LAND SURFACE TEMPERATURE RETRIEVAL BASED ON BEIJING THERMAL INFRARED DATA OF HJ-1B

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ABSTRACT: Small Satellite for Environment and Disaster Monitoring and Forecasting has characteristics of high temporal resolution and wide swath. This article is based on the modified single-channel method, combined with the HJ-1B multispectral data and MODIS data for land surface temperature retrieval of Beijing. Then the retrieved results are compared with EOS MODIS products and the results illustrate that: a) The land surface temperature is closer to the actual situation; b) HJ-1B land surface temperature is lower than those of EOS MODIS by comparing the retrieved result with the land surface temperature products of EOS MODIS; c) The urban heat island effect in Beijing urban area is very obvious by analysis of the land surface temperatures distribution maps.

1. INTRODUCTION

Land Surface Temperature (LST) is an important geophysical parameter for describing the surface of the natural environment. It is the core parameter of urban climate research and the key index for urban heat island effect. According to the radiative transfer equation, scholars carry out a large number of researches on LST retrieval for different thermal infrared sensors and propose many algorithms for thermal infrared LST retrieval such as the absolute surface temperature algorithm (Malaret,1985), Mono-window algorithm(Qin,2001) and Single-channel algorithm(Jimenez-Munoz, 2003).

The Small Satellite for Environment and Disaster Monitoring and Forecasting was successfully launched on September 6, 2008, The nadir spatial resolution of HJ-1B thermal channel (IRS4) is 300m. The spectral range of IRS4 is 10.5-12.5μm, which is very close to the spectral range of TM6 (10.4-12.5μm). They all have only one thermal infrared band, so the LST retrieval with IRS4 can learn from TM6. However, there are some differences between IRS4 and TM6 thermal infrared spectral band response functions (Figure 1), which produce some impact on algorithm coefficient.

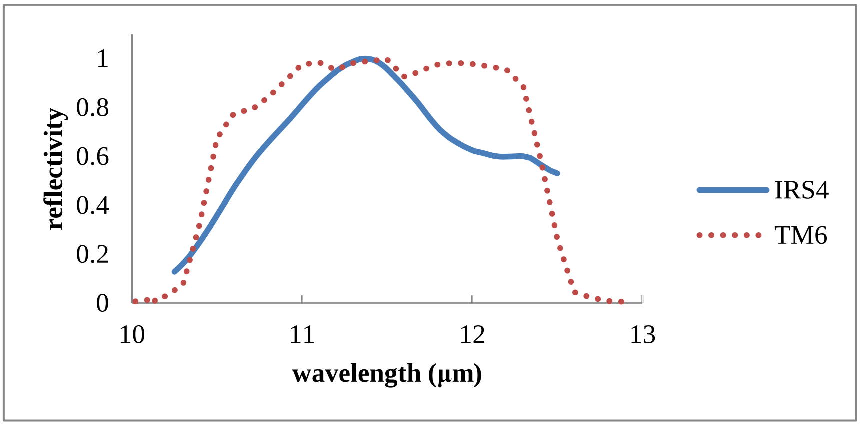

Fig 1: The spectral band response functions of IRS4 and TM6

Recently, scholars have undertaken a number of researches about LST retrieval with HJ-1B IRS4. Duan et al (Duan, 2008) used simulated data of IRS4 to revise the thermal infrared single-channel algorithms for TM6. Li et al (Li, 2010) retrieved LST from IRS4 Data in the main city of Beijing and analyzed the surface temperature distribution. Zhou et al (Zhou, 2011) analyzed the effects of view angle when retrieving LST from IRS4 and improved single-channel algorithm with the view zenith angle-coefficients of atmosphere functions.

Currently, LST retrieval in large area with HJ-1B thermal infrared data is rarely. This paper retrieves LST of Beijing from IRS4 with the modified single-channel algorithm. The MODIS LST product will be adopted as a standard to test the LST retrieval result.

The study site is Beijing, covers Latitude 39°28'-41°05 ' and Longitude 115°25'-117°30'. HJ-1B data was provided by China Centre for Resources Satellite Data and Application. Data transit time on September 11, 2010. The Auxiliary Data include the multispectral data of HJ-1B, MODIS data and LST product.

