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Comparative Analysis of Land and Air Temperature in Romania since A.D. 1961

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Abstract: Daily time series with continuous records of mean air and soil temperature from 127 meteorological stations—fairly distributed over the country—were used to compute monthly temperature trends, as well as changes in the timing of the first and the last frost days over Romania since 1961. Results show that the frequency of the number of days with daily temperature averages below 0 °C in case of air and soil surface temperature is stable for most months, except for January, when (for both soil and air temperature), the number of days with a temperature below 0 °C is decreasing in the majority of the stations. The occurrence of the first day with (mean air and soil surface) temperatures below 0 °C, presents a delay in the south, south-east, and west, and an earlier occurrence in eastern and central regions. The occurrence of the last day with a mean air and soil surface temperature below 0 °C shows a stable trend for most stations (except for some small areas in the north, south-east and south-west of Romania). The regime of the land temperature is more stable, due to the physical characteristics of the soil, compared to the more versatile atmosphere. Linkages between thermal parameters and large-scale atmospheric circulation are also discussed.

Keywords: air temperature; soil surface temperature; nonparametric test; Mann–Kendall; Sen's slope estimator; atmospheric circulation; Romania

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1. Introduction

The most important factor that drives all the climatological processes on Earth is the Sun's energy—the ultraviolet, visible, and a limited portion of infrared energy [1]. Changes in the intensity and composition of the solar radiation hitting the Earth may produce changes in global and regional climate. In recent years, solar variations appear to have a significant impact in Europe in winter. By means of statistical analysis it is possible to identify decadal and centennial signals of solar variability in climate data. These are interpreted as non-uniform responses across the globe, perhaps with the largest impacts in mid-latitudes [2].

Many studies have linked climate change to the urban development from the last century. Thus, the connection between urban built environment and global changes is seen in the increase in urban air temperatures, the energy consumption rate, the increased use of raw materials, pollution, and the production of waste, conversion of agricultural to developed land, loss of biodiversity, and water shortages [3]. As air temperature is a result of a thermodynamic process of the land heated by the Sun's radiation [4], this study aims to reveal and assess whether important changes in land temperature regime can be identified through statistical methods, using meteorological data provided by 127 Romanian weather stations during the 1961–2015 period. For many years, researchers were concerned about the impact of climate change on the ecosystem. In this respect, Brown et al. (1997) stated that natural ecosystems contain many individuals and species interacting with each other and with their abiotic environment, exhibiting complex dynamics in which small perturbations can be amplified to cause large changes [5]. In that research they have investigated the variation of the meteorological parameters and supposed that the changes could have been caused by a shift in regional climate (the winter precipitation throughout the region became substantially higher than average in the analyzed period) and that these changes illustrate the kinds of large, unexpected responses of complex natural ecosystems that can occur in response to both natural perturbations and human activities. Another problem related to climate change is land use. Variations over the years in land use and surface cover type may be of equal importance with the presence of greenhouse gases [6]. Therefore, ecosystems and human lives are affected in many ways by climate change:

- Climate change over the past decades had produced numerous shifts in the distributions and abundances of species and has been implicated in one species-level extinction [7]; Kelly and Goulden [8] expect that climate change will shift plant distribution as species expand in newly favorable areas and decline in increasingly hostile locations. Their study comparing the year 1977 with the period 2006–2007 showed that southern California's climate warmed at the surface, the precipitation variability increased, the amount of snow decreased during the 30-year period preceding the second survey, and the average elevation of the dominant plant species rose by ≈65 m between the surveys.
- It is supposed that further temperature rises will have a profound impact on commercial fisheries through continued shifts in distribution and alterations in community interactions [9].
- Baker et al. (2004) showed that corals containing unusual algal symbionts (that are thermally tolerant and commonly associated with high-temperature environments) are much more abundant on reefs that have been severely affected by recent climate change [10].
- Agricultural adaptation must be made in a more coherent manner due to the likelihood of further changes occurring, and there are many potential adaptation options available for marginal change of existing agricultural systems (often variations of existing climate risk management) [11].
- Using four different global datasets, Nita et al. [12] showed that the last decade was the warmest in Europe, USA, southern Africa, northern Siberia and most of Australia, since modern measurements have been introduced.

