lower, pointing to highly uncomfortable bioclimatic conditions in most of the country's regions, but the corresponding critical temperatures slightly increase, revealing that the thermoregulating efforts of the human body become less intense than in July.

4. The Relative Strain Index (RSI)

The Relative Strain Index (RSI) is a relevant bioclimatic index used for the assessment of the bioclimatic stress due to overheating conditions, when air-temperatures increase over $+26^0$C. Its values may quantitatively be derived from air-temperature (^{0}C) and vapour pressure (hPa) according to W.J. Kyle's [2] formula: $RSI = (Ta - 21) / (58 - e)$ (3)
in which : Ta = air-temperature (°C) and e = real/effective vapor pressure (hPa). Since no direct measurements of the real/effective vapor pressure are made at most weather stations in Romania, the above-mentioned formula had to be accordingly changed in order to include the available relative humidity-RH (%). Consequently, e (the real/effective vapor pressure (hPa)) could more readily be computed according to the equation:

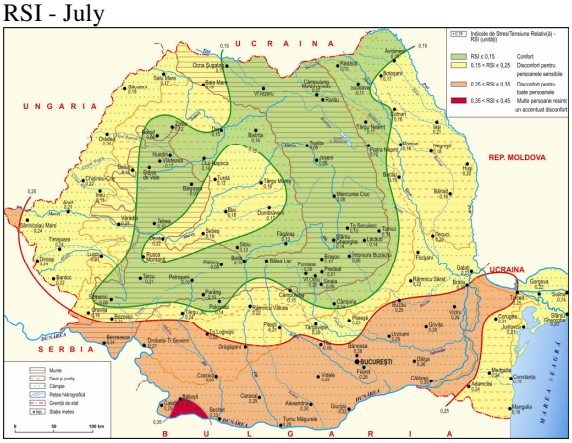
$$e = (6.112 \cdot 10^{(7.5 \cdot Ta/(237.7+Ta))} \cdot RH/100) \quad (4)$$

The corresponding RSI values which we obtained for the summer season (Fig. 3 a-c) clearly delimit some typical areas of bioclimatic risk. For instance, in June, the RSI values ≤ 0.15, actually describing conditions of bioclimatic comfort, are specific of most of Romania's territory, with the exception of the Romanian Plain, which is roughly characterized by slightly uncomfortable values (0.15<RSI≤0.25), which might put the most vulnerable population at risk with overheating. In July**,** the bioclimatically comfortable area shrinks to the mountainous region and the bioclimatic stress due to overheating gets even more intense in the Romanian Plain, where the RSI values (0.25<RSI≤0.35) actually indicate physiological discomfort for all people alike; all the remaining territory of the country being characterized by RSI values ranging between 0.15 and 0.25, which point to chances of overheating risk for more than 50% of the inhabiting population.

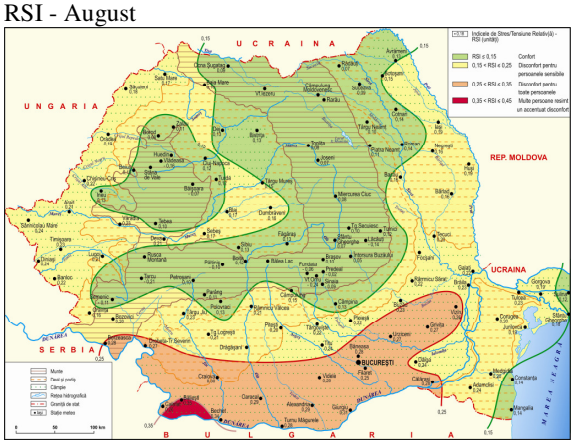
Fig. 3. The Relative Strain Index (RSI) in Romania (1960-1990)

