Determining the Optimal Aerosol Model and Assumed DT Surface Reflectance in Aerosol Optical Depth Retrieval Procedure for Satellite Images

Chien-Hui Liu

***Abstract*—Aerosol optical depth (AOD) is one of the essential parameters to monitor air pollution using remote sensing technique. It is also the key parameter in atmospheric correction (AC) of satellite images. Dark target (DT) method is the most popular method in AOD retrieval from space. Assumptions of DT surface reflectance and aerosol model should be made, thus could cause errors in AOD retrieval and also the following-on AC. A fixed aerosol model is usually selected in AOD retrieval for a given study area; thus, it is not able to account for regions with larger aerosol variations. In this study, the optimal aerosol model and assumed DT surface reflectance are determined in AOD retrieval for SPOT satellite data. Darkest pixel (DP) target is used as DT. Retrieval of AOD is performed at red band using DP. The accuracy of the AOD retrieval is assessed by ground measured sunphotometer data.**

***Index Terms*—Dark Target, Aerosol Optical Depth, Atmospheric Correction, Remote Sensing.**

I. Introduction

Aerosol is the main uncertain factor in global change research. It is very important to clarify the role of aerosol in global warming and simplify the complex problem [1]. In contrary to the sparse sampling by ground measurements, satellite remote sensing has the advantage of large-area and repetitive monitoring [2]. Remote sensing of aerosol can be used to monitor air pollution and applied in public health studies [3]. Atmospheric correction (AC) of satellite data is the essential work of the remote sensing community, and the preliminary step is to determine the aerosol characteristics including aerosol model and aerosol optical depth (AOD). Hence it is very important to determine aerosol characteristics from satellite images.

Atmospheric correction (AC) of remotely sensed data aims to correct atmospheric effect of images including absorption and scattering by atmospheric gas molecules and aerosols. The most uncertain factors are aerosol characteristics such as aerosol optical depth (AOD) and aerosol model accounting for concentration and type, respectively. Though ground measurement is the most accurate method, available measurements are sparse and not able to be applied in AC of the historical images [4]. Therefore, it is necessary to develop a method based on image itself [5], [6]. Aerosol model is usually properly selected and fixed, and then AOD is then derived based on radiative transfer model [7], [8] over dark targets (DT) or bright target (BT) [9]. DT method is used based on its stable and low reflectance as a result of small error of retrieved AOD. DT surface reflectance can be well assumed using the high correlation between surface reflectances in visible and middle-infrared bands [10]. Accuracy of retrieved AOD for DT is sensitive to assumed DT surface reflectance, since an error of 0.01 in assumed surface reflectance can cause error of 0.1 in retrieved AOD [8], [11]. To compensate DT method, deep blue method in AOD retrieval for BT such as semiarid and urban areas with much darker reflectance in blue bands can be applied [12]. Sometimes, simultaneous determination of AOD and surface reflectance or aerosol model and AOD of satellite image are also obtained [5], [13]. Multi-sensor atmospheric correction and cloud screening (MACCS) method can be implemented for several satellites including FORMOSAT-2, LandSat, VENμS and Sentinel-2 in AOD retrieval over land for AC of these data. The method comprises two parts: a multi-spectral method assuming a constant relationship between surface reflectance at different bands and a multi-temporal method assuming the surface reflectances are unchanged with time. Though the accuracy of retrieved AOD by MACCS can be up to 0.07 in most cases, MACCS uses a fixed aerosol model for a given site, hence it not applicable at regions for large variations of aerosol characteristics.

This study aims to determine the optimal aerosol model and assumed DT surface reflectance in AOD retrieval for SPOT satellite data. DT is defined as darkest pixel (DP) of the image. Test site in Taoyuan, Taiwan is selected. The accuracy of retrieved AOD is assessed by Aerosol Robotic Network (AERONET) data. The algorithm is confined to cloudless images with uniform atmospheric effect.

II. Methodology

A. *Satellite Images*

Experiments are conducted over Taoyuan test site in Taiwan. Total of 37 SPOT satellite images are acquired from Center for Space and Remote Sensing Research (CSRSR), National Central University (NCU). The temporal ranges of these images are 2006/10~2010/5. Images with only cloudless and uniform atmospheric effect, which are determined by visual interpretation, are acquired. Test area covers spatial range with 12 km x 12 km.