Other studies regarding the soil temperature reflect some changes compared to a previous reference period (1961–1990). O.V. Reshotkin and O.I. Khudyakov [13], studying meteorological data from weather stations located in the European part of Russia, have determined that the average annual temperature has increased by 0.5, . . ., 1.0 °C. K. Dorau et al. [14], processing meteorological data from north Rhine-Westphalia (Germany), have concluded that in summer months the warming effect of the soil is more intense. Soil humidity is correlated to soil temperature. Almendra-Martin et al. [15] found a tendency towards drier soil conditions in Europe. García-García et al. found a faster increase in soil hot extremes compared to air hot extremes—both in intensity and in frequency—over central Europe [16].

There are two main objectives of this paper: (1) to investigate changes in the days of occurrence of the first and the last frost over Romania from observational data (which may affect vegetation development) in the context of regional climate change; (2) to analyze trends in land and air temperature and their connection with large-scale atmospheric circulation.

2. Materials and Methods

Romania is the largest country in southeastern Europe, with an area of 238,391 km^2. The terrain is almost equally distributed between mountains (Carpathians), hills, and lowland regions. The elevation range is between zero and 2544 m.a.s.l. The country has a transitional climate between temperate and continental with four distinct seasons, and has several climatic influences. The continental temperate climate is strongly influenced by orography, with the Carpathian Mountains significantly affecting the air circulation [17,18].

Romania includes most of the Carpathian chain, the lower basin of the Danube, and part of the western shore of the Black Sea, from which it follows that this is a Carpatho-Danubian-Pontic country, within which the main geographical features of the continent interfere [19].

The surface of the territory presents a great diversity of the main forms of relief, distributed approximately proportionally: plains and meadows (below 200 m altitude) occupy 33%, hills and plateaus (with heights between 200 and 800 m) 37%, and mountains (over 800 m altitude) 30% [20]. The mountainous region, composed of three main units (eastern, southern, and western Carpathians), represents the highest and most rugged relief unit within the country. Through their height, massiveness, and orientation towards the main components of the atmospheric circulation, the Carpathian Mountains are the most important factor of the underlying surface, influencing the climate of the entire territory of the country. They represent an obstacle in the way of the air masses (in particular the eastern and southern Carpathians), determining appreciable differences in the distribution of the characteristics of the meteorological regime and the climate, on either side of the mountains. Under the influence of the mountains, the directions of movement of cyclones change, the fronts are deformed, and in the case of advection from the west (characteristic at this latitudes), a series of thermodynamic processes take place inside the air masses. Furthermore, on the sheltered slopes, foehnal effects are produced, which causes important changes in cloudiness, precipitation, temperature, and air humidity. The climate regime is thus wetter and more moderate in Transylvania and the Western Plain and drier and more continental in the southern and eastern part of the country [20].

Therefore, Romania presents a temperate-continental climate with oceanic influences in the western and central regions (higher humidity, abundant precipitation, and westerly winds), sub-Mediterranean climate in the southwest (with reduced thermal contrasts between winter and summer), continental-excessive climate in the southeast and east (with obvious thermal contrasts between the two extreme seasons), Scandinavian-Baltic climate in the northeast of the country (with moderate and wet summers and early and frosty winters), Pontic climate in the southeast (moderate, with high insolation, low rainfall and breezes), and in the south, transitional climatic influences (where eastern and western circulations interfere). Furthermore, the bioclimatic disparities induced by the Carpathian chain are visible in the presence of alpine and subalpine pastures and boreal and nemoral forests [21].

Romania has a great diversity of soils. Over a quarter of the country's surface (26.7%) is covered by soils from the chernisols class, another quarter (25.5%) by the luvisols class, and the third quarter (25.5%) by the group of mountain soils represented by the cambisols, andisols, spodisols, and umbrisols classes. Alluvial soils occupy one tenth of the surface (9.2%). The rest of the surface (13.1%) is occupied by locally distributed soils represented by hydrisols (3.2%), salsodisols (0.8%), pelisols (1.6%), various protisols (5.3%), and lakes and swamps (2.2%) [19].

