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Intelligent temporal analysis of surface air temperature series for hydrometeorological monitoring

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ABSTRACT

Relevance: The ability to forecast weather conditions is essential for societal development, as it helps minimize damage caused by weather anomalies. At specific points in time, the state of environmental parameters is recorded by a hydrometeorological monitoring system. One of the parameters recorded is surface air temperature. Trends in changes to the current state of the natural environment cannot be determined without knowledge of its previous state and a model of meteorological processes. Therefore, the collection and intelligent analysis of data on the dynamics of temperature processes for subsequent refinement of the meteorological process model remains a relevant task. **Aim and research objectives:** To conduct an intelligent analysis of long-term time series of surface air temperature to obtain information on the temporal characteristics of surface air temperature variability. **T**o assess changes in temperature trends, temperature trend patterns, and the scales of temperature variability processes. **Methods:** Time series analysis method. **Scientific novelty:** A temporal analysis was performed on long-term time series of surface air temperature observations not previously presented in research: temperature changes, the scales of these changes, and trends in temperature variability were assessed. **Practical significance:** The use of the obtained data in hydrometeorological monitoring systems to refine models of meteorological processes, improve the accuracy of identifying patterns in climate dynamics, and support forecasting decisions. **Results:** For long-term temperature time series with different properties (different lags, different durations), amplitude characteristics of air temperature changes and temperature trends were obtained, and the scales of temperature change were estimated. **Conclusions:** As a result of the study, changes in temperature patterns, temperature trends, and the scales of temperature variability processes were assessed over twenty years (from two thousand and five to two thousand and twenty-four) and over one hundred forty-four years (from one thousand eight hundred and eighty-one to two thousand twenty-four) based on an intelligent analysis of four surface air temperature observation series with lags of one year, one month, one day, and three hours.

Keywords: Surface air temperature; temperature series; temporal analysis; regression; variability trends

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INTRODUCTION

Climate change monitoring is one of the most important tools for assessing the state of the natural environment, detecting trends in its condition, and mitigating the consequences of identified dangerous trends. Monitoring involves collecting and analyzing data on temperature, humidity, precipitation, ocean levels and salinity, greenhouse gas concentrations, and other indicators that affect the planet's climate system. Such observations and subsequent analysis of the results allow us to understand natural fluctuations and anthropogenic impacts on the climate, and to make important administrative decisions at the regional and governmental levels, by international organizations and scientific communities to develop measures to adapt to these changes. In general, climate observation is the key to understanding the causes and consequences of changes on our planet, to developing effective ways to adapt to changes and develop in the future.

Of the entire spectrum of observations, one of the most important is considered to be the observation of surface air temperature [1]. In practice, the results of such observations are instantaneous or interval time series with different

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time steps (constant or variable) and different durations. This is a sequence of time-ordered numerical indicators characterizing the level of development of the phenomenon under study. These series contain information that needs to be extracted and analyzed.

The extraction and analysis of information from such series is carried out using various methods. The need for temporal, spectral, and spectral-temporal (scale-temporal) analysis of air temperature observation series is due to a number of important tasks and advantages related to the understanding and modeling of climatic and meteorological processes. These tasks include identifying periodic components, separating signals and noise, distinguishing between process scales, and improving forecast models. Other very important tasks include analyzing changes and trends, detecting non-stationary processes, justifying data processing methods, and studying interactions between processes.

Other tasks also arise. In general, it can be noted that there is an urgent need to integrate methods of temporal, spectral, and spectral-temporal (scale-temporal) analysis into a single computational model. The article presented by the authors to the reader's attention is the first in a series of articles devoted to the analysis of long-term series of surface air temperature. It discusses the features of temporal analysis of such series. Subsequent articles will reflect the results of studies of these time series using spectral, spectral-temporal (scale-temporal) analysis methods and corresponding models.

The article presented here aims to conduct an intellectual analysis of long-term time series of surface air temperature data not previously reported in the literature to obtain information on the temporal characteristics of temperature variability; as such, it represents a scientific innovation. It is the first in a series of articles devoted to the analysis of long-term surface air temperature time series. It presents solutions to problems involving the assessment of temperature variations, temperature trends, and the scales of temperature variability processes. Subsequent articles will present the results of studies conducted on these time series using spectral and spectral-temporal (scale-temporal) analysis methods to identify periodic components, separate signals from noise in the series, distinguish between different scales of processes, and detect non-stationary processes.

LITERATURE REVIEW AND STATEMENT OF THE PROBLEM

Time series contain both meaningful information and random fluctuations. In some cases, random components may not be entirely random; they may be related to the dynamics of certain synoptic and climatic processes. Knowledge of the dynamic characteristics of temperature helps to develop more accurate models that take into account periodic components and their impact on forecasts. Time series may contain long-term trends and changes that can be identified by other methods of analysis, which is important for assessing climate change. Thus, time series analysis is an important tool for gaining a deep understanding of the structural features of temperature series, improving the accuracy of climate assessments, and developing effective forecasting methods.

A large number of studies are devoted to solving the above problems, the results of which are reflected in numerous publications. The review mainly covers papers devoted to temporal and other types of analysis of observation series for various meteorological variables and forecasting the future behavior of series. Article [2] examines issues related to the construction of homogenized temperature and precipitation series based on data from weather stations and analyzes the quality of the series and their differences. Papers [3], [4], [5] examine observation series in different countries and regions, the dynamics of these series, and forecasts, including temperature forecasts. A significant part of the articles examines trends in the behavior of various observation data in different regions of the globe [6], [7], [8].

Many papers are devoted to the study of the dynamics of climate indices [9], [10], [11]. The statistical parameters of series as a set of random variables are studied [12]. Significant attention in the studies is paid to the assessment of global long-term changes in meteorological parameters and anomalies, including temperature [13], [14], [15]. The seasonal dynamics of meteorological variables and, to a large extent, temperature is analyzed [16], [17]. Forecasts are made for all weather elements [18], [19]. Article [20] is devoted to the description of climate data analysis.

The papers listed below reflect the application of various methods of analysis for the analysis of a wide range of meteorological variables in different regions of the globe. In paper [21], in addition to the temperature series, the solar activity series is studied, and in [22], an analysis of wind speed and gusts in the surface layer of the atmosphere is carried out. The study of the possibility of forecasting precipitation in different conditions is described in [23] and [24]. Papers [25] and [26] are devoted to identifying precipitation cycles and finding cyclical patterns in climate data. Articles [27] provide a fairly detailed overview of the analysis of climate data using various methods.

The analysis of climate data and river flow using regression and wavelet analysis is presented in [28]. The paper [29] shows the results of assessing the short-term and long-term periodicity of droughts, as well as the trend component of these processes. An analysis of the literature sources cited shows that there are many studies in the field of hydrometeorology. These studies are very diverse, ranging from local assessments of climate parameters to global assessments of the state of the climate.

