ISSN: 2688-8645

Inversion of Land Surface Temperature in Jinan City based on Landsat8 Data

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Abstract

In recent years, remote sensing technology has become more and more mature, and a variety of land surface temperature inversion algorithms have been proposed, and how to use these related algorithms to summarize the change trend of land surface temperature and analyze the future urban development has become a research hotspot. Taking Jinan City as an example, this paper selects Landsat 8 OLI and TIRS remote sensing images in 2017 and 2018, uses ENVI software to use the atmospheric correction method to invert the temperature of the study area, and compares the measured data of 10 stations in Jinan with the inversion results of this study, with errors of 1.86 and 1.90, respectively, and uses linear regression analysis to obtain the correlation coefficients between the inversion temperature and the measured land temperature of 0.8815, respectively, 0.8756, that is, the correlation is high, and the rationality of using the atmospheric correction method to invert the surface temperature of Jinan City is obtained.

Keywords

Land Surface Temperature Inversion; Landsat 8; Regression Analysis.

1. Introduction

The surface temperature is the temperature obtained by the sun's heat energy reaching the ground and reflecting and absorbing the remaining heat energy, and then measuring the ground temperature. At present, some scholars have carried out relevant research and proposed land surface temperature inversion algorithms based on remote sensing thermal infrared band remote sensing [1], which mainly have three types: single-channel algorithm, split-window algorithm and atmospheric correction method. Among them, Qin Zhihao uses the data of the land satellite TM6 to invert the single-window algorithm of land surface temperature [2], and gives the estimation of the specific emissivity and atmospheric number of the surface according to the characteristics of the TM6 thermal infrared band. The split-window algorithm is mostly based on MODIS/NOAA/AVHRR and other image data with two thermal infrared bands, among which the MODIS data has an ideal effect in the inversion of land surface temperature[1], but its resolution is low and the inversion accuracy is not high enough. The atmospheric correction method eliminates the radiation error caused by the influence of the atmosphere and inverts the true surface reflectivity of the ground object, which mainly relies on the information of the image itself, and some information that cannot be directly obtained on the image can be found in the corresponding literature [3], which has strong practicability.

In this paper, taking Jinan City, Shandong Province as the study area, on the basis of summarizing the previous achievements, using Landsat 8 data as the data source, the temperature of Jinan was inverted by atmospheric correction method, and the normalized vegetation index was calculated according to the reflection values of infrared and thermal

ISSN: 2688-8645

infrared, and the vegetation coverage was introduced. According to the real-time atmospheric water vapor content in Jinan, an appropriate atmospheric transmittance model was selected to estimate the atmospheric transmittance [4]; According to the band10 radioluminance image, the blackbody radiance is calculated at the same temperature, and finally the surface inversion temperature is calculated, and then the difference of specific emissivity and the relationship between land surface temperature and vegetation coverage are compared[5]. The data processing mainly includes multispectral data radiometric calibration and atmospheric correction, thermal infrared data radiometric calibration, etc.

2. Data acquisition and Data Processing

2.1. Overview of the Study Area

Jinan is the capital of Shandong Province, located in the central and western part of Shandong Province, south of Mount Tai and north of the Yellow River, between 36°01′ ~37°32N′ and 116°11′ ~117°44′E, located in the middle latitudesAffected by solar radiation, atmospheric circulation and geographical environment, it is a temperate monsoon climate, with an average annual temperature of 13.8 °C, a maximum temperature of 42.5 °C, and a minimum temperature of minus 19.7 °C. Due to the special geographical location of Jinan, it will be difficult to eliminate heat pollution once it occurs, which makes it necessary to study its surface temperature.

2.2. Data Acquisition

In this paper, we downloaded the satellite images of Jinan City, Shandong Province from Landsat8 (OLI and TIRS) on May 16, 2017 and May 3, 2018 from the "Geospatial Data Cloud" website, and the measured meteorological data were queried from the 2345 historical weather website, and the administrative division map of Shandong Province was obtained from Baidu, and the map of Jinan City was cropped by ENVI.

