



Summer and Autumn Long-term Dynamic of Air Temperature in Central Ukraine


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ABSTRACT

Formulation of the problem. This is the second part of a trilogy dedicated to the analysis of climate indicators in central Ukraine over the entire period of instrumental observations, which analyzes air temperature data from the weather stations of Uman, Kropyvnytskyi, and Poltava. This work addresses issues related to the 13th Sustainable Development Goal, which is to combat climate change and strengthen resilience and adaptation to climate-related hazards and disasters in all countries.

The purpose of this study was to analyze data from weather stations in central Ukraine that have the longest period of observation and to find patterns in the dynamics of temperature indicators over the past 140-200 years.

Data and methods. To characterize the climate of central Ukraine, we analyzed the average monthly and average annual temperatures of Uman, Kropyvnytskyi, and Poltava, which have the longest continuous or almost continuous period of observation. Based on these data, we have constructed graphs of changes in the average annual and average monthly temperatures for the winter and spring seasons. To analyze the dynamics of temperature indicators, we constructed linear and 11-year moving trends.

Results. At all weather stations, there is a trend towards an increase in both average annual air temperatures and temperatures for certain months. In particular, in Uman, the average annual temperature over the entire observation period (138 years) has increased from +6.8°C to +8.6°C, i.e. by 1.8 degrees. In Kropyvnytskyi, average annual temperatures over 149 years increased from +7.4°C to +8.9°C, i.e. by 1.5 degrees. In Poltava, the average annual temperature over 199 years has increased from +5.9°C to +8.7°C, i.e. by 2.8 degrees (since 1886 from +6.4°C to +8.7°C, i.e. by 2.3 degrees). At all weather stations, the most significant increase in average annual temperatures occurred between 1989 and 2023. Temperatures in the autumn months increased the least. Over the entire observation period, average monthly temperatures in September/October/November increased from 0.3/0.1/0.1°C in Uman, 0.6/0.1/1.8°C in Kropyvnytskyi to 1.5/1.2/1.9°C (since 1886 – 0.9/0.9/1.7°C) in Poltava. All three meteorological stations have common periods of temperature increases and decreases, in particular, a decrease in average monthly summer temperatures occurred from 1947-1969 to 1985-1995; from 1986-1996 to 2023, an increase in air temperature. Air temperatures in the summer months have increased quite significantly. Over the entire period of observation, the average monthly temperature in June/July/August increased from 0.9/0.3/0.7°C in Kropyvnytskyi, 1.9/1.3/1.6°C (since 1886 – 1.3/1.2/1.4°C) in Poltava to 2.0/1.1/1.1°C in Uman. The greatest increase in average monthly autumn temperatures occurred from 1999-2001 to 2023. Analyzing the graphs of 11-year moving averages, one can see the presence of periods of increase and decrease in average monthly temperatures lasting about 33 years or doubled periods lasting about 66 years.

Scientific novelty. For the first time, the data of meteorological stations in central Ukraine for the entire period of observation (138 years – Uman, 149 years – Kropyvnytskyi, 199 years – Poltava) were analyzed and regularities in the dynamics of temperature indicators were determined.

The practical significance lies in the possibility of using the results of the study to predict future climate change.

Keywords: climate, temperature, climate action, average monthly air temperature, territory of Ukraine, regional climate changes, summer, autumn.

In cites: Helevera Olha, Mostipan Mykola, Topolnyi Serhii. (2024). Summer and Autumn Long-term Dynamic of Air Temperature in Central Ukraine. *Visnyk of V. N. Karazin Kharkiv National University, series "Geology. Geography. Ecology"*, (61), 144-155. <https://doi.org/10.26565/2410-7360-2024-61-12>

Problem statement. The issue of analysing and forecasting changes in weather and climate conditions over time is the most challenging in climatology. Periodic changes in climate indicators remain insufficiently studied. A detailed, high-resolution understanding of the temporal and spatial patterns of climate change over previous centuries is essential to assess the extent to which the changes of

the late 20th and early 21st centuries may be unusual of pre-industrial natural climate variability.

Analysis of recent research and publications. Temperature fluctuations for Europe since before 1500 are discussed in detail in the paper 'European Seasonal and Annual Temperature Variability, Trends, and Extremes Since 1500'. The authors used multi-proxy reconstructions of monthly and

seasonal surface temperature and found that the European climate of the late 20th and early 21st century is very likely (>95% confidence level) to be warmer than at any time in the last 500 years. This is consistent with findings for the entire Northern Hemisphere. Average European winter temperatures between 1500 and 1900 are $\sim 0.5^{\circ}\text{C}$ lower (0.25°C for annual mean temperatures) compared to the 20th century. Summer temperatures have not experienced a systematic cooling on a century-long scale relative to current conditions. The coldest European winter was in 1708-1709; 2003 had the hottest summer on record [6].

Since 1757, there has been a trend towards summer cooling (-0.06°C per decade) until the early 20th century, with 1902 being the coldest summer on record. Subsequently, there has been an extremely strong, unprecedented warming (linear trend of $+0.7^{\circ}\text{C}$ per decade), probably marked by the hottest summer decade from 1994 to 2003. European summer temperatures show other multi-decadal periods with comparable, though less strong, warming trends (1731-1757, 0.42°C per decade; 1923-1947, 0.45°C per decade, respectively). The summer of 2003 exceeded European summer temperatures from 1901 to 1995 by about 2°C . The summer of 2003 was probably warmer than any other summer before 1500 [6, 9].

The 19th century (-0.32°C) was the coldest in the last half millennium [6]. This is consistent with reconstructions for the entire Northern Hemisphere [2]. The coldest decadal periods were observed in the second half of the 19th century and at the end of the 17th century. Decadal continental annual temperature changes during pre-industrial times appear to be driven primarily by solar variability [16, 17], although long periods of volcanism may also have contributed to the cooling in Europe.

