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MODELING OF SPATIAL CHANGE OF METEOROLOGICAL VALUES FOR SOLVING OF AGROMETEOROLOGICAL TASKS

Ph.D V.V. Golubtsov
Ph.D V.I. Lee
Ph.D L.V. Lebed
Ph.D P.C. Doraiswamy

Article presents a number of equations which were developed basing on Gauss method for spatial interpolation of air temperature and precipitation over wheat-sowing area of the Northern Kazakhstan. The meteorological values are considered as input data for agrometeorological models. The researches were implemented within the framework of Kazakhstan- American partner project from the International Scientific and Technology Center (ISTC).

For the modeling of agrometeorological conditions of growing and yield formation of spring wheat in the Northern Kazakhstan the most important are air temperature and precipitation. Since air temperature and precipitation are measured on the limited number of observation stations they do not fully reflect actual distribution of meteorological values throughout the territory. Particularly it applies to precipitation fallen within short period of time. It happens because fields of air temperature and precipitation are not homogeneous and isotropic. It was revealed that spatial distribution of these meteorological values depends upon altitude, longitude and latitude. Besides that, precipitation measured at the meteorological stations does not conform to the actual values. The difference in measured and actual precipitation depends on the type, intensity and wind speed. Unbiased data on air temperature and precipitation can be obtained by modeling and further adjustment.

Air temperature modeling

As the result of studies based on the sifting method V.V. Golubtsov and V.I. Lee [1] obtained the following equation for the modeling of air temperature averaged for the day or longer periods:

$$\theta(\varphi,\lambda,z) = A_\varphi\varphi^2 + B_\varphi\varphi + C_\lambda\lambda^2 + D_\lambda\lambda + E_z z^2 + F_z z\,, \qquad (1)$$

where $\theta(\varphi, \lambda, z)$ – air temperature, °C; φ – latitude, radian; λ – longitude, radian; z – altitude, km; $A_\varphi, B_\varphi, C_\lambda, D_\lambda, E_z, F_z$ – parameters.

Gaussian method and using expansion of function $\theta(\varphi, \lambda, z)$ about a point (φ_0, λ_0, z_0) into Taylor's series [2] were applied to identify parameters in the equation]. The following equation comes out:

$$\theta(\varphi,\lambda,z)=\theta(\varphi_0,\lambda_0,z_0)+\gamma_2(\varphi-\varphi_0)+\gamma_3(\lambda-\lambda_0)+\gamma_4(z-z_0)+\gamma_5(\varphi-\varphi_0)^2+\gamma_6(\lambda-\lambda_0)^2+\gamma_7(z-z_0)^2, \quad (2)$$

where $\theta(\varphi,\lambda,z)$ and $\theta(\varphi_0,\lambda_0,z_0)$ – daily temperatures in the points (φ, λ, z) and (φ_0, λ_0, z_0). Correspondingly: $\gamma_2 = 2A_\varphi \ \varphi_0 + B_\varphi$, $\gamma_3 = 2C_\lambda\lambda_0 + D_\lambda$, $\gamma_4 = 2E_z z_0 + F_z$, $\gamma_5 = A_\varphi$, $\gamma_6 = C_\lambda$, $\gamma_7 = E_z$.

Annual course of γ_i (i = 2…7) parameters can be approximated through equation bellow:

$$\gamma = \gamma_{ai}\cos[2\pi(t-\pi_{ai})/365], \quad (3)$$

where γ_{ai} – average value of γ_i parameter; $A_{\gamma i}$ – half of the oscillation amplitude of parameter γ_i; t – current time from the beginning of the year, days; τ_{ai} – time from the beginning of the year corresponding to the maximum of γ_i, days.

