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The thermal inversion phenomena on ground level and in the free atmosphere in the first 3000 m above Moldova, Romania

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Abstract. This study presents the complex results obtained through the analysis of the manifestation of thermal inversion on ground level compared with those in the free atmosphere under 3000 m, above the territory between Siret and Prut Rivers. The research was based on data obtained from the network of experimental observations that includes 15 observation points on air temperature at 2 m in altitudinal amplitude of 583 m. The observation point's density is finely homogenized for all altitudinal levels. The deficient analysis of thermal inversion in altitude was partial solved using aerological data from peripheral station: București Băneasa, Chernivt and Odessa. The phenomenon was observed within all altitude levels of about one third of the analyzed cases. Also in more than one third of the cases there are present multiple layers of inversion. The maximum frequency is during the night and especially in winter at ground level. There is a similarity in the manifestation of inversions at ground level with those in altitude. In the periods with high frequency, thickness, intensity and duration of thermal inversions at ground level, similar phenomena characterized the inversions in the upper atmosphere.

Key Words: orographic barrier, thermal gradients, aerological data.

Introduction. Thermal inversions represent a complex phenomenon specific to the depression form of relief that introduces changes in the thermal conditions (Apostol 1986) through stable air stratification (Matveev 1958; Erhan 1981) where the vertical thermal gradient is negative (Matveev 1958), due to their morphological features, this being due to the interdependence of general circulation and characteristics of the active surface, the cause of their production (Apăvăloae et al 1988, 1994).

Thermal inversions are associated with stable stratification conditions or "the most stable" (Friedrich et al 2012) of the air in the low troposphere, the persistence of atmospheric stability conditions. The increase in temperature with altitude, and various characteristics of the air humidity, the thermal inversions influence the formation of clouds in the inversion layer (Horiguchi et al 2014), the transport of aerosols and the speed of the wind (Ahrens 1985).

Thermal inversions occurrence, the intensity and frequency is a consequence of the altitude of the terrain morphology, fragmentation, orientation and degree of closure to external relief (Apăvăloae et al 1988).

Normally, the atmosphere is characterized by a decrease in temperature of the air proportional to the elevation, there are few cases where the temperature tends to rise in altitude, which is characterized by vertical thermal gradients that are negative or null (Apăvăloaei et al 1994). The extra-Carpathian Moldova shows climatic differences between north and south, set by latitude (Mihăilă 2006; Machidon et al 2012), and the higher areas, take the characteristics of the upper atmosphere, cooled by the increasing distance from the thermal source and increased effective radiation. Bellow the average altitude of the Carpathians, air circulation is strongly influenced by them (Apostol & Sfîcă 2011), so blocking the eastern circulation results in outlining a negative thermal anomaly (Apostol 1990, 2004) determining a stable vertical distribution of air with a thickness of 600-800 m (Clima României 2008). The contribution of specific synoptic structures specific in the formation of these phenomena manifest themselves as some cold reservoirs in the winter season (Apostol 2004; Ștefan 2004; Rao et al 2010), less intese than those in the Romanian Plain due to the heat generated by friction with the slopes.

Material and Methods. Observations on air temperature at ground level in the extra-Carpathian Moldova between Siret and Prut are taken under the altitude of 500 m, where the influence of the active surface and the Carpathians induce specific climatic features. The vertical analysis was performed at the following altitudinal levels: ground level, 100 m, 200 m, 300 m, 400 m, 500 m, 1000 m, 1500 m, 2000 m, 2500 m, 3000 m. This altitudinal gap was chosen because the atmospheric layers close to the ground level produces active energy exchanges (Ștefan 2004) and with the exceeding of the average altitude of the Eastern Carpathians the influence of the active surface is reduced (Philandras et al 2013). The network of experimental observations was made on air temperature records every hour, covering well the existing gaps in the national network of meteorological observation. It should be noted that in the region, the official observation network does not covers high altitudes in the region.

