Study on the Difference of Surface Temperature among Different Vegetation Landscapes Detected by Ground Thermal Infrared Remote Sensing

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Abstract: Surface vegetation cover is a difficult problem in surface temperature inversion by thermal infrared remote sensing, thus this paper selected water body as the reference surface, measured surface temperature of five different vegetation landscape types (high tree, tree-shrub-grass, grass, shrub, and tree-grass) by using ground thermal infrared remote sensing instrument and analyzed the temperature difference along the Wenyu river. The results showed that there were seasonal differences of surface temperature among different vegetation landscape, the seasonal variation of shrub surface temperature was the most stable, but those of tree-shrub-grass was the most unstable; the directional difference of the surface temperature among vegetation landscape was influenced by the slope, given the consistent slope, the order of directional difference of surface temperature among vegetation landscape types was: tree-grass > high tress > tree-shrub-grass > shrub > grass; there was different respond relationship between surface temperature and vertical temperature among vegetation landscape, in which there was linear equation model \((y = b_1x + b_0)\) for the two types of high-tree and shrub, Joe forest and shrub forest, “S” type curve model \((y = \exp (b_0 + b_1/x))\) for the three types of tree-grass, grass, and tree-shrub-grass.

1. Introduction

The surface temperature is the comprehensive reflection of surface water-thermal equilibrium, which is the core parameter in most surface flux remote sensing simulation. With the development of thermal infrared remote sensing (TIR) technology, the measurement technology of surface temperature also has the huge development: from the original ground fixed-point measurement to a wide range observation and inversion by TIR technology [2]. Due to many factors influencing on large area observation results by remote sensing technology, therefore, it need fixed-point observation data for estimation and verification, in which scale conversion is the definite method for estimating and validating regional surface flux, but the scale conversion is a long-term difficult problem in the research of regional land surface temperature inversion[3].

For scale problem, many different methods were used to integrate parameters at small scale to calculate the surface flux at large scale [4]. Moran considered the scale expansion caused by the surface energy balance of the remote sensing parameters and flux controlled by two factors: one is the uncertainty of remote sensing signal and surface parameters and the nonlinear relationship between the energy flux, the other is the homogeneity of the surface itself [5]. Therefore, it is necessary to consider...
both of homogeneity of the underlying surface and the space representational problem, when the estimation results through the satellite remote sensing method are verified by using the observation value of the flux point on the ground [3]. The surface of water body is relatively homogeneous, and surface of vegetation coverage, due to the different types of vegetation community composition, directly affect the surface energy balance.

Ground thermal infrared instruments have been used to measure the surface temperature of crops at home and abroad [6]. The surface temperature of different vegetation composite landscape types under multi-layer coverage (large-scale remote sensing images interpreted as woodland, garden land and grassland) has not been reported. At the large scale, the average temperature of the surface temperature is obtained from the surface temperature by thermal infrared inversion, for example: the TM thermal infrared channel, one pixel covers the actual area with 120x120m². The surface temperature was measured by ground infrared remote sensing instrument, at the same time, the ground measurement of surface temperature don't need to consider the process of temperature and enrage complex transmission, could also provide experimental basis for land surface temperature inversion of complex vegetation land use types (such as forest, garden and grass land) at large scale. Therefore this article choose the Wenyu river riparian zone as the research area, using ST80 infrared thermometer to measure vegetation and water temperature at riparian zone for detecting the surface temperature difference of different vegetation types of (season, direction and vertical field), for providing the theory basis of surface temperature inversion at the large scale by using the thermal infrared remote sensing technology.

2. Methodology

2.1. Theoretical Basis

The theory basis of thermal infrared remote sensing inversion at large scale is heat conduction equation, during the process of the earth-atmosphere radiation transferring of thermal infrared remote sensing, the ground and atmosphere are source of thermal infrared radiation, radiant energy are absorbed, scattered and emitted through many layer atmosphere. The heat conduction equation [7] is as follows:

$$L_{j}^{\text{Sensor}}(\theta) = \tau_{j}(\theta) e_{j}(\theta) B_{j}(T_{g}) + L_{j}^{\text{ATM}}(\theta) + \tau_{j}(\theta) \int f(\theta', \phi, \theta, \phi') L_{j}^{\text{ATM}}(\theta') \cos(\theta') d\sigma'$$  \hspace{1cm} (1)

