

A Comparison of Interpolation Methods for Estimation of Air Temperature

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Abstract

The present article deals with the estimation of air temperature with selected spatial interpolation methods. There are a number of methods of spatial interpolation, which allows to estimate the values if they are not available measurement data. One of the important indicators for many practical analyses is the air temperature. It is well known fact that the air temperature is dependent on the altitude. However, not all of the interpolation methods in their algorithms allow to take into account this important factor that can significantly affect the final estimate. For the estimation of air temperature were chosen method IDS (Inverse Distance Squared) and its modification GIDS (gradient plus inverse distance squared) and GIDS-a. The first method was implemented directly in the software. For the method GIDS and - a GIDS was created application through VBA.

Keywords: interpolation methods, inverse distance squared, gradient plus inverse distance squared, air temperature

Introduction

Currently are happening significant climate changes which will influence the future of country and life around us. It is generally known that the air temperature and other climate characteristics are significantly complex of combination thermodynamical, dynamical and microphysical atmospheric processes, affected by the complicated interaction of the relief, which are variable within range of spatial and time scales. It is essential to know these events, locate, or the correctly estimate. Interpolation methods are currently an integral part of the analysis in the natural sciences. They are used for the estimation the mercury content in the soil [10], prediction of evapotranspiration [15], air quality data [23], changes in terrestrial ecosystems in China [24]. Another important use of interpolation methods is in the determination of volume for example: waste in landfills [3], random piles of raw materials [22], and stocks in the surface quarry [13], [18], but also in determining the coordinates of modern measuring technologies [12].

By comparing interpolation methods for estimating air temperatures are devoted the works of authors Stahl [21], Chai [4]. Authors as Jarvis and Stuart are in their works [11] devoted the impact of other variables such as topographic factors and land use to estimate air temperature.

Method of gradient plus inverse distance squared – GIDS, as well as assessment of her suitability for using in climatology are dealt (the first time mentioned in the year 1998) from the authors as IA Nalder and R. W. Wein [16].

For documentation of temperature in Slovakia conditions was for the estimation created the application of specific GIDS interpolation method and its modifications and GIDS-a, using programming in VBA - ArcGIS 9.x environment. The advantage of these methods is the calculation having regard to the elevation of input climatological stations.

Study area and input data

Time Clauses and spatial distribution of air temperature significantly affects the life cycle of plants, animals and even humans. Slovakia is situated in temperate climates and is characterized with the annual running of air temperature with the summer maximum in July and winter minimum in January. Air temperature measured at climatological stations is impacted by physical processes in the atmosphere affected by local phenomena. It is primarily determined by altitude.

In Slovakia are total 92 climatological stations (situation to 1. 1. 2013 [20]) administered by the Slovak hydrometeorological institute, which record the meteorological-climatological data (eg. air temperature, soil temperature, air pressure,

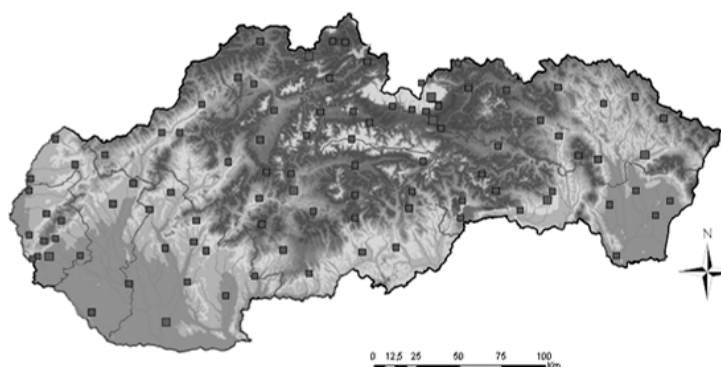


Fig. 1. Location of climatological stations [20]

Rys. 1. Lokalizacja stacji klimatologicznych [20]