The 20th century (1901-2000) was the warmest since 1500. There was a strong warming trend of $+0.08^{\circ}\text{C}$ per decade in the 20th century. In the last 30 years (1974-2003), temperatures were $\sim 0.45^{\circ}\text{C}$ higher than the second warmest 30-year periods (1722-1751 and 1750-1779) of the reconstructions. Nine of the warmest European years have occurred since 1989. 1989 ($+1.3^{\circ}\text{C}$) and the decade from 1994 to 2003 ($+0.84^{\circ}\text{C}$) were likely the warmest in more than half a millennium [6].

Air temperatures in each of the last three decades have been higher than all previous decades since 1850, and the first decade of the 21st century was the warmest. In the Northern Hemisphere, the period from 1983 to 2012 was the warmest 30-year period in the last 1400 years. The average global surface temperature increased by 0.85°C between 1880 and 2012, calculated using a linear trend based on several separately developed data series [10].

According to the expected future climate change, the change in the average global surface temperature in the short term over the period 2016-2035 compared to 1986-2005 is likely to be in the range of $0.3-0.7^{\circ}\text{C}$. This estimate assumes no major volcanic eruptions or long-term changes in total solar radiation [11]. However, in late 2021 and early 2022, the Hunga Tonga-Hunga Ha'apai (HTHH) volcano erupted, releasing huge amounts of water vapor into the atmosphere, leading to an increase in temperature in the winter months in the northern hemisphere [13].

Studies of the dynamics of climatic indicators for the territory of Ukraine and its regions are ongoing [7, 8, 24], but they often do not cover the entire period of instrumental observations [19, 23]. Researchers note that the average annual temperature has increased by $0.6\pm 0.2^{\circ}\text{C}$ over 100 years [3, 4]. There have been attempts to predict climate change based on the projection of regional climate characteristics (for example, in Odesa region). According to them, in the near future (until 2030), changes in the average annual air temperature relative to the current period will be $+0.44^{\circ}\text{C}\pm 0.3^{\circ}\text{C}$, and its value will be 10.9°C . Insignificant changes in the average monthly air temperature (within $\pm 0.05^{\circ}\text{C}$) are expected from January to March, and from April to the end of the year, a gradual increase in average monthly air temperatures is expected. The largest increases are expected in December, September and July ($+0.8^{\circ}\text{C}\pm 0.5^{\circ}\text{C}$, $+0.79^{\circ}\text{C}\pm 0.4^{\circ}\text{C}$, $+0.74^{\circ}\text{C}\pm 0.4^{\circ}\text{C}$, respectively). The smallest confidence intervals were obtained for August $\pm 0.2^{\circ}\text{C}$, and the largest for January $\pm 0.7^{\circ}\text{C}$ [14].

Projections of changes in air temperature in Ukraine by the middle of the XXI century indicate unambiguous warming in all months of the year. Changes in the average annual temperature in this period are projected to be $+1.41\pm 0.2^{\circ}\text{C}$, and its value is 11.9°C , which is 1.0°C higher than in the previous period. The maximum changes are expected, as in the previous period, in December, at $+2.05\pm 0.4^{\circ}\text{C}$. Unlike in the near future, significant changes will occur in August $+1.81\pm 0.4^{\circ}\text{C}$ and January $+1.61\pm 0.6^{\circ}\text{C}$, the smallest in spring with a minimum in February $+0.79\pm 0.4^{\circ}\text{C}$. In the summer months, warming will occur unevenly: the maximum is in August, but in July the temperature changes are significant and amount to $+1.68\pm 0.3^{\circ}\text{C}$ [14]. Compared to 1961-1990, the average monthly air temperature in spring and autumn will undergo the smallest changes (up to 1°C), while the temperature increase in summer and winter will be $2.5-3.5^{\circ}\text{C}$ [27].

In June, the average monthly temperature in Ukraine increased by $0.4-0.7^{\circ}\text{C}$, and in the west, up to 1.0°C over a 100-year period. From July to August, a slow decline (up to 1.0°C) in air temperature

begins, which is increasing further. In August, the direction of the isotherms for both study periods coincides, with a temperature increase of 1.0°C over most of the territory and 0.5°C in the south-east. The largest temperature increase occurred in the far south, where the temperature reached 22.0°C . It also warmed up by 1.0°C in the west, where the temperature reached 18.0°C . In July and August, the air temperature increased by $1.5\text{-}2.0^{\circ}\text{C}$ across the territory compared to the climatological standard norm (1961-1990). In September, the air temperature remained almost unchanged. In October, an increase of 1.0°C was observed in the southeast, and $0.1\text{-}0.5^{\circ}\text{C}$ in the rest of the country. In November, in most areas, the air temperature has increased in recent years (by 0.4°C), while in some areas it has decreased [20].

The average annual air temperature over the past almost twenty years has been on a general upward trend, despite the fact that two periods can be clearly distinguished in the time distribution: 2000-2006 and 2007-2018. In the former case, there was a slight decrease, and in the latter, an increase in the value of this characteristic. In the northern and northeastern regions of Ukraine, the annual temperature increased by $1.0\pm 0.2^{\circ}\text{C}/100$ years; in the southern and southwestern regions only by $0.5\pm 0.1^{\circ}\text{C}/100$ years; there is a decrease in the amplitude of the seasonal temperature course by $\sim 0.4\text{-}0.5^{\circ}\text{C}$: significant warming in the cold season ($1.0\text{-}2.0^{\circ}\text{C}/100$ years), for spring ($1.5\text{-}2.0^{\circ}\text{C}/100$ years); warming was insignificant in the summer months [4].

Other researchers argue that from 2000 to 2020, the air temperature in Ukraine increased significantly, especially during the warm season, when extreme temperatures became more frequent both in the country and worldwide [22].

