Tropical nights (1976–2019) as an indicator of climate change in Ukraine

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Abstract. The article presents the results of an analysis of the number, frequency and intensity of tropical nights in Ukraine. We have selected such weather stations that are located at different latitudes and correspond with the north, west, east, and south as well as the central part of Ukraine. This was done in order to analyse the differences in tropical nights across latitudes. Also we have weather stations located at the approximately one latitude to analyse how tropical nights vary in longitude. Data from weather stations for 1976-2019 were under analysis. We can say that the increase in the minimum air temperature during summer is on the whole territory of Ukraine. This leads to the fact that since the mid-1990s tropical nights begin to be observed in the east of Ukraine, as well as in the south. After 2000, tropical nights also have begun to be observed in the centre and even in the west of Ukraine. Between two half-periods (1976-1997 and 1998-2019) the increase of number of tropical night events in the south of Ukraine (up to 300 cases) is much more significant than the increase in their number in the northwest (up to 20 cases). As well as the frequency, the intensity of tropical nights also increases. There are cases with minimum daily air temperatures above 25°C. The analysis of the North Atlantic Oscillation (NAC) and the Mediterranean (Cairo-Algeria) indices in the context of explaining the tropical night's occurrence in Ukraine turned out to be quite effective.

1. Introduction

The concept of tropical nights was introduced in 2005 as an important indicator of climate change by the Predictability (CLIVAR) project's Expert Team on Climate Change Detection, Monitoring, and Indices (ETCCDMI) [1]. Teaming up with other professionals, the "Expert Team on Climate Change Detection" and Indices ETCCDI defined "tropical nights" as days when the daily minimum temperature exceeds 20 °C. In 2007, the Intergovernmental Panel on Climate Change, an international group of scientists who represented more than 130 countries, presented its Fourth Assessment Report, which contains bird's-eye summaries about current and past climate change, its impact on environment and populations, as well as about possible measures to counteract such changes. This report declares that there is a 90% chance that the climate change we are seeing now is due to human activities [2]. The human genesis of current climatic changes is confirmed by paleoclimatic research founded on the greenhouse gas content analysis of air bubbles frozen in ice.

These studies show that there has not been such thousand years high concentration of CO_2 as it is today over the past 650,000 years (and over these years were many global warming events of Earth climate). Furthermore, as compared with the preindustrial era (1750), the percentage of carbon dioxide in the troposphere increased by a third. Current global methane concentrations and nitric oxide have also significantly exceeded the pre-industrial values. In fact, increasing of the frequency and duration of tropical nights is one of consequences of the climate change mentioned above.

According to prospective estimates [2], the Earth surface air temperature will increase during the 21st century under any considered emission scenarios. In all likelihood, tropical nights will occur more frequently and will longer, and at the same time many regions, extreme precipitation events will become more intense and frequent. Extremely low temperatures will still be observed in some cases in winter. The processes of warming and acidification of World Ocean and average global sea level rising will continue. It has been determined that with an increase of average global air temperatures over most of the land surface on daily and seasonal time scales, extremely high temperatures will be observed more often, which will form under certain synoptic conditions [3], and much less often − extremely low temperatures.

2. Literature review

Tropical nights before now were observed, as a rule, only in tropical (low) latitudes. For example, in [4] we can find an analysis of tropical nights in Nigeria for 1971-2012. For this country, hot nights are a common occurrence, but their amount is increasing. It was believed that tropical nights are a local and their frequency had a relationship with land cover changes by the urbanization process [5]. There were more tropical nights at high-rise buildings and commercial business district areas with low sky view factors than in mountain foothill areas [6]. It goes without saying that in urban stations, tropical night occurrences are climatologically higher, more active and frequent. An urban heat island as the additional heat leads to the urban concentrated activity of tropical nights [7].

However, due to the global warming in recent decades, they can also be observed at higher latitudes [8-11]. Here they have become not only a climate change, but also as a medical and environmental problem. The increment of amount of the tropical nights influences on human welfare directly. It should be noted that tropical nights, in particular, an increase of their intensity and frequency, affect human health and life, and can create negative stress heat loads on the human body [2, 12]. When there are these nights, it is more difficult for the human body to cool down, especially for sick or elderly people. So, the growth of amount of the tropical nights can lead to an increase of population morbidity and mortality rate especially in a regions where there is a large percentage of the old-age population [13].There is strong evidence concerning the impact of heat stress on mortality from high temperatures over a wide range of locations [12]. This impacts the health sector. As well as the energy sector is affected by a higher electricity demand during summer due to increased use of air conditioning. The same story is about road traffic, because the number of road accidents increases during tropical nights [14], tourism [15], etc.

