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Long-Term Changes in Temperature, Precipitation, and Moisture Conditions in the Kyiv Region: Evidence from the Boryspil Weather Station (1976–2019)

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Abstract. This study focuses on the analysis of data from the meteorological station in Boryspil, Ukraine, for the period from 1976 to 2019, regarding air temperature and precipitation. Long-term monthly and annual trends were established through statistical processing and visualization using time series and graphs. It was found that both global and local air temperature

trends demonstrate a steady increase, albeit with a slight slowdown in recent years. Seasonal temperature variations were characterized, showing accelerated warming in spring and summer. The stabilization of minimum temperature values after 2000 was identified, accompanied by an increase in January, March, August, September, and December. Maximum air temperature trends were analyzed, revealing a downward tendency over the last decade, despite pronounced increases in July, August, and September. A contrasting stability in maximum temperature levels from January to March was established. The average annual precipitation in Boryspil was estimated at 566.2 mm, with a monthly rate of approximately 47.2 mm and an average of 194 days with precipitation per year. The precipitation distribution was characterized as relatively stable throughout the observation period, despite periodic extremes. Moisture conditions were assessed using Ivanov's humidity coefficient and Selyaninov's hydrothermal coefficient, calculated based on the ratio of annual precipitation to evaporation and the sum of precipitation and active temperatures. A steady negative trend in the humidity coefficient was identified, indicating a transition from excessive to insufficient moisture. A deterioration in moisture conditions was determined, particularly after 2003, based on the dynamics of the hydrothermal coefficient. A correlation analysis was conducted, revealing a statistically significant relationship between the hydrothermal coefficient, the humidity coefficient, and key climatic indicators such as average air temperature and relative humidity. The maximum correlation values were found between the humidity coefficient and average air temperature ($r = -0.72$) and relative humidity ($r = 0.83$). It was confirmed that the impacts of global warming manifest at the local level through alterations in thermal regimes and precipitation patterns, influencing agricultural practices and economic sectors. The urgent need for climate research was emphasized to ensure effective monitoring and adaptive responses to climate change. It was highlighted that understanding local manifestations of global climate trends facilitates proactive adaptation measures.

Keywords: air temperature, precipitation, meteorological observations, Ivanov's humidity coefficient, Selyaninov's hydrothermal coefficient, climate.

Довгострокові зміни температури, опадів та умов зволоження в Київській області за даними метеостанції Бориспіль (1976-2019 рр.)

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Анотація. Дослідження фокусується на аналізі даних метеорологічної станції в Борисполі (Україна) за період з 1976 по 2019 роки, що стосуються температури повітря та атмосферних опадів. У дослідженні розглядаються тенденції зміни температури повітря та опадів з акцентом на локальні прояви, як наслідки глобального потепління. Встановлено, що глобальні, так і ло-

кальні тренди температури повітря демонструють постійне зростання, з деяким уповільненням темпів зростання у останні роки. Сезонний аналіз показує більш швидке зростання температури навесні та влітку. Розподіл мінімальної температури демонструє стабілізацію після 2000 року, хоча й зі збільшенням значень мінімальної температури у січні, березні, серпні, вересні та грудні. Аналіз максимальної температури повітря показує тенденцію до її зниження протягом останнього десятиліття, з вираженим підвищенням у липні, серпні та вересні, що контрастує зі стабільними рівнями з січня по березень. Середньорічна кількість опадів у Борисполі 566,2 мм, місячна норма – близько 47,2 мм, а кількість днів з опадами становить 194 на рік. Розподіл опадів залишається стабільним протягом спостережуваного періоду, незважаючи на періодичні екстремуми. Розглянуто умови зволоження території за допомогою коефіцієнта зволоження Н.М. Іванова – Г.М. Висоцького та гідротермічного коефіцієнта Г.Т. Селянінова (ГТК). Визначення цих показників базується на відношенні річної кількості опадів до випаровуваності, а також на сумі опадів та активних температур за певний період. Аналіз показав стійкий негативний тренд коефіцієнта зволоження, що свідчить про перехід від надмірного до недостатнього типу зволоження. Динаміка гідротермічного коефіцієнта також вказує на погіршення умов зволоження, особливо після 2003 року. Кореляційний аналіз дозволив встановити статистично значущий взаємозв'язок між гідротермічним коефіцієнтом та коефіцієнтом зволоження і такими показниками, як середня температура повітря та відносна вологість. Встановлено, що максимальні значення коефіцієнта кореляції спостерігаються між коефіцієнтом зволоження та середньою температурою повітря ($r = -0,72$) і відносною вологістю ($r = 0,83$). Ці результати підтверджують важливість використання зазначених коефіцієнтів для оцінки гідротермічних умов території та їх змін у контексті кліматичних досліджень. Вплив глобального потепління проявляється на місцевому рівні через зміну теплового режиму та структури опадів, що впливає на сільське господарство та інші сектори економіки. Дослідження підкреслює гостру потребу в кліматичних дослідженнях для ефективного моніторингу та реагування на зміни клімату. Розуміння локальних проявів глобальних кліматичних тенденцій полегшує проактивні заходи з адаптації до змін клімату.

Ключові слова: температура повітря, атмосферні опади, метеорологічні спостереження, коефіцієнт зволоження Іванова-Висоцького, гідротермічний коефіцієнт Селянінова, клімат.

Introduction

The relevance of this research is driven by the need to assess the climatic changes that are already occurring. The current state of the climate system is characterized by the continuation of the global warming phase, which is happening against the backdrop of increased solar activity, heightened El Niño activity, and a restructuring of atmospheric circulation (Global, 2015; IPCC, 2019; Climate, 2021). It is important to understand that global warming is manifested not only in long-term changes in the near-surface air temperature of the planet and its individual regions. The extremity (intensity) of near-surface air temperature has increased, as well as the intensity and frequency of adverse weather events, which cause significant damage. According to the report by the Intergovernmental Panel on Climate Change (Climate, 2021), from 1991 to 2010, the number of natural anomalies increased by 2.6 times compared to previous decades, leading to a 7.3-fold increase in economic damage in developed countries.

