

ГЕОГРАФІЯ

UDC 551.4:631.6

*Yu.F. Kobchenko, Ph.D. Earth Sciences, Assist. Professor,
O.Yu. Kobchenko, M.Sc. Physics and Mathematics,
V.N. Karazin Kharkiv National University*

SPACE-TIME TENDENCIES OF AIR TEMPERATURE CHANGE IN CLIMATE WARMING PERIOD IN THE TERRITORY OF UKRAINE

Ю.Ф. Кобченко, О.Ю. Кобченко. ПРОСТОРОВО-ЧАСОВІ ТЕНДЕНЦІЇ ЗМІНИ ТЕМПЕРАТУРИ ПОВІТРЯ У ПЕРІОД ПОТЕПЛІННЯ КЛІМАТУ НА ТЕРИТОРІЇ УКРАЇНИ. Розглянуті питання особливостей просторово-часової тенденції змін температури повітря у період потепління клімату на території України. Проаналізувавши статистичні показники гідрометеорологічних даних метеостанцій України за 1970-2014 рр. було показано, що зміни річної температури за 100-літній період, в межах території дослідження, становлять 3,1-3,5°C, а зміни місячних температур показали більш відчутні коливання температури повітря і особливо це характерно для літніх місяців, де різниці температур між періодом потепління і періодом похолодання за липень і серпень місяці становлять 5.3 і 5.1°C відповідно. Методами математичної статистики і зокрема дисперсного аналізу показано часовий розподіл змін річних і місячних температур і розміщення їх по ієрархічних рівнях. Аналіз розподілу змін температури повітря у період потепління клімату на території України показав, що середня річна температура з 1970 по 2014 рік складає у Луганську 8.1°C, у Харкові 7,4°C, у Львові 6,7°C. Якщо порівняти хід температури повітря за 40 років з даними багатолітніх досліджень, то прийдемо до висновку, що клімат на території України поступово теплішає, але у східних регіонах країни це відбувається інтенсивніше.

Метод аналізу просторово-часової тенденції змін температури повітря у період потепління клімату на території України дозволяє уніфікувати гідрометеорологічні характеристики розглянутих років і можуть бути використані для вирішення певних завдань у різних галузях економіки.

Ключеві слова: Погода, клімат, температура, гідрометеорологічні характеристики, методи математичної статистики, дисперсний аналіз.

Ю.Ф. Кобченко, О.Ю. Кобченко. ПРОСТРАНСТВЕННО-ВРЕМЕННЫЕ ТЕНДЕНЦИИ ИЗМЕНЕНИЯ ТЕМПЕРАТУРЫ ВОЗДУХА В ПЕРИОД ПОТЕПЛЕНИЯ КЛИМАТА НА ТЕРРИТОРИИ УКРАИНЫ. Рассмотрены вопросы особенностям пространственно-временной тенденции изменений температуры воздуха в период потепления климата на территории Украины. Проанализированы статистические показатели гидрометеорологических данных метеостанций Украины за 1970-2014 гг. Было показано, что изменения годовой температуры за 100-летний период, в пределах территории исследования, составило 3,1-3,5°C, а изменения месячных температур показали более ощутимые колебания температуры воздуха и особенно это характерно для летних месяцев, где разницы температур между периодом потепления и периодом похолодания за июль и август месяцы составляет 5.3 и 5.1°C соответственно. Методами математической статистики и в частности дисперсного анализа показано временное распределение изменения годовых и месячных температур и размещения их по иерархическим уровням. Анализ распределения изменений температуры воздуха в период потепления климата на территории Украины показал, что средняя годовая температура с 1970 по 2014 год составляет в Луганске 8.1°C, в Харькове 7,4°C, во Львове 6,7°C. Если сравнить ход температуры воздуха за 40 лет с данными многолетних исследований, то приходим к выводу, что климат на территории Украины постепенно теплеет, но в восточных регионах страны это происходит интенсивнее.

