https://doi.org/10.31871/IJNTR.8.6.15
International Journal of New Technology and Research (IJNTR)
ISSN: 2454-4116, Volume-8, Issue-6, June 2022 Pages 04-06

Developing a Semi-Empirical Model to Infer Aerosol Optical Depth from SPOT Satellite Images

Chien-Hui Liu

***Abstract*—In this study, a semi-empirical model to retrieve aerosol optical depth (AOD) from SPOT satellite images is developed. It is based on linear regression between top-of-atmosphere reflectance of darkest pixel target at red band and ground-measured AOD550 (AOD at 550 nm). Its physical concept is explained. Test area over Tainan, Taiwan, is selected. Sun-photometer data over Chen-Kung_Univ station of Aerosol Robotic Network data are implemented. The results show that high determination coefficient (0.77) of the model is obtained, which indicates the feasibility of the developed model. Limitation of the developed model is also described.**

***Index Terms*—Aerosol Optical Depth, SPOT satellite, Dark Target, Sunphotometer.**

I. Introduction

Currently, aerosol is an important factor when climate change issue is concerned [1], [2]. Aerosol optical depth (AOD) is also the main uncertain factor, when atmospheric correction (AC) of remotely-sensed data is needed. Radiative transfer model (RTM) is usually used with both assumptions of aerosol model and surface reflectance of dark target (DT) for retrieval of AOD [3]–[5]. In addition to the complexity of the RTM, these assumptions can also cause errors.

Current AOD retrieval from satellite remote sensing relies on mainly dark target method [6]. RTM is usually applied in AOD retrieval and AC for remote sensing data. Assumptions of aerosol model and surface characteristics, usually dark target, have to be made in such approach. Thus, they can cause errors. Therefore, a simple method able to retrieve AOD with comparable accuracy is worth noticing.

Alternative approach is the contrast reduction method [7]. Dark object subtraction is simple, hence further improved and widely used in AC and surface reflectance retrieval for Landsat data [8], [9]. However, this method doesn't determine AOD information. Hence, a simple algorithm in AOD retrieval is worthy to develop

A semi-empirical model to derive AOD from top-of-atmosphere (TOA) reflectance of dark target (DT) at red band DT is proposed. This study also introduces the physical concept of the semi-empirical model, which is based on linear regression between TOA reflectance of DT and ground-measured AOD550 (AOD at 550 nm). Currently, DT is selected as darkest pixel (DP). The algorithm is confined to cloudless images with uniform atmospheric effect.

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

II. Methodology

A. Data

Test site Tainan is selected in this study. Total 31 SPOT satellite images, purchased from Center for Space and Remote Sensing Research (CSRSR) of National Central University (NCU) over Tainan are acquired. These data amount are large, compared with the previous study [4], to obtain significant result. The temporal range of these images is 2002/04~2011/04. 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. Fig. 1 shows SPOT HRV image over Tainan, taken on 2002/11/12.

Fig. 1. SPOT satellite image over Tainan test site with false-color band combinations: near infrared (red), red (green) and green (blue).

Sunphotometer data over Chen-Kung_Univ station corresponding to Tainan area is used to verify the inversion of AOD from the SPOT satellite imagery. Ground-measured AOD data are obtained from sunphotometer measurements thanks to the inversion algorithm from Aerosol Robotic Network (AERONET) developed by NASA [10]. The sunphotometer-measured AOD data within 30 minutes of SPOT satellite overpass time are averaged and used to develop the AOD retrieval algorithm, i.e. the semi-empirical model.