In early August 2021, the IPCC released its latest – sixth – report on climate change, which contains detailed forecasts of the dynamics of near-surface air temperature, precipitation, and soil moisture for various regions of the Earth. Fig. 1 shows scenarios of changes in near-surface air temperature associated with different global warming levels (GWL).

Fig. 1a illustrates the response of global near-surface air temperature to anthropogenic greenhouse gas emissions for two scenarios (SSP1-2.6 and SSP3-7.0). The time when a given simulation reaches a GWL, for

example, $+2^{\circ}\text{C}$, relative to 1850–1900, is taken as the time when the central year of a 20-year running mean first reaches that level of warming (see the dots for $+2^{\circ}\text{C}$) (it is worth noting that not all simulations reach all levels of warming). Fig. 1b shows the change in near-surface air temperature, precipitation (expressed as a percentage change), and soil moisture (expressed in standard deviations of interannual variability) for three GWLs. The number in the top right corner of the panels indicates the number of model simulations averaged across all models that reach the corresponding GWL in any of the five Shared Socio-economic Pathways (SSPs).

Given the causes of global warming, it is important to note that a gradual increase in near-surface air temperature has been observed since the beginning of the twentieth century, while a rapid rise was observed in the second half of the last century (Fig. 2). Fig. 2a shows changes in global surface temperature reconstructed from paleoclimate archives (solid grey line, years 1–2000) and from direct observations (solid black line, 1850–2020), both relative to 1850–1900 and decadal averaged. The vertical bar on the left shows the estimated temperature (very likely range) during the warmest multi-century period in at least the last 100,000 years, which occurred around 6,500 years ago during the current interglacial period (Holocene). The Last Interglacial, around 125,000 years ago, is the most recent candidate for a period of higher temperature. These past warm periods were caused by slow (multi-millennial) oscillations of the Earth's orbital elements. The grey shading with white diagonal lines shows the very likely ranges for the temperature reconstructions.

Fig. 2b shows changes in global surface temperature over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to CMIP6 climate model simulations of temperature responses (Copernicus, 2021) to both human and natural drivers (brown) and natural drivers only (solar and volcanic activity, green). Solid-colored lines show the multi-model average, and shaded colors show the very likely range of simulations. The published results prove the leading role of anthropogenic factors in the rapid warming observed in recent decades.

The general patterns of climate change mentioned above have various manifestations with different regional and local expressions. Global warming is not uniform; it results in the redistribution of atmospheric characteristics and weather phenomena – both over

time and across different areas (Klimat, 2003; Klok et al., 2023, 2022; Kornus et al., 2023; Kornus & Lynok, 2017; Tymofiev et al., 2022; Savchuk et al., 2020; Shcherban, 1991). Studies currently being conducted show that temperature exhibits a stable upward trend (Martazinova, 2016, 2019; Osadchyi et al., 2018; Osadchyi & Babichenko, 2013; Donat & Alexander, 2012), while precipitation changes are more complex (Martazinova & Shcheglov, 2018; Zamfirova & Khokhlov, 2020; Khokhlov et al., 2020; Khokhlov & Yermolenko, 2015; Snizhko, 2021). These changes provoke the transformation of the natural environment, significantly impacting the economy of the region. The ratio of heat and moisture is the leading factor determining the development of terrestrial ecosystems.

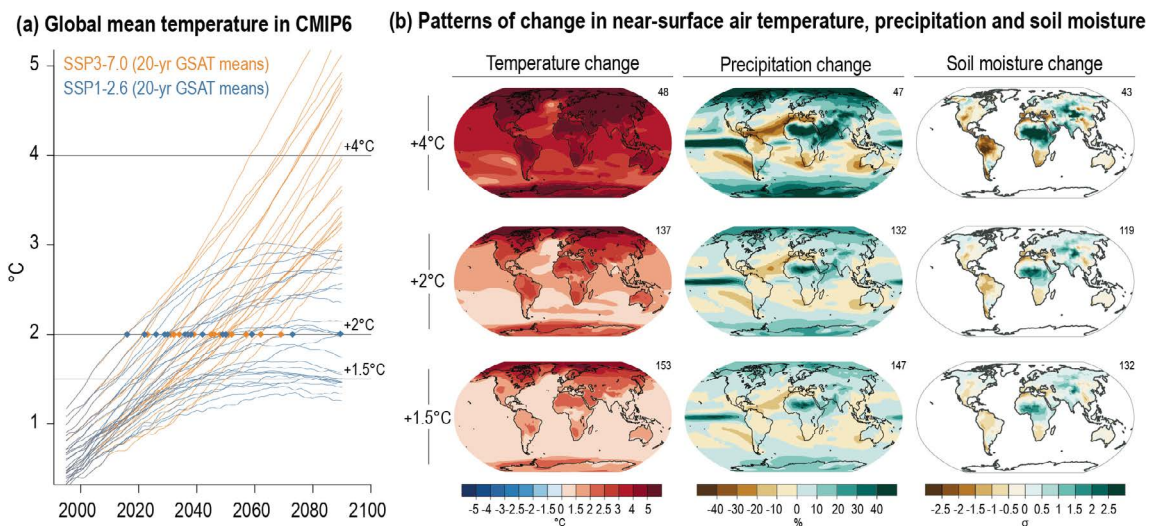


Fig. 1. Changes in global temperature calculated as part of the sixth phase of the Coupled Model Intercomparison Project (CMIP6) and spatial changes in near-surface air temperature, precipitation, and soil moisture under different warming scenarios (+1.5, +2, and +4°C) (Climate, 2021; CMIP6, 2021).