In order to build an adequate climate model for successful weather forecasting, as much data as possible obtained from research is needed. An analysis of the publications cited leads to the conclusion that it is necessary to continue current research that allows us to track climate change. Temporal analysis plays an important role in these studies. With its help, information can be extracted from long-term time series of varying lengths and with varying time steps, which can subsequently be used as the basis for creating algorithmic (software) support for intelligent systems in hydrometeorology.

AIM AND RESEARCH OBJECTIVES

Thus, the aim of this study is to conduct an intelligent analysis of long-term time series of surface air temperature in order to obtain information on the temporal characteristics of surface air temperature variability.

The objectives of the study are:

1) to assess changes in temperature trends;

2) to identify trends in surface air temperature patterns;

3) to distinguish between the scales of temperature variability processes.

RESEARCH MATERIALS AND METHODS

The research materials consisted of four time series, each with its own characteristics. The first series is a series of 144 years of annual observations of surface air temperature from 1881-2024 (hereinafter referred to as Series A). The second is a series of 144 years of monthly observations of surface air temperature for the same period (hereinafter referred to as Series B). The third is a series of 20 years of 8-times-daily observations of surface air temperature from 2005-2024 (hereinafter referred to as Series C). The fourth is a series of 20 years of daily observations of maximum and minimum surface air temperatures from 2005-2024 (hereinafter referred to as Series D).

The first two series are identical in duration but have different time steps: the first has an annual time step (Fig. 1) and values representing average annual air temperatures, while the second has a monthly time step (Fig. 2) and values representing average monthly air temperatures. In the theory of numerical series, the above-mentioned temperature values are commonly referred to as series levels. In this paper, to avoid confusion with other levels, we will refer to the temperature values in the series as series readings.

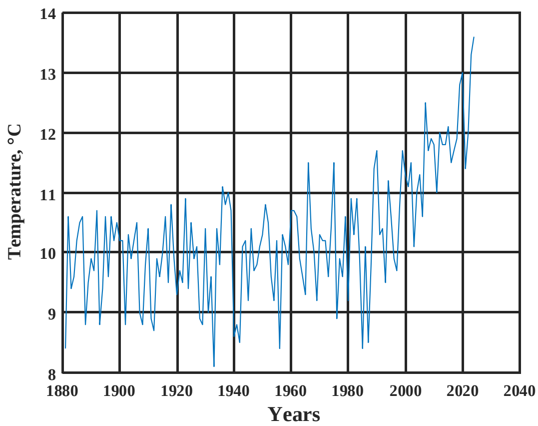

Fig. 1. **Series A – series of average annual air temperatures for the 1881-2024 period (144 readings)**

***Source*: compiled by the authors**

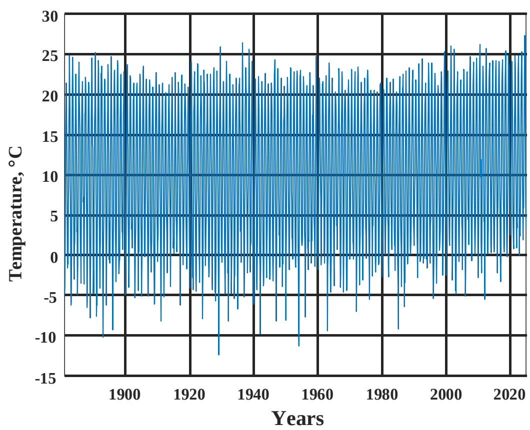

Fig. 2. **Series B – series of average monthly air temperatures for the 1881-2024 period (1728 readings)**

***Source*: compiled by the authors**

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The third series represents a series of air temperature values for 20 years with a time step of three hours and is therefore called an 8-times-daily series (8 measurements per day). A graphical representation of this series is shown in Fig. 3.

The fourth series is a series with a one-day time step of minimum and maximum daily air temperatures over 20 years. A graphical representation of this series is shown in Fig. 4.

The objectives of the time series analysis determine the necessary depth of research.

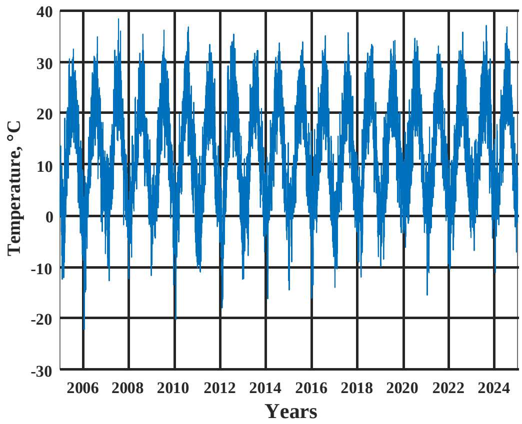

Fig. 3. **Series B – series of three-hour air temperatures for the 2005-2024 period (58,440 readings)**

***Source*: compiled by the authors**

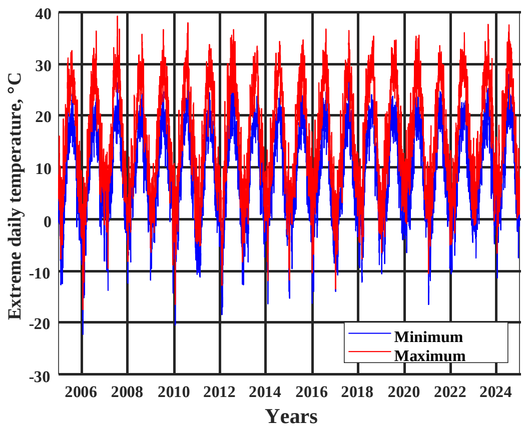

Fig. 4. **Series D – series of daily minimum and maximum air temperatures for the 2005-2024 period (7305 readings)**

***Source*: compiled by the authors**

This may be the construction of a simple model describing the behavior of the series in the most general form, in order to determine the temporal parameters of hydrometeorological events. Or, with more in-depth research and an attempt to explain its behavior, a hypothesis about the behavior of the series is accepted and a more complex model is constructed that allows for the identification of the frequency or temporal-frequency characteristics of processes.

Achieving these goals makes it possible to predict the future behavior of the series and, on this basis, warn of upcoming adverse events. With even deeper analysis, it is possible to jointly consider the development of several series of other variables over temperature (precipitation, solar radiation flux, ozone levels and other trace gas components, geophysical factors, etc.). In this case, the series under consideration becomes one of the vectors of multidimensional observations. This makes it possible to make more reliable long-term climate forecasts.

The research examined all four series in general terms. In the first stage of the research, one of the outcomes of which is this article, a temporal analysis method was selected.

In this article, the temporal analysis of a numerical series of meteorological data consists of constructing a simple model describing the behavior of the series in the most general form and, based on the constructed model, evaluating the temporal parameters of the process. The construction was carried out for several values of the temporal intervals of analysis. Subsequently, after obtaining the results of time series analysis, the same series were subjected to spectral, spectral-temporal (scale-temporal) analysis in order to identify the components of the series, their dynamics, scales, and energy.

