THE BIOCLIMATIC STRESS IN DOBRUDJA

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Resumé. *Ce travail se propose de mettre en évidence les principales aires de stress bioclimatique au chaleur en Dobrogea, sur la base de l'analyse du régime et de la répartition de quelques indicateurs climatiques spécifiques, tels l'indice estivale de Scharlau, l'Indice du stress relative, l'indice hivernal de Scharlau et l'indice du pouvoir de refroidissement du vent. En utilisant les valeurs moyennes mensuelles de la température (^{0}C), de l'humidité de l'air (%) et de la vitesse du vent (m/s) pour 30 ans (1961-1990), obtenues de 10 stations météorologiques réparties sur l'ensemble de la region, nous avons calculé les valeurs spécifiques pour la saison chaude (juin-august), que pour la saison froide (novembre-mars), qui nous ont permis d'avoir une image de l'intensité et de la répartition spatiale des aires de stress bioclimatique au chaleur ou au froid. Les résultats obtenus, dont les valeurs ont été confrontées aux échelles globales unanimement acceptées, montrent que le risque bioclimatique au chaleur et au froid est influencé de manière importante par le type de circulation générale d'air et par les conditions physico-geographiques.*

1. Introduction

Dobrudja is a historical province confined to the area bounded by the Danube river and the Black Sea, including the Dobrudja Plateau and the Danube Delta. **The Dobrudja Plateau**, lying between the Danube river and the Black Sea, mainly consists of three distinct divisions. The *Southern Dobrudja Plateau*, which lies south of the Capidava-Ovidiu fault-line, consists of 10-180 m-high, gently-undulating relief forms, separated by closely-spaced and dry river-valleys; the *Central Dobrudja Plateau*, centrally-drained by the Casimcea river, is mainly consisting of low limestone flatlands (10 m) pierced by green-schist (metamorphic) ridges reaching as high as 300 m and the *Northern Dobrudja Plateau* displays eroded remains of a former mountain range, consisting of north-western Măcin Mts. (467 m), the central Niculițel tableland area, the eastern sedimentary-warped Tulcea Hills and the southern 300 m-high Babadag tableland area, separated by widely-spaced river-valleys. The **Danube Delta**, stretching in the Romanian sector over a total area of 4,340 km, along the three main distributaries of the Danube river (Chilia, Sfântu-Gheorghe and Sulina), is mainly represented by sand-banks that emerged either along the shore of the Black Sea or along submerged natural levees developed along the river-channels when floodwater dispersed laterally, separated by many large lakes on intervening side-channels.

Dobrudja's climatic personality results from the complex interaction of radiative, dynamic and physical-geographical factors. Due to its favourable geographical location (its southern location determining higher solar altitudes and its eastern exposure favouring lower cloudiness), lower altitudes, relatively uniform landforms and the proximity of the Black Sea, the radiation budget is among the highest in the country (> 125 $W/cm^2 \cdot yr$). The physical-geographical factors are largely different over the two specific types of active surface-layers: the land surface, with greatly varying altitudes, vegetation cover and humidity content, and the marine or fluvial surface, with particular topo-climatic or microclimatic features, although the climatic influence of the latter surface is largely attenuated by the prevalence of the western air-circulation pattern over the Romanian territory, Dobrudja included (with a mean annual frequence of 45%), which actually reduce the sea's climatic influences to only a 15-25 km-wide strip of shore. The dynamic factors play an important role in the formation of the typical seasonal climatic contrasts of the Dobrudjan territory since the pressure field and the air-circulation pattern greatly change from winter (when the mean pressure field is characterized by the presence of a vast low-pressure area over Iceland, a well-developed anticyclone over Eastern Europe and Asia opposing to the Azores High, and an extensive low-pressure area over the Mediterranean) to summer (when the Azores High extends farther to the East, thus blocking the Icelandic Low, which favours the eastward extension of the SW-Asian Low) (S. Ciulache, V. Torică, 2007).