Метод анализа пространственно-временной тенденции изменений температуры воздуха в период потепления климата на территории Украины позволяет унифицировать гидрометеорологические характеристики рассматриваемых лет и могут быть использованы для решения определенных задач в различных отраслях экономики.

Ключевые слова: Погода, климат, температура, гидрометеорологические характеристики, методы математической статистики, дисперсний аналіз.

Statement of the Problem. Temperature regime, as a component of a climatic system, reflects the relationship between weather-climatic conditions and human activity, indicating the degree of being favorable to humans. The climate of Ukraine is favorable for human life, but the occurrences of natural atmospheric phenomena, sometimes taking catastrophic character, especially in recent decades due to the climate change, cause damage to different sectors of the economy and other spheres of human activity.

The World Meteorological Organization, which is a specialized agency of the United Nations on the state of the Earth's atmosphere and climate,

plays a leading role at the international level to monitor and protect the environment, promotes cooperation in the establishment of networks for making meteorological, climatological, hydrological observations, as well as the exchange, processing and standardization of related data, has found out that over the past 100 years the average surface temperature has risen by about 0.74°C. The level of average warming over the past 50 years almost doubles the figures for the last 100 years. At the end of the 90s of the 20th century and early 21st century we experienced the highest annual temperatures since records began registering the current temperature data. In view of the fact that

the problem of global climate change is a major problem in the world, there is a need in the scientific substantiation and methodical support of climate change assessment for preventive measures.

Ukrainian climatologists, on the basis of modern ideas about the nature of the climate, give an important place to the factors and conditions shaping the regional climate, the scale of natural and man-made climate change and variability, develop scenarios and forecast possible changes in the climate of Ukraine under the influence of global warming. This enables to find a more efficient way to use climate information for development of research projects, improve operational service production organizations, to solve a number of other practical problems. In the proposed article on the basis of this approach, attempts are made to analyze the features of the space-time changes in air temperature on the territory of Ukraine in the light of new warming tendency and to apply objective means to develop effective generalization of hydro-meteorological information methods of mathematical statistics.

Initial conditions. The founder of climatology O.I. Voyeykov was the first to systematically study climatic components, including temperature. Later they were involved in the study by P.I. Brounov, V.H. Rotmystrov, R.Ye. Davyd, P.I. Koloskov, T.H. Selyanynov and others. Later science has made significant contributions to the study of these issues.

Climatological studies in Ukraine have long traditions. The most complete characterization of climate in Ukraine and its components are presented in the monographs "Climate of Ukraine" (1967), edited by H.F. Pryhotka, A.V. Tkachenko and V.M. Babichenko and "Climate of Ukraine" (2003), edited by V.M. Lipinski, V.A. Dyachuk and V.M. Babichenko. A special section is devoted in these publications to climate change in Ukraine and temperature fluctuations. In the 80s, climatologists of the UkrNDHMI under the leadership of V.N. Babichenko prepared the monograph "The temperature of the Air in Ukraine" (1987), which highlighted the patterns of temperature in Ukraine, sharing its main parameters, century changes and the impact on economic activity.

Under the theme of "Climate of Large Cities" in 80s and 90s, a climatological description of the main cities in the country was prepared. UkrNDHMI together with Hydrometeorological Center of Ukraine and universities compiled and published a number of books, including "Climate of Kiev" (1980) and "Climate of Kharkov" (1983),

where separate sections provide temperature characteristics, their changes and fluctuations.

Climatologists of research institutes, research centers, universities of Ukraine paid great attention to the study of temperature in Ukraine. From 50s to 80s, I.O. Buchynskyy, M.T. Hook (UkrNDHMI) found their brief and slight fluctuations. H.P. Dubynskyy, A.D. Babych, Yu.F. Kobchenko (Kharkiv University), based on the scientific theme of hydrometeorologic support of irrigation, studied the effect of irrigation on climate change. H.I. Shvebs, E.O. Burman studied the effect of landscapes on climate, under the direction K.T. Lohvynova studied climate change under the influence of natural and anthropogenic factors; they were continued by V.F. Martazinova, M.B. Barabash, I.V. Trofimova which drew conclusion on climate regime and precipitation change in Ukraine in the 20th century against the backdrop of global climate change.