A series of meteorological observations $M(time)$ can be represented as several components: $M(time) = Tr(time) + Sn(time) + Rg(time) + Ns(time)$. Here, $Tr(time)$ is the trend or long-term change, $Sn(time)$ is the seasonal component, $Rg(time)$ is more or less regular fluctuations relative to the trend or oscillations, and $Ns(time)$ is changes in the form of a non-systematic or random effect. Such a decomposition of a series into components is convenient for analysis. However, it should be understood that by applying this approach to model building, the researcher limits himself to the framework of this particular series model. Nevertheless, the above model of the series was used in the study. At the same time, it was necessary to take into account the fact that the trend $Tr(time)$ and seasonality $Sn(time)$ in the series under study are intertwined. It is difficult to separate one without simultaneously highlighting the other. Therefore, it became necessary to select trends in such a way as to preserve the possibility of obtaining the maximum amount of data from the transformed series.

When constructing a trend, an essential requirement is its smoothness, which naturally means representing the trend as a continuous and differentiable function. Such functions are constructed using mathematical regression. The task of mathematical regression is to approximate the data (x_i, y_i) with a certain function $f(x)$ that best minimizes the set of errors $|f(x_i)-y_i|$. Regression boils down to selecting unknown coefficients that determine the analytical dependence $f(x)$. The simplest and most commonly used regression is linear. The data (x_i, y_i) is approximated by the linear function $f(x)=b+a\cdot x$. On the coordinate plane (x, y), a linear function is represented by a straight line. Linear regression is often referred to as the least square's method, since the coefficients a and b are calculated from the condition of minimizing the sum of the squares of errors $|b+a\cdot x_i -y_i|$. Polynomial regression means approximating data (x_i, y_i) with a polynomial of degree k $f(x)=a+b\cdot x+c\cdot x^2+d\cdot x^3+...+h\cdot x^k$. When k=1, the polynomial is a straight line; when k=2, it is a parabola); when k=3, it is a cubic parabola, and so on. Since any smooth function under general assumptions can be locally represented by a polynomial with a high degree of accuracy, it is quite possible to find a polynomial in this local region that reflects the behavior of the function with a small error. The local region must be moved along the series under study and an estimate must be calculated for each, for example, the midpoint of the local region. The coefficients of the polynomial can be calculated in different ways. This is the moving average method for constructing a smooth trend function.

In this article, trends were selected and calculated using various functions: linear (linear regression); parabolic (quadratic regression); cubic parabolic (cubic regression); moving average with a third-order polynomial and window sizes of 7 and 21 with Spencer weighting coefficients. Various trends were selected to better separate the trend and seasonal components of the series. Since the process of separating components is iterative, the best trend must ultimately be selected. It is the best in the sense that, as noted above, it will allow us to obtain the greatest amount of information after subtracting the trend from the series. In our case, removing the trend from the series should preserve the greatest number of oscillating and random components for further spectral analysis with minimal distortion.

This is necessary so that subsequent types of analysis can still identify temperature data with synoptic processes. The oscillations $Rg(time)$ and random components $Ns(time)$ of the series are identified by spectral and spectral-temporal methods, and the results of this analysis will be discussed in subsequent articles.

However, one important feature of the analysis of meteorological series should be noted. In some cases, the requirement for trend smoothness has to be abandoned. This situation arises when constructing annual and seasonal climate normal in temporal analysis. These climate normals change every year in the current 30-year climate period, and the changes cease at the end of the current climate period and the onset of a new climate period. Therefore, the function is not smooth, but stepped.

RESULTS OF THE STUDY AND THEIR DISCUSSION

It should be noted that the analyzed series did not require noise reduction or any other preprocessing. They were formed after careful desk processing, including checking and eliminating outliers and checking and restoring missing data.

Results of the study of the series with a one-year time step (Series A) and their discussion

Since 1960, the World Meteorological Organization has recommended identifying thirty–year climate cycles when analyzing climate conditions. This approach was used to evaluate the entire Series A. The results of the evaluation are shown in Fig. 5 and Table 1.

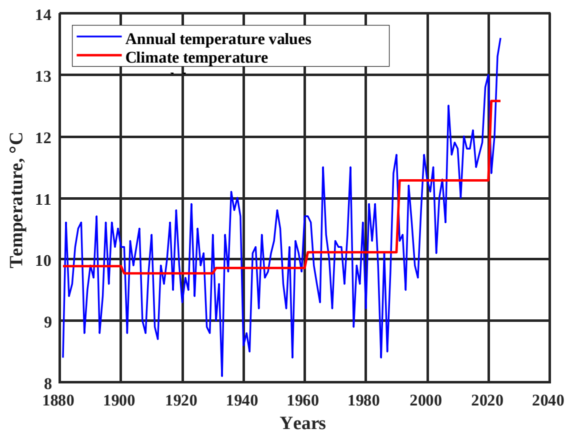

Fig. 5. **Temperature values and thirty-year climate normals for the 1881-2024 period**
***Source*: compiled by the authors**

The temperature trend for the climatic period since the 1930s has also been positive. This indicates that temperature swings are increasing in each period, at least until 2020.

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Table 1. **Values of climate normal's, maximum and minimum average annual temperatures, and temperature trends for the climate period 1881-2024**

Climate period, years	Climate normal, °C	Maxi-mum average annual tempe-rature, °C	Mini-mum average annual tempe-rature, °C	Tempe-rature range for the climatic period, °C
1881-1900	9.9	10.7	8.4	2
1901-1930	9.8	10.9	8.7	2.2
1931-1960	9.9	11.1	8.1	3
1961-1990	10.1	11.7	8.4	3.3
1991-2020	11.3	13.0	9.5	3.5
2021-2024	12.6	13.6	11.4	2.2

***Source*: compiled by the authors**

The temperature trend for a climate period is the difference between the maximum and minimum average annual temperatures in the corresponding climate period.

When analyzing the data obtained, it should be noted that the first and last periods are incomplete. The first period covers 20 years instead of 30, and the last period covers only 4 years. Therefore, the data for these periods are approximate; they are more reliable for the first period than for the last. Nevertheless, it is clear that the climate normal has been increasing since the 1960s. Maximum average annual temperatures have been rising since the beginning of the series, and minimum temperatures have been increasing since the 1990s.

As noted above, when conducting temporal analysis, one of the stages of the study is to identify *Tr*(*time*) – the trend or long-term change in the series – as one of the main components of the series. Constructing a trend requires determining the degree of the selected polynomial and the size of the moving window in which the averaging is performed. All these operations allow for selecting a trend that provides the best opportunity for subsequent extraction of information from the series after subtracting the trend from it.