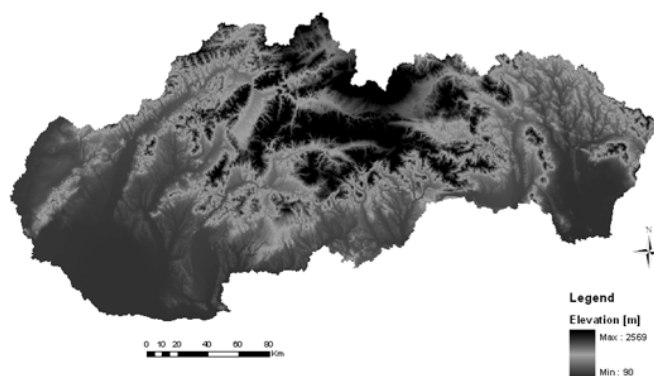


Fig. 2. Digital terrain model of Slovak republic (Source: Data provided and processed by © GISAT) [6]

Rys. 2. Cyfrowy model terenu Republiki Słowacji (źródło: Data provided and processed by © GISAT) [6]

rainfall rate and wind direction). From this data it is possible to create different characteristics of the estimates based on interpolation methods.

Input data about air temperature for analysis constitutes from field of points representing a network of 59 selected climatological stations in Slovakia, which represents their position (Fig. 1). Data from these stations have been used from reports of Slovak hydrometeorological institute.

Another input is created from a digital terrain model of the Slovak republic SRTM (Shuttle Radar Topography Mission) DEM in the national coordinate system S-UTCN and with cell size 100 m (Fig. 3).

During processing of terrain mapping and measuring results the observers and geodesists come across a generally well known problem which lies in the discrepancy between Cartography Cartesian left-handed coordinate system (in Slovak Republic usually S-UTCN, resp. its valid national implementation UTCN03) and right-handed coordinate systems usually used in graphical utility software and CAD software [7].

The most important factors affecting the accuracy of the DMR are the density and distribution

of entry points, the method of collecting input data and interpolation method. [5].

Methods

Interpolation is the estimation procedure of the unknown values from the known (typically measured) values in the area. Usually, interpolation is the local estimate, when the estimated value of the variable - interest at the point, where the primary has not been detected or measured (as opposite to a global estimation given by calculating the mean value for the whole area).

To estimate the characteristics of the methods was with methods GIDS respectively GIDS-a used the method of IDS. Those first two applied methods are a sort of "variation" of IDS method, where the mathematical basis is based exactly on this method. IDS interpolation method is directly implemented in the ArcGIS Spatial Analyst program extension under the program ArcMap.

Method IDS (inverse distance squared)

IDS are a deterministic method, which is for the calculation used a weighted linear average.

Weight, which is used in the calculation of the inverse of the distance measurement d from a local estimate of the power p . Interpolated values obtained from the following:

$$z_k = \frac{\sum_{i=1}^n \frac{f_i}{d_i^p}}{\sum_{j=1}^n \frac{1}{d_j^p}} \quad (1)$$

where:

n – the total number of known neighbor points for point i ,

f_i – the measured value at point i ,

d_{ij} – the distance between the point i and the point j ,

p – a positive power parameter,

In the method of IDS for a positive power parameter p value scales used 2. Coefficient p represents the simplest model of spatial interpolation with concept of spatial autocorrelation, which are based on the assumption that the relationship between the estimated value of the most intense closer to the value and decreases with increasing distance.

Balance of data points entering to the final linear combination are estimated on the basis of changes in power p . The lower power, the more similar to the weights assigned to the data points. Generally for the method, the value of the weight decreases with increasing distance from the interpolated points. The preferred use of this method is dense and uniformly distributed inputs, so well described local changes necessary for a good result analysis. The input data forming the agglomerates formation may occur interference “bull eyes” effect. Consider Horák [9] is possible to mitigate this effect introduced in the formula so smoothing factor (uncertainty). Consequently, for an exact interpolation method becomes approximation method [9].

