A Comparative Study of Two Temperature Interpolation Methods: A Case Study of the Middle East of Qilian Mountain

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Abstract: Background, aim, and scope The Middle East section of Qilian Mountain was used as the study area, and the temperature interpolation method based on DEM was compared. Materials and methods The temperature average correction method and Anusplin method were used to interpolate the monthly average temperature, seasonal average temperature and annual average temperature of 13 meteorological stations in the study area, and the average absolute error and root mean square error were determined by cross-validation method. The absolute value of the coefficient and index difference evaluates the verification site interpolation results. Results (1) The average absolute error and root mean square error of the vertical temperature correction method ranged from 0.07 °C to 1.36 °C and 0.09 °C to 1.65 °C, and the range of Anusplin ranged from 0.16 °C to 1.3 °C and 0.24 °C -1.49 °C; (2) Anusplin and temperature vertical correction method on the average absolute error and root mean square error index, the absolute difference between the low temperature season index is 0.09 °C and 0.00 °C, respectively, the high temperature season is 0.30 °C and 0.32 °C. Conclusion The temperature vertical correction method is superior to Anusplin in MAE, RMSE and $R^2$ in July, August and September; the accuracy of temperature vertical correction in summer and autumn is higher than that of Anusplin, and Anusplin is more IT is suitable for interpolation in low temperature season, and the vertical temperature correction method is more suitable for interpolation in high temperature season; the error of the two interpolation methods on the annual scale is larger, and the accuracy of temperature and temperature interpolation of Anusplin is much higher than the vertical correction method of temperature. Recommendations and perspectives Different interpolation methods are applicable to different regions, and there is no method that is absolutely suitable for the study area, and only a method that is relatively suitable for the study area. In general, the Anusplin method is more accurate than the temperature vertical correction method for the temperature of the Middle East in Qilian. The former is more suitable for the interpolation of temperature in the study area.

1. Introduction

In October 2018, the IPCC released the \textit{Special Report on Global Warming of 1.5 °C}. According to the report, the global temperature rises by 0.2±0.1 °C every decade, and has now increased by 1 °C. According to the trend, the global temperature rise will reach 1.5 °C in the year 2030 to 2052 \cite{1}. As an important climatic factor, temperature is closely related to human production and the stability of natural ecosystems. It is widely used in the research of related disciplines such as agricultural science,
atmospheric science and resource environment. Therefore, based on the limited meteorological observation data combined with the geographical factors affecting the temperature, the use of high-precision temperature interpolation method is a kind of compensation for the sparse and uneven distribution of meteorological sites.

Satellite remote sensing technology provides a new way to invert the ground temperature in a wide range\cite{2}. Different inversion images are used for different research purposes to obtain different inversion accuracy. The parameters used in the inversion are complex, and the precision is also high. On the contrary, the parameters are simple and the precision is low, so it is only suitable for general research\cite{3}. In addition, satellite remote sensing can obtain a wide range of space weather data, but it is not continuous due to satellite transit time restrictions and weather. In this way, long-term sequence analysis\cite{4} cannot be performed, and it is inconvenient to popularize.

Therefore, it is still one of the commonly used methods to use the observation data of the existing meteorological observation stations in the target area to interpolate and fit the meteorological data of the study area with the local fitting method\cite{5}. At present, the methods of spatial interpolation using observation data from discrete meteorological stations include Ordinary Kriging (OK)\cite{6}, Inverse Distance Weighted (IDW)\cite{7}, trend surface\cite{8}, PRISM\cite{9}, Thin Plate Smoothing Spline (TPS)\cite{10}. Among them, Kriging and TPS are most appropriate. However, in mountainous areas and plateaus in northwestern China, meteorological stations are sparse and unevenly distributed. Consequently, there is no absolute optimal solution in the above spatial interpolation methods, and only the corresponding optimal solution that is suitable for the study area\cite{11}.