If a series consists, for example, of a set of different harmonics or can be represented in this form, then as a result of trend identification, the energy of oscillations with a period shorter than the trend period increases. In addition, the energy of oscillations with a short period will increase due to oscillations with a long period. That is, there is a possibility that cyclical oscillations may be distorted by the trend exclusion procedure. The same can happen with any oscillations, since a prolonged oscillation is taken as a long–term trend when calculating the trend. The remainder of the series after trend exclusion loses some of the dynamics that should have been considered as fluctuations around the trend. Therefore, various functions were selected as trends, which would allow the optimal function to be chosen from among them to solve a specific problem using other methods. When studying a series with a one–year time step (Series A), trends were calculated (Fig. 6, Fig. 7, Fig. 8, Fig. 9 and Fig. 10).

All the trends obtained reflect the dynamics of the series under study, but each in its own way.

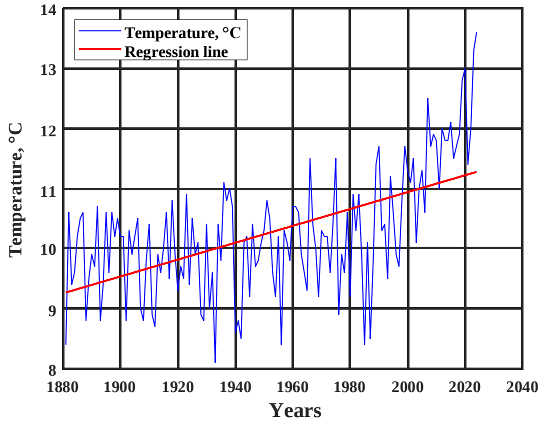

Fig. 6. **Series A with a linear regression trend superimposed**
***Source*: compiled by the authors**

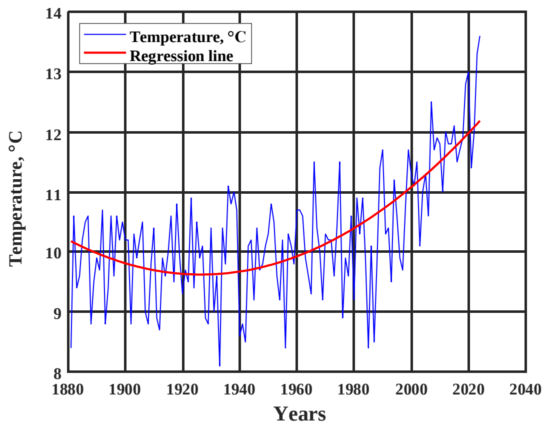

Fig. 7. **Series A with a quadratic regression trend superimposed**
***Source*: compiled by the authors**

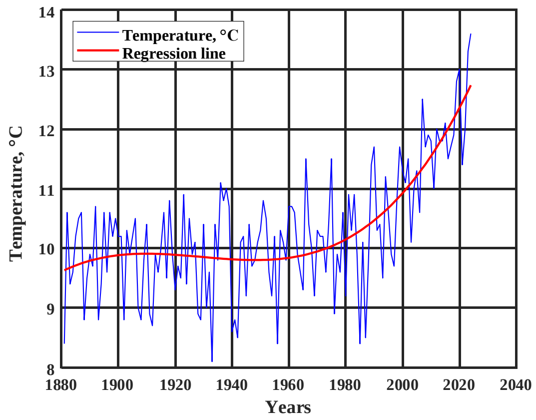

Fig. 8. **Series A with a cubic regression trend superimposed**
***Source*: compiled by the authors**

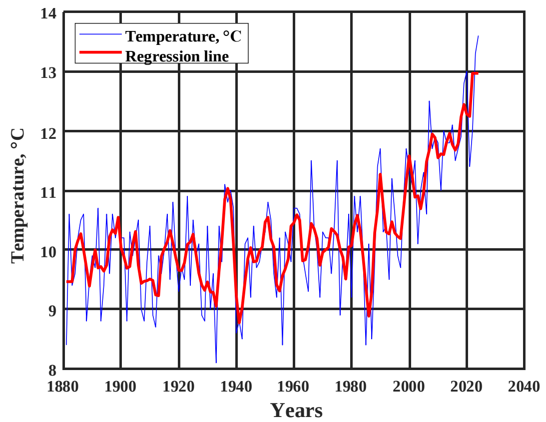

Fig. 9. **Series A with a moving average trend superimposed with a window of 7 series readings**
***Source*: compiled by the authors**

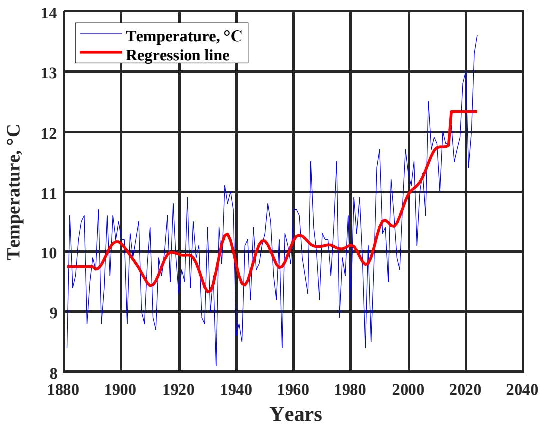

Fig. 10. **Series A with a moving average trend superimposed with a window of 21 series readings**
***Source*: compiled by the authors**

They all minimize the totality of errors, but further analysis of the trends obtained and the selection of the optimal trend must be carried out in relation to the specific task being solved.

For the subsequent spectral analysis of the series, a similar optimization was performed. The result will be presented in the next article.

Results of the study of the series with a monthly time step (Series B) and their discussion

A temporal analysis of the series with a monthly time step (Series B) was performed. This series allows us to highlight the values of monthly temperatures by season.

Seasonal temperature values were obtained by calculating the arithmetic mean of the monthly temperature for three months of each season.

The calculated seasonal temperature values with seasonal climate normals superimposed for the 1881-2024 period are shown in Fig. 11 and Table 2.

Analysis of the temperature values in Fig. 11 shows that, according to the data of the series under study, the calendar autumn is warmer than the calendar spring throughout the entire series analyzed.

