Atmospheric correction of hyperspectral data using MODTRAN model

Xu Yuanliua,∗, Wang Runshengb, Liu Shengweib,Yang Sumingb,Yan Bokunb

a School of the Earth Sciences and Resources, China University of Geosciences, Beijing 100083
b China Aero Geophysical Survey & Remote Sensing Center for Land and Resources (AGRS), Beijing 100083

ABSTRACT

The solar radiance obtained by a sensor is modified by atmosphere interaction, affected by its path through the atmospheric absorption and scattered in the combined Sun-surface-aircraft. In this paper, we described a method using RTM to simulate atmospheric spectral for deriving surface reflectance from Hyperspectral data (Hyperion). Preliminary application of the technique to Hyperion data indicates that the retrieval results are reasonable, and available techniques including retrieval of water vapor amount with MODTRAN look-up- table.

Key words: MODTRAN, Hyperspectra, atmospheric correction

1. INTRODUCTION

Solar radiation is affected by its path through the atmospheric absorption and scattered in the combined Sun-surface-sensor. The radiance obtained by a sensor is modified by the atmosphere as well as by the Earth's surface[1]. In order to properly ascertain the surface reflectance from hyperspectral data, scientists have developed some methods, such as relative correction, empirical line method, RTM (Radiative Transfer Model), and empirical line-RTM method. Empirical line method retrieves surface reflectance from hyperspectral data and field measurements of two targets, which have contrasting reflectance. However, because of atmospheric gas absorption features from hyperspectral data over scenes with water vapor amount and AOT (Aerosol optic thickness) variations, the empirical line method can not retrieves surface reflectance[2] effectively. Therefore, alternative atmospheric correction methods by radiative transfer model has been developed. Three atmospheric correction software packages (ATREM, ACORN, FLAASH) have been evaluated for atmospheric correction of hyperspectral data (AVIRIS data) for reflectance[3].

In this paper, we described a method with MODTRAN to simulate atmospheric spectral for deriving surface reflectance from hyperspectral data (Hyperion). This method utilizes existing atmospheric correction techniques, and added APDA (Atmospheric Precorrected Differential Absorption) to retrieve water vapor amount on a pixel-by-pixel[4]. The results of atmospheric correction are compared with results of Flaash atmospheric correction module. Preliminary application of the technique to Hyperion data indicates that retrieval results are reasonable, and available techniques including retrieval of water vapor amount with MODTRAN look-up- table.

∗ Corresponding author: xyl_richard@163.com
2. METHOD

2.1 MODTRAN radioactive transfer model

MODTRAN (MODerate spectral resolution atmospheric TRANSsmittance algorithm and computer model) is developed by AFRL/VSBT in collaboration with Spectral Sciences, Inc. The MODTRAN Code calculates atmospheric transmittance and radiance for frequencies from 0 to 50,000 cm\(^{-1}\) (wavelength: 200nm to \(+\infty\)) at moderate spectral resolution, primarily 2 cm\(^{-1}\) (20cm\(^{-1}\) in the UV)\(^{[5][6]}\). Except for its molecular band model parameterization, MODTRAN adopts all the LOWTRAN 7 capabilities, including spherical refractive geometry, solar and lunar source functions, and scattering (Rayleigh, Mie, single and multiple), and default profiles (gases, aerosols, clouds, fogs, and rain). The input file of MODTRAN is named tape5 or *.tp5, and the mainly output files are tape6, tape7, tape7.scn, and tape8 files.

The optical interaction effect between sun-atmosphere-surface and surface-atmosphere-sensor is constituted three sets. It is showed that the radiance at the sensor is composed of three different contributions: (1) radiation scattered by the atmosphere into the viewing direction, which is not affected by surface. (2) radiation reflected from the target and directly transmitted in the viewing direction. (3) radiation reflected from the background (surroundings) and diffusely transmitted to the sensor, which is called the adjacency effect.

Assumed that the surface is uniform and has a Lambertian reflectance, the radiance at a downward looking aircraft sensor can be written in a simplified form as follow\(^{[8]}\).

\[
L = G_t \frac{\rho}{1 - \rho \cdot S} + G_b \frac{\rho_e}{1 - \rho_e \cdot S} + L_o
\]  

(1)

Where \(\rho\) is target region reflectance, \(\rho_e\) is surrounding region reflectance, \(S\) is atmospheric spherical albedo, \(L\) is the radiance at the sensor, \(L_o\) is the radiance of atmosphere backscattering, \(G_b\) surrounding pixel coefficient (depend on atmospheric and geometric condition), \(G_t\) target pixel coefficient (depend on atmospheric and geometric condition).

