AEROSOL RETRIEVING OVER URBAN AREA USING SPOT/HRG IMAGERY

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KEY WORDS: Aerosol optical depth, SPOT, Radiative Transfer Equation

ABSTRACT: Retrieving aerosol optical depth (AOD) over urban areas from satellite imagery is a challenging issue because of the large variance in surface reflectivity, especially for high spatial resolution imagery. However, based on the concept of the blurring effect of aerosols in the visible imagery, the reflectance contrast between the bright and dark objects can provide the information of aerosol loading. The principle is that, after the correction of the solar incidence and satellite view angle, the remaining variation of the apparent reflectance over an unchanged surface is affected by the pollutants. The overall AOD can be derived from the dispersion of the apparent reflectance over urban areas with a referenced image (under a clear atmosphere). The results show that the referenced AOD should be as small as possible to retrieve more accurate AOD. The size of the target window (i.e. AOD spatial resolution) is also another factor that affects the accuracy of AOD retrieval. Validating by several different sizes, it reveals that the window size at 51x51 (5.1 kmx5.1 km) can provide the most accurate results. Examples of the AOD derivation over Taipei City (Taiwan) using this method show that most of the cases exhibit the retrieving feasibility (error <30%). To overcome the retrieved uncertainties, more parameters of the metadata such as azimuth angle and satellite orientation will be examined further.

1. INTRODUCTION

The aerosol loading has been a growing concerned issue in the recent decades. Among these different aerosol sources, man-made pollutants play an important role in the Sun-Earth energy budget balance (Hansen *et al*., 1990). Not only have they been linked to the global climate changes, they are also strongly correlated with the air quality. The effects of aerosols were initially considered to be an atmospheric cooling mechanism, due to their ability in reflecting solar radiation back into space. However, recent studies have shown that the brown clouds induced by aerosols produce roughly the same amount of warming as greenhouse gases over areas spanning from the Indian Ocean to Southwestern Asia (Ramanathan *et al*., 2007).

Many approaches have been developed for the retrieval of aerosols via remote sensing. One of the most popular methods is the Dense Dark Vegetation (DDV) method which based on the Radiative Transfer Equation (RTE) to derive the aerosol optical depth (Holben *et al*., 1992; Santer *et al*., 1999). In order to extract the path radiance for the AOD estimation, the downward flux and upward transmission effect must be minimized by selecting dark (low reflectivity) areas in the visible spectral bands. Since forests and agricultural areas usually exhibit lower reflectance, they are considered to serve as better candidates. However, the need for a sufficient amount of the low reflectivity targets limits the applications during wintertime or for sparse canopy areas (Borde *et al*., 2003). Therefore, other approaches based on look-up tables (LUTs) have been generated via radiative transfer codes (e.g. MODTRAN) for various land surfaces (Liang *et al*., 2001; Hsu *et al*., 2004; Guanter *et al*., 2007). Nevertheless the downsides of the DDV method, the reflectance ratios between the visible bands (0.49 and 0.66μm) and shortwave IR band (2.1μm) of dark objects are still a useful approach of aerosol retrievals (Kaufman *et al*., 1997).

On the other hand, multi-view instruments onboard satellites implemented an alternative way to retrieve AODs. Instruments such as the Polarization and Directionality of the Earth's Reflectances (POLDER), Multi-angle Imaging Spectro Radiometer (MISR) and Advanced Along-Track Scanning Radiometer (AATSR) have the capabilities to acquire the apparent radiation over the same area almost at the same time. Thus many approaches have been

developed for AOD retrieval using multi-view observations. For example, the retrieval scheme for POLDER is based on the LUTs includes aerosol size distributions (Vachon *et al.*, 2004).
Aforementioned atmospheric corrections of satellite data apply either the ratio (difference) of the visible spectral bands or by the aid of simulation tools (LUTs). Urban areas due to its surface complexity the AOD retrieval still a challenging issue. The goal of this paper is to assess the aerosol loading over an urban area of Taipei City. The method applied in this study is based on the variations on backscattered radiance and takes into account the blurring effect which could reduce the standard deviation of the reflectance and increases reflectance.