In the 90s at UkrNDHMI, V.M. Voloshchuk on the basis of modern science developed new approaches and methods to study changes and variability of climate. They are based on model calculations and climatic paleo-reconstructions that allow objectively to address this important issue in climatology. The evidence of global warming of the planet was obtained, which levels off the spatial and temporal distribution of temperature field.

Statement of the Problem. The paper aims to study the spatial and temporal patterns of air temperature distribution during climate warming in Ukraine. Since Ukraine territory lies within various natural areas, it is important to track temperature change trends both in time and in area. In the study of these issues one should have an objective assessment of the impact of natural and anthropogenic factors on the level of weather and climate change, as defined in the following objectives: to study the initial conditions of this problem; analyze the data of the Hydrometeorologic Service since 1970, when the beginning of a new period was determined by the climatological changes towards warming; identify the empirical connections of the spatiotemporal distribution of the studied air temperature with the natural and anthropogenic factors.

Exposition of basic material. The problem of climate change is a global problem that requires participation of the entire international community. The result of the efforts of the international community was the signing in 1992 of the Framework Convention on Climate Change. Ukraine is one of the participants in this process and in 1997 it became a full Party, and has committed to climate research in the state [1,6,10]. To solve this problem working up "Climate program of Ukraine" which insertion development of an effective system of

climatological information, projected climate change and environmental consequences of these changes.

Conducting scientific, technical and socio-economic assessments of global climate change and related issues The World Meteorological Organization (WMO) and the Intergovernmental Panel on Climate Change (IPCC) at the United Nations showed that the global climate during the late XX century changed in the direction of warming and air temperature near the earth's surface increased by $0,6\pm 0,2^{\circ}\text{C}$ [12,13]. In 1998 the average annual global temperature proved to be 0.7°C higher as compared with the surface air temperature over the period of 1961-1998 and was 15.5°C . This is still a record year in terms of warming.

According to instrumental observations, the researchers [1,2,5] have found out that the Earth's climate is changing and the need to work up climate prediction and climate protection activities determines the relevance of climate change both on global, and regional scale.

The dynamics of regional climate within Ukraine, as stated in the book "Climate of Ukraine" published by V.M. Lipinskiy [6] to some extent repeat the characteristics trait of the global climate change. Climate of Ukraine is perceptible to the global climate change that it's confirmed of long course anomalies in global and regional air temperature.

The intensity of temperature changes in regional climate can be judged based on its comparison with global averaged temperature. According to the research of the Ukrainian Research Hydrometeorological Institute, the temperature at the end of XIX, the beginning of the XXI century, rose in Ukraine by 0.8°C . For some decades an increase in air temperature averages 0.5°C , for the last 30 years it has doubled.

According to UkrNDHMI analysis of structural connection regional and global temperature gives chance to predict the most likely regional

climate changes in the first decade of the XXI century. It was determined that if the global temperature rises by another $0,3-0,4^{\circ}\text{C}$ in two or three future decades, the regional increase in separate seasons may be: in winter and spring by $0,5-0,8^{\circ}\text{C}$, in summer and fall by $0,3-0,9^{\circ}\text{C}$ as compared to the temperatures of the existing regime in Ukraine. It will decrease the temperature between seasons. Given the hierarchical connections of global, regional and local climates [10], and the fact that regional and local temperature is linearly related to global temperature, we can assume that in general increase in regional and local annual temperature can be more intense than the annual increase in temperature in the global climate system by 1,3-1,5 times and it will be $1,0-1,5^{\circ}\text{C}$ above the temperature regime in Ukraine. The main features of the regime change in temperature for the 100th anniversary, which were recorded in Ukraine, can be seen at certain stations, which determines the climate dynamics at the local level.

