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The use of the GIS technology for climatic mapping

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The Institute of Geography of the Moldavian Academy of Sciences has initiated the release of digital climatic map series as part of a GIS environment. The goal in creating such maps is to provide the user community with a computerized product useful in studies requiring meteorological input. The maps will enable one to obtain the necessary information at any point or within any unit of territory taking into account their topography. Since the available climatic data represent sample locations, while in most cases the spatial models are based on a regular grid principle, the data, first of all, should be expanded to the geographical grid knots. The climate parameter values at the knots form the so-called digital map or the model of this parameter (represented by relative files) that enables following operations within GIS, in particular matching with other information. Thus, the use of GIS technology for climatic mapping involves the mathematical analysis and the conversion of long-term meteorological observations into the climatic variable spatial fields.

The problem of digital climatic map creation gets complicated by the field dimension increase, for example, when third physical measure (elevation) is introduced, as well as during transition from macro- to microclimatic mapping. In the latter case terrain orography already appears as the powerful factor of climate forming.

This poster summarizes the procedures used in creating digital climatic maps, the problems encountered in producing and integrating these digital data into a GIS.

The mathematical models have combined climatic variables with topographic patterns, derived from digital elevation model, to map the different parameters of solar radiation, air temperature, and precipitation for Moldova. The factors that were evaluated in considering different methodologies included both zone (latitude, longitude, absolute and relative elevation) and orographic (slope, aspect, relief) ones. The performance of three methods was evaluated:

a) statistical, through the relationships among climatic measures and the above-mentioned factors;

b) geostatistical, viz. kriging of elevation-adjusted data. This interpolation method optimizes the weights assigned to neighboring data points according to spatial statistical structure of meteorological fields;

c) topoclimatic, viz. mapping the corrections for the factors influencing the meteorological element variations.

Statistical method. Statistical approach itself reduces to describing the meteorological element (Z) value at point x as statistical function of an influencing factor (F) set:

$$Z(x) = f(F_1, F_2, \ldots, F_n). \quad (1)$$

The subset of independent variables that "best" predict dependent, or response variable can be determined by various model-selection methods.

Table 1. Optimal sets of the factors, significantly influencing upon air temperature regime, the coefficients of determination (R2), and model standard errors (e)

Month	Mean Temperature			Maximal Temperature			Minimal Temperature		
	Factors	R^2	ε,°C	Factors	R^2	ε,°C	Factors	R^2	ε,°C
January	ϕ,h,α	0.94	0.2	ϕ,h,α,d	0.95	0.2	ϕ,h,α,d,a,λ	0.96	0.4
February	ϕ,h	0.91	0.2	ϕ,λ,h,α	0.92	0.2	ϕ,h	0.84	0.3
March	ϕ,h	0.85	0.2	ϕ,h,d,α	0.93	0.2	ϕ,λ,h,a	0.87	0.3
April	ϕ,h,α	0.86	0.2	ϕ,h	0.95	0.1	ϕ	0.48	0.4
May	ϕ,h	0.80	0.2	ϕ,h	0.96	0.1	ϕ	0.46	0.5
June	ϕ,h	0.92	0.2	ϕ,h	0.98	0.1	ϕ,d	0.67	0.4
July	ϕ,h	0.88	0.3	ϕ,h,λ	0.98	0.2	ϕ,d	0.75	0.4
August	ϕ,h,α	0.89	0.3	ϕ,h	0.97	0.2	ϕ,d,λ	0.75	0.5
September	ϕ,d	0.82	0.3	ϕ,h	0.96	0.2	ϕ,λ	0.61	0.6
October	ϕ,h	0.96	0.2	ϕ,λ,h,α	0.99	0.1	ϕ,h	0.64	0.5
November	ϕ,h,d	0.95	0.2	ϕ,h,α,d	0.98	0.1	ϕ,h,a	0.80	0.3
December	ϕ,h,λ	0.90	0.2	ϕ,h,d	0.88	0.2	ϕ,h,α	0.90	0.2

ϕ — latitude, sec; λ — longitude, sec; h — absolute elevation, m; α — slope, grade; a — aspect, grade; d — coefficient of dissection.