Here: $\psi$ and $\theta$ are respectively the azimuth and apex angle of sensor, $\theta'$ and $\Theta'$ are the azimuth and the apex angle of the atmosphere downward radiation. $L_{j}^{\text{Sensor}}$ is the thermal infrared radiation brightness on the j-band received by the remote sensor as angle of view is $\theta$, $\tau_{j}(\theta)$ is the atmospheric transmittance on the j band as apex angle is $\Theta$, $L_{j}^{\text{ATM}}(\theta)$ is the atmospheric upward radiation on the j band as apex angle is $\Theta$, $L_{j}^{\text{ATM}}(\theta)$ is the atmospheric downward radiation on the j band as apex angle is $\Theta$. $f(\theta', \phi, \theta, \phi')$ is the surface bidirectional reflectance distribution function, $\sigma'$ is the integral of hemispheres, $d\sigma'$ is the differential solid angle.

Due to the complexity of the equation, most scholars simplified the equation as follows:

$$L_{j}^{\text{Sensor}} = [e_{j} \ast B_{j}(T_{g}) + (1-e_{j})L_{j}^{\text{ATM}}] \tau_{j} + L_{j}^{\text{ATM}}$$  \hspace{1cm} (2)

In which, $B_{j}(T_{g}) = \int_{\Theta}^{\Theta_{\ast}} \frac{e_{j} B_{j}(T_{g}) d\Theta}{\int_{\Theta}^{\Theta_{\ast}} e_{j} B_{j}(T_{g}) d\Theta}$, $f(\psi)$ is the spectral response of the sensor on j band, $B_{j}(T_{g})$ can be calculated by Planck's law.

The new ST80 infrared thermometer, launched in 2000 by the Raytek company, was used in this article. The range of temperature was minus 30 -760 °C (25 - 1400°F), and that of spectral response
was 8 to 14 μm. The equipment was easy to use, just in advance setting the surface emissivity for reducing the ratio of the surface emissivity on the accuracy of the surface temperature of error.

2.2. Measure Method
Reference on divisions of vegetation vigorous growth period in Beijing, it divided respectively three periods of early vigorous vegetation growth (from late March to early May), keeping growth (from early May to early September), and late vigorous vegetation growth (from early September to late November). Using ST80 handheld infrared thermometer, it measured temperature on vegetation and water surface in three stages, and set emissivity with 0.98 for vegetation cover surface, 0.97 for non-vegetation cover surface, 0.99 for the water [8]. The air temperature was measured by the Asman Ventilation Psychro-meter.

3. Research area
It chose samples set at Wenyu river of Beijing. According to vegetation distribution of Wenyu river riparian zone, seven representative fields were chosen as the experimental observation points, each point represented the typical different vegetation community of Wenyu river riparian zone. The specific vegetation coverage of sample points was shown in table 1.

| Vegetation landscape | tree (%) | shrub (%) | grass (%) | early vegetative vigorous growth | keeping vigorous growth | late vegetative vigorous growth |
|----------------------|---------|-----------|-----------|----------------------------------|------------------------|---------------------------------|
| tree                 | 100     | 0         | 0         | surface information was close to bare ground | almost all vegetation was green and vigorous | vegetation has fallen leaves, and the parts appeared yellow |
| tree-shrub-grass     | 15      | 15        | 70        | ground surface information was almost the soil information | almost all vegetation was green and vigorous | vegetation has fallen leaves, and parts of it appeared yellow, especially grass, some of the grass was turning yellow, some were yellowing, others were green |
| grass                | 0       | 0         | 100       | surface information was soil information | vegetation was flourishing, and the ground was almost green | grass was deserted, shrub began to have yellow leaves |
| shrub-grass          | 0       | 30        | 70        | parts of grass began to turn green, surface temperature close to bare | vegetation is thriving and green | |
| tree-grass           | 40      | 0         | 60        | vegetation began to return, but the surface information was still close to the bare ground | vegetation was flourishing, and the ground was almost green | vegetation began to have fallen leaves, and some of them were falling |

4. Results and discussion
4.1. Seasonal Difference of Surface Temperature of Different Vegetation Landscape
Vegetation growth is affected by the season, which results in different physiological and biochemical characteristics of different vegetation in different seasons, thus indirectly affecting the surface temperature of vegetation canopy. Fig 1A showed the seasonal difference of surface temperature of different vegetation landscape types. It can be seen that the surface temperature of different vegetation landscape had a seasonal difference, and the surface temperature was the highest during the period of vegetation flourishing growth, which was synchronized with the air temperature change. In order to better reflect the seasonal difference of surface temperature between vegetation landscape, Fig.1 B showed the stability of the seasonal change of surface temperature between periods of vegetation growth season, it can be seen that the seasonal changes in surface temperature of shrub was most stable and that of tree-shrub-grass was most unstable.
4.2. Directional Difference of Surface Temperature of Different Vegetation Landscape