GIDS - (gradient plus inverse distance squared)

This statistical method has been proposed as a method to interpolate climate data broader territorial scope. Mathematical apparatus of GIDS method eliminates the impact of terrain slope and thus reduces the average absolute error. The GIDS method combining multiple linear regressions with the method of inverse distance weighting (IDW), the altitude acts as a covariate. Least squares linear regression is calculated regression coefficients (C_x , C_y and C_e) representing x , y [16]. This calculation is required to gain unmeasured location for any variable Z . GIDS interpolation method simply based on the formula (1):

$$Z_k = \frac{\sum_{i=1}^N \frac{Z_i + C_x(X_k - X_i) + C_y(Y_k - Y_i) + C_e(E_k - E_i)}{d_i^2}}{\sum_{i=1}^N \frac{1}{d_i^2}} \quad (2)$$

where by [17]:

Z_k – the estimated value at an unmeasured point on the known coordinates X_i , Y_i ,

Z_i – measured value at the location,

X_i – X-coordinate for the location,

Y_i – Y-coordinate,

E_i – elevation value,

d_i – distance from the measured location i to k .

Method GIDS – a

Author T.X. Yue in his contribution in the field of climatology [24] extended the method GIDS the next parameter a , which represents the change in temperature depending on altitude. The vertical temperature gradient is changed not only in time but also locally, the values fluctuate in a wide range of values of the global gradient $-0.0065^\circ\text{C m}^{-1}$ to a positive value at the time of temperature inversions. In the originally paper this method is called as GIDS-a, its calculation is given by the modified method of GIDS:

$$Z_k = \frac{\sum_{i=1}^N \frac{Z_i + [a(E_k - E_i) + C_x(X_k - X_i) + C_y(Y_k - Y_i) + C_e(E_k - E_i)]/2}{d_i^2}}{\sum_{i=1}^N \frac{1}{d_i^2}}, \quad (3)$$

where a is the temperature gradient [17].

Results and discussion

For the calculation of the air temperature estimate by interpolation methods GIDS and GIDS-a is necessary to calculate regression coefficients (C_x , C_y and C_e), which are covered by the calculation by the equations (2) and (3). These coefficients characterize the expected change of dependent variable at a unit change in the independent variables. Regression statistics (Tab. 1) was calculated by using Excel for each variable for the month December 2013. The coefficients are shown in Table. 2 constitute input data for application of GIDS or GIDS-methods in program ArcGIS.

Since the program ArcGIS has not provided for calculating directly the method GIDS or GIDS-a, on the basis of the algorithm shown in Fig. 3 was created application in Visual Basic for Applications.

Created toolbars (named climatological data) is built into ArcMap – ArcGIS environment. A panel is provided with two menu buttons GIDS and GIDS-a, which are named by the individual methods. When working with two of the buttons

Tab. 1. Results of the regression statistics

Tab. 1. Wyniki regresji statystycznej

SUMMARY OUTPUT

Regression statistics	
Multiple R	0,95011616
R Square	0,90272072
Adjusted R Square	0,89699841
Standard Error	0,54639405
Observations	55

ANOVA

	df	SS	MS	F	Significance F
Regression	3	141,2912215	47,0970738	157,7545891	8,61401E-26
Residual	51	15,22586937	0,29854646		
Total	54	156,5170909			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	0,0770935	2,6539273	0,0290488	0,9769390	-5,2508878	5,4050748	-5,2508878	5,4050748
X	-0,0000080	0,0000007	-11,5587553	0,0000000	-0,0000094	-0,0000066	-0,0000094	-0,0000066
Y	0,0000012	0,0000022	0,5666002	0,5734711	-0,0000032	0,0000057	-0,0000032	0,0000057
E	-0,0027637	0,0001830	-15,1017472	0,0000000	-0,0031311	-0,0023963	-0,0031311	-0,0023963

Tab. 2. Calculation of the regression coefficients

Tab. 2. Obliczenie współczynników regresji

Average air temperature – December 2013			
Coefficient	Ce	Cx	Cy
	-0,0027636581	-0,0000080212	0,0000012497

you need to have loaded a layer of digital terrain model and also a layer of stations with measured climate data. For input values are considered also the regression coefficients that users enter through the dialog box. After entering all the input values occurs the process of interpolation from selected method. Button-GIDS and works on the same principle as the preceding, but there is a need to insert another input parameter (the value of the temperature gradient). For the presented calculation was used the value of global temperature gradient $a = -0,0065 \text{ } ^\circ\text{C}\cdot\text{m}^{-1}$. After completion of the calculation in ArcMap is created a new raster layer, which contains the resulting value of estimate.

