An Atmospheric Correction Algorithm For GF-2 Image Based On Radiative Transfer Model

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Abstract. The accuracy of atmospheric correction is a key factor affecting the quantitative application of GF-2 satellite. Due to the lack of short-wave infrared band in GF-2, it is impossible to use method of dark pixel for atmospheric correction. Therefore, a method of atmospheric correction coefficient lookup table (LUT) based on 6S (Second Simulation of the Satellite Signal in the Solar Spectrum) radiation transfer model and aerosol optical thickness (AOT) parameters retrieved from MODIS data is proposed, and the atmospheric correction of GF-2 satellite multispectral data is carried out. Dunhuang radiation correction field with flat and uniform surface is selected as the experimental area. The accuracy of the correction results is evaluated by synchronous measured data, and the normalized vegetation index NDVI before and after atmospheric correction is compared. The results show that the minimum relative error is only 0.9%. The image data after atmospheric correction can more truly reflect the reflection characteristics of ground objects. NDVI after atmospheric correction greatly enhances the contrast of vegetation information and highlights the ability of vegetation information discrimination of GF-2 satellite sensor.

1. Introduction

The successful launch of GF-2 satellite on August 19, 2014 marks that China’s remote sensing satellites have entered the era of high spatial resolution of the sub-meter level [1]. The specific parameters of multispectral data are shown in Table 1. However, atmospheric correction is a key step in the quantitative inversion of surface parameters from GF-2 image data [2-3].

At present, there are three main methods of atmospheric correction. It includes image feature model, linear regression model and radiation transfer model. Radiative transfer method is a method based on complex radiative transfer principle. It can reasonably describe atmospheric scattering and absorption by using radiative transfer model to retrieve surface reflectance. Since 1972, Turner and Spencer have been used to assess atmospheric effects by simulating the atmosphere surface system. They have become one of the earliest models of atmospheric radiative transfer. They are highly accurate and highly applicable in many atmospheric correction methods [4-7].

GF-2 satellite lacks bands for retrieving atmospheric parameters, which makes it difficult for the atmospheric correction of GF-2 satellite data. An atmospheric correction algorithm based on synchronous MODIS data-assisted GF-2 image is proposed in this paper. The AOT is retrieved using MODIS synchronous data, and the atmospheric correction coefficient LUT of GF-2 image is established to correct the atmospheric correction of GF-2 image. After atmospheric correction of a
GF-2 image, the effect of atmospheric correction of GF-2 image is discussed from two aspects of ground spectrum and NDVI.

Table 1. Technical Indicators for Effective Load of GF-2 Satellite.

| load | Band range (μm) | Spatial resolution (m) | Width | Side swing | Days of revisit |
|------|------------------|------------------------|-------|------------|----------------|
| GF-2 | 1                | 0.45~0.90              | 1     |            |                |
|      | 2                | 0.45~0.52              |       |            |                |
|      | 3                | 0.52~0.59              | 4     | + 35 degrees | 5 days         |
|      | 4                | 0.63~0.69              |       |            |                |
|      | 5                | 0.77~0.89              |       |            |                |

2. Atmospheric Correction Principle

Assuming that the land surface is a uniform Lambert surface and the atmosphere is vertically uniform, the apparent radiance received by the sensor is as follows (1):

$$L(\tau_s, \mu_s, \mu, \phi) = L_0(\tau_s, \mu_s, \mu, \phi) + F_d(\tau_s, \mu_s)T^+ (\mu_s)\frac{T^1 (\mu_s) \rho}{[1 - S(\tau_s)\rho]}$$  \hspace{1cm} (1)

The apparent radiance $L(\tau_s, \mu_s, \mu, \phi)$ received by the sensor consists of atmospheric path radiation $L_0(\tau_s, \mu_s, \mu, \phi)$ and surface reflection radiation. Among them, $F_d(\tau_s, \mu_s)$ denotes the incident radiation flux density in the vertical direction between the top of the atmosphere and the sun light, $S$ denotes the atmospheric hemispheric reflectance, $\rho$ represents the surface reflectance; $T^1 (\mu_s)T^+ (\mu_s)$ represent the upper and lower radiation transmittance composed of the atmospheric absorption; $\mu_s$ and $\mu$ represent the cosine values of the solar zenith angle and the sensor zenith angle, respectively. $\phi$ represents relative azimuth angles of solar azimuth and sensor azimuth[8].