Today the frequency of tropical nights is increasing or they are fixed where there were no such events at all before. Tropical nights began to appear on the coasts of oceans with cold currents [16] and even in mountainous regions. For example, in [17] the forecast was made, according to which tropical nights will occur in mountainous Switzerland at an altitude above 1500 m asl in the last three decades of the 21st century.

It should confess that the growth of number of the tropical night events is one of the main evidences of the global warming process over Ukraine. The number of such events has increased especially significantly since the end of the 20th century. Their appearance is associated with certain climatic, first of all, circulation processes. Previous studies have generally suggested that anticyclonic circulations induce extreme heat [18]. However, some recent studies have indicated that high temperature weather in particular regions can result from various types of circulation anomaly [19]. Today the large-scale atmospheric circulation anomalies are elaborated as a main factor affecting air temperature.

In addition the impact of remote factors also contributes to air temperature variation. To sum up we can said that the tropical nights are raises the need to adapt to new climate actuality in one region or another, as well as considering that such events will be repeated more and more often.

3. Methodology

The purpose of this study is to analyze the frequency and repeatability of tropical nights over Ukraine, as one of the indicators of climate change. The data from weather stations since 1976 to 2019 were under analysis. The images of positive anomalies of the surface minimum air temperature provided by the NOAA/ESRL Physical Sciences Laboratory (Boulder Colorado) from their Web site. In addition to the analysis daily minimum air temperature, the objectives of the study included the construction and analysis of linear trends of the temporal distribution and intensity of tropical nights at the selected stations.

The data about Mediterranean Oscillation Indices (MOI) as well as North Atlantic Oscillation (NAO) obtained from Climatic Research Unit of the University of East Anglia. In the course of the work, well-known methods of mathematical and statistical analysis were used. All figures implemented through the built-in functions of the software Microsoft Excel (was used to calculate the correlation coefficients) and Surfer from Golden Software LLC (to make isoline maps).

4. Results and discussion

The paper presents a comparative analysis of the frequency of tropical nights at 13 weather stations in Ukraine for the observation period 1976-2019. Selected stations: Vinnytsia (49,2°N, 28,6°E), Ivano-Frankivsk (49.0°N, 24.4°E), Kyiv (50.4°N, 30.6°E), Kovel (51.2°N, 24.7°E), Nikopol (47.6°N, 34.4°E), Kharkiv (49.9°N, 36.6°E), Odesa (46.5°N, 30.7°E), Sumy (50.9°N, 34.7°E), Chernihiv (51.4°N, 31.1°E), Poltava (49.5°N, 34.6°E), Zhytomyr (50.2°N, 28.6°E), Lviv (49.8°N, 24.0°E) and Kherson (46.6°N, 32.6°E). As can be seen, the above-mentioned weather stations are located in different geographical regions of Ukraine. It is made to possible say about spatial distribution and heatwaves tendencies over Ukraine.

It is interesting to note that the minimum extremes were observed quite a long time ago − mainly in the 80s years of XX century, and the maximums − in the first decade of current century (table 1).

Table 1. Characteristics of the minimum air temperature at certain Ukraine' weather stations for the period 1976-2019.

	Average		Extreme	
	minimum	maximum	maximum	minimum
Poltava	-18.6°C (1987)	19.6°C (2010)	25.3°C (1981)	-29.2°C (1987)
Zhytomyr	-20.1°C (1987)	17.2°C (2010)	23.2°C (2012)	-33.3°C (1987)
Lviv	-15.6°C (1985)	16.0°C (2012)	21.7°C (2007)	-28.5°C (1985)
Kyiv	-17.6°C (1987)	19.5°C (2001)	24.9°C (2010)	-27.8°C (1987)
Kherson	-15.9°C (1985)	19.6°C (2002)	25.2°C (2017)	-26.3°C (2006)
Chernihiv	-21.6°C (1987)	18.5°C (2010)	22.9°C (1999)	-35.9°C (1987)

4.1. Frequency of the tropical nights in a changing climate

For the spatial analysis of distribution of the minimum air temperature extremes in Ukraine, the correlation coefficients between the average maximum air temperature over Ukraine and the average maximum air temperature at individual stations in July for the corresponding period were computed (Table 2) and analysed.

