A C++ program for retrieving land surface temperature from the data of Landsat TM/ETM+ band6

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Abstract

A C++ language-based software tool for retrieving land surface temperature (LST) from the data of Landsat TM/ETM+ band6 is developed. It has two main functional modules: (1) Three methods to compute the ground emissivity based on land use/cover classification image, NDVI image and the ratio values of vegetation and bare ground and (2) Converting digital numbers (DNs) from TM/ETM+ band6 to LST. In the software tool, Qin et al.’s mono-window algorithm and Jiménez-Muñoz and Sobrino’s single channel algorithm are programmed to retrieve LST. It will be a useful software tool to study the thermal environment of ground surface or the energy balance between the ground and the bottom atmosphere by using the thermal band of Landsat TM/ETM+.

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1. Introduction

In the recent years, thermal environment has been paid great attention including the greenhouse effect and global warming. It not only refers to the air temperature, but also the land surface temperature (LST). As is well known, the LST has a direct impact on air temperature and it is also one of the key parameters in the physics of land-surface processes on regional and global scales, combining surface–atmosphere interactions and the energy fluxes between the atmosphere and the ground (Wan and Snyder, 1996). LST is required for a wide variety of scientific studies—from climatology to hydrology to ecology and biogeology (Running et al., 1994). As the development of thermal remote sensing technology, the LST over an entire large area could be easily acquired by using the thermal remote sensing technology.

The Landsat Program is the longest running enterprise for acquisition of imagery of the earth from space. The instruments on the Landsat satellites have acquired millions of images that are a unique resource for global change research and applications in agriculture, geology, forestry,
region planning, education and environment. The temporal resolution of the sensor is 16 days. On the descending (N to S) daytime portion of an orbit, the satellite crosses the equator at approximately 10:00 AM local solar time. Landsat TM/ETM+ band 6, with the spatial resolution of 120 × 120 m for TM6 and 60 × 60 m for ETM+ 6, respectively, records the surface radiance in 10.4–12.5 μm spectral range and provides information about radiant values which are determined by temperature and the emissivity of the surface. It is quite suitable to study the thermal environment, especially for an urban area. More information about Landsat program can be found on the web of http://landsat.gsfc.nasa.gov/.

Many studies have been finished by using thermal band of Landsat TM/ETM+ (Aniello et al., 1995; Weng, 2003; Weng et al., 2004; Kato & Yamaguchi, 2005). Additionally, Voogt and Oke (2003) gave a complete review of thermal remote sensing study on urban climates.

As far as the Landsat TM and ETM+ are concerned, three different single-channel methods have been proposed to retrieve LST from their thermal bands. These three methods are: (i) the radiative transfer equation, (ii) Qin et al.’s, (2001) mono-window algorithm, and (iii) Jiménez-Muñoz and Sobrino’s algorithm (Sobrino et al., 2004). For the first method, it needs in situ atmospheric profile launched simultaneously with the satellite passes and it is a big constraint for using it. Usually, the second and third methods are used when the ground truth data is not available.

Although different methods and applications have been discussed, there are still no tools for retrieving LST directly from TM/ETM + band6. In this paper, we developed a software tool for retrieving LST directly from TM/ETM + band6 based on (ii) Qin et al.’s, (2001) mono-window algorithm and (iii) Jiménez-Muñoz and Sobrino’s algorithm. It will be greatly useful and convenient for those who are studying the ground thermal environment and urban heat island effects by using Landsat TM/ETM + band6.

2. Methods to calculate LST

It is well known that any object will emit thermal electromagnetic energy as its temperature is above absolute zero (K). Based on this principle, the signals received by the thermal sensors (TM/ETM + ) can be converted to at-sensor radiance \( L_{\text{sensor}} \) using Eq. (1):

\[
L_{\text{sensor}} = \text{gain} \times \text{DN} + \text{bias},
\]

where \( L_{\text{sensor}} \) is spectral radiance of thermal band in W/(m² sr μm); \( \text{gain} \) is the slope of the radiance/DN conversion function; \( \text{DN} \) is the digital number of a given pixel from a L1G product; \( \text{bias} \) is the intercept of the radiance/DN conversion function (Landsat Project Science Office, 2002). The gain and bias values can be found in header files of TM/ETM + image.