Climatic factors may have important positive and negative influences on the human body mainly 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 which may greatly depreciate or improve the human energetic potential. These influences are quantitatively expressed by means of some key bioclimatic indices, which may also be important vehicles to raise public awareness of the risks of critical climatic conditions as well as of the need of adopting protective measures. From this point of view, by analyzing the time and space distribution of some relevant heat or cold-related bioclimatic indices, the present bioclimatic study aims at providing a representative image of not only the intensity of heat or cold stress, but also of the extent of the risk areas due to overheating or overcooling in one of Romania's touristically important geographical regions: Dobrudja.

2. Input data and methods

By using the monthly mean or maximum values of air-temperature (^{0}C) and the mean monthly air-humidity values (%) on one side, and wind-speed (m/s), on the other side, obtained from 10 weather stations in the area of interest, for a period of 30 years (1961-1990), we have first calculated, by means of the Scharlau K.(1950) and Kyle W.J. (1992*)* formulas, the corresponding values of the Summer Scharlau Index - IS (units) and of the Relative Strain Index – RSI (units) and the associated critical temperatures (^{0}C), which, in the absence of wind, but in certain conditions of air-humidity, compose the bioclimatic state of heat-stress (N. Ionac, 2005). In this respect, special attention was given to the limits within formulas could be applied, so that the values of the resulting bioclimatic indices apply only to the warm-season months (June-August), when input data, especially air-temperatures, keep higher than certain specified thresholds.

Then, we have calculated, on a NOAA[1] methodology, the corresponding wind-chill values (W/m^2), which reflect the intensity of the human body heat loss due to the combined effect of more physical processes (such as radiation, convection, conductibility and evaporation), and then, by means of the Siple P.A., Passel C.F.[2](1945) and Scharlau K.[3](1950) formulas, we have also calculated the equivalent wind-chill temperature values (^{0}C), on one side, and the values of the Winter Scharlau Index (units) and associated critical temperatures (^{0}C) (N. Ionac, S. Ciulache, 2006), which, in the absence of wind, but in certain conditions of air-humidity, compose the bioclimatic state of cold-stress, on the other side, especially during the cold-season months (November-March). The software calculation methods we have used, have originally been derived from the mathematical formulas which are currently being used worldwide for each bioclimatic index of interest in the present study.

3. Results

The results we have obtained, fully concordant with the unanimously accepted global approaches, clearly show that either heat or cold-related bioclimatic stress in the area of interest is mostly connected to the main air-circulation pattern over the Dobrudjan territory in summer as well as in winter but, however, under specific topo-climatic conditions, the intensity and spatial pattern of heat or cold-stress changes according to the nature and extent area of the particular factor of influence.

3.1. The *Summer Scharlau Index (IS)*, experimentally derived by K. Scharlau in order to establish the level of human discomfort due to overheating, that is the intensity of the heat-stress, 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 of tissue processes, thus affecting the efficiency of the thermoregulatory mechanisms. Scharlau's formula must first be applied to calculate the input *critical temperatures*, which represent the corresponding air-temperature values **above** which, according to the actual values of air-humidity, the human body feels physiologically uncomfortable because of the overheating processes, especially when local temperatures are higher than the critical ones. The output values of the Summer Scharlau Index– IS (units), actually representing the difference between the critical temperature (Tc) and the local air-temperature (Ta), describe a state of bioclimatic comfort whenever they maintain above 0, but the lower they decrease, the more intense the heat-stress becomes, according to a scale of bioclimatic sensations associated to hot-humid environments.

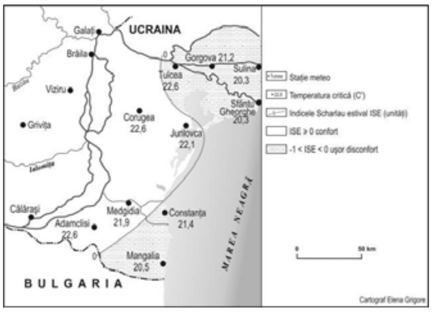
The intensity of the heat-stress and the extent of the heat-risk area as described by the IS values obviously changes from one place to another, for the same moment of time, and from one month to another, for the same place. The analysis of the summer IS values in Dobrudja (Fig. 1) shows that, at the beginning of the warm season (June), most of the area of reference is largely characterized by "comfortable" values (IS>0), with the exception of the easternmost periphery of the Danube Delta, along the Black Sea shoreline, where IS values indicate a state of weak bioclimatic discomfort (-1<IS<0), mainly due to the increasing evaporation rates which prevent the human body from eliminating the inner heat excess, so that the inner body's temperature increases, thus creating stressful overheating discomfort sensations. The corresponding critical temperature values in June accordingly range from 20.1^{0}C on the shoreline weather stations (Sulina and Sfântu Gheorghe), to 22.6^{0}C in the heartland of the Central and Southern Dobrudja Plateaus (Corugea and Adamclisi, respectively), with south-facing gently-sloping interfluvial surfaces.

