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TENDENCIES IN CLIMATE CHANGES IN POLAND AND UKRAINE DURING THE LAST CENTURIES AND THEIR CAUSES

Abstract: The paper describes tendencies in changes of air temperature in Poland and Ukraine on the basis of a long series of measurements made in Warsaw (1779–2000), Cracow (1826–2000), Lviv (1824–2002) and Kiev (1812–2002). Air temperature in these cities in the years 1825–2002 is positively correlated with the North Atlantic Oscillation (NAO) Index. Values of the *r* correlation coefficient are much higher in winter months than during the summer and they decrease with distance from the Atlantic Ocean. Of interest are air temperature changes in Warsaw, Cracow, Lviv and Kiev in the XIXth –XXth centuries together with forecasts until the year 2100. Significant dependence of the climate of Poland and Ukraine on the NAO index stems from similar temperature cycles and the eight-year, eleven-year and one-hundred-year NAO index. Forecast credibility results from the similar periodicity of air temperature, the NAO index and solar activity. The forecast mean annual temperature values for 2001–2100 were obtained from the interference of statistically important temperature cycles, determined by the sinusoidal regression method.

Key words: air temperature, NAO, solar activity, spectrum, periods, tendencies, forecast

INTRODUCTION

The objective of the paper is to determine the tendencies in air temperature changes in Europe in XVIIIth –XXth centuries, with particular focus on Poland and Ukraine. Furthermore, the paper aims at defining the dependence of air temperature on the North Atlantic Oscillation and solar activity as well as on the forecast climate changes in the XXIth century.

The last most significant cooling of Europe's climate took place in 1600, 1700 and in 1830, i.e. during the century minima of solar activity and maxima of volcanic activity. Climate coolings and warmings are shaped by the inflow fluctuations of solar energy to the Earth surface, dependent on the solar constant and the content of volcanic dust in the atmosphere which absorbs and dissipates solar radiation.

Europe's climate is dominantly influenced by two negatively correlated centres of atmospheric pressure fields. They are the Icelandic Low and the Azores High and are related to the annual temperature fluctuations between waters of the North Atlantic and mainland Europe (the North Atlantic Oscillation – NAO). The NAO index, defined by P. D. Jones et al. (1997), has been accepted as the measure of the meridional pressure gradient. It is the standard atmospheric pressure difference at sea level between Gibraltar and southwest Iceland. The index values of the NAO are determined by the parallel air mass transport to the East – NAO > 0 and meridional – NAO < 0.

CIRCULATION CONDITIONS OF THE CLIMATE OF POLAND AND UKRAINE

Large values of the *r* correlation coefficient give testimony to the significant interrelation of air temperature fields in Poland and Ukraine with the North Atlantic Oscillation in winter months. During the years 1825-2000, air temperature is correlated positively (r>0) with changes in the NAO (Tab.1, significant values at the level of 0,05, according to Student's test, are underlined).

Table 1.
The correlation coefficients (*r*) between air temperature in Europe and the NAO index in 1825-2000

Stations	I	II	IIII	IV	V	VI	VII	VIII	IX	X	XI	XII
Warsaw	0,57	0,55	0,49	0,12	0,13	0,13	0,13	0,08	0,27	0,25	0,30	0,41
Cracow	0,52	0,38	0,44	0,11	0,16	0,12	0,12	0,10	0,30	0,19	0,31	0,38
Lviv	0,49	0,44	0,40	0,12	-0,02	0,05	0,15	0,16	0,22	0,05	0,20	0,33
Kiev	0,40	0,35	0,34	0,05	0,01	0,02	0,06	0,04	0,14	0,08	0,17	0,17

The r correlation coefficients are much greater in winter months than during the summer and they decrease with distance from the Atlantic Ocean: January (Warsaw – r = 0,57, Cracow – r=0,52, Lviv – r=0,49, Kiev – r=0,40); July (Warsaw – r = 0,13, Cracow – r =0,12, Lviv – r=0,15, Kiev – r=0,06).