Radiance values from the TM/ETM+ thermal band were then transformed to at-sensor brightness temperature, namely top-of-atmosphere brightness temperature, using thermal calibration constants supplied by the Landsat Project Science Office (2002) according to Eq. (2):

\[
T_{\text{sensor}} = \frac{K_2}{\ln(K_1/L_{\text{sensor}} + 1)},
\]

where \( T_{\text{sensor}} \) is effective at-satellite temperature (brightness temperature) in K. \( K_1 \) and \( K_2 \) are pre-launch calibration constants and they are pre-settled (For Landsat 7 ETM +, \( K_1 = 666.09 \) W/(m² sr μm), and \( K_2 = 1282.71 \) K; for Landsat 5 TM, \( K_1 = 607.76 \) W/(m² sr μm), and \( K_2 = 1260.56 \) K) (Landsat Project Science Office, 2002). Therefore, values of \( K_1 \) and \( K_2 \) are written in the program for the convenience, but the values of bias and gain have to be input manually for ETM+ band6 because their values maybe different for different images (bias and gain values are fixed for TM band6).

The temperature calculated by Eq. (2) is not the actual LST, but the top-of-atmosphere brightness temperature. To obtain a reasonably high quality of LST, four steps of correction process may be required according to Voogt and Oke (2003): (1) spectral radiance conversion to at-sensor brightness temperature; (2) correction for atmospheric absorption and re-emission; (3) correction for surface emissivity; and (4) correction for surface roughness. The first step is just the calculation process of Eq. (2) described above. The second to fourth steps of correction process are usually very complicated. In order to simplify the correction process, Qin et al’s, (2001) mono-window algorithm and Jiménez-Muñoz and Sobrino’s (2003) single-channel algorithm were proposed, respectively.
2.1. Qin et al.'s mono-window algorithm

Qin et al.'s (2001) mono-window algorithm was expressed as follows:

\[ T_s = \frac{a_6(1 - C_6 - D_6) + [b_6(1 - C_6 - D_6) + C_6 + D_6]T_{sensor} - D_6 T_s}{C_6}, \]  

where \( T_s \) is the land surface temperature in K, \( T_{sensor} \) is the brightness temperature in K computed from Landsat TM/ETM+ band6, \( T_a \) is the effective mean atmospheric temperature (K), \( a_6 \) and \( b_6 \) are constants with values of \(-67.355351\) for \( a_6 \) and \( 0.458606 \) for \( b_6 \) when the LST is between 273.5 and 343.5 K. \( C_6 \) and \( D_6 \) can be calculated by the following equations:

\[ C_6 = \varepsilon \tau_6, \]  
\[ D_6 = (1 - \tau_6)[1 + (1 - \varepsilon)\tau_6] \]  

where \( \varepsilon \) is the ground surface emissivity and \( \tau_6 \) is the atmospheric transmittance. \( T_a, \varepsilon, \tau_6 \) are the three parameters needed to convert the brightness temperature to LST. According to the work of Qin et al. (2001, 2003), \( \tau_6 \) could be estimated by atmospheric water content and \( T_a \) could be calculated by the linear equations corresponding to the four standard atmospheres (Eq. (6c)):

\[ T_a = 25.9396 + 0.88045T_0 \] (For USA 1976),  
\[ T_a = 17.9769 + 0.91715T_0 \] (For tropical),  
\[ T_a = 16.0110 + 0.92621T_0 \] (For mid-latitude summer),  
\[ T_a = 19.2704 + 0.91118T_0 \] (For mid-latitude winter),  

where \( T_a \) is the effective mean atmospheric temperature; \( T_0 \) is the near-surface air temperature.

2.2. Jiménez-Muñoz and Sobrino’s single-channel algorithm

In Jiménez-Muñoz and Sobrino’s (2003) single-channel algorithm, the LST is given by the following equation:

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

with

\[ \gamma = \left( \frac{c^2 L_{sensor}}{T_{sensor}^2} \left[ \frac{\lambda^4}{c_1} L_{sensor} + \lambda^{-4} \right] \right)^{-1}, \]  

\[ \delta = -\gamma L_{sensor} + T_{sensor}, \]  

where \( T_s \) stands for the land surface temperature in K; \( \varepsilon \) is the ground surface emissivity; \( L_{sensor} \) is the at-sensor radiance in W/(m\(^2\)sr\(\mu m\)), \( T_{sensor} \) is the at-sensor brightness temperature in K, \( \lambda \) is the effective wavelength in \(\mu m\), \( c_1 = 1.19104 \times 10^8 \) W\(m^{-2}\)sr\(^{-1}\)\(\mu m^{-1}\) and \( c^2 = 14387.7 \mu m \) K. The atmospheric parameters of \( \psi_1, \psi_2 \) and \( \psi_3 \) can be obtained as functions of the total atmospheric water vapor content (w) according to the following equations particularized for TM/ETM + 6 data:

\[ \psi_1 = 0.14714w^2 - 0.15583w + 1.1234, \]  
\[ \psi_2 = -1.1836w^2 - 0.37607w - 0.52894, \]  
\[ \psi_3 = -0.04554w^2 + 1.8719w - 0.39071. \]  

2.3. Emissivity preparation

From above, it can be found that the ground emissivity is essential to both algorithms. In this paper, three methods are provided to calculate the emissivity and they are: (1) method based on classification image; (2) method based on NDVI image and (3) method based on the ratio values of vegetation and bare ground.

2.3.1. Method based on classification image

This method is the simplest method, which refers to the land use/cover information and assigns an emissivity value to every land category according to its class ID value. The classification image and emissivity values for every land category are the key to this method. For landsat TM/ETM+ data, the classification image is generally created by image classification algorithm like Maximum Likelihood or K-mean’s method using the bands except band6. The accuracy of classification image would have a distinct impact on the final LST results. Approaches to acquire classification image from TM/ETM + data can recur to image processing software such as RSI ENVITM (http://www.rsinc.com).

The determination of emissivity for every land category is very critical in calculating the LST. For the Landsat ETM+ data, one pixel covers an area of \(30 \times 30\) m on the ground, which is probably comprised of several land objects. Therefore, the emissivity from a pixel is determined by land objects and their emitting directions (Dozier and Warren, 1982). Different techniques have been designed to estimate the emissivities of ground objects to
mitigate the effect of emissivity on estimated LST (e.g., Gillespie et al., 1998; Watson, 1992; Snyder et al., 1998). It seems more appropriate to correct the effect of emissivity on LST derived from thermal remote sensing image by assigning an emissivity value to each land cover category of the classification image (Snyder et al., 1998). According to the previous studies, emissivity value of every land category ranges from 0.950 to 0.99 (Lillesand and Kiefer, 1994; Nichol, 1994; Snyder et al., 1998).

2.3.2. Method based on NDVI image

According to Van de Griend and Owe’s (1993) study, the relationship between emissivity and NDVI can be expressed by the following equation (Eq. (11)) when the NDVI value ranges from 0.157 to 0.727.

\[
\varepsilon = 1.0094 + 0.047 \times \ln(NDVI).
\]  

(11)

For the area that the NDVI value is out of the range (0.157–0.727), it is divided into five ranges and their corresponding emissivity values could be input manually through the program interface.

2.3.3. Method based on the ratio of vegetation and bare ground

This method was proposed by Valor and Caselles (1996). For Landsat TM/ETM+ thermal band, the ground emissivity can be calculated by following equation:

\[
\varepsilon = \varepsilon_v P_v + \varepsilon_g (1 - P_v) + 4 \langle d \varepsilon \rangle P_v (1 - P_v),
\]  

(12)

where \( \varepsilon \) stands for ground emissivity; \( \varepsilon_v \) is emissivity of pure vegetation cover area; \( \varepsilon_g \) is emissivity of pure bare ground area; \( \langle d \varepsilon \rangle \) is revised parameter averagely 0.01; \( P_v \) is the percentage of vegetation in one pixel and can be simply calculated by Eq. (13):

\[
P_v = \frac{NDVI - NDVI_g}{NDVI_v - NDVI_g},
\]  

(13)

where \( NDVI_g \) stands for the NDVI value of pure bare ground area; \( NDVI_v \) stands for the NDVI value of pure vegetation cover area.

3. Program and guidance of the software tool

The program was developed by C++ language and can be run on Microsoft Windows™ systems with a friendly interface (available on the website of http://www.gig.ac.cn/zjq/LST.htm for download). There are three main menu items: (i) NDVI calculation; (ii) Emissivity preparation and (iii) LST calculation. Fig. 1 is the flowchart of the software tool. All the parameters used in the program can be directly input through the interface.

