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Assessing the influence of height above sea level and geographic coordinates on surface air temperature values for a plain part of Ukraine

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SUMMARY

The main principles of the methodology for assessing the influence of height above sea level and geographic coordinates (latitude and longitude) on the values of annual and average monthly temperature in Ukraine for the period 1991-2020 are proposed. Thus, the annual surface air temperature decreases by an average: of 0.69ºC per 100 m of height above sea level, of 0.51ºC with a shift of one degree of latitude to the north, and of 0.08ºC with a shift of one degree of longitude to the East. The altitudinal and latitudinal gradients of temperature have the greatest spatiotemporal variability and the longitudinal gradient has the smallest one. These gradients generate «microclimatic noise» of temperature. On their basis, a regional semi-empirical model of the spatiotemporal distribution of the average monthly temperature for the plain part of Ukraine for the period 1991-2020 was worked out. A comparison of values of model average annual and monthly temperature for 58 meteostations in Ukraine with their actual values showed a statistically significant correlation. Additionally, validation of semi-empirical model average monthly temperature for 10 other stations was carried out.

Introduction

The climatic characteristics of meteoparameters in the certain physical-geographical region depend on its height above sea level and geographic coordinates (latitude and longitude), so they constitute sets of multifactorial climatic fields (Daly, 2002; Lookingbill, 2003; Voloshchuk, 2003). The effect of climatic altitudinal zonality is most pronounced in mountainous regions (Lookingbill, 2003). The reaction of meteoconditions to terrain height changes is less noticeable in the plain land regions (up to altitudes of 350-400 m above sea level), but it can still form a certain microclimate. The microscale features of the meteostations location generate a specific "microclimatic noise" and transfer their climatic fields to the rank of stochastic ones. The basic principles of the methodology for assessing the dependence of meteoparameters (surface air temperature and precipitations) on the area height above sea level and geographical coordinates were researched by Voloshchuk and others (Voloshchuk, 2003; Boychenko, Serdyuchenko, 2005; Boychenko, Voloshchuk, 2007; Boychenko, 2008).

Method and Theory

In this study we used empirical data (monthly air temperature values {T}, ºC per month) for 58 meteostations (a set of Ω_{58}), that are almost uniformly located on the territory of Ukraine (with height above sea level to 350 m), for the period 1991-2020 (CGO, 2021). The model was validated for 10 additional meteostations (a set of Ω_{10} stations that are not included in Ω_{58}) on the calculated height above sea level, latitude and longitude gradients. The software packages MS Excel and XLSTAT were used for the statistical analysis and graphical design.

Method for determining the altitudinal, latitudinal, and longitudinal gradients of meteorological parameters. Altitudinal (G_h), latitudinal (G_ϕ), and longitudinal (G_λ) gradients of air temperature for the set of Ω_{58} were estimated using the least squares method. It is assumed that the parameters of the selected function take such values {T} that the average squared deviations of the empirical data for {T} from those estimated by the selected function would be the smallest. Note that G_h, G_ϕ, and G_λ, which characterize the effect of landscape, may be a weak signal against a background of high noise. To calculate the *altitudinal* gradient G_h (and G_ϕ, G_λ, according to a similar scheme) of the meteorological parameter {T}, the following relations were used:

$$G_h = \frac{D_h}{D_o},\ x_1 = h_k - < h >,\ \ x_2 = \varphi_k - < \varphi >,\ x_3 = \lambda_k - < \lambda >, \tag{1}$$

$$G_h = \frac{D_h}{D_0},\ D_h = \begin{vmatrix} < x_1 T > & < x_1 x_2 > & < x_1 x_3 > \\ < x_2 T > & < x_2^2 > & < x_2\, x_3 > \\ < x_3 T > & < x_2 x_3 > & < x_3^2 > \end{vmatrix}, D_o = \begin{vmatrix} < x_1^2 > & < x_1 x_2 > & < x_1 x_3 > \\ < x_1 x_2 > & < x_2^2 > & < x_2\, x_3 > \\ < x_1 x_3 > & < x_2 x_3 > & < x_3^2 > \end{vmatrix}$$

Let us expand D_h in terms of the algebraic complements of the column of its determinant, namely:

$$D_h = < (T - < T >)[x_1 D_1 - x_2 D_2 + x_3\, D_3] >,$$

$$D_1 = \begin{vmatrix} < x_2^2 > & < x_2 x_3 > \\ < x_2 x_3 > & < x_3^2 > \end{vmatrix},\ D_2 = \begin{vmatrix} < x_1 x_2 > & < x_1 x_3 > \\ < x_2 x_3 > & < x_3^2 > \end{vmatrix},\ D_1 = \begin{vmatrix} < x_1 x_2 > & < x_1 x_3 > \\ < x_2^2 > & < x_2 x_3 > \end{vmatrix} \tag{2}$$

where h_k, φ_k, λ_k are height, latitude and longitude for the *k-th* meteostation, $k = \overline{1.58}$; $<h>$, $<\varphi>$ and $<\lambda>$ are the average values of the height above sea level, latitude, and longitude for all considered meteostations.