Table 2. The correlation coefficients between the average maximum air temperature in Ukraine and the average analysed maximum air temperature at weather stations for the period 1976-2019.

	Maximum air temperature, °C / year	Correlation coefficient	Notes
Vinnytsia	22.8 / 2017	0.79	
Zhytomyr	23.2 / 2012	0.87	
Lviv	21.7 / 2007	0.83	
Poltava	25.3 / 1981	0.81	
Kherson	25.2 / 2017	0.88	
Ivano-Frankivsk	20.4 / 1988	0.77	
Kyiv	24.9 / 2010	0.88	
Kovel	21.4 / 2017	0.77	
Nikopol	26.9 / 1991	0.87	
Kharkiv	26.0 / 2010	0.78	
Odesa	26.7 / 2017	0.88	max
Sumy	23.2 / 1981	0.75	min
Chernihiv	22.9 / 1999	0.84	

As can be seen, the distribution and trends of the minimum air temperature on the territory of Ukraine are differing significantly depending on the region. It was established that the distribution vector of the minimum air temperature extremes in summer has a clearly expressed southern component, directed to the north of the country, with a slight shift to the northwest, which can be seen in figure 1.

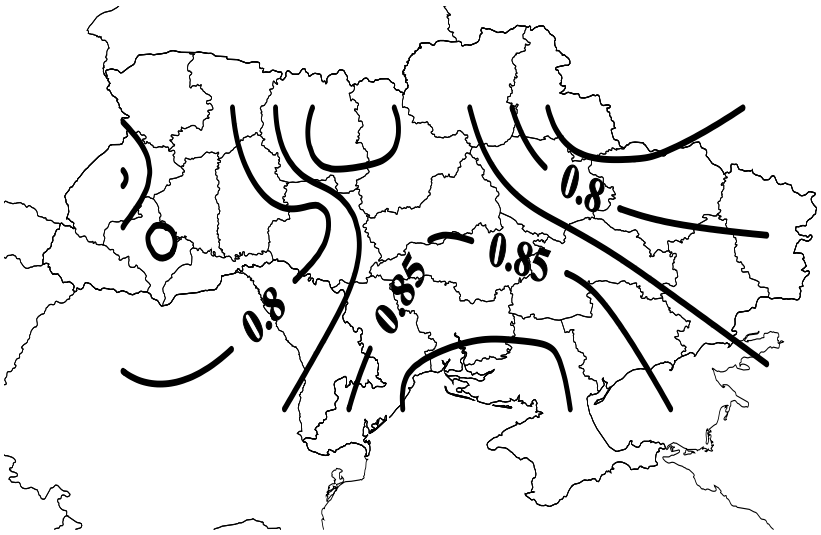

Figure 1. Distribution of the correlation coefficient between the average maximum air temperature over Ukraine and the average maximum air temperature at individual stations in July for the period 1976-2019.

It is important to note, the fact that the eastern and north-eastern territories of Ukraine are the most active in terms of changes of the minimum air temperature, especially during the cold period of the year.

In the transitional seasons, there is an increase of changes activity of the minimum air temperature in the western and north-western regions, which is associated with the activation of the corresponding circulation processes.

As can be seen, such processes include advection of warm air masses from northeast (figure 2) and east (figure 3), the frequency of which increasing. This indicates not only an increase of the daily minimum air temperatures, but also other climate changes, in particular summer atmospheric circulation.

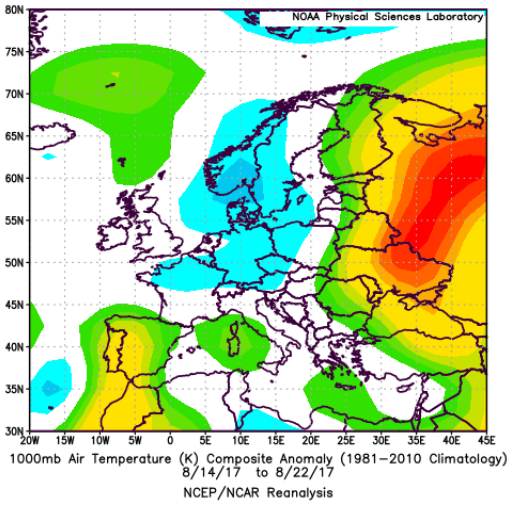

Figure 2. Positive anomalies of the surface minimum air temperature over east of Ukraine for the period from 08/14/2017 to 08/22/2017 compared to the climatic norm of 1981-2010 [20].