By graphical representation (Fig. 4) through the interpolation method can monitored the diversity of the estimation results of the average air temperature in Slovakia.

From the resulting average interpolated monthly temperatures we can demonstrate a significant impact of the continentality on climate of Slovakia. In winter, the eastern part of Slovakia compared with places the same latitude on the west almost about $1,5^\circ\text{C}$ colder. For the output produced by the method IDS can be observed the formation of ring structures „bull eyes“ around the measuring stations.

From the above image is a visible impact of altitude to air temperature. While the „classic“

interpolation method interpolated temperatures smoother method GIDS respectively GIDS-a trying to as closely as possible represent an estimate of the temperature, the temperature is seen as „copying“ landscape. Areas with a higher altitude have a lower temperature.

The distribution and the number of discrete points in the field along with the properties of mathematical interpolation functions have important impact on the accuracy of the interpolation [2].

Authors Vicente Serrano [19], Goodale [8], Stahl [21], Benavides [1] presented in their works the testing of equipment without deletion points and the statistical parameters are calculated with all input and comparing the estimated values.

Accuracy was assessed based on the error analysis (Tab. 3) by calculating of statistical indicators:

- mean error – ME

$$ME = \frac{1}{n} \sum_{i=1}^n \hat{z}(x_i) - z(x_i) \quad (4)$$

- mean absolute error – MAE

$$MAE = \frac{1}{n} \sum_{i=1}^n |\hat{z}(x_i) - z(x_i)| \quad (5)$$

- mean square error – MSE

$$ME = \frac{1}{n} \sum_{i=1}^n (\hat{z}(x_i) - z(x_i))^2 \quad (6)$$

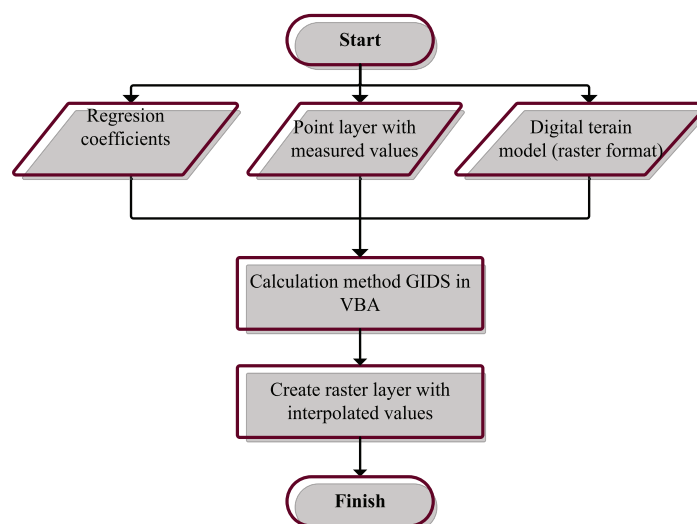


Fig. 3. The algorithm of GIDS method [17]

Rys. 3. Algorytm metody GIDS [17]

Tab. 3. The achieved precision of parameters

Tab. 3. Osiągnięta dokładność parametrów

<i>Errors</i>	<i>Methods</i>		
	IDS	GIDS	GIDS - a
<i>ME [°C]</i>	0,00011874	0,05836499	0,09561213
<i>MAE [°C]</i>	0,00108432	0,07566103	0,12555530
<i>MSE [°C]</i>	0,00000767	0,05552836	0,15467728
<i>RMSE [°C]</i>	0,00276863	0,23564456	0,39329033
<i>EF</i>	0,99999820	0,98693779	0,96361449

– root mean square error – RMSE

$$RMSE = \left\{ \frac{1}{n} \sum_{i=1}^n \hat{z}(x_i) - z(x_i) \right\}^{\frac{1}{2}} \quad (7)$$

where:

$Z(x_i)$ – measured value in point x_i ,

$\hat{Z}(x_i)$ – estimated value in measured point x_i ,

n – is number of comparing couples.