Points of observations from the experimental network that exceed an altitude of 400 m are Deleni observation point located in Dealul Mare - Hârlău and operates at an altitude of 487 m and the observations points at Ivanesti, located in the northern Hills of Simila to an altitude of approx. 460 m.

The analysis of vertical thermal gradients within the network using data from experimental observations, has the same time of analysis, showing the thermal behavior and thermal gradients monthly regime in 2013.

The thermal analysis in the extra-Carpathian Moldova was done with data from the network of experimental observations that includes 14 points of observations, including: two automatic weather stations (Cârja and Mădârjac) and 12 data logger (Larga Jijia, Dacia, Dancu, Ştefăneşti, Ciric Răducăneni, Roșiești, Roman, Tudora, Păun, Ivănești, Deleni) (Figure 1).

The data base for the temperature analysis in altitude resulted from a number of 950 soundings performed at the aerological stations București - Băneasa, Chernivt and Odesa, provided by the University of Wyoming (http://weather.uwyo.edu/upperair/sounding.html) framed in a triangle favourable analysis of temperature in the free atmosphere. The values used in the analysis were those from 00 UTC and 12 UTC and brought to Eastern European Time (EET) or UTC +2.

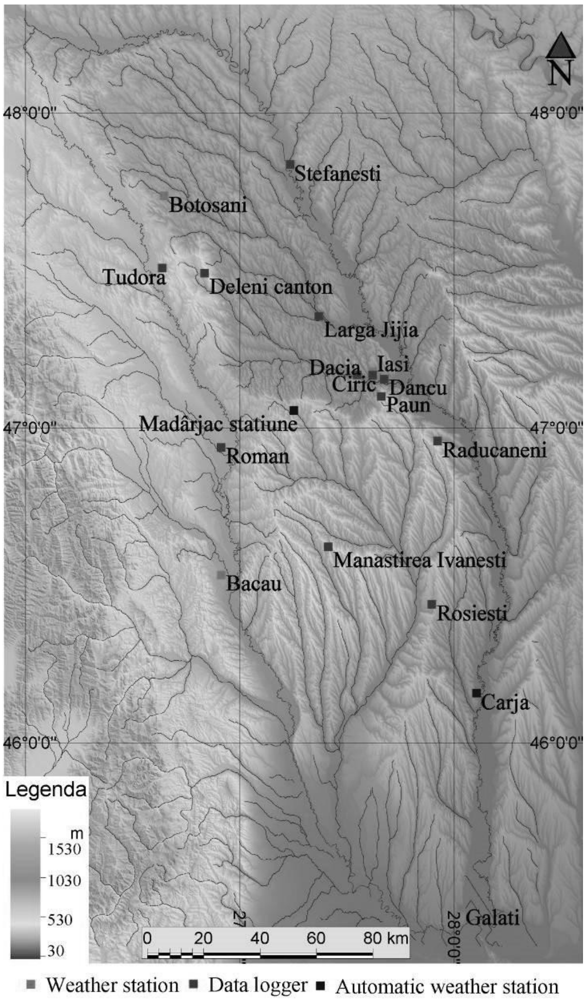

Figure 1. Spatial distribution of mean temperatures at 00 UTC in 2013 in extra-Carpathian Moldova.

With TNT Mips 6.9 GIS software was performed the spatialisation of ground air temperature distribution in the area between Siret and Prut rivers. The method used for modeling was kriging based on multiple regression equation involving the correlation between the recorded temperatures and point altitude. The residual kriging, favorable for the correlation between the two tipes of residues (Patriche 2009), renders best the latitude and longitude variation of air temperature in the conditions of altitudinal and landscape fragmentation homogeneity, characteristic for the analyzed area.

Table 1

Aerological station network from eastern Romania

Aerological stations	*Station number*	*Elevation (m)*	*Latitude (degr.)*	*Longitude (degr.)*
Odesa	33837	42	46.43	30.76
București-Băneasa	15420	91	44.5	26.13
Chernivt	33658	246	48.3	25.9

Results and Discussion

Thermic regime at ground level in 2013. The year 2013 was highlighted by positive thermal differences from the annual average in the main meteorological stations in the analyzed area: Botoșani, Cotnari, Iași, Roman, Bacău and Galați, these vary between 1°C and 2.5°C, the maximum being at Roman, in the Siret corridor, where the thermal inversion phenomena is frequent (Sfîcă 2009).