The annual course of the r correlation coefficient of air temperature (T) with the NAO index in Poland and Ukraine are well transcribed by sinusoidal regression equations ($0 \leq t \leq 1$):

Warsaw $r = 0,435 + 0,209\sin(2\pi t+1,4636)$
Cracow $r = 0,365 + 0,169\sin(2\pi t+1,4924)$
Lviv $r = 0,393 + 0,173\sin(2\pi t+1,6364)$
Kiev $r = 0,330 + 0,154\sin(2\pi t+1,6575)$

with a range of: 0,209, 0,169, 0,173, 0,154 (respectively) and respective multicorrelation coefficients R: 0,928, 0,889, 0,847, 0,928. The diagrams of these sinusoids during the period of one year (Fig. 1) are characterized by maxima in winter months and minima during the summer.

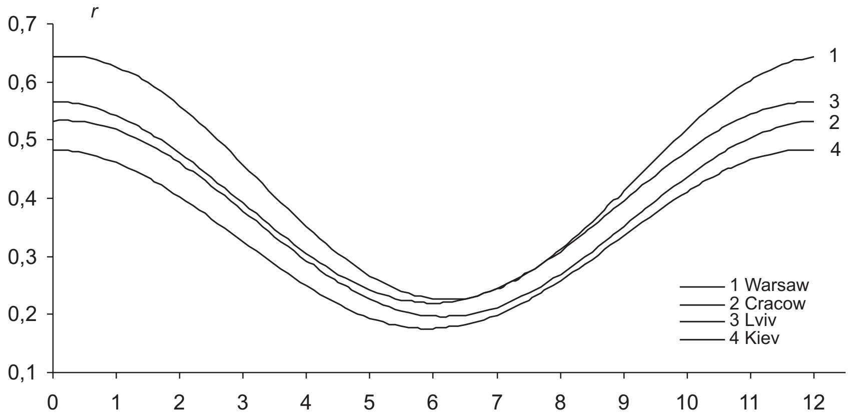


Fig.1. The annual course of the correlation coefficient of air temperature in Warsaw, Cracow, Lviv and Kiev with the North Atlantic Oscillation index (NAO).

The positive values of the correlation coefficient (r>0**)** prove that winters are warmer with greater meridian pressure gradients and cooler with smaller gradients. During more intensive zonal circulation (western) more heat accumulated in waters of the North Atlantic is transmitted into the atmosphere.

The relationship of the mean annual air temperature field in Poland and Ukraine with the NAO index during the years 1825-2002 is characterised by linear regression equations:

Warsaw $T = 0{,}663\ NAO + 7{,}706$

Cracow $T = 0{,}587\ NAO + 8{,}144$,

Lviv $T = 0{,}366\ NAO + 7{,}391$

Kiev $T = 0{,}496\ NAO + 6{,}963$

with determination coefficients $R2$: 12,59, 10,45, 4,03, 5,98 %, respectively. They are diagrammed as linear regressions in Fig. 2a and 2b. The highest regression coefficients characterize air temperature in Warsaw (0,66) and Cracow (0,59) and the lowest in Kiev (0,50) and in Lviv (0,37).

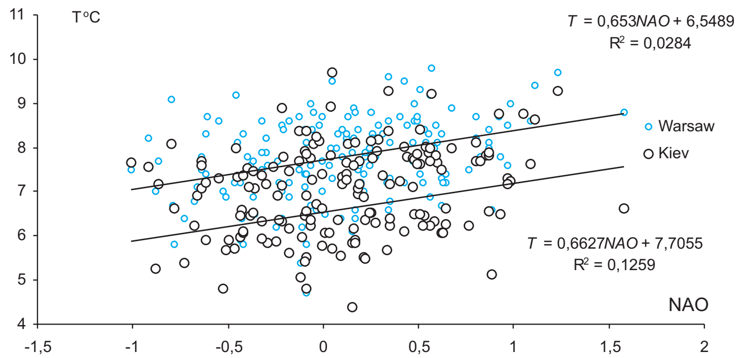
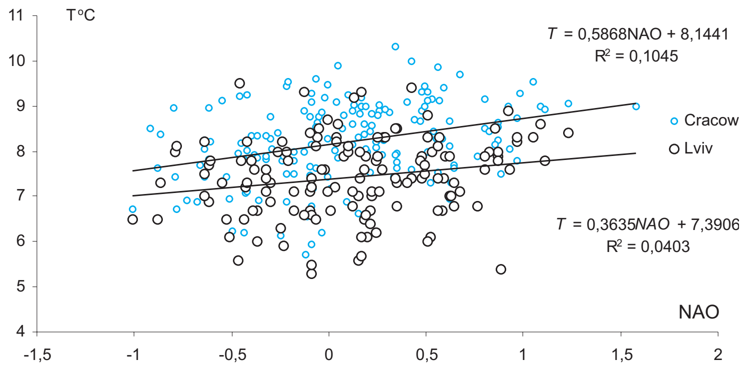


Fig. 2a. The interrelationship between the mean annual air temperature in Warsaw and in Kiev and the North Atlantic Oscillation NAO in 1825-2002.