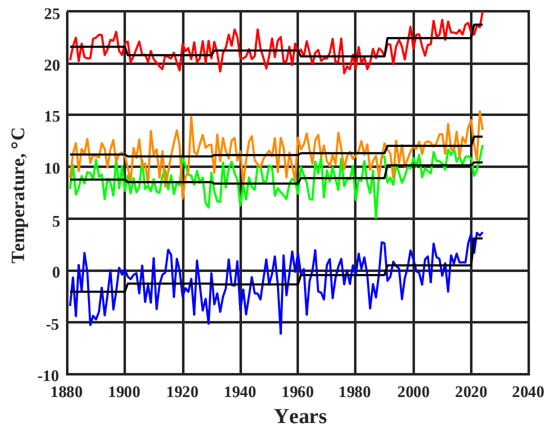

Fig. 11. **Seasonal temperature values and seasonal climate normal’s for the 1881-2024 period**
***Source*: compiled by the authors**

Table 2. **Seasonal climate normal’s for temperature in °C for the 1881-2024 period**

Climate period, years	Season			
	Winter	Spring	Sum-mer	Fall
1881-1900	-2.0	8.8	21.6	11.2
1901-1930	-1.3	8.6	20.8	11.0
1931-1960	-1.4	8.4	21.2	11.2
1961-1990	-0.5	8.9	20.7	11.3
1991-2020	0.5	10.2	22.4	12.0
2021-2024	3.1	10.5	23.7	12.9

***Source*: compiled by the authors**

Over the 1881-2020 periods, spring, summer, and autumn showed positive dynamics: +1.4 °C, +0.8 °C, and +0.8 °C, respectively. However, the most significant dynamics were observed in the winter season, amounting to +2.5 °C. Its climate normal crossed the zero thresholds and is currently positive. It is too early to draw conclusions for the subsequent climate period (2021-2024), but the general trend of temperature increase, specifically in relation to winter, is clearly visible.

Results of the study of the series with a three-hour time step (Series C) and discussion

Temporal analysis of a series of 3-hourly observations allows us to identify the daily temperature range as the difference between the maximum and minimum temperatures per day at established observation times. The result of the temporal analysis of the series of 3-hourly observations in the form of information on the daily temperature range is shown in Fig. 12. The abscissa of each point corresponds to the time, and the ordinate corresponds to the value of the daily temperature range.

The periodic structure of the daily temperature range is clearly visible in the graph in Fig. 12. It is modulated by the seasonal temperature variation. In winter, the daily temperature range is generally small, while in summer it increases.

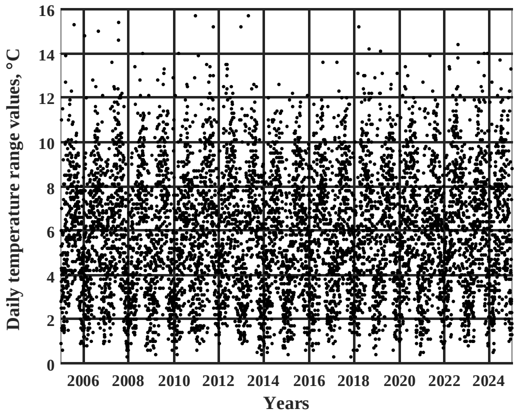

Fig. 12. **Daily temperature range values for the 2005-2024 period**
***Source*: compiled by the authors**

The histogram of the distribution of daily temperature range values is shown in Fig. 13.

The histogram clearly shows that in 55% of the observations, the daily temperature range is between 4°C and 8°C, and in 80 % of observations, it is between 3°C and 9°C.

The distribution of daily temperature range values by month of the year at different threshold values ΔT_{trs} is shown in the graphs in Fig. 14.

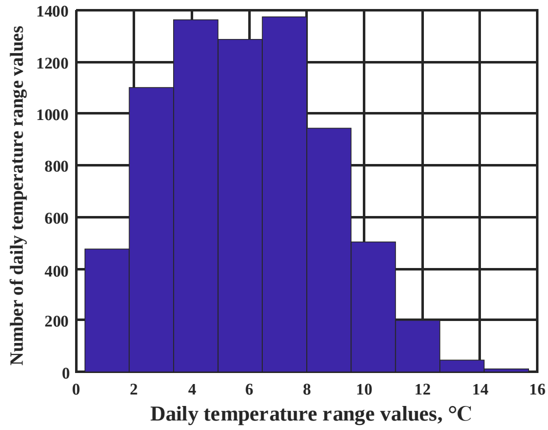

Fig. 13. **Histogram of the distribution of daily temperature range values for the 2005-2024 period**
***Source*: compiled by the authors**

Analysis of the distribution of daily temperature range values shown in Fig. 14 indicates that daily ranges up to 8 °C mainly occur at the end of summer and beginning of autumn (July-September). Large daily temperature ranges, approximately 10 °C and above, begin to split and also appear in the spring (March-May). This leads to the conclusion that winter and summer temperature regimes are more stable than those in spring and autumn. Moreover, the greatest temperature variability is observed in spring. Large temperature fluctuations in spring prevail over fluctuations in other seasons, except for early autumn.

Results of the study of the series with a daily time step (Series D) and discussion

The series of maximum and minimum daily temperatures is intended for calculating extreme climate indices. This is necessary because meteorological parameter data are obtained at regulated three-hour observation intervals. This can lead to the omission of extreme values of these parameters, which may be reached between observation intervals.

It is easy to see from the graph in Fig. 4 that for the entire observation period, the maximum temperature of 39.3°C was recorded on July 23, 2007, and the minimum temperature of -22.3°C was recorded on January 23, 2006.

Currently, 76 extreme indices are used in global climate science, 12 of which characterize air temperature.

These are:

1. *TG* – average daily air temperature for the study period *j* (month, season, year), °C.