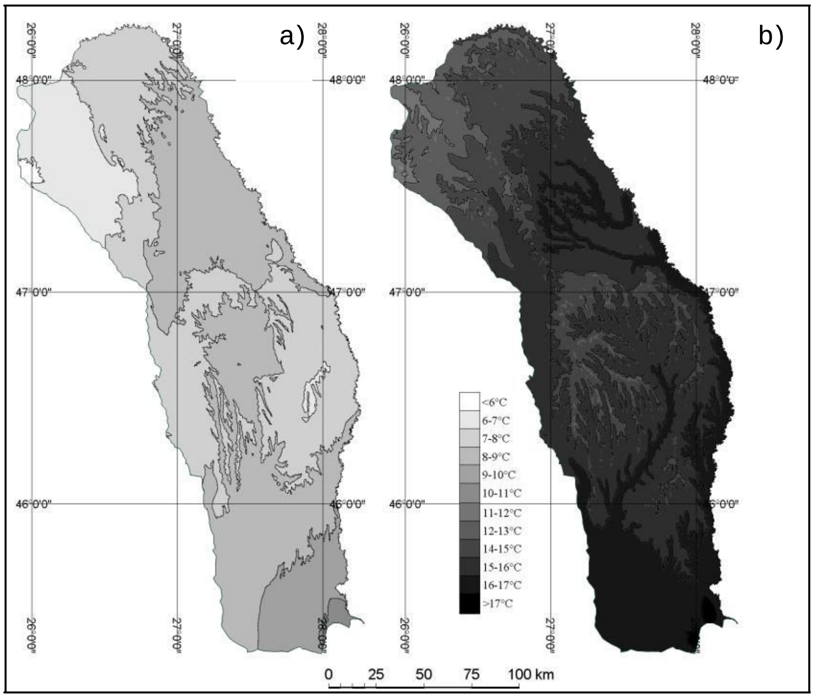

Figure 2. Spatial distribution of mean temperatures at 00 UTC and 12 UTC in 2013 in the extra-Charpathian Moldova.

In the extra-Carpathian Moldova delimited by the Siret and Prut valleys, in 2013 there were observed major thermal differences imposed by the position and various climatic influences.

Thermal gradient values show a complex temporal and spatial distribution both vertically and horizontally. The negative values being specific to concave landforms, where cold air and dense stagnates outlining areas with lower temperatures than those nearby (Stoenescu 1951).

The maps of the spatial distribution of mean temperatures (Figure 2) from 00 UTC (a) and 12 UTC (b) of 2013 highlight a homogeneous of thermic values during the night with values between 6 and 10°C and a diversity during the day caused by the enhanced dynamics caused by the heating of the nederlying active surface and atmospheric circulation (Polvani & Sobel 2002). Areas where the recorded temperatures are lower than the annual average overlap the river valleys, where the frequency of thermal inversions is high and is caused by the concentration effect of the air currents (Oke 1987).

The atmospheric stability specific to the winter season due to the extending of Siberian anticyclone, often leads to record low temperatures due to cold air settling in low areas. The high frequency of the Siberian baric maxima induces lower multianual mean temperatures in the Volovățului, Ibănesei, Cozancei and Tutovei Hills.

Thermic regime in the upper atmosphere above Moldova in 2013. With increasing altitude, the temperature drops to an average gradient of 0.6°C (Ahrens 1985), but in the year 2013 occurred a predominantly reverse situation where the temperature on higher levels of altitude was much higher than at ground level. The main element that caused this development was atmospheric dynamics and advection of mediterranean air masses of hot and humid air mass over the cold continentalized and sedimented air mass at the orographic barrier of the Carpathian mountains (Bordei 2008).

