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Case study of atmospheric correction on CCD data of HJ-1 satellite based on 6S model

Xiaojuan Xue\textsuperscript{1,2}, Qingyan Meng\textsuperscript{1,*}, Yong Xie\textsuperscript{1}, Zhangli Sun\textsuperscript{1}, Chang Wang\textsuperscript{1,2}, Hang Zhao\textsuperscript{1,2}

\textsuperscript{1}Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing 100101, China
\textsuperscript{2}University of Chinese Academy of Sciences, Beijing 100039, China

E-mail: xxj.0923@163.com; mqy@irs.ac.cn

Abstract: In this study, atmospheric radiative transfer model 6S was used to simulate the radioactive transfer process in the surface-atmosphere-sensor. An algorithm based on the look-up table (LUT) founded by 6S model was used to correct pixel by pixel. Then, the effect of atmospheric correction on CCD data of HJ-1 satellite was analyzed in terms of the spectral curves and evaluated against the measured reflectance acquired during HJ-1B satellite overpass, finally, the normalized difference vegetation index (NDVI) before and after atmospheric correction were compared. The results showed: (1) Atmospheric correction on CCD data of HJ-1 satellite can reduce the “increase” effect of the atmosphere. (2) Apparent reflectance are higher than those of surface reflectance corrected by 6S model in band1~band3, but they are lower in the near-infrared band; the surface reflectance values corrected agree with the measured reflectance values well. (3)The NDVI increases significantly after atmospheric correction, which indicates the atmospheric correction can highlight the vegetation information.

Keywords: HJ-1B/CCD, Atmospheric correction, 6S radiative transfer code, Look-up table

1. Introduction

Atmospheric correction, a prerequisite for remote sensing data to quantitatively analyze surface parameters, mainly eliminates the impact on features of atmospheric scattering and absorption from molecules and aerosols. It is essential to achieve the real surface reflectance\textsuperscript{[1]}. In recent years, quantitative remote sensing has developed rapidly, especially the use of multi-temporal remote sensing data to monitor and analyze the global resources and environment, climate change and so on. Therefor the accurate calibration of remote sensing data and inversion methods of surface physical parameters have become more important\textsuperscript{[2]}. Current atmospheric correction models can generally be summarized as follows: image feature-based model, the linear regression model based on the prior knowledge of the ground, theoretical models of atmospheric radiative transfer\textsuperscript{[3]}, and atmospheric correction method based on radiative transfer model with a higher precision of all atmospheric correction methods, such as 6S(Second Simulation of the Satellite Signal in the Solar Spectrum)\textsuperscript{[4]}, LOWTRAN\textsuperscript{[5]}, MORTRAN \textsuperscript{[5]}, ATCOR \textsuperscript{[6]}, there are UVRAAD, ATREM and TURNER and so on\textsuperscript{[7]}.

In this study, the atmospheric radiative transfer model 6S was taken to conduct atmospheric
correction on CCD data of HJ-1 satellite. The apparent radiances associated with different atmospheric parameters are simulated by 6S, which are further used to create look-up table. Thereafter, atmospheric correction on CCD data of HJ-1 satellite is achieved pixel by pixel. After that, the effect of atmospheric correction on CCD data of HJ-1 satellite is discussed in terms of the spectral curves, by comparing with the NDVI. Results show that the atmospheric radiative transfer model 6S is effective for reducing atmospheric effects to get absolute reflectance.

2. Data Source and Study Area
In this paper, we estimate the surface reflectance of CCD1 data of HJ-1B satellite without cloud in Xilin Gol, Inner Mongolia on August 5, 2012. The study area is located around 43°24’ N, 116°48’ E. The major surface features are vegetation, sand and water, vegetation is typical steppe, including goat grass, grass and forb community.

3. Principles of Atmospheric Correction

In the assumed case of the Lambertian surface, the apparent reflectance of a satellite can be defined through Eq.(1):

$$\rho_{\text{toa}}(\theta_s, \theta_v, \phi_s - \phi_v) = \rho_0(\theta_s, \theta_v, \phi_s - \phi_v) + \frac{T(\theta_s)T(\theta_v)\rho_s(\theta_s, \theta_v, \phi_s - \phi_v)}{1 - \rho_0(\theta_s, \theta_v, \phi_s - \phi_v)S}$$

Where $\rho_{\text{toa}}(\theta_s, \theta_v, \phi_s - \phi_v)$ denotes the reflectance at the top of atmosphere, $\theta_s$, $\theta_v$, $\phi_s$, $\phi_v$ represent solar zenith angle, solar azimuth angle, view zenith angle and view azimuth angle respectively. $\rho_0$ is path reflectance constituted by the molecular scattering and aerosol scattering, $T(\theta_s)$, $T(\theta_v)$ function are downlink and uplink atmospheric path transmittance, $\mu_s = \cos \theta_s$, $\mu_v = \cos \theta_v$, $S$ is spherical albedo, $\rho_s(\theta_s, \theta_v, \phi_s - \phi_v)$ is surface reflectance, the Eq.(1) can be converted to the following form:

$$\rho_s(\theta_s, \theta_v, \phi_s - \phi_v) = \frac{\rho_{\text{toa}}(\theta_s, \theta_v, \phi_s - \phi_v) - \rho_0(\theta_s, \theta_v, \phi_s - \phi_v)}{T(\theta_s)T(\theta_v) + (\rho_{\text{toa}}(\theta_s, \theta_v, \phi_s - \phi_v) - \rho_0(\theta_s, \theta_v, \phi_s - \phi_v))S}$$

