EVALUATION OF MODIS AND NCEP ATMOSPHERIC PRODUCTS FOR
LAND SURFACE TEMPERATURE RETRIEVAL FROM HJ-1B IRS THERMAL
INFRARED DATA WITH GROUND MEASUREMENTS

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ABSTRACT
In this paper, two atmospheric profile sources were assessed for land surface temperature retrieval purposes. One is the MODIS atmospheric profiles product (MOD07), and the other is the National Center for Environmental Prediction (NCEP) operational global analysis data. Atmospheric profiles were used as the input to the MODTRAN4 radiative transfer model to calculate atmospheric parameters involved in atmospheric correction with the aim of retrieving land surface temperature (LST) in the case of the TIR domain. The LST retrievals from the HJ-1B IRS data were compared with ground measured temperatures obtained from a series of field campaigns in Hebei province, China, from May to September 2010. Ground measurements were performed over four land cover types: bare soil, full-cover wheat, full-cover corn and water surface. Six days of measurements over the water surface and three days over land were collected. The results indicate that the LST derived from HJ-1B IRS data using the NCEP and MOD07 profiles both showed good agreement with the ground LSTs, with Root Mean Square Error (RMSE) of 1.19 and 1.51 K for NCEP and MOD07, respectively. The results presented in this paper show that the MODIS and NCEP atmospheric profiles are useful for accurate atmospheric correction in the TIR domain when local soundings are not available. In particular, the NCEP profile provides higher accuracy, whereas the MOD07 profile provides a higher spatial resolution.

Index Terms— land surface temperature, NCEP, MOD07, ground measurements, HJ-1B IRS,

1. INTRODUCTION
Land surface temperature (LST) is an important parameter of land surface energy balance and climate change research. To retrieve accurate LST from remote sensing data for Earth observation applications, the atmospheric effects must be corrected in advance. Therefore, an accurate radiative transfer model (RTM) such as MODTRAN4, and the atmospheric profiles must be acquired. The atmospheric profiles can usually be obtained by launching an atmospheric sounding near the time of sensor overpass. However, local soundings are not available in most realistic conditions. Therefore, other sources of atmospheric profiles should be used instead of sounding profiles. Currently, the possible sources of atmospheric profiles can be obtained from satellite sounders or from the output of meteorological forecasting models, such as the National Centers for Environmental Prediction (NCEP) Global Data Assimilation System product.

NCEP profiles were first used in the standard atmospheric correction (AC) for ASTER thermal infrared (TIR) data to obtain the land-leaving radiance [1]. Then, NCEP profiles were gradually used for ACs of different satellite data, such as MODIS and Landsat TM/ETM+. Barsi et al. [2] developed a web-based atmospheric correction tool (ACT) for Landsat TM/ETM+ thermal band data. Barsi et al. [2] and Coll et al. [3] have validated that this web-based ACT can provide Land Surface Temperature (LST) estimates within an accuracy of ±1 K for water surface and full-cover rice areas. Elicott et al. [4] developed a parametric model for atmospheric correction in TIR for MODIS data, and the inputs of this model are the NCEP profiles. Li et al. [5] adapted this parametric model to Chinese HJ-1B Infrared Scanner (IRS) data, and they used NCEP profiles for retrieving LST from IRS data. Thus, NCEP profiles have already been used in many studies. They found that the different sources of profiles are useful for accurate LST retrieval when the local soundings are not available.

MOD07 is the existing atmospheric profile product with the highest spatial resolution, but its use and validation have been very limited from 2000 to the present. Therefore, it is necessary to assess the accuracy of MOD07 profiles for LST retrieval. The objective of this paper is to assess the accuracy of atmospheric profiles extracted from...
MOD07 and NCEP products for LST retrieval from HJ-1B Infrared Scanner (IRS) data with ground measurements.

2. METHODOLOGY

2.1 Theoretical basis for LST retrieval in the TIR

The satellite imagery used in this paper is the HJ-1B IRS data [5]. The HJ-1B satellite is equipped with two CCD cameras and one infrared scanner (IRS), which was launched on September 9, 2008. The IRS has four bands (band 1 0.75-1.10 µm, band 2 1.55-1.75 µm, MIR band 3 3.50-3.90 µm, band 4 10.5-12.5 µm) with 720 km swath. It scans ±30° from nadir and the spatial resolution for band1-3 is 150 m and 300 m for band4.