Above the three air stations and free atmosphere the average temperatures at 00 UTC shows a leveling of ground values in the range between 500 and 1000 m altitude, where active surface underlying loses of its influence in favor of the atmospheric general circulation (Merlis & Schneider 2011; Bărcăcianu et al 2014).

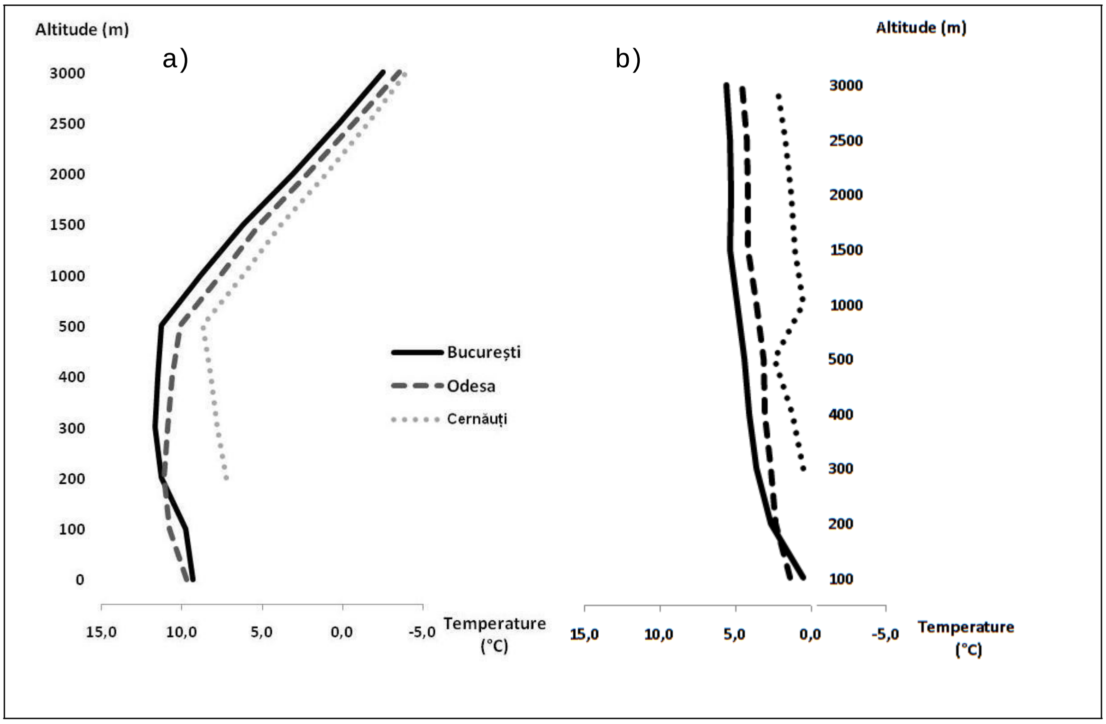

Figure 3. Vertical distribution of mean temperatures in 2013 in the upper atmosphere at 00 UTC above Bucharest-Băneasa, Odessa and Cernivt aerological station.

Below the altitude of 500 m average temperatures at 00 UTC of 2013 confirms the presence of vertical thermal inversions. For those at 12 UTC, available only for air station Bucharest-Băneasa are not favorable to detect thermal inversions, as it should be, because during the day the vertical thermal regime is subjected to solar radiation.

In Figure 3 are represented the thermic evolution on vertically above the analyzed aerological station. In situation a) the curves associated to 500 m show slight increase in the atmospheric stability. Situation b) presents the differences between the evolution of temperature in 2013 and the situation in which the ground temperature would have decreased constantly with a gradient of 0.6/100 m.

The differences of the ideal temperature evolution in altitude (0.6°C/100 m), differs on the three aerological stations (Apostol 2004; Mihăilă 2006). The most spectacular thermal jumps were recorded between the ground and 200 m altitude, with overruns of more than 2°C above the mean at the ground level (Shaevitz & Sobel 2004).