B. *Ground-Measured Aerosol Optical Depth Data*

Sunphotometer data over EPA_NCU station corresponding to Taoyuan area are used to verify that the

Chien-Hui Liu, Department of Digital Media and Product Design, Transworld University, Douliu, Taiwan, R.O.C.

accuracy of AOD inversion from the SPOT satellite images. Sunphotometer-measured AOD data within 30 minutes of SPOT satellite overpass time are averaged and used to validate the AOD retrieval algorithm.

C. Aerosol Model and Optical Depth Retrieval

Top-of-atmosphere (TOA) reflectance ρ^{TOA} is simulated by 6SV [14]. Both aerosol model and DT surface reflectance ρ_{DT} have to be assumed, when inferring AOD550 from ρ^{TOA} of DT. AOD550 denotes the AOD at 550 nm, which is used to parameterize aerosol optical depth for 6SV. Aerosol models in 6SV such as continental, maritime, urban, desert and biomass-burning types are considered. DT is selected because of smaller error in retrieved AOD from TOA when compared with other targets. Here DT is determined from the darkest pixel (DP). AOD retrieval is performed with DP at red band [17]. RMSEs at wide range of ρ_{DP} (0.0 ~ 0.03 with step of 0.001) are computed by comparing retrieved AOD and ground-measurement AOD data from AERONET for every considered aerosol model. Both of the optimal aerosol model and assumed ρ_{DP} are determined at the minimum RMSE.

III. Results and Discussion

Fig. 1 illustrates the histogram and related statistics of sunphotometer measured AOD550 for the 37 SPOT satellite images. The range of ground measured AOD550 is 0.051 ~ 0.81. Over 50% images are taken at quite clear sky with AOD550 around and below 0.2 (0.23 for clear sky considered in 6S [13]. Mean and standard deviation of AOD550 measured are 0.33 and 0.22, respectively. Few images are taken in hazy sky, which is 0.76 considered in 6S. Hence, one can see the images considered here are in diverse haziness of sky.

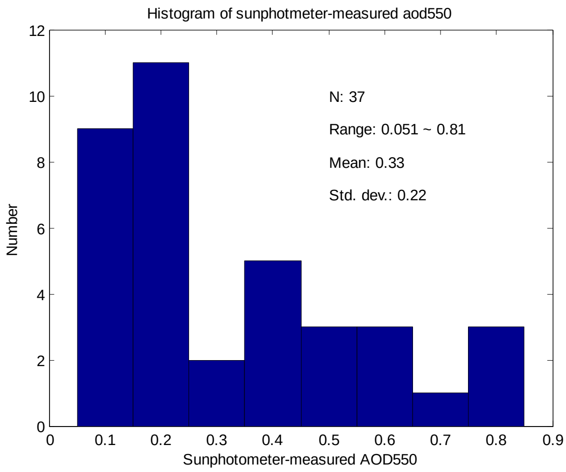

Fig. 1. Histogram and statistics of sunphotometer measured AOD550.

The relationship between measured and SPOT retrieved AOD550 is shown for various aerosol models including continental, maritime, desert and biomass burning in Fig. 2. DP reflectance (DPR) at red is considered as 0.02 (Fig. 2), which is the mean value assumed suggested by [6]. The linear least squares fit and RMSEs are also shown. The slopes are 1.144, 0.772, 0.970 and 1.093 for continental, maritime, desert and biomass burning aerosol models, respectively; and the intercepts are -0.096, -0058, -0.080 and -0.095, respectively. The R^2 values are 0.71, 0.66, 0.70 and 0.70, respectively. The discrepancy between the measured and retrieved AOD550 can be attributed to assumed aerosol model and DT reflectance at red. The RMSEs range from 0.16 to 0.19 for the four aerosol models with largest error (0.19) if maritime aerosol model is assumed.