In this paper, the middle eastern section of Qilian Mountain with complex terrain and high elevation gradient is selected as the study area. The elevation value extracted from the digital elevation model (DEM) is the covariate, and the special software Anusplina based on TPS and the temperature vertical correction method of vertical temperature correction based on OK are adopted. It is intended to achieve spatial interpolation of the monthly average temperature, the seasonal average temperature, and the annual average temperature of the study area. The interpolation results are cross-validated, and the accuracy of temperature data fitting at different time scales is compared so as to find a more suitable interpolation method for the study area.

2. Data and methods

2.1 Overview of the study area
Qilian Mountain is located on the northeastern edge of the Qinghai-Tibet Plateau, across the northeastern part of Qinghai Province and the western border of Gansu Province. It lies in the transitional zone between the first and second steps of China. It consists of a series of fault block mountains and fault basins. From south to north, there are Daban Mountain, Lenglong Mountain, South Shule Mountain, South Tuole Mountain, Tuole Mountain, and South Zoulang Mountain\cite{12}. The mountainous area is divided into three parts, including the western, the middle and the eastern section\cite{13}. It is a plateau continental climate with long and cold winters, short and cool summers, and large annual range of temperatures. The mountains which are 3,500 m above sea level have snow all year round and are distributed with modern glaciers. The Datong River, Shiyang River and Heihe River originate here. This is also the main water source in the Hexi Corridor area\cite{14}.
2.2 Data preprocessing

The meteorological data in this paper is from China Meteorological Data Network (http://cdc.cma.gov.cn). It is estimated that the average monthly temperature, average season temperature and annual average temperature of 16 stations from January to December in 2017 will be obtained. Seasonal division adopts the standard of meteorological division method, which divides the year from March to May into spring, from June to August into summer, from September to November into autumn, and from December to February into winter. The temperature data of different time scales of each station is extracted and converted into the required *.dat file of Anusplin operation by SPSS.

The elevation data (Figure 1) uses the ASTER GDEM V2 version with an original spatial resolution of 30 m × 30 m. The data comes from the Geospatial Data Cloud Platform of the Computer Network Information Center of the Chinese Academy of Sciences (http://www.gscloud.cn). Raw data is resampled to 1000 m x 1000 m with ArcGIS. The elevation data of each site is extracted as a covariate of the temperature correction in the temperature vertical correction method.

3. Research methods

3.1 Ordinary Kriging Interpolation

Kriging interpolation is based on spatial autocorrelation, and ordinary Kriging interpolation is one of its commonly used interpolation methods. This interpolation method is a linear estimate of the regionalized variable. It assumes that the data is normally distributed and that the expected value of the regionalized variable is unknown. The interpolation process is similar to the weighted moving average. The weight value is determined from spatial data analysis (Yan Naixia, 2012), which is not only able to predict the surface, but also provides measurement of the certainty or accuracy of the prediction.

The general formula for the Ordinary Kriging is:

$$Z(\mathbf{x}_0) = \sum_{i=1}^{n} K_{i0}Z(\mathbf{x}_i)$$  \hspace{1cm} (1)

Where $Z(\mathbf{x}_i)$ (i=1, 2, …,n) is the observed value of n sample points, $Z(\mathbf{x}_0)$ is the estimated
value, $K_i$ is the site weight, and the weight is determined by the Kriging formula:

$$\sum_{i=1}^{n} K_i C(x_i, x_j) - L = C(x_i, x_0)$$  \hspace{1cm} (2)

Where $C(x_i, x_j)$ is the covariance between the sample points of the station, $C(x_i, x_0)$ is the covariance between the sample point and the interpolation point of the station, and $L$ is the Lagrangian multiplier; $\sum_{i=1}^{n} K_i = 1$

### 3.2 Temperature Vertical Correction Method

The vertical variation of temperature has a large effect on the spatial interpolation results (Ishida and Kawashima, 1993), because the temperature will decrease regularly as the elevation increases. The lapse rate of temperature is 0.065 °C/m [17] (indicating that the temperature decreases by 0.65 °C for every 100 m increase in elevation). According to formula (3), the station temperature value at the original elevation is corrected to that at the zero elevation of the station, that is, the corrected temperature value is obtained [18]. The formula for the calculation is as follows:

$$T_1 = T_2 + 0.0065H_1$$  \hspace{1cm} (3)

$$T_3 = T_4 - 0.0065H_2$$  \hspace{1cm} (4)

Where $T_1$ is the zero-elevation temperature of the measured point, $T_2$ is the actual elevation temperature of the measured point, $T_3$ is the temperature obtained by interpolation on the actual elevation, $T_4$ is the temperature obtained by interpolation on the zero elevation, and $H_1$ is the elevation of the actual measured height point, $H_2$ is the elevation of the interpolation point.