2. LAND SURFACE TEMPERATURE RETRIEVAL

2.1 Single-Channel Algorithm

Based on the radiative transfer equation, Jimenez-Munoz and Sobrino developed a generalized single-channel method in order to retrieve LST by using the following equation:

$$T_s = \gamma[\varepsilon^{-1}(\psi_1 L_{sensor} + \psi_2) + \psi_3] + \delta \quad (1)$$

$$\gamma = \{\frac{c_2 L_{sensor}}{T_{sensor}}[\frac{\lambda^4}{c_1} L_{sensor} + \lambda^{-1}]\} \quad (2)$$

$$\delta = -\gamma L_{sensor} + T_{sensor} \quad (3)$$

Where L_{sensor} is the at-sensor radiance, T_{sensor} is the at-sensor brightness temperature, λ is the effective wavelength, $c_1 = 1.19104 \times 10^8 W \cdot \mu m^4 \cdot m^{-2} \cdot sr^{-1}$ and $c_2 = 1.43877 \times 10^4 \mu m \cdot K$. The atmospheric functions, ψ_1, ψ_2 and ψ_3 can be obtained as a function of the total atmospheric water vapor content (ω). The atmospheric functions modified by duan et al (Duan,2008) for HJ-1B data based on the spectral band response functions according to the following equations. the effective wavelength of IRS4 is 11.484 μm.

$$\psi_1 = 0.0412\omega^2 - 0.0936\omega + 0.9856 \quad (4)$$

$$\psi_2 = -0.7174\omega^2 - 0.08812\omega - 0.3941 \quad (5)$$

$$\psi_3 = 0.2639\omega^2 + 0.6499\omega + 0.4703 \quad (6)$$

2.2 Image Data Processing

We use the following relation to convert the *DN* value of the raw image to the at-satellite radiance image using absolute calibration coefficients.

$$L = DN / a + L_0 \quad (7)$$

Where *L* is at-satellite radiance, *DN* is the digital number of the raw image, a is the absolute calibration coefficient of the gain equal 59.421, and L_0 is the offset equal 0.42815.

According to Planck function to solve the at-sensor brightness temperature, the equation is as following:

$$T_{sensor} = \frac{c_2}{\lambda \ln\left(\frac{c_1}{L_\lambda \pi \lambda^5 + 1}\right)} \quad (8)$$

Where $c_1 = 3.741775 \times 10^{-22} W \cdot \mu^{-1} \cdot m^3$, $c_2 = 0.0143877 m \cdot K$.

2.3 Estimation of the Total Atmospheric Water Vapor Content

Band 2 and 19 of MODIS data are sensitive to the total atmospheric water vapor content. The atmospheric water vapor content could be retrieved from MODIS data according to the following equation (Yoram.J.K,1992):

$$\omega = [\frac{\alpha - \ln(\frac{\rho_{19}}{\rho_2})}{\beta}]^2 \quad (9)$$

Where α and β are constants, α=0.02，β=0.6321; ρ_{19} and ρ_2 illustrate the ground reflectivity of band 2 and 19 of MODIS data respectively.

2.4 Land surface emissivity estimation from NDVI

The knowledge of land surface emissivity (LSE) is necessary to LST retrieval. A modified approach named the NDVI Thresholds Method (Sobrino,2001) has been used to obtain the emissivity values from the NDVI considering different cases:

(a) NDVI < 0.05, ε=0.793.
(b) NDVI>0.7, ε=0.99.
(c) 0.05⩽NDVI⩽0.7, ε=0.004P_v+0.986

Where P_v is the vegetation proportion obtained according to:

$$P_v = [(NDVI - NDVI_s)/(NDVI_v - NDVI_s)]^2 \quad (10)$$

Where $NDVI_s = 0.5$ and $NDVI_v = 0.2$.

Utilizing the multispectral data of HJ-1B in band 3 and 4 which located in red and near infrared, respectively, the vegetation index is constructed according to the following equation:

$$\mathrm{NDVI} = (\mathrm{Band}_4 - \mathrm{Band}_3)/(\mathrm{Band}_4 + \mathrm{Band}_3) \tag{11}$$

3. RESULTS AND ANALYSIS

3.1 Analyzing the LST Retrieved with HJ-1B Thermal Infrared Data

According to the above illustrated formula and data processing theory, the LST (figure 1) was retrieved from HJ-1B IRS4 data of Beijing by using modified single-channel algorithm. The figure shows the LST distribution in Beijing on the day.