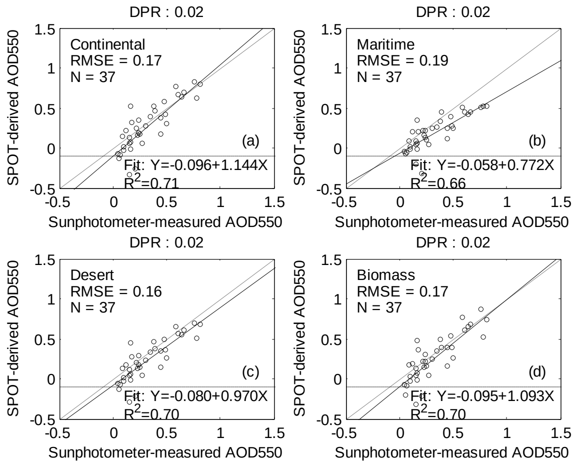

Fig. 2. The relationship between measured and SPOT retrieved AOD550 for various aerosol models. DPR at red band is 0.02.

To better understand the effect of assumed DPR on the relationship between measured and retrieved AOD550, case similar to Fig. 2 except assumed DPR of 0.01 and 0.0 is illustrated in Fig. 3 and Fig. 4. RMSEs are almost reduced for all considered aerosol models. RMSE is smallest (0.12) for maritime aerosol, which can be considered as optimal aerosol model.

Since Taiwan is an island located at East Asia where dust storms are common during late winter and spring [15], [16], it seems quite reasonable that maritime aerosol model is the most suitable in Taoyuan.

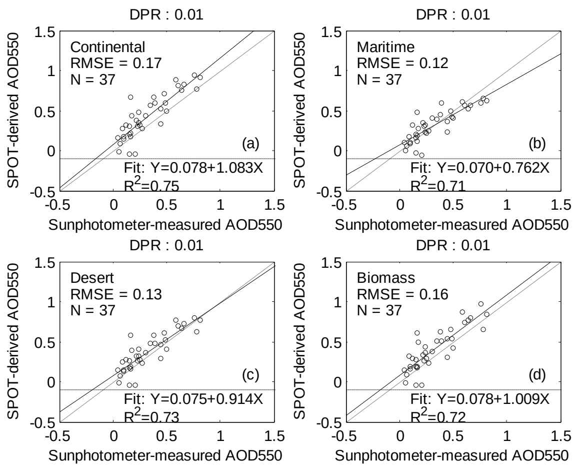

Fig. 3. Same as Fig. 2, except DPR at red band of 0.01.

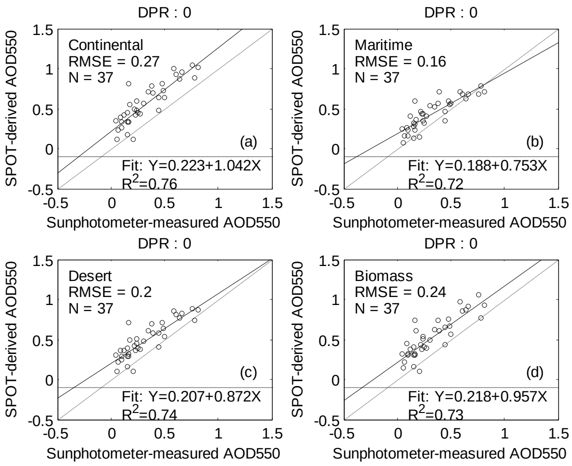

Fig. 4. Same as Fig. 2, except DPR at red band of 0.0.

IV. Conclusion

In this paper, optimal aerosol model and assumed DT surface reflectance in AOD retrieval for SPOT satellite data are determined. DT is defined as darkest pixel (DP) of the image. Retrieval of AOD is performed at red band using DP. The result shows that the most suitable aerosol model in AOD retrieval is maritime in Taoyuan, Taiwan. RMSE of retrieved AOD can be 0.12, when DT reflectance at red band is assumed to be 0.01.

Acknowledgement

Thanks go to Prof. Neng-Huei Lin in department of atmospheric sciences, National Central University and Prof. Po-Hsiung Lin in department of atmospheric sciences, National Taiwan University, all in Taiwan, R.O.C, for their support of AERONET data.

References

[1] I. Held, "Simplicity amid complexity," *Science*, vol. 343, no. 6176, pp. 1206–1207, 2014.

[2] A. A. Chudnovsky et al., "Fine particulate matter predictions using high resolution Aerosol Optical Depth (AOD) retrievals," *Atmos. Environ.*, vol. 89, pp. 189–198, 2014.