In the Eq.(2), $S$, $\rho_0$, $T(\theta_s)$, $T(\theta_v)$ are four atmospheric correction parameters, $T(\theta_s)T(\theta_v)$ can be replaced by T. The Eq.(2) shows that atmospheric correction needs three atmospheric correction parameters $S$, $\rho_0$, $T$. It is very difficult to obtain target atmospheric correction parameters by solving the radiative transfer equation. The commonly used method is the look-up table method [8].
4. Theory of Atmospheric Correction

4.1. Algorithm of Apparent Reflectance

DN values of HJ-1B/CCD image can be converted to apparent radiance through Eq. (3).

\[ L_\lambda = \frac{DN}{g} + L_0 \]  

(3)

Where \( L_\lambda \) denotes the measured apparent radiance; DN refers to pixel value in the original image; \( g \) is band’s corresponding gain; \( L_0 \) is band’s corresponding bias. The calibration coefficients can be acquired from the metadata file, which are included in the downloaded data.

\[ \rho_{TOA} = \pi \cdot L_\lambda \cdot d^2 / E_\lambda \cdot \cos(\theta_s) \]  

(4)

In the Eq.(4), \( \rho_{TOA} \) represents the apparent reflectance of \( \lambda \)-band. \( L_\lambda \) refers to the apparent radiance of \( \lambda \)-band in the upper atmosphere, and the value can be calculated from the CCD data’s spectral response functions, \( \theta_s \) denotes the sun zenith angle.

4.2. Algorithm of Surface Reflectance

For atmospheric correction on CCD data of HJ-1 satellite, four steps are involved. First, creating a Look-up table with atmospheric parameters of \( S, \rho_0, T \); Second, selecting the appropriate data from the look-up table according to the bands, solar zenith angle, solar azimuth angle, view zenith angle and view azimuth angle of each pixel. Solar zenith angle and view azimuth angle can be obtained indirectly from the header file. Satellite zenith angle and view azimuth angle can be obtained from the downloaded Sat_Zenith_Azimuth.txt file; Thirdly, using different aerosol optical depth from look-up table to interpolate the data to get \( S, \rho_0, T \) of each pixel by pixel interpolation. AOD was measured used of CE318; Finally, substituting the three atmospheric parameters of \( S, \rho_0, T \) into equation (2) and combining with \( \rho_{TOA} \) to calculate the surface reflectance.

In this study, the look-up table based on 6S was established by assuming that underlying surface is a homogeneous lambert because of the experimental area is flat grassland. Due to the differences in the spectral response functions for four bands’ of CCD data, it is necessary to establish the look-up table for each band. The changes of aerosol parameters, solar zenith angle, satellite zenith angle and other parameters are usually taken into account during atmospheric correction. The main parameters in 6S model are in Table 1.

<table>
<thead>
<tr>
<th>Main parameters</th>
<th>Set contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric parameters</td>
<td>12 solar zenith angle(0°~66°, the step is 6°); 12 view zenith angle (0°~66°, the step is 6°); 16 view azimuth angle(0°~180°, the step is 12°)</td>
</tr>
<tr>
<td>Climate patterns</td>
<td>Midlatitude summer</td>
</tr>
<tr>
<td>Aerosol parameters</td>
<td>Continental</td>
</tr>
<tr>
<td>Aerosol concentration</td>
<td>6 optical thickness at 550nm (0.0001, 0.25, 0.5, 1, 1.5, 1.95)</td>
</tr>
<tr>
<td>Sensor altitude</td>
<td>-1000</td>
</tr>
<tr>
<td>Spectral Band definition</td>
<td>HJ-B/CCD 1~4</td>
</tr>
<tr>
<td>Environment parameters</td>
<td>Lambertian surface</td>
</tr>
<tr>
<td>Latitude</td>
<td>1276m</td>
</tr>
</tbody>
</table>

With these atmospheric parameters and 6S, the look-up table is built and then atmospheric correction on CCD data of HJ-1 satellite can be achieved by means of IDL programming.
5. Results and Analysis of Atmospheric Correction

5.1. Reflectance Before and After Atmospheric Correction

Figure 2 is the reflectance of HJ-1B/CCD images before and after atmospheric correction, from Figure 2, we can find an obvious change between (a) and (b). The aerosols and dust effects were eliminated effectively after atmospheric correction, original appearance of target was restored, and image contrast has improved significantly.

Figure 2. Resultant Graph of 3, 2, 1 bands (left: apparent reflectance, right: 6S reflectance)

In this paper, 100 samples of different typical features (vegetation, soil and water) within the study area of HJ-1B/CCD were selected. We compared and analyzed the apparent reflectance, the corrected reflectance by 6S and the measured surface reflectance on three typical surface features respectively.