Rys. 2b. The interrelationship between the mean annual air temperature in Cracow and in Lviv and the North Atlantic Oscillation NAO in 1825-2002.

PERIODIC AIR TEMPERATURE CHANGES DURING THE XVIIITH–XXTH CENTURIES

Europe's air temperature in the XVIIIth–XXth centuries is characterised by a cyclical nature of about 8-, 11-, 100- and 180-years.

Air temperature cycles: periods Θ, amplitudes *b*, phases *c*, have been determined by the J. Boryczka (1998) sinusoidal regression method, changing the period with interval $\Delta\Theta = 0{,}1$ year in the range of 2,0–200 years:

$$y = a + b \sin(2\pi t/\Theta + c)$$

Periods (Θ) – are local minimum sequences of reminder variance ε^2 (spectrum), i.e. maxima correlation coefficient *R*.

In Europe, an approximately 8-year period of air temperature with large amplitude $\Delta T = 2b$ (Tab. 2) is dominating.

Table 2.
8-year period of air temperature in Europe

Stations	Winter		Summer		Year	
	Θ	ΔT	Θ	ΔT	Θ	ΔT
Warsaw	8,3	1,59	7,1	0,66	7,8	0,56
Cracow	8,3	1,87	7,8	0,33	7,8	0,45
Lviv	8,3	1,30	7,9	0,56	7,9	0,45
Kiev	7,8	1,30	7,0	0,78	7,8	0,55

The air temperature amplitudes in an approximately 8-year cycle are almost twice greater in winter (Warsaw – 8,3 (1,6 °C), Cracow – 8,3 (1,9 °C), Lviv – 8,3 (1,3 °C) and Kiev – 7,8 (1,3 °C) than in summer (Warsaw – 7,1 (0,7 °C), Cracow – 7,8 (0,3 °C), Lviv – 7,9 (0,6 °C) and Kiev – 7,0 (0,8 °C). The amplitudes of the mean annual air temperature in these cities in an 8-year cycle approximate 0.5 °C.

For a long time, an approximately 11-year cyclical nature of air temperature, associated with the 11-year sun-spot cycle, has been known. Periods of approximately 11-year air temperatures and ΔT (°C) amplitudes in chosen locations in winter, summer and year are presented in Table 3.

The air temperature oscillation range in this about 11-year period also is half smaller in the summer than in the winter.

Also in Europe, in air temperature measurement series there are approximate 100-year and 180-year periods (Tab. 4 and 5).

Table 3.
11-year periods of air temperature in Europe

Stations	Winter		Summer		Year	
	Θ	ΔT	Θ	ΔT	Θ	ΔT
Warsaw	11,6	0,53	11,3	0,22	11,3	0,34
Cracow	11,3	0,84	11,4	0,26	11,3	0,39
Lviv	11,2	1,11	10,7	0,06	11,2	0,32
Kiev	11,2	1,32	11,4	0,08	11,1	0,54

Table 4.
100-year periods of air temperature in Europe

Stations	Winter		Summer		Year	
	Θ	ΔT	Θ	ΔT	Θ	ΔT
Warsaw	113,4	1,22	75,0	0,88	106,1	0,32
Cracow	90,1	0,54	88,6	0,60	84,4	0,16
Lviv	108,8	1,20	74,1	1,44	125,0	0,58
Kiev	91,8	1,28	70,2	0,72	95,1	0,20

Table 5.
180-year periods of air temperature in Europe

Stations	Winter		Summer	
	Θ	ΔT	Θ	ΔT
Warsaw	218,3	0,44	208,2	0,66
Cracow	168,3	0,43	-	-
Lviv	-	-	195,3	1,10
Kiev	-	-	-	-

Air temperature in Europe is characterised by a cyclical nature similar to the North Atlantic Oscillation NAO with a dominating winter period of 7,8 years (Tab. 6).