[3] M. Al-Hamdan, W. Crosson, E. Burrows, S. Coffield, B. Crane, and M. Barik, "Development and validation of improved PM2. 5 models for public health applications using remotely sensed aerosol and meteorological data," *Environ. Monit. Assess.*, vol. 191, no. 2, pp. 1–16, 2019.

[4] M. S. Moran, R. D. Jackson, P. N. Slater, and P. M. Teillet, "Evaluation of simplified procedures for retrieval of land surface reflectance factors from satellite sensor output," *Remote Sens. Environ.*, vol. 41, no. 2–3, pp. 169–184, 1992.

[5] C. H. Liu, A. J. Chen, and G. R. Liu, "An image-based retrieval algorithm of aerosol characteristics and surface reflectance for satellite images," *Int. J. Remote Sens.*, vol. 17, no. 17, pp. 3477–3500, 1996.

[6] Y. J. Kaufman and C. Sendra, "Algorithm for automatic atmospheric corrections to visible and near-IR satellite imagery," *Int. J. Remote Sens.*, vol. 9, no. 8, pp. 1357–1381, 1988.

[7] O. Hagolle, M. Huc, D. Villa Pascual, and G. Dedieu, "A multi-temporal and multi-spectral method to estimate aerosol optical thickness over land, for the atmospheric correction of FormoSat-2, LandSat, VENµS and Sentinel-2 images," *Remote Sens.*, vol. 7, no. 3, pp. 2668–2691, 2015.

[8] C.-H. Liu and G.-R. Liu, "Aerosol optical depth retrieval for SPOT HRV images," *J Mar Sci Technol*, vol. 17, no. 4, pp. 300–305, 2009.

[9] A. M. Sayer, N. C. Hsu, C. Bettenhausen, and M.-J. Jeong, "Validation and uncertainty estimates for MODIS Collection 6 'Deep Blue' aerosol data," *J. Geophys. Res. Atmospheres*, vol. 118, no. 14, pp. 7864–7872, 2013.

[10] Y. J. Kaufman, D. Tanré, L. Remer, E. Vermote, A. Chu, and B. N. Holben, "Remote sensing of tropospheric aerosol from EOS-MODIS over the land using dark targets and dynamic aerosol models," *J Geophys Res*, vol. 102, pp. 17051–17067, 1997.

[11] Y. J. Kaufman, A. E. Wald, L. A. Remer, B.-C. Gao, R.-R. Li, and L. Flynn, "The MODIS 2.1-/spl mu/m channel-correlation with visible reflectance for use in remote sensing of aerosol," *IEEE Trans. Geosci. Remote Sens.*, vol. 35, no. 5, pp. 1286–1298, 1997.

[12] V. Sharma, S. Ghosh, M. Bilal, S. Dey, and S. Singh, "Performance of MODIS C6. 1 dark target and deep blue aerosol products in Delhi national capital region, India: application for aerosol studies," *Atmospheric Pollut. Res.*, vol. 12, no. 3, pp. 65–74, 2021.

[13] J. Guang, Y. Xue, Y. Li, S. Liang, L. Mei, and H. Xu, "Retrieval of aerosol optical depth over bright land surfaces by coupling bidirectional reflectance distribution function model and aerosol retrieval model," *Remote Sens. Lett.*, vol. 3, no. 7, pp. 577–584, 2012.

[14] S. Y. Kotchenova, E. F. Vermote, R. Matarrese, F. J. Klemm Jr, and others, "Validation of a vector version of the 6S radiative transfer code for atmospheric correction of satellite data. Part I: Path radiance," *Appl. Opt.*, vol. 45, no. 26, pp. 6762–6774, 2006.

[15] T.-H. Lin, "Long-range transport of yellow sand to Taiwan in spring 2000: observed evidence and simulation," *Atmos. Environ.*, vol. 35, no. 34, pp. 5873–5882, 2001.

[16] C.-Y. Lin et al., "Long-range transport of Asian dust and air pollutants to Taiwan," *Terr Atmos Ocean Sci*, vol. 15, no. 5, pp. 759–784, 2004.

[17] Hadjimitsis, D. G., Clayton, C. R., & Retalis, A. (2004). On the darkest pixel atmospheric correction algorithm: a revised procedure applied over satellite remotely sensed images intended for environmental applications. *Remote Sensing for Environmental Monitoring, GIS Applications, and Geology III*, 5239, 464-471.