Using thermal infrared instrument to measure the surface temperature had not only included the vegetation information also the soil information, which should be caused by shadow effect from surface structure of the mixed vegetation and soil [9], therefore, resulted in directional difference of surface temperature measured in different direction, and the thermal directivity of the surface radiation temperature should be studied [10]. Researchers considered that the surface temperature of different vegetation landscape could be measured in different directions, which could be helpful for the inversion of thermal infrared remote sensing technology. In this paper, variance analysis was used to study the directional difference of surface temperature of different vegetation landscapes, and the results were shown in table 2. It could be seen that: 1) the directional difference of the surface temperature of vegetation landscape was influenced by slope, the same grass landscape type with No. 3 and 6 sample had different direction difference of surface temperature, No. 3 sample had extremely significant difference in significant value of 0.00, but No. 6 sample had no significant difference performance with significant value of 0.18; 2) compared with temperature of water surface, under the condition of the slope consistence, the directional difference of the surface temperature had significance of different vegetation landscape type (except for No. 6 sample), and that of water had not significant. Directional difference of different vegetation landscape was different, some was significant, and some was not. The directional difference of surface temperature, like tree, shrub and tree-grass vegetation landscape, was very significant with less than 0.01 of significant values, and also the same characteristic of tree-shrub-grass and shrub vegetation landscape, significance level value with 0.02 and 0.02, only surface temperature of No. 6 sample was not significant vegetation landscape.
with significance level value of 0.18. Overall, in the case of consistent slope, directional differences of different vegetation landscape were sorted as: tree > grass > tree-shrub-grass > shrub > grass, therefore, surface temperature of grass vegetation landscape based on ground observation could be directly used in large scale remote sensing inversion.

**TABLE 2. Directional difference of LST in different vegetation landscape.**

| Vegetation landscape | Sample No. | east  | south | west  | north | Significance level |
|----------------------|------------|-------|-------|-------|-------|-------------------|
| tree                 | 1          | 19.71 | 20.59 | 19.61 | 20.62 | 0.01**            |
| contrast             | 19.33      | 19.32 | 19.33 | 19.35 | 0.18  |                   |
| tree-shrub-grass     | 2          | 21.65 | 21.39 | 21.57 | 21.96 | 0.02*             |
| contrast             | 21.12      | 21.10 | 21.10 | 21.09 | 0.07  |                   |
| contrast             | 25.92      | 25.43 | 24.69 | 25.80 | 0.00**|                   |
| grass                | 3          | 21.22 | 21.23 | 21.20 | 21.22 | 0.39              |
| contrast             | 6          | 26.82 | 27.34 | 26.93 | 26.71 | 0.18              |
| shrub                | 4          | 23.35 | 22.90 | 22.83 | 23.70 | 0.04*             |
| contrast             | 21.14      | 21.14 | 21.14 | 21.12 | 0.34  |                   |
| tree-grass           | 5          | 23.05 | 23.13 | 23.03 | 22.66 | 0.00**            |
| contrast             | 7          | 22.71 | 22.92 | 22.80 | 23.28 | 0.00**            |
|                      | 21.98      | 21.99 | 21.94 | 21.67 | 0.57  |                   |

(note: * stands for significant difference, between 0.01 and 0.05, and ** stands for significant difference, with a significant value less than 0.01. Contrast means water surface, N=16.)

**4.3. Difference Comparative of Surface Temperature between Different Vegetation Landscape Types**

Due to the existence of the differences in time, space, the seasonal and different vegetation itself, there was difference between the mean surface temperatures of vegetation landscape. In order to confirm if there was a difference in mean surface temperature of different vegetation landscape type in river riparian zone or not, this research further compared surface temperature of two different vegetation landscape for variance analysis. The results were showed in table 3. It could be seen that average surface temperature of different types of vegetation landscape has the difference, there were very significant difference among tree, tree-shrub-grass, grass, significantly different from shrub and tree-grass type with significance level value of 0.000, and average surface temperature of shrub and tree-grass had significant differences with significant level of 0.025 and 0.012 respectively. The results may be that the mean can not reflect the difference of surface temperature of different vegetation landscape. It was indicated that the average value of the surface temperature with remote sensing image inversion was error.