1) LST in the center of Beijing is higher than that in suburban, the distributed tendency of which is reduced gradually outward from the central city. In the central of Beijing, the east side is significantly higher than the west side on LST. Urban construction speeds up causes this area LST to be high; the big area's workshop and the fragmentary factory work also causes this region LST higher. In the nearby suburban counties, the mountainous makes the LST is obviously lower in county.

2) The highest temperature points in Beijing located at steel industry area and the Capital Airport reaches as high as 34℃; The LST of places such as railway station and other airports are more than 30℃; in the places of Information Industry Base, business areas and densely residential areas, the LST is also higher than 30 ℃.

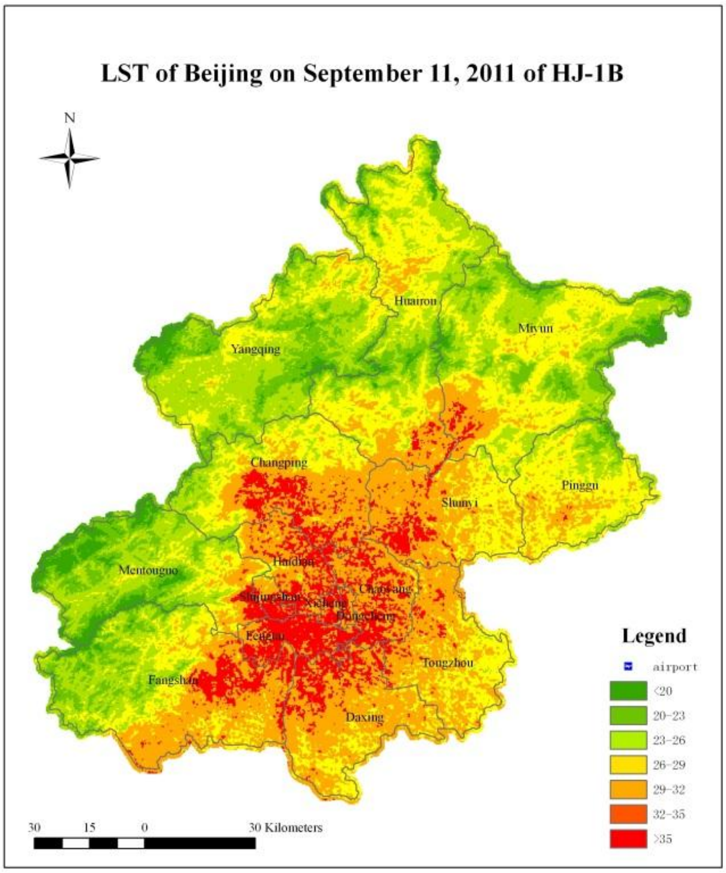

Fig 1: LST retrieval result with HJ-1B thermal infrared data in Beijing

3.2 Comparison with the MODIS LST Product

The best way for validation of LST retrieval accuracy is to use the LST synchronization land surface observations data. But using the archived remote sensing data to retrieve LST, it always lacks of the corresponding observations data of LST for verification. In order to analyze the LST retrieval results for verification, the EOS MODIS LST product on the same day (fig2) are selected compared to HJ-1B, within an accuracy of 1K. The transit time of MODIS data is 11:45 am which is close to that of HJ-1B (11:20 AM). This study verifies the accuracy of the LST retrieval through the feature profiles construction and the typical surface features temperatures statistics.