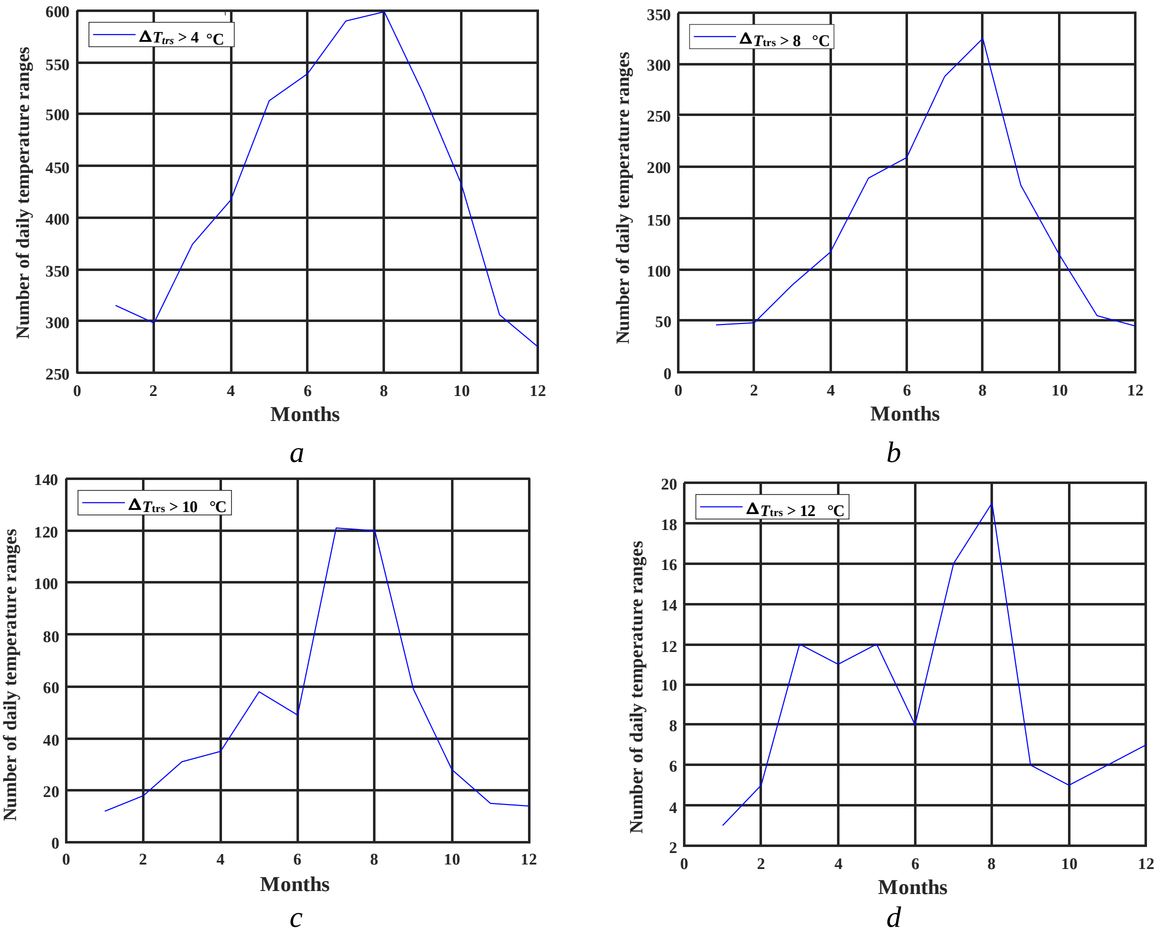

Fig. 14. **Distribution of daily temperature range values by month of the year at different threshold values ΔT_{trs} for the 2005-2024 period:**
a – ***ΔT_{trs} > 4 °C*** ; *b* – ***ΔT_{trs} > 8 °C***; *c* – ***ΔT_{trs} > 10 °C***; *d* – ***ΔT_{trs} > 12 °C***
***Source*: compiled by the authors**

2. *ATR* – amplitude of annual air temperature fluctuations, defined as the difference between the average monthly temperatures of the warmest and coldest months during the study period *j*, °C.

3. *TN* – average daily minimum air temperature for the study period *j*, °C.

4. *TX* – average daily maximum air temperature for the study period *j*, °C.

5. *DTR* – average daily air temperature amplitude for the period *j*, °C.

6. TN_j – daily minimum air temperature for period *j*.

7. *TXx* – the highest of the daily maxima (absolute maximum) air temperatures for the study period j, °C.

8. *FD* – number of frosty nights, i.e., days with a minimum negative temperature (Tn_{ij}< 0 °C) during period *j*, days.

9. *SU* – number of «summer days», i.e. days with a maximum temperature above 25 °C (Tx_{ij} > 25 °C) during period *j*, days.

10. *CSU* – maximum number of consecutive «summer days» during the study period *j*, days.

11.*TR* – number of «tropical nights», i.e. days with a minimum temperature is exceeding 20 °C (*TN* > 20 °C) during period *j*, days.

12. GSL – growing season length: the period between the start of at least a 6-day period with an average daily air temperature above 5 °C (TG > 5 °C) and the start of a period of at least 6 days with an average daily temperature below 5 °C (TG < 5 °C) within the period j, days.

Of all the twelve temperature indices listed above, *FD*, *SU*, *TR*, and *CSU* are of greatest interest for analysis. Analysis of these indices will allow conclusions to be drawn about the state of the climatic regime of air temperature.

Based on the data on the minimum and maximum daily air temperatures, extreme indices were calculated, the values of which are given in Table 3. The *CSU* index is the maximum number of consecutive «summer days» during the study period – 70 days, starting from June 24, 2022.

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Table 3. **Values of extreme air temperature indices for the 2005-2024 period**

Index	Number of days observed	Number of days meeting the index requirement
		%
FD	7305	1091
		14.9
SU	7305	1746
		23.9
TR	7305	720
		9.8

***Source*: compiled by the authors**

The total number of consecutive «summer days» (number of days in a sequence ≥ 2) for the entire observation period was 153. The histogram of the distribution of the lengths of the sequences of «summer days» is shown in Fig. 15.

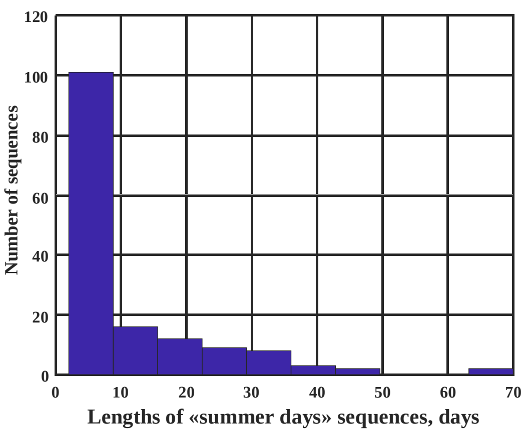

Fig. 15. **Histogram of the distribution of the lengths of "summer days" sequences (*CSU* index) over 20 years (for the 2005-2024 period)**
***Source*: compiled by the authors**

The histogram clearly shows that out of 153 sequences, 100 sequences (65 %) have duration of no more than 10 days. The 70-day sequence starting on June 24, 2022, is a unique single case in all 20 years of observations.

CONCLUSION

The objectives set for this study, namely:

- assessing changes in surface air temperature;
- identifying temperature trends;
- determining the scales of temperature variability, have been achieved.

Analysis of the results obtained allows us to draw the following *conclusions.*

1. For a 144-year temperature series with an annual lag:

- the climate normal for temperature, starting in the 1960s, has been increasing and has reached a value of 12.6 °C;
- maximum annual average temperatures have been rising since the beginning of the series and have reached 13.6°C, while minimum values have also been increasing since the 1990s and have reached 11.4 °C;
- the temperature trend over the climatic period, starting in the 1930s, has also shown a positive trend, reaching 3.5°C. This indicates that the range of average annual temperatures is increasing in each period, at least through 2020.

2. For a 144-year temperature series with a monthly lag:

- throughout the entire series, seasonal climate temperature normal's increase with slight fluctuations: in winter from -2.0°C to 3.1°C, in spring from 8.8°C to 10.5°C, in summer from 21.6 °C to 23.7°C, and in autumn from 11.2°C to 12.9 °C;
- calendar autumn is warmer than calendar spring throughout the entire series;
- the most significant change occurs in the winter season and amounts to +2.5°C. Its climatic normal has crossed zero and has a positive value.