The value of $\theta(\varphi_0,\lambda_0,z_0)$ can be derived from data of meteorological stations located in Northern Kazakhstan through the following equation:

$$\theta(\varphi_0,\gamma_0,z_0)=\frac{1}{n}\sum_{i=1}^{n}\{\theta(\varphi_i,\lambda_i,z_i)-[\gamma_2(\varphi_i-\varphi_0)+\gamma_3(\lambda_i-\lambda_0)+\gamma_4(z_i-z_0)+\gamma_5(\varphi_i-\varphi_0)^2+\gamma_6(\lambda_i-\lambda_0)^2+\gamma_7(z_i-z_0)^2]\}, \quad (4)$$

where n – number of meteorological stations; $\theta(\varphi_i,\lambda_i,z_i)$ – change in daily air temperature at station with coordinates $(\varphi_i,\lambda_i,z_i)$.

Equations (2)…(4) allow calculation of daily air temperatures for any area in Northern Kazakhstan during the year. Basing on the results equations were deduced for modeling of maximal and minimal air temperatures also. Table 1 presents parameters of equation for modeling of air temperature for Northern Kazakhstan.

Table 1

Parameters of equation for modeling of air temperature for Northern Kazakhstan

	γ_{ai}	$A_{\gamma i}$	τ_{ai}	$\gamma_{max\ ai}$	$A_{\gamma\ max\ i}$	$\tau_{max\ i}$	$\gamma_{min\ ai}$	$A_{\gamma\ min\ i}$	$\tau_{min\ i}$
γ_2	-21,55	-27,14	155	-35,79	-32,45	166	-13,47	-22,26	100
γ_3	116,51	255,40	155	-2,78	-1,87	140	-0,75	1,76	180
γ_4	-4,2	-14,50	150	-2,62	-6,84	166	-0,14	-4,70	166
γ_5	-2,15	-26,32	166	178,42	-212,5	170	425,17	-264,0	205
γ_6	-1,037	-2,89	145	5,63	-5,66	166	2,50	1,52	190
γ_7	-2,75	3,04	145	-2,83	-6,69	170	-0,35	-11,75	166

Modeling of precipitation

The following equation was deduced for the modeling of precipitation in Northern Kazakhstan for the day or longer periods. Equation have the following form:

$$x(\varphi,\lambda,z) = x(\varphi_0,\lambda_0,z_0)[1 + \kappa_2(\varphi - \varphi_0) + \kappa_3(\lambda - \lambda_0) + \kappa_4(z - z_0) + \kappa_5(\varphi - \varphi_0)^2 + \kappa_6(\lambda - \lambda_0)^2 + \kappa_7(z - z_0)^2], \quad (5)$$

where $x(\varphi,\lambda,z)$ and $x(\varphi_0,\lambda_0,z_0)$ – precipitation in the points with coordinates (φ,λ,z) and $(\varphi_0,\lambda_0,z_0)$, correspondingly; $k_2 = (2 A_\varphi \varphi_o + B_\varphi) / x(\varphi_0, \lambda_0, z_0)$, $k_3 = (2C_\lambda\lambda_0 + D_\lambda) / x(\varphi_0, \lambda_0, z_0)$, $k_4 = (2 E_z z_0 + F_z) / x(\varphi_0, \lambda_0, z_0)$, $k_5 = A_\varphi / x(\varphi_0, \lambda_0, z_0)$, $k_6 = C_\lambda / x(\varphi_0, \lambda_0, z_0)$, $k_7 = E_z / x(\varphi_0, \lambda_0, z_0)$.

The annual course of k_i (i = 2…7) parameters as curves approximated through the equation below:

$$k_i = k_{ai} + A_{ki} \cos[2\pi(t - \tau_{ki})/365], \quad (6)$$

where k_{ai} – average value of k_i parameter; $A_{\gamma i}$ – half of the oscillation amplitude of parameter k_i; t – current time from the beginning of the year, days; τ_{ki} – time from the beginning of the year corresponding to the maximum of k_i, days.

Table 2 presents values for k_{ai}, A_{ki}, τ_{ki} parameters. The value $x(\varphi_0,\lambda_0,z_0)$ in the equation (5) can be calculated basing on data of meteorological stations in the area through the equation below:

$$x(\varphi_0,\lambda_0,z_0) = \frac{1}{n}\sum_{i-1}^{n}\{x(\varphi_i,\lambda_i,z_i)/[\kappa_2(\varphi_i - \varphi_0) + \kappa_3(\lambda_i - \lambda_0) + \kappa_4(z_i - z_0) + \kappa_5(\varphi_i - \varphi_0)^2 + \kappa_6(\lambda_i - \lambda_0)^2 + \kappa_7(z_i - z_0)^2]\}, \quad (7)$$

where n – number of stations; $x(\varphi_i,\lambda_i,z_i)$ – measured precipitation at the station i with coordinates $(\varphi_i,\lambda_i,z_i)$.