In July, the initial comfortable area (with IS values >0) in the heartland of continental Dobrudja shrinks westwards, while all the 15-25 km-wide strip along the Black Sea shore becomes slightly uncomfortable (-1<IS<0) mainly due to the more intense evaporation processes over the adjoining water areas, which consequently create more humid conditions and, therefore, create a physiological state of stress. The limits of the moderately discomfortable bioclimatic areas (- 3<IS≤-1) restrict to the whole territory of the Danube Delta, mostly because of the continentalized effects of the hot eastern air-masses and tropical SW Asian advections which largely increase the evaporation rates, as well as to the southernmost extents of the Romanian coastline, so that the risk of heat-stroke must be taken into account as a potential risk to human health. However, the critical temperatures are not too much different from those in June. Their values generally range from 20.0^{0}C along the Black Sea shore (Sulina, Sfântu Gheorghe and Mangalia) to 23.1^{0}C at Adamclisi.

In August, slightly discomfortable values (-1<IS<0) are specific of the northern and southern peripheries of the Black Sea shoreline areas, while comfortable IS values (IS>0) centrally extend from the inner continental regions to the lacustrine Razim-Sinoe complex, lying almost midway between the two opposing peripheries. However, the amplitude of the critical temperatures decreases, the Tc values ranging from 20.3^{0}C in Sulina and Sfântu Gheorghe, to 22.6^{0}C at Adamclisi.

3.2. *The Relative Strain Index (RSI)*, which is a most relevant bioclimatic index revealing the actual extent of the heat exchange budget of the human body under overheating conditions and pointing not only to the intensity of bioclimatic stress due to heat exposure, but also to the potential negative effects that bioclimatic extremes might have on human physiology, was calculated on the basis of monthly maximum values of air-temperature (^{0}C) and mean values of relative humidity (%).The resulting RSI values clearly reveal not only the spatial extent of the bioclimatic stress areas due to overheating in the specific summer months (June, July and August), but also their variation from one critical month to another.

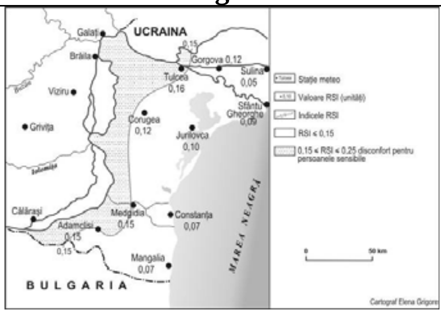
Unlike the ISE values, the Relative Strain Index (RSI) values are not so highly variable in space and time, but they nevertheless, better evidence the potential area of risk due to overheating. For instance, in June, the RSI values maintain within the accepted limits of bioclimatic comfort (RSI≤0.15) all over the eastern, maritime façade of the Dobrudjan territory, possibly due to the influence of the sea-breezes cooling effect (Fig. 2), gradually increasing westwards, along the Danube river floodplain areas, where they indicate uncomfortable bioclimatic conditions (RSI>0.15). These values generally range from a 0.05 minimum in the Danube Delta (Sulina) to a 0.16 maximum, in Tulcea, where continental, dry climatic influences are markedly increased.