The most appropriate method to retrieve LST from single-channel thermal data, as is the case of HJ-1B/IRS, is by inversion of the radiative transfer equation (RTE) according to the following expression:

\[ B_i(T_s) = \frac{L_i^{sen} - L_i^{\uparrow}}{\tau_i e_i} - \frac{1 - e_i}{e_i} L_i^{\downarrow} \]  

where \( L_i^{sen} \) is at-sensor radiance of channel i, \( T_s \) is the land surface temperature, \( B_i(T_s) \) is the blackbody radiance of channel i, \( \tau_i \) and \( e_i \) are the atmospheric transmittance and land surface emissivity of channel i, and the \( L_i^{\uparrow} \) and \( L_i^{\downarrow} \) are the atmospheric upwelling and downwelling radiance of channel i, respectively, \( c_1 \) and \( c_2 \) are the Planck’s radiation constants, with values of 1.19104×10^8 m^4·sr^−1 and 14387.7 mK, respectively. \( \lambda \) is wavelength.

The use of the central wavelength value in Eq. (2) for LST inversion introduces some error in \( T_s \) because the sensor has a certain channel width (referred as bandpass effects). To reduce these errors, we adapted a quadratic approximation for the Planck function.

Taking into account the spectral response function of HJ-1B IRS thermal channel, the integrated channel radiance was calculated by Eq.(3) between 260 and 340 K in step of 1 K.

\[ B_i(T_s) = \frac{\int_{\lambda_1}^{\lambda_2} B_i(T_s) f(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} f(\lambda) d\lambda} \]  

where B is the Planck function, \( T_i \) is the land surface temperature in channel i, \( f(\lambda) \) is the spectral response function, \( \lambda_1 \) and \( \lambda_2 \) are the lower and upper wavelength boundaries.

A quadric expression (Eq.4) was built between the channel radiance and temperature with \( R^2=1 \).

\[ B_i(T_s) = 0.0004986T_s^2 - 0.1694T_s + 15.14 \]  

\( T_s \) can be finally inverted by solving Eq.(4):

\[ T_s = \frac{0.1694 + \sqrt{0.1694^2 - 4 \times 0.0004986 \times [15.14 - B_i(T_s)]}}{2 	imes 0.0004986} \]  

2.2 Atmospheric profiles

In this section, we will provide a brief description of the two atmospheric profile sources used in this paper. First is the NCEP profile at a one degree spatial resolution, and second is the MODIS MOD07 product at a 5 km spatial resolution. The atmospheric profiles extracted from the two sources were converted into the MODTRAN4 format to compute three atmospheric parameters (transmittance, upwelling and downwelling radiance). Minor atmospheric constituents were assigned to the mid-latitude summer (MLS) standard atmosphere included in MODTRAN4, assumed to be representative of atmospheric conditions from May to September in China in this study.

2.2.1 NCEP profiles

The NCEP data used in this study are NCEP final operational global analysis data in the GRIB1 format, downloaded from the website http://dss.ucar.edu/datasets/ds083.2. The data are on a 1°×1° longitude/latitude grid and generated globally every 6 hours (0:00, 06:00, 12:00, 18:00 UTC). The extracted atmospheric profiles have 26 mandatory levels from 1000 mb to 10 mb; other vertical atmospheric parameters include geopotential height, air temperature and relative humidity.

We followed the method proposed by Barsi et al. [5] when extracting profiles from NCEP data. The surface elevation was also considered. First, the profiles are extracted from the four grid corners surrounding a specific location. The four corner profiles were interpolated for each time, and then overpass time profiles were interpolated, resulting in a single profile according to the latitude and longitude of the location. After that, the profile was linearly interpolated according to the elevation of the location. If the surface elevation of the given location is lower than the altitude of the first level (1000 mb), the elevation interpolation was not performed. The overpass time of the HJ-1B satellite in our study area is approximately 03:00 UTC, and thus, the NCEP data at 0:00 and 06:00 UTC are used. The interpolation in time and space is linear.