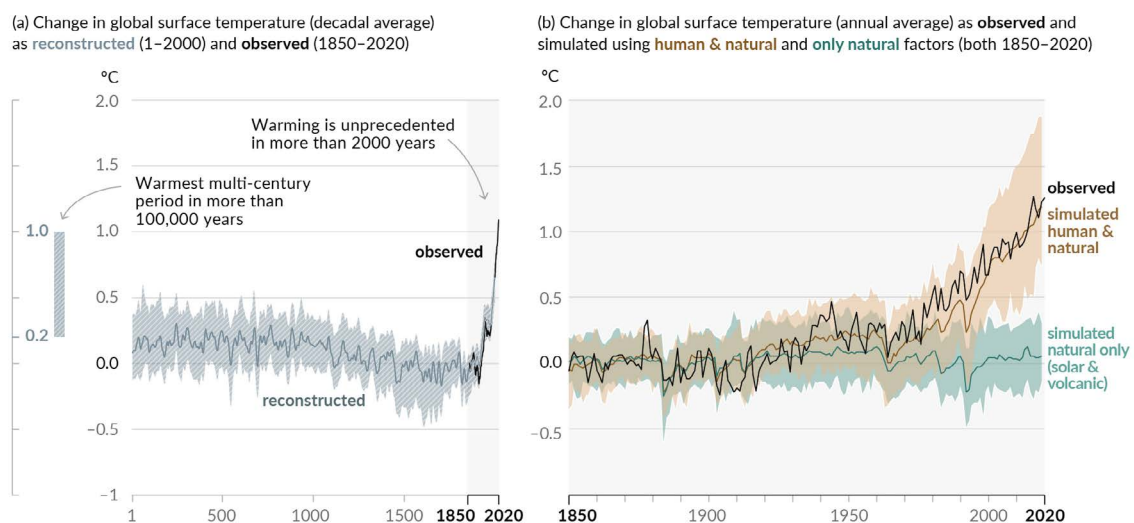


Fig. 2. Change in global surface temperature (Climate, 2021)

Assessments of climate change are based on observations obtained from meteorological stations. These data and their analysis allow for the identification and evaluation of specific manifestations of global warming. This, in turn, paves the way for the development of adaptation measures by local communities to address climate change. A detailed characterization of the main climate-forming factors, climatic regions, as well as an assessment of climate change in the Kyiv region is provided in (Martazina & Ivanova, 2010).

Since our study is based on data from a city's weather station, the work by Shevchenko O. and Snizhko S. (Shevchenko & Snizhko, 2019) is particularly relevant. Using representative Concentration Pathway (RCP) scenarios, the authors analyze temperature and precipitation trends, focusing on urban areas, and assess potential impacts on infrastructure and public health. The findings indicate an increase in average temperatures and changes in precipitation patterns, which could lead to more frequent heatwaves and altered urban hydrological regimes.

The study by Diadin et al. (2023) is also devoted to urban areas. This article investigates factors affecting the resilience of urban water resources to climate change. Key indicators include drought frequency, groundwater levels, and water source contamination. The research suggests adaptation strategies to ensure a sustainable water supply in urban areas.

The article by Kuryliuk et al. (2018) focuses on the local effects of global warming. This study examines climate change effects in the Rivne region and their consequences for aquatic ecosystems. The authors analyze temperature trends, precipitation dynamics, and moisture levels, assessing their local impact. The research includes predictions of possible future changes and suggests adaptation strategies for climate resilience.

The work by Lyalko et al. (2016) is notable from an applied perspective. This study examines the main climatic characteristics – beginning, end, and duration – of the heating period across Ukraine. The authors analyze how these parameters have changed in the context of modern climate conditions, revealing alterations in the temperature regime. The research underscores the significance of understanding these climatological characteristics for adapting to evolving climatic conditions.

Shevchenko O. examines the impact of climate change on agricultural land use in Ukraine (Shevchenko, 2023). This paper explores the effects of temperature shifts, declining precipitation, and increasing droughts. The author assesses the impact on key crops

such as wheat, corn, and sunflowers, proposing different adaptation strategies.

Our paper examines the peculiarities of changes in temperature, precipitation, and moisture levels in the Kyiv region from 1976 to 2019. The initial data for the work consists of time series of the main meteorological indicators obtained at the Boryspil weather station.

The aim of the article is to analyze long-term trends in air temperature, precipitation, and moisture conditions in the Kyiv region based on observations from the Boryspil weather station (1976–2019) and to assess their implications in the context of the local manifestations of climate change.

Material and research methods

The study is based on data obtained from observations at the Boryspil weather station (50°21'09"N, 30°57'18"E) during the period from 1976 to 2019. These electronic data were obtained from the Sectoral State Archive of Hydrometeorological Observations, which is part of the State Emergency Service of Ukraine, housed at the Central Geophysical Observatory named after Borys Sreznevskiyi. The Boryspil weather station was selected due to its central location within the Kyiv region (situated 10 km from the geographical center of the Kyiv region, which is located on the outskirts of the Hnidyn village, Boryspil District) (Hudyma et al., 2012). Additionally, it is a station with an extended range of observations, including soil temperature measurements and actinometric observations, which may allow for an expansion of research topics in the future.

The selected period includes part of the baseline climatological period (1961–1990) and the majority of the modern period (1991–2020), enabling a comparison of trends in both historical and contemporary contexts. Using a longer-than-standard climatological period helps smooth out short-term fluctuations and enhances the reliability of trend analysis. Since the late 20th century, global temperatures have been rising at an accelerated pace; thus, studying a 44-year period encompasses both the onset of modern warming and its subsequent development, making it possible to assess the rate and scale of changes. Within this time series, two 22-year observation periods (1976–1997 and 1998–2019) were compared. This division may also be useful for analyzing potential influences of solar activity, which could be explored in future research.

The quality of the data used in the study is ensured by the unification of observation methods, compliance with standardized procedures for measuring

temperature, precipitation, humidity, etc., as well as the use of approved instruments and the standardized location of measuring equipment. Measurements are carried out at strictly defined times for weather forecasts, which minimizes the possibility of subjective errors. The collected data are verified and corrected, if necessary. For example, in the case of detection of abnormal values, possible sources of errors are checked. Since the Boryspil weather station has been operating for decades using unchanged methods, its data are comparable between different observation periods, which allows for the analysis of long-term climate trends. Standardized observation methods also guarantee the homogeneity and stability of the data series, which are critical for detecting climate change. In addition, unified measurement procedures enable comparisons of Boryspil's results with those of other stations, enhancing their local representativeness and making the conclusions drawn more generalizable.