By transforming the above formula, the following uniform Lambert surface reflectance $\rho(\tau_s, \mu_s, \mu, \phi)$ can be obtained.

$$\rho(\tau_s, \mu_s, \mu, \phi) = \frac{\rho_s(\tau_s, \mu_s, \mu, \phi) - \rho_s(\tau_s, \mu_s, \mu, \phi)T^1 (\mu_s)T^+ (\mu_s)(\rho(\tau_s, \mu_s, \mu, \phi) - \rho_s(\tau_s, \mu_s, \mu, \phi))S}{T^1 (\mu_s)T^+ (\mu_s)}$$  \hspace{1cm} (2)

Among them, $\rho_s(\tau_s, \mu_s, \mu, \phi)$ represents the apparent reflectance of GF-2, $\rho_s(\tau_s, \mu_s, \mu, \phi)$ represents the apparent reflectance of atmospheric path radiation caused by Rayleigh scattering and aerosol scattering.

The atmospheric correction process can be divided into the following three steps:

(1) Obtaining AOT by dark pixel method [9];

(2) The atmospheric correction LUT is established, and three atmospheric correction coefficients ($S$, $\rho$ and $T^1 (\mu_s)T^+ (\mu_s)$) are calculated under the corresponding atmospheric parameters and observation conditions.

(3) Three atmospheric correction coefficients obtained in (2) are introduced into formula (2). Apparent reflectance $\rho_s(\tau_s, \mu_s, \mu, \phi)$ obtained from GF-2 image data can be used to calculate surface reflectance $\rho(\tau_s, \mu_s, \mu, \phi)$.

The following are the main steps of atmospheric correction.

2.1. Data preprocessing

The pretreatment of GF-2 satellite multispectral data includes the calculation of apparent radiance and apparent reflectance.

2.1.1. Radiation calibration of GF-2 image. According to the radiation calibration coefficients of each band of the sensor, the DN value is converted to the apparent brightness, that is, the radiation brightness at the pupil of the sensor. The radiation calibration formula is as follows:

$$L = Gain \cdot DN + Offset$$  \hspace{1cm} (3)
Among them, \( L \) represents the radiation brightness value of the sensor, \( DN \) is the Gray value of GF-2 image, \( Gain \) and \( Offset \) are the absolute calibration coefficient gain and deviation of the image respectively.

### 2.1.2. Calculation of apparent reflectance of GF-2 Image

On the basis of the above calculation of apparent radiance, the apparent reflectance of the atmospheric top is obtained according to the following calculation formula.

\[
\rho_s = \frac{\pi \cdot L \cdot d^2}{ESUN \cdot \cos \theta_s} \tag{4}
\]

Among them, \( d \) is the correction factor of solar-terrestrial distance; \( L \) is the apparent radiance and \( \theta_s \) is the zenith angle of the sun. \( ESUN \) is the solar irradiance in the upper atmosphere. \( ESUN \) is calculated by integrating the spectral response function of GF-2 image and the solar spectral irradiance data. The \( ESUN \) formula is as follows.

\[
ESUN = \int_{\lambda_1}^{\lambda_2} E(\lambda) \cdot f(\lambda) d\lambda \int_{\lambda_1}^{\lambda_2} f(\lambda) d\lambda \tag{5}
\]

Among them, \( E(\lambda) \) is the solar spectral irradiance outside the atmosphere at the wavelength; \( f(\lambda) \) denotes the spectral response function at the wavelength \( \lambda \).