Recent studies on country-wide climatic changes in Romania over the last decades showed an increase in extreme events like heat waves [22–24] and drought [25], which also affect the streamflow regime [26], the terrestrial ecosystems [27–31], and human health [32]. Here, the increase in frequency of thermal extremes is of particular interest [33–37]. Several studies highlighted the influence of large-scale circulation patterns and air temperature and precipitation regimes [38–41].

On a national level, the studies and the observation data revealed an increase in temperature in almost all months of the year, from one reference period to the next (Table 1).

There has also been observed a changed precipitation regime, which decreased in six months of the year and registered a small increase in the other six (Table 2).

For this study, a long-term series of daily mean air (measured at 2 m above ground) and soil temperature (measured at the bare soil surface) measurements were used, as well as daily minimum soil temperature (measured at the bare soil surface) from the national weather station network of Meteo Romania (Romanian National Meteorological

Administration), covering the 1961–2015 period. We have chosen to analyze the mean air temperature instead of the daily minimum temperature, because the first shows a more stable and persistent atmospheric condition. The analysis was extended to all Romanian weather stations that provided this kind of information during the above mentioned period, resulting in a total number of 127 weather stations, distributed as follows: 40 stations located at elevations below 100 m, 24 stations located at elevations between 101 m and 200 m, 24 stations with heights between 201 m and 300 m, 14 stations with heights between 301 m and 400 m, 6 stations with heights between 401 m and 500 m, 10 stations with heights between 501 m and 600 m, 5 stations with heights between 601 m and 700 m, 2 stations with heights between 701 m and 800 m, one station positioned at 923 m height, and one station located at a height of 1090 m (Figure 1).

Table 1. Average monthly temperature (°C) for the mentioned reference periods (source: Meteo Romania).

Climatological Normal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961–1990	−3.2	−1.2	3.1	9.1	14.3	17.6	19.2	18.6	14.8	9.3	4	−0.7
1971–2000	−2.4	−1	3.3	8.9	14.3	17.7	19.3	18.8	14.5	9.1	3.3	−0.7
1981–2010	−2.1	−1	3.5	9.3	14.9	18.3	20.2	19.7	14.8	9.6	3.8	−0.8

Table 2. Average monthly precipitation amount (mm) for the mentioned reference periods (source: Meteo Romania).

Climatological Normal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961–1990	36.4	34.9	35.1	51.3	75.4	89.4	78.5	64	45.6	37.5	43.7	42.4
1971–2000	31.2	29.2	32.8	52.8	72.9	88.7	77.8	63.5	51.6	42.3	40.2	39.4
1981–2010	33.6	31.6	38.3	51.3	66.5	84.5	77.9	64.7	55	43.5	41.5	44.8