To assess changes in local climate of Kharkiv area in modern time, we used climatology standard rules summarized in climatological references [8,9,11,12]. Climatological edition of 1950 includes processed meteorological data for the period from 1891 to 1935, which enables to make a picture of the climate at the early twentieth century. Climatological information in 1967-69 edition includes a number of meteorological observations within the 1917-1961 biennium. It brought new Climatological standard norms characterizing features of climate in mid-twentieth century. Inventory of climate in Ukraine, in 1990 and 2005 editions, give updated Climatological standard rules for the defined periods. Climatological data presented in these sources are summarized in Table 1 and give reason to analyze the overall assessment of climatological changes in the study area, i.e. to determine the trends of climate change at the local level.

Table 1

Average monthly and annual air temperature

Year of publication	Months												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
1950	-5.9	-5.0	0.8	10.6	19.0	22.0	24.8	23.8	18.4	10.9	2.0	-4.0	9.8
1967	-7.4	-7.0	-1.8	7.0	14.8	18.2	20.2	19.2	13.5	6.6	0.2	-5.0	6.5
1990	-7.5	-6.3	-1.0	8.1	14.9	18.1	19.5	18.7	13.5	6.8	0.7	-4.0	6.8
2005	-5.5	-4.9	-0.8	8.5	14.7	18.0	20.4	19.0	13.4	7.0	-0.4	-4.9	7.2

Changes in annual temperature over 100-year period within the territory of a study is $3,1-3,5^{\circ}\text{C}$. Fluctuations in annual temperature correspond to the above period, i.e during the warming observed in the late XIX to the 50s of XX century. It was

9.8°C , in a subsequent period down to $6.5-6.8^{\circ}\text{C}$ and later again rises to $7,2^{\circ}\text{C}$.

Analyzing changes in monthly temperatures it should be noted that there are more tangible fluctuations in air temperature. This is typical for the

summer months. Thus, the temperature difference between the period of warming and cooling in July and August months are 5.3 and 5.1°C, respectively. In the transitional seasons change in monthly temperatures, characterized by the temperature difference between these periods is slightly lower. Yes, this temperature difference for April and October months is 3.6 and 4.1°C, respectively. For the winter months the downward trend in the temperature

difference remains. For example, in January it is 1.6 °C, and in February – 2.0°C. If we consider the indirect seasonal temperature changes according to calculations of climatic guides 1950, 1967 (table 2), the temperature difference between the periods of warming and cooling are lower compared to the monthly difference. Thus, the difference between summer temperatures is 5.1°C, winter is 1.7°C, Spring - 3.1°C, fall - 2.4°C.

Table 2

Indirect seasonal temperatures according to climatic guides of 1950, 1967 edition (weather station Kharkiv)

Seasons	1950 year of publication	1967 year of publication	Difference
Winter	- 5.0	- 6.7	1.7
Spring	10.1	7.0	3.1
Summer	23.8	18.7	5.1
Autumn	9.1	6.7	2.4

Method of determining the dynamics of the climate at the local level has been used in our work to specify the extent of climatological processes and climatic features influence on the size of the country as compared to western and eastern regions of Ukraine. The climatic conditions of territories of Ukraine are influenced by strengthening continental climate from west to east.

To clarify this question, we attempted to compare the climatic characteristics and trends to

changes in temperature on the example of some weather stations in Ukraine, located on the latitudes from west to east. Meteorological stations in the south of the country were not considered. For this we used data reference materials and data of meteorological stations in Zolochiv and Kharkiv.

According to the inventory of climate of Ukraine a comparative table of thermal regime of the territories with meteorological stations (table 3) was compiled.