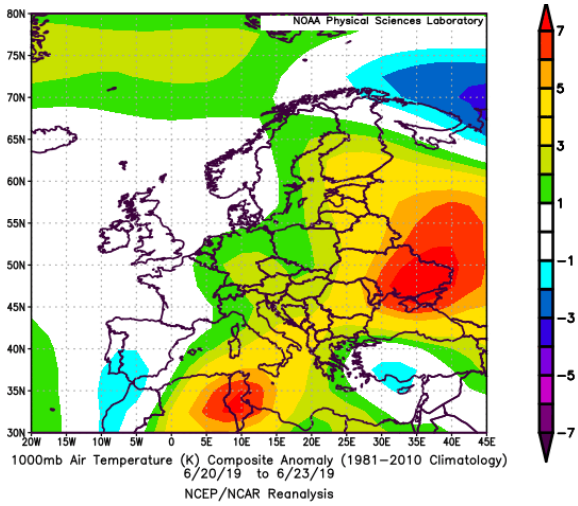

Figure 3. Positive anomalies of the surface minimum air temperature over east of Ukraine for the period from 06/20/2019 to 06/23/2019 compared to the climatic norm of 1981-2010 [20].

Next figure 4 shows the anomalies in the distribution of days when the tropical night phenomenon was observed at the selected stations. It should be clarified that by anomalies we understand the difference in the number tropical nights for the observation semi-periods of 1976-1997 and 1998-2019. The positive values obtained by us from the results of calculations indicate that the number of tropical nights increased almost throughout the territory of Ukraine at large. It also indicates a climate warming.

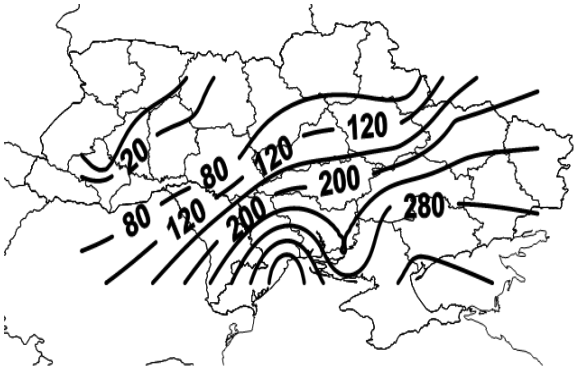

Figure 4. Anomalies of distribution of the number of tropical nights for the observation periods 1976-1997 and 1998-2019.

It is quite clear that the increase of number of the tropical night events in the south of the country (up to 300 cases) is much more significant than the increase in their number in the northwest Ukraine (up to 20 cases).

The analysis of linear trends of the tropical nights frequency for individual weather stations shows an increase of their number for all stations (Figure 5).