3.1. NDVI calculation

This is a small function of LST software tool, which can be run from the menu of NDVI calculation. For Landsat TM/ETM+, the NDVI is calculated by the following equation:

\[
NDVI = \frac{(\text{band4} - \text{band3})}{(\text{band4} + \text{band3})}.
\]  

(14)

In the program, about three items need to be filled in including (i) band3 image file; (ii) band4 image
file and (iii) NDVI output path and filename. Usually, the band3 and band4 image files must be co-registered so that they have the same size and cover the same area, otherwise, errors may occur. The NDVI output file, with the file type in raw and data format in floating point type, has the same line and pixel numbers with the input band3 and band4 images.

3.2. Emissivity preparation

This program item includes three sub-items corresponding to three methods for emissivity calculation described above.

3.2.1. Based on classification image

Fig. 2(a) shows the interface of using classification file. The command to run this application appears in the emissivity preparation menu. The first step is to input the classification file name. The input classification file should be in raw format with data type of byte. At most fourteen land classes can be used, which is enough for the spatial resolution of TM/ETM+ data. For each land class, there is a corresponding class value (or class ID value). The emissivity is assigned to one class just according to its class ID value. The emissivity of each land class can be input manually on the application interface. If the class number is less than fourteen, just input the emissivity values corresponding to the class values appearing in the classification file and leave alone the others. Finally, input the saving location and resultant emissivity filename.

3.2.2. Based on NDVI image

Fig. 2(b) is the application interface of calculating emissivity based on NDVI. Totally, three steps are needed to run this application. The first step is to input the NDVI file, which may be just the result calculated from Section 3.1. The input NDVI file should be in raw format with data type in floating point. In the second step, the NDVI is divided into six ranges with each range user-defined. When the NDVI value is between 0.157 and 0.727, the emissivity is computed by Eq. (11). For the other NDVI ranges, fixed emissivity values are assigned to

![Fig. 2. Applications’ interface for calculating emissivity: (a) Using classification file; (b) using NDVI file.](image-url)
them. According to our experience and statistical characteristics of different images, the land use is mostly like the water or urban used land while NDVI is less than 0.157, and it is absolutely the vegetation land while NDVI is larger than 0.727. Therefore, just fill in the blanks with emissivity values corresponding to NDVI ranges. The last step is to fill in the output filename. The output emissivity file format is raw and data type is floating point. It has the same pixel and line numbers with the NDVI file.

3.2.3. Based on the ratio of vegetation and bare ground

The application interface of calculating emissivity based on the ratio value of vegetation and bare ground looks like Fig. 2(b). Four steps are needed to perform this application with first three steps similar to the method based on NDVI. The difference is that the determination of NDVI ranges. If a pixel’s NDVI value is between that of bare ground and full vegetation cover area, then Eq. (12) is used to compute the emissivity. The final fourth step is to input three necessary parameters used in this method: (1) emissivity value of full vegetation cover area; (2) emissivity value of bare ground area and revised parameter \( \langle d e \rangle \).

3.3. LST calculation

In this part, two methods of calculating the land surface temperature are programmed, including the Qin et al.’s mono-window algorithm (Fig. 3(a)) and Jiménez-Muñoz and Sobrino’s algorithm (Fig. 3(b)). These two algorithms have five similar steps to run them.

The first step is to select the satellite sensor type, Landsat 5 TM or Landsat 7 ETM+. For the Landsat 5 TM6, the values of bias and gain are 1.2378 and 0.055158, respectively, and they are fixed (Chander and Markham, 2003). If Landsat 7 ETM+ is selected, the bias and gain values found
in the ETM + image header files should be input manually.

The second step is to input the parameters about the atmospheric conditions. In Qin et al.’s monowindow algorithm, atmospheric transmittance and effective mean atmospheric temperature are needed. In Jiménez-Muñoz and Sobrino’s algorithm, the parameter needed is total atmospheric water vapor content \((\omega)\) in g/cm\(^2\).

From the third to the fifth steps are just the inputs of filenames. The third one is the TM/ETM + band6 file with data type in byte. The fourth one is the emissivity file calculated from Section 3.2. The fifth step is to input the calculated resultant LST filename and path. The resultant LST file is in raw format with data type in floating point and has the same line and pixel sizes with the input emissivity file.

For the convenience of reading/writing file, all the file formats used in the program are in raw format. In addition, the lines and pixels per line of all image files used in the program, including band3, band4, NDVI, emissivity and LST files, are same. All files can be opened by image processing software such as RSI ENVI\(^TM\) after input image lines and pixels per line correctly.