Table 2

Parameters of equation for modeling of precipitation for Northern Kazakhstan

	k_{ai}	A_{ki}	τ_{ki}
k_2	2,25	7,89	180
k_3	-28,21	127,89	210
k_4	0,4	6,35	180
k_5	3,8	8,88	166
k_6	0,27	-1,12	166
k_7	0,61	-0,88	180

Equations (5)…(7) allow modeling precipitation for the day or longer period on the on the territory of Northern Kazakhstan starting from any time t. It is advisable to use the equation below in order to eliminate differences between measured and actual precipitation when modeling:

$$x_s^*(h_j,t) = x_s(h_j,t) + m_z / [x_s(h_j,t)]^{n_S}, \quad (8)$$

$$x_1^*(h_j,t) = x_1(h_j,t) + m_1 / [x_1(h_j,t)]^{n_1}, \quad (9)$$

where $x_s^*(h_j,t)$, $x_1^*(h_j,t)$ – actual solid and liquid precipitation, mm; $x_s(h_j,t)$, $x_1(h_j,t)$ – measured solid and liquid precipitation, mm; m_s, m_l, n_s, n_l – parameters.

Parameters of equations (8) and (9) were calculated basing on the method provided by A.P. Broslavsky and S.P. Chistyaeva [3] and long-term data from meteorological stations. Table 3 provides parameters m_s, n_s, m_l, n_l for several meteorological stations in Northern Kazakhstan.

Table 3

Parameters of equation for correction of precipitation for several stations in Northern Kazakhstan

Station	m_l	n_l	m_s	n_s
Akmola	0,82	0,86	1,52	0,44
Atbasar	0,78	0,82	1,27	0,52
Alekseevka	0,77	0,83	1,58	0,47
Balkashino	0,79	0,83	1,15	0,75
Esil	0,85	0,92	1,32	0,64
Zhaltyr	0,81	0,87	1,11	0,67
Kazgorodok	0,78	0,84	1,98	0,46

In order to distinguish precipitation by phase state (snow or rain) the method by G.E. Glazyrin [4] was used that suggests identification of critical values of air temperature θ_1 and θ_2 by altitude. When average daily air temperature $\theta \geq \theta_2$ precipitations are considered to be liquid, when $\theta \leq \theta_1$ – solid, and if $\theta_1 < \theta < \theta_2$ – precipitation is mixed. The amount of liquid (x_l) and solid (x_s) precipitation can be estimated using the following equations, correspondingly:

$$x_1 = \begin{cases} x & if \quad \theta \geq \theta_2 \\ x(\theta - \theta_1)/(\theta_2 - \theta_1) & if \quad \theta_1 < \theta < \theta_2 \\ 0 & if \quad \theta \leq \theta_2 \end{cases}, \qquad (10)$$

$$x_S = x - x_1, \qquad (11)$$

where x – total amount of precipitation, mm.

As it is shown in Glazyrin's studies [4], critical value of the temperature θ_1 changes slightly with the altitude. This change can be taken as equal to minus 1,25 °C. Dependence of parameter θ_2 upon the altitude derives from:

$$\theta_2 = \theta_{min} + (\theta_{max} - \theta_{min})/[exp(a + bz) + 1], \qquad (12)$$

where θ_{min} = 4 °C – temperature, to which θ_2 approaches to if $z \leq 0$ km; θ_{max} = 10 °C – temperature, to which θ_2 approaches to if $z \to \infty$; a = 4,61 and b = -1,42 – empirical parameters.