These results were processed using standard statistical analysis techniques through the built-in functions of Microsoft Excel and Statistica software (StatSoft Inc.) and visualized in graphs, illustrating the dynamics of monthly and annual near-surface air temperature and precipitation at the specified station.

To characterize the humidity of the study region, Ivanov's Humidity Coefficient (HC) was calculated. This coefficient is calculated as the ratio of annual precipitation (P, mm) to annual evaporation (E, mm), which is obtained by summing the evaporation values for each month (E_{month}) as follows:

$$HC = \frac{P}{\sum E_{\text{month}}}, \quad (1)$$

where HC is Ivanov's Humidity Coefficient, P is yearly precipitation (mm) and E_{month} is monthly evaporation (mm). To calculate monthly evaporation, as N. Ivanov suggested, the following equation was used (2):

$$E = 0.0018(25 + T)^2 (100 - r), \quad (2)$$

where E is monthly evaporation (mm), T is mean monthly temperature (°C) and r is mean monthly relative humidity (%).

For the description of moisture conditions in the study area, Selianinov's Hydrothermal Coefficient (HTC) was used. It represents the correlation between the amount of precipitation during the period when the mean daily temperature exceeds +10 °C and the sum of temperatures (in degrees) during the same period. HTC was calculated by applying the formula developed by G. Selianinov (Selianinov, 1928):

$$HTC = \frac{R}{0.1 \sum T}, \quad (3)$$

where R is the total precipitation (mm) and T is the sum of temperatures (°C) for months with mean tem-

peratures exceeding +10 °C, primarily corresponding to the vegetation period (April–October). This index can also be calculated on a monthly level for the same period. HTC has been widely applied in studies related to the identification of moist and dry periods (Păltineanu et al., 2007), the assessment of climate favorability for agriculture and natural vegetation development (Kwiatkowski, 2015; Leblois & Quirion, 2013).

Results and discussion

Let us consider the features of spatiotemporal changes in air temperature and precipitation at the Boryspil weather station.

Mean Air Temperature

It is known that the thermal regime of the atmosphere is one of the most important indicators of weather conditions and the climate of specific areas. The consequences of current changes in near-surface air temperature (global warming effects) are already being felt today, making it extremely relevant and important to study the mechanisms of these changes to develop strategies for their prevention or mitigation.

The curve of the mean annual near-surface air temperature at the Boryspil weather station (Fig. 3a) shows a clear upward trend, similar to the global air temperature discussed earlier. Notably, there has been a certain slowdown in the rate of increase in near-surface air temperature over the last two decades, along with a decrease in its amplitude.

The comparative distribution of the long-term mean monthly near-surface air temperature for different observation periods at this station is shown in Fig. 3b. The relative position of the curves illustrating the annual temperature variations clearly shows that the most intense temperature increase is observed during the spring and summer seasons. In view of this, it would be interesting to conduct a comparative analysis of the temperature distribution across specific gradations.

It should be noted that the mean temperature value is a calculated indicator, so for a more objective analysis, many authors, such as (Klok et al., 2022; Savchuk et al., 2020, etc.), suggest using its extreme values – absolute minimum and maximum.

Minimum air temperature

As is well known, the minimum air temperature (T_{min}) is the lowest temperature observed at a given location over a certain period: a day, month, year, etc. The distribution of the minimum temperature at the Boryspil weather station is shown in Fig. 4a. Notably, since the 2000s, there has been a certain stabilization of this climatic parameter. The increase in T_{min} did

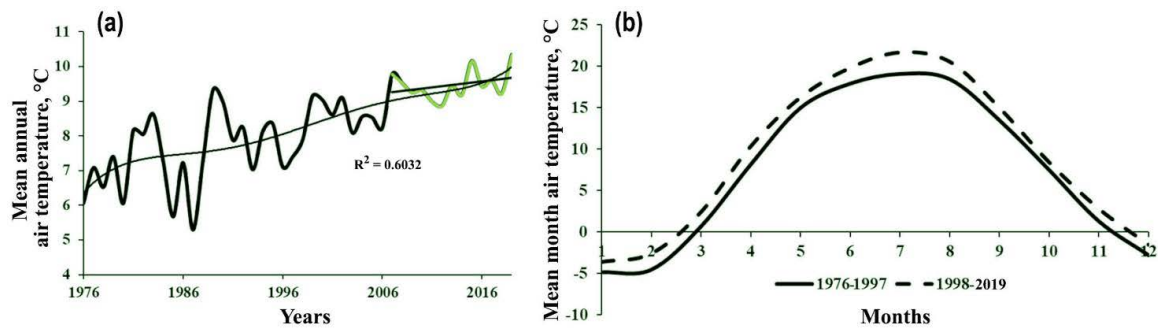


Fig. 3. Dynamics of the mean annual and monthly near-surface air temperature according to observations at the Boryspil weather station (1976-2019)

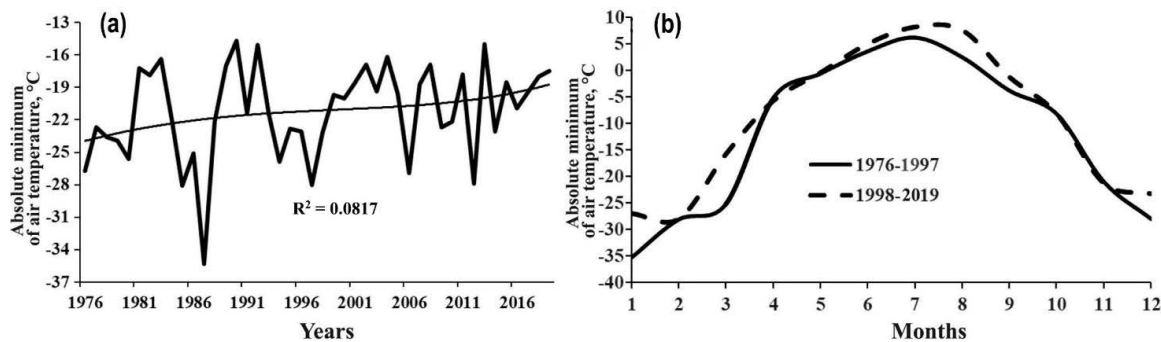


Fig. 4. Distribution of annual and monthly absolute minimum near-surface air temperature according to observations at Boryspil weather station (1976–2019)

not occur in all months of the year, as can be seen from Fig. 4b, but only in January, March, August, September, and December.