2.3. Landsat 8 Data Preprocessing

(1) Image mosaic and cropping

After converting the acquired data into a unified coordinate system, the multispectral images and thermal infrared images of Landsat 8 were stitched and mosaic, and then the mosaic images were cropped with the vector boundaries of Jinan City to obtain the images of Jinan.

(2) Radiation calibration

Multispectral images of Jinan City were selected for radiometric calibration

(3) Atmospheric correction

The model adopts the FLAASH model, the mesoscale conversion factor of the model parameters is 1, the center coordinates of the graph are set according to the image metadata, the sensor type is Landsat8 OLI, the altitude is 0.011Km, the atmospheric model is set to the mid-latitude summer according to the longitude and latitude of Jinan City, and the aerosol model adopts no aerosol, and the multispectral images for radiometric calibration are atmospherically corrected.

3. Land Surface Temperature Inversion Algorithm

In recent years, scholars at home and abroad have proposed many algorithms for land surface temperature inversion, such as the single-window algorithm and atmospheric correction method in the single-channel algorithm, and the split-window algorithm in the multi-channel algorithm.

ISSN: 2688-8645

3.1. Single-window Algorithm

The single-window algorithm is a land surface temperature inversion algorithm based on the TM thermal infrared band, which has been verified by many scholars and has high inversion accuracy and is suitable for landsat8 data [6]. The formula is

$$T_s = \frac{a(1-C-D)+[b(1-C-D)+C+D]T_{10}-DT_a}{C} \tag{1}$$

$$C = \varepsilon\tau \tag{2}$$

$$D = (1-\tau)[1+(1-\varepsilon)\tau] \tag{3}$$

where T_{10} is the brightness temperature (K), ε the surface specific emissivity, τ the atmospheric transmittance, and T_a the atmospheric average temperature (K). A and b are coefficients. It is usually necessary to obtain the air temperature and relative humidity data of the study area, estimate the absolute water vapor pressure e, and then use the relationship between the atmospheric moisture content and the ground water vapor pressure to estimate the atmospheric water vapor content and atmospheric transmittance, and τ finally estimate the brightness temperature according to Planck's theorem.

3.2. Splitting Algorithm

The split-window algorithm uses the 10th and 11th bands of thermal infrared to invert the surface temperature, and then obtains the surface heat radiative transfer equation [7], and substitutes the temperature value (253~323K) into the simplified Planck equation for calculation, and then uses linear fitting to obtain the approximate linear equation, where let a=0.1409 and b=32.4643, c=0.1199, d=26.8936, in the resulting system of equations, will be T_a、T_s regarded as unknowns, order

$$\begin{aligned} A &= a(1-\tau_{10})[1+(1-\varepsilon_{10})\tau_{10}] \\ B &= aT_{10}+b\tau_{10}\varepsilon_{10}-b+b(1-\tau_{10})[1+(1-\varepsilon_{10})\tau_{10}] \\ C &= c(1-\tau_{11})[1+(1-\varepsilon_{11})\tau_{11}] \\ D &= cT_{11}+d\tau_{11}\varepsilon_{11}-d+d(1-\tau_{11})[1+(1-\varepsilon_{11})\tau_{11}] \end{aligned} \tag{4}$$

The matrix is performed to solve the unknowns, and the value of the T_s true surface temperature is

$$T_s = \frac{BC-AD}{a\tau_{10}\varepsilon_{10}C-c\tau_{11}\varepsilon_{11}A} \tag{5}$$

3.3. Atmospheric Correction Method

The basic principle of the atmospheric correction method is that the total amount of thermal radiation observed by satellite sensors subtracts the influence of the atmosphere on the surface thermal radiation to obtain the surface thermal radiation intensity, which is then converted into the corresponding surface temperature.