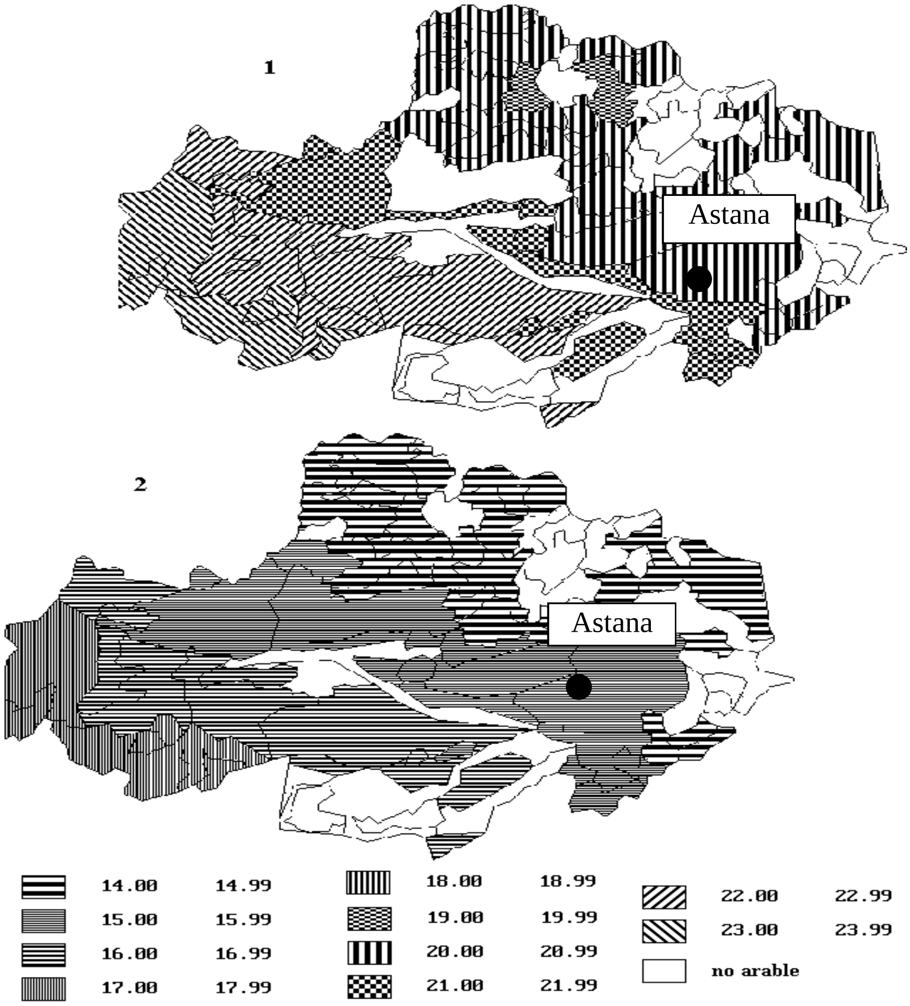

Figure 1 – Simulation of daily temperature of air (℃) for July 11, 1998(1) and for June 20, 1999 (2) on area of the Akmolinskaya oblast.

Practical using of the results

The derived equations were used for modeling of daily average, maximal and minimal air temperatures, as well as daily precipitation in Northern Kazakhstan in various agrolandscapes. Data of meteorological stations for 1971…2000 ere attracted for calculation of parameters of the equations. Figures 1 and 2 show the examples of maps with calculated air temperatures and precipitation in various landscapes of Akmola oblast for different days in June July 1998 and 1999. Analysis of these maps showed that equations satisfactory reflect the distribution of air temperature and precipitation in Northern Kazakhstan.