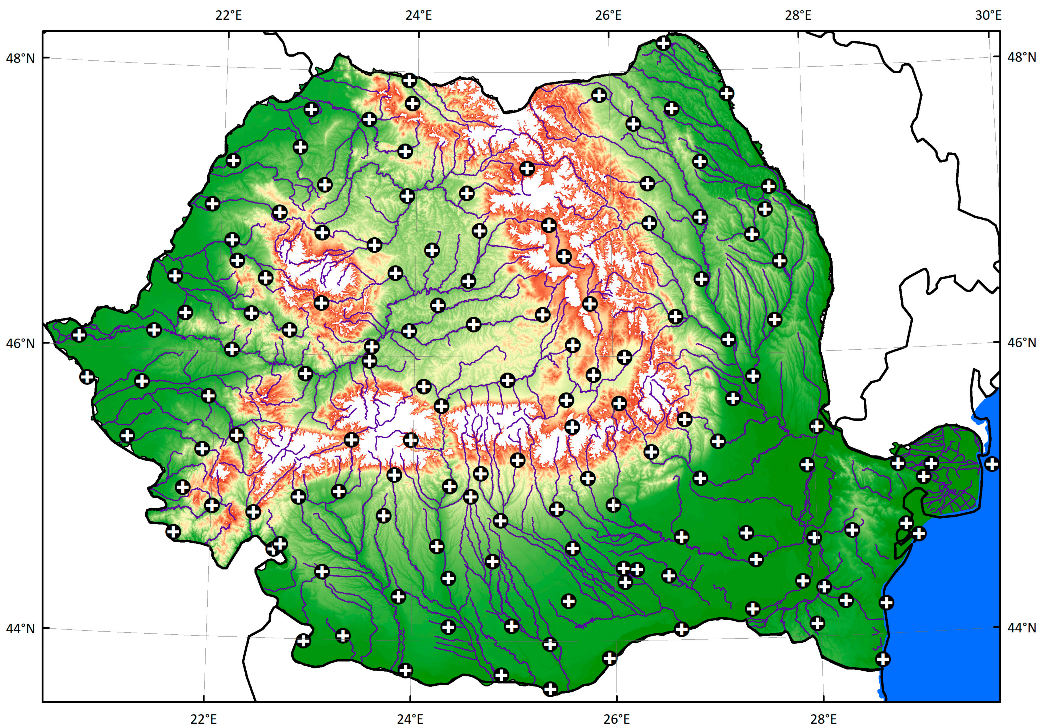


Figure 1. Spatial distribution of the selected weather stations over Romania. The Blue area represents the Black Sea.

For all the weather stations, the soil temperature measurements were performed with mercury-in-glass and alcohol thermometers. Regarding the air temperature, this parameter was measured with mercury-in-glass thermometers until the automatic equipment was installed at the weather stations. Thus, for the analyzed data, at the end of 2015, 77.3% of the stations performed automatic measurement of the air temperature, gradually starting/beginning with the year 1999.

The local significance of trends has been analyzed with the nonparametric Mann–Kendall (MK) test [42,43], which is a rank-based procedure particularly appropriate for non-normally distributed data, time series containing outliers, and non-linear trends [44].

The null and the alternative hypothesis of the MK test for trends in the random variable x are

$$\begin{cases} H_0 : Pr(x_j > x_i) = 0.5,\ j > i \\ H_A : Pr(x_j < x_i) \neq 0.5,\ \text{(two-sided test)} \end{cases} \tag{1}$$

The MK statistic S is

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \tag{2}$$

where x_j and x_k are the data values in years j and k, respectively, with $j > k$, n is the total number of years, and $sgn()$ is the sign function:

$$sgn(x_j - x_k) = \begin{cases} 1,\ \text{if } x_j - x_k > 0 \\ 0,\ \text{if } x_j - x_k = 0 \\ -1,\ \text{if } x_j - x_k < 0 \end{cases} \tag{3}$$

The distribution of S can be well approximated by a normal distribution for large n, with mean zero and standard deviation given by

$$\sigma_S = \sqrt{\frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18}} \tag{4}$$

Equation (4) gives the standard deviation of S with the correction for ties in data, with t_i denoting the number of ties of extent i. The standard normal variate Z_S is then used for hypothesis testing:

$$Z_S = \begin{cases} \frac{S-1}{\sigma_S} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma_S} & \text{if } S < 0 \end{cases} \tag{5}$$

The null hypothesis is rejected at significance level α, if $|Z| > Z_{\alpha/2}$, where $Z_{\alpha/2}$ is the value of the standard normal distribution with an exceedance probability $\alpha/2$. For the present analysis, the significance level was fixed at 10% (two-tail test).

The trend magnitude was computed with the nonparametric Sen's slope estimator (also known as Theil–Sen estimator or Kendall–Theil robust line), which is suitable for quasi-linear trends and is less affected by outliers and non-normally distributed data [45]. The slope is computed between all pairs i of the variable x:

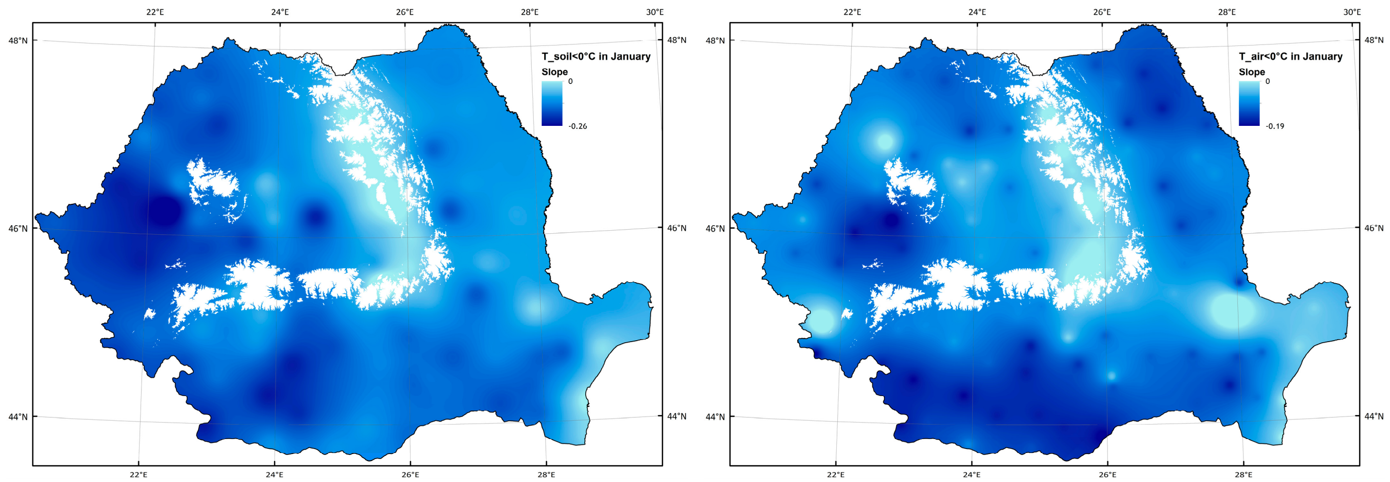
$$\beta_i = \frac{x_j - x_k}{j - k},\ \text{with } j > k;\ j = 2, \ldots, n;\ k = 1, \ldots, n-1 \tag{6}$$

where I = 1, . . ., N. For n values in the time series x this will result in $N = n\ (n - 1)/2$ values of β_i. The slope estimate b is the median of β_i, i = 1, . . ., N.

3. Results and Discussion

For each station, the statistical trend analysis of the annual frequency of the number of days with mean temperatures (soil surface and air) below zero Celsius in the August–May interval was computed. With very few exceptions, the statistical processing of the soil surface and the air temperature did not result in a significant value (which could reflect a notable change in the behavior analyzed climatic zones), except January. January is the only month when both soil surface and air temperature show statistically significant decreasing trends.

The decrease trend in the case of soil surface covers smaller areas compared to air temperature, but as a whole the behavior is similar in Figure 2.



(**a**) (**b**)

Figure 2. Magnitude (Sen's slope) of trends of the frequency of the number of days with a mean soil surface temperature below 0 °C in January (**a**) and a mean air temperature below 0 °C for the same month (**b**), over the period 1961–2015. Elevations above 1100 m.a.s.l. are in white (no station with soil temperature data is available above 1100 m.a.s.l.; therefore, the spatial interpolation would not be relevant for these areas).

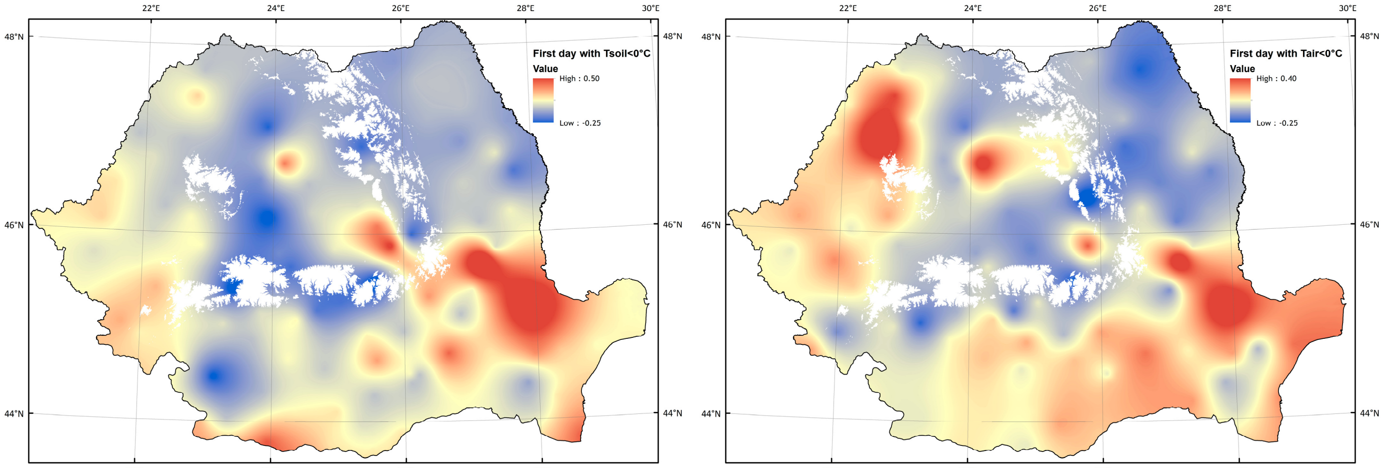
The second analysis of the data had in view the detection of a shift in the first day and the last day with temperatures (soil surface and air) below zero Celsius. This could be important as a sign of a climatic change, first of all for the life cycle of the vegetation, if the shift had important values.