The urban topoclimate known by the familiar theory of urban chimney (Baker et al 1969) puts its mark on the vertical thermal variation, meaning that the maximum growth associated to Bucharest as infrastructure and its morphology is compact compared to the city Chernauti and Odessa. Changes captured in the vertical evolution over Odessa are due to the moderating influence of the Black Sea and the ones at his upper-air station over to Cernivt are caused by its proximity to the orographic barrier of the Carpathians.

The considerable declines varied depending on the particular climate of the aerological station but also the general atmospheric dynamics.

Quantifiable parameters of thermal inversions in the first 3000 m above extra-Carpathian Moldova. The distribution of mean air temperature in depression and valley areas is a consequence of thermal inversion phenomena specific to the periods of pronounced stability under the influence of the Siberian anticyclone and the southward extending of the Scandinavian anticyclone.

Cold air masses from the north-east have a maxim thickness between 500-600 m (Apostol 2004; Sfîcă 2009). Even after the withdrawal of the baric maxima, the depression areas are invaded by cold air that settles on the bottom of the valley corridors and depression, increasing thermal inversion phenomena (Bourne et al 2010; Bradley et al 1992)

The frequency on the ground of the thermal inversions is confirmed by the vertical frequency (Figure 4).

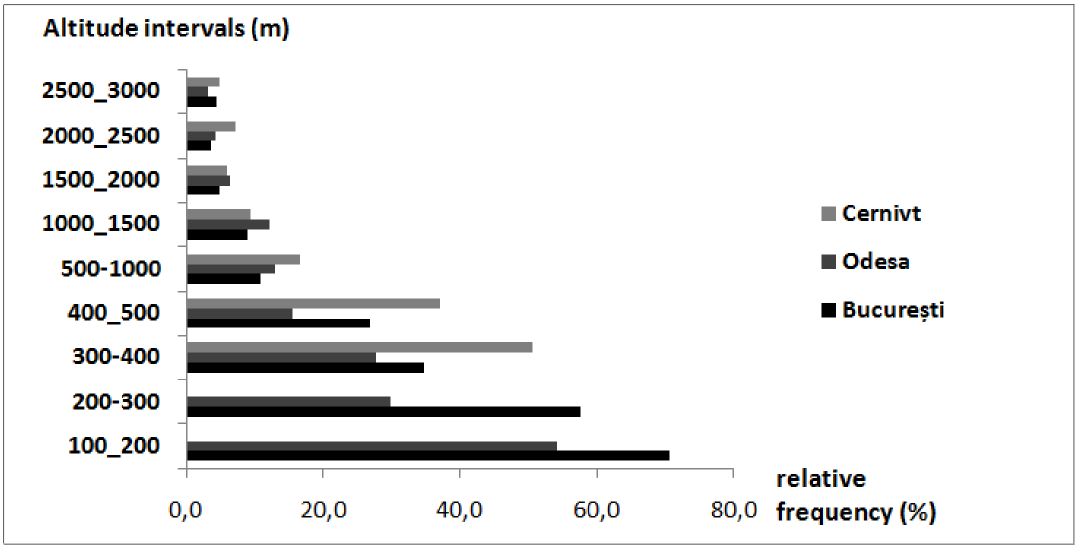

Figure 4. Absolute frequency of thermic negative gradients on altitudinal levels in 2013 above Bucharest-Băneasa, Odessa and Cernivt aerological stations.

In this case, up to 3000 m, the maximum altitude is associated with the level of 500 m. In the first 200 m the position of the aerological station Bucharest-Băneasa in the Carpathian-Balkan depression favors maximum recording rates over 50%, with high intensity and negative thermal gradients, and above Cernăuţi the thermal negative gradients present moderate values but their frequency is higher than the southern aerological stations analyzed.

The thickness of the thermal inversions is dictated mainly by the thickness of cold continental air masses generally under 500-600 m because they often remain confined in the space in front of the Carpathians, favoring the stagnation of cold and dense air and installation of stratus type clouds or fog (Apostol & Sfîcă 2013). By detecting vertical stratification phenomena whose gradient is reversed negative, their resulting cumulative thickness has values of about 2000 m, therefore two thirds of the examined altitudinal range.