The thermal infrared radiance value received by the satellite sensor L_λ is composed of three parts: the upward radiation brightness $L\uparrow$ of the atmosphere, the energy of the real radiation brightness of the ground to reach the satellite sensor after passing through the atmosphere; The energy reflected after the downward radiant energy $L\downarrow$ of the atmosphere reaches the ground. The expression for the luminance value of the thermal infrared radiation received by the satellite sensor L_λ can be written as:

$$L_\lambda = [\varepsilon B(T_s)+(1-\varepsilon)L\downarrow]\tau + L\uparrow \tag{6}$$

where is the ε specific emissivity of the earth's surface, the T_s true temperature of the earth's surface (K), the $B(T_s)$ brightness of the thermal radiation of the blackbody, and τ the transmittance of the atmosphere in the thermal infrared band. Then T the radiant brightness of a blackbody with a temperature in the thermal infrared band $B(T_s)$ is:

$$B(T_s) = \frac{L_\lambda - L\uparrow - \tau(1-\varepsilon)L\downarrow}{\tau\varepsilon} \tag{7}$$

The true temperature of the ground T_s can be obtained as a function of Planck's formula.

In view of the special geographical location of Jinan and its complex topography, which makes the return of water vapor and hot air accumulate and is not easy to diffuse, and the influence of atmospheric absorption and radiation on sunlight and radiation from the target is more obvious, so it is particularly important to eliminate the influence of the atmosphere, so this study used the TIRS10 band of Landsat 8 images to invert the land surface temperature by atmospheric correction method.

4. Land Surface Temperature Inversion and Accuracy Analysis

Based on the research process of the atmospheric correction method, the final requirement to obtain the inversion temperature of the surface requires the help of the Planck function, and the following describes how to calculate the various parameters required in the Planck function, aiming to obtain the results.

4.1. NDVI Exponential Operation

In this experiment, the index was calculated using Band Math $NDVI$, and the calculation formula is:

$$NDVI = (NIR - R)/(NIR + R) \tag{8}$$

NIR Refers to the near-infrared band reflection value, which R refers to the red band reflection value.

4.2. Calculate Vegetation Coverage

Vegetation coverage can be used to evaluate the degree of vegetation coverage in Jinan, and this experiment uses mixed pixel decomposition with the following formula:

$$F_v = (NDVI - NDVI_s)/(NDVI_v - NDVI_s) \tag{9}$$

Among them, F_v it is the vegetation coverage, the $NDVI$ normalized difference vegetation index, the $NDVI_v$ whole vegetation coverage, and $NDVI_s$ the pure bare soil.

4.3. Calculation of Surface Specific Emissivity ε

According to previous studies, it is difficult to accurately measure the specific emissivity of the earth's surface, and the relative value of emissivity can only be obtained through certain assumptions. Remote sensing images can be divided into three types: water bodies, towns, and natural surfaces [8], and the specific emissivity of the three surfaces can be calculated using the following empirical formulas:

$$\varepsilon = 1.0094 + 0.047\ln(NDVI) \tag{10}$$

Among them, ε it is the surface specific emissivity and $NDVI$ the normalized difference vegetation index.

ISSN: 2688-8645

4.4. Calculate Atmospheric Transmittance τ

According to previous studies, the 31 band of MODIS LIB data, which is similar to the TIRS10 data of landsat 8 data, can be used for atmospheric water vapor content inversion, and the center band and wavewidth of the two are similar. Then, the atmospheric transmittance model applied to the 31-band can be applied to TIRS10 of landsat 8 data, and the general atmospheric transmittance calculation equation for the 31-band can be obtained by simulating the atmospheric profile data at mid-latitudes [9].

$$\tau_{31} = 2.89798 - 1.88366 - (\omega / - 21.22704) \tag{11}$$

The atmospheric transmittance can be calculated by the deformation of equation (11) to obtain the atmospheric transmittance of the landsat8 data TIRS10 τ.