Table 3

Average and extreme temperature of air at weather stations of Ukraine

Cities	Average temperatures		Average maximum temperatures		Absolute maximum temperatures		Average minimum temperatures		Absolute minimum temperatures	
	Jan	Yul	Jan	Yul	Jan	Yul	Jan	Yul	Jan	Yul
Lviv	- 4.1	18.3	- 1.8	19.8	11	36.0	- 6.0	14.1	- 33.5	6.7
Rivno	- 4.8	18.5	- 2.2	21.5	11	36.2	-8.4	12.8	-34.3	6.5
Zhytomyr	- 5.6	18.7	- 2.5	22.4	11	36.7	-8.7	13.0	-34.8	6.2
Kyiv	- 5.9	19.3	- 3.2	24.8	8	37.2	-8.5	14.6	-35.2	6.1
Poltava	- 7.1	19.5	-3.5	26.1	8	37.6	-10.1	14.8	-35.4	6.0
Kharkiv	-7,3	20,9	-3,8	26,4	8,6	38,8	-10,1	14,2	-35,6	6,0
Donetsk	-7,6	22,4	-4,5	25,7	10,0	39,2	-10,2	14,3	-36,0	5,1
Lugansk	- 8.0	22.0	-5.8	27.3	11.5	40.3	- 10.9	14.6	-42.2	4.0

The data for January and July for all aggregation levels exceeding showed average values and absolute air temperature in the specified areas of Eastern cities compared to the cities of Western territory. The difference between average monthly temperature in the winter is on average of 3.9-4.0°C, in the summer - 3.5-3.7°C. Medium and absolute maximum and minimum temperatures are slightly higher as compared to the previous ones. Thus, the average maximum temperature differ-

ence in winter temperatures is 4.0°C and summer - 7.5°C, the absolute maximum temperature difference in winter - 3.4°C, and in summer - 4.3°C. Average minimum temperatures in winter make difference of 4.6°C, in the summer - 2.0°C. The absolute minimum temperature difference in winter temperatures is 8.7°C and summer - 2.7°C.

Comparing only the data of the investigations, it is not possible to be sure in tendencies of warming and climate change age. To convincingly

demonstrate increasing temperature it is necessary to statistically calculate local climate change based on natural climate fluctuations against the background of global warming and thus, prove that the climate affects the eastern regions of continental component.

To analyze the changes in the local climate a number of statistical meteorological observations from 1970 to 2014 were taken according to weather stations in Lviv, Kharkiv and Lugansk, as indicative of different regions in Ukraine. This period, according to anomaly global averaged surface temperature over the past 140 years, given in the book "Climate of Ukraine" [6], refers to the period of maximum warming of global climate. Thus, it is important to identify trends in climate change at the local level against the background of global warming.

To study this question, we used the average decade, the average monthly and average annual air temperature. To reduce random variations and identification of common patterns of temperature changes five years of moving average were calculated, then these data constructed a trend character-

izing the basic pattern of temperature change over time.

The long-term march of temperature according to the values of the trend, as seen in the graph (Fig.1,2,3) tends to increase. During the study period the value of the average annual air temperature, according to a weather station Lviv is about 1.5°C, Kharkiv - 1.7°C, and Luhansk - 2.5°C. But the importance of temperature (trend) in Lugansk exceeds the values in comparison to the previous station by almost 1°C, indicating the growing influence of the continental part of atmospheric processes. In the context of a long-term linear trend in air temperature we observed almost periodic fluctuations in average temperature. Physical nature of modern fluctuations of temperature is defined as the natural and man-made processes. City changes the century – long course of air temperature. In all major cities with increasing population we observed increase in average annual temperature regardless of fluctuations in natural climate. Trending temperature for some seasons and months of the study showed distinct fluctuations in air temperature under the trend values (table 4).