It is assumed that the "microclimatic noise" at the considered network of meteostations is statistically independent. Then, using relations (1), the variance G_h can be expressed in terms of the variance {T} (we denote the variance of a random variable by $dsp\{T\}$). Since we are identifying and evaluating an "extremely weak signal against a background of very large noise," then, in order to justify the statistical significance of the result obtained based on the relation (2), the root-mean-square error (s) is necessary:

$$dsp\{G_h\} = \frac{dsp\{T\}}{nD_o} D_1,\ s = \chi\sqrt{dsp\{G_h\}} \tag{3}$$

where n is the number of considered meteostations, $dsp\{T\}$ is the dispersion of the $\{T\}$ values.

Results of investigations

Assessment of the height above sea level and geographical coordinates influence on surface air temperature values in Ukraine for the period 1991-2020. By approximations (1) and (2), the altitudinal, latitudinal, and longitudinal gradients were calculated, namely their average annual values, seasonal variation and dispersion by approximations (3).

Altitudinal gradient of temperature. In accordance with the calculations, the average annual value of the altitudinal gradient of temperature is $G_h\{T\} = -0.69 \pm 0.23^oC$ per 100 m. The seasonal course of gradients has a pronounced non-monotonic character (see Figure 1A). The highest values of $G_h\{T\}$ are typical for November-December and July-August within the limits of $-0.69 \div -0.71^oC$ per 100 m, and the lowest values in April-May and September-October within the limits of $-0.48 \div -0.59^oC$ per 100 m. Thus, with a shift of 100 m height above sea level, the temperature decreases by an average of 0.69^oC.

Latitudinal gradient of temperature. The average annual value of this region's latitudinal gradient of temperature $G_\varphi\{T\}$ is -0.51 ± 0.11^oC per 1^oN (Northern latitude). The $G_\varphi\{T\}$ values have a pronounced seasonal variation. For example, the monthly gradients $G_h\{T\}$ takes on maximum values $-0.64 \div -0.71^oC$ per 1^oN in August-October and minimum values $-0.26 \div -0.27^oC$ per 1^oN in April-May (see Figure 1B). Thus, with a shift of one latitude degree to the north, the temperature decreases by an average of 0.51^oC.

Longitudinal gradient of temperature. The average annual value of the longitudinal gradient of temperature $G_\lambda\{T\}$ for Ukraine is -0.08^oC per 1^oE (East longitude) for the period 1991-2020. The seasonal course of the $G_\lambda\{T\}$ has a pronounced seasonal character. The longitudinal gradient has positive values in the warm period of the year (May-September), which fluctuate within $0.01 \div 0.04^oC$ per 1^oE, and negative values in the cold season (October-April), in the range of $-0.08 \div -0.03^oC$ per 1^oE (see Figure 1C). Thus, with a shift of one longitude degree to the East, the surface air temperature decreases by an average of 0.08^oC.

As we can see, temperature's altitudinal and latitudinal gradients have the most significant spatiotemporal variability and the longitudinal gradient has the smallest one. These gradients generate «microclimatic noise».

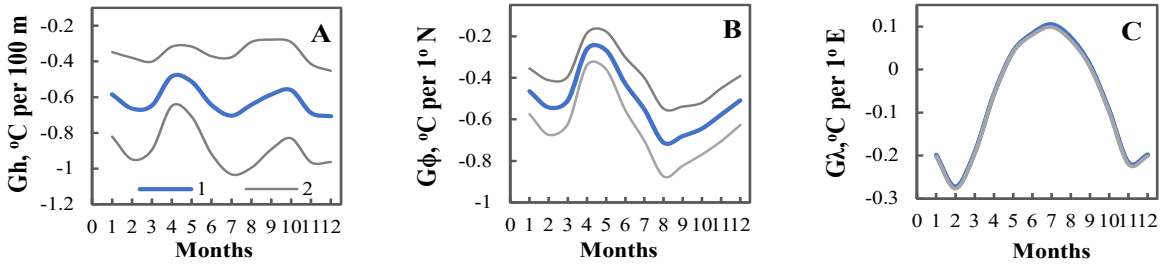

Figure 1 *Seasonal variation of the altitudinal $G_h\{T\}$* **(A)**, *latitudinal $G_\varphi\{T\}$* **(B)**, *and longitudinal $G_\lambda\{T\}$* **(C)** *gradients of the surface air temperature in Ukraine* (*average values for the 1991-2020 period: 1 – value of gradient; 2 – ±s*)

Also, the gradients were calculated for each year for the period 1991-2020 and are shown in Fig. 2.

