Correlation Analysis of Urban Land Surface Temperature and Fluxes Based on Remote Sensing Technology

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Abstract: Land surface temperature and fluxes (soil heat flux, sensible heat flux and latent heat flux) of the Nanchong city in Sichuan Province on September 20, 2007, were retrieved using Landsat ETM+ images. Then based on sampling points in study area, surface temperature and each flux were compared with scatter diagram, and simulated the function to explore their correlation. The research results are the following: 1) Land surface temperature had positively correlation with both soil heat flux and sensible heat flux, but negatively correlation with latent heat flux. 2) Surface temperature was absolutely affected by sensible heat flux.

Keywords: Land surface temperature, Soil heat flux, Sensible heat flux, Latent heat flux, Correlation analysis.

1. Introduction

In recent years, with the development of urbanization, the scale of city has expanded continuously, the population of which has increased sharply, and large amount of natural surface, for example, woodland, farmland and grassland, etc, have changed into building, road, etc., which uses cement as main materials, in addition a lot of heat, which is from cars, computers, air conditionings, refrigerators, mobile phones, and IPADs, etc., has discharged into air. Theses have caused obvious Heat Island Effects, which is seriously affecting city people’s quality of life.

At present, there are two methods of urban heat island research using remote sensing technology. The first is retrieving land surface temperature, the second is retrieving land surface fluxes. But the relationship between surface temperature and heat fluxes has not yet been studied specially. Based on this, taking the Nanchong city in Sichuan Province as an example, the correlation between surface temperature and heat fluxes, which was retrieved respectively using remote sensing technology, was explored to provide basis for research work of Urban Heat Island.

2. Research Region and Data Source

The Nanchong City lies in the northeast of Sichuan Basin, and locates in the middle reaches of the Jialing River (see Fig. 1). The topography is mainly hilly, and the altitude is from 26 to 480 meters. The research region is the urban area of the Nanchong city, which locates in the west of the Jialing River and the east of the Xi River, including the Shunqing District, the Jialing District and the...
Gaoping District. The Shunqing District and the Jialing District lies in the west of the Jialing River, and the Gaoping District lies in the east of the Jialing River. The Jialing River flows through the east side of the urban from north to south. The urban area is surrounded by the highway. The highway from Chengdu to Nanchong runs across the south of urban area.

This research used Landsat-7 ETM+ data obtained on September 20, 2007, DEM and atmosphere temperature. The projection of the ETM+ images was UTM 48N, the ellipsoid and reduced plane of which was WGS84, the spatial resolution of which was 30 m. The quality of images was good. DEM was downloaded from Global Mapper, and its projection and resolution was same as ETM+ images.

3. Retrieving Land Surface Temperature

3.1. Radiation Calibration

Radiation calibration is a process of converting the digital value of remote sensing data into spectral radiance value of sensor. The model is Formula (1) [1].

\[
L_{\lambda} = \frac{L_{\text{max}} - L_{\text{min}}}{Q_{\text{max}} - Q_{\text{min}}} (Q_{\lambda} - Q_{\text{min}}) + L_{\text{min}},
\]  

where \( \lambda \) is the band value, \( L_{\lambda} \) is the spectral radiance by the sensor (W·m\(^{-2}\)·sr\(^{-1}\)·μm\(^{-1}\)), \( Q_{\lambda} \) is the digital number of analyzed pixel, \( Q_{\text{max}} \) is the maximum recorded (255), \( Q_{\text{min}} \) is the minimum recorded, \( L_{\text{max}}, \) and \( L_{\text{min}} \) are the maximum and minimum spectral radiance, detected for \( Q_{\text{min}} \) and \( Q_{\text{max}} \).

3.2. Radiation Calibration

1) Retriving brightness temperature (BT).