The changes in the temperature regime observed now are confirmed by changes in atmospheric circulation in Europe, which has led to an increase in the duration of sunshine [18] and changes in the characteristics of the radiation balance, including in most regions of Ukraine. [25]. The temperature increase in Europe and Ukraine has been stronger than the global average in recent decades [5]. There has been an increase in the duration and severity of droughts in most regions, especially in the central part of Ukraine, which negatively affects agriculture [26].

Highlighting the previously unresolved parts of the general problem to which the article is devoted. Climate change with a resolution from seasonal to annual over the past centuries has been covered in a number of studies, including climate modelling experiments with estimates of natural and anthropogenic radiative forcing and empirical reconstructions [10, 12, 15, 17]. Reconstructions of

hemispheric and global temperatures do not provide information on regional-scale variations, such as characteristic seasonal patterns of climate change that have occurred, in particular, in central Ukraine over the past centuries. Currently, much attention is being paid to the study of local (regional) climates, as trends in air temperature are ambiguous in different regions. Therefore, it is important to study the climate of central Ukraine over the longest possible period of instrumental observations.

The aim of this study is to analyse data from the meteorological stations in central Ukraine that have the longest continuous or almost continuous period of observations (Uman, Kropyvnytskyi, Poltava). The objectives of the study are to determine the following: changes in average annual air temperatures; changes in average monthly air temperatures in summer and autumn seasons; periods of increase and decrease in temperature indicators over the entire period of instrumental observations (138-199 years) in central Ukraine.

Main material of the research. To characterise the climate of central Ukraine, meteorological data from meteorological stations with the longest continuous or almost continuous period of observation were taken. In particular, the following temperature indicators are analysed:

1. The meteorological station in Uman (Cherkasy region), located at latitude 48.77, longitude 30.23, is situated at an altitude of 216 m above sea level. The meteorological station has been operating since 1885 and has continuous data for 138 years.

2. The meteorological station in Kropyvnytskyi (Kirovohrad region), which has the following coordinates: latitude 48.52, longitude 32.20, located at an altitude of 171 m above sea level. The meteorological station has been operating since 1874, however, meteorological data for 1941-1944 are partially or completely missing. The meteorological data were analysed for 149 years.

3. The meteorological station in Poltava has the following coordinates: latitude 49.60, longitude 34.55, located at an altitude of 160 m above sea level. The meteorological station has been operating since 1824, however, meteorological data for 1832-1835, 1858, 1865-1885, 1941-1943 are partially or completely missing. The meteorological data were analysed for 199 years.

A number of scientists identify periodic components of climate change, the main one being the eleven-year cycle of solar activity (Schwabe cycle) [2]. Therefore, in addition to the empirical data, we added eleven-year rolling periods to the graphs.

The analysis of the data from the meteorological station in Uman for 138 years showed the following: the average annual air temperature is $+7.65^{\circ}\text{C}$. The lowest temperature was recorded in

1942 at $+4.8^{\circ}\text{C}$. The highest temperature was in 2021 – $+10.7^{\circ}\text{C}$. According to the linear trend graph, the average annual temperature over the entire observation period has increased from $+6.8^{\circ}\text{C}$ to $+8.6^{\circ}\text{C}$, i.e. by 1.8 degrees. Between 1885 and 1987, there was almost no increase in the average annual temperature. Instead, from 1989 to 2023, there was a rather significant increase in temperature, according to the eleven-year moving average graph (Fig. 1).

The analysis of 149 years of data from the meteorological station in Kropyvnytskyi showed the following: the average annual air temperature was $+8.19^{\circ}\text{C}$. The lowest temperature was recorded in 1987 at $+5.9^{\circ}\text{C}$. The highest temperature was in 2020 at $+11.0^{\circ}\text{C}$ and in 2023 at $+11.2^{\circ}\text{C}$. According to the linear trend graph, the average annual temperature over the entire observation period increased from $+7.4^{\circ}\text{C}$ to $+8.9^{\circ}\text{C}$, i.e. by 1.5 degrees. Between 1874 and 1987, there was almost no increase in the average annual temperature. In contrast, from 1989

to 2023, there was also a fairly significant increase in temperature, according to the eleven-year moving average.

The analysis of the data from the meteorological station in Poltava over 199 years showed the following: the average annual air temperature was $+7.31^{\circ}\text{C}$. The lowest temperature was recorded in 1840 at $+4.6^{\circ}\text{C}$. The highest temperature was recorded in 2020 at $+10.6^{\circ}\text{C}$. According to the linear trend graph, the average annual temperature over the entire period of observation has increased from $+5.9^{\circ}\text{C}$ to $+8.7^{\circ}\text{C}$, i.e. by 2.8 degrees (since 1886 from $+6.4^{\circ}\text{C}$ to $+8.7^{\circ}\text{C}$, i.e. by 2.3 degrees). Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1824 to 1863 – temperature increase; from 1887 to 1933 – slight temperature fluctuations; from 1934 to 1975 – slight temperature increase; from 1976 to 1987 – slight temperature decrease; from 1989 to 2023 – quite a significant temperature increase (Fig. 1).



Fig. 1. Average annual temperatures in $^{\circ}\text{C}$ in central Ukraine (Uman, Kropyvnytskyi, Poltava):
1 - empirical data; 2 - eleven-year moving averages; 3 - linear trend

Characteristics of summer months of the year

June: in Uman, the average monthly temperature among the studied meteorological stations was the lowest at 17.93°C . The lowest temperature was recorded in 1925 at $+14.6^{\circ}\text{C}$. The highest temperature was observed in 2019 at $+22.4^{\circ}\text{C}$. According to the linear trend graph, the average monthly temperature in June for the entire observation period increased from $+16.9^{\circ}\text{C}$ to $+18.9^{\circ}\text{C}$, i.e. by 2.0 degrees. Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1885 to 1921 – a slight decrease in temperature; from 1922 to 1964 – a slight increase in temperature; from 1965 to 1994 – a slight decrease in temperature; from 1995 to 2023 – an increase in temperature.