2. THEORETICAL BASIS

Atmospheric effect will modify the satellite observed radiation intensity through absorption and scattering. Under a clear sky the main alternation of radiometric intensity is the aerosol optical depth τ . The AOD retrieval can be achieved under two assumptions. First the spectral response in a certain window size is variable in space and time. Second Atmospheric composition will be considered within each array to be variable in time. Sifakis (1992) derived the relations between reflectance and AOD shown in Equations (1) and (2),

$$\frac{\sigma_1(\rho^*)}{\sigma_2(\rho^*)} = \exp[(-\tau_1/\cos\vartheta_{v1}) + (\tau_2/\cos\vartheta_{v2})] \tag{1}$$

$$\ln\left[\frac{\sigma_1(\rho^*)}{\sigma_2(\rho^*)}\right] = (-\tau_1/\cos\vartheta_{v1}) + (\tau_2/\cos\vartheta_{v2})$$

$$\tau_2 = [\ln\left(\frac{\frac{\sigma_1(\rho^*)}{\bar{\rho}_1}}{\frac{\sigma_2(\rho^*)}{\bar{\rho}_2}}\right) + (\tau_1/\cos\vartheta_{v1})]\cos\vartheta_{v2} \tag{2}$$

Where ϑ_v is the incidence angle, ρ^* is the satellite observed reflectance in specific window, $\bar{\rho}^*$ is the mean of reflectance, and $\sigma(\rho^*)$ is the standard deviation (STD) of reflectance. Subscripts are parameters in different observations. In order to mitigate the possibility of the retrieved AOD τ_2 become negative, the first term on the right side of Equation (2) should be positive.

3. REFERENCE IMAGE SELECTION

As discussed above, the of the log term in Equation (2) should be greater than the denominator to guarantee that the retrieved AOD is positive. Heavy aerosol loading will blur the image more than that of the light one. Figure 1 shows that two different SPOT5 images (20050920 and 20100321) exhibit quite different mean and STD values. According to a set of sun photometer observed AOD at 545nm (green), the value is 0.047 under a very clean day (20050920), but a much higher value (1.416) could be obtained under a turbid day (20100321). The mean and STD of reflectance are shown in the image respectively. The STD to mean ratio of 20050920 is greater than that of 2010032, and can guarantee the derived τ_2 is positive. It is important that the referenced data should be as clean as possible to obtain reasonable results.

4. DATA PROCESSING AND ANALYSIS

When cloud-free SPOT5 images are applied, even though a small part of cirrus cloud in the image can result in misleading. The observation time of sun photometer and satellite overpass time should be as close as possible (in general less than one hour) to avoid the atmospheric change. By using sun photometer observed AOD data and applying the Ångström law, the AOD for SPOT5 green band can be derived. There are thirteen cases that match the time requirements. Images covering the urban area of Taipei City is selected, and the sun photometer site is located at 25.030°N, 121.500°E where is surrounded by buildings and roads and less vegetated surfaces. However the size of the target area will affect the AOD results, we adopt nine different window sizes (11x11, 31x31, 5x51, 71x71, 9x91, 111x111, 131x131, 151x151 and 171x171) to find out which one is the best window size to retrieve AOD.   .