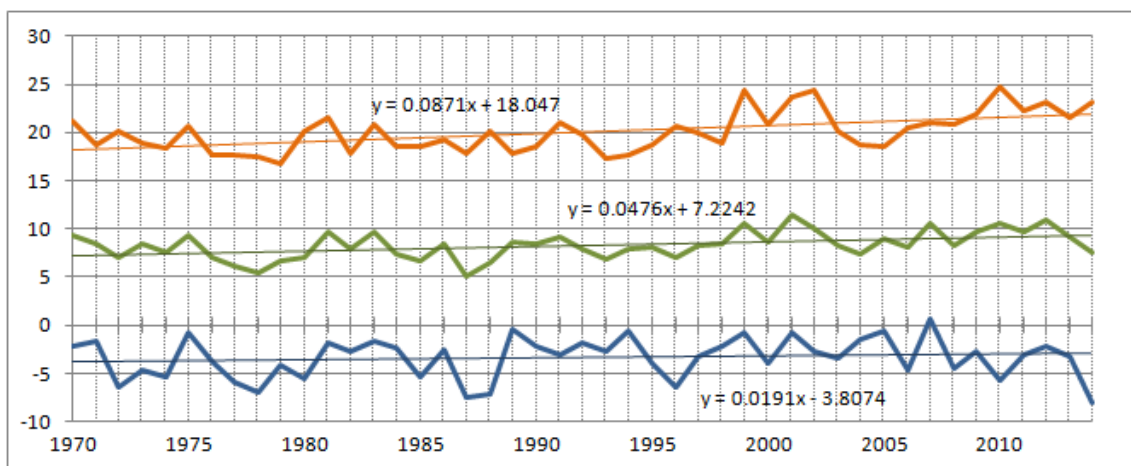


Fig. 1. Average monthly and yearly air temperatures from Lviv meteo-station

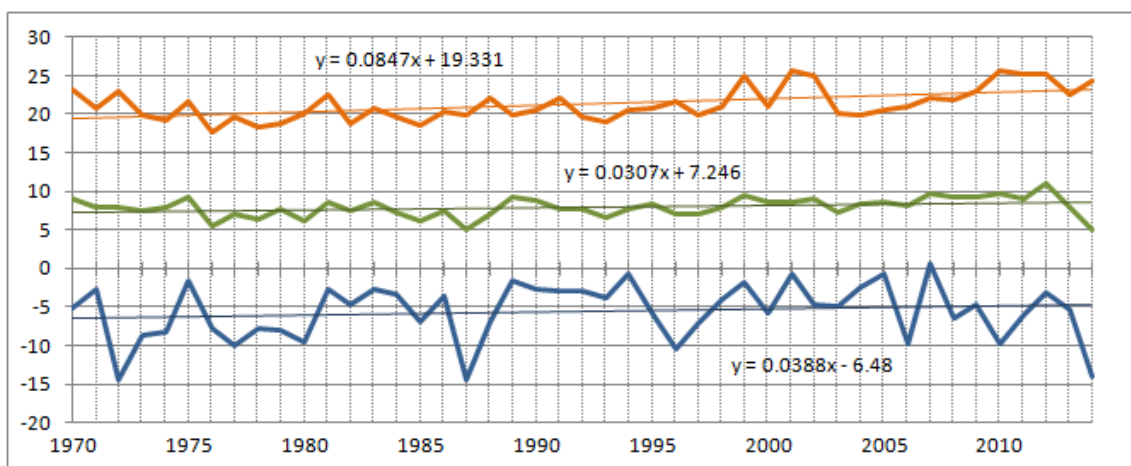


Fig. 2. Average monthly and yearly air temperatures from Kharkiv meteo-station

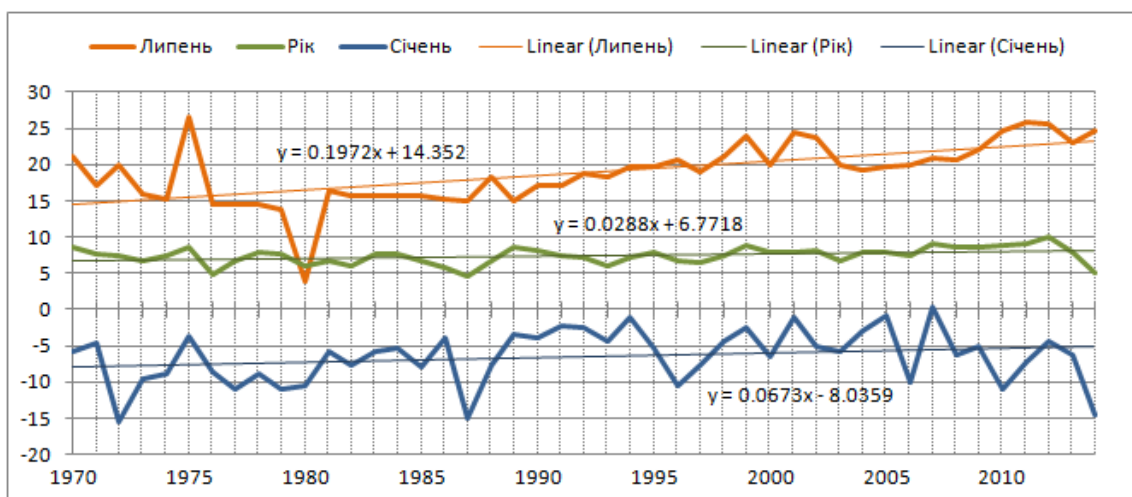


Fig. 3. Average monthly and yearly air temperatures from Luhansk meteo-station

Table 4

Increased average and annual of the air temperature according to weather stations

	Lugansk			Kharkiv			Lviv		
	Jun	Jul	Year	Jun	Jul	Year	Jun	Jul	Year
Increase	0.0673	0.1972	0.0288	0.0388	0.0847	0.0307	0.0191	0.0871	0.0476

According to this technique the graphs for individual seasons and months of the study showed that the overall trend is the planned increase in air temperature in January and July in accordance with the values of the trend. For 45-year period in winter the temperature trend showed increase by 2,4°C in Lviv, Kharkiv 2.7 °C and 3,0°C in Lugansk and summer 3,0°C, 3.5°C, 4,8°C, respectively.

From year to year fluctuation in average air temperature in some months is greater than for the year. In the early period (first decade) some increase in air temperature was noted. In the following years (80-90 years) the temperature trend decreased accordingly. In the last decade the difference was not so clear.

Comparing changes in global and regional annual temperature, it should be noted that the global temperature in the last period increased by 0.6 °C for research of UkrSRHMI [6]. Regional increase in annual temperature is 0.8°C, and we estimate annual temperature research territory as an important indicator of the local climate, increased by 1.4°C.

Comparing only the data of the multi-year investigations, it is not possible to conclude on trends of gradually warming climate and changes in the course of a century air temperature. To convincingly demonstrate increasing temperature based on natural climate fluctuations we need to make statistical calculations of local climate change against the background of global warming and thus prove that climatic conditions affect large industrial cities by anthropogenic activities.