### 2.2. Calculation of AOT based on MODIS

MODIS short-wave infrared (2.12 um) has high atmospheric transmittance and is sensitive to the optical properties of aerosols. Based on MODIS data, dark target method is used to retrieve AOT. The basic idea is to assume that the aerosol has little influence on the 2.12 um band, and that the apparent reflectance of red band in short wave is equal to its location. The surface reflectance is estimated by using the linear relationship \( \rho_{\text{red}}^* = 0.25 \rho_{\text{red}} \) and \( \rho_{\text{blue}}^* = 0.5 \rho_{\text{blue}} \) between the blue and red bands and the short-wave red bands. Then, the relationship between \( \tau_{\text{blue}} \), \( \tau_{\text{red}} \) and atmospheric correction coefficients such as \( S \), \( \rho(\mu_s, \mu_r, \phi) \) and \( T(\mu_s)T(\mu_r) \) is assumed by 6S calculation under different atmospheric aerosol modes and observation conditions. Based on this, the AOT LUT is established. Finally, the AOT in blue and red bands \( (\tau_{\text{blue}}, \tau_{\text{red}}) \) are obtained by the AOT LUT.

After calculating the AOT in blue and red bands, according to the exponential relationship \( \tau_i = \alpha \lambda_i^b \) between the AOT and the wavelength proposed by Angstrom, the AOT of other bands can be determined. In the formula, \( \tau_i \) and \( \lambda_i \) are the corresponding bands of AOT and central wavelength respectively; \( \alpha \) is called atmospheric turbidity parameter, \( b \) is the parameter that characterizes the relative size of aerosol particles. The larger the \( b \), the smaller the particle size. The AOT in blue and red bands can be calculated by Angstrom formula.

\[
b = \frac{\ln \tau_{\text{blue}} - \ln \tau_{\text{red}}}{\ln \lambda_{\text{blue}}^b - \ln \lambda_{\text{red}}^b} \tag{6}
\]

Substituting Formula into Relation \( \tau_i = \alpha \lambda_i^b \) is available:

\[
\alpha = \frac{\tau_{\text{blue}}}{\lambda_{\text{blue}}^b} = \frac{\tau_{\text{red}}}{\lambda_{\text{red}}^b} \tag{7}
\]

In the formula \( \tau_{\text{blue}}, \lambda_{\text{blue}}, \tau_{\text{red}} \) and \( \lambda_{\text{red}} \) are the AOT and central wavelength corresponding to the blue and red bands respectively.

### 2.3. Construction of atmospheric correction coefficient LUT

The atmospheric correction coefficient LUT is established. Firstly, the atmospheric model is set up, taking AOT, solar zenith angle and solar observation azimuth as variables. According to the
geographical location and seasonal characteristics of the image, each variable is set, and other values can be obtained by linear interpolation.

Because the surface reflectance of the study area is lower than 0.6, in order to facilitate the establishment of the LUT, this paper assumes that the three surface reflectance are 0, 0.2 and 0.5. After selecting the atmospheric model, the data of solar zenith angle, solar azimuth angle, satellite zenith angle and satellite azimuth angle are read from the GF-2 image metafile. The AOT calculated in section 2.2 is input. The 6S program is run three times continuously. The three simulated apparent reflectance are \( \rho_0 \), \( \rho_{0.2} \) and \( \rho_{0.5} \), respectively. By substituting the results into formula (8), a three-dimensional first-order equation system of atmospheric range radiation term \( \rho_a \), atmospheric absorption radiation transmittance \( T \) and atmospheric hemispheric reflectance \( S \) is obtained. The solution expressed by the parameters of simulated apparent reflectance is obtained as follows:

\[
\begin{align*}
\rho_a &= \rho_{0.0} \\
S &= \frac{2\rho_{0.5} - 5\rho_{0.2} + 3\rho_{0.0}}{\rho_{0.5} - \rho_{0.2}} \\
T &= (\rho_{0.2} - \rho_{0.0})(5 - S)
\end{align*}
\]

2.4. Atmospheric Correction of GF-2 Based on LUT

Based on the retrieved AOT from MODIS data and the pixel-by-pixel interpolation of atmospheric correction LUT, the corresponding atmospheric correction coefficient is calculated, and then the surface reflectance is calculated. The atmospheric correction process is shown in the following figure.

![Figure 1. Flow of atmospheric correction of GF-2 image.](image)

3. Results and discussion

3.1. Atmospheric Correction for Spectral Contrast Analysis of Ground Objects

The Dunhuang radiometric calibration field is located on the fan alluvial surface. The area is open, the surface is flat and uniform, and the vegetation coverage is small. It can be considered as a uniform Lambert surface, as shown in Figure 4. Field experiments were conducted on 23 August 2015 to obtain ground reflectance data, as shown in the figure 5. Atmospheric correction is carried out by selecting GF-2 images of Dunhuang area in August 23, 2015 and MODIS images of synchronous transit. The inverted apparent reflectance and surface reflectance are compared with the measured data.
Figure 2. Ground observation sites in the study area.

