GIS Analysis of Temperature Variation in Ukraine for 2000-2020

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Abstract: The presented paper is dedicated to the problem of temperature changes variations for Ukraine. As an input data source, NOAA National Centers for Environmental Information data were used. Based on preliminary studies, the temperature analysis workflow was developed. The feature of the deployed workflow is an application of GIS analysis for temperature trend detection. As the main functions of GIS analysis, overlay analysis and Kriging interpolation were used. The temperature surfaces were constructed using the Kriging interpolation method to determine the temperature trend. The overlay analysis was applied based on the temperature surfaces for different time intervals. After overlaying procedure, the difference between two georeferenced surfaces was calculated. These differences allowed us to track the temperature changes throughout time. The results of surfaces subtraction were used for temperature variation analysis for different time intervals. The general picture emerging from the research is that the temperature grows for 0.2 C° each five years. As in previous studies, the results confirm that there is a distinct tendency in the temperature rising for one degree of Celsius during the last twenty years. The temperature trend has an essential geographical association. The most significant temperature changes are related to the southeast of Ukraine, proving the desert regions' increasing.

Keywords: Climate change, Temperature distribution, Temperature difference, Overlay Analysis, Kriging Interpolation.

1. INTRODUCTION

There is no point to emphasize the importance of examination of the issue of global temperature variation. A huge set of publications are devoted to such a complex and significant problem. Especially the study of the problem of temperature variation is substantial because it can be one of the clues to overcoming the more global problems – climate change and global warming. The goal of the presented paper is to consider the given issue in the tight liaison with time for the territory of Ukraine. It is well-known that the second largest desert in Europe - Oleshky Sands is placed in the southeast of Ukraine in the Kherson region [1]. By many recent observations, the desert tends to grow. The temperature variation plays not the last role in this process. At the same time, Ukraine is considered one of the largest delivers of agricultural production globally [2]. The black earth ("chernozem") is the most fertile type of ground and takes almost two-thirds of Ukraine's land [3]. The most fertile land is placed in the East and South of the country. That is why the suggested problem is of great importance not only for Ukraine itself but for the world economy too.

It is clear that the study has a distinct geographical direction. GIS allows establishing the relationship between different phenomena and their geographic location. Just to mention a few GIS applications that embrace such phenomena that lead to climate change and are aftermath: deforestation, air pollution, urbanization, etc. [4-11]. The temperature change, especially growth, is being considered as a result of human impact on the environment. Of important to have a clear and comprehensive model of temperature changes to predict its possible variation in the future. To this aim, different data sources can be used. Generally speaking, those data sources can be divided into two main origins: ground-based and satellite-based. The application of both has its own pros and cons. However, for any data type, GIS may help to unfold the hidden relationships. Among the miscellaneous studies, it is worth mentioning [12, 13] where GIS simulated air temperature variation based on ground stations observations, including wind velocity, wind direction, air temperature, and cloud amount. An output of the simulation was the maps of temperature and wind variation. The work [14] outlined regression models for temperature variation with further leverage to temperature prediction and its portrays on maps. The presented papers aimed to predict temperature for urban areas. Similar models were considered in [15]. The study [16] revealed that mixed regression models fit well to temperature prediction tailored to geographical location. For mixed regression models construction, observations from 70 meteorological stations that span recording intervals from 3 to 21 years were used. In this paper, temperature and precipitation variations were considered in time and spatial domain. The models

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allow predicting temperature and precipitation. Such the approach works well for mountainous countries. The problem of temperature variation has not been discussed in that study. The authors [17] have established the link between the temporal and spatial trends of extreme temperature. They have proposed to calculate the values of extreme-temperature indices for the agro-pastoral ecotone of northern China. The analysis was based on observations that cover the time from 1960 to 2016. The observations were made on national meteorological stations. The extreme temperature examination has been accomplished in [18]. The authors used linear regression, principal component analysis, and correlation analysis to determine temperature extremes' temporal variability and spatial distribution. In [19], authors used eleven temperature indices to determine locations in South Asia where extreme temperature changes are highly possible. The broader time interval for the Asia-Pacific network has been studied in [20]. The conclusion is that there are seasonal asymmetric changes for extreme temperature relative to increases in temperature means for the Asia-Pacific observation network. Similar tasks were examined for different locations and time intervals in [21-28]. The presented researches have focused on various statistical tools but failed to explore the total capacity of GIS Analysis. The closest relation to the given study has a work [29]. The authors considered temperature and precipitation variations for 1901-2000. The analysis was accomplished for Europe. The continent has been divided into six regions where one of them almost embraces Ukraine territory. For the region, the indices

for daily temperature and precipitation extremes were assigned and analyzed. It is essential that the temperature changes in Ukraine for the last twenty years have not been considered.