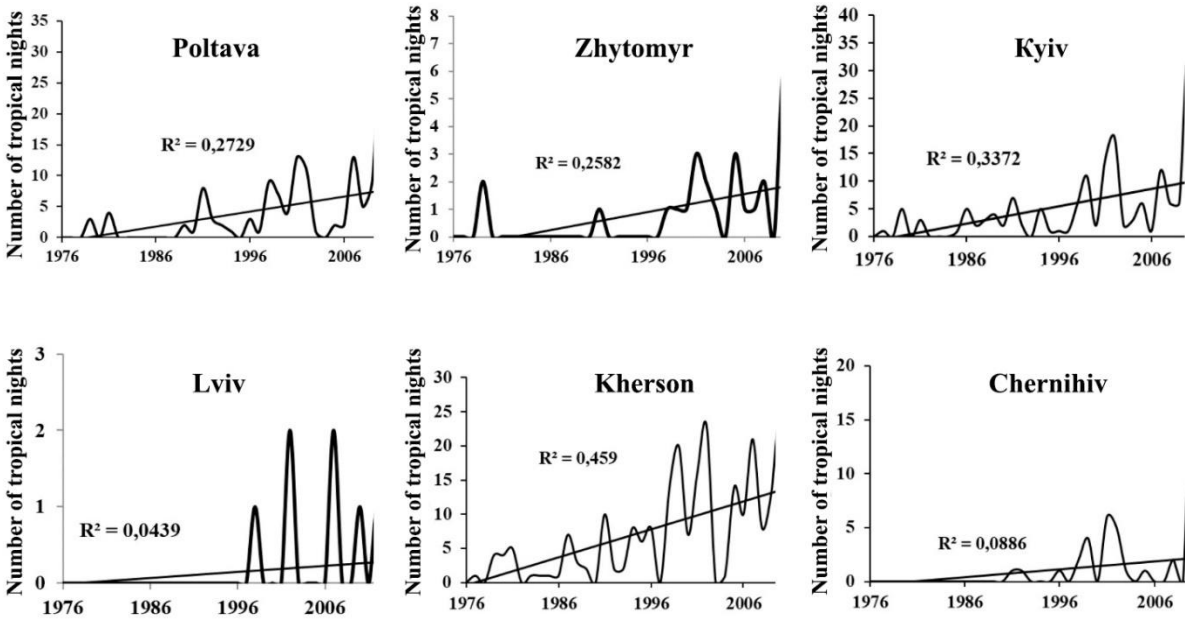

Figure 5. Linear trends of the tropical nights' distribution at the some stations of Ukraine for the observation period 1991-2019.

It should be noted that at Kherson weather station, the increase of number of the tropical nights is maximum. In the centre of Ukraine (weather stations Kyiv and Poltava), the trend is somewhat less, but these events were observed here throughout all analysed period. In the Western Ukraine, represented by weather stations Lviv and Zhytomyr, as well as in the north (Chernihiv), until the mid-1990s, the tropical nights was either not observed at all, or it was noted infrequently. But since 1995, we have seen an increase of number of the tropical nights for all weather stations in Ukraine, including Lviv, where they are now recorded stably almost every year.

In addition to analysing the frequency of tropical nights, this paper analyses the determination coefficients (R^2) of linear trends of the tropical nights' distribution at the above-mentioned weather stations, which is shown in the figure 6.

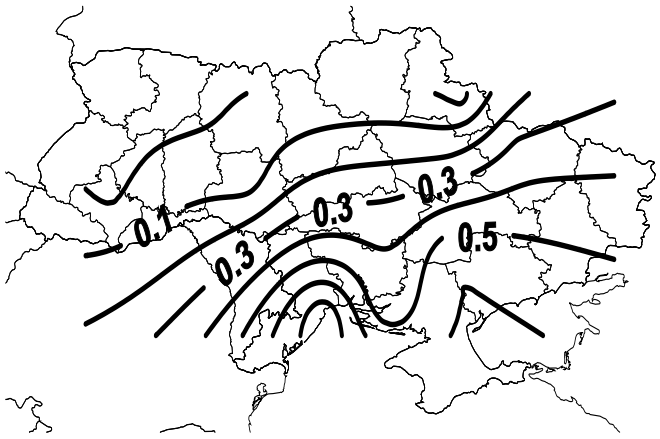

Figure 6. Determination coefficients of linear trends of the tropical nights' distribution over Ukraine for the period 1976-2019.

The configuration of the isolines in both (figure 4 and figure 6) figures is very similar. That is, in areas with a large number of tropical nights (south of Ukraine), there are also more rapid trends towards an increase of their frequency. The characteristics of linear trends and their reliability are given in Table 3.

Table 3. Characteristics of linear trends of the tropical nights' distribution by some weather stations of Ukraine for the period 1976-2019.

	Trend for 44 years, days	Statistical error, days	Determination coefficient	F-statistic
Poltava	0.240	0.060	0.27	15.8
Zhytomyr	0.060	0.020	0.25	14.6
Lviv	0.008	0.006	0.04	1.9
Kyiv	0.310	0.070	0.34	21.4
Kherson	0.410	0.070	0.46	35.6
Chernihiv	0.070	0.040	0.09	4.1

The most significant positive trend of the tropical nights increase (1976-2019), quite expectedly, was recorded in Kherson − 0.41 days with tropical nights / 44 years. For weather station Poltava and Kyiv, the trends are 0.24 and 0.31 days / 44 years. Weather stations Chernihiv, Zhytomyr and Lviv have the smallest trends − 0.07, 0.06 and 0.01 days with tropical nights per 44 years. It should be noted that we obtained statistically significant trends, which is confirmed by the corresponding values of the F-statistics. Only for Lviv, the results are not statistically significant, which can be explained by the short duration here of series of the observations with the cases of tropical nights.