Figure 3. In-situ measured spectra data.

The apparent radiances values of the four measured points corresponding to the image positions are compared with the apparent reflectance, surface reflectance and measured data retrieved from the above model.

Figure 4. Comparison of the TOA reflectance of GF-2 image before and after the atmospheric correction, (a) ~ (b) represents the reflectance of four sampling points of S1~S4, respectively.

As shown in the figure 6, it can be found from the comparison results that the surface reflectance of GF-2 can be obtained after atmospheric correction, the blue band is reduced, and the red and infrared bands are obviously improved. After atmospheric correction, the coincidence degree between the reflectance of ground objects on the image and the measured reflectance on the ground is improved, which can truly reflect the reflection characteristics of ground objects.

Table 4 below lists the comparison of measured surface reflectance and atmospheric reflectance before and after atmospheric correction at four verification points, and calculates the relative error.
between measured surface reflectance and atmospheric correction before and after atmospheric correction. It is not difficult to find from the table that the maximum relative error before correction is S3 blue band, up to 42.4%. After atmospheric correction, the relative error is reduced to 13.2%, and the minimum relative error is S1 green band, which is only 0.9%. Compared with the relative error of reflectance before atmospheric correction, the difference between the reflectance after atmospheric correction and the measured data is obviously narrowed, and the atmospheric correction effect is obvious.

Table 2. Comparision of the TOA reflectance of GF-2 before and after the atmospheric correction.

| Sample | Items | Blue | Green | Red | NIR | Sample | Items | Blue | Green | Red | NIR |
|--------|-------|------|-------|-----|-----|--------|-------|------|-------|-----|-----|
| MD     |       | 0.179| 0.215 | 0.242| 0.249| MD     |       | 0.151| 0.184 | 0.232| 0.236|
| BA     |       | 0.208| 0.205 | 0.227| 0.224| BA     |       | 0.215| 0.204 | 0.209| 0.203|
| S1     | AA    | 0.185| 0.213 | 0.235| 0.240| S3     | AA    | 0.171| 0.192 | 0.220| 0.221|
|        | BRE(%)| 16.2 | 4.7   | 6.2  | 10.0 | ARE(%) | 3.4  | 0.9  | 2.9   | 3.6 | 13.2 |
|        |       |      |       |      |      |        |      |      |       |      |      |
| MD     |       | 0.166| 0.199 | 0.222| 0.229| MD     |       | 0.159| 0.192 | 0.218| 0.228|
| BA     |       | 0.203| 0.198 | 0.210| 0.209| BA     |       | 0.202| 0.186 | 0.208| 0.205|
| S2     | AA    | 0.175| 0.190 | 0.215| 0.221| S4     | AA    | 0.179| 0.194 | 0.225| 0.219|
|        | BRE(%)| 22.3 | 0.5   | 5.4  | 8.7  | ARE(%) | 5.4  | 4.5  | 3.2   | 3.5 | 12.6 |
|        |       |      |       |      |      |        |      |      |       |      |      |
| MD     |       | 0.166| 0.199 | 0.222| 0.229| MD     |       | 0.159| 0.192 | 0.218| 0.228|
| BA     |       | 0.203| 0.198 | 0.210| 0.209| BA     |       | 0.202| 0.186 | 0.208| 0.205|
| S3     | AA    | 0.171| 0.192 | 0.220| 0.221| S4     | AA    | 0.179| 0.194 | 0.225| 0.219|
|        | BRE(%)| 27.0 | 3.1   | 4.6  | 10.1 | ARE(%) | 12.6 | 1.0  | 3.2   | 3.9 | 3.9  |

MD: Measured data, BA: Before atmospheric correction, AA: After atmospheric correction, BRE: Relative error before correction, ARE: relative error after correction.