Summing up, this study aims to analyze temperature variation for Ukraine's territory from a geographical point of view and investigate the association between temperature variation and time on one hand and temperature changes and geographical location on the other hand. This paper comprises four parts. Section one provides a brief introduction to the problem. Section two deals with data sources and used methods. In section three, the results of the temperature analysis by GIS are provided. Section four is dedicated to discussion.

2. MATERIALS AND METHODS

First of all, it is necessary to present the content and the source of the data that have been used for analysis. The NOAA National Centers for Environmental Information (NCEI, https://www.ncdc.noaa.gov) has been leveraged as a major data source. Upon request, the NOAA database delivered information about thirty-one ground observation stations in Ukraine and surrounding countries. The total set of observation stations is presented in Figure **1**.

However, after detailed analysis and data preparation, it was found out that only six stations have observation records without significant gaps or data missing. Moreover, almost 50% of the stations have
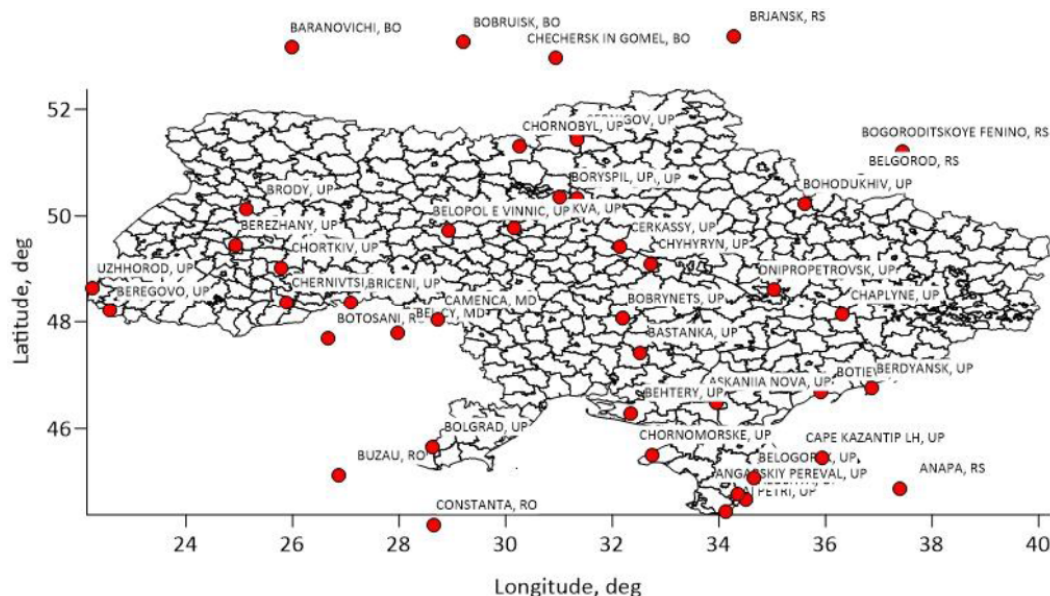

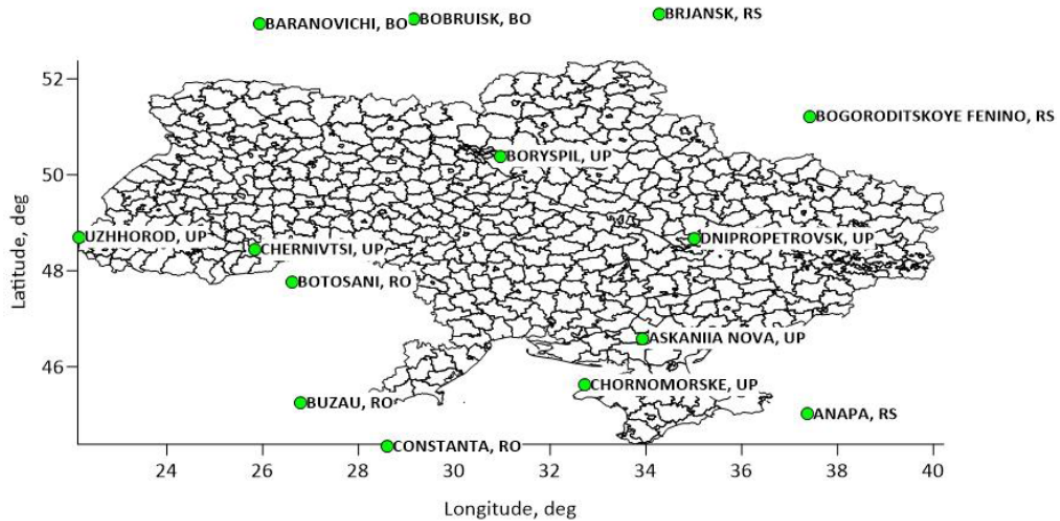**Figure 1:** The distribution of temperature observation stations.