### 3.3 Anusplin

The local thin plate smoothing spline uses the optimal smooth parameters in the interpolation process to achieve the best balance of fidelity and smoothness. This not only ensures reliable accuracy, but also allows the introduction of other factors as covariates, such as the DEM elevation factor used herein.

The theoretical model formula is as follows [19]:

$$Z_i = f(x_i) + b'y_i + e_i$$  \hspace{1cm} (5)

Where $Z_i$ is the point to be interpolated at the space $b$, that is the value of the meteorological element to be interpolated; $x_i$ is a $d$-dimensional spline independent variable, which is the meteorological element value of the known control points around the position; $f$ is an unknown smooth function for $x_i$; $y_i$ is an independent covariate, and elevation is the independent covariate of this paper; $b'$ is the coefficient of the independent covariate; $e_i$ is the random error.

In Anusplin, variable variables including independent variables, covariates, covariate units, and spline times, all have an impact on the final interpolation result. Therefore, 9 models are used to simulate the interpolation of temperature, and the appropriate model is selected according to the optimal model judgment criteria (Table 1).

| Model number | Independent variable | covariate | Spline number | Model name |
|--------------|----------------------|-----------|---------------|------------|
| 1            | Longitude, latitude, elevation |           | 2            | Three-variable thin disk smooth spline function |
| 2            | Longitude, latitude, |           | 3            | Three-variable thin disk smooth |

Table 1: Function models of 9 kinds of thin disk smooth splines
4. Results analysis

4.1 Analysis of interpolation results

As shown in Fig. 2 and Fig. 3, both the temperature vertical correction method and the Anusplin can better express the temperature distribution characteristics. At the same time, they conform to the law of lapse rate of temperature, showing the distribution of low elevation with high temperature and high elevation and low temperature. In the complex terrain of the study area, the two interpolation methods are more accurate, because the temperature distribution is consistent with the topographic trend with clear texture and the temperature characteristics of different geographic units are well represented. From the highest temperature and the lowest temperature, the highest temperature of the temperature vertical correction method appears in June, and the lowest temperature appears in December. The highest temperature of Anusplin fitting temperature appears in July, and the lowest temperature appears in December. The temperature rise and downward trend of the two methods are consistent, indicating that the two methods can generally fit the temperature distribution in the study area.

4.2 Cross-validation analysis at different time scales

The four indicators of mean absolute error (MAE), root mean square error (RMSE), determination coefficient R² and absolute value of the difference between the two methods are analyzed by cross-validation. The results are as follows:

1) Monthly scale. MAE and RMSE of the vertical temperature correction method are respectively between 0.07 °C and 1.36 °C and 0.09 °C to 1.65 °C. Anusplin ranges from 0.16 °C to 1.31 °C and from 0.24 °C to 1.49 °C (Figure 3). The maximum and minimum values of MAE of the temperature vertical correction method are smaller than that of Anusplin. When it comes to RMSE, the minimum value of the vertical temperature correction method is smaller than the minimum value of Anusplin, but the maximum value of the latter Anusplin is slightly smaller than the maximum value of the former. In terms of the coefficient of determination, they are so close that the degree of correlation between the two is above 0.99 (Figure 4). However, from the perspective of the dominant interpolation method, the number of dominant months is the same in terms of MAE, while Anusplin has a clear advantage in terms of RMSE. Under the condition that the absolute difference between the two indicators is not much different, the two indexes can be combined to determine that the interpolation precision of Anusplin is higher. In addition, it is found that in July, August and September, the temperature vertical correction method exceeds Anusplin in terms of MAE, RMSE and R².