Table 6.
Periods of the North Atlantic Oscillation (NAO) in 1825-2000

Winter		Summer		Year	
Θ	R	Θ	R	Θ	R
7,8	0,27	7,8	0,17	7,8	0,29
11,3	0,13	10,3	0,20	11,2	0,18
105,1	0,17	83,2	0,17	119,9	0,12

In time sequences of the *NAO* index (winter – 11.3 years, R=0,14, summer – 10.3 years, R=0,20, year – 11,2, R=0,18) there also occurs an approximately 11-year cyclical nature synchronic with the 11-year sun spot cycle.

The influx of solar energy to the Earth surface depends on the activity of the Sun because in the 11-year cycle the sun constant changes. It is the greatest in the vicinity of the sun spot maxima (Kondratiev and Nikolski 1970). Short term changes of solar activity are not significant in shaping the climate because of the very slow penetration of heat into the deeper layers of the Earth. Of greater importance are long term cycles of solar activity, e.g. 102 – and 107 – year periods (Tab.7).

Table 7.
Periods of 100 – and 180-years in solar activity and solar constant zones (years)

Solar activity	Periods (years)	
Wolf's numbers (1700-2000)	102,0	187,3
Solar constant (1700-2000)	102,0	187,0

Large amounts of energy are accumulated in deeper layers of the Earth in vicinity of the maxima of these cycles.

TENDENCIES IN CLIMATE CHANGES IN POLAND AND UKRAINE IN THE XVIIITH -XXTH CENTURIES

Changes in air temperature in Warsaw, Cracow, Lviv and Kiev together with linear regression and forecasts up to the year 2100 are presented in Fig. 3-6. Air temperature tendencies (*A*) in these cities, determined by linear regression equations $T = A_o + A ,t$, expressed in ^{o}C/100 years, are given in Tab. 8. They characterise the mean air temperature increase for 100 years in appropriate time intervals. Generally, air temperature trends in European cities increase in winter ($A > 0$) and decrease in summer ($A < 0$).

Table 8.
Tendencies of air temperature changes in Poland and Ukraine (^{o}C/100 years)

Station	Period	Winter	Summer	Year
Warsaw	1779-1998	1,12	-0,06	0,55
Cracow	1827-1997	1,48	0,31	0,85
Lviv	1824-2002	0,04	-0,57	0,16
Kiev	1812-2002	1,83	0,47	0,73

In Poland and Ukraine winters are becoming warmer. For example, in the years 1779-2000, winters were warmer by 1,1°C per 100 years and summers were cooler by almost 0,1°C.

An even greater air temperature increase occurs in Cracow – 1,5°C/100 years and Kiev – 1,8°C/100 years. The mean annual air temperature increased in Warsaw by 0,6, in Cracow by o 0,9 and in Kiev by 0,8°C per 100 years.

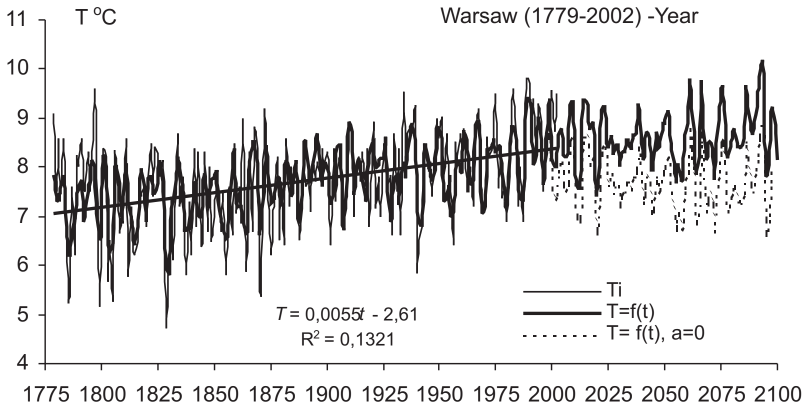


Fig. 3. Changes in the mean annual air temperature in Warsaw during the years 1779-2100 – forecast for the years 2001-2100.