Figure 2: The distribution of the stations selected for analysis.

terminated data collection five-seven years ago. It makes the correct analysis badly possible. To overcome the given problem, it was decided to include additional observation stations that are placed in surrounding countries near the Ukrainian border. The selected stations for the further analysis and their distribution are presented in Figure **2**.

The temperature analysis is a typical case of time series analysis. According to recommendations [30], most of the time series can be presented in the following way.

$$x(t) = x_p(t) + x_t(t) + x_n(t), \tag{1}$$

where $x_p(t)$ – periodic element; $x_t(t)$ – trend element; $x_n(t)$ – measurement noise.

In expression (1), the periodic element presents seasonal temperature variation. The trend element is of great interest insofar as it displays the total temperature changes throughout time. The last element is measurement noise. It is supposed to be white noise if the measurements are not contaminated with systematic errors. The standard procedure for the temperature analysis includes a filtering procedure to rule out or reduce the level of the white noise. The next step is trend analysis. The various regression models are being used for this aim. After the trend identification, the last step is an analysis of periodic variations. The trend analysis is the main task regarding the paper's purpose. GIS analysis was offered to deal with this task. The analysis procedure can be presented in the following flowchart (Figure **3**).

In the given workflow, the regression analysis is introduced for comparison. The regression model simulates the temperature at one specific point. It is the main drawback of regression models. An attempt to model the temperature as a regression surface runs into a problem due to low accuracy. The regression models are a subclass of polynomial models. Polynomial surfaces are too simple in comparison to the most natural surfaces. Except for their simplicity, regression models lack extrapolating of results beyond
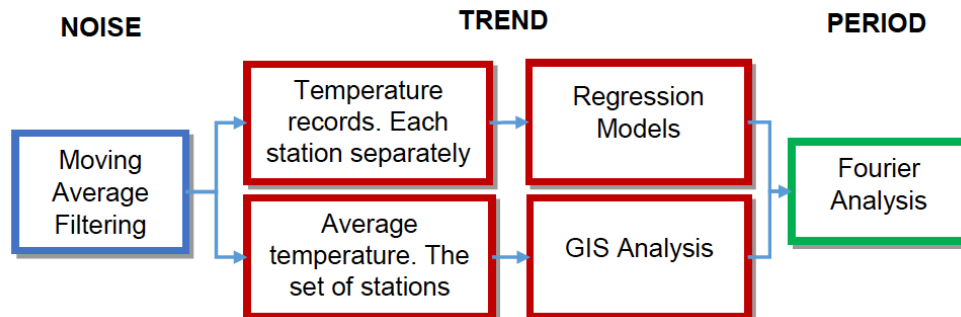

Figure 3: Temperature analysis workflow.

INPUT **GIS ANALYSIS** **OUTPUT**

Average temperature. The set of → Temperature interpolation for various years → Surface differences → Trend surfaces
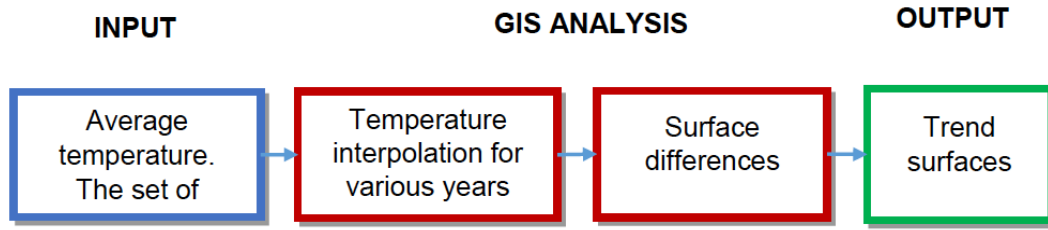
Figure 4: Temperature GIS analysis workflow.

the area of data control. Unlike the regression models, GIS has a bunch of approximation and interpolation models. Since the data previously were filtered by the moving average method, the interpolation procedure is preferable. The key point is the selection of an appropriate interpolation method for the GIS analysis. Among the various interpolation methods, the geostatistical Kriging interpolation has been chosen. The workflow of GIS analysis is presented in Figure **4**.

The workflows in Figure **3** and Figure **4** have been implemented at the next step, and the results are presented.

3. RESULTS

According to the workflow in Figure **3**, the first step of data analysis is data filtering. The moving average method has been applied for each station observation. Thus, the observations became free of local extreme values and measurement noise. The sample cases of filtering results are presented in Figure **5** - Figure **7**.