B. Empirical Model of Aerosol Optical Depth Retrieval

Remotely sensed TOA reflectance basically consists of two parts: atmospheric reflectance and surface reflectance, including target and adjacency. To derive AOD from DT, homogeneous surface is usually assumed. However, significant error can be generated. Simulation showed that relative errors of retrieved AOD550 could be up to 100% and 97% at blue and red bands, respectively, in the case of medium contrast, i.e. DT reflectance 0.01~0.06 and background (adjacent) reflectance 0.12, for AOD550=0.23 [11]. In fact, such an error can further be propagated and inducing error in surface reflectance of larger than 0.01 in AC for most cases [12]. It is difficult to know beforehand the adjacency reflectance of DT; hence background reflectance is usually assumed to be the same as that of DT. When these errors and also surface reflection are neglected, TOA reflectance ρ^{TOA} can be written as:

$$\rho^{TOA} = \frac{\omega_0 P}{4\mu\mu_0} AOD550 + \varepsilon, \qquad (1)$$

where ω_0 and P are single scattering albedo and phase function for aerosol as single scattering approximation is assumed for low aerosol concentration. The $\mu\mu_0$ are multiplication of cosine of viewing and solar zenith angles. The ε is the error due to neglect of surface reflection. To infer AOD550 from ρ^{TOA}, eq. (1) is rewritten as:

$$AOD_{550} = a_1 * \rho^{TOA} + a_0. \qquad (2)$$

where a_1 and a_0 are the linear-regressed coefficients. Since DT reflectance is very low at red band, e.g. 0.01 [5], [13], empirical model is performed at this band here. Because derivation of eq. (2) can be physically plausible, it is named as semi-empirical model here. Currently, DT is selected as darkest pixel (DP) for every image [14]. This means that ρ^{TOA} used in performing linear regression is ρ^{TOA} of DP in every SPOT image.

III. Results and Discussion

Histogram and statistics of ground-measured AOD550 for the 31 SPOT satellite images is illustrated (Fig. 2). Ground measured AOD550 ranges from 0.17 ~ 1.4. Less images are taken at quite clear sky with AOD550 around and below 0.2 (0.23 for clear sky considered in 6S) [15]. In fact, many images are taken in hazy sky, which is 0.76 considered in 6S. Mean and standard deviation of all AOD550 measured taken accounted in Tainan site are 0.58 and 0.27, respectively. Hence, one can see the images considered here are in diverse haziness of sky.

Linear regression is applied to describe the relationship between SPOT satellite image retrieved AOD and ground-measured AOD over Tainan site using proposed empirical model (eq. (2)) (Fig. 3). High determination coefficient (0.77) is obtained, indicating the feasible assumption of empirical model. As Fig. 2 shows that AOD550 is zero, i.e. atmosphere with aerosol concentration, minimum ρ^{TOA}, i.e. ρ^{TOA} of DP, is not zero. This is because of Rayleigh scattering of molecules. This account for negative intercept, i.e. -0.378, of the empirical model (eq. (2)), when using DP TOA reflectance to infer AOD550.

IV. Conclusion

This study develops a semi-empirical model to retrieve AOD from top-of-atmosphere (TOA) reflectance of darkest target at red band. The physical concept of the semi-empirical model is also expressed. It is based on linear regression between TOA reflectance of darkest pixel and ground-measured AOD550. High determination coefficient (0.77) is obtained. This model is currently confined to cloudless images with uniform atmospheric effect.

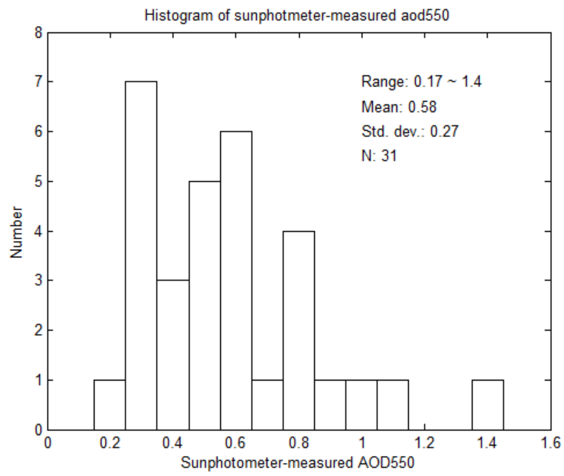

Fig. 2. Histogram and statistics of ground-measured AOD550 over Tainan.