2.2.2 MOD07 profiles

In this study, we will only use the MOD07 products collected from the Terra platform because its overpass time is close to that of HJ-1B. MOD07 consists of several parameters, which include total ozone burden, atmospheric stability, temperature and moisture profiles, and atmospheric water vapor. All of these parameters are produced day and night at a 5×5 1-km pixel resolution when at least 9 observations are cloud-free, providing a
total of 20 atmospheric levels from 1000 hPa to 5 hPa. Atmospheric profiles were extracted for a single pixel centered at the latitude and longitude of our ground measurement sites. For a given pixel, values of air temperature, dew point temperature and geopotential height were extracted from MOD07 for the 20 nominal pressure levels.

2.3 Ground measurements and satellite data
To assess the accuracy of the two sources of atmospheric profiles for retrieving LST from HJ-1B IRS TIR data, we carried out a series of ground measurements in Hebei province, China, from May to September, 2010 [6]. Two field sites were chosen, one located in Huailai county (41°21’N, 115°46’E), and the other located in Baoding city (38°42’N, 115°23’E), the altitudes of these two sites are 480 m and 30 m, respectively.

Ground measurements were performed over four land cover types: bare soil, full-cover wheat, full-cover corn and water surface. There is a large lake in the Huailai site (Guanting Lake), so a temporary moored self-made buoy was constructed to measure the water surface skin temperature. A CAMPBELL SI-111 precision infrared radiometer is installed on the buoy, which is approximately 1.5 m above the water surface. The absolute accuracy of the radiometer is ±0.2 ºC. Measurements of the skin temperature were made every five seconds, and the data were transmitted through a wireless sensor network. Six days of measurements over the water surface and three days of ground measurements over land were collected. For the ground measurements over land, the ground temperatures were measured by person with several TIR radiometers(8-14 μm). The instruments include two FLUKE 63/66 radiometers, two RAYTEK ST60 radiometers, and three domestic IRTA-301AL (http://www.irtc.com.cn/infra.htm) precision infrared radiometers. All the radiometers were calibrated after each field campaign using a MIKRON M340 calibration blackbody.

The Huailai and Baoding sites are very flat. Two points of ground measurements for bare soil and three points for corn were obtained in the Huailai site on May 1, 2010, and September 22, 2010, respectively. Only one point of measurement for wheat was obtained at the Baoding site on May 13, 2010. The distance between the different points is more than 400 m, which is larger than 1 pixel size. During the field campaigns, the radiometers were carried back and forth along transects approximately 50 m long, observing the surface at view angles close to the nadir. The field of view of the radiometers was 30-50 cm on the soil/crop surface. Measurements were made at a rate of more than 20 per minute. The data were collected during periods of 15-20 minutes centered at the satellite overpass time. We recorded the time of the measurements and the corresponding radiometric temperatures every minute. With these data, we obtained the ground LSTs to be compared with the satellite-derived LSTs.

We have only considered temperatures measured within 2 minutes around the satellite overpass time. These measured radiometric temperatures were corrected for emissivity and the downward sky irradiance effect, and were then compared with the satellite-derived LSTs. These data were averaged for each point, and the standard deviation was also calculated.

3. RESULTS
In order to assess the accuracy of these two sources of atmospheric profiles for LST retrieval from the HJ-1B IRS TIR data, Eqs. (1) and (5) were used to derive the LST from IRS TIR data.

For the land surface emissivity of HJ-1B IRS channel 4, typical emissivity values of land surface were adopted for LST estimation: 0.97 for bare soil, 0.986 for full-cover vegetation (wheat and corn) and 0.99 for water surface. In order to reduce the error caused by image geometric registration or surface heterogeneity, we also calculated the mean value of 3×3 pixels centered on the measured point. There are two and three points of measurements on May 01, 2010 and September 20, 2010, respectively. The results of the comparison between the ground LSTs and the HJ-1B IRS LSTs derived from the two sources of atmospheric profiles are shown in Table 1.

The LST results derived from the two profiles both showed good agreement with the ground LSTs, but the NCEP profile was more accurate. The NCEP profiles have an average bias of 0.14 K and an RMSE of 1.19 K for the 1-pixel case. The MOD07 profiles have an average bias of -0.05 K and an RMSE of 1.51 K. The low RMSE results indicate that the NCEP and MOD07 profiles are both valid for retrieving LSTs from IRS TIR data in the validation site. The 3×3 pixel average LSTs also agree well with the ground LSTs, and there are no large differences with the 1-pixel results. This result indicates that the validation sites are homogeneous at the 300m scale and can be used for HJ-1B IRS LST validation in the future.