As one may see, the temperature tends to grow. However, leveraging these graphs without their geographical reference makes analysis complicated. The average temperature distribution over Ukrainian
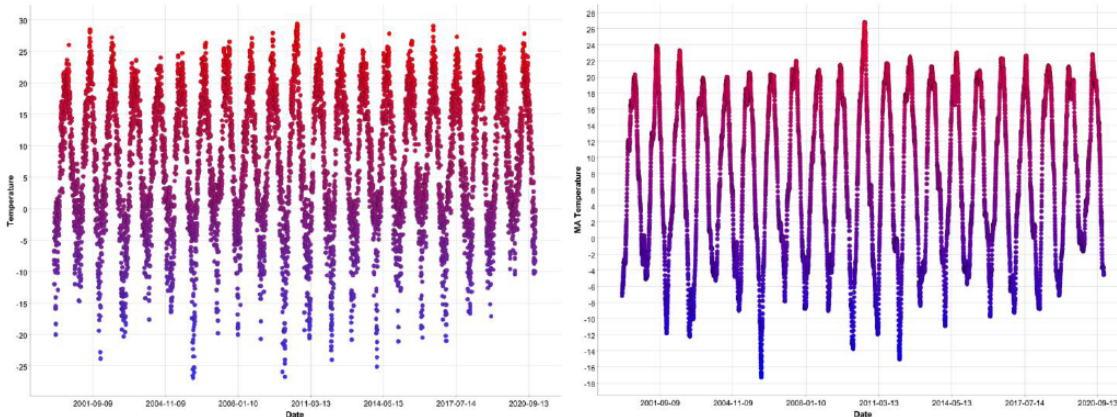

Figure 5: Temperature records and filtered results (station Bogoroditskoye Fenino, RUS).
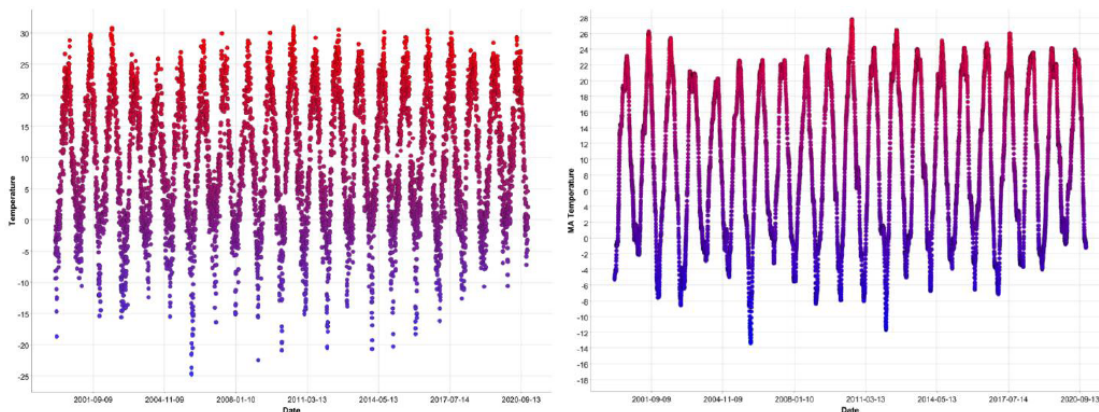

Figure 6: Temperature records and filtered results (station Chernivtsi, UKR).
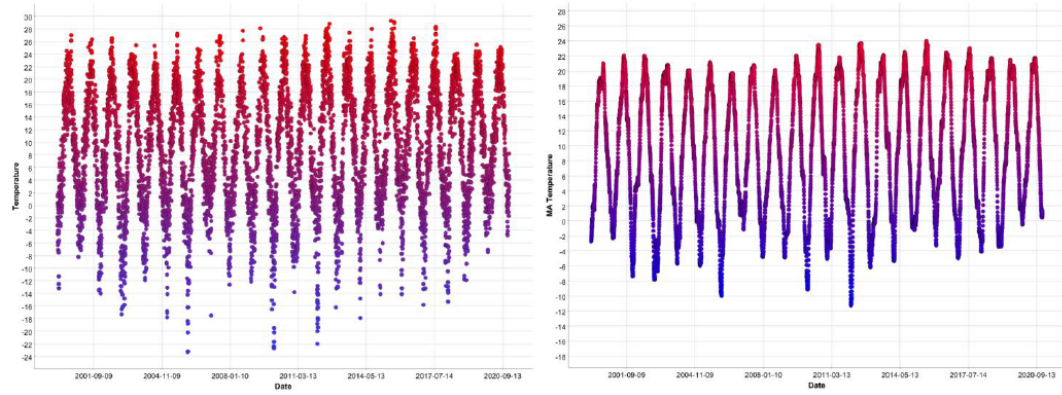
Figure 7: Temperature records and filtered results (station Dnipropetrovsk, UKR).

territory for two outmost dates is presented in Figure **8** and Figure **9**. Such a presentation facilitates the examination procedure and makes the temperature dynamics more clear. The contour maps have been built using Kriging interpolation with standard parameters.