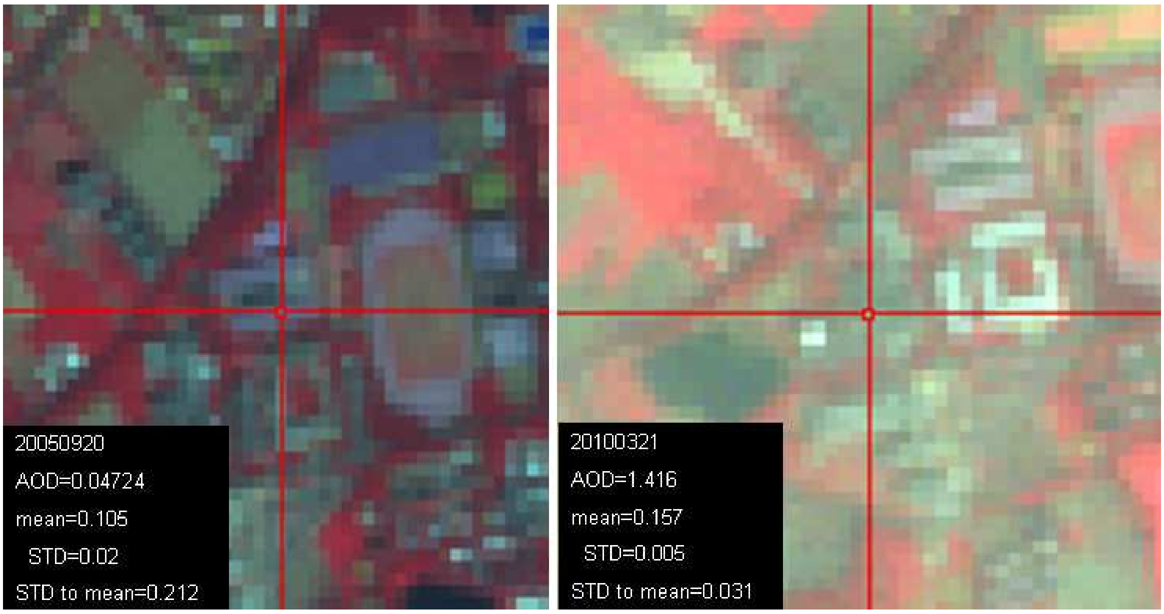

Figure 1. SPOT5 images on 20050920 and 20100321. The values of sun photometer observed AOD, and their means and STDs of reflectance are shown in the black panels.

5. RESULTS

According to the prerequisite condition, this study applies the cleanest image (20050509, AOD=0.047) as a referenced image. Other images are considered as targets. Parts of the retrieved results are shown in Figure 2. The mean error percentage (estimated sunphotometer measured), STD, regression and R^2 are shown in each panel. Two dashed lines represent slope=1.2 and 0.8. The 11x11 window shows that the estimated AODs are underestimated while comparing to the measured. As the window gets larger, the underestimation phenomenon gets improved, but the measured AOD greater than 0.5 are overestimated still. However, the measured AODs around 0.5 show that there is a quite large retrieved gap. This may be attributed to other parameters, such as azimuth angle, orientation angle. Therefore, it is strongly recommended that the parameters should be investigated in the further researches.

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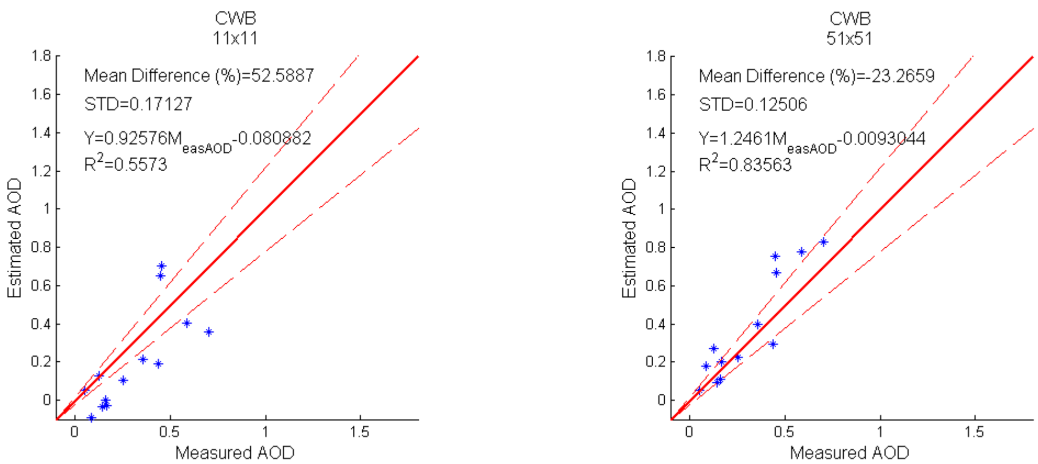