Such a comprehensive study of the issues of space-time structure of the distribution of temperature in the period of warming climate on the territory of Ukraine makes it possible to use a common approach to the handling of information in the hydrometeorological climatological purposes. Based on the analysis, it was concluded that the dynamics of the climate study area, both at the regional and the local levels, repeats the characteristics trait of change of the global climate. This benefit permits to effectively use climatological information for working up research projects, improving operational service of the production organization, solving a number of other practical tasks.

Conclusions. On the basis of the study, the following conclusions can be made: for the study of space-time structure of temperature distribution during the period of climate warming on the territory of Ukraine it is necessary to use hydrometeorological information both at the global and regional, as well as at local levels; selected array of meteorological data from 1970, which established the beginning of a new period of climatological changes allows sufficient duration of the meteorological array, which informs on climatological findings; methods of mathematical statistics as the basis for atmospheric processes allow us to fully characterize the spatial and temporal structure of the distribution of temperature in the period of climate warming. This integrated approach allows to conduct a unified analysis and synthesis in space and time of all available information on the qualitative state of atmospheric air.

The analysis of the distribution in air temperature changes during the climate warming in Ukraine has showed that the average annual temperature from 1970 to 2014 in Lugansk was 8.1°C, in Kharkiv 7.4°C, and in Lviv 6.7°C. If we compare the temperature variation in the air for 40 years with these long-term studies, we arrive at the conclusion that the climate in Ukraine is gradually warming, but in the Eastern regions of the country it is more intense.

Based on the analysis, it was concluded that the dynamics of the climate study area, both at the regional and the local level, repeats the characteristics of global climate change. This will permit to more effectively use the climatological information for working on research projects, improving operational maintenance of the manufacturing companies, solving a number of other practical tasks.

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