Clear Sky Fitting of Multifilter Rotating Shadowband Radiometer Data for Aerosol Optical Depth Determinations

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Abstract

The retrieval algorithm of atmospheric column Aerosol Optical depth (AOD) from multi-filter rotating shadow-band radiometer (MFR 7) data at 870 nm at Sri Samrong district in Sukhothai province of Thailand is described and validated. In order to provide good data for clear sky, the empirical fit is investigated for both clear and cloudy days. The comparison reveals good agreement on retrieval AOD by Langley analysis of data between some identified clear sky periods and clear sky fitting. Finally a 10-day-period of atmospheric column AOD is determined including the cloudy days with the instrumental calibration coefficient of 1.002 ± 0.005.

Keywords: clear sky, MFR 7, AOD, instrumental calibration coefficient, diffuse ratio, Langley analysis, Retrieval

INTRODUCTION

In recent years, Multi-Filter Rotating Shadow-band Radiometer has become a popular network instrumentation as ground-based sun photometer network, it can be used to produce a land-based aerosol climatology in addition to satellite retrievals, being nowadays performed mostly over ocean (Alexandrov *et al.* 2002). Since, climate effects of atmospheric aerosol are becoming a major environmental concern (Ramanathan *et al*. 2001). Aerosols display substantial and temporal validations due to their short lifetimes (a week or less) and various natural and anthropogenic emission sources (Zhao *et al*. 2003). They affect the radiative balance of the Earth/atmosphere system via the direct effect whereby they scatter and absorb solar and terrestrial radiation, and via the indirect effect whereby they modify the microphysical properties of clouds thereby affecting the radiative properties and lifetimes of clouds (Haywood *et al*. 2003). Tropospheric aerosols with their direct and indirect radiative influences continue to be one of the most significant sources of uncertainty in climate change modeling. The validation of satellite retrieval algorithm for surface irradiance requires accurate surface measurements (Long and Ackerman 2000). Disagreement between satellite retrieval and surface measurements may arise from many resources, even if all physical properties of the atmospheric state are well available.

Aerosol Optical Depth (AOD) is a main parameter in the field of atmospheric science because it can give a rough idea about aerosol in the atmosphere for both monitoring and modeling earth system process and global climate change. Generally, AOD is estimated using model calculations with radiation codes, e.g. in 2003, Haywood *et al*. derived AODs at different wavelengths from in situ measurements of the scattering and absorption coefficients and from various radiometric measurements and compared the results with ones derived from surface-based Aerosol Robotic Network (AERONET) sun photometer site in the same locations (Haywood *et al.* 2003). A year later, Zhao *et al*. presented the regional validation results for an Advanced Very High Resolution Radiometer (AVHRR) independent two-channel aerosol retrieval algorithm by comparing the retrievals with observation from AERONET to facilitate the utilization of long term AVHRR aerosol products in climate studies (Zhao *et al*. 2004).

In this work, atmospheric column AOD retrievals and a determination of instrumental calibration constant are performed by Langley analysis from clear day data at wavelength 870 nm. AODs are retrieved from the direct and diffuse downwelling irradiances measured by MFR 7 which strongly influence by the presence of aerosols and their relations with air mass modification. The qualified data for AOD retrieval algorithm should be good clear sky radiance data. Firstly, the normalized diffuse ratio variability test is applied to measured data for eliminating some presence of clouds and temporal variations in haze or sub-visual cirrus measurements before a determination. Secondly, an empirical fit for clear sky is carried out in order to provide good data for clear sky. To monitor a validated fitting, atmospheric column AODs are retrieved from the fitted data, and then compare to the unfitted data results. This will provide a significant guidance for precision of AOD retrieval with clear sky radiance data for the further work in this field.

INSTRUMETAL AND OBSERVATION

In this work, all data were collected at Sri Samrong district, Sukhothai province, Thailand (17° 0′ 21″ N, 99° 49′ 35″ E), using MRF-7 (User Guide 2000) which is a field instrument that measures global or total, direct and diffuse components of solar irradiances with up to 7 wavelengths (broadband, 415, 500, 615, 673, 870 and 940 nm). It is equipped with one broadband channel and six narrowband channels. A microprocessor-controlled shadowband alternately shades and exposes an instrumental diffuser, enabling the system to measure all three irradiance components by one detector. The band is rotated to measure total irradiance and the diffuse horizontal irradiance is measured when the sun is completely blocked. In order to obtain the direct normal component, total irradiance is subtracted from corrected diffuse component and divided by the cosine of solar zenith angle.

Aerosols and Rayleigh scatterings contribute atmospheric extinction in all channels (Alexandrov *et al.* 2002) whilst water vapor does at 940 nm and the other gaseous absorbers i.e., NO_2 and O_3 do at 415, 500, 615 nm and 500, 615, 673 nm, respectively. As a result, it is rather convenient to retrieve AOD from the measured data at 870 nm channel since the extinction source is primary aerosol with little contribution from gaseous absorbers. However the measured data from both clear and partly cloudy days are still required for the retrieval algorithm. It is remarkable to retrieve daily AOD for consecutive days, although cloudy days are found. Therefore, the empirically fitting for clear sky is required before AOD determination. To validate the retrieval, good data of clear sky for less cloudy days was initially obtained then following up with clear sky fitting to retrieve AODs.

RETRIEVAL ALGORITHM

Instrumental calibration constant and atmospheric column AOD

Firstly, the clear (defined as cloudless) or partial cloudy days were manually selected