

Regional extrapolation of meteorological data in a distributed hydrological model

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Abstract The following tasks are considered: (a) obtaining the regional dependencies for climatic norms of air temperature, precipitation and humidity as functions of altitude, latitude and longitude; (b) preparing a regional information database; and (c) developing a method of extrapolation of long-term series of temperature, precipitation and humidity measurements on a basic network into arbitrary points in the Central Asian region. The estimated quality of computed long-term series of precipitation, humidity and air temperature at fourteen control points turned out to be satisfactory.

Key words Central Asia; computation; spatial extrapolation; meteorological data

INTRODUCTION

Linear or nonlinear empirical functions with constant or time-dependent coefficients are used in mathematical models to describe a spatial variability of temperature, T , and precipitation, P (e.g. Alexeev, 1971; Borovikova *et al.*, 1972; Konovalov, 1985; Shentsis, 1982). These variables may also be estimated at some point in space in regular grid nodes using an initial set of irregularly distributed data. There are eight different methods for doing this (kriging, minimum curvature, nearest neighbour, etc.) contained, for example, in the GIS SURFER (Keckler, 1997). Another method is optimal interpolating of known variable values weighted by distance (Gandin, 1963). A method of weighted interpolation is used also by Alexeev (1971) and in the expert system PRISM (Daly *et al.*, 1994).

It is supposed that the considered regional system to determine meteorological characteristics at arbitrary points within plain and mountain areas of Central Asia should provide the following: (a) the ability to operate at a regional scale, (b) simplicity and validation of the computational method, (c) the ability to compute a vertical profile of a variable at a given point, and (d) acceptable quality of the computed results.

INITIAL DATA AND METHODS

The initial data consist of: (a) climatic norms of monthly sums of precipitation and monthly means of air temperature and humidity from data of 660 meteorological stations and posts located in Central Asia in the altitude range 0.60–4.2 km above sea level, and between latitude 35–45°N and longitude 67–81°E; and (b) long-term series of year-round ten-day sums of precipitation and mean ten-day values of air temperature and humidity at 22 basic meteorological stations, mainly for 1935–1995.

The results of searching and analysing the linear and nonlinear versions of the multivariate equations for temperature, T , precipitation, P , and humidity, H : $T = T(z, \varphi, \lambda)$, $P = P(z, \varphi, \lambda)$, $H = H(z, \varphi, \lambda)$, where z is altitude, φ is latitude and λ is longitude, are presented in Table 1. As one may note, the most efficient regional empirical equations to calculate long-term monthly values of meteorological characteristics have the following general forms: $T = T(z, \varphi, \lambda)$, $P = P(z, z^2, z^3, z^4, \varphi, \lambda)$, $H = H(z, z^2, \varphi, \lambda)$, i.e. altitude z plays a different role to describe the spatial variability of T , P and H ; in addition, the contributions of latitude and longitude are rather essential.

Table 1 Coefficients of correlation of the regional dependencies 1–8 within Central Asia.

Months	$P = P(z)$	$P = P(z, \varphi, \lambda)$	$P = P(z, z^2, z^3, z^4, \varphi, \lambda)$	$T = T(z)$	$T = T(z, \varphi, \lambda)$	$H = H(z)$	$H = H(z, \varphi, \lambda)$	$H = H(z, z^2, \varphi, \lambda)$
I	0.53	0.74	0.77	0.78	0.85	0.76	0.87	0.91
II	0.51	0.73	0.75	0.84	0.89	0.77	0.89	0.93
III	0.58	0.76	0.81	0.80	0.84	0.81	0.91	0.94
IV	0.62	0.76	0.82	0.95	0.98	0.82	0.87	0.90
V	0.65	0.72	0.86	0.96	0.98	0.85	0.88	0.91
VI	0.53	0.66	0.77	0.91	0.94	0.84	0.87	0.89
VII	0.30	0.60	0.76	0.95	0.98	0.75	0.83	0.85
VIII	0.28	0.57	0.72	0.94	0.97	0.71	0.80	0.81
IX	0.30	0.54	0.71	0.94	0.97	0.71	0.79	0.82
X	0.68	0.74	0.82	0.93	0.97	0.80	0.87	0.90
XI	0.57	0.70	0.75	0.82	0.91	0.87	0.94	0.95
XII	0.53	0.71	0.76	0.78	0.85	0.78	0.89	0.93