Figure 3. The Compared Object Spectrum from Three Features

As shown in Figure 3 (a), (b) and (c), the surface reflectance values corrected by 6S model agree with the measured reflectance values well of vegetation, soil and water. Three surface features' spectral responses of apparent reflectance are higher than those of surface reflectance corrected by 6S model in blue band (band1), green band (band2), red band (band3), but it’s opposite in the near-infrared band (band4). Atmospheric correction reduces the “increase” effect of atmospheric scattering in the visible bands and increases the “reduction” effect of water vapor absorption in the near-infrared bands, which makes the reduction in the visible bands and increase in the near-infrared bands. The most obvious change is blue band followed by green band and red band in the visible bands because of the different selectivity of atmospheric scattering that has larger impact on shortwave, but lower impact on long wavelength.

Uncertainty (or relative error) is usually used to compare and analyze the pros and cons of two or more methods in the scientific research, the calculation method of uncertainty is $|V1-V2|/V2$ ($V1$ is calculated value, $V2$ is actual value)\[9\]. We compared the uncertainty of the apparent reflectance with the uncertainty calibrated reflectance by 6S model to analyze the effect of atmospheric correction. The two Uncertainties were calculated as:

1. Uncertainty of the apparent reflectance: $|V1-V2|/V2$ ($V1$ is apparent reflectance, $V2$ is measured reflectance, symbol “||” is to calculate the absolute value).

2. Uncertainty of calibrated reflectance by 6S model: $|V1-V2|/V2$ ($V1$ is calibrated reflectance, $V2$ is measured reflectance, symbol “||” is to calculate the absolute value).

The Uncertainty of the apparent reflectance and uncertainty of calibrated reflectance by 6S model
of three features are showed in table 4.

**Table 2. Uncertainty of Vegetation, Soil and Water before and after Atmospheric Correction**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Uncertainty of the apparent reflectance</th>
<th>Uncertainty of calibrated reflectance by 6S model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Band1</td>
<td>Band2</td>
</tr>
<tr>
<td>vegetation</td>
<td>42%</td>
<td>29%</td>
</tr>
<tr>
<td>soil</td>
<td>30%</td>
<td>10%</td>
</tr>
<tr>
<td>water</td>
<td>60%</td>
<td>15%</td>
</tr>
</tbody>
</table>

From Table 2, we can find that the uncertainties of vegetation, soil and water have an obviously reduction after atmospheric correction, so atmospheric correction pixel by pixel based on 6S model has an obvious effect.

5.2. Effect of Atmospheric Correction on NDVI

In the evaluation of atmospheric correction, we usually use normalized difference vegetation index (NDVI) to make a quantitative analysis of atmospheric calibration results. In order to verify the effect atmospheric correction on CCD data of HJ-1 satellite, we compare the NDVI before atmospheric correction with that after atmospheric correction. Some studies[10] show that NDVI can verify the effect of atmospheric correction. The computational formulas of NDVI before atmospheric correction and after atmospheric correction are showed as follows:

\[
NDVI_{\text{TOA}} = \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}}} \quad (5)
\]

\[
NDVI = \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}}} \quad (6)
\]

![Figure 4. NDVI Histogram before and after Correction](image)

From figure 4, it’s easy to find that the NDVI increased after atmospheric correction significantly. It is mainly due to the electromagnetic wave undergo a process of scattering and with absorption with the various gases, water vapor and particulate in the atmosphere before entering the sensor, which increases the reflectance in red band and decreases reflectance in near-infrared band, so the NDVI values reduce according to formula (6) and (7). Atmospheric correction eliminates the increased surface irradiation and "brightness" due to atmospheric scattering, while compensates the loss of radiant energy due to atmospheric absorption. After atmospheric correction, the contrast of red band and near-infrared band is increased, which promotes the increase of NDVI, therefore NDVI can better reflect vegetation biomass.

6. Conclusion

The look-up table established through 6S model by assuming that underlying surface is a homogeneous lambertion surface and the impact of bidirectional reflectance distribution function (BRDF) effect is small enough to be neglecting in this paper. These two assumptions will introduce some errors, therefor it need further studies in near future. The main procedures and conclusions are:
According to different atmospheric parameters, we can generate the look-up table of atmospheric correction on CCD data of HJ-1 satellite, the atmospheric correction algorithm based on 6S is applicable in the study area in this paper.

The atmospheric correction on CCD data of HJ-1B satellite is achieved pixel by pixel through IDL programming. Analyzing from the spectral curves, we find that atmospheric correction can largely reduce the “increase” effect of the atmosphere. Atmospheric corrected reflectance agreed with measured surface reflectance well with errors of four HJ-1 CCD bands 21%.

Reflectance in the visible wavelengths of vegetation, soil and water decreased after atmospheric correction, whereas it increased in the near-infrared wavelengths, there are more errors in the four bands before atmospheric correction.

The contrast between two bands is enhanced after atmospheric correction. NDVI values become larger, which indicates that the atmospheric correction can highlight the vegetation information.

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