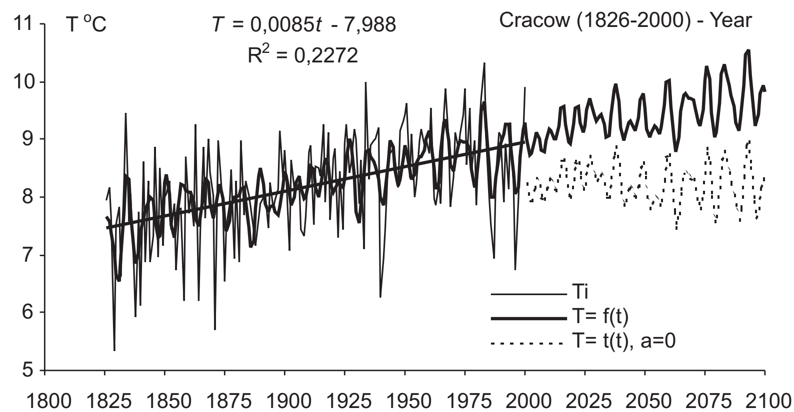


Fig. 4. Changes in the mean annual air temperature in Cracow during the years 1826-2100 – forecast for the years 2001-2100.

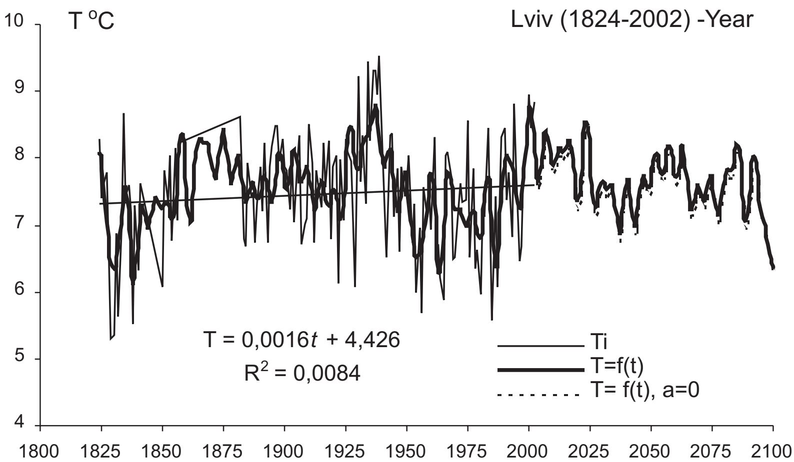
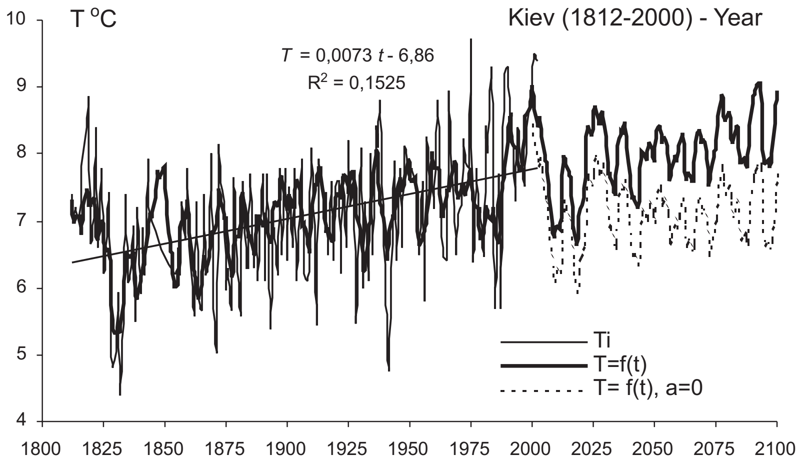


Fig.5. Changes in the mean annual air temperature in Lviv during the years 1824-2100 – forecast for the years 2001-2100.



Rys.6. Changes in the mean annual air temperature in Kiev during the years 1812-2100 – forecast for the years 2003-2100.

The increasing tendency in solar activity (radiation intensity) during the last centuries, by changes in the overall atmospheric circulation, may cause significant share of the increasing warming of the Earth's climate. Synchronic oscillations of the Wolf number and the NAO index in 1825-2000 (Fig. 7) give testimony to the dominating role of solar activity in shaping the Earth's climate in the progressive warming of climate in XIX[th] and XX[th] centuries.