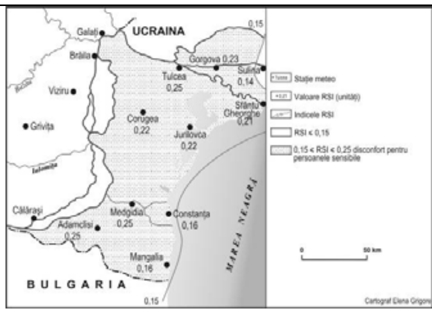
August

Fig. 1.
The Bioclimatic Heat-Stress in Dobrudja
(1961-1990)
The Summer Scharlau Index – IS (units)
and Critical Temperatures (^0C)

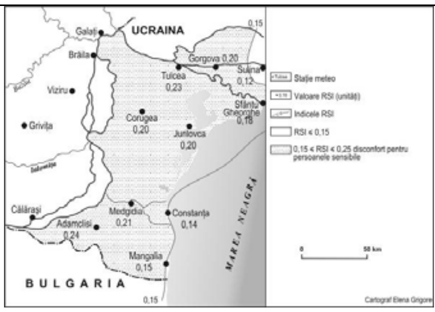
Summer Scharlau Index	Bioclimatic Stress
IS ≥ 0	Bioclimatic Comfort
- 1 < IS < 0	Weak discomfort
- 3 < IS ≤ -1	Moderate discomfort
IS ≤ -3	Stressful discomfort



June



July



August

Fig. 2.
The Bioclimatic Heat-Stress in Dobrudja
(1961-1990)
The Relative Strain Index- RSI (units)

Relative Strain Index	Bioclimatic discomfort
RSI ≤ 0.15	Bioclimatic comfort
0.15 ≤ RSI ≤ 0.25	Bioclimatic discomfort for more sensitive persons*
0.25 ≤ RSI ≤ 0.35	Bioclimatic discomfort for all persons
0.35 ≤ RSI ≤ 0.45	Overheating risk for more than 50% of the population
RSI ≥ 0.45	Heat-stroke risk for all population

* In case of older and sick people, the RSI values equalling to 0.20 actually represent the maximum limit of tolerance, above which heat stroke is evident.

In July, the whole Dobrudjan territory is characterized by bioclimatic discomfortable conditions (0.15≤RSI≤0.25) affecting almost 25% of the exposed population, especially the younger and the older people, mainly because of the liability to extremely hot and dry advections of tropical, continental air-masses, especially in the north-eastern, deltaic areas. This time, the RSI values range from

0.14 at Sulina to 0.25 at Tulcea, Medgidia and Adamclisi, where they might put at risk the more sensitive persons.

In August, the RSI values are very close to the lower safe limit of 0.15. Unlike July, the RSI values are slightly lower and they are more evenly distributed over the territory's total area. A slight risk of overheating is, nevertheless, possible to the South-Westernmost periphery of the Southern Dobrudja Plateau, where the RSI values reach 0.24 units at Adamclisi.

3.3. The *Winter Scharlau Index (IS)* (units), reflecting the level of human discomfort due to overcooling, that is the intensity of the cold-stress, describes a state of bioclimatic comfort whenever it maintains above 0 and the lower it decreases, the more intense the cold-stress becomes. The associated *critical temperatures* represent the corresponding air-temperature values **below** which, according to the actual values of air-humidity, the human body feels physiologically uncomfortable because of the cooling processes, especially when local temperatures are lower than the critical ones.

The intensity of the cold-stress and the extent of the cold-risk greatly changes 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 winter IS values in Dobrudja (Fig. 3) shows that, at the beginning of the cold season (November), most of the area of reference is largely characterized by "comfortable" values (IS>0); the corresponding critical temperature values in November accordingly ranging from 2.6^{0}C at the south-western peripheries (Adamclisi), to 3.1^{0}C at the mouths of the Danube's tributaries into the Black Sea (Sulina and Sfântu Gheorghe).