Based on spectral radiation value of pixels on sensor, BT can be calculated directly by Planck's radiation function or an approximation Formula (2) [2-3].

\[
T = K_2 \ln(1 + K_1/L_{\lambda}),
\]  

where \( T \) is the BT of pixels and its unit is K, \( K_1 \) and \( K_2 \) are the pre-launch calibration constants, as for ETM+ band62, \( K_1 \) is 666.093W·m\(^{-2}\)·ster\(^{-1}\)·μm\(^{-1}\), and \( K_2 \) is 1282.708 K.

2) Retrieving land surface temperature (LST).

LST can be calculated according to Formula (3) [4].

\[
T_s = \frac{T_{\text{rad}}}{1 + (\lambda \cdot T_{\text{rad}} / \rho) \ln \varepsilon},
\]  

where \( T_s \) is the LST and its unit is K; \( T_{\text{rad}} \) is the BT; \( \lambda \) is the center wavelength (11.4 μm); \( \rho = h \cdot c / \sigma \), where \( h \) is the Planck constant (6.626×10\(^{-34}\)J·s\(^{-1}\)), \( c \) is the velocity of light (2.998×10\(^{8}\)m/s), \( \sigma \) is the Boltzmann constant (1.38×10\(^{-23}\)J/K); \( \varepsilon \) is the surface emissivity, when \( NDVI < 0.05 \), \( \varepsilon = 0.973 \), when \( NDVI > 0.7 \), \( \varepsilon = 0.99 \), when \( 0.05 \leq NDVI \leq 0.7 \), \( \varepsilon = 0.004P_v + 0.986 \), where \( P_v \) is the vegetation proportion in pixel, \( NDVI \) is the NDVI value of vegetation and bare land.

4. Retrieving Land Surface Fluxes

This research is mainly based on the surface energy balance Equation (4) [7].

\[
R_n = LE + H + G + PH,
\]
where \( R_n \) is the net radiation, \( LE \) is the latent heat flux, \( H \) is the sensible heat flux, \( G \) is the soil heat flux, and the unit is \( \text{w} / \text{m}^2 \). \( PH \) is the energy for plant photosynthesis and biomass increased, and can be neglected in actual calculation because its value is very small.

\[
R_n = Q(1 - \alpha) + \varepsilon_a \sigma T_s^4 - \varepsilon_s \sigma T_s^4, \quad (5)
\]

where \( Q \) is the total solar radiation, \( Q = Gd \tau_{sw} \cos \theta \), \( G \) is the solar constant (1367 \text{w} / \text{m}^2), \( d \) is the sun-earth distance, \( \theta \) is the zenith angle, \( \beta \) is the solar elevation, \( \alpha \) is the surface albedo, \( \alpha = 0.356 R_i(i) + 0.130 R_i(3) + 0.373 R_i(4) + 0.085 R_i(5) + 0.072 R_i(7) - 0.0018 \) [9], \( R_i(i) \) is the band surface reflectance, \( \sigma \) is the Stefan-Boltzmann constant, and its value is \( 5.67 \times 10^{-8} \text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-4} \), \( \varepsilon_a \sigma T_s^4 \) is the atmospheric long wave radiation, \( \varepsilon_s \sigma T_s^4 \) the atmospheric emissivity, \( \varepsilon_a = 1.08(-\ln \tau_{sw})^{0.265} \) [10], \( \tau_{sw} \) is the atmospheric transmittance, \( \tau_{sw} = 0.75 + 2 \times 10^{-5} \times Z \) [11], \( \varepsilon_s \sigma T_s^4 \) is the surface long wave radiation, \( \varepsilon_s \) the surface emissivity, \( T_a \) the near surface air temperature, \( T_s \) the land surface temperature, \( Z \) the altitude at the measurement point and its value is from DEM.

2) Estimating soil heat flux (G).

The soil heat flux is the heat stored in the soil layer, and often estimated using the empirical formula. In this paper, the soil heat flux is calculated based on the Formula (6) [12] proposed by Bastiaanssen in 2000.

\[
G = R_n \cdot T_s \left( 0.0038 \alpha + 0.0074 \alpha^2 \right) \cdot \\
\left( 1 - 0.98 NDVI T_a \right) / \alpha, \quad (6)
\]

where \( R_n \) is the surface net radiation, \( T_s \) is the surface temperature, \( \alpha \) is the surface albedo.