The retrieval of target region reflectance \(\rho\) involves computing a spatially averaged radiance image \(\bar{L}\) from which the spatially averaged reflectance, and the spatially averaged reflectance \(\rho_e\) is estimated using the approximate equation.

The spatial averaging is performed using Gaussian function that describes the relative contributions to the pixel radiance.

\[
\rho = \frac{L - L_o + \frac{G_b}{G_t} \cdot (L - \bar{L})}{G_b + G_t + (L - L_o) \cdot S}
\]  

(2)

Where \(L, L_o, S, G_b, G_t\) are same as them in Equation (1), and \(\bar{L}\) is spatial averaging.

In order to be able to determine all five effective parameters for a given atmospheric state and geometry, three MODTRAN4 runs should be carried, with spectrally flat surface albedos of 0%, 50%, and 100%, respectively, and all of three runs are set for a uniform Lambertian surface reflectance\(^{[7][8]}\). MODTRAN outputs corresponding each wavelength to Hyperion are PATH (total path radiance), GRFL (radiance contribution due to ground-reflected sunlight), and TOT (total ground-reflected radiance contribution), as well as the extraterrestrial spectral solar irradiance. For PATH, the results obtained for 0% and 100% albedo are used, which are respectively called PATH\(_0\) and PATH\(_{100}\). For GRFL, only the output for 100% albedo is required (GRFL\(_{100}\)), and for GTOT one needs the outputs for 50% and 100% albedo.
respectively called $\text{TOT}_{50}$ and $\text{TOT}_{100}$.

$$S = \frac{\Delta \text{TOT}_{100} - 2 \Delta \text{TOT}_{50}}{\Delta \text{TOT}_{100} - \Delta \text{TOT}_{50}} \tag{3}$$

$$G_b = \Delta \text{PATH}_{100} (1 - S) \tag{4}$$

$$G_r = \Delta \text{GRFL}_{100} (1 - S) \tag{5}$$

$$L_o = \text{PATH}_0 \tag{6}$$

Where $\Delta \text{TOT}_{100} = \text{TOT}_{100} - \text{TOT}_0 = \text{TOT}_{100} - \text{PATH}_0$, $\Delta \text{TOT}_{50} = \text{TOT}_{50} - \text{TOT}_0 = \text{TOT}_{50} - \text{PATH}_0$, $\Delta \text{PATH}_{100} = \text{PATH}_{100} - \text{PATH}_0$, $\Delta \text{GRFL}_{100} = \text{GRFL}_{100} - \text{GRFL}_0 = \text{GRFL}_{100}$.

After the atmospheric parameters retrieval being performed, Equation (2) is solved with Equation (3)-(6) for the pixel surface reflectance in all of the sensor channels.

### 2.2 Hyperspectral data (Hyperion)

The Hyperion sensor aboard the EO-1 satellite (launched in Nov. 21th 2000) is an experimental sensor that merges the spectral resolution of airborne hyperspectral instruments with the practicality of satellite remote sensing\[9\]. The spatial resolution of Hyperion is 30m, and spectral resolution is about 10nm in VNIR-SWIR region. Hyperion is a push broom sensor, collecting simultaneously across 256 detectors along the track of the satellite's orbit.

The image used in this study is located in 35.38 N 116.8 E, and image date is May 7th 2005. In this study, we use part of a whole scene to experience the method, and only 196 of the 242 total Hyperion bands were used in the atmospheric correction, because many of the bands exhibited low signal to noise ratio or other problems.

### 3. RESULT

#### 3.1 Algorithm implementation

Atmospheric correction of hyperspectral data typically consists of three steps\[10\].

① The retrieval of atmospheric parameters: water amount and AOT (Aerosol Optical Thickness). The water vapor amount can be retrieved on a pixel-by-pixel by the ratio of water absorption bands and reference bands.

② Retrieval of reflectance from radiance is accomplished by solution of the radiative transfer equation for the given column water vapor and AOT.

③ An optional post-processing step called spectral polishing has been shown to remove many artifacts remaining from the correction process.

After analyzing the prior method\[11\], the algorithm of atmospheric correction implementation for the derivating the surface reflectance from Hyperion data could be accomplished as following steps:

1. The input files of MODTRAN are defied by the Hyperion flight time and on the geographic location (latitude and longitude) of the scene, which created a MODTRAN output files LUT with variable albedo(0%, 40%, 50%, 100%),
water vapor amount (0.4 ~ 4.0 g/cm²), visibility (5.0 ~50 km).