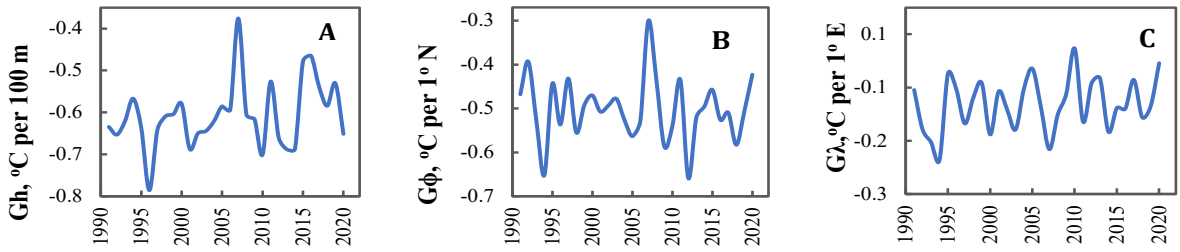

Figure 2 *Time course of the average annual values of altitudinal $G_h\{T\}$* **(A)**, *latitudinal $G_\varphi\{T\}$* **(B)**, *and longitudinal $G_\lambda\{T\}$* **(C)** *gradients of surface air temperature in Ukraine*

Semi-empirical model of the spatiotemporal distribution of the average monthly surface air temperature for the plain part of Ukraine for the period 1991-2020. Known that an equation depicting the relationship between experimental data is called semi-empirical if its form is determined theoretically, and some of the coefficients included in it are determined experimentally. In the first approximation, the dependence of the meteorological parameter (in this case, the surface air temperature) on the geographical coordinates and height of landscapes above sea level for the plain part of Ukraine (excluding the regions of the Ukrainian Carpathians and the Crimea Peninsula) can be represented as a linear function:

$$T\{mod(k,m)\} \approx < \mathrm{T}(m) > + G_h(m)(h_k - < h >) + G_\varphi(m)(\varphi_k - < \varphi >) \ldots$$
$$\ldots + G_\lambda(m)(\lambda_k - < \lambda >) + \varepsilon(r) \qquad (4)$$

where $<T(m)>$ is the average monthly surface air temperature on the territory for a certain month $m = \overline{1.12}$; G_h, G_φ, and G_λ are altitudinal, latitudinal, and longitudinal temperature's gradients; $\varepsilon\{\mathrm{r}\}$ is a dimensionless random function, the value of which depends on orography and proximity to the seas. Based on approximation (4), for each station and each month, the value of the climatic norm of the temperature T{mod(k,m)} was calculated for the set Ω_{58}. A comparison of model estimates of the average annual and average monthly values (for January, April, July, and October) of temperature T{mod} with their actual values T{fact} for the set Ω_{58} is shown in Fig. 3 (the reliability of the linear approximation is 94-97%). The method was also validated when constructing semi-empirical models of the seasonal behavior of the surface air temperature in Ukraine for 10 additional meteostations Ω_{10}, which were not included in the set Ω_{58}. As we can see, the model quite well approximates the seasonal course of temperature and describes the process for Ω_{10}.