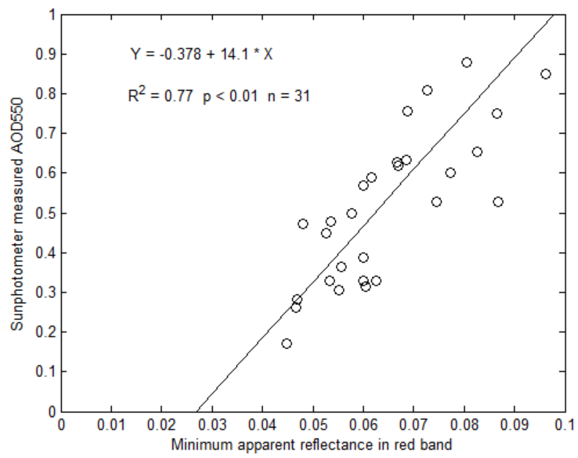

Fig. 3. Relationship between SPOT satellite retrieved AOD and ground-measured AOD over Tainan (NCKU) site.

Acknowledgement

Thanks go to Prof. Po-Hsiung Lin in department of atmospheric sciences, National Taiwan University, in Taiwan, R.O.C, for his support of AERONET data.

References

[1] C. E. Adler and G. Hirsch Hadorn, "The IPCC and treatment of uncertainties: topics and sources of dissensus," *Wiley Interdiscip. Rev. Clim. Change*, vol. 5, no. 5, pp. 663–676, 2014.

[2] N. Bellouin *et al.*, "Bounding global aerosol radiative forcing of climate change," *Rev. Geophys.*, vol. 58, no. 1, p. e2019RG000660, 2020.

[3] 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.

[4] 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.

[5] 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.

[6] R. C. Levy *et al.*, “The Collection 6 MODIS aerosol products over land and ocean,” *Atmospheric Meas. Tech.*, vol. 6, no. 11, pp. 2989–3034, 2013.
[7] D. Paronis and N. Sifakis, “Satellite aerosol optical thickness retrieval over land with contrast reduction analysis using a variable window size,” in *IGARSS 2003. 2003 IEEE International Geoscience and Remote Sensing Symposium. Proceedings (IEEE Cat. No. 03CH37477)*, 2003, vol. 2, pp. 1276–1278.
[8] L. Cui *et al.*, “Assessment of atmospheric correction methods for historical Landsat TM images in the coastal zone: A case study in Jiangsu, China,” *Eur. J. Remote Sens.*, vol. 47, no. 1, pp. 701–716, 2014.
[9] A. Makarau, R. Richter, R. Müller, and P. Reinartz, “Haze detection and removal in remotely sensed multispectral imagery,” *IEEE Trans. Geosci. Remote Sens.*, vol. 52, no. 9, pp. 5895–5905, 2014.
[10] B. N. Holben *et al.*, “AERONET—A federated instrument network and data archive for aerosol characterization,” *Remote Sens. Environ.*, vol. 66, no. 1, pp. 1–16, 1998.
[11] C.-H. Liu, “Error analysis of retrieved aerosol optical depth due to adjacency effect for ROCSAT-2 RSI bands,” *Terr. Atmospheric Ocean. Sci.*, vol. 16, no. 1, pp. 241–250, 2005.
[12] L. Chien-Hui, “Error propagation from aerosol retrieval to atmospheric correction due to adjacency effect for FORMOSAT-2 RSI band,” *TAO Terr. Atmospheric Ocean. Sci.*, vol. 18, no. 4, p. 8, 2007.
[13] C.-H. Liu, “A normalization scheme of bidirectional reflectances and normalized vegetation indices for short-term multi-angular SPOT satellite images,” *J. Mar. Sci. Technol.*, vol. 11, no. 4, p. 4, 2003.
[14] D. G. Hadjimitsis, C. R. Clayton, and A. Retalis, “On the darkest pixel atmospheric correction algorithm: a revised procedure applied over satellite remotely sensed images intended for environmental applications,” in *Remote Sensing for Environmental Monitoring, GIS Applications, and Geology III*, 2004, vol. 5239, pp. 464–471.
[15] S. Y. Kotchenova, E. F. Vermote, R. Matarrese, and F. J. Klemm Jr, “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.