4.5. Calculate the Radiant Brightness Value of a Blackbody at the Same Temperature

According to the introduction of the atmospheric correction method in 3.3 above, the radiant brightness value of a blackbody with temperature T in the thermal infrared band is deformed $B(T_s)$, and the expression of the thermal infrared radiance value received by the satellite sensor L_λ is deformed to obtain the formula:

$$B(T_s) = \frac{L_\lambda - L\uparrow - \tau(1-\varepsilon)L\downarrow}{\tau\varepsilon} \tag{12}$$

Among them L_λ, it can be obtained from the radiometric calibration of the thermal infrared image, where L_λ , , $L\uparrow$, τ ε, are $L\downarrow$ all known values at this time, and the radiant brightness value of the blackbody with temperature T in the thermal infrared band is obtained by bringing the above equation into the above equation $B(T_s)$.

4.6. Inversion Results

According to the radiant brightness value of the blackbody with a temperature of T, the true surface temperature is obtained by the inverse function of Planck's formula T_s, which is as follows:

$$T_s = \frac{K_2}{\ln(K_1 / B(T_s) + 1)} \tag{13}$$

For TIRS Band10, $K_1 = 774.89W/(m2\mu msr), K_2 = 1321.08K$

After the above process is completed, the results can be output in the ENVI software, as shown in Figure 1-2, which are the results of temperature inversion in Jinan in 2017 and 2018, respectively.

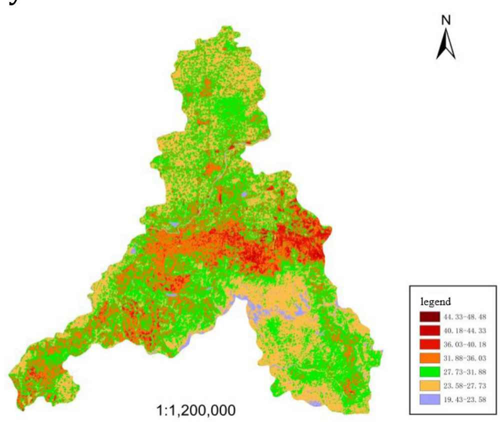

Fig 1. Temperature inversion results in 2017

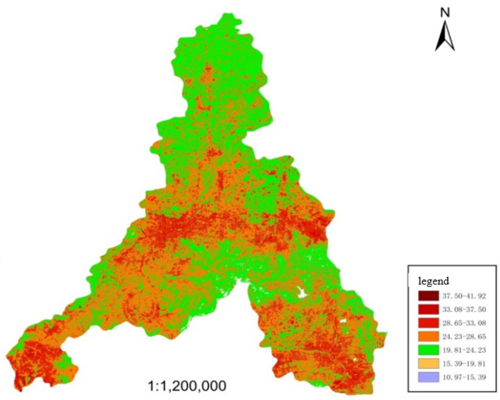

Fig 2. Temperature inversion results in 2018

ISSN: 2688-8645

4.7. Accuracy Analysis

In order to accurately verify the accuracy of temperature inversion, this paper compares the measured land data with the inversion data. The imaging time of Landsat8 image is about 10:50 a.m. every day, so the measured land temperature in the same time period is obtained by interpolation, and the two are compared, as shown in Table 1 and Table 2:

Table 1. Comparison between the inversion and measured data on May 16, 2017

Site	Land surface temperature (°C).		
	Inversion temperature	Measured data	Atmospheric correction error
Mashan Town	33.33	30.78	2.55
Huaiyin Square	33.70	31.24	2.46
Taiping Town Government	30.07	28.12	1.95
Municipal government	34.47	32.15	2.32
Springs Square	33.90	29.99	3.91
Pingyin Ancheng artillery point	31.64	29.33	2.31
Thermoelectric companies	30.99	30.01	0.98
Shanghe Jade Emperor Temple	31.00	29.98	1.02
Yellow River Town	29.55	28.64	0.91
Seven Star Terrace	24.34	24.12	0.22
average value	31.30	29.45	1.86