In December, the southern sector of the Romanian shore on the Black Sea is chracterized by IS values describing a slight discomfort (-1<IS<0) due to overcooling, mainly because of the greater amount of heat released by sea-waters during winter, which keep air-temperatures positive. On the contrary, in the remaining continental parts of the Dobrudjan Plateaus, as well as in the Danube Delta, the intensity of the bioclimatic discomfort increases, so that the IS values get lower (-3<IS≤-1).The critical temperatures range from 2.9^{0}C in a N-S oriented, centrally-located sector (Gorgova, Jurilovca, Constanța), to 3.2^{0}C both to the North-Eastern regions of the Danube Delta (Sulina and Sfântu Gheorghe) and to the South-Western continental parts of the Central Dobrudja Plateau (Medgidia), reaching the highest values (3.4^{0}C) at Corugea, in the heartland of the Dobrudjan Plateau, meaning that the drier, continental climatic conditions obviously increase the cold-stress as, in fact, lower air-temperatures do.

In January, the area of the moderate discomfortable IS values (-3<IS≤-1) extends over most of the Dobrudjan territory, except for a small area in the souhernmost sector of the Black Sea shore, where the milder bioclimatic effects (-1<IS<0) are due to the heat surplus released by the sea-waters during winter. The critical temperatures range from 2.7^{0}C at Jurilovca, to 3.2^{0}C at Corugea, reflecting wide differences of the cooling processes along the same alignment, between the continental and lagoon/maritime sectors.

In February, the IS values describe a most irregular pattern of variation, since most of the Dobrudjan territory is characterized by moderate discomfortable bioclimatic conditions, while the southern peripheries of the Danube Delta and the Southern Dobrudjan Plateau are dominated by an intense cold-stress, with IS values lower than -3. The corresponding critical temperatures range from 2.7^{0}C in Jurilovca, located on the shore of the Razim-Sinoe lagoon complex, to 3.1^{0}C towards the seaward limits of the Danube Delta (Sulina and Sfântu Gheorghe), where the more humid conditions create an acute physiological state of bioclimatic stress.

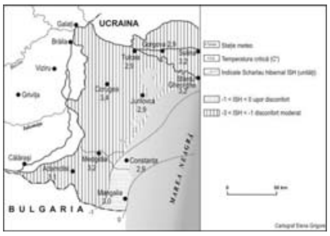
In March, „comfortable" IS values (IS>0) are specific of all the Dobrudjan territory. However, the amplitude of the critical temperatures increases, the Tc values ranging from 2.2^{0}C at Adamclisi, to 3.0^{0}C at Sfântu Gheorghe.

3.4. The *Wind-Chill Index (Wind-Chill)*, basically reflecting the combined action of air-temperature (^{0}C) and wind speed (m/s) on the heat budget of the human body, actually represents the intensity of the heat energy that the human body surface unit loses through various physical processes (radiation, convection, evaporation etc.), being accordingly expressed in W/m^2. The Wind-Chill formula (Siple and Passel, 1945) also allows the calculation of the *Wind-Chill Equivalent Temperature*, that is the actual temperature the human body feels at certain values of air-temperature and wind-speed, starting from the finding that the wind increases the evaporation and consequently increases the heat exchange rates of the human skin.

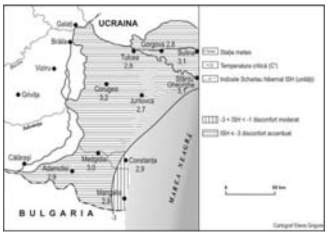
Unlike the SI values, the Wind-Chill values in Dobrudja are more sparsely distributed, yet there appearing important differences from one month to another. For instance, in November, the bioclimatic conditions are generally very chilly (Wind-chill= 600-800 W/m^2) in most areas, but turn into a cold stress (Wind-chill= 800-1000 W/m^2) in a centrally-lying area, extending from the southern outlets of the Danube river into the Black Sea, to the southern limits of the seaside Cape Midia-Cape Siutghiol sector, with large sand-depositions intervening between seaward-extending promontories of varying dimensions, where lower air-temperatures largely compensate for the heat loss due to wind movements. The equivalent wind-chill temperatures increase from -1.7^{0}C at Adamclisi, to 3.9^{0}C at Gorgova.