The low altitude respectively 91 m Bucharest and 43 m to Odessa, and the high frequency of warm and moist advection (Lolis et al 2012) results in a small thickness of inversion layers.

Trough the Ponto-Carpathian basin characteristics, looking like the bottom of a sack (Bordei 2008) stagnant cold air masses on large areas and long radiative cooling at 00 UTC hours accommodated record low values of thermal gradients in both winter and summer (Figure 5).

At Cernivt station the cumulative thickness of the inversion layers is greater due to its position in the Carpathian area, where the dynamics is dictated by cold advection from the north and east and the negative thermal gradient is moderate as values.

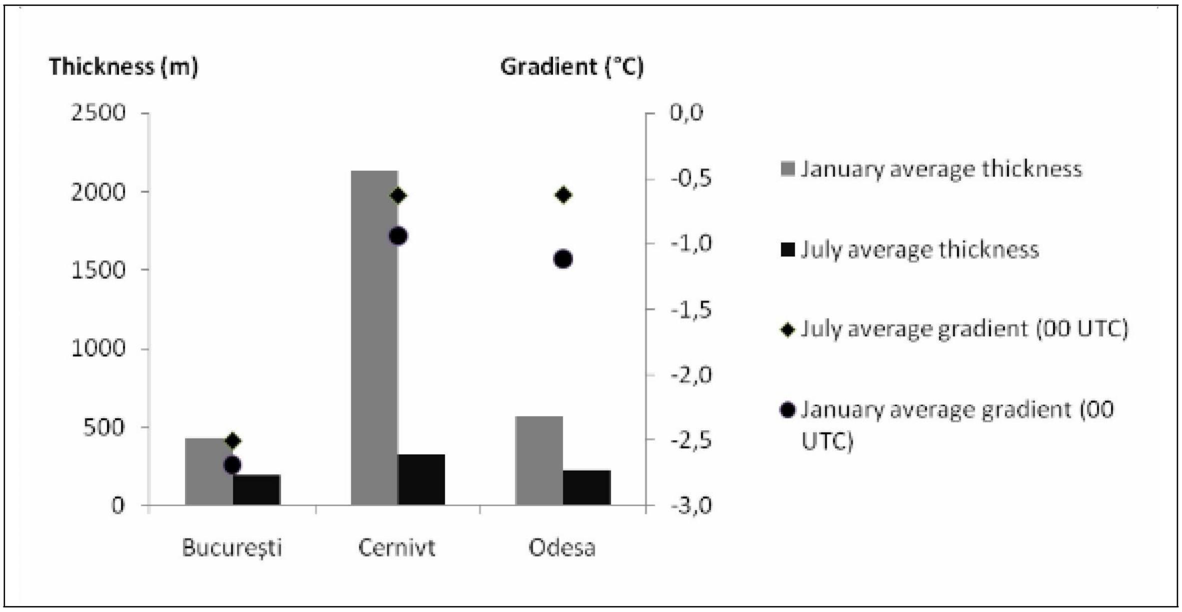

Figure 5. Mean thickness of inversion layers and average gradient in January and July 2013 at 00 UTC above Bucharest-Băneasa, Odessa and Cernivt aerological stations.

Pearson correlation values of the ground situation with the one in the atmosphere was achieved by calculating the thermal gradients between weather stations and observation points, representative for those resulting from atmospheric surveys. Thus we used the negative thermal gradients on the Deleni-Tudora profile, with a difference of 231 m, Deleni-Roman with an altitude difference between 487 m and 205 m, both correlated with the gradients registered above the Cernivt station up to 500 m.

At the aerological station Odessa, were associated analysis data from Botosani, Iasi because their altitude records in 392 m under the Cernivt station and the Ivanesti-Galaţi profile. The thermal inversion phenomena characteristic of the last profile was correlated with the Bucharest values to observe the characteristics of the phenomena on a large scale.

The results showed a very good correlation in January, representative of the cold season, on the vertical 200-400 m altitudinal range and spatially to the north of extra-Carpathian Moldova.