Statistical approach has been used for air temperature regime mapping. The meteorological data of 13 Moldavian weather stations from 1963 to 1992 served as initial material. Four alternative criteria were used in selection of the best model for the temperature estimation equation:

— *Forward Selection*. The procedure begins with no variables in the model and adds them one by one until no remaining variable produces a significant F-statistic reflecting the variable's contribution to the model;

— *Backward Elimination*. The procedure begins with all variables in the model and deletes them one by one while all remaining variables produce a significant F-test;

— *Adjusted R^2 (R^2_a) Selection*. This statistic is an alternative to coefficient of determination R^2 that is adjusted for the number of parameters in the model;

— *Mallows' Cp Selection*. This statistic is a measure of total squared error.

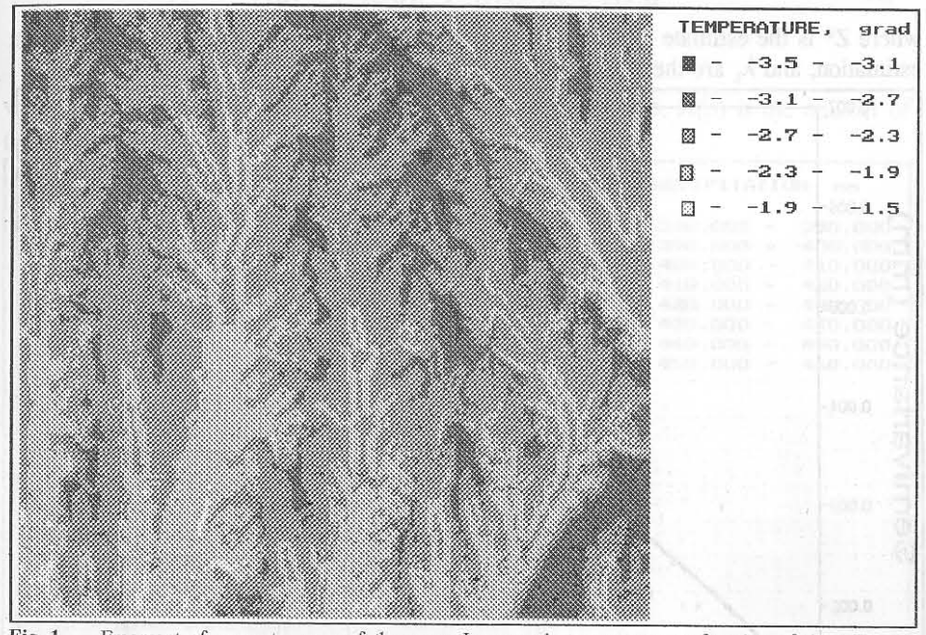

Fig. 1 Fragment of computer map of the mean January air temperature as function of the zone and orographic factors

All these methods are realized in the SAS Statistical System [3].

The factor optimal set obtained by comparison of four procedures results is cited in table 1. Monthly mean maximal and mean air temperatures have the most highest accuracy of mapping; absolute minimal temperature has the least accuracy.

Possibility of GIS being developed allows one to receive the orography features at each regular grid knot with any density of knots. Matching regression model with digital relief model gives a climatic characteristic matrix. The printer visualization example of a such computerized map it cited in fig.1.

Geostatistical method. In this approach climatic data are to be converted into a digital format through the use of kriging geostatistical procedure. The basic goal of geostatistical methods such as kriging is to interpolate values for points or areas, which have not been sampled, using data from surrounding sample points. The kriging estimators are linear combinations of the sample values [2]:

$$Z^*(x_0) = \sum_{k=1}^{n} \lambda_k \, z(x_k), \qquad (2)$$

where Z^* is the estimate for Z at point x_0, n is the number of data points of z used in estimation, and λ_k are the associated weights.