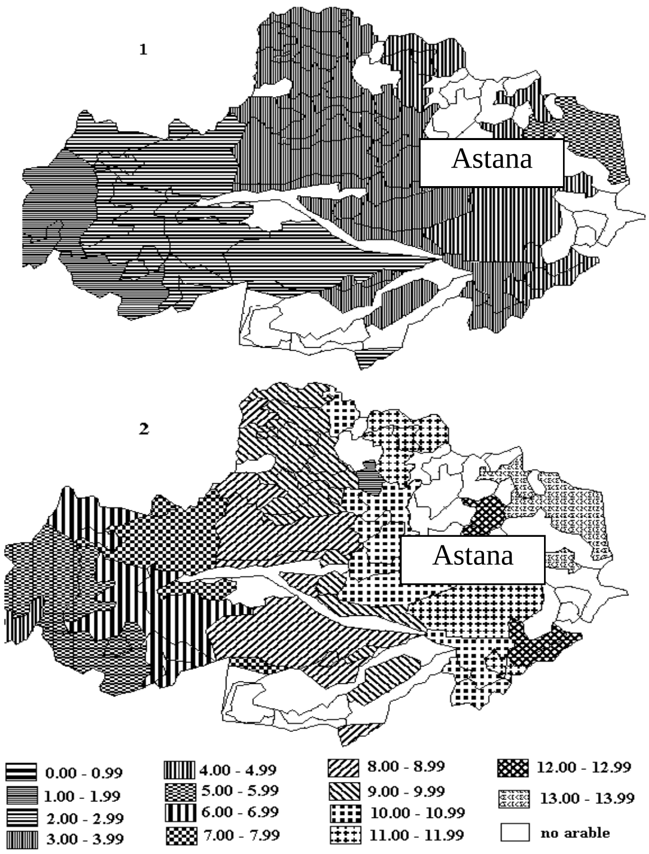

Figure 2 – Simulation of precipitations (mm) for June 19, 1999 (1) and for June 20, 1999(2) on area of the Akmolinskaya oblast.

Authors of the article used these data as input information for the modeling of soil moisture dynamic [5], modeling of spring wheat yield and distribution of diseases of the sowing in various agrolandscapes and for solving other agrometeorological tasks also.

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Kazakh Research Institute of Ecology and Climate
U.S. Department of Agriculture, Agricultural Research Service, Hydrology and Remote Sensing Laboratory

МОДЕЛИРОВАНИЕ ПРОСТРАНСТВЕННОГО ИЗМЕНЕНИЯ МЕТЕОРОЛОГИЧЕСКИХ ВЕЛИЧИН ДЛЯ РЕШЕНИЯ АГРОМЕТЕОРОЛОГИЧЕСКИХ ЗАДАЧ

Канд. геогр. наук	В.В. Голубцов
Канд. техн. наук	В.И. Ли
Канд. геогр. наук	Л.В. Лебедь
Доктор наук	Р.С. Дораисвами

В статье представлены математические уравнения, разработанные на базе метода Гаусса для пространственной интерполяции температуры воздуха и атмосферных осадков на территории Северного Казахстана. Эти основные метеорологические величины являются входными данными в агрометеорологических моделях урожайности зерновых культур. Исследования выполнены в рамках казахстанско-американского партнерского проекта Международного научно-технического центра (МНТЦ).

АГРОМЕТЕОРОЛОГИЯЛЫS М…СЕЛЕЛЕРДІ ШЕШУ ¦ШІН МЕТЕОРОЛОГИЯЛЫS ШАМАЛАРДЫҢ КЕҢІСТІКТЕ ‡ЗГЕРУІН МОДЕЛЬДЕУ

Геогр. Јылымд. канд.	В.В. Голубцов
Техн. Јылымд. канд.	В.И. Ли
Геогр. Јылымд. канд.	Л.В. Лебедь
¤ылым докторы	Р.С. Дораисвами

Мајалада СолтЃстік Sазајстан территориясы бойынша ауа температурасын ж„не атмосфералыј жауын-шашынды кеЎістікте интерполяциялау Ѓшін, Гаусс „дісініЎ негізінде јайта жасалЈан математикалыј теЎдеулер келтірілген. Бґл негізгі метеорологиялыј шамалар д„нді дајылдардыЎ астыј †німділігініЎ агрометеорологиялыј модельдерінде негізгі м„ліметтер болып табылады. Зерттеулер Халыјаралыј Јылыми-техникалыј орталыјтыЎ (Х¤ТО) јазајстан-америкалыј жобасыныЎ к†лемінде орындалЈан.