### 4. Example

#### 4.1. Data preparation

In this section, an example of Guangzhou city, located in Guangdong province, China, is provided to show the usage of the software. The example data is subsetted from one scene (path/row: 122/44) of Landsat 7 ETM + image dated on 10 January 2003. A systematical geometric and radiometric correction has already been performed to the image data to a quality level of 1G before delivery. All bands including the thermal band were re-sampled using the nearest neighbor algorithm with a pixel size of 30 \(\times\) 30 m. The resultant RMSE was found to be less than 0.5 pixels. The example data can be downloaded from the website of http://www.gig.ac.cn/zjq/LST.htm. Table 1 lists files used in the example.

#### 4.2. \(LST\) calculation

After finishing the preparation of TM/ETM + data and atmospheric parameters in the last section, there are still 3 steps to calculate \(LST\) from Landsat TM/ETM + data:

The first step is to calculate NDVI from band3 and band4 according to the description in Section 3.1. The resultant NDVI output file was named as

<table>
<thead>
<tr>
<th>File name</th>
<th>File format</th>
<th>Data type</th>
<th>File size</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band3</td>
<td>raw</td>
<td>Byte</td>
<td>1543 (\times) 1536</td>
<td>Input file for TM/ETM + band 3</td>
</tr>
<tr>
<td>Band3.hdr</td>
<td>hdr</td>
<td>Txt</td>
<td>—</td>
<td>Description for band3 file</td>
</tr>
<tr>
<td>Band4</td>
<td>raw</td>
<td>Byte</td>
<td>1543 (\times) 1536</td>
<td>Input file for TM/ETM + band 4</td>
</tr>
<tr>
<td>Band4.hdr</td>
<td>hdr</td>
<td>Txt</td>
<td>—</td>
<td>Description for band4 file</td>
</tr>
<tr>
<td>Band6</td>
<td>raw</td>
<td>Byte</td>
<td>1543 (\times) 1536</td>
<td>Input file for TM/ETM + band 6</td>
</tr>
<tr>
<td>Band6.hdr</td>
<td>hdr</td>
<td>Txt</td>
<td>—</td>
<td>Description for band6 file</td>
</tr>
<tr>
<td>Ndvi</td>
<td>raw</td>
<td>Float</td>
<td>1543 (\times) 1536</td>
<td>NDVI calculated from band3 and band4</td>
</tr>
<tr>
<td>Ndvi.hdr</td>
<td>hdr</td>
<td>Txt</td>
<td>—</td>
<td>Description for Ndvi file</td>
</tr>
<tr>
<td>Emissivity</td>
<td>raw</td>
<td>Float</td>
<td>1543 (\times) 1536</td>
<td>Emissivity computed from NDVI and further used as input file when compute LST</td>
</tr>
<tr>
<td>Emissivity.hdr</td>
<td>hdr</td>
<td>Txt</td>
<td>—</td>
<td>Description for emissivity file</td>
</tr>
<tr>
<td>LST-Qin</td>
<td>raw</td>
<td>Float</td>
<td>1543 (\times) 1536</td>
<td>Output LST file used Qins’ mono-window algorithm</td>
</tr>
<tr>
<td>LST-Qin.hdr</td>
<td>hdr</td>
<td>Txt</td>
<td>—</td>
<td>Description for the output file of LST</td>
</tr>
<tr>
<td>LST-s-channel</td>
<td>raw</td>
<td>Float</td>
<td>1543 (\times) 1536</td>
<td>Output LST file used single channel algorithm</td>
</tr>
<tr>
<td>LST-s-channel.hdr</td>
<td>hdr</td>
<td>Txt</td>
<td>—</td>
<td>Description for the output file of LST-s-channel</td>
</tr>
<tr>
<td>Parameter</td>
<td>txt</td>
<td>txt</td>
<td>—</td>
<td>Parameters used in the example</td>
</tr>
</tbody>
</table>
NDVI.raw, which could be found in the example data.