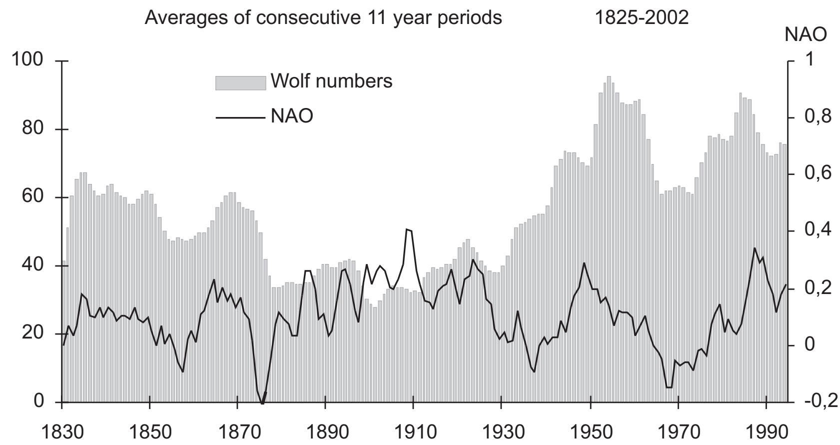


Fig.7. Synchronic oscillations of the Wolf number and the NAO index in 1825-2000.

Increase in solar activity is one of the reasons for climate warming in the XIX[th] and XX[th] centuries. The synchronicity of changes of total solar radiation reaching the Earth's surface (φ = 65o), content of the O^{16} oxygen isotopes and CO_2 concentration in the atmosphere from before 40 000 years allows us to conclude that concentration of CO_2 in the atmosphere is greater during years when more solar radiation reaches the Earth's surface. Simply, concentration of CO_2 in the atmosphere is greater when water in the oceans is warmer, i.e. when it is warmer (Boryczka 2004).

FORECASTS OF AIR TEMPERATURE CHANGES IN POLAND AND UKRAINE IN THE XXI[ST] CENTURY

In identifying the natural causes of the Earth's climate change it is of fundamental significance to check the similarity between the cause and effect cycles. It is pertinent to point out the analogical cyclic nature of the alleged causes, i.e. astronomic variables (solar activity, parameters of the Solar System) and effects, i.e. climatological variables (atmospheric circulation, air temperature).

In forecasts, it has been assumed that the extreme of the defined cycles with quite large amplitudes (statistically significant) will be repeated, as in the XVIIIth-XXth centuries. Analogical periods of solar activity and other astronomic variables warrant such assumptions. Furthermore, approximately 100-year and 180-year periodicities are characterised by paleotemperature – concentration of isotope 18O sea settlements and ice core, content of organic substances in lake settlements dating back a dozen thousand years and dendrological sequences – the width of tree rings (pine, spruce, larch, oak) growing in Europe several hundred years ago.

Prognostic functions $T = f(t)$ – are resultant interference of statistically significant cycles: $T = a_0 + at + \Sigma\, b\sin(2\pi\, t/\Theta + c)$. For example, the prognostic function of the mean annual air temperature in Kiev is:

$$T = 7{,}098+0{,}191 \sin(2\pi t/3{,}2 +1{,}0898)+0{,}273\sin(2\pi t/7{,}8 +0{,}2372) +$$
$$+0{,}297 \sin(2\pi t/11{,}1-1{,}2975) +0{,}292\sin(2\pi t/12{,}8 -0{,}3359) +$$
$$+0{,}241\sin(2\pi t/25{,}6+0{,}9773+0{,}230\sin(2\pi t/30-2{,}0333)+$$
$$+0{,}218(2\pi t/36{,}5 -2{,}8467)+ 0{,}161\sin(2\pi t/46{,}7+3{,}0150)+$$
$$+0{,}104\sin(2\pi t/95+1{,}1891)$$

The accuracy estimation of this prognostic function of air temperature are multicorrelation coefficient R=0,626 and standard deviation δ=0,84 °C. In Fig. 3-6 are presented the approximation function $T = f(t)$ and values extrapolated outside the range of measurement – prognosed values. The coldest summers in Warsaw, with a mean annual air temperature of about 6,5 °C, will occur somewhere around the years 2012, 2020 and 2057. In Lviv, it may be expected to be cold in the years 2038-2044.The mean annual air temperature will be about 6,7-6,9 °C. In Kiev, a significant air temperature decrease will probably occur as soon as 2009 (6,1 °C) and 2018 (5,9 °C). The forecast values, taking under consideration the linear element at (a>0, partially anthropogenic) are usually greater.

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