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4.2. The intensity of tropical nights and climate warming

In this study, by the "intensity" of tropical nights, we mean an increase of cases of the exceeding air temperatures above certain thresholds. In particular, cases were analysed when the minimum air temperature at night exceeded 20°C and 23°C. There is a steady increase of cases with minimum daily temperatures of 20 °C and above. What about the threshold of 23°C, these values first appeared at Kherson weather station from the mid-90s of the twentieth century and where their number today is approximately constant (Figure 7).

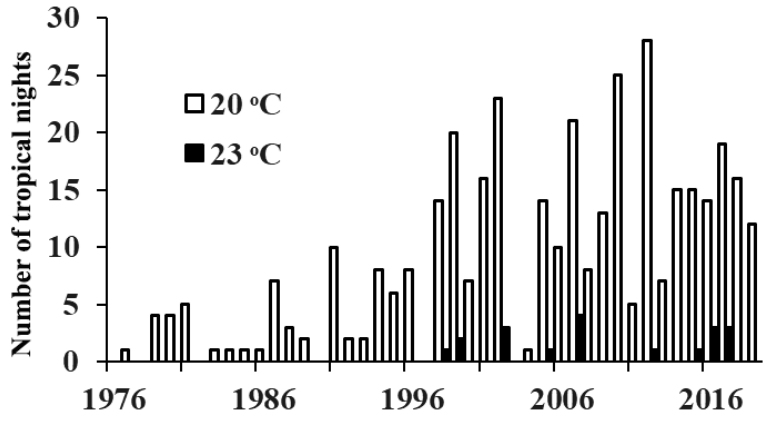

Figure 7. Distribution of the tropical nights with temperatures above 20°C and 23°C at Kherson weather station for the observation period 1976-2019.

Starting with the 2000s, the intense tropical nights began to appear in the centre (Poltava) and northeast (Sumy) of Ukraine. As can be seen (figures 5 and 7), the trends of climate warming (amount, frequency as well as intensity of the tropical nights) in Ukraine are clear.

4.3. Climatic indices and tropical night events

It should be noted that the weather conditions are determined by the interaction of the main three climate components – solar irradiation, atmospheric circulation and the underlying surface (land or ocean). The source of energy for processes in the atmosphere is the Sun (its activity), due to which the centres of action of the atmosphere (baric centres) and elements of general circulation of the atmosphere are formed. They determine the specific climatic conditions of a certain area of the globe. Among these baric centres and circulation elements, one can note the Westerlies in temperate latitudes, Icelandic Low, Azores High (North Atlantic Anticyclone), the Siberian winter anticyclone, etc. At the same time, the interaction between these centres of atmosphere action, as well as a change in their space-time structure, leads to the emergence of slow climatic signals (teleconnections) – modes of variability or oscillations, causing periodic changes in the circulation system and, accordingly, changes in the nature of weather conditions in any region.

In the Atlantic-European region, there are several oscillations that, to one degree or another, determine the variability of weather conditions in Ukraine. Among of them, one can see Arctic Oscillation, North Sea Caspian Pattern, with anomaly centers over the North and Caspian Seas, Mediterranean Oscillation, Western Mediterranean and Eastern Mediterranean Oscillations, Scandinavian Pattern, etc.

Taking into account the processes leading to the appearance of tropical nights, especially in the south of Ukraine, in our opinion, it would be logical to apply Mediterranean Oscillation Indices (MOI), which is the difference of normalized pressure between Cairo (30.1°N, 31.4°E) and Algiers (36.4°N, 3.1°E) [21]. A comparative analysis of the number of tropical nights at Kherson weather station and the curve of intra-annual distribution of the MOI index values (Figure 8) revealed their significant coincidence.