The distribution of Tmin across its gradations over the two 22-year observation periods is interesting, as shown in Fig. 5. Only the gradations of 0°C, 20°C, and 25°C demonstrate an increase in the frequency of the corresponding temperatures in the second observation period (1998–2019) compared to the 1976–1997 period.

The increase in the frequency of the 0°C gradation needs to be studied in more detail, as its occurrence in April or September may lead to late spring or early

autumn frosts, which are an unfavorable agrometeorological phenomenon.

Maximum air temperature. The highest air temperature recorded during a given year of observations at the Boryspil weather station demonstrates a downward trend over the past decade (Fig. 6a).

A comparative analysis of the annual distribution of T_{max} over the two 22-year observation periods is shown in Fig. 6b. The increase in maximum monthly temperatures occurred in the warm months (July, August, and September warmed the most), while during the cold months (October–March), the level of Tmax either remained unchanged or decreased (January–March).

The analysis of the distribution of cases of daily T_{max} across its gradations is shown in Fig. 7.

It is important to note the significant increase in the frequency of extremely high values (>25 °C) of maximum daily near-surface air temperature, which can be extremely dangerous for agriculture and other sectors, especially in conjunction with prolonged dry periods (droughts). Research by Ukrainian scientists indicates that over the past decades, there has been a persistent trend of an increasing duration and frequency of droughts not only in southern Ukraine but also in the central and northern parts of the country (Adamenko, 2014; Dmytrenko, 2010; Klimat, 2003; Savchuk et al., 2020).

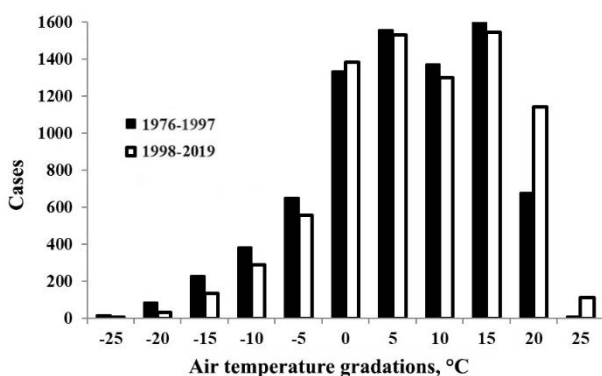


Fig. 5. Distribution of cases of minimum near-surface air temperature by gradation according to observations at Boryspil weather station (1976–2019 pp.)

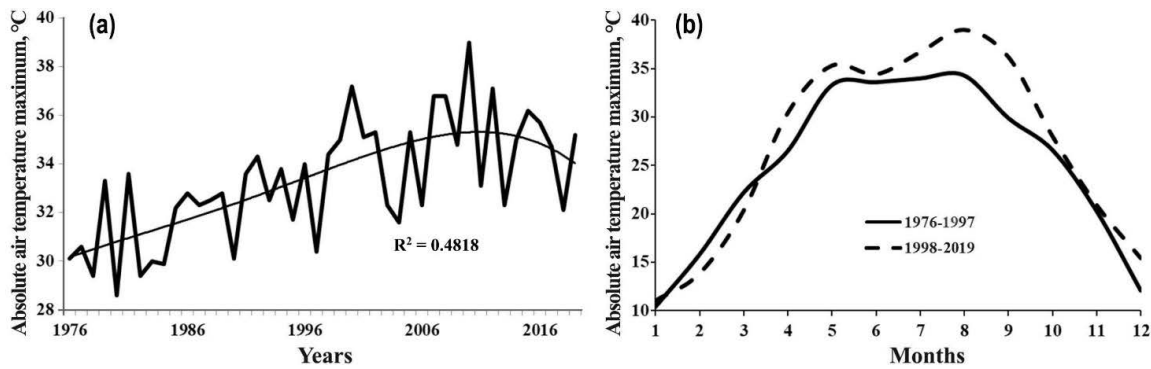


Fig. 6. Dynamics of maximum annual and monthly air temperatures according to observations at Boryspil weather station (1976-2019)

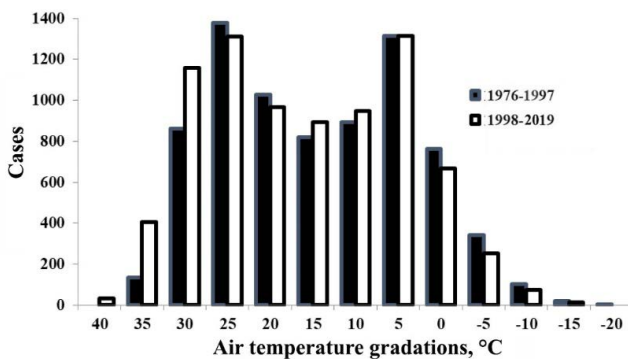


Fig. 7. Distribution of cases of the maximum daily near-surface air temperature by gradation according to observations at the Boryspil weather station (1976-2019)

Atmospheric precipitation. The average long-term precipitation amount at the Boryspil weather station for the period 1976-2019 is 566.2 mm, which is close to the average baseline for Ukraine (Adamenko, 2014). The monthly average is 47.2 mm, and the average number of days with precipitation is 194. The main characteristics of precipitation are shown in Table 1. It should be noted that the maximum precipitation (daily, monthly, and annual) was observed quite a long time ago – in 2002.