The second step is to calculate the ground emissivity. Totally three methods are programmed in the software, but only the third method based on the ratio of vegetation and bare ground was introduced in this example. However, a classification image classified from ETM+ bands 1, 4 and 7 by using a supervised method with the maximum likelihood algorithm was still provided in the example data, which could be tested to calculate the emissivity by users manually. In Valor and Caselles’ work (1996), analysis was performed to the methods of calculating emissivity based on NDVI and the ratio value of vegetation and bare ground. It seems that the last method based on the ratio of vegetation and bare ground was more precise. With the help of RSI ENVI™ software, the NDVI was divided into 4 ranges, with emissivity corresponding to each range listed in Table 2. The resultant output file was named as emissivity.raw in the example data.

The final step is retrieving land surface temperature from band6 with the atmospheric conditions and emissivity file as input parameters. For both algorithms, the first step is to select the sensor type. In the example, Landsat ETM+ was selected with bias value $-0.0670866$ and gains value $0.0670866$.

If Qin et al.’s mono-window algorithm is chosen, the atmospheric transmittance and effective atmospheric temperature have to be input. The effective mean atmospheric temperature ($T_a$) and atmospheric transmittance ($\tau_a$) were estimated as 286 K and 0.65, respectively according to the weather conditions from the local meteorological observatories. The emissivity file needed in this application was just the output file calculated above. The band6 file is the pre-subset file that has the same pixel numbers with emissivity file. After inputting all the necessary parameters on the application interface, the program can be run. The file named as LST-Qin.raw in the example is the LST result computed from Qin et al.’s mono-window algorithm.

If Jiménez-Muñoz and Sobrino’s algorithm is chosen, the total atmospheric water vapor should be input and the process is similar to Qin et al.’s mono-window algorithm. According to the steps described in Section 3.3, the final LST will be calculated and the temperature result will be stored in the output file. The final output LST file has the same pixel numbers with NDVI and band6 files. Like the emissivity file, the file format of LST is also in raw format and the data type is floating point. The file named as LST-s-channel.raw in the example is the LST result computed from Jiménez-Muñoz and Sobrino’s algorithm.

According to the results computed from the program, the temperature error was shown about 0.5–1.5 K for Qin et al.’s mono-window algorithm and 0.7–1.5 K for Jiménez-Muñoz and Sobrino’s algorithm. Because we only have the actual ground surface temperature of one station, the validation of computed LST is limited to some extent. However, the result still showed the applicability of the two algorithms. More validation work would be found in the article “Land surface temperature retrieval from LANDAT TM5” (Sobrino et al., 2004).

5. Conclusion

A LST software tool is developed and it is very helpful for those who study the thermal environment of ground surface or the energy balance between the ground and the bottom atmosphere by using the thermal band of Landsat TM/ETM+ data. This software tool provides two methods to retrieve LST from TM/ETM+ band6, which are (i) Qin et al.’s mono-window algorithm and (ii) Jiménez-Muñoz and Sobrino’s algorithm. The precision of the LST calculated by this software tool is following the algorithms and the parameters used in the program. In addition, an option to calculate
NDVI and three methods to calculate emissivity are also integrated in the software tool for convenience. As for the three methods of calculating emissivity, the third method based on the ratio value of vegetation and bare ground is recommended. The second method based on NDVI may need to meet some specific conditions (Valor and Caselles, 1996). There is a precondition to use the first method based on classification that the user has to acquire a classification image and know emissivity values for every land use category. For the comparison of (i) Qin et al.’s mono-window algorithm and (ii) Jiménez-Muñoz and Sobrino’s algorithm, it can be found in the work of Sobrino et al. (2004). With the aid of radiosounding data, better results are obtained with the Qin et al.’s mono-window algorithm, but the Jiménez-Muñoz and Sobrino’s algorithm seems to improve the results in particular situation (Sobrino et al., 2004).

There still exist constraints while using the LST software. Firstly, the input and output files are all in raw format. The user has to know the image pixels and lines as well as the data type, so that they can be opened by other image processing software. If the offset (head size) of data files is zero like in formats opened by other image processing software, the software tool can also be opened by RSI ENVI™ or ER-Mapper™ after the header information is input. On the other hand, some necessary atmospheric parameters need to be prepared prior to the calculation. The acquisition of atmospheric data, especially at the time when the satellite passes, is essential to the retrieval of LST. Usually, there are three methods: (i) Measuring the temperatures and water vapor content along traverses with thermometers mounted on automobiles; (ii) Collecting atmospheric data from weather stations; (iii) Download from the websites. Taking China for example, there is an online climate data center (CDC) at http://cdc.cma.gov.cn/english/index.jsp. More advantages and functions would be expected in the future version of LST software tool.

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