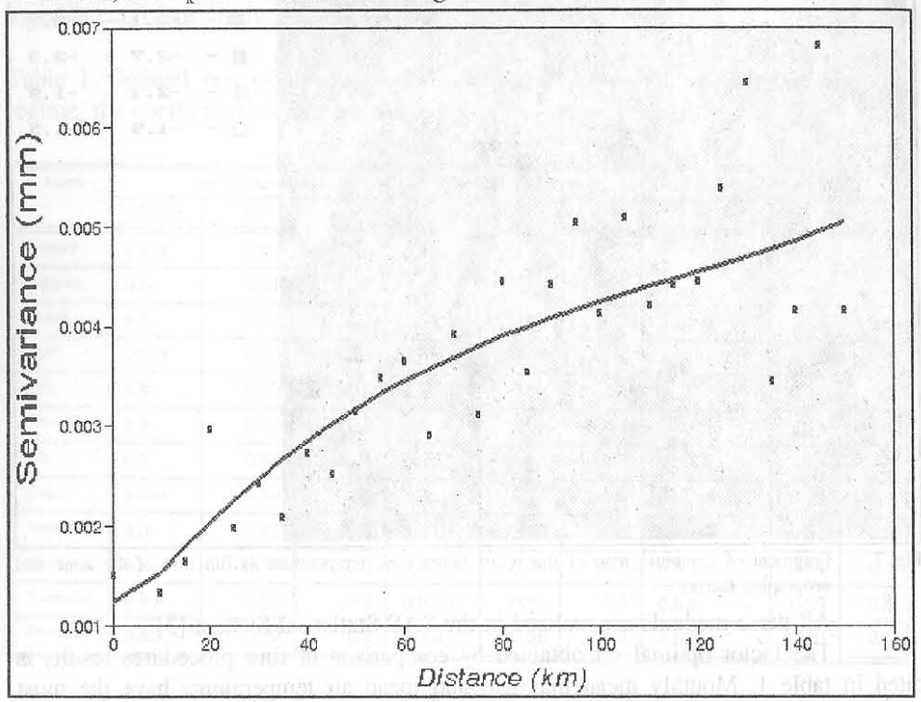

Fig. 2 Sample and model semivariograms for ln annual precipitation in Moldova

The weights in eqn. (2) are determined by solving the system of equations [2]:

$$\begin{cases} \sum_{k=1}^{n} \lambda_k \, \gamma(x_m, x_k) + \mu = \gamma(x_m, x_o) & m = 1,\dots,n \\ \sum_{k=1}^{n} \lambda_k = 1 \end{cases} \qquad (3)$$

where the g values are the semivariograms of interpolating variables and m values are the Lagrange multipliers.

The semivariogram function is a measure of the spatial correlation of a random variable as a function of separation distance and it is estimated by the function:

$$\gamma(\rho) = \left[\frac{1}{2} N(\rho)\right] \sum_{k=1}^{N(\rho)} [z(x_k+\rho) - z(x_k)]^2 \qquad (4)$$

where $\gamma(\rho)$ is the semivariance of Z at a separation distance ρ. $N(\rho)$ is the number of pairs of points in a distance interval $(\rho+\Delta\rho)$.

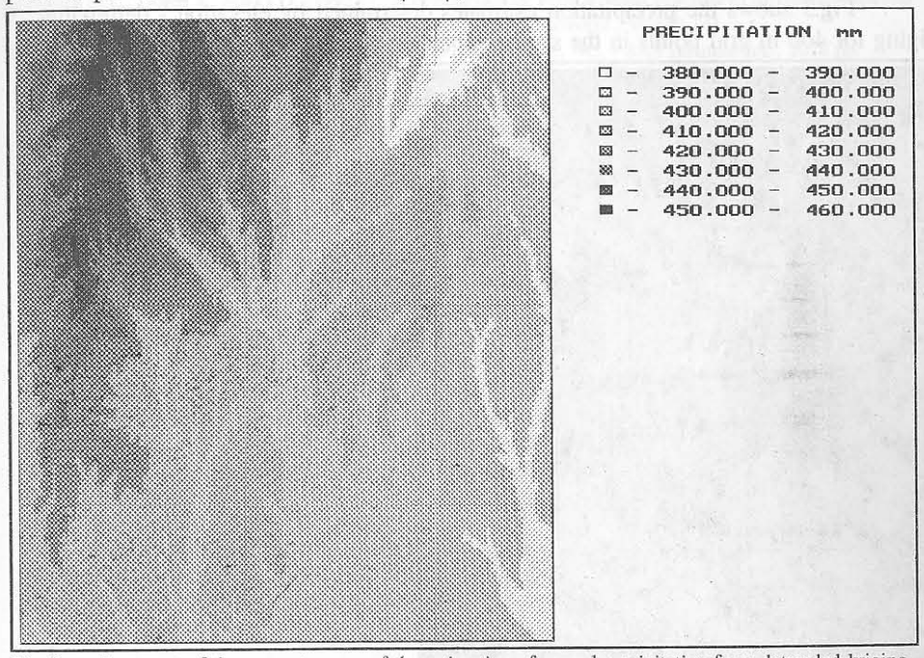

Fig. 3 Fragment of the computer map of the estimation of annual precipitation from detrended kriging

In our study kriging was used for making mean annual precipitation estimates on a regular grid of points. But simple kriging does not explicitly account for the influence of elevation on precipitation except as it reflected in the precipitation of surrounding weather stations. If, however, the neighboring stations are at different elevations than the point being estimated, the estimate is likely to be in error. To address this problem, we likely to [1] performed linear regression on precipitation vs. elevation, substracted the regressed elevation effect, and performed kriging on the elevation-adjusted data.