The annual precipitation amounts throughout the entire period under analysis are distributed quite evenly – there are no significant trend changes in this characteristic, as shown in Fig. 8. However, in some years, precipitation has been extremely small, or on the contrary, very large, with the range of variation in the annual precipitation total being about 400 mm (Fig. 8).

At the same time, there is a steady downward trend in the number of days with precipitation at the

Boryspil weather station, as shown in Fig. 9. The fact that the decrease in the number of days with precipitation occurs against the background of a stable annual amount of precipitation indicates an increase in the precipitation intensity and, accordingly, a decrease in its effectiveness.

Fig. 10 demonstrates the distribution of the modal component of monthly precipitation amounts, by which we mean, as is customary in mathematical statistics, any local maximum of the distribution density. Whereas before 2000 it was observed exclusively in the warm season, today we have seen its shift to the winter months. Considering the variable nature of recent winters, characterized by frequent thaws that hinder sustainable snow accumulation, it can be concluded that the effectiveness of precipitation has somewhat decreased in recent years.

An interesting aspect of analyzing the dynamics could be the examination of annual precipitation totals relative to the climatological norm, the distribution of which can be seen in Fig. 11. In this case, the climato-

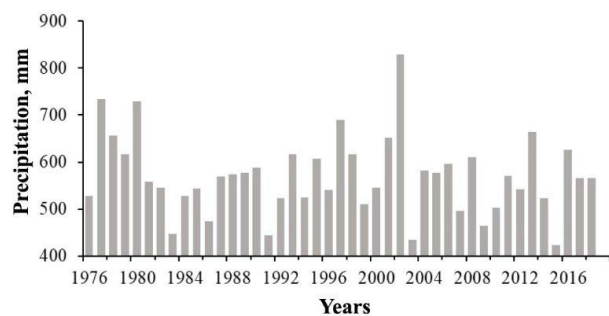


Fig. 8. Distribution of annual precipitation according to observations at Boryspil weather station (1976-2019)

Table 1. Descriptive statistics of precipitation at Boryspil weather station (1976–2019): mean values and variability.

observation period		mean annual number of days with precipitation	mean value		maximum value, mm			standard deviation, mm
start, date	end, date		mm/month	mm/year	day	month	year	
01.01.1976	31.11.2019	194	47.2	566.2	99.7 1.05.2002	180.2 5.2002	829.0 2002	32.6

logical norm refers to the average multi-year precipitation value for the period 1961-1990 (560 mm).

It should be noted that over the past decades, in some years, the annual precipitation has been significantly lower than the long-term norm, and this trend has continued in recent years. Overall, negative precipitation anomalies prevail over positive ones.

Humidification of the territory. The simplest way to assess moisture conditions is by calculating Ivanov's humidity coefficient (HC), which characterizes the ratio of annual precipitation to evapotranspiration for the same period and is one of the main climatic indicators of aridity or humidity in the climate. It should be considered that potential evapotranspiration is used in computations, not real evapotranspiration, since part of the precipitation is usually not evaporated but instead seeps into the soil, runs off as surface runoff, etc.

In addition, we note that according to the results of observations at the Boryspil weather station, there is a decrease in relative air humidity (Fig. 12).

The results of calculating the HC according to observations of near-surface air temperature, precipitation and relative humidity at the Boryspil weather station for the period 1976-2019 are shown in Fig. 13.

It is important to note that a stable negative HC trend (Fig. 13a) was observed throughout the entire period indicated, although until the early 2000s, low HC values were observed episodically – only in selected years: 1981, 1983, 1986, and 2000. At the same time, during our observation period, there was a transition of moisture conditions from excessive (HC = 1.5-2.0) to insufficient (HC < 1.0) types (Fig. 13b).

Selyaninov's hydrothermal coefficient (HTC) has an advantage over the previous coefficient, as it characterizes not only the incoming part of the water balance (precipitation), but also the unproductive loss of moisture (evaporation from the soil surface, vegetation, etc.), which is closely related to air temperature. Accordingly, it is more objective and functions in a sufficiently wide range of temperature and precipitation combinations. In the current system of agrometeorological services in Ukraine, this indicator is widely used, as well as in Bosnia and Herzegovina, Bulgaria, Kazakhstan, and Lithuania (Hydro-thermal, 2024). Using HTC, it is possible to determine how much evaporation is compensated by precipitation. Accordingly, lower values of the indicator characterize greater aridity of climatic conditions (however, it should be noted that the HTC does not take into account moisture reserves in the soil and uses only air temperature to estimate evapotranspiration).

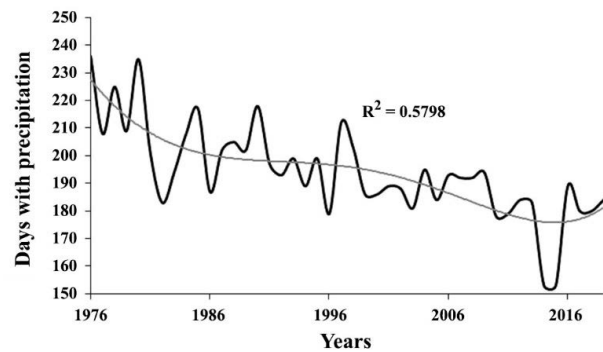


Fig. 9. Dynamics of the annual number of days with precipitation according to Boryspil weather station for the observation period 1976-2019.