3. For a 20-year temperature series with a three-hour lag:

- the diurnal temperature range exhibits a pronounced periodic component with a seasonal cycle;
- values of the diurnal temperature range vary between 1 and 16°C, and in 80 % of observations, the diurnal range varies between 3 and 9 °C;
- daily ranges of 1 to 10 °C occur during the summer and early fall; larger daily ranges are observed not only during the summer but also during the spring.

4. For a 20-year temperature series with a daily lag:

- the maximum temperature in the series was determined to be 39.3°C, observed on July 23, 2007, and the minimum temperature was determined to be -22.3°C, recorded on January 23, 2006;
- the values of extreme indices were determined:

number of frost nights – 14.9 %;
number of "summer days" – 23.9 %;
number of "tropical nights" – 9.8 %;

- 65 % of "summer day" sequences last no more than 10 days, and the 70-day sequence beginning on June 24, 2022, is a unique one-time occurrence over the entire 20-year observation period.

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REFERENCES

1. Boychenko, S. & Maidanovyc, N. "A century-long tendency of change in surface air temperature on the territory of Ukraine". *Geophysical Journal*. 2024; 46 (2): 53–79, https://www.scopus.com/pages/publications/85210572589. DOI: https://doi.org/10.24028/gj.v46i2.297227.

2. Dumitrescu, A., Micu, D., Guijarro, J. et al. "Long-term homogenized air temperature and precipitation datasets in Romania 1901-2023". *Scientific data*. 2025; 1116, https://www.scopus.com/pages/publications/105009898277. DOI: https://doi.org/10.1038/s41597-025-05371-4.

3. Bergström, H. & Moberg, A. "Daily air temperature and pressure series for Uppsala (1722-1998)". *Climatic change*. 2002; 53: 213–252, https://www.scopus.com/pages/publications/0036114016. DOI: https://doi.org/10.1023/A:1014983229213.

4. Gelevera, O. F. "Long-term dynamics of climatic indicators according to the data of the Kropyvnytskyi weather station". *Scientific Bulletin of the Kherson State University*. *Series Geographical Sciences*. 2019; 10: 107–113 (In Ukrainian). DOI: https://doi.org/10.32999/ksu2413-7391/2019-10-15.

5. Borovska, H. & Khokhlov, V. "Climate data for Odesa, Ukraine in 2021-2050 based on EURO-CORDEX simulations". *Geoscience Data Journal.* 2024; 11 (2): 148–159, https://www.scopus.com/pages/publications/85162246242. DOI: https://doi.org/10.1002/gdj3.197.

6. Kumar, P., Lahiri, B., Nageswararao, M. M. & Sangma, S. N. "Trend analysis and changepoint detection of monthly, seasonal and annual climatic parameters in the Garo Hills of Northeast India". *Recearch Square*. 2023, https://www.scopus.com/pages/publications/85154589413. DOI: https://doi.org/10.21203/rs.3.rs-1412182/v1.

7. Gaddikeria, V., Sarangi, A., Singh, D. K., et al. "Trend and change-point analyses of meteorological variables using Mann-Kendall family tests and innovative trend assessment techniques in New Bhupania command (India)". *Journal of Water and Climate Change.* 2024; 15 (5): 2033, https://www.scopus.com/pages/publications/85196061971. DOI: https://doi.org/10.2166/wcc.2024.462.

8. Ercan, C., Abu Arra, A. & Şişman, E. "Investigation of precipitation and temperature trends using classical and innovative approaches with corresponding frequencies in Antalya Basin, Türkiye". *Physics and Chemistry of the Earth, Parts A/B/C.* 2025; 139: 103958, https://www.scopus.com/pages/publications/105004547376.
DOI: https://doi.org/10.1016/j.pce.2025.103958.

9. Yu, Y., Schneider, U., Yang, S., Becker, A. & Ren, Z. "Evaluating the GPCC full data Daily analysis Version 2018 through ETCCDI indices and comparison with station observations over mainland of China". *Theoretical and Applied Climatology*. 2020; 142: 835–845, https://www.scopus.com/pages/publications/85089385562. DOI: https://doi.org/10.1007/s00704-020-03352-8.

10. Dunn, R. J. H., Herold, N., Alexander, L. V., Donat, M. G., Allan, R., Bador, M., et al. "Observed global changes in sector-relevant climate extremes indices". *Earth and Space Science*. 2024; 11 (4), https://www.scopus.com/pages/publications/85189623696. DOI: https://doi.org/10.1029/2023EA003279.

11. Adeyeri, O. E., Laux, P., Ishola, K. A., Zhou, W., et al. "Homogenising meteorological variables: Impact on trends and associated climate indices". *Journal of Hydrology*. 2022; 607. https://www.scopus.com/pages/publications/85124462225.
DOI: https://doi.org/10.1016/j.jhydrol.2022.127585.

12. Nerantzaki, S. D., Papalexiou, S. M., Rajulapati, C. R. & Clark, M. P. "Nonstationarity in high and low-temperature extremes: insights from station observations". *Earth Future.* 2023; 11 (11): e2023EF003506. DOI: https://doi.org/10.1029/2023EF003506.

13. Nita, I. A., Sfîcă, L., Voiculescu, M., Birsan, M. V. & Micheu, M. M. "Changes in the global mean air temperature over land since 1980". *Atmospheric Research*. 2022; 279, https://www.scopus.com/pages/publications/85136181526.

DOI: https://doi.org/10.1016/j.atmosres.2022.106392.

14. Olonscheck, D., Schurer, A. P., Lücke, L. & He-gerl, G. C. "Large-scale emergence of regional changes in year-to-year temperature variability by the end of the 21st century". *Nature Communications*. 2021; 12, https://www.scopus.com/pages/publications/85121313489. DOI: https://doi.org/10.1038/s41467-021-27515-x.

15. Twardosz, R. & Kossowska-Cezak, U. "Large-area thermal anomalies in Europe (1951-2018). Temporal and spatial patterns". *Atmospheric Research*. 2021. 251, https://www.scopus.com/pages/publications/85098598461. DOI: https://doi.org/10.1016/j.atmosres.2020.105434.

16. Helevera, O., Mostipan, M. & Topolnyy, S. "Long-term dynamics of air temperature in the winter and spring seasons in central Ukraine". *Bulletin of the V. N. Karazin Kharkiv National University, series "Geology. Geography. Ecology"*. 2023; 59: 83–94 (In Ukrainian). DOI: https://doi.org/10.26565/2410-7360-2023-59-07.

17. P'yasetska, S. V. & Shcheglov, O. M. "The current nature of changes in the average monthly air temperature during 2006-2020". *Bulletin of the V. N. Karazin Kharkiv National University. Series "Geology. Geography. Ecology"*. 2023; 58: 217–230 (In Ukrainian), https://www.scopus.com/pages/publications/85213718268. DOI: https://doi.org/10.26565/2410-7360-2023-58-17.