In Kropyvnytskyi, the average monthly temperature was the highest among the meteorological stations studied, at $+18.92^{\circ}\text{C}$. The lowest was observed in 1887 and 1894 at 15.4°C . The highest was in 1875 at 23.4°C . According to the linear trend graph, the average monthly temperature in June for the entire observation period slightly increased from $+18.5^{\circ}\text{C}$ to $+19.4^{\circ}\text{C}$, i.e. by 0.9 degrees. Analysing the graph of eleven-year moving averages, the fol-

lowing periods can be distinguished: from 1874 to 1921 – a slight decrease in temperature; from 1922 to 1947 – a slight increase in temperature; from 1948 to 1994 – a slight decrease in temperature; from 1995 to 2023 – an increase in temperature.

The average monthly temperature in Poltava was $+18.54^{\circ}\text{C}$. The lowest temperature in 1846 was 12.4°C . The highest temperature in 1901 was $+23.5^{\circ}\text{C}$. According to the linear trend graph, the average monthly temperature in June over the entire observation period has increased from $+17.5^{\circ}\text{C}$ to $+19.4^{\circ}\text{C}$, i.e. by 1.9 degrees (since 1886 – from $+17.5^{\circ}\text{C}$ to $+19.8^{\circ}\text{C}$, i.e. by 2.3 degrees). Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1825 to 1934 – temperature fluctuations; from 1935 to 1957 – a slight increase in temperature; from 1958 to 1995 – a slight decrease in temperature; from 1996 to 2023 – an increase in temperature (Fig. 2).

All three meteorological stations have common periods of temperature increases and decreases, in particular, the average monthly temperature in June increased from 1922-1934 to 1947-1957; from 1948-1965 to 1994-1995 the temperature decreased; from 1995-1996 to 2023 the air temperature increased.

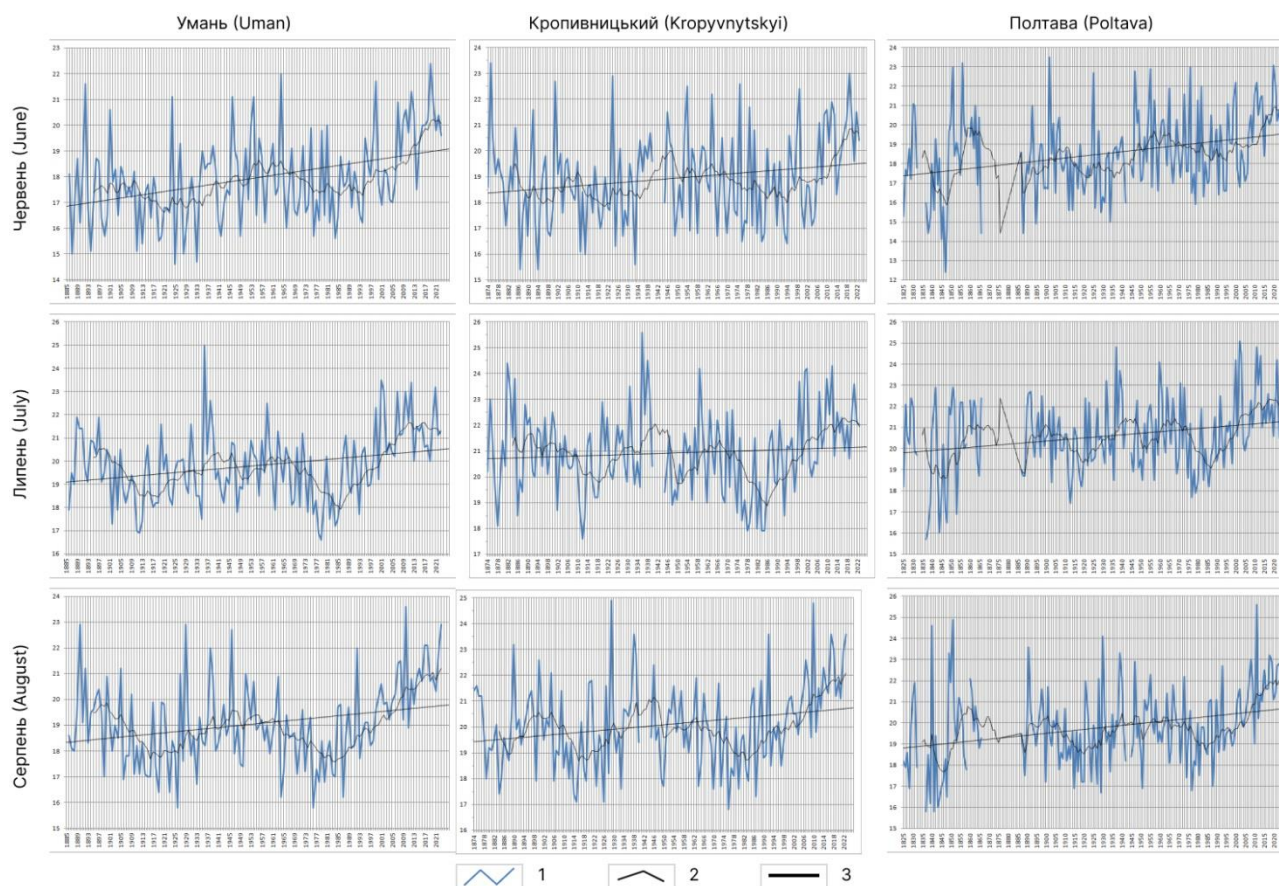


Fig. 2. Average temperatures in $^{\circ}\text{C}$ in summer months (June, July, August) in central Ukraine (Uman, Kropyvnytskyi, Poltava) : 1 – empirical data; 2 – eleven-year moving averages; 3 – linear trend