The differences have been calculated and presented in Table **1** to get the quantitative values of the temperature changes.
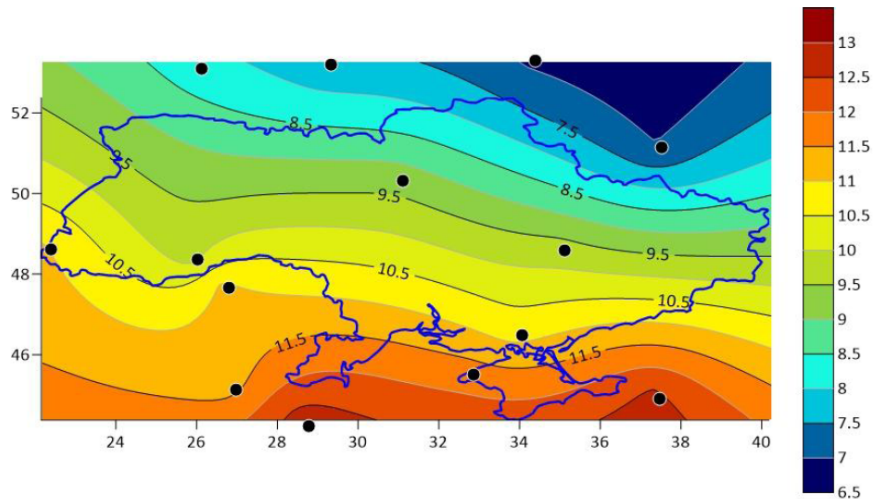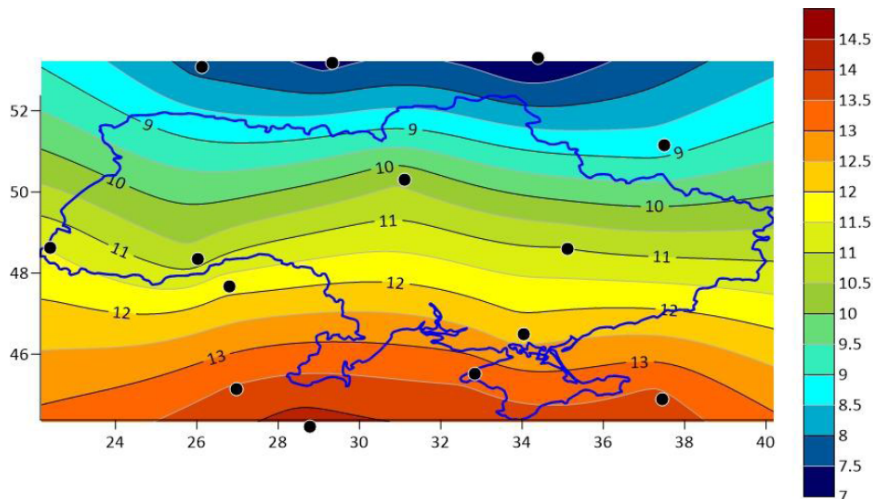

Figure 8: Average temperature for 2000.

Figure 9: Average temperature for 2020.

**Table 1:   Temperature Differences at Observation Stations**

Name	Temp 2000, C°	Temp 2020, C°	Difference, C°
Bogoroditskoye Fenino, RUS	7.0	8.8	1.8
Chernivtsi, UKR	9.8	10.7	0.8
Dnipropetrovsk, UKR	9.7	11.0	1.3
Askaniia Nova, UKR	10.7	12.2	1.5
Buzau, ROM	11.3	13.5	2.2
Botosani, ROM	11.1	11.8	0.7
Anapa, RUS	12.6	13.6	1.0
Uzhhorod, UKR	11.0	11.5	0.5
Constanta, ROM	12.7	14.2	1.5
Bobruisk, BEL	7.7	7.4	-0.3
Chornomorske, UKR	11.7	13.3	1.6
Baranovichi, BEL	8.3	7.9	-0.3
Brjansk, RUS	6.9	7.0	0.1
Boryspil, UKR	9.3	10.4	1.1

The data in Table **1** provide preliminary evidence that there has been a significant change in the temperature during the last twenty years. On average, for the whole country, the temperature has been grown to one degree of Celsius. But, it is crucial to understand the temperature change with liaison to its geographical sense. The geographical temperature distribution is essential as long as one may conclude from Table **1**, Figure **8**, and Figure **9** that the temperature decrease has been observed for some stations. That is why the next step is GIS analysis using its powerful tool, the overlay analysis. The average temperatures for 2000 and 2020 were considered as georeferenced surface layers and were overlaid. After overlaying procedure, the difference between the two surfaces was calculated. The obtained differences were interpolated using Kriging interpolation. The results of the interpolation are presented in Figure **10**.