Table 2. Comparison of inversion and measured data on May 3, 2018

Site	Surface temperature (°C)		
	Inversion temperature	Measured data	Atmospheric correction error
Mashan Town	27.1	24.97	2.13
Huaiyin Square	28.66	25.16	3.5
Taiping Town Government	25.60	24.65	0.95
Municipal government	29.49	27.65	1.84
Springs Square	30.66	27.36	3.3
Pingyin Ancheng artillery point	27.31	25.03	2.08
Thermoelectric companies	27.01	26.12	0.89
Shanghe Jade Emperor Temple	25.70	23.79	1.91
Yellow River Town	23.69	23.11	0.58
Seven Star Terrace	21.79	20.19	1.6
average value	26.70	24.80	1.9

ISSN: 2688-8645

Due to the limited number of measured data samples in this experiment, and the errors will occur in the interpolation process according to the temperature broadcast by the meteorological station and the data collected by the satellite in the field measurement, in order to improve the convincing power of this experiment, the correlation analysis of the two-year inversion results and the measured data is carried out, as shown in Fig. 3 and Fig. 4.

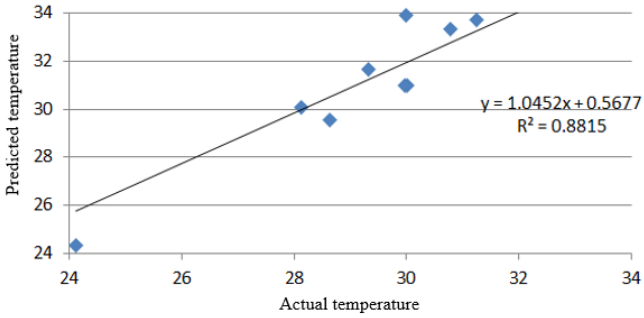

Fig 3. Temperature in 2017

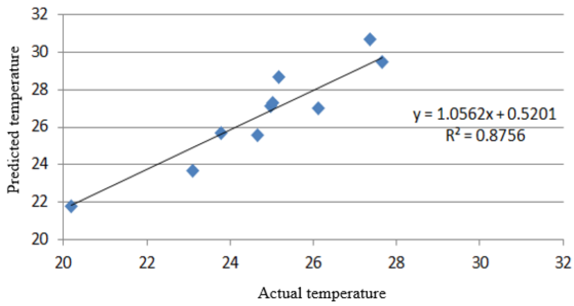

Fig 4. Temperature in 2018

From Table 1 and Table 2, the average errors obtained in 2017 and 2018 were 1.86 and 1.90, and the linear regression analysis of the inversion and measured data in 2017 and 2018 yielded that the two-year budget estimation constants were 0.5677 and 0.5201, with an average of 0.5439 and correlation coefficients of 0.8815 and 0.8756, respectively, indicating that the inversion results of this study were reasonable.

5. Conclusion and Discussions

After the accurate calculation of the atmospheric transmittance and the specific emissivity of the surface in this experiment, according to the accuracy analysis results, the real surface temperature of Jinan can be calculated by inverting the surface temperature of Jinan by using the atmospheric correction method according to the estimation constant obtained by linear regression, which has good applicability. In terms of urban planning, the density of buildings and green vegetation should be rationally arranged to reduce the heat island effect and improve the quality of the environment. In terms of the economy, we should appropriately adjust the industrial structure, focus on the development of the tertiary industry, decentralize industry, and develop a green economy.

According to the error between the inversion results and the measured data, the shortcomings of this experiment are summarized: (1) The humidity, air pressure, wind speed and other general information of Jinan are not obtained in real time. (2) The image data acquisition is incomplete, the number of downloaded data periods is too small, and the time interval between the two periods of images is large. (4) The parameters used by the model algorithm are model-based parameters, which will be different from the actual parameters, which will affect the accuracy of the algorithm model built when processing images.

Acknowledgments

Funding: This work was supported from the projects of "The Natural Science Basic Research Plan in Shaanxi Province of China" (Program No. 2024JC-YBQN-0329). Internal scientific research projects of Shaanxi Land Engineering Construction Group (DJNY2023-TD-1, DJNY-ZD-2023-3, DJNY2024-16, DJNY2024-36).

ISSN: 2688-8645

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