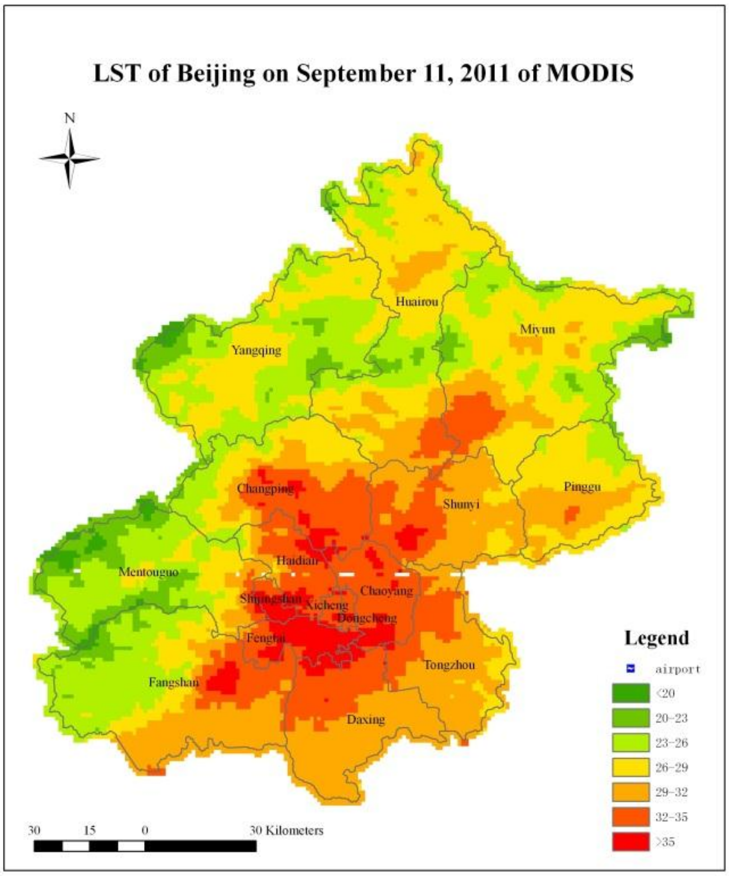

Fig2: MODIS LST Product

The center point of Beijing is set as the origin of coordinates, the feature profiles are selected from northeast southwest (NE-SW) and northwest southeast (NW-SE) direction respectively, to establish rectangular coordinate system in the space (Figure 3). In the NE-SW direction, 76 profiles points are select and the points' number in the NW-SE direction is 42 with 2km intervals. The aim of building a feature profile is to compare the LST retrieval with MODIS LST products.

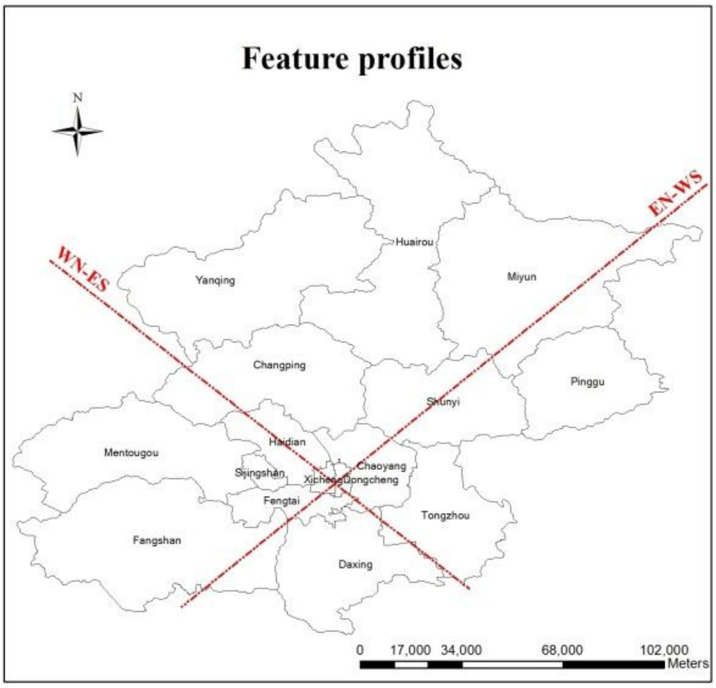

Fig3: Schematic diagram of feature profiles

Through LST extracting from profile points and making the surface temperature change curve, the LST product of MODIS is compared to that retrieved from HJ1-B to analyze their differences in horizontal direction. As the MODIS product's spatial resolution is 1Km and the HJ1-B spatial resolution is 300m and in order to make the temperature results more comparable in different resolutions, the study using the mean value of 3 × 3 center location pixel value of HJ-1B as each profile point for LST extracting. The results are showing in figure 4 and figure 5.