The visual analysis of Figure **10** provides convincing evidence in favor of the overlay analysis. The temperature variation has a thorough geographical dependency. The obtained tendency in temperature variation will be considered later in the Discussion section.

However, from Figure **10**, it is hard to comprehend the dynamic of temperature changes yearly. Figure **10** demonstrates the total temperature changes throughout twenty years. The observation period was
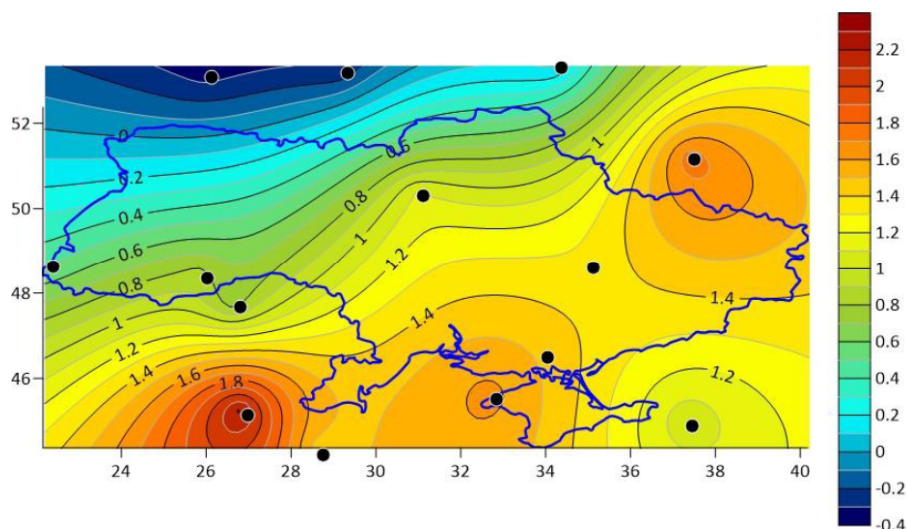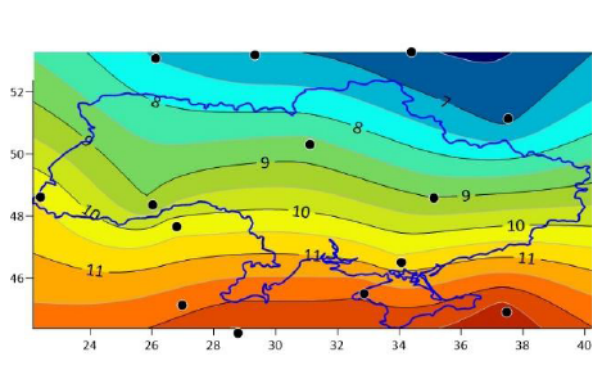

Figure 10: Temperature changes for 2000-2020.

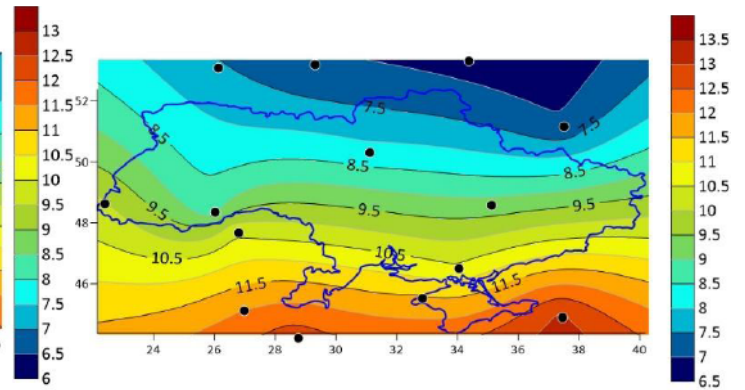**Figure 11:** Temperature distribution for 2000-2005.

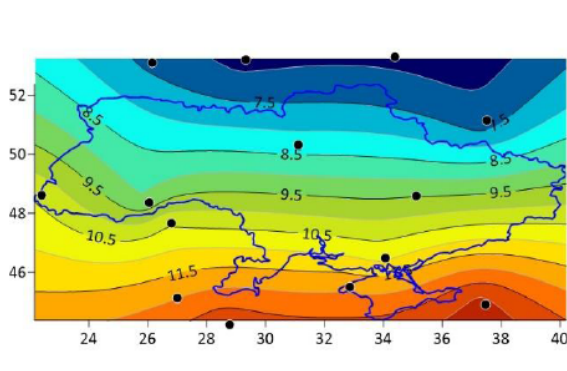**Figure 12:** Temperature distribution for 2000-2010.