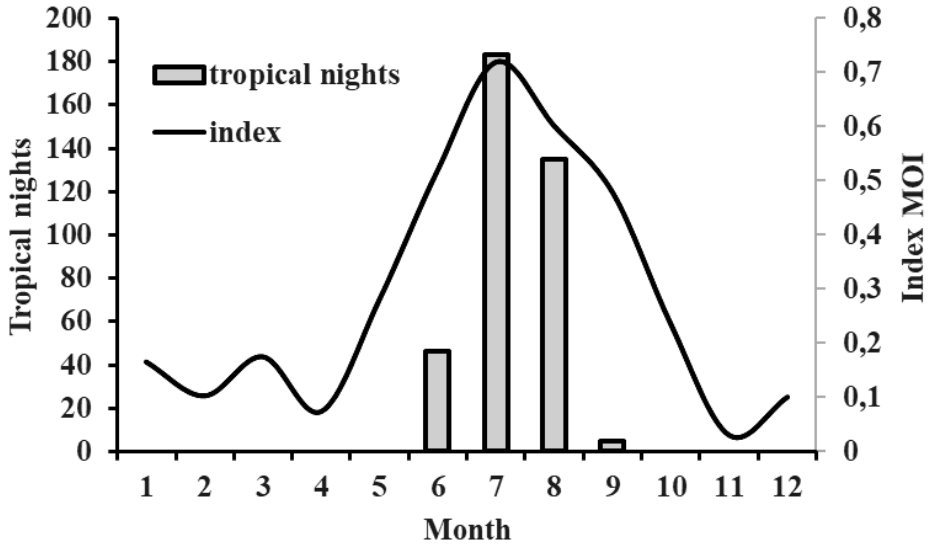

Figure 8. Intra-annual long-term distribution of MOI and tropical nights at Kherson weather station for the period 1976-2019.

Further, we analysed all the cases of tropical nights at Kherson weather station and the values of MOI index, which were at the same time. The results of this comparative analysis, for example the summer of 1998, are shown in Figure 9. The significant synchronism of distribution of the data for both climate indicators should be noted.

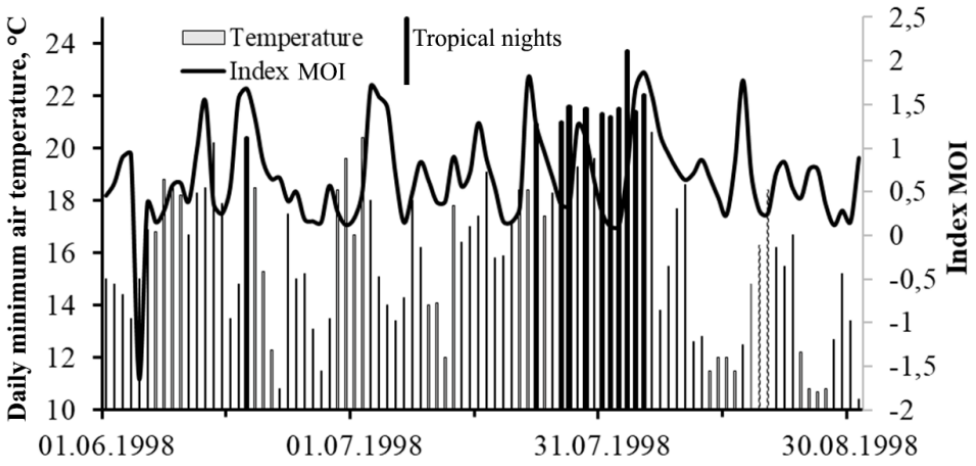

Figure 9. The MOI indices, temperature and frequency of tropical nights at Kherson weather station during 1/06/1998-31/08/1998.

Our research indicates the appearance of tropical nights, as well as an increase their frequency over the past decades in the western part of Ukraine. This may be due to changes in the interaction between the Azores High and Icelandic low, the nature of which can be seen from the analysis of North Atlantic Oscillation (NAO) [22]. The decrease of NAO index (in fact, the activation of Azores High) leads to the increase of air temperature, which can be seen on Figure 10.