2) Seasonal scale. The number of dominant months fitted by the two in the MAE and RMSE each accounts for 2 seasons (Figure 3). MAE of the temperature vertical correction method ranges from 0.18 °C to 1.40 °C, while MAE of Anusplin ranges from 0.25 °C to 1.13 °C. The absolute difference between the two indicators is between 0.00 °C and 0.32 °C, which signifies that the two indicators have
little difference in the low temperature region, and Anusplin has a slight advantage in the high temperature region. In addition, the accuracy of the temperature vertical correction method in summer and autumn average temperature is higher than that of Anusplin. This phenomenon is similar to the temperature vertical correction method on the monthly average temperature. In the analysis of the coefficient of determination, the correlation between the two is above 0.99, and Anusplin is slightly dominant (Fig. 4).

(3) Annual scale. The values of MAE and RMSE for the vertical correction method are significantly larger than the latter, and the absolute values of the difference between the two are respectively 2.71 °C and 3.07 °C (Fig. 3). In the terms of the annual scale, the interpolation error of the former is much larger than the latter. What’s more, it can be seen from the figure that the annual average temperature coefficient of the vertical correction method is much lower than the latter, and the absolute difference between the two is 0.45 (Fig. 4).

The cross-validation results of MAE, RMSE and $R^2$ at 17 different time scales in the monthly, seasonal and annual scales comprehensively show that Anusplin respectively has the dominant proportions of 52.94%, 58.82% and 52.94%, and the overall interpolation accuracy is higher than temperature vertical correction method.
Figure 3 Monthly average temperature/season average temperature/annual average temperature interpolation result of Anusplin
5. Conclusion

(1) On the monthly scale: The maximum and minimum of the MAE of the temperature vertical correction method are smaller than Anusplin, and the minimum of the RMSE of the vertical temperature correction method is smaller than the minimum of Anusplin, but the latter maximum is slightly smaller than the former maximum. In terms of the coefficient of determination, the degree of correlation between the two is indistinguishable and both above 0.99. However, from the perspective of the dominant month of interpolation, the number of dominant months in the MAE is equal, but Anusplin has a clear advantage in RMSE. In the case that the absolute difference between the two indicators is not much different, the two indicators can be combined to determine higher accuracy of the Anusplin interpolation. Besides, it is found that the temperature vertical correction method exceeds Anusplin in the MAE, RMSE and $R^2$ in July, August and September.

(2) On the seasonal scale: The index difference of the MAE and RMSE of Anusplin and the temperature correction method is respectively 0.09 °C and 0.00 °C in the low temperature season, and is 0.30 °C and 0.32 °C in the high temperature season. At the same time, the temperature vertical correction method has higher fitting accuracy in summer and autumn than Anusplin, which indicates that Anusplin is more suitable for interpolation in low temperature season on the seasonal scale, and the temperature vertical correction method is more suitable for interpolation in high temperature season. This phenomenon is consistent with the temperature vertical correction method suitable for interpolation on higher monthly scales. Judging from the coefficient of determination, the degree of similarity between the two is closely above 0.99. From the number of MAE, RMSE and $R^2$ indicators, in addition to the average relative error and root mean square error, Anusplin slightly dominated the coefficient of determination. As is shown from the dominant number of MAE, RMSE and $R^2$, Anusplin has a slight advantage in the coefficient of determination in addition to the average relative error and RMSE.

(3) On the annual scale: The differences between the two methods are outstanding on MAE, RMSE and $R^2$. The three values of Anusplin are 0.85 °C, 1.06 °C and 0.52 °C, which are much smaller than the value of the temperature vertical correction method of 3.57 °C, 3.07 °C and 0.45 °C. It can be seen that on the annual scale, Anusplin’s temperature interpolation accuracy is much higher than that of the temperature vertical correction method.

Figure 4 MAE and RMSE distribution of average temperature in two interpolation methods
Figure 5 $R^2$ distribution of 2 kinds of interpolation method

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