It can be observed that the worst results were obtained for bare soil. The differences were 2.38 K and 3.02 K for the NCEP and MOD07 profiles for point 2, respectively. Due to the lack of atmospheric information of the lower atmosphere, the MOD07 profiles achieved poor results, and the water surface achieved the best results. All the differences were under 1 K except the result from August 14, 2010 for the NCEP profile, whereas the differences for MOD07 were all above 1 K, except for the result of September 14, 2010. This result indicates that the NCEP profiles have higher accuracy than the MOD07 profiles for LST retrieval from IRS data. The vegetation also obtained good results and were all below 2 K.
4. CONCLUSION

In this paper, the accuracy of two atmospheric profile sources for deriving LSTs from HJ-1B IRS TIR data were assessed. The results indicate that the LST derived from the HJ-1B IRS data using the MOD07 and NCEP profiles both showed good agreement with the ground LSTs, but the NCEP profiles achieved higher accuracy than the MOD07 profiles. The main advantage of the MOD07 product is its high spatial resolution (5 km), and the MOD07 product will be widely used in the future. Therefore, it can be concluded that these two atmospheric profile sources are both useful for accurate atmospheric correction in the TIR domain when local soundings are not available, particularly for sensors with only one thermal channel. The combination of these two data for profile extraction should be considered in the future, where MOD07 provides the spatial resolution and NCEP provides the accuracy.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Table 1. Comparison of ground and IRS LSTs derived from two sources of profiles

<table>
<thead>
<tr>
<th>Case</th>
<th>Date</th>
<th>Land cover type</th>
<th>Ground LST±σ (K)</th>
<th>IRS LST (K)</th>
<th>IRS-Ground LST (K)</th>
<th>IRS LST (K)</th>
<th>IRS-Ground LST (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>05/01/2010</td>
<td>Soil 1</td>
<td>312.78±1.13</td>
<td>311.69</td>
<td>311.31</td>
<td>-1.09</td>
<td>-1.47</td>
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<tr>
<td>2</td>
<td>05/01/2010</td>
<td>Soil 2</td>
<td>313.36±1.11</td>
<td>310.98</td>
<td>310.87</td>
<td>-2.38</td>
<td>-2.49</td>
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<tr>
<td>3</td>
<td>05/13/2010</td>
<td>Wheat</td>
<td>295.61±0.84</td>
<td>295.89</td>
<td>296.72</td>
<td>-0.28</td>
<td>-1.11</td>
</tr>
<tr>
<td>4</td>
<td>07/18/2010</td>
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<td>298.06±0.18</td>
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<td>298.71</td>
<td>0.85</td>
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<td>5</td>
<td>08/14/2010</td>
<td>Water</td>
<td>297.15±0.23</td>
<td>298.94</td>
<td>299.20</td>
<td>1.79</td>
<td>2.05</td>
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<td>6</td>
<td>08/15/2010</td>
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<td>298.27±0.87</td>
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<td>298.74</td>
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<td>7</td>
<td>09/14/2010</td>
<td>Water</td>
<td>296.87±0.42</td>
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<td>297.20</td>
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<td>8</td>
<td>09/22/2010</td>
<td>Water</td>
<td>290.29±0.06</td>
<td>291.05</td>
<td>291.19</td>
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<td>9</td>
<td>09/22/2010</td>
<td>Corn 1</td>
<td>289.85±1.40</td>
<td>291.60</td>
<td>291.49</td>
<td>1.75</td>
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<tr>
<td>10</td>
<td>09/22/2010</td>
<td>Corn 2</td>
<td>292.45±1.35</td>
<td>291.28</td>
<td>291.37</td>
<td>-1.17</td>
<td>-1.08</td>
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<tr>
<td>11</td>
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<td>291.99±1.43</td>
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<tr>
<td>12</td>
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<td>291.14</td>
<td>291.21</td>
<td>0.9</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Bias (K) | 0.14 | 0.21 | -0.17 | -2.13
Standard deviation (K) | 1.23 | 1.35 | 1.58 | 1.60
RMSE (K) | 1.19 | 1.31 | 1.51 | 1.53

σ, the standard deviation of measured temperatures