Precipitation data were obtained from 95 National Weather Service stations which ranged in elevation from 10 to 320 m. Annual precipitation includes rainfall and

snow-water equivalents. For Moldova precipitation (P) and elevation (h) are positively correlated with r=0.64. The regression equation is: P=430+0.25 h.

To construct a sample (experimental) semivariogram all possible pairs of data points were examined, the pairs were grouped by distance classes, and one half of the variance in difference in values (semivariance) was graphed vs. the distance class. A theoretical curve (model semivariogram) was fit to these points by least-squares nonlinear regression. The sample semivariogram for ln precipitation is shown in fig.2. It was fit for the points below 80-100 km by a multiplicative model $y=ax^b$, where $a=5.466 \times 10^{-4}$ and b=0.457.

Fig.3 shows the precipitation estimates determined by elevation - detrending kriging for 400 m grid points in the southern part of Moldova.

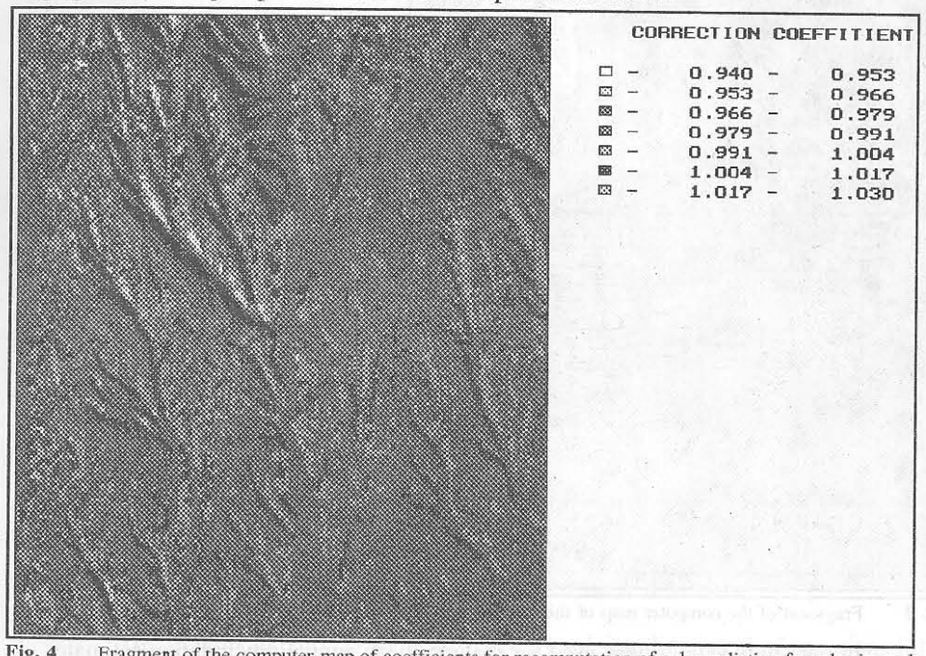

Fig. 4 Fragment of the computer map of coefficients for recomputation of solar radiation from horizontal surface on different slopes

Topoclimatic methods. There are climatic parameters for which both these methods are unacceptable, for example, solar radiation which is measured in Moldova at one station only, or early frosts, mainly depending on terrain orography. In this case we suggest that the corrections for the factors influencing the meteorological element variations should be mapped. The correction values used were estimated through the long-term field studies. Such a map example is shown in fig.4. For its construction digital relief model and the coefficients of recomputation of solar radiation from horizontal surface on different slopes were used.

Thus, all described methods appear to be suitable, with details of the computation depending on the climatic parameters and the specific questions to be answered in each case. We think that the concept of climatic mapping within GIS could be usefully applied in other parts of the world.

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