3.2. Effect of Atmospheric Correction on NDVI

Vegetation index is a widely used remote sensing data product. Vegetation index is needed in many remote sensing models and ecological models driven by remote sensing information. In order to verify the atmospheric correction effect of GF-2 data, the normalized vegetation index NDVI before and after correction was compared. The NDVI formula is as follows.

\[
NDVI = \frac{\rho_{\text{nir}} - \rho_{\text{red}}}{\rho_{\text{nir}} + \rho_{\text{red}}}
\]  

(9)

Among them, \(\rho_{\text{nir}}\) and \(\rho_{\text{red}}\) represent the reflectance of near infrared and red bands, respectively.

Figure 5. NDVI of Typical Terrain before and after Atmospheric Correction.

The three reflectance of vegetation, water and Gobi in remote sensing images are selected. According to the above formulas, NDVI of the three objects is calculated, as shown in the following figure. NDVI of the three types of terrain changed before and after atmospheric correction, especially the vegetation NDVI increased the most. It can be seen that atmospheric correction increased the
ability of NDVI to extract vegetation information. After atmospheric correction processing, it can be helpful to distinguish the difference between vegetation and other terrain.

4. Conclusions and Prospects
In this paper, the atmospheric correction of GF-2 satellite multispectral data is realized by using 6S radiation transfer model and MODIS aerosol inversion data. Then, the atmospheric correction effect of GF-2 satellite multispectral data is studied by combining ground measured spectral data and NDVI. The following conclusions are drawn:

(1) Compared with the relative error of reflectance before atmospheric correction, the difference between the reflectance after atmospheric correction and the measured data is obviously narrowed, and the reflectance data after atmospheric correction reflects the reflection characteristics of ground objects more truthfully.

(2) After atmospheric correction, the NDVI of water body, Gobi and vegetation changed. The NDVI of atmospheric correction greatly enhanced the contrast of vegetation information and highlighted the ability of vegetation information discrimination of GF-2 satellite.

(3) The study area is open, flat and uniform, assuming that it is a uniform Lambertian surface, without considering the two-way reflection characteristics of the objects. In future studies, the effects of Bi-direction Reflectance Distribution Function (BRDF), adjacent pixels (reflection from the surrounding environment) and cross-radiation terms on the results will be considered to improve the accuracy of the results, so that the method can be used in more complex areas.

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Reference
[1] Wang, Z.W., Liu, S.X., Dai, J.W., et al. (2015) Registration Strategy for GF-2 Satellite Multispectral and Panchromatic Images. Spacecraft Recovery & Remote Sensing, 36 (4): 48-53.
[2] Li, W., Kang, X.G., Chen, L. (2007) A fast atmospheric correction algorithm for MODIS remote sensing images. Signal Processing, 23 (5): 751-754.
[3] Ghulam, A., Qin, Q.M., Zhu, L.J. (2004) 6S model based on atmospheric correction of visible and Near-Infrared data and sensitivity analysis. Acta Scientiarum Naturalium Universitatis Pekinensis, 40 (4).
[4] Kaufman, Y.J., Remer, L. (1994) Detection of Forest Using Mid-IR Reflectance: An Application for Aerosol Studies. IEEE Transactions on Geo Science and Remote Sensing, 32 (3): 672-684.
[5] Qi, X.Y., Tian, Q. J. (2005) The advances in the study of atmospheric correction for optical remote sensing. Remote Sensing for Land & Resources, 25 (4): 1-6.
[6] Liu, Z.L., Ma, J.J. (2012) Retrieval of AOT over bright surface areas using MODIS data. Journal of Atmospheric and Environmental Optics, 7 (5): 358-363.
[7] Atzberger. (2002) Definitions and terms related to electromagnetic radiation and its interaction with matter, unpublished manuscript.
[8] Li, Q.L., Xue, Y.Q., Wang, J.Y., etc. (2006) Atmospheric correction of PHI Hyper Spectral imagery. Journal of Infrared and Millimeter waves, 25 (4): 316-320.
[9] Kaufman, Yoram J., Andrew, E. Wald, Lorraine, A. Remer, et al. (1997) The MODIS 2.1 um channel-correlation with visible reflectance for use in remote sensing of aerosol. IEEE Transactions on Geo Science and Remote Sensing, 35 (5): 1286-1298.