For error analysis without draining the points may be calculated excluding those specified errors also a model of efficiency [14]:

$$EF = 1 - \frac{\sum_{i=1}^n (\hat{z}(x_i) - z(x_i))^2}{\sum_{i=1}^n (\bar{z}(x_i) + z(x_i))^2} \quad (8)$$

Whereby the value of efficiency coefficient of the model is closer to the value 1, thus the model appears to be more effective for using.

By statistical parameters is possible to quantify the total error of methods and thus decide about quality or the accuracy of the resulting model.

The higher RMSE for a GIDS and GIDS-a may be caused by more frequent of occurrence of extreme errors. Maximum deviations achieved methods for estimating temperature stations at high elevations. The impact has probably less dense measuring network of climatological stations at higher elevations. Though the values of parameters for the method IDS appear to be best, this method is trying to smooth the model, what in the estimation of the air temperature is not useful. This method ignores the impact of altitude, which we cannot be missed in the comparing with the methods GIDS and GIDS-a.

In the selected profile (Fig. 7) can be monitored visible difference in the average temperature through the implemented methods.

Conclusion

Implemented applications allow us to use some method of spatial interpolation, but not all are designed especially for estimating climatological data. The advantage of GIS programs is the possibility to program their own applications and tools. The developed application brings together the mathemat-

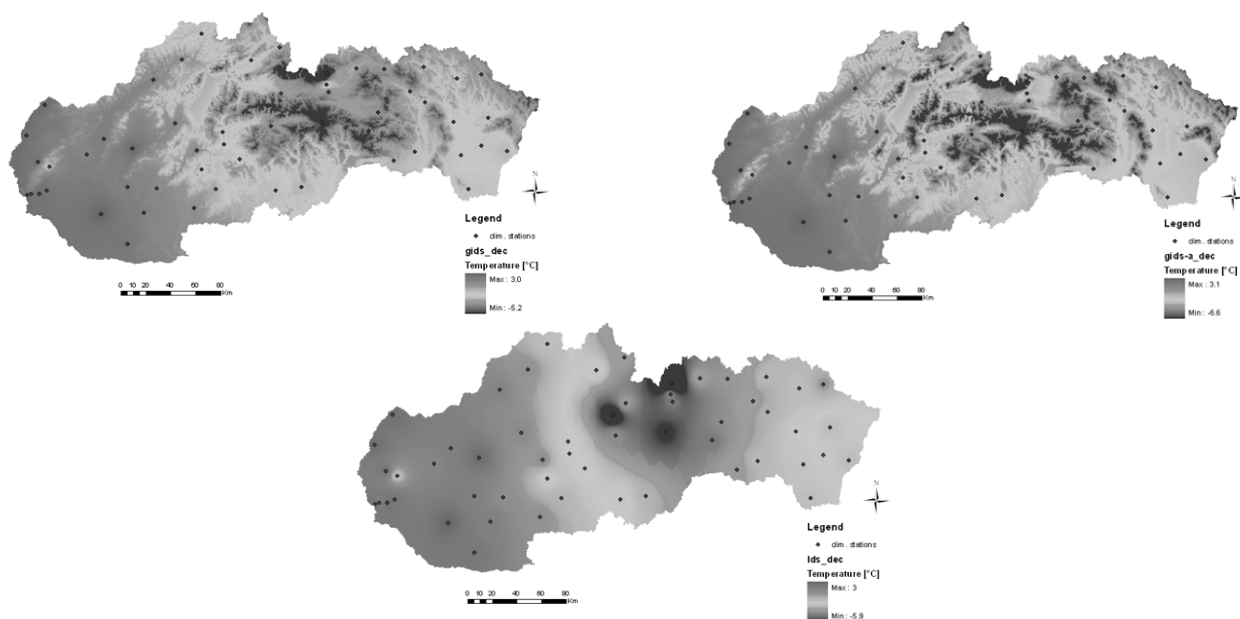


Fig. 4. Presentation of the estimate of the average air temperature for the month of December 2013