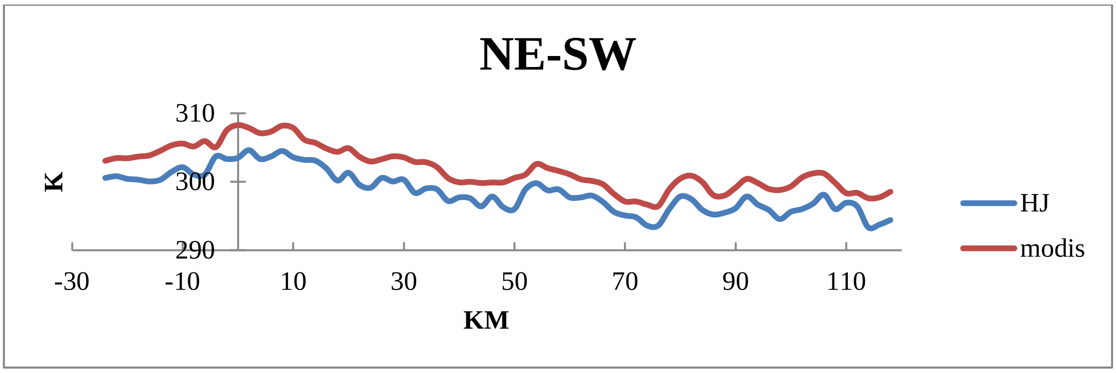

Fig 4: Distribution of LST in NE-SW profile

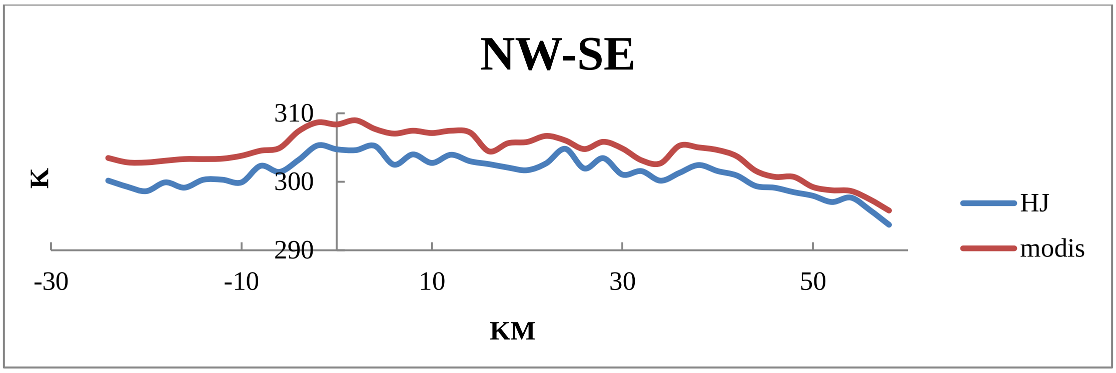

Fig 5: Distribution of LST in NE-SE profile

Figure 4 and Figure 5 show the changes of LST along the different profile directions and the relationship between the MODIS LST products and the retrieved LST of HJ-1B. From the figure, it is easy to find the LST of MODIS product is higher than LST retrieval from HJ-1B. In the NE-SW direction, the maximum difference is 4.87 K as the minimum difference is 1.35 K; In the NW-SE direction, the maximum difference is 4.53 K as the minimum difference is 0.96 K. Along the direction of profile line, the changes of LST with the distance are significant. The contrast of LST between in urban region and suburban region is obvious. The profile points nearby center point is high, the lowers is far away from that region. The main reason is that the region with high urbanization degree mainly located in the center of profile where temperature is higher; the countryside distributes in the urban peripheral located at the profile edge, the temperature is lower. The change tendencies of LST that retrieved from HJ-1B and MODIS LST product in the horizontal direction is consistent. The urban heat island effect is obvious in Beijing.

According to the land use classification map of Beijing, five typical surface features (urban, water, grassland, farmland and forest) are selected for LST statistics. The study chooses the representative features to calculate the average temperature (table 1) of region, such as: city center in urban and suburban counties; major reservoirs and similar big water body etc.

Tab1: The average temperature of typical surface features

	urban		water		grassland		farmland		forest	
	HJ	MODIS	HJ	MODIS	HJ	MODIS	HJ	MODIS	HJ	MODIS
1	301.88	306.16	294.46	297.88	295.88	299.64	299.14	304.34	294.94	298.82
2	302.88	308.26	294.59	298.22	295.87	299.28	299.28	304.20	294.41	297.74
3	304.32	309.64	295.0	299.38	295.33	298.90	299.15	304.66	295.33	298.24
4	303.32	308.54	294.42	298.44	295.33	298.62	298.50	303.18	294.13	297.62
5	302.58	307.06	294.95	298.73	295.47	299.06	298.37	302.46	293.93	297.58

Table 1 shows the LST of MODIS product is higher than the LST retrieved from HJ-1B. The average value of temperature difference in urban is up to 4.94K; which in water is 3.86K, in the grassland is about 3.54K, in the farmland is about 4.88K; in the forest is 3.45K. Linear fitting for the first three sets of data in table 1 between HJ-1B and MODIS (figure 6), Using the last two sets of data in table1 to compute the root-mean-square error, the result is 0.55.