To develop the scheme of spatial extrapolation for temporal ranges $T = T(t, z, \varphi, \lambda)$, $P = P(t, z, \varphi, \lambda)$ and $H = H(t, z, \varphi, \lambda)$, where t is time, let us write the simple and obvious formula for calculating the variable X at an arbitrary point 2 from data at a basic point 1:

$$X_2 = X_1 + [X_1 \cdot \{(X_2 - X_1) / X_1\}] \quad (1)$$

where the term between braces ($\{\}$) would be denoted as the parameter $a = (X_2 - X_1) / X_1$. If $a \approx \text{const}$ we obtain a simple and rather reliable computing method: $X_2 = X_1 + \bar{a} \cdot X_1$, or $X_2 = X_1(1 + \bar{a})$ where $\bar{a} = (X_2 - X_1) / \bar{X}_1$ (where the line above the variable denotes the averaging procedure). To control the hypothesis $\bar{a} \approx \text{const}$, the long-term series of precipitation, air temperature and humidity measurements from several meteorological stations in Central Asia are used. This study shows that the assumption $\bar{a} \approx \text{const}$ can be accepted for extrapolation of mean monthly values of air temperature and humidity for points located at different distances. For spatial extrapolation of precipitation, the quality of results may be substantially improved after (a) obtaining and using the empirical dependencies $a_p = a_p(t)$, (b) using the representative basic meteorological points for approximately homogeneous climatological regions, and (c) extending the period for summarizing precipitation.

In this research the fields of T , P and H in Central Asia are presented by their climatic norms computed in the nodes of a regular grid. A kriging method (Keckler, 1997) is used for data relating to all months of the year and for several altitudinal

levels. It was assumed that the spatial variability of T , P and H within each altitudinal level depends only on the latitude φ and longitude λ . This approach turned out to be effective to solve (a) extrapolation of the values of X from m basic meteorological stations, $X_m(z_{0m}, \varphi_{0m}, \lambda_{0m})$, to n arbitrary points, $X_n(z_{0n}, \varphi_{0n}, \lambda_{0n})$, within a certain altitudinal level, $z_0 = \text{const}$; and (b) analytical approximation of the vertical profile of meteorological element X at a point z_0, φ, λ . A set of $x(z_L, \varphi, \lambda)$ values in the nodes of L regular grids is used for this procedure. These are estimated by grids on L altitudinal levels for each t th month of a year.

ESTIMATING THE QUALITY OF THE METHOD

The results presented in Table 2 show that correspondence between actual and computed air temperatures at meteorological stations located in a wide elevation range and in different climatic conditions may be regarded as rather satisfactory. Analogous estimations of quality for extrapolations of precipitation are presented in Table 3. Owing to the

Table 2 Correlation coefficients between measured and computed air temperature ranges.

Station	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
A	0.78	0.84	0.79	0.89	0.89	0.68	0.86	0.84	0.75	0.91	0.83	0.74
B	0.88	0.73	0.68	0.55	0.79	0.66	0.84	0.77	0.80	0.91	0.82	0.90
C	0.94	0.94	0.94	0.83	0.95	0.84	0.93	0.94	0.93	0.89	0.83	0.88
D	0.88	0.84	0.84	0.78	0.86	0.71	0.76	0.87	0.71	0.82	0.85	0.74
E	0.88	0.66	0.57	0.20	0.60	0.46	0.80	0.79	0.90	0.89	0.83	0.87
F	0.91	0.95	0.89	0.85	0.81	0.83	0.63	0.62	0.76	0.87	0.83	0.91
G	0.91	0.94	0.94	0.82	0.89	0.92	0.83	0.92	0.91	0.81	0.96	0.92
H	0.68	0.88	0.87	0.93	0.91	0.93	0.85	0.80	0.87	0.86	0.87	0.82
I	0.94	0.98	0.92	0.90	0.86	0.93	0.80	0.87	0.83	0.91	0.93	0.96
J	0.91	0.96	0.87	0.83	0.90	0.88	0.89	0.91	0.90	0.89	0.87	0.90
K	0.88	0.90	0.82	0.82	0.83	0.88	0.87	0.86	0.84	0.85	0.89	0.88
L	0.84	0.94	0.94	0.93	0.93	0.83	0.88	0.72	0.81	0.91	0.94	0.82
M	0.95	0.96	0.95	0.91	0.94	0.90	0.90	0.82	0.81	0.94	0.96	0.94

Meteorological stations: A: Fedchenko Glacier, B: Sarytash, C: Severtsova Glacier, D: Dekhauz, E: Daraut-Kurgan, F: Samarkand, G: Sanzar, H: Gulcha, I: Isfana, J: Minchukur, K: Dehavs, L: Tangivoruh, M: Tos. (I–XII are months.)