July: In Uman, the average monthly temperature was the lowest among the meteorological stations studied, at $+19,80^{\circ}\text{C}$. The lowest was recorded in 1979 at $+16,6^{\circ}\text{C}$. The highest was recorded in 1936 at $+25,0^{\circ}\text{C}$. According to the linear trend graph, the average monthly temperature in July for the entire observation period increased from $+19,3^{\circ}\text{C}$ to $+20,4^{\circ}\text{C}$, i.e. by 1.1 degrees. Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1885 to 1918 – a slight decrease in temperature; from 1920 to 1946 – a slight increase in temperature; from 1947 to 1986 – a slight decrease in temperature; from 1987 to 2023 – an increase in temperature.

In Kropyvnytskyi, the average monthly temperature among the studied weather stations was the highest at $20,90^{\circ}\text{C}$. The lowest was observed in 1912 at $17,6^{\circ}\text{C}$. The highest was also in 1936, at $25,6^{\circ}\text{C}$. According to the linear trend graph, the average monthly temperature in July over the entire observation period hardly changed. It was $+20,8^{\circ}\text{C}$ and became $+21,1^{\circ}\text{C}$, i.e. increased by 0.3 degrees. Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1874 to 1918 – a slight decrease in temperature; from 1920 to 1940 – a slight increase in temperature; from 1947 to 1986 – a slight decrease in tem-

perature; from 1987 to 2023 – an increase in temperature.

The average monthly temperature in Poltava was $20,59^{\circ}\text{C}$. The lowest temperature was observed in 1836 – $15,7^{\circ}\text{C}$. The highest temperature was in 2001, at $25,1^{\circ}\text{C}$. According to the linear trend graph, the average monthly temperature in July over the entire period of observation has increased from $+19,9^{\circ}\text{C}$ to $+21,2^{\circ}\text{C}$, i.e. by 1.3 degrees (since 1886 – from $+20,1^{\circ}\text{C}$ to $+21,3^{\circ}\text{C}$, i.e. by 1.2 degrees). Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1825 to 1919 – temperature fluctuations; from 1920 to 1942 – a slight increase in temperature; from 1945 to 1967 – slight temperature fluctuations; from 1969 to 1986 – temperature decrease; from 1988 to 2023 – temperature increase (Fig. 2).

All three meteorological stations have common periods of temperature increases and decreases, in particular, the increase in average monthly July temperatures occurred from 1920 to 1940-1946; from 1947-1969 to 1986, there was a decrease in temperature; from 1987-1988 to 2023, there was an increase in air temperature.

August: in Uman, the average monthly temperature among the studied meteorological stations was the lowest at $+19,03^{\circ}\text{C}$. The lowest temperature

was recorded in 1926 and 1976 at $+16.8^{\circ}\text{C}$. The highest temperature was in 2010 at $+23.6^{\circ}\text{C}$. According to the linear trend graph, the average monthly temperature in August over the entire observation period increased from $+18.5^{\circ}\text{C}$ to $+19.6^{\circ}\text{C}$, i.e. by 1.1 degrees. Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1885 to 1917 – a slight decrease in temperature; from 1920 to 1946 – a slight increase in temperature; from 1947 to 1985 – a slight decrease in temperature; from 1986 to 2022 – an increase in temperature.

In Kropyvnytskyi, the average monthly temperature was the highest among the meteorological stations studied, at 20.03°C . The lowest temperature was also observed in 1976, at 16.8°C . The highest temperature was in 1929 at $+24.9^{\circ}\text{C}$ and in 2010 at $+24.8^{\circ}\text{C}$. According to the linear trend graph, the average monthly temperature in August over the entire observation period increased slightly from $+19.7^{\circ}\text{C}$ to $+20.4^{\circ}\text{C}$, i.e. by 0.7 degrees. Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1874 to 1916 – a slight decrease in temperature; from 1917 to 1946 – a slight increase in temperature; from 1947 to 1985 – a slight decrease in temperature; from 1986 to 2023 – an increase in temperature.

The average monthly temperature in Poltava was 19.79°C . The lowest temperature in 1836 and 1840 was 15.8°C . The highest temperature in 2010 was 25.6°C . According to the linear trend graph, the average monthly temperature in August over the entire observation period slightly increased from $+18.9^{\circ}\text{C}$ to $+20.5^{\circ}\text{C}$, i.e. by 1.6 degrees (since 1886 – from $+19.1^{\circ}\text{C}$ to $+20.7^{\circ}\text{C}$, i.e. by 1.6 degrees). Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1825 to 1901 – temperature fluctuations; from 1902 to 1920 – a slight decrease in temperature; from 1920 to 1939 – a slight increase in temperature; from 1940 to 1964 – slight temperature fluctuations; from 1968 to 1985 – a decrease in temperature; from 1990 to 2023 – an increase in temperature (Fig. 2).

All three meteorological stations have common periods of temperature increases and decreases, in particular, a decrease in the average monthly temperature in August occurred in 1916-1920; from 1917-1920 to 1939-1946, a slight increase in temperature; from 1947-1968 to 1985, a slight decrease in temperature; from 1986-1990 to 2023, an increase in air temperature. Thus, the summer season was the warmest in Kropyvnytskyi and the coldest in Uman.