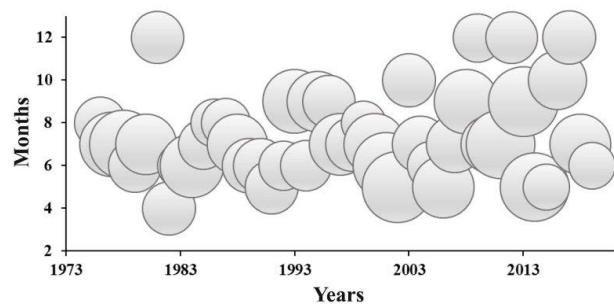


Fig. 10. Distribution of the modal component of total monthly precipitation according to observations at Boryspil weather station (1976-2019)

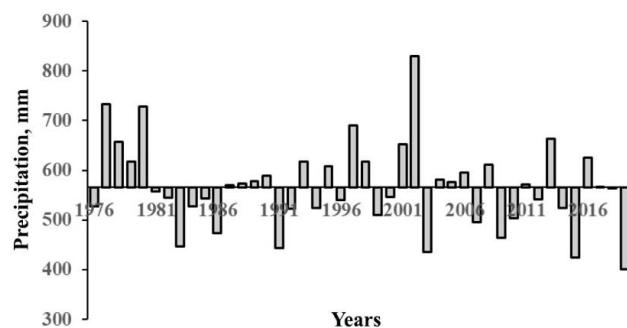


Fig. 11. Distribution of total annual precipitation relative to the long-term norm according to observations at the Boryspil weather station (1976-2019)

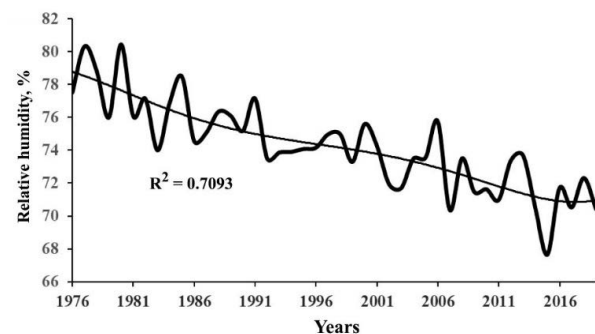


Fig. 12. Dynamics of mean annual relative air humidity according to observations at Boryspil weather station (1976-2019)

The dynamics of the distribution of absolute values of HTC at the Boryspil weather station is quite illustrative, as can be seen from Fig. 14. The first observation period (1976-1999) is characterized by an almost zero trend in HTC change, while later we have an intensive decrease in moisture conditions (Fig. 14a). As can be seen from Fig. 14b, which shows the distribution of HTC value deviations relative to the climatological norm for the period 1961-1990, dry years prevail over wet years.

Over the past 17 years (since 2003), HTC values have almost always been below normal (with the exception of 2006, 2008, 2013, and 2014), although in those years the exceedance of the normal was negligible. At the same time, not all months of the warm season of the year show a negative HTC trend: for example, in May it increases, and in August-September it is quite stable (Fig. 15).

Correlations. The values of indicators characterizing the hydrothermal conditions of the study area that were obtained in this work were subjected to correlation analysis to establish the relationship and interdependence between them. We expected that HTC and HC should correlate best with air temperature and humidity or precipitation (in the first case, the correlation should be negative). The results of the correlation analysis are shown in Table 2.

The maximum values of the correlation coefficient (r) are observed for the relationship between HC and mean annual air temperature ($r = -0.72$) and relative humidity ($r = 0.83$). Fig. 16 shows the correlation fields for the aforementioned most correlated indicators.

Conclusions

The analysis confirms the presence of climatic changes, as recorded by observations at the Boryspil meteorological station. First of all, there is a stable tendency toward increasing climate aridity – both Ivanov’s humidity coefficient and Selyaninov’s hydrothermal coefficient demonstrate a steady negative trend throughout the study period.

The increase in air temperature, observed based on the 1976-2019 data, occurs both due to an increase in extreme values and a gradual rise in average temperatures overall. However, in recent decades, maximum temperatures have shown a negative trend. A comparative analysis of the results of two different 22-year observation periods (1976-1997 and 1998-2019) showed a more significant temperature increase in the spring-summer period rather than over the entire temperature dataset.

The annual sum of precipitation remains constant for the entire analyzed period, but its distribu-

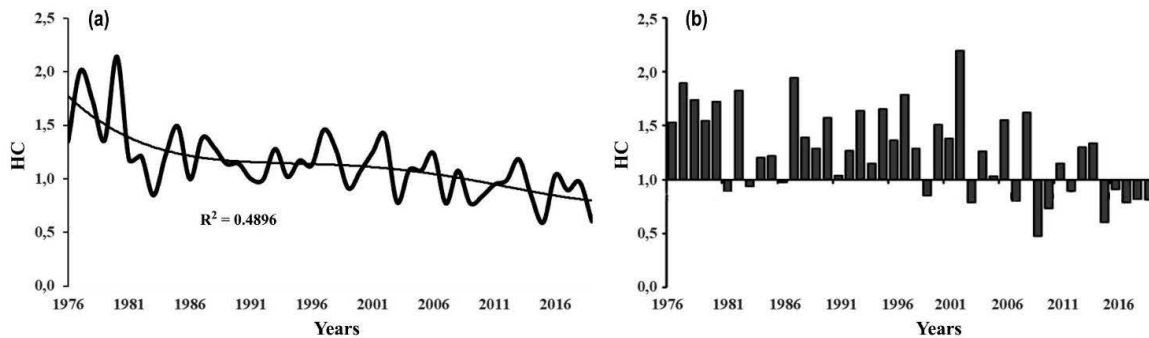


Fig. 13. Dynamics of HC according to observations at Boryspil weather station (1976-2019)

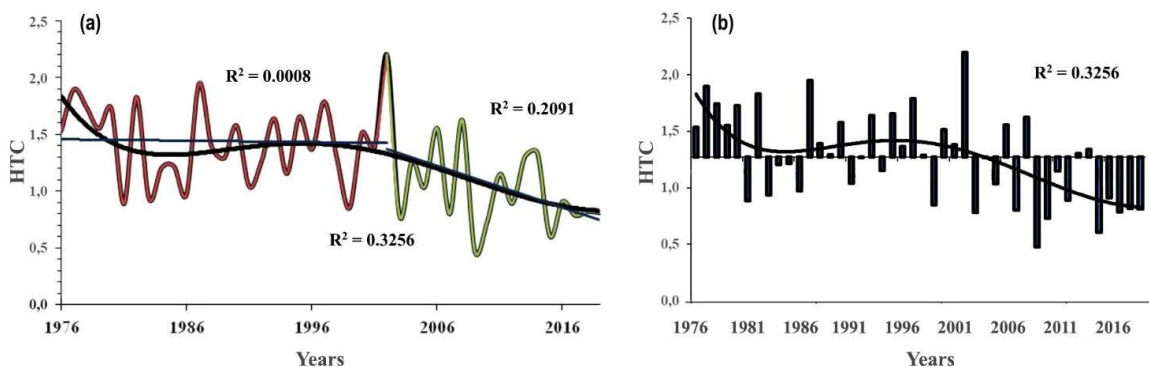


Fig. 14. Dynamics of HTC according to observations at Boryspil weather station (1976-2019)