Table 3 Correlation coefficients between measured and computed precipitation ranges.

Station	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
A	0.87	0.66	0.81	0.71	0.74	0.85	0.76	0.51	0.57	0.73	0.52	0.54
C	0.92	0.78	0.80	0.72	0.88	0.83	0.77	0.65	0.62	0.81	0.40	0.60
D	0.78	0.73	0.74	0.59	0.56	0.66	0.74	0.50	0.50	0.78	0.64	0.57
F	0.66	0.72	0.78	0.68	0.71	0.66	0.69	0.51	0.60	0.87	0.66	0.69
G	0.62	0.74	0.81	0.65	0.74	0.58	0.66	0.58	0.50	0.85	0.71	0.69
I	0.69	0.51	0.61	0.63	0.60	0.65	0.65	0.58	0.67	0.73	0.66	0.71
J	0.64	0.77	0.79	0.64	0.75	0.68	0.62	0.68	0.60	0.80	0.73	0.70
M	0.76	0.62	0.85	0.61	0.55	0.50	0.67	0.77	0.68	0.88	0.65	0.65
N	0.94	0.90	0.97	0.95	0.95	0.92	0.83	0.82	0.81	0.82	0.74	0.63

Names of meteorological stations A–M are as in Table 2; N: Tavildara.

Table 4 Number of cases sorted according to percentage differences between parameters of computed and measured T , P and H time series.

Index	<-101	-100 to -81	-80 to -61	-60 to -41	-40 to -21	-20 to 0	0-20	21-40	41-60	61-80	81-100	>100
\bar{T}	3	5	6	6	11	51	37	21	9	2	2	3
σT	0	0	0	1	8	35	81	27	2	0	0	0
\bar{P}	6	3	3	9	10	17	40	30	22	13	2	1
σP	5	1	8	5	11	21	30	40	20	5	6	4
\bar{H}	0	0	0	0	5	48	41	2	0	0	0	0
σH	1	4	3	6	14	25	22	13	7	2	0	0

Note: \bar{T} , \bar{P} and \bar{H} are mean values; σT , σP and σH are standard deviations.

larger variability of the precipitation field compared to that of air temperature, the quality of P extrapolation in general turned out to be worse. The correspondence between parameters of calculated and measured long-term ranges of monthly sums of precipitation are nevertheless considered as rather high, and acceptable for modelling of hydrological processes for areas of 300 km² and more. Table 4 presents distribution of percentage differences between the mean and standard deviation values of computed and measured time series of the considered meteorological variables. It is important that these distributions have symmetrical form and the majority of cases related to T and H is concentrated within differences 0–±20%.

CONCLUSION

A universal method of spatial and temporal extrapolation of the monthly precipitation sums and mean monthly humidity and air temperature has been developed for the Central Asian territory in the area 35–45°N and 66–81°E. The method is a part of the model with distributed parameters used for determination of hydrological regime and mass balances of glacier aggregations and their groups in the river basins of Central Asia.

The suggested method consists of the following main stages:

1. Computation of mean monthly values of air temperature or monthly sums of precipitation in the nodes of a regular grid at given mean altitude above sea level. Such a grid is computed for several altitudinal levels.
2. Determination of a coefficient of horizontal extrapolation of the data at a basic meteorological station to a point with given coordinates at the common altitudinal level.
3. Determination of the long-term average values of variables at a point with given coordinates at all altitudinal levels and analytical description of a vertical profile of variables at this point.
4. Extrapolation of variable values determined on the common altitudinal level to the given altitude, using an equation obtained at stage 3.

Quality estimates of the method have shown a rather satisfactory convergence of the statistical parameters of time series of air temperature and humidity. Analysis of the quality of parameters of precipitation ranges should be continued.

A long-term series of ten-day precipitation sums and mean ten-day values of air temperature and humidity for 22 basic meteorological stations of Central Asia have been prepared for practical extrapolation of T , P and H .

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