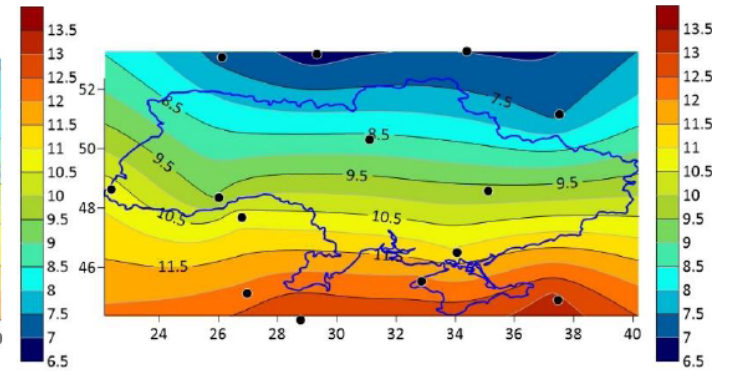**Figure 13:** Temperature distribution for 2000-2015.

Figure 14: Temperature distribution for 2000-2020.

divided into four intervals (2000-2005; 2005-2010; 2010-2015; 2015-2020) to understand these changes in detail. For each interval, the temperature distribution plots have been created (Figure **11** – Figure **14**).

These plots were created using Kriging interpolation. The overlay analysis between the intervals was accomplished. The surface differences

were calculated, and the appropriate plots were created. The dynamic and geography of the temperature changes become clear from Figure **15** – Figure **17**.

The results yielded a significant correlation between temperature change and time on one hand, and geographical location on the other hand. The general
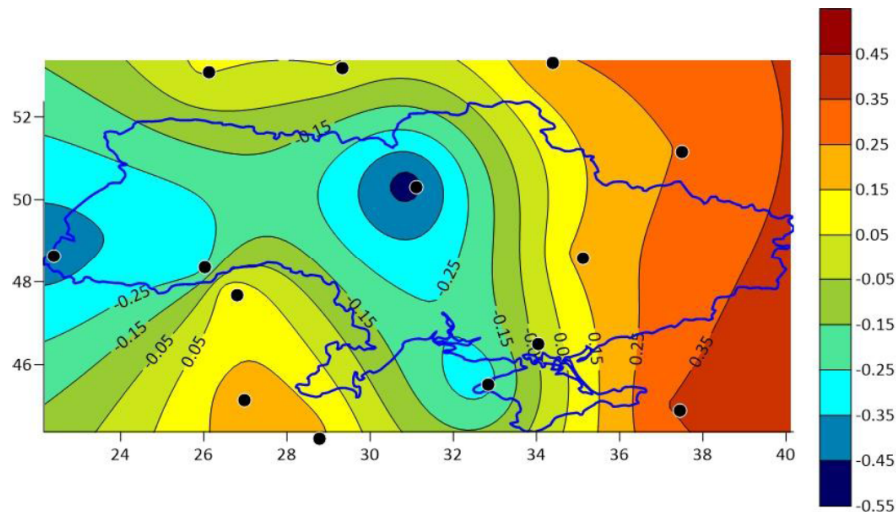

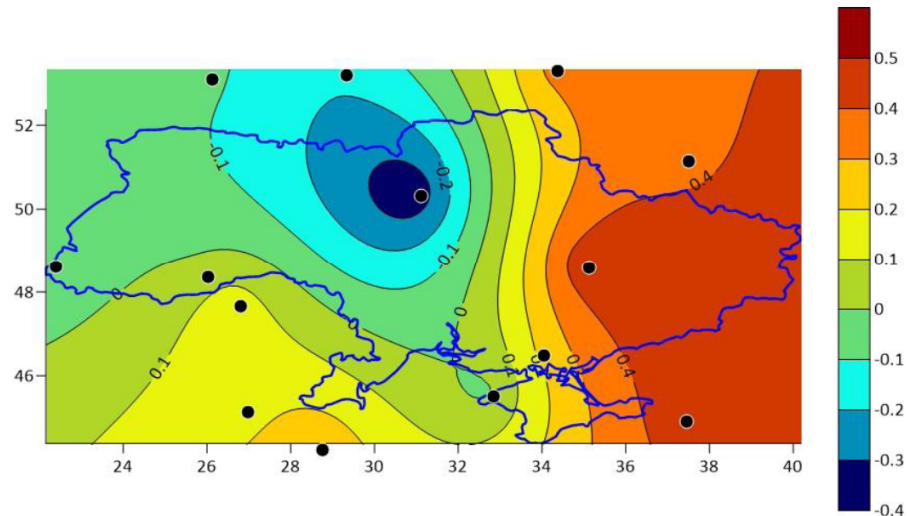**Figure 15:** Temperature changes for 2005-2010.