In December, the bioclimatic stress intensifies as wind-chill values get higher than 800 W/m^2 all over Dobrudja. The associated cold stress (Wind-chill = 800-1000 W/m^2) is specific of a large area and the North-Eastern peripheries are at risk due to the intense overcooling processes determined by the more frequent advections of cold, dry arctic air from the Siberian High. The equivalent wind-chill temperatures generally decrease to very low values: 2.5^{0}C in Gorgova vs. -6.5^{0}C in Jurilovca.

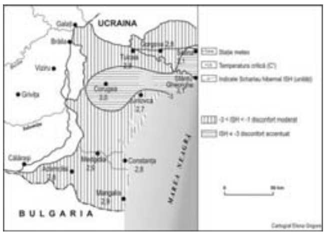
November



December



January



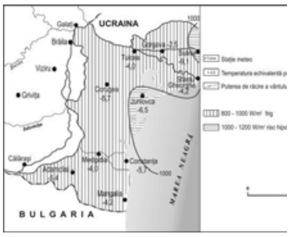
February

March

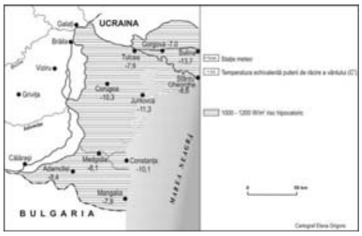
Fig. 3.
The Bioclimatic Cold-Stress in Dobrudja
(1961-1990)
The Winter Scharlau Index (units) and Critical Temperatures (^0C)

Winter Scharlau Index	Bioclimatic Stress
IS ≥ 0	Bioclimatic Comfort
- 1 < IS < 0	Weak discomfort
- 3 < IS ≤ -1	Moderate discomfort
IS ≤ -3	Stressful discomfort

November

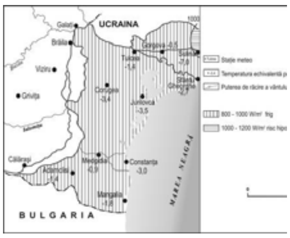


December



January

February



March

Fig. 4.
The Bioclimatic Cold-Stress in Dobrudja
(1961-1990)
Wind-Chill (W/m^2)
and Wind-Chill Equivalent Temperatures (^0C)

Wind-chill (W/m^2)	Bioclimatic Effects
600 < Wind-chill < 800 W/m^2	Very cool
800 < Wind-chill < 1 000 W/m^2	Cold
1 000 < Wind-chill < 1 200 W/m^2	Very cold
Wind-chill > 1 200 W/m^2	Freezing risk

In December, the bioclimatic stress intensifies as wind-chill values get higher than 800 W/m^2 all over Dobrudja. The associated cold stress (Wind-chill = 800-1000 W/m^2) is specific of a large area and the North-Eastern peripheries are at risk due to the intense overcooling processes determined by the more frequent advections of cold, dry arctic air from the Siberian High. The equivalent wind-chill temperatures generally decrease to very low values: 2.5^{0}C in Gorgova vs. -6.5^{0}C in Jurilovca.

In January, the wind-chill values point to almost freezing conditions (Wind-chill >1 100 W/m^2) in the entire Dobrudjan territory, so that the overcooling risk is spatially possible everywhere in the region. The equivalent wind-chill temperatures approximately keep the same pattern of space variation as in January, but this time their values get even lower (-7.0^{0}C in Gorgova as compared to -13.7^{0}C in Sulina).

In February, the intense cold-stress area (Wind-chill >1 100 W/m^2) shrinks as the southern or northernmost peripheries are characterized by milder bioclimatic conditions (Wind-chill = 800-1000 W/m^2). But unlike January, the wind-chill equivalent temperatures range within higher limits (from -5.3^{0}C at Gorgova, to -13.9^{0}C at Sulina).

Towards spring, namely in March, the distribution pattern of wind-chill values reflect cold conditions in most of the territory ((Wind-chill = 800-1000 W/m^2), except for the North-Easternmost corner of the Danube Delta, where the hypothermia risk is still possible due to the higher intensity of the cold stress (Wind-chill >1 100 W/m^2). The equivalent wind-chill temperatures decrease to lower values: 0.5^{0}C at Gorgova, in the heartland of the Danube Delta, and -7.0^{0}C at Sulina.

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