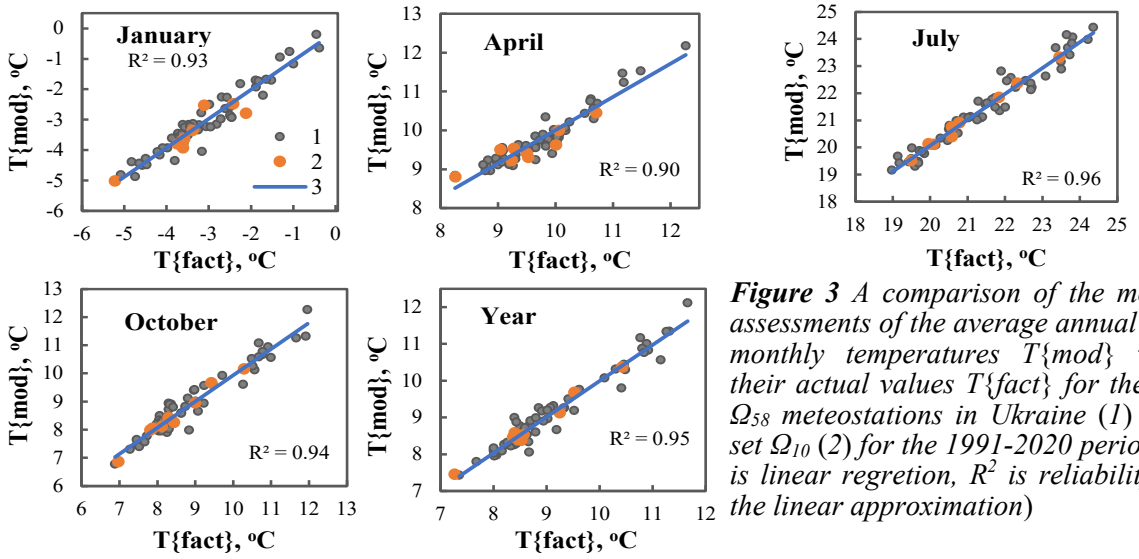

Figure 3 *A comparison of the model assessments of the average annual and monthly temperatures T{mod} with their actual values T{fact} for the set Ω_{58} meteostations in Ukraine (1) and set Ω_{10} (2) for the 1991-2020 period (3 is linear regretion, R^2 is reliability of the linear approximation)*

Also, the model value of the average annual temperature for each station and each year for the period 1991-2020 was calculated. For example, average annual temperature *T{fact}* recorded at meteostations Kyiv, Kherson, Lviv, and their model values *T{mod}* for the period 1991-2020 are presented in Fig.4.

A comparison T{*mod*} with their actual values *T{fact}* for these meteostations for the period 1991-2020 are presented in Fig.5.

Conclusions

The main principles of the methodology for assessing the influence of height above sea level and geographic coordinates (latitude and longitude) on the values of average annual and monthly temperatures in Ukraine for the period 1991-2020 are proposed. The altitudinal and latitudinal gradients of temperature have the greatest spatiotemporal variability and the longitudinal gradient has the smallest one. On their basis, authors worked out the regional semi-empirical model of the spatiotemporal distribution of the average monthly temperature for the plain part of Ukraine for the period 1991-2020. A comparison of the model assessments of the average annual and monthly

temperature for 58 meteostations in Ukraine with their actual values showed a statistically significant correlation.

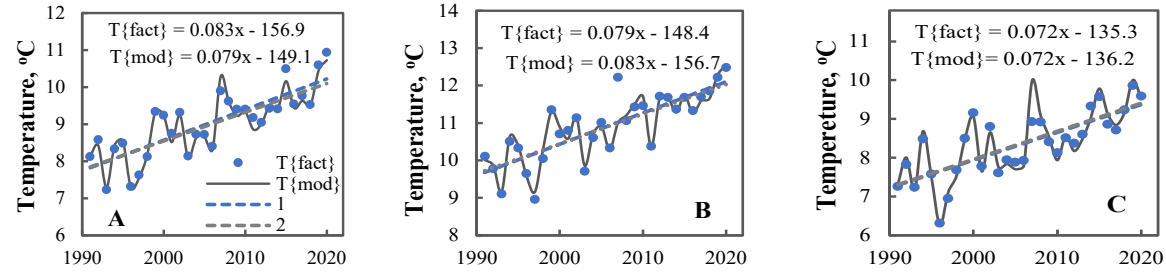

Figure 4 *Average annual temperature T{fact} recorded at meteostations Kyiv (A), Kherson (B), and Lviv (C) and their model values T{mod} for the period 1991-2020 (1 and 2 are linear trends)*

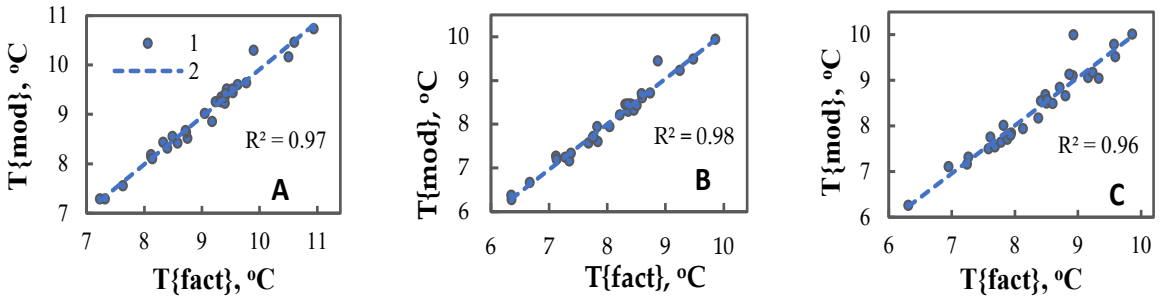

Figure 5 *A comparison of the model assessments of the average annual temperature T{mod} with their actual values T{fact} for meteostations Kyiv (A), Kherson (B), and Lviv (C) for the period 1991-2020 (2 is linear regression, R^2 is reliability of the linear approximation)*

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