Characteristics of autumn months of the year

September: in Uman, the average monthly temperature was the lowest among the meteorological stations studied – 13.97°C . The lowest temperature was recorded in 1959 at $+10.8^{\circ}\text{C}$. The highest

temperature was in 1909 at 18.3°C and in 2023 at 18.4°C . According to the linear trend graph, the average monthly temperature in September over the entire observation period hardly changed. It was $+13.8^{\circ}\text{C}$ and became $+14.1^{\circ}\text{C}$, i.e. increased by 0.3 degrees. Analysing the eleven-year moving average graph, the following periods can be distinguished: from 1885 to 1954 – slight temperature fluctuations; from 1956 to 1966 – slight temperature decrease; from 1967 to 2000 – slight temperature fluctuations; from 2001 to 2023 – temperature increase.

In Kropyvnytskyi, the average monthly temperature among the studied weather stations was the highest at 14.76°C . The lowest temperature was observed in 1997 at 11.3°C . The highest temperature was also in 1909, at 20.2°C . According to the linear trend graph, the average monthly temperature in September hardly changed over the entire observation period. It was $+14.5$ and became $+15.1$, i.e. increased by 0.6 degrees. Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1874 to 1954 – slight temperature fluctuations; from 1955 to 1966 – slight temperature decrease; from 1967 to 1997 – slight temperature fluctuations; from 1999 to 2023 – temperature increase.

The average monthly temperature in Poltava was 14.29°C . The lowest temperature was in 1843, at 9.6°C . The highest temperature was also in 1909, at 19.4°C . According to the linear trend graph, the average monthly temperature in September over the entire period of observation slightly increased from $+13.5^{\circ}\text{C}$ to $+15.0^{\circ}\text{C}$, i.e. by 1.5 degrees (since 1886 – from $+14.0^{\circ}\text{C}$ to $+14.9^{\circ}\text{C}$, i.e. by 0.9 degrees). Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1825 to 1997 – insignificant temperature fluctuations; from 1999 to 2023 – temperature increase (Fig. 3).

All three weather stations have common periods of rising and falling temperatures, in particular, from 1999-2001 to 2023, when the air temperature increased.

October: In Uman, the average monthly temperature was $+7.81^{\circ}\text{C}$. The lowest temperature was recorded in 1920 at $+1.1^{\circ}\text{C}$. The highest temperature was recorded in 1918 at $+13.1^{\circ}\text{C}$. According to the linear trend graph, the average monthly temperature in October over the entire observation period hardly changed. It was $+7.8^{\circ}\text{C}$ and became $+7.9^{\circ}\text{C}$, i.e. increased by 0.1 degrees. Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1885 to 1915 – a slight decrease in temperature; from 1917 to 1935 – a slight increase in temperature; from 1936 to 1951 – a slight decrease in temperature; from 1952 to 1966 – a slight increase in temperature; from 1967 to 2023 –

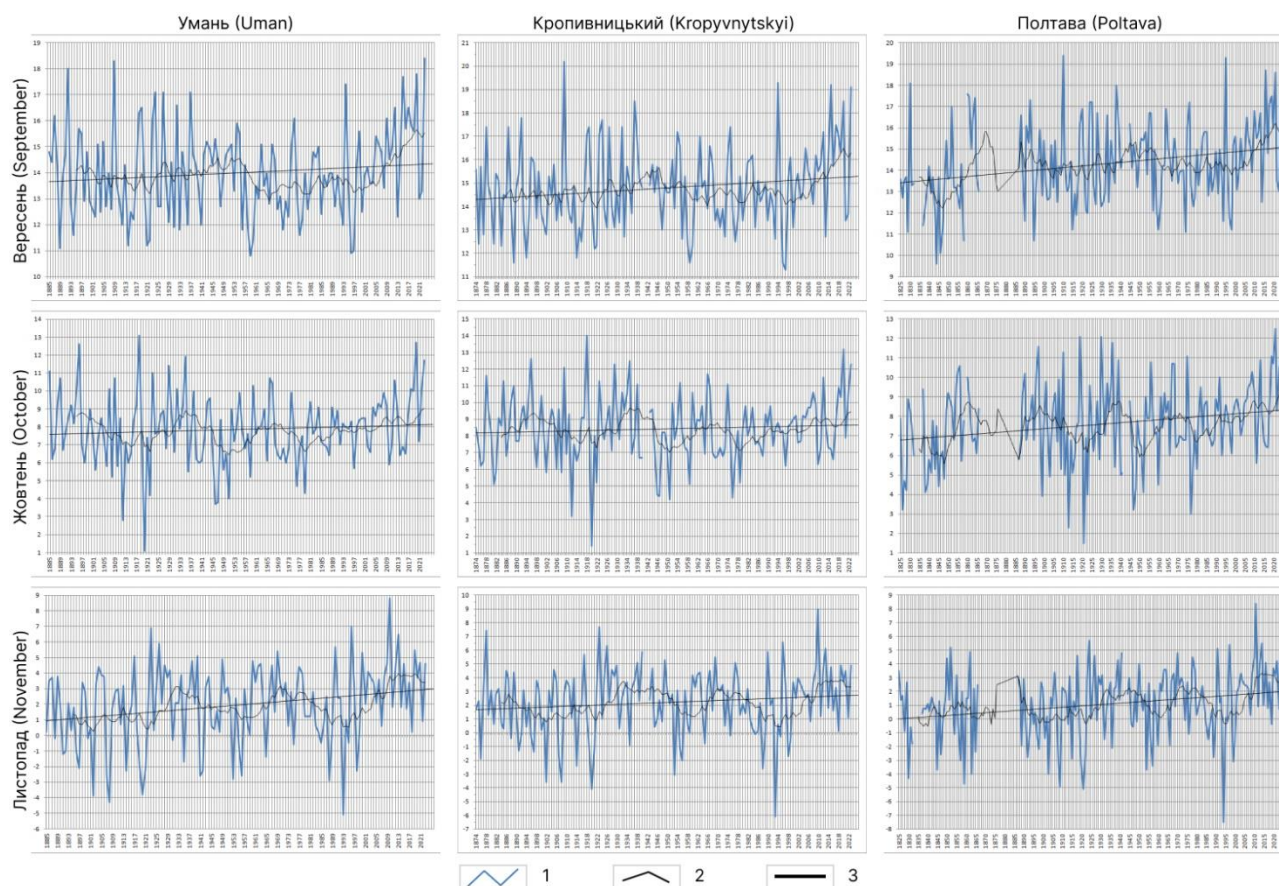


Fig. 3. Average temperatures in $^{\circ}\text{C}$ in autumn months (September, October, November) in central Ukraine (Uman, Kropyvnytskyi, Poltava): 1 – empirical data; 2 – eleven-year moving averages; 3 – linear trend

slight temperature fluctuations.