RSI - June

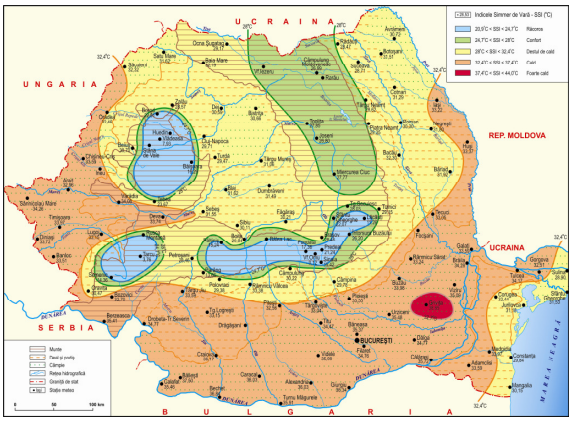
RSI - July



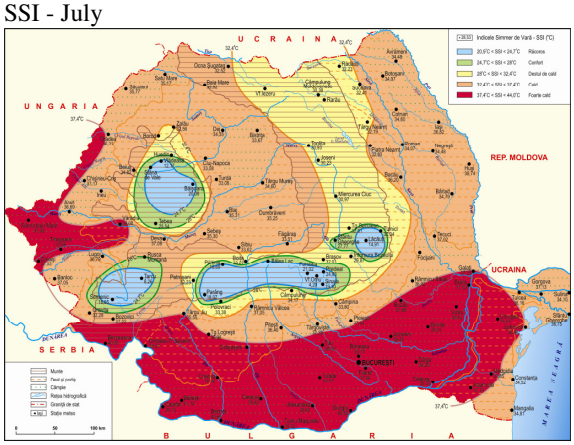
RSI - August



SSI – June



SSI - July



SSI – August

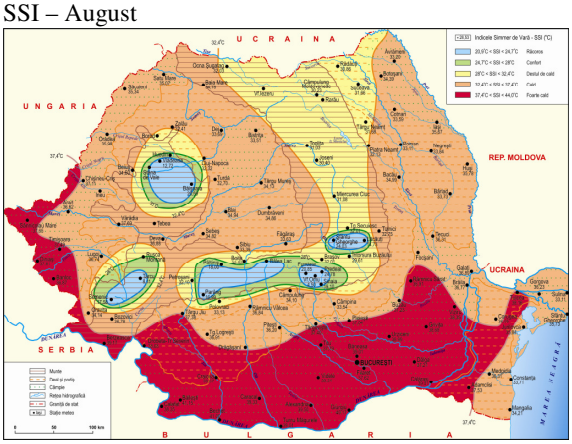


Fig. 4. The Summer Simmer Index (SSI) in Romania (1960-1990)

A very small area in the SW periphery of the country is actually characterized by a very intense overheating risk for all the exposed population ($0.35<RSI\leq0.45$) because of the liability to extremely hot and dry advections of tropical, continental air-masses from N Africa, and it must seriously be taken into account in bioclimatic assessments and alerts. In August, the area of intense overheating risk ($0.25<RSI\leq0.35$), in which most of the population is exposed to risk, still extends over a large portion of the Romanian Plain, so that we may easily draw the conclusion that the bioclimatic conditions in most of the country's southern areas area are potentially hazardous to human health. The heat stroke area still persists in the Calafat-Băileşti-Bechet region, meaning that the specific topo-climatic conditions in the sand-duned areas of the Oltenia Plain play an important role in heat-exchange processes and, therefore, largely influence human body's heat budget.

5. The Summer Simmer Index (SSI)

This most recent bioclimatic index, presented by W.J. Pepi [3] at the 80th AMS Conference, which took place in Long Beach (California), on June, 11th, 2000, best describes the bioclimatic stress due to overheating since it has been derived from physiological tests and human experiments performed over more than 75 years, by specialists from the Kansas State University. Its values (^{0}F) may easily be computed from the equation:

$$(SSI) = 1.98 \times (T_a^* - (0.55 - 0.0055 \times (RH)) \times (T_a^*-58)) - 56.83 \quad (5)$$

in which: T_a^* = dry-bulb air-temperature (°F) and RH = relative humidity (%), on condition that air-temperature values range from $+22^0$C to $+53^0$C.

In order to make W.J. Pepi's formula operable in SI units, air-temperature values have to be conversed from Fahrenheit into Celsius degrees, according to the formula: $T_a(°F) = (9 / 5) \cdot T_a(°C) + 32.$ (6)

The spatial distribution of the critical SSI values in Romania, during the warm season, reveals, like the RSI values, that most of the country's territory lies within the limits of uncomfortable bioclimates and the stress due to overheating may turn into a serious challenge for health-care services (Fig. 4 a-c). For instance, in June, the bioclimatic conditions in the mountainous regions with altitudes higher than 1,500 m are perceived as cooling ($20.9^0C<SSI<24.7^0C$), while the lower surrounding slope areas, especially in the Eastern Carpathians, have comfortable conditions ($24.7^0C<SSI<28^0C$). However, more than 2/3 of the country's territory, namely all the areas inside the Carpathian Arc as well as the Subcarpathian hilly belt, most of the Moldavian Plateau and the Black Sea coastline area, is characterized by uncomfortable SSI values indicating a moderate bioclimatic stress ($28.0^0C<SSI<32.4^0C$), while the remaining 1/3 is clearly at risk due to overheating conditions, since the SSI values are higher than 32.4^0C in most

of the Western and Romanian Plains, but especially in a highly risk-prone area in the heartland of the Bărăgan steppe-plain area, where bioclimatic conditions are perceived as very hot. In July, the SSI values range from hot ($32.4^0C<SSI<37.4^0C$) to very hot ($37.4^0C<SSI<44^0C$) limits in most of the country's geographical regions, except for the Eastern and Southern Carpathians, where the SSI values indicate comfortable or even cooling bioclimatic conditions mainly due to the air-temperature decrease with altitude. The heat-stroke area reaches its maximum extensions in the low-lying parts of the Western Plain and all of the Romanian Plain and continental Dobrudjan Plateau, so that protective measures are recommended to all their inhabitants. In August, the spatial pattern of the SSI values is not very different from the previous month, thus showing that not only the extension of the overheating risk areas are important in bioclimatic assessments, but also the duration of the critical conditions. Moreover, the SSI extreme values generally increase in from July to August, meaning that despite the fact that the areas of higher bioclimatic risk get largely reduced, the intensity of the overheating physiological stress increases.

6. Conclusions

The intensity and the spatial extent of the bioclimatic stress due to overheating in Romania, relevantly expressed by some bioclimatic indices specific of the warm summer season, are directly connected to the distribution of major relief forms and to the air-masses circulation pattern. The bioclimatic stress due to overheating generally decrease with altitude, but represents a serious hazard in the country's western and southern regions, exposed to frequent advections of hot, tropical air-masses from Northern Africa. However, some local topoclimatic conditions may also play a major part in intensifying the bioclimatic stress, such as the sand-duned region in the southern part of the Oltenia Plain.

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