The retrieval of aerosol over land surface from GF-1 16m camera with Deep Blue algorithm

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Abstract. As Chinese new satellite of high resolution for earth observation, the application of air pollution monitoring for GF-1 data is a key problem which need to be solved. In the paper, based on Hsu et al (2004) Deep Blue algorithm, by taking count of the characteristic of GF-1 16m camera, the contribution of land surface was removed by MODIS surface reflectance product, and aerosol optical depth (AOD) was retrieved from apparent reflectance in blue band. So, Deep Blue algorithm was applied to GF-1 16m camera successfully. Then, we collected GF-1 16m camera data over Beijing area between August and November, 2014, and the experiment of AOD was processed. It is obvious that the retrieved image showed the distribution of AOD well. At last, the AOD was validated by ground-based AOD data of AERONET/PHOTONS Beijing site. It is showed that there are good agreement between GF-1 AOD and AERONET/PHOTONS AOD, (R>0.7). But GF-1 AOD is obviously larger than ground-based AOD which may be brought by the difference of filter response function between MODIS and GF-1 camera.

1. Introduction
The high-resolution satellite (GF-1) was successfully launched into orbit in April 2013. The satellite operates in a sun-synchronous orbit with an average orbit height of 644km. It is an optical imaging remote sensing satellite with a design life of 5-8 years. GF-1 equipped with four medium-resolution camera and the spatial resolution of subastral point is 16m. GF-1 has blue, green, red, near infrared four bands. With its sweeping 200km-wide viewing swath and four cameras (WFV1, WFV2, WFV3, WFV4), it can achieve the observation of 800km width and cover the whole territory of China in 4 days (Bai et al, 2013). Since the successfully launched, GF-1 can provide high spatial resolution, high precision and wide coverage of space observation services for the departments of land resources, agriculture, and environmental protection in the atmospheric environment, water environment and ecological environment (Zhao et al, 2015).

Aerosol is a suspension of fine solid or liquid particles in air whose radius range from 0.001\mu m-20\mu m. As an important component of the troposphere, the aerosol is an important parameter to monitor air pollution, and the aerosol emitted by human is closely related to air pollution such as PM\textsubscript{2.5} and haze. The high-resolution aerosol distribution produced by high-resolution remote sensing data of GF-1 will not only provide data for large-scale, high-resolution air pollution monitoring, but also for the application of new domestic sensor data significance. Therefore, it is urgent to study the aerosol retrieve of GF-1 data.
The difficulty in retrieving aerosol over land using satellite remote sensing is the removal of the contribution of surface reflectance. There are some successful methods to remove surface contribution, such as Dark Target algorithm, multi-angel algorithm and Deep Blue algorithm. Because of low reflectance over dense vegetation in red and blue bands, Dark Target algorithm (Kaufman, and Sendra, 1988; Kaufman et al, 1997; Sun et al, 2006; Wang et al, 2009) has been successfully applied to remove surface contribution. But for bright-reflecting regions, such as bare soil, desert et al, the retrieval results is not good. Diner et al (2005) obtained the aerosol information from the multi-angle observations of MISR according to the difference from different observation angles of surface and aerosol. Based on the strong contribution of aerosol to observations in the blue-band, Hsu et al (2004, 2006) developed Deep Blue algorithm which was successfully applied to Arabian Peninsula and other bright-reflecting regions by using SeaWIFS image.

In this paper, based on Deep Blue algorithm, we obtained blue-band surface reflectance library by using MODIS reflectance products, and presented the data processing flow for GF-1 16m, then performed experiment over Beijing area. Finally, retrieved AODs over Beijing are validated by ground-based measurements of AERONET/PHOTONS.

2. Basis Theory and Algorithm

For a Lambertian surface under a plane-parallel atmosphere, the upward reflectance $L_{TOA}$, at the top of the atmosphere (TOA), can be written as a function of surface reflectance (Tanré et al, 1979):

$$
\rho_{TOA}(\mu_s, \mu_v, \varphi) = \rho_0(\mu_s, \mu_v, \varphi) + \frac{T(\mu_s)T(\mu_v)r}{[1 - rS]}
$$

(1)

Where $r$ is the Lambertian reflectance, $\rho_0$ is path radiance, $S$ is the atmospheric backscattering ratio, $T$ is atmospheric transmission. And $\mu_s$, $\mu_v$, $\varphi$ are atmospheric observation geometrical parameters, indicate the cosine of solar zenith angle, the cosine of sensor zenith angle, relative azimuth angle respectively. In Eq. (1), $S$, $\rho_0$, $T(\mu_s)$, $T(\mu_v)$ are four parameters representing the scattering and absorption of light through the whole atmosphere. In the case of known aerosol patterns and scattering of atmospheric molecules, they are only related to the observation angle and aerosol optical depth. When observation geometrical parameters are known, the correspondence between AOD and these four atmospheric parameters is simulated and calculated by using the radiation transport model, and then AOD can be retrieved by using Dark Target algorithm or Deep Blue algorithm.