In Kropyvnytskyi, the average monthly temperature was the highest among the meteorological stations studied, at 8.37°C . The lowest temperature was also observed in 1920, at $+1.4^{\circ}\text{C}$. The highest temperature was in 1918, at $+14.0^{\circ}\text{C}$. According to the linear trend graph, the average monthly temperature in October over the entire observation period hardly changed. It was $+8.3^{\circ}\text{C}$ and became $+8.4^{\circ}\text{C}$, i.e. increased by 0.1 degrees. Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1874 to 1915 – a slight decrease in temperature; from 1917 to 1935 – a slight increase in temperature; from 1936 to 1951 – a slight decrease in temperature; from 1952 to 1966 – a slight increase in temperature; from 1967 to 2023 – slight temperature fluctuations.

In Poltava, the average monthly temperature among the studied weather stations was the lowest at $+7.57^{\circ}\text{C}$. The lowest temperature was also in 1920, at $+1.5^{\circ}\text{C}$. The highest temperature was in 2020 at 12.5°C . According to the linear trend graph, the average monthly temperature in October for the entire observation period slightly increased from $+6.9^{\circ}\text{C}$ to $+8.1^{\circ}\text{C}$, i.e. by 1.2 degrees (since 1886 – from $+7.3^{\circ}\text{C}$ to $+8.2^{\circ}\text{C}$, i.e. by 0.9 degrees). Analysing the graph of eleven-year moving averages, the

following periods can be distinguished: from 1825 to 1860 – a slight increase in temperature; from 1898 to 1923 – a decrease in temperature; from 1924 to 1939 – an increase in temperature; from 1940 to 1952 – a decrease in temperature; from 1953 to 2023 – a slight increase in temperature (Fig. 3).

All three meteorological stations have common periods of temperature increases and decreases, in particular, a decrease in the average monthly temperature in August occurred from 1915 to 1923; from 1917 to 1924 to 1935 to 1939, a slight increase in temperature; from 1936 to 1940 to 1951 to 1952, a slight decrease in air temperature.

November: In Uman, the average monthly temperature was $+1.91^{\circ}\text{C}$. The lowest temperature was recorded in 1993 -5.1°C . The highest temperature was in 2010 at 8.8°C . According to the linear trend graph, the average monthly temperature in November over the entire observation period slightly increased from $+1.0^{\circ}\text{C}$ to $+2.8^{\circ}\text{C}$, i.e. by 1.8 degrees. Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1885 to 1922 – slight temperature fluctuations; from 1923 to 1934 – slight temperature increase; from 1935 to 1959 – slight temperature decrease; from 1960 to 1969 – slight temperature increase; from 1970 to 1993 – slight temperature de-

crease; from 1994 to 2023 – temperature increase.

In Kropyvnytskyi, the average monthly temperature was the highest among the meteorological stations studied, at +2.18°C. The lowest temperature was observed in 1993 -6.1°C. The highest temperature was in 2010, at +9.0°C. According to the linear trend graph, the average monthly temperature in November hardly changed over the entire observation period. It was +1.9°C and became +2.5°C, i.e. increased by 0.6 degrees. Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1874 to 1922 – slight temperature fluctuations; from 1923 to 1934 – slight temperature increase; from 1935 to 1959 – slight temperature decrease; from 1960 to 1969 – slight temperature increase; from 1970 to 1993 – slight temperature decrease; from 1994 to 2023 – temperature increase.

In Poltava, the average monthly temperature among the studied weather stations was the lowest at +1.04°C. The lowest temperature was -7.5°C in 1993. The highest temperature was observed in 2010 at +8.4°C. According to the linear trend graph, the average monthly temperature in November over the entire period of observation slightly increased from +0.0°C to +1.9°C, i.e. by 1.9 degrees (since 1886 – from +0.2°C to +1.9°C, i.e. by 1.7 degrees). Analysing the graph of eleven-year moving averages, the following periods can be distinguished: from 1825 to 1921 – slight temperature fluctuations; from 1922 to 1945 – temperature increase; from 1946 to 1960 – slight temperature decrease; from 1961 to 1973 – slight temperature increase; from 1974 to 1994 – slight temperature decrease; from 1995 to 2023 – slight temperature increase (Fig. 3).

At all the studied weather stations over the entire observation period, the lowest average monthly temperatures in November were recorded in 1993, and the highest in 2010. All three weather stations had common periods of temperature increases and decreases, in particular, from 1922-1923 to 1934-1945 – a slight increase in temperature; from 1935-1946 to 1959-1960 – a slight decrease in temperature; from 1994-1995 to 2023 – an increase in air temperature.

Thus, the autumn season was the warmest in Kropyvnytskyi, and the coldest (except for Septem-

ber) in Poltava.

Conclusions. The analysis of meteorological data from meteorological stations in central Ukraine over the entire period of observation showed the following: average annual temperatures increased from 1.5°C in Kropyvnytskyi, 1.8°C in Uman to 2.8°C (since 1886 2.3°C) in Poltava. The highest average annual temperatures at all weather stations were recorded in 2020, 2021 and 2023.