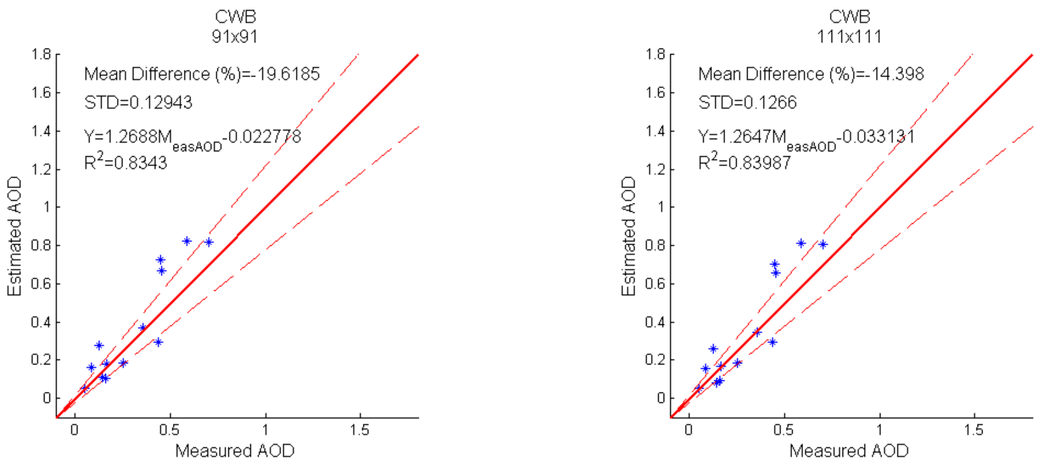

Figure 2. Different window size retrieving results in Taipei. The solid line and dashed lines are slopes at 1:1, 1.2:1 (steeper) and 0.8, respectively.

From Table 1, as the window size is larger than 31x31, the STDs are around 0.13 and R^2 are from 0.83 to 0.86. Results show that the STD and R^2 values are both quite stable and are insensitive to the window size. Additionally smaller windows due to their landcover variability are not good for retrieving. For simplicity, the window size at 51x51 will be adopted in future works.

Table 1. The retrieved regression equation, R^2, STD, and error percentage, and for different window sizes. Meas in regression equation represents measured AOD

Size	Regression Eq.	R^2	STD	Error (%)
11	Y=0.92576*Meas-0.080882	0.56	0.17	-52.59
31	Y=1.1041*Meas-0.0067254	0.76	0.13	9.67
51	Y=1.2461*Meas-0.0093044	0.84	0.13	23.27
71	Y=1.2702*Meas-0.030437	0.83	0.13	15.83
91	Y=1.2688*Meas-0.022778	0.83	0.13	19.62
111	Y=1.2647*Meas-0.033131	0.84	0.13	14.40
131	Y=1.2597*Meas-0.038122	0.84	0.13	11.73
151	Y=1.2608*Meas-0.055927	0.85	0.12	2.68
171	Y=1.2758*Meas-0.072974	0.86	0.12	-4.58

According to the equations, the selected referenced image (denominator term) does affect the retrieving results. This study fixed the window size at 51x51 and applied several different observed AODs (e.g. 0.127, 0.163 and 0.438) as a referenced image to retrieve the AOD. Results show that the retrieved error for AOD=0.127 is -61.74%, AOD=0.163 is 51.74% and AOD=0.438 is 100.53%. Compared to the AOD=0.047 (23.27%), the latter referenced errors are large. It reveals that the retrieved error is proportional to the observed AOD.

6. SUMMARY

Retrieving AOD over urban is a challenging task. However, based on a simplified RTE it can be overcome. A reference image under a most clean day and a 51x51 window size are best for obtaining the retrieving results. Results show that the R^2 is insensitive to the window size as it is larger than 51x51. Different level of aerosol loading will cause diverse results. To minimize the risk of unstable results, the candidate of a referenced image should be as clean as possible. Parameters applied in this study are reflectance and incidence angle only. To improve the proposed methodology, factors such as azimuth, orientation… etc should be included in future work.

ACKNOWLEDGEMENT

This research was primarily supported by the National Science Council of Taiwan under grant: NSC100-2119-M-008-001.

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