Because the signal reflected by atmosphere is stronger than that reflected by land surface of most land types in blue band, Deep Blue algorithm retrieves AOD by substituting surface reflectance in previous year into Eq. (1) assuming that the surface reflectance are constant in the same day of different years. In this paper, after obtaining surface reflectance from MODIS surface reflectance product in the third band, the correspondence between AOD and atmospheric parameters are pre-computed by radiation transport software and stored in lookup table.

Surface reflectance are obtained from MODIS 500m surface reflectance product (MOD09). MODIS surface reflectance products are received after atmospheric corrections for gaseous scattering and absorption, aerosol scattering and absorption, cirrus contamination, BRDF coupling and the adjacency effect (Vermote and Kotchenova, 2008). In order to eliminate the short-term change in surface reflectance, 8-Day synthesized product is selected. These products are stored in different files of MODIS sinusoidal projection grid ($10^\circ \times 10^\circ$). In this paper, the China’s surface reflectance in blue band is obtained through band extraction, re-projection, resample, image cutting, and mosaic with the help of ENVI.

As is shown in Figure.1, the blue band of GF-1 WFV is close to the MODIS, but the spectral responses are also different. The band width and center wavelength of MODIS are smaller than WFV camera, and also there are some differences between WFV cameras. In order to analyze the applicability of MODIS blue-band surface reflectance products in WFV cameras, we analyzed the reflectivity difference of GF-1 16m camera and MODIS in the blue-band using the typical surface spectral data of vegetation, water, soil and cement. Spectral data were measured by Analytical Spectral Devices (ASD). The wavelength of spectral data ranges from 350nm to 2500nm with step of 1nm.
Using the response function of the GF-1 16m camera and MODIS, the corresponding surface reflectance is computed by convoluting the spectral data. The results are shown in Table 1.

The Table 1 indicates that reflectance in blue band of GF-1 16m is bigger than MODIS in different surface generally. The deviation is approximately 0.002-0.007, and there are also minor differences between the different GF-1 16m cameras. Since the MODIS sensor has a low overall reflectance, the surface contribution of MODIS reflectance products will be underestimated and then conduct the overestimation of retrieved AOD results.

### Table 1.

| Surface Type       | WFV1 | WFV2 | WFV3 | WFV4 | MODIS |
|--------------------|------|------|------|------|-------|
| Mixed vegetation   | 0.02 | 0.02 | 0.02 | 0.02 | 0.02  |
| Grassland          | 0.02 | 0.02 | 0.02 | 0.02 | 0.02  |
| Laterite           | 0.10 | 0.10 | 0.10 | 0.10 | 0.09  |
| Cement floor       | 0.22 | 0.22 | 0.22 | 0.22 | 0.21  |
| Water              | 0.05 | 0.06 | 0.05 | 0.05 | 0.05  |

### 3. Data Processing Flow

**3.1. Building lookup table**

The lookup table was built by radiation transport function through setting different conditions in 6SV1.0 (Kotchenova et al, 2006). The LUT contains pre-computed atmospheric parameters at the self-defining band of four 16m cameras of GF-1. The aerosol model was used continental model and the AODs were set to six values in 0-2, and there were twelve solar zenith angles in 0-66°, six sensor zenith angles in 0-35°, and sixteen relative azimuth angles in 0-180°.

**3.2. Compute viewing geometry**

GF-1 16m camera with auxiliary files to provide the image center point’s solar zenith angle, solar azimuth, view zenith angle, view azimuth angle and transit time, calibration coefficients and other auxiliary data. GF-1 16m camera’s field angle is about 16°, the size of each image is 200km*200km, the difference in the view zenith angle and solar zenith angle of entire image is 8° and 1° respectively. So the deviation from revision can’t be ignored, we need to calculate the observation geometry for each pixel (Wang et al, 2015). The solar zenith angle can be expressed as follows (Jacobson, 2005):

\[
\cos \theta_s = \sin(\text{lat}) \sin \delta + \cos(\text{lat}) \cos \delta \cos t
\]

Where lat is latitude of corresponding pixel, \(\delta\) is the solar declination, \(t\) is the hour angle.
The view zenith angle is obtained by linear interpolation of the zenith angle of image center which extracted from the auxiliary file based on the camera field angle.