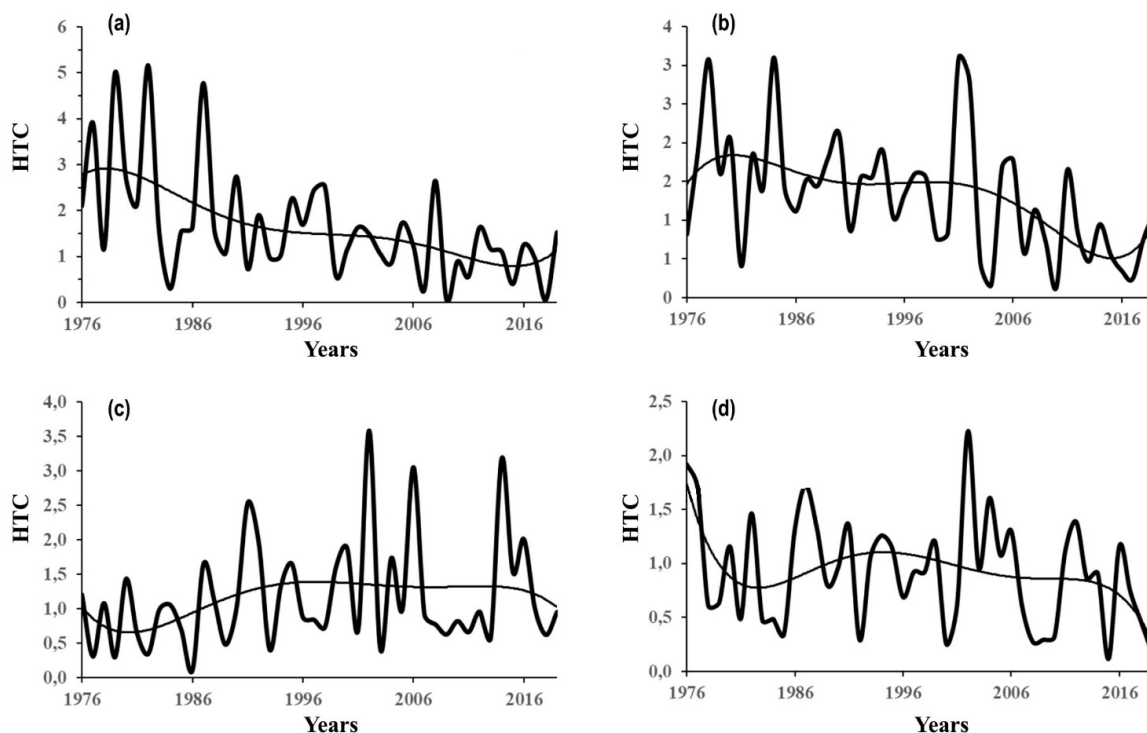


Fig. 15. HTC dynamics: (a) – in April, (b) – in June, (c) – in May, (d) – in August (based on the results of observations at the Boryspil weather station for 1976-2019).

Table 2. Correlation coefficients between moisture indices and meteorological variables

Index	Mean air temperature, °C	Maximal air temperature, °C	Minimal air temperature, °C	Precipitation, mm	Relative air humidity, %
HTC	-0.52	-0.46	-0.24	0.57	0.57
HC	-0.72	-0.58	-0.38	0.40	0.83

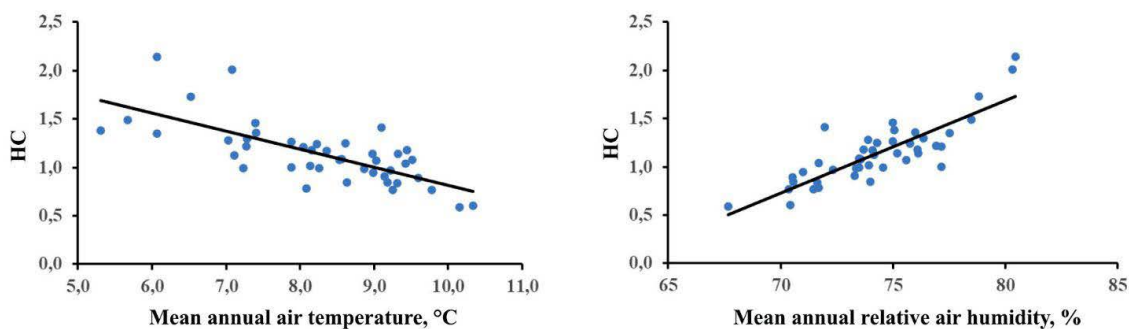


Fig. 16. Correlations between the HC and: a) mean annual air temperature, b) relative humidity (according to observations at the Boryspil weather station for 1976-2019)

tion throughout the year has changed – the amount of precipitation has increased in the cold months, which reduces its overall effectiveness. The decrease in the number of days with precipitation against the background of a stable amount of precipitation indicates an increase in precipitation extremes, which is consistent with well-documented global climate change trends.

The above findings allow us to recommend studying the possibility of cultivating more heat-loving crops in the study area due to the rising background component of air temperature. Given the redistribution of atmospheric precipitation, it is worth reconsidering the sowing dates of crops and, if possible, creating optimal conditions for maximizing the effectiveness of winter precipitation.

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