The profile from the south of Ivănești-Galați and the one between Iași and Botosani are assigned high values of about 0.4 higher than the situation at Odessa the explanation consisting in the openness of the circulations to the east, northeast and north. Negative values of Pearson correlation values over Bucharest indicate specific features of the southern Carpathians inversions, with very low frequency and gradients.

Conclusions. Positive thermal deviations of 2013 were not a required thermal inversion phenomenon of evolution, outlining the areas where the frequency was high and the vertical analysis of thermal gradients calculated from radiosoundings and profiles made between points of observation of the area examined confirmed their known spatial manifestation.

So the concave forms of the depressions and river valleys, especially Siret and Prut rivers and the Volovăţului, Ibănesei, Cozancea and the Tutovei hills recorded high frequency phenomena associated with thermal stability, one other reason being the high frequency of the maximum Siberian baric.

In altitude, the average number of inversion layers under 3000 m calculated for the survey at 00 UTC differs, the January average, representative for the cold season is approximately 2 layers, and for July their altitude increases due to heating the earth's surface and the number is reduced to 0.5. The thickness is variable, in the summer cumulating under 500 m for the three analyzed stations and in the winter is 500 m thick, associated in the southern stations, Odessa and Bucharest. Above the upper-air station in Cernivt, the average thickness reaches in January at 00, values of about 2000 m, the gradient values ranging between 0 and -1°C.

By analyzing the gradient profiles characterizing the situation on the ground with the values resulting from the processed radio surveys, the correlations reveal similar mechanisms in the northern part of the exterior carpathian Moldova between Siret and Prut, toward the south of the region the situation is complex due to the particularities of the local dynamics.

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References

Ahrens C. D., 1985 Meteorology today. An introduction to weather, climate and environment. West Publishing Company, 576 pp.

Apăvăloae M., Apostol L., Pîrvulescu I., 1994 Inversiunile termice din Culoarul Moldovei (sectorul Câmpulung Moldovenesc – Frasin) și influența lor asupra poluării atmosferei. Analele Universității „Ștefan cel Mare", Suceava, anul 5, secțiunea Geografie-Geologie.

Apăvăloae M., Pîrvulescu I., Apostol L., 1988 Caracteristici ale inversiunilor termice din Podișul Fălticenilor. Lucrările Seminarului Geografic „Dimitrie Cantemir", nr. 8, 1987, Universitatea „Al. I. Cuza", Iași.

Apostol L., 2004 Clima Subcarpaților Moldovei. Editura Universității Suceava, 439 pp.

Apostol L., 1990 Anomalii ale temperaturii aerului pe teritoriul Moldovei. Lucrările Seminarului Geografic „Dimitrie Cantemir", nr. 9, 1988, Universitatea „Al. I. Cuza", Iași.

Apostol L., 1986 Distribuția temperaturilor medii ale lunii ianuarie între Munții Vrancei și Balta Brăilei. Lucrările Seminarului Geografic „Dimitrie Cantemir", nr. 6, 1985, Universitatea „Al. I. Cuza", Iași.

Apostol L., Sfîcă L., 2011 Influence of the Siret river corridor on wind conditions. Prace i Studia Geograficzne T.47:483–491.

Apostol L., Sfîcă L., 2013 Thermal differentiations induced by the Carpathian Mountains on the Romanian territory. Carpathian Journal of Earth and Environmental Sciences 8(2):215–221.

Baker D. G., Enz J. W., Paulus H. G., 1969 Frenquency, duration, commencent time and intensity of temperature inversions at St. Paul – Mineapolis. J Appl Meteor 8:747-753.

Bărcăcianu F., Apostol L., Moroșanu A. G., 2014 Characteristics of thermal anomalies occurring during the cold season above Bucharest, as determined on the basis of radio and satellite soundings. Proceedings of the VIth International

Conference ,,Air and water – components of the environment", Faculty of Geography, „Babeş-Bolyai" University, Cluj-Napoca, pp. 180-187.