Thus, it can be observed that the western and southern parts of Romania—in particular the southeastern part—register an important shift of the first day of freezing, because of the tendency manifested by the dynamical high-pressure centers, the Azores Anticyclone, and the African one, to be prevalent in the last decades, at our latitudes (Figure 3). Also, the Mediterranean cyclones with trans-Balkan trajectory, which often affect the south-east of Romania, with a retrograde movement in the Black Sea, bring a mild climate in this part of the country.

Regarding the Oituz Pass (central-east), where there is a decrease in the number of days with temperatures below 0 °C, the reason with respect to atmospheric circulation could be as follows: on south circulation over Carpathians (a type of circulation induced by Mediterranean trans-Balkan cyclones in the cold season) there is a foehn-type wind (known in the region as "the snow eater" or "the black wind") that brings sudden warming and melting of snow in the Brașov and Făgăraș basins (southern Carpathians).

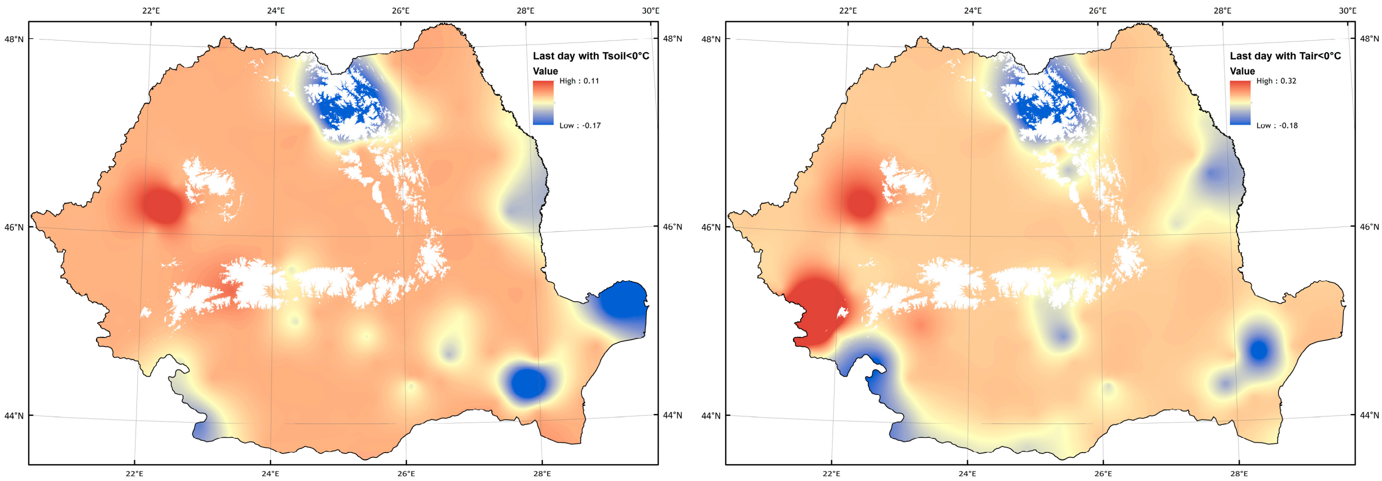
Given the prevalence of an air circulation from the north and north-east (due to the two anticyclones occurring during the cold season), the influence of the Carpathian curvature requires a split of the atmospheric fluid flow to east pericarpathian to over Moldolva, and to west pericarpathian over the Pannonian Plain, and then to west-northwest Romania and particularly in Transylvania. Winter anticyclones are seasonal and semi-permanent. They develop in polar or arctic mass and they are put in motion from the polar cap (Scandinavian Anticyclone) or over the East European Plain, through subsidence over the consistent layer of snow (Eastern European Anticyclone).