Temperatures in autumn months increased the least. Over the entire observation period, average monthly temperatures in September increased from 0.3°C in Uman, 0.6°C in Kropyvnytskyi to 1.5°C (since 1886 0.9°C) in Poltava. The average monthly temperature in October increased from 0.1°C in Uman and Kropyvnytskyi to 1.2°C in Poltava (0.9°C since 1886). The average monthly temperature in November increased from 0.6°C in Kropyvnytskyi and 1.8°C in Uman to 1.9°C (since 1886 1.7°C) in Poltava. All three weather stations had common periods of temperature increases and decreases, in particular, an increase in average monthly autumn temperatures occurred from 1999-2001 to 2023.

The temperatures of summer months have increased quite significantly. Over the entire period of observation, the average monthly temperature in June increased from 0.9°C in Kropyvnytskyi, 1.9°C (since 1886 2.3°C) in Poltava to 2.0°C in Uman. The average monthly temperature in July increased from 0.3°C in Kropyvnytskyi, 1.1°C in Uman to 1.3°C in Poltava (1.2°C since 1886). The average monthly temperature in August increased from 0.7°C in Kropyvnytskyi and 1.1°C in Uman to 1.6°C (since 1886 1.6°C) in Poltava. All three meteorological stations had common periods of temperature increases and decreases, in particular, a decrease in average monthly summer temperatures occurred from 1947-1969 to 1985-1995; from 1986-1996 to 2023, an increase in air temperature.

Analyzing the 11-year sliding graphs, one can notice the presence of periods of increase-decrease in average monthly temperatures lasting about 33 years or doubling periods lasting about 66 years. Due to the lack of meteorological data for a long period, such patterns are difficult to identify, but this is a promising area for further research.

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Authors Contribution: All authors have contributed equally to this work

Conflict of Interest: The authors declare no conflict of interest

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Багаторічна динаміка температури повітря літнього та осіннього сезонів у центральній Україні

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Це друга частина трилогії, присвяченої аналізу кліматичних показників центральної України за весь період інструментальних спостережень, в якій проаналізовано дані про температуру повітря з метеостанцій Умані, Кропивницького та Полтави. Ця робота стосується питань, пов'язаних з 13-ю Ціллю сталого розвитку, яка полягає у боротьбі зі зміною клімату та посиленні стійкості й адаптації до пов'язаних з кліматом небезпек і катастроф у всіх країнах. На всіх метеостанціях спостерігається тенденція до підвищення як середньорічної температури повітря, так і температури для окремих місяців. Зокрема, в Умані середньорічна температура за весь період

спостережень (138 років) зросла з $+6,8^{\circ}\text{C}$ до $+8,6^{\circ}\text{C}$, тобто на 1,8 градуса. У Кропивницькому середньорічна температура за весь період спостережень (149 років) зросла з $+7,4^{\circ}\text{C}$ до $+8,9^{\circ}\text{C}$, тобто на 1,5 градуса. У Полтаві середньорічна температура за весь період спостережень (199 років) зросла з $+5,9^{\circ}\text{C}$ до $+8,7^{\circ}\text{C}$, тобто на 2,8 градуса (з 1886 року з $+6,4^{\circ}\text{C}$ до $+8,7^{\circ}\text{C}$, тобто на 2,3 градуса). На всіх метеостанціях найбільш значне зростання середньорічних температур відбулося в період з 1989 по 2023 рік. Найменше зросла температура в осінні місяці. За весь період спостережень середньомісячна температура вересня зросла від $0,3^{\circ}\text{C}$ в Умані, $0,6^{\circ}\text{C}$ у Кропивницькому до $1,5^{\circ}\text{C}$ (з 1886 року – 0,9) у Полтаві. Середньомісячна температура у жовтні зросла від $0,1^{\circ}\text{C}$ в Умані та Кропивницькому до 1,2 (з 1886 р. – 0,9) градусів у Полтаві. Середньомісячна температура в листопаді зросла з $0,6^{\circ}\text{C}$ у Кропивницькому, $1,8^{\circ}\text{C}$ в Умані до $1,9^{\circ}\text{C}$ (з 1886 року – 1,7) у Полтаві. Усі три метеостанції мають спільні періоди підвищення та зниження температури, зокрема, з 1947-1969 по 1985-1995 рр. спостерігалось зниження середньомісячних літніх температур; з 1986-1996 по 2023 рр. – підвищення температури повітря. Температура повітря в літні місяці підвищилася досить суттєво. За весь період спостережень середньомісячна температура червня зросла від $0,9^{\circ}\text{C}$ у Кропивницькому, $1,9^{\circ}\text{C}$ (з 1886 р. – 2,3) у Полтаві до $2,0^{\circ}\text{C}$ в Умані. Середньомісячна температура липня зросла з $0,3^{\circ}\text{C}$ у Кропивницькому, $1,1^{\circ}\text{C}$ в Умані до 1,3 (з 1886 року – 1,2) градусів у Полтаві. Середньомісячна температура у серпні зросла з $0,7^{\circ}\text{C}$ у Кропивницькому та $1,1^{\circ}\text{C}$ в Умані до $1,6^{\circ}\text{C}$ (з 1886 року – 1,6) у Полтаві. Усі три метеостанції мають спільні періоди підвищення та зниження температури, зокрема, підвищення середньомісячних осінніх температур відбулося з 1999-2001 по 2023 рік.

Ключові слова: *клімат, температура, кліматичні дії, середньомісячна температура повітря, територія України, регіональні зміни клімату, літо, осінь.*

Внесок авторів: всі автори зробили рівний внесок у цю роботу

Конфлікт інтересів: автори повідомляють про відсутність конфлікту інтересів

Надійшла 5 червня 2024 р.

Прийнята 18 вересня 2024 р.