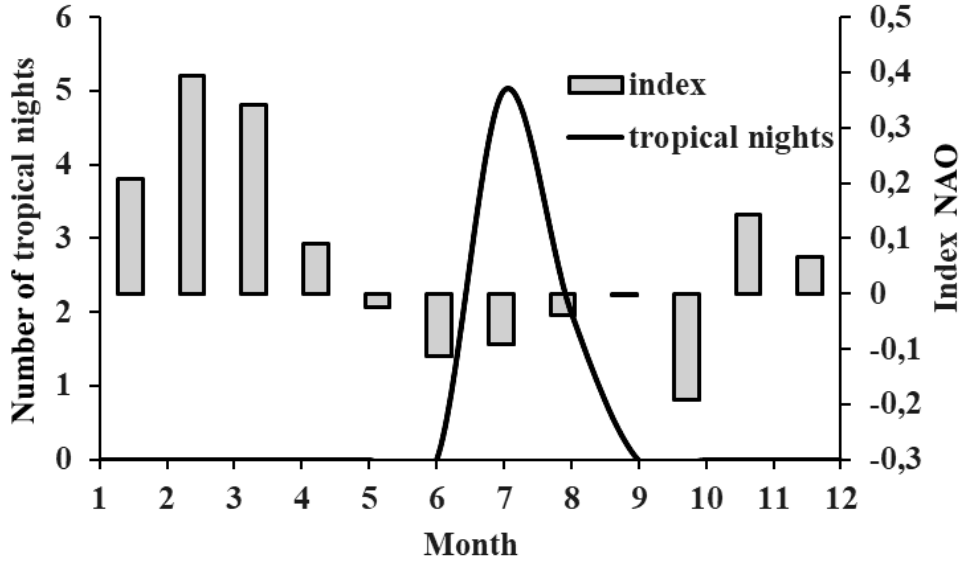

Figure 10. Intra-annual long-term distribution of NAO Index and the number of tropical nights at Lviv weather station for the period 1976-2019.

The role of NAO in the formation of extremely high minimum daily temperatures is clearly visible on the example of tropical nights at Lviv weather station occurred July 10-11, 2002 (Figure 11). On that date the NAO index fell to negative values.

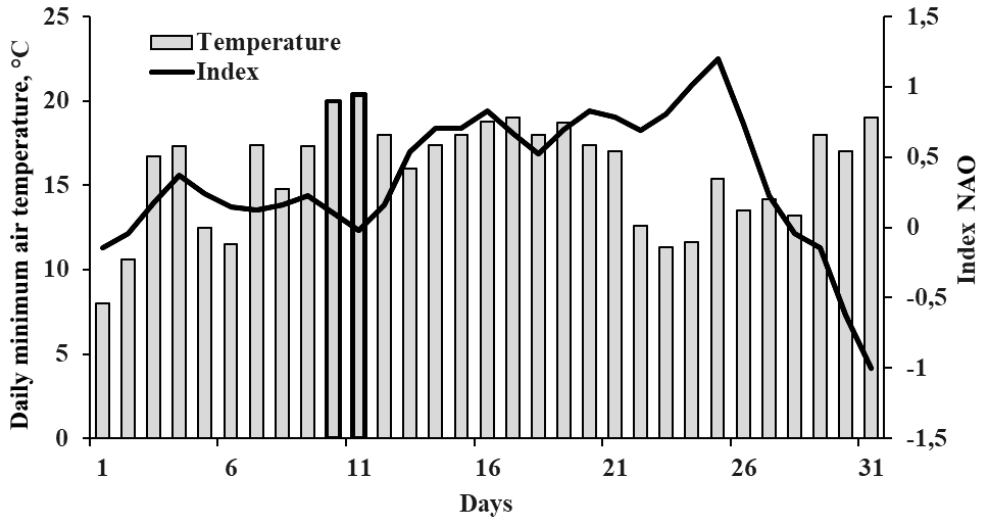

Figure 11. The NAO indices, air temperature during July 2002 and tropical nights at Lviv weather station in July 10-11, 2002.

We should point out that for all the weather stations there are a clear connection between the registered rising of the minimum daily air temperatures and the values of global climate indices. We should confess that the increase of the frequency as well as the intensity of tropical nights in Ukraine is a consequence of global warming.

5. Conclusions

The obtained results are consistent with the global warming trends. There is a directly proportional relationship − an increase of air temperature leads to increase of number of the tropical nights over Ukraine. The intensive increase of frequency of the tropical nights in east and centre of Ukraine has detected since 1990s. In recent decades, the events of tropical nights have begun to be observed quite steadily in the western regions of Ukraine.

The events of tropical nights over the past years have been increasingly observed during the advection of heat air from east and northeast, at the moments of existence of the certain blocking circulation processes (when hot weather sets in for a period of up to several weeks or even more). This issue requires further study. As the frequency of tropical nights is increases, their intensity is also increases.

The analysis of the North Atlantic Oscillation (NAO) indices and Mediterranean Oscillation (MOI) in the context of tropical nights in Ukraine turned out to be quite effective. There is a clear connection between the rising minimum daily air temperatures and the values of global climate indices. This indicates that the increase of the frequency as well as the intensity of tropical nights in Ukraine is a consequence of global warming. It makes possible to use of the climate indices for predicting this phenomenon in the future.

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