Bordei N. I., 2008 Fenomene meteoclimatice induse de configurația Carpaților în Câmpia Română. Editura Academiei Române Publishing House, Romania.

Bourne S., M., Bhatt U. S., Zhang J., Thoman R., 2010 Surface-based temperature inversions in Alaska from a climate perspective. Atmospheric Research doi:10.1016/j.atmosres.2009.09.013

Bradley R. S., Keimig F. T., Diaz H. F., 1992 Climatology of surface-based inversions in the North American Arctic. J Geophys Res 97(D14):15699–15712.

Erhan E., 1981 Contribuții la studiul inversiunilor de temperatură din Depresiunea Câmpulung Moldovenesc. Lucrările Seminarului Geografic „Dimitrie Cantemir", nr. 1, 1980, Universitatea „Al. I. Cuza", Iași.

Friedrich K., Lundquist J. K., Aitken M., Kalina E. A., Marshall R. F., 2012 Stability and turbulence in the atmospheric boundary layer: A comparison of remote sensing and tower observations. Geophys Res Lett 39(3) L03801, doi: 10.1029/2011GL050413.

Horiguchi M., Hayashi T., Adachi A., Onogi S., 2014 Stability dependence and diurnal change of large-scale turbulence structures in the near-neutral atmospheric boundary layer observed from a meteorological tower. Boundary Layer Meteorol 151(2):221–237.

Lolis C. J., Bartzokas A., Lagouvardos K., Metaxas D. A., 2012 Intra-annual variation of atmospheric static stability in the Mediterranean region: a 60-year climatology. Theoretical and Applied Climatology 110(1-2):245–261.

Machidon O., Apostol L., Machidon D., Buruiană D., 2012 Study of the evolution of the air temperature in Moldavia region (Romania) over the last 76 years. Annals of DAAAM for 2012 & Proceedings of the 23rd International DAAAM Symposium, 23(1):688- 692, Published by DAAAM International, Vienna, Austria.

Merlis T. M., Schneider T., 2011 Changes in zonal surface temperature gradients and walker circulations in a wide range of climates. J Clim 24(17):4757–4768.

Mihăilă D., 2006 Câmpia Moldovei - studiu climatic. Editura Universității Suceava Publishing House, Suceava, Romania, 465 pp.

Matveev L. T., 1958 Meteorologie generală. Tradus de T. Mândrescu, București 1964.

Oke T. R., 1987 Boundary layer climates. Second Edition, reprinted 2006, Routledge, New York, U.S.A.

Patriche C., 2009 Metode statistice aplicate în climatologie. Terra Nostra Publishing House, Iaşi, Romania.

Philandras C. M., Nastos P. T., Kapsomenakis I. N., Repapis C. C., 2013 Climatology of upper air temperature in the Eastern Mediterranean region. In: Advances in Meteorology, Climatology and Atmospheric Physics. Helmis C. G., Nastos P. T. (eds), Springer Atmospheric Science.

Polvani L. M., Sobel A. H., 2002 The hadley circulation and the weak temperature gradient approximation. J Atmos Sci 59:1744–1752.

Rao A. D., Babu S. V., Murty P. L. N., Pandey S., 2010 Impact of stratification on internal waves and differential wearing of thermal inversions on the east coast of India. Nat Hazards (Dordr) 57(3):577–595.

Sfîcă L., 2009 Culoarul Siretului: Studiu climatic. PhD Thesis, "Al. I. Cuza" University, Iaşi, Romania.

Shaevitz D. A., Sobel A. H., 2004 Implementing the weak temperature gradient approximation with full vertical structure. Mon Wea Rev 132:662-669

Stoenescu S., 1951 Clima Bucegilor, memorii și studii, D.G.H., I.M.C. Editura Tehnică publishing House, Bucharest, Romania.

Ștefan S., 2004 Fizica atmosferei, vremea și clima. Editura Universității București Publishing House, pp. 292-324.

*** (2008), Clima României, Administraţia Naţională de Meteorologie, Editura Academiei Române.

*** http://weather.uwyo.edu/upperair/sounding.html

*** http://www.ogimet.com/

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