**TABLE 3. Mean differences of LST in different vegetation landscape.**

| vegetation landscape | Sample No. | mean | 1. | 2. | 3. | 4. | 5. | 7 |
|----------------------|------------|------|----|----|----|----|----|----|
| tree                 | 1          | 20.13| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| tree-shrub-grass     | 2          | 21.65| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| grass                | 3          | 25.46| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| shrub                | 4          | 23.19| 0.00| 0.00| 0.00| 0.00| 0.00| 0.025|
| tree-grass           | 5          | 22.97| 0.00| 0.00| 0.00| 0.00| 0.025| 0.641|
|                      | 7          | 22.93| 0.00| 0.00| 0.00| 0.00| 0.012| 0.641|

(note: * stands for significant difference, between 0.01 and 0.05, and ** stands for significant difference, with a significant value less than 0.01. Contrast means water surface, N=16.)
4.4. Difference between Surface Temperature and Air Temperature

The air temperature change will inevitably lead to the change of surface temperature; a large number of tests had set up the relationship between the air temperature and the surface temperature. Because of the difference of the research object, the correlation relationship between air temperature and the surface temperature was different. In this article, the response relationship between air temperature and surface temperature of different vegetation landscape types was established by regression analysis, and the results were shown in Table 4. It can be seen that the relationship between the surface temperature and air temperature of the sample point (tree type and shrub type) was a linear equation model (y=b1X + b0) with R2 for 0.914 and 0.964; The relationship between surface temperature and air temperature of other sample points (such as grass type, tree-shrub-grass and tree-grass type) was expressed as "S" curve model (y=exp(b0A + b1/x)) with R2 respectively of 0.850, 0.783, 0.880, 0.872, 0.839, in which the No. 3 sample point (slope was 45°, grass type) with lowest R2, meaning that there was the weakest relationship of surface temperature and air temperature. These results showed that the surface temperature of the vegetation landscape type at river riparian was related to the surrounding temperature, and different vegetation coverage resulted in different correlation models. It should provide an experimental basis on widespread use of these models by air temperature data at meteorological sites for inversion of surface temperature of vegetation landscape such as tree, tree-shrub-grass, grass, shrub and shrub-grass.

| vegetation landscape | Sample No. | model | b1   | b0   | F   | R2  | Significance level |
|----------------------|------------|-------|------|------|-----|-----|--------------------|
| tree                 | 1          | a.    | 4.191| 0.854| 148.357| 0.914 | 0                  |
| tree-shrub-grass     | 2          | b     | 3.488| 7.387| 79.515 | 0.85 | 0                  |
| grass                | 3          | b     | 3.687| 8.565| 50.529 | 0.783 | 0                  |
| shrub                | 4          | a.    | 0.004| 1.043| 374.84 | 0.964 | 0                  |
| tree-grass           | 5          | b     | 3.548| 8.291| 95.099 | 0.872 | 0                  |
|                      | 7          | b     | 3.55 | 8.569| 72.974 | 0.839 | 0                  |

(note: a means function model of y=b1X + b0; b means function model y=exp(b0A + b1/x); x and y represent respectively air temperature and surface temperature. Sample size N=16.)

5. Conclusion

Based on above difference analysis of surface temperature This test in Beijing at the Wenyu river riparian, the results showed that: 1) There was seasonal difference of surface temperature of different vegetation landscape, the seasonal changes in surface temperature of shrub was most stable and that of tree-shrub-grass was most unstable; 2) The directional difference of the surface temperature of vegetation landscape was influenced by slope, in the case of consistent slope, directional differences of different vegetation landscape were sorted as: tree-grass > tree > tree-shrub-grass > shrub > grass, therefore, surface temperature of grass vegetation landscape based on ground observation could be directly used in large scale remote sensing inversion; 3) Average surface temperature of different types of vegetation landscape has the difference, there were very significant difference among tree, tree-shrub-grass, grass, significantly different from shrub and tree-grass type, and average surface temperature of shrub and tree-grass had significant differences; 4) It can be seen that the relationship between the surface temperature and air temperature in vegetation landscape of tree and shrub types was a linear equation model (y=b1X + b0); The relationship between surface temperature and air temperature of other sample points (such as grass type, tree-shrub-grass and tree-grass type) was expressed as "S" curve model (y=exp(b0A + b1/x)). It should provide an experimental basis on widespread use of these models by air temperature data at meteorological sites for inversion of surface temperature of vegetation landscape such as tree, tree-shrub-grass, grass, shrub and shrub-grass.
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