Rys. 4. Prezentacja oceny średniej temperatury powietrza dla miesiąca grudnia 2013

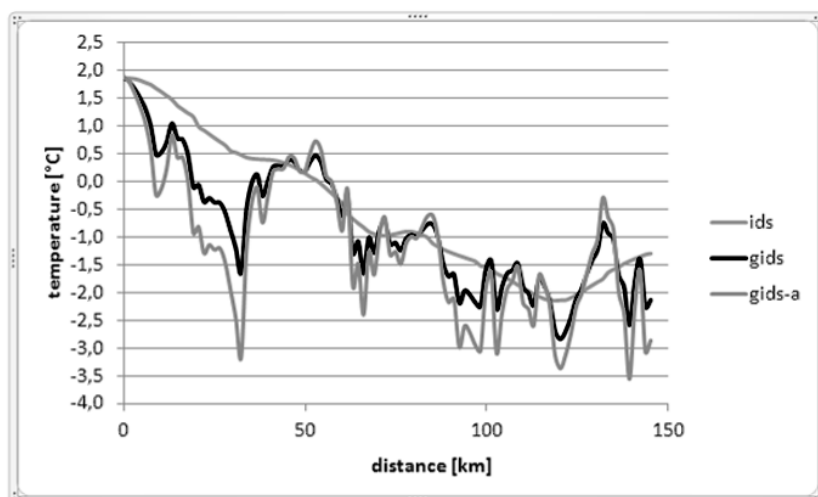


Fig. 5. Profile of development the average air temperature for the month December in the selected area

Rys. 5. Profil zmian średniej temperatury powietrza dla miesiąca grudnia na wybranym obszarze

ical basis of standard interpolation methods taking into account the combination of height ratios measuring stations. This capability is available for this type of data is very important. Through the analysis of applied methods – calculation of statistical indicators can choose the most accurate method for the selected sample of data. Neither of method is not completely reliable, since all methods provide "only" estimates of the variable. Except of the interpolation method has a significant impact on the accuracy of modeling the origin of the input data.

When choosing a method is extremely important to consider the type of interpolated data and appropriateness of the choice of the interpolation method for the type of data. The estimation of measured characteristics depend on properly selected type of interpolation methods, but the accuracy of the calculation depends mainly on the input data and the quality and accuracy of the digital terrain model – relief.

This article was prepared with financial support from VEGA project No.1/0369/13.

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Porównanie metod interpolacyjnych w celu oceny temperatury powietrza

Prezentowany artykuł omawia zagadnienie oceny temperatury powietrza za pomocą wybranych przestrzennych metod interpolacyjnych. Istnieje wiele metod przestrzennej interpolacji, które pozwalają na ocenę wartości, jeśli dane pomiarowe nie są dostępne. Jednym z ważnych wskaźników do wielu praktycznych analiz jest temperatura powietrza. Jest wiadomym faktem, że jest ona zależna od wysokości. Jednakże, nie wszystkie metody interpolacyjne w swych algorytmach pozwalają na wzięcie pod uwagę tej istotnej zmiennej, która może znacząco wpłynąć na końcową wartość estymowanego wskaźnika. Do oceny temperatury powietrza wybrano metodę IDS (metoda odwrotnych kwadratów odległości) oraz jej modyfikację GIDS (gradientowa metoda odwrotnych kwadratów odległości) oraz GIDS-a. Pierwsza metoda została zastosowana bezpośrednio w programie komputerowym. Dla metod GIDS i GIDS-a utworzono aplikację za pośrednictwem VBA.

Słowa kluczowe: metody interpolacji, metoda odwrotnych kwadratów odległości, gradientowa metoda odwrotnych kwadratów odległości, temperatura powietrza