And, for the shift observed in the middle of the country, in Transylvania, it can be justified by the extension of that warm cyclonic influence, because in the internal mountain curvature area the wind is channeling from Bărăgan Plain (southern Romania) through the Oituz Pass. Also, for the north-west area of the Transylvania region (the center of the country), the canalization of the wind from the west through the Someş river valley (central north) ensures a temperature regime less severe than in the Moldova (eastern) region, which is directly exposed to northern influences from the Baltic Sea, or eastern Transylvania (Figure 4).



(**a**) (**b**)

Figure 3. Trends in the timing (occurrence) of the first day with a soil surface temperature below 0 °C (**a**) and of the first day with a mean air temperature below 0 °C (**b**), over the period 1961–2015. Elevations above 1100 m.a.s.l. are in white (since no station with soil temperature data is available above 1100 m.a.s.l., the spatial interpolation might not be relevant for these areas).



(**a**) (**b**)

Figure 4. Trends in the timing of the last day with a soil surface temperature below 0 °C (**a**) and of the last day with a mean air temperature below 0 °C (**b**), over the period 1961–2015. Elevations above 1100 m.a.s.l. are in white (since no station with soil temperature data is available above 1100 m.a.s.l., the spatial interpolation might not be relevant for these areas).

The evolution of the first day with a temperature below zero seems to be more stable in the case of soil than in the case of air. In both representations, the south-east of the country shows a delay regarding the occurrence of the first frost, up to 2 days in 50 years. In the east part of the country (Moldova region), the trends show an early occurrence of the first frost, up to 1 day in 50 years. In the south area of the country (Muntenia and Oltenia regions), the most significant delay for the first day with a temperature below 0 °C is in the case of air temperature. The western part of the country is showing an opposite trend for the trends of the first day with temperature below 0 °C in the case of soil surface and air.

Overall, for the majority of the analyzed stations, the trend for the first day with a temperature below zero Celsius is to delay (1–2 days in 50 years). The last analysis is about the change in the occurrence of the last day with a temperature below zero Celsius. In the context of climatic change, this computation should show an increase in the period with low temperatures.

Even so, in both cases (Figure 4a,b), the occurrence trend is showing an increase in very few and small areas (in north, south-west, and south-east). In the south-west of the country, consistent with the early occurrence of the first day with an air temperature below zero Celsius, the analysis shows a delay of the last day with air temperature below zero Celsius up to 1.5 days in 50 years.

Our results are in strong agreement with recent studies on air temperature in Romania, which has increased over the entire country since 1961, with increases in maximum air temperature presenting higher magnitudes than those in minimum air temperature [35]. The warming trend has also been confirmed by the upward trends in hot-related thermal extremes, like the number of summer days (country-wide) and the number of tropical nights (at lower elevations) [33]. Also, Micu et al. concluded that the warming intensity was stronger at lower latitudes in the Carpathian Mountains region [46].

4. Conclusions

Overall, the frequency analysis of the number of days with daily temperature averages below zero Celsius in the case of air and soil surface temperature show stability for the majority of the months, except January.

In January, for both analyzed temperatures for almost all analyzed stations there are statistically significant decreasing trends for the number of days with daily temperature averages below zero Celsius, which can indicate a warming of the climatological regime of this month in Romania.

Regarding the occurrence of the first day with (air and soil surface) daily temperature averages below zero Celsius, different regions of Romania show distinct trends—delay of the occurrence in south, south-east, and west and an early occurrence in eastern and middle regions.

The occurrence of the last day with (air and soil surface) daily temperature averages below zero Celsius shows a stable trend for the majority of the analyzed stations. Only in some small areas in the north, south-east, and south-west are indications of a decreasing date of occurrence (up to almost one day in 50 years). Last but not least, in the western region there are two cases of delay of the last day with daily air temperature averages below zero Celsius up to 1.5 days in 50 years.

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