18. Elshewey, A. M., Shams, M. Y., Elhady, A. M., Shohieb, S. M., Abdelhamid, A. A., Ibrahim, A. & Tarek, Z. "Forecasting of monthly relative humidity in Delhi, India, using SARIMA and ANN models". *Sustainability*. 2023; 15 (1). https://www.scopus.com/pages/publications/85128091520. DOI: https://doi.org/10.3390/su15010757.

19. Perelygin, B., Borovska, H., Hnatovska, H., Sergienko, A., Tkach, T. & Shtefan, N. "Devising a forward propagation artificial neural network application technology for nowcasting weather elements". *Eastern-European Journal of Enterprise Technologies*. 2025; 1/2 (133): 18–32, https://www.scopus.com/pages/publications/85219723390.
DOI: https://doi.org/10.15587/1729-4061.2025.321664.

20. Yiou, P., Baert, E. & Loutre, M. F. "Spectral analysis of climate data". *Surveys in Geophysics*. 1996; 17: 619–663, https://www.scopus.com/pages/publications/0030372499.
DOI: https://doi.org/10.1007/BF01931784.

21. Akinpelu, J. A., Salawu, S. O. S., Oladimeji, B. & Jegede, O. O. "Harmonic investigation of temperature and sunshine using Fourier series: A case study of the northern and western stations in Nigeria". *Scientific African*. 2023; 22, https://www.scopus.com/pages/publications/85175721222. DOI: https://doi.org/10.1016/j.sciaf.2023.e01965.

22. Parra-Plazas, J., Gaona-Garcia, P. & Plazas-Nossa, L. "Time series outlier removal and imputing methods based on Colombian weather stations data". *Springer Nature Link*. 2023. 30, https://www.scopus.com/pages/publications/85159125975. DOI: https://doi.org/10.1007/s11356-023-27176-x.

23. Utrabo-Carazo, E., Azorin-Molina, C., Aguilar, E., & Brunet, M. "A spectral analysis of near-surface mean wind speed and gusts over the Iberian Peninsula". *Geophysical Research Letters*. 2023; 50 (8), https://www.scopus.com/pages/publications/85158945335.
DOI: https://doi.org/10.1029/2023GL103323.

24. Randrianantenainasoa, J. G., Rakotozafy, L. V., Solonjara, A. F., Rasolonirina, M., Randrianantenaina, F. R., Tsaravola, R. S. & Rabesiranana, N. "Impact of climate change at local level: the case of the Mandraka catchment, Eastern Central of Madagascar". *Climate Interactions*. 2025; 1 (1). DOI: https://doi.org/10.1080/29966876.2025.2560135.

25. Meng, X., Wang, Y., Zhang, Y., et al. "Research on hourly precipitation prediction along railways based on ERA5 reanalysis and post-processing correction". *Journal of Atmospheric and Solar-Terrestrial Physics*. 2025. 277, https://www.scopus.com/pages/publications/105020939333. DOI: https://doi.org/10.1016/j.jastp.2025.106666.

26. Ilyés, C., Mohammed, M. A. A., Szabó, N. P. & Szűcs, P. "A hybrid approach for exploring the spatiotemporal patterns of precipitation in Sudan: Insights from neural network clustering and Fourier-wavelet transform analysis". *Water Cycle*. 2026; 7: 151–163, https://www.scopus.com/pages/publications/105017117414.

DOI: https://doi.org/10.1016/j.watcyc.2025.07.004.

27. Yarleque, C., Vuille, M., Hardy, D. R., Posadas, A. & Quiroz, R. "Multi-scale assessment of spatial precipitation variability over complex mountain terrain using a high-resolution spatio-temporal wavelet reconstruction method". *Journal of Geophysical Research Atmospheres*. 2016; 121 (20): 12,198–12,216. DOI: https://doi.org/10.1002/2016JD025647.

28. Ghaderpour, E., Zaghloul, M. S., Dastour, H., Gupta, A., Achari, G. & Hassan, Q. K. "Least-squares triple cross-wavelet and multivariate regression analyses of climate and river flow in the Athabasca river basin". *Journal of Hydrometeorology*. 2023; 24: 1883–1900, https://www.scopus.com/pages/publications/8517582015. DOI: https://doi.org/10.1175/JHM-D-23-0013.1.

29. Yerdelen, C., Abdelkader, M. & Eris, E. "Assessment of drought in SPI series using continuous wavelet analysis for Gediz Basin, Turkey". *Atmospheric Research*. 2021. 260, https://www.scopus.com/pages/publications/85107648756. https://doi.org/10.1016/j.atmosres.2021.105687.

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Інтелектуальний часовий аналіз рядів приземної температури повітря для гідрометеорологічного моніторингу

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АНОТАЦІЯ

Актуальність.датність прогнозувати погодні умови має важливе значення для розвитку суспільства, оскільки допомагає мінімізувати збитки, спричинені погодними аномаліями. У певні моменти часу стан параметрів навколишнього середовища фіксується системою гідрометеорологічного моніторингу. Одним із параметрів, що реєструються, є температура повітря біля поверхні. Тенденції змін поточного стану природного середовища неможливо визначити без знання його попереднього стану та моделі метеорологічних процесів. Тому збір та інтелектуальний аналіз даних про динаміку температурних процесів для подальшого вдосконалення моделі метеорологічних процесів залишається актуальним завданням. **Мета та завдання.** Провести інтелектуальний аналіз довгострокових часових рядів температури приземного шару повітря з метою отримання інформації про часові характеристики мінливості температури приземного шару повітря. Оцінити зміни температурних трендів, закономірності температурних трендів та масштаби процесів мінливості температури. **Методи.** Метод аналізу часових рядів. **Наукова новизна.** Проведено часовий аналіз довготривалих часових рядів спостережень температури приземного повітря, які раніше не представлені в науці: оцінено зміни температури, масштаби цих змін та тенденції мінливості температури. **Практичне значення.** Використання отриманих даних у системах гідрометеорологічного моніторингу для уточнення моделей метеорологічних процесів, підвищення точності виявлення закономірностей у динаміці клімату та підтримки рішень щодо прогнозування. **Результати.** Для довгострокових часових рядів температури з різними характеристиками (різні лаги, різну тривалість) було отримано характеристики амплітуди змін температури повітря та температурні тренди, а також оцінено масштаби температурних змін. **Висновки.** У результаті дослідження на основі інтелектуального аналізу чотирьох рядів спостережень приземної температури повітря з лагами один рік, один місяць, один день та три години оцінено зміни температурних закономірностей, температурні тренди та масштаби процесів температурної мінливості за двадцять років (з дві тисячі п'ятого року по дві тисячі двадцять четвертий рік) та за сто сорок чотири роки (з тисяча вісімсот вісімдесят першого року по дві тисячі двадцять четвертий рік).

Ключові слова: приземна температура повітря; температурні ряди; часовий аналіз; регресія; тренди мінливості

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