3) Estimating sensible heat flux (H).

The sensible heat flux is the exchange energy between land surface and atmosphere, and is determined by the surface temperature, temperature and air resistance. The model is Formula (7) [12].

\[
H = \frac{\rho_{air} \cdot C_p \cdot \frac{dT}{r_{ah}}}{}, \quad (7)
\]

\[
\rho_{air} = 349.635 \times ((T - 0.0065Z) / T)^{26} / T, \quad (8)
\]

where \( \rho_{air} \) is the air density (kg·m⁻³), and is calculated by Formula (8) [13-14], \( C_p \) is the air specific heat at constant pressure (1004 J·kg⁻¹·K⁻¹), \( dT \) is the temperature difference at the height of \( Z_1 \) and \( Z_2 \), \( Z_1 \) (0.01 m) is the bare land roughness length, \( Z_2 \) (2m) is the reference height of meteorological data, \( a(T_r - 0.0065 Z) + b \), a and \( b \) are constants, and their values are obtained by selecting the “cold point” and “hot point” from remote sensing image; \( r_{ah} \) is the corrected aerodynamic resistance, unstable, and can be calculated through multiple recursive calculation.


The latent heat flux is the heat energy of evaporation or condensation water, can be calculated by the surface heat balance Equation (9).

\[
LE = R_n - H - G \quad (9)
\]

5. Correlation Analysis of Land Surface Temperature and Fluxes

To analyze the correlation between surface temperature and heat fluxes, 163 sampling points were uniformly selected in study area. Then, the values of land surface temperature, soil heat flux, sensible heat flux, and latent heat flux of sampling points were obtained through spatial analysis between sampling points data and surface temperature, soil heat flux, sensible heat flux, latent heat flux, respectively. Finally, surface temperature and soil heat flux, sensible heat flux, latent heat flux of each sampling point were compared with scatter diagram respectively, and least square method was used to simulate the function (Fig. 4–6).
The analysis results showed that,

1) Land surface temperature (y) and soil heat flux (x) was positively related, the fitting relationship: $y=0.0052x^2-0.7455x+325.88$, and the correlation coefficient was 0.66. All data distributed in the right part of the function symmetry axis, so land surface temperature was increased smoothly with increasing soil heat flux.

2) Land surface temperature (y) had absolutely linear positive correlation with sensible heat flux (x), the fit function was: $y = 0.1694x + 298.74$, and the correlation coefficient was 1. So land surface temperature was increased linearly with increasing sensible heat flux.

3) Land surface temperature (y) was negatively correlated with latent heat flux (x), the fit function was $y=-8 \times 10^{-5}x^2+0.0684x+286.85$, and the correlation coefficient was 0.55. All data distributed in the right part of the function symmetry axis, so land surface temperature was decreased smoothly with increasing latent heat flux.
6. Conclusion and Discussion

The Nanchong city in Sichuan Province was taken as an example, the correlation between land surface temperature and heat fluxes were researched. The main conclusions are the following:

1) Land surface temperature had positively correlation with both soil heat flux and sensible heat flux, but negatively correlation with latent heat flux.
2) Land Surface temperature was absolutely effected by sensible heat flux.
3) Influence mechanism of heat island effect is that the impervious surface area has higher soil heat flux, lower latent heat flux, because it cuts off the soil-atmosphere heat exchange, its evapotranspiration is small, energy conservation ability is weak, speed of absorbing or releasing energy is high, and higher sensible heat flux, because its roughness is lower, and its albedo is higher, most of solar radiation is reflected to the atmosphere, more heat in life is discharged in addition, and conversely, the natural surface or vegetation cover area has lower soil heat flux, higher latent heat flux, and lower sensible heat flux. So the land surface temperature of impervious surface area is higher, which of natural surface or vegetation cover area is lower.

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