3.3. Obtain upward reflectance and discard cloudy and water pixel
The process of obtaining upward reflectance contains two steps. Firstly, by radiometric calibration coefficients from xml files, convert the DN value to apparent radiance.

\[ L = Gain \times DN + Bias \]  

(3)

Where Gain is calibration slope, Bias is calibration intercept, DN is radiometric calibration coefficient.

Then obtain upward reflectance by normalizing:

\[ \rho_{\text{TOA}} = \frac{\pi L}{d^2 F_0 \cos \theta_s} \]  

(4)

Where \( d \) is the ratio of the solar-terrestrial distance of the satellite transit and the average solar-terrestrial distance. \( F_0 \) is the external solar irradiance of the atmosphere.

Clouds are removed through the threshold. It is shown that, in the red-band, cloud reflectance is generally greater than 0.2. Thus, in our algorithm, when apparent reflectance is greater than 0.2, the pixel is removed as cloud (Ackerman et al. 2010). At the same time, using red-band and near-infrared, we can compute NDVI and remove the pixel of NDVI<0 which is considered water.

3.4. AOD retrieval
Firstly, we calculated the longitude and latitude of the pixel to be retrieved, and searched the corresponding surface reflectance in the surface reflectance image which extracted according to the transit time of GF-1. After that, according to zenith angle computed, we obtained the atmospheric parameters at different optical thicknesses through the linear interpolation of the lookup table, and then input into Eq. (1) with surface reflectance to get the upward reflectance. At last, the optical thickness of aerosol was obtained by linear interpolation using the blue-band upward reflectance of GF-1 16m camera.

4. Result and validation
Based on the algorithm and data processing flow above, WFV4 image over Beijing area on the afternoon of September 18, 2014, was chosen to retrieve AOD images shown in Figure 2. As the retrieve result is shown, this algorithm basically reflects the spatial distribution of aerosol, and in the western and northern mountains, the aerosol optical depth is small. But in the eastern and southern areas, such as Beijing and Tianjin, the aerosol optical depth is larger due to the influence of human activities. In addition, the retrieve results in northern are abnormal because this algorithm can’t retrieve this area with fractus correctly.

The algorithm is validated by ground-based measurements of AERONET/PHOTONS Beijing station. AERONET (Aerosol Eobotic NETwork) is built by NASA and PHOTONS and the purpose of this project is to meet the high requirements of aerosol parameter retrieval accuracy needed for satellite data validation and improved understanding of the radiative effects of aerosol. The AERONET provides globally distributed observations of AOD, size distribution, and phase function (Holben, et al. 1998). AOD from AERONET/PHOTONS are derived from the sun radiance in 440nm, 675nm, 870nm and 1020nm. For comparing with AOD from WFV4, AODs from AERONET/PHOTONS are converted to that in 550nm by Angstrom equation.

\[ \tau_\alpha(\lambda) = \beta \lambda^{-\alpha} \]  

(5)

Where \( a \) is Angstrom exponent, \( \beta \) is Angstrom turbidity coefficient, \( \lambda \) is wavelength.

In order to reduce the aerosol deviation in spatial, AOD from AERONET/PHOTONS within 8km were averaged. And AOD from WFV-4 with half-hour were also averaged is to remove the observations instability of time. From August to November in 2014, we obtained ten pairs of valid validated data removing the influence of cloud (Figure 3).
Figure 2. the retrieved AOD image over Beijing area in September 18, 2014. Left is true color image, and right is AOD image.

Figure 3. the comparison between GF-1 AOD and AERONET/PHOTONS AOD.

As is shown in Figure 3, the retrieve results have good correlation with the values from AERONET, correlation coefficient is close to 0.8. But in general, the values are larger than ground observations. From the Table 1, we can find that blue-band surface reflectance of MODIS is less than GF-1 16m camera for most of surface conditions, and this maybe because the blue-band center wavelength is less than GF-1 16m camera. Therefore, this algorithm will be underestimated surface contribution and result in a small retrieval results.

5. Conclusion
In this paper, Deep Blue algorithm has been applied to GF-1 16m camera. The results are shown as below.

(1) The MODIS and GF-1 16m camera are similar in blue-band, so MODIS surface reflectance products can be used to retrieve land aerosol using the Deep Blue algorithm.

(2) The results retrieved in Beijing area from August to November indicate that this algorithm can better reflect the spatial distribution of aerosol.

(3) The validation shows that the results retrieved from this algorithm have good correlation with the observations. But in general, the value is larger than the data from ground-based measurement and it may be caused by underestimation of surface reflectance.
Acknowledgments
Thanks to Chen Hongbin and Philippe Goloub for ground-based measurement of Beijing station of AERONET/PHOTONS. This work was supported by the National Key R&D Program of China (2016YFC0201507), and the National Natural Science Foundation of China (Grant No. 41471367).

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