(2) The most important atmospheric parameters are retrieved on a pixel by pixel with high spectral resolution feature, which is derived from the 940 nm water vapor features in the measured data by APDA technique. The LUTs of water vapor amount are created for retrieval.

(3) Spatial averaging of the radiance using Gaussian function is created for reflectance retrieval (Equation (2)).

(4) After MODTRAN parameter are retrieved accurately on pixel by pixel, the coefficients of atmospheric correction are calculated by Equation (3)~(6).

(5) Full reflectance spectrum retrieval is finished with equation (2).

3.2 Experiment results

Our method for surface reflectance retrievals has been applied to a Hyperion data for testing (Site:35.4N 116.8E, date: May 7th 2005, time:2.6). Fig 1. shows a band of the image (left), and the spectra of a pixel(right). The surface of the image is covered by vegetation (darker gray region), water(black region), soil(gray region) and buildings(white region). The results of atmospheric correction is obtained by MODTRAN model.

![Figure 1. Study site(left) and radiance(right)](image)

The water vapor amount is important for atmospheric correction and hyperspectral data on a pixel-by-pixel basis is generally the practical way to obtain the water vapor values. In this paper, we retrieved the water vapor amount by three methods (Flaash, LIRR and APDA[^4]), and the difference of three water vapor amount methods is the calculation of radiance ratio in water absorption[^4]. The results obtained for atmospheric water vapor retrieval in 940nm showed in Fig 2. The retrieval of water vapor amount is converged about 1.567 (Flaash),1.436 (LIRR) and 1.72 (APDA), and the mean values are 1.553(Flaash), 1.412(LIRR),1.701(APDA). The APDA water vapor distribution is much less biased than the Flaash and LIRR water vapor. LIRR and APDA water vapor have difference of 5%~10% with Flaash, and Flaash value is between LIRR and APDA. The prior study has proven the APDA is the most stable and accurate way to retrieve water vapor[^4]. Each method is suitable for water vapor retrieval of the vegetation region, and the effects in vegetation region is better than the other region. In the APDA image water and soil pixels caused some anomalistic water vapor, which suggested that there is still an opportunity to improve the water vapor retrieval.
After retrieving the parameters of atmospheric correction (water vapor amount), we calculated the coefficient in equations (4)–(7). The Fig 3. shows the atmospheric correction coefficients: the radiance of atmosphere backscattering \( L_0 \) (dashed), surrounding pixel coefficient \( G_b \) (dotted line), target pixel coefficient \( G_t \) (solid line), and those meanings are explained in equation (2).

The result of reflectance retrieval has been compared with the different atmospheric correction approaches (Flaash). The solid line is our retrieval result, and the dotted line is Flaash result. The dashed in Fig 4. is the atmosphere spherical albedo. The two reflectance results are similar with each other in Fig 4. Owing to ‘polishing’, which was the post-processing, the result of Flaash is more smooth than our result.

In order to quantitatively assess the correction of reflectance atmospheric, the deviation from unity was calculated with ratio spectra between Flaash and our algorithm but omitting the water absorption opaque channels (at 1400, 1900 and 2400 nm, marked as shaded areas in Fig. 5). The ratio is fluctuated near 1.0 except for water vapor absorption region (Fig. 5), which suggested the atmospheric correction is reasonable, and available.
4. CONCLUSIONS

Atmospheric correction with radioactive transfer codes is generally influenced by two atmospheric parameters—water vapor amount and AOT (Aerosol Optic Thickness).

Water vapor amount is estimated from the data on a pixel-by-pixel basis by water vapor absorption bands at 940nm[12]. A look-up-table for retrieving water vapor from these radiances is generated using MODTRAN4 and then fitted in a least-squares sense against the Hyperion data. One dimension of the table is the reference to absorption ratio and the other is the reference radianc.

Radiance at sensor is affected by atmospheric aerosol because of the quantity of backscatter and the attenuation of the surface-reflected radiances. Kaufman has shown that for typical "dark" terrain, the shortwave reflectance values (at 660 nm and 490nm in particular) can be estimated from the reflectance at 2100nm by empirical ratios. The 2100nm reflectance can be retrieved from an initial retrieval with an estimated aerosol.

Deriving surface reflectance from Hyperion data with MODTRAN model is described in this paper and the method is available in retrieving surface reflectance in 400-2500 nm region from Hyperion data. The atmospheric correction of hyperspectral data has an advantage: water vapor amount can be retrieved on a pixel by pixel, which is impossible in field measurement of surface water vapor absorption features. Preliminary application of the
technique to Hyperion data indicates that retrieval results are reasonable and available techniques including retrieval of water vapor amount with MODTRAN look-up-table.

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REFERENCES