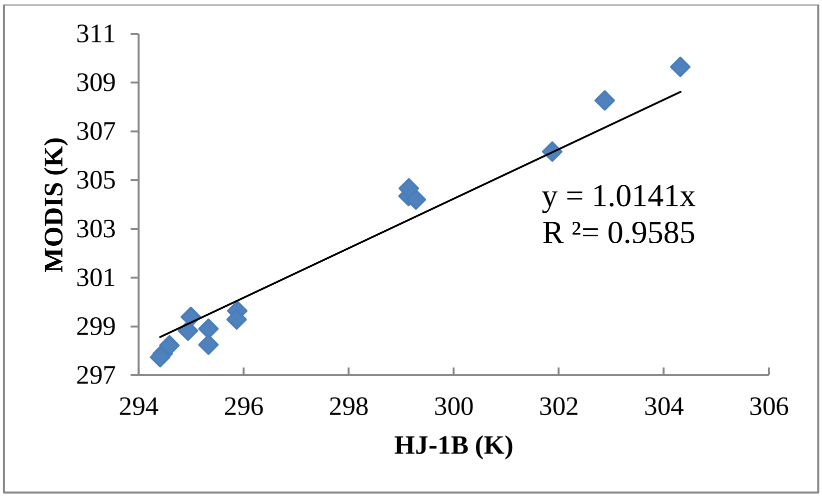

Fig6: The LST regression relationship between HJ-1B and MODIS

4. CONCLUSIONS

Based on above two methods for verifying the LST retrieval, the results illustrate there is a good uniformity between LST retrieved from HJ-1B and the MODIS LST product. Using thermal infrared data of HJ-1B to retrieve LST can get satisfactory accuracy, which suggests its application prospect in monitoring and analysis of urban hot environment. The following reasons may cause the LST of MODIS products is higher than LST retrieved from HJ-1B. (a) The transition time of MODIS is 25 minutes behind that of HJ-1B. (b) The land surface temperature changed quickly especially after 11:00 am. (c) There are scale effects between the two data due to the different spatial resolution.

According to the characteristic of HJ-1B thermal infrared data, this study retrieves the LST of Beijing by the modified single-channel algorithm and verifies the inversion result with MODIS LST product on the same day. We find the inversion result is reliable. The LST distribution tendency shows that there is an urban heat island effect in Beijing. The central city temperature is the highest, to the suburb, the outer suburb area decreases progressively in turn.

REFERENCES:

Duan SB. et al. 2008.Two single-channel algorithms for retrieving land surface temperature from the simulated HJ-1B data. Progress in Nature Science.18(9),pp.1001-1008.

Jimenez-Munoz, J.C., Sobrino J.A., 2003. A generalized single-channel method for retrieving land surface temperature from remote sensing data. Journal of Geophysical. Research. 108(D22),pp. 4688-4696.

Li YF. et al. 2010. Land Surface Temperature Retrieval and Distribution Analysis Using HJ-1B Thermal Infrared Data-In eight districts in downtown Beijing as an example. Journal of Captial Normal University (Natural Science Edition), 31(1), pp.70-75

Malaret,E. et al, 1985. Landsat4 and Landsat5 Thematie Mapper data quality analysis. Photogrammetric Engineering and Remote Sensing, 51, pp.1407-1416

Qin ZH. et al, 2001. Mono-window Algorithm for Retrieve Land Surface Temperature from Landsat TM6 data. Acta Geographica Sinca, 56(4),pp.456-466.

Sobrino, J. A., et al. 2001. A comparative study of land surface emissivity retrieval from NOAA data. Remote Sensing of Environment, 75, pp.256– 266.

Zhou J. et al. 2011. A modified single-channel algorithm for land surface temperature retrieval from HJ-1B satellite data. J. Infrared Millim.Waves. 30(1),pp.61-67