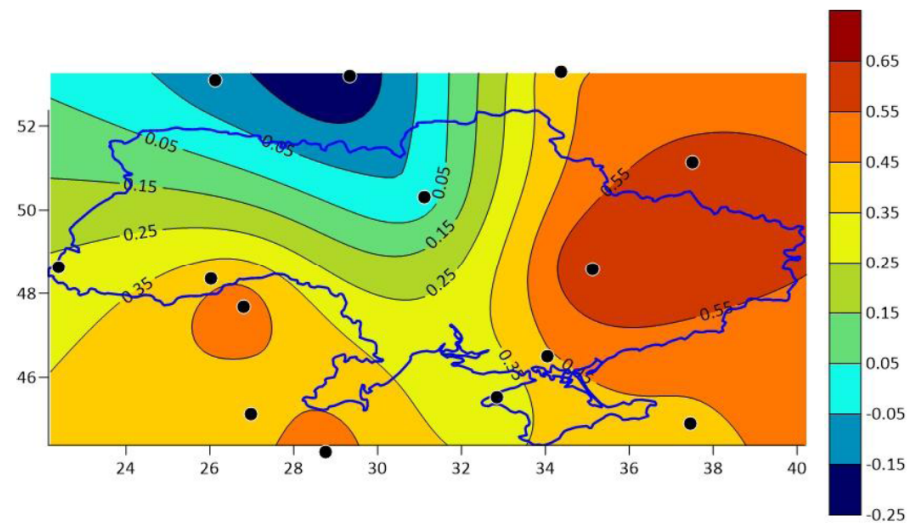**Figure 16:** Temperature changes for 2005-2015.

Figure 17: Temperature changes for 2005-2020.

picture emerging from the research is that the temperature grows for 0.25 C° each five years.

4. DISCUSSION

Before we discuss the results in detail, it would be wise to consider the general tendency of the temperature changes. Figure **8** and Figure **9** are the graphic summaries of the temperature changes during the twenty years. It can be inferred from these figures that Ukrainian territory is affected by temperature changes. However, the essential fact is the geographical temperature changes distribution. As shown in Figure **10**, a significant difference in temperature levels was observed. The northwest territory suffers considerably lesser from temperature changes than the south or southeast. Whereas for the northwest, the temperature changes are almost zero degrees Celsius, in the south and southeast, the

temperature changes exceed plus one and a half degrees Celsius. It is worth mentioning that the most significant temperature variation is observed precisely in the region where the second largest desert in Europe - Oleshky Sands is located. That fact explains the desert growth for the last decades.

The observations were divided into four intervals to comprehend the temperature changes in detail. The temperature variation surfaces using Kriging interpolation have been constructed (Figure **11** – Figure **14**). Despite the visual presentation, it is hardly possible to recognize a significant temperature change from these figures. The temperature seems to change evenly from north to south with a slight growth up to a half-degree Celsius. That results imply that the temperature changes cannot be detected only from surfaces analysis regardless of precise interpolation

models or regression models for approximation. After the surfaces overlaying and further subtraction, the directions of the temperature changes became evident. Figure **15** – Figure **17** show particularly interesting patterns. The temperature rising trend is not in the south. From year to year, the temperature increases from east to west. That is why the western regions are mostly not affected by temperature changes. For time interval 2005-2010, the temperature variation between the eastern and the central territories equals +0.6 C°. For time interval 2005-2015, the temperature variation between the eastern and the central territories is the same, the higher temperature region has moved to the west up to four hundred kilometers. Finally, for 2005-2020, the temperature change reached out to +0.3 C° for the central territories. At the same time, Figure **17** demonstrates that the whole territory was detected a global temperature growth from +0.3 C° in the west up to + 0.7 C° in the southeast.

5. CONCLUSIONS

In the presented paper, the problem of temperature changes variations for Ukraine has been addressed. The global temperature change trend and its variation for the country's different regions have been revealed by applying the overlay analysis as one of the key GIS tools. In light of the presented results, few conclusions can be drawn. Overall, these studies provide support for the validity of GIS analysis. Taken altogether, the data presented above provide evidence that the temperature increases by 0.2 C° each five years. Results obtained by differences calculation at the observation stations are consistent with our findings, which show a global temperature growth up to +1.0 C°. By far, the given findings are not generalizable beyond the study sample, insofar as the analyzed observations were collected in Ukraine and surrounding countries. An interesting side finding was that the temperature rising trend is from east to west. That fact has been unfolded thanks to the GIS application. The findings suggest a need for a longer time span analysis and involvement of precipitations, wind strength, and its direction observations. Future studies will have to focus on developing more complex models, including the observations mentioned above. Future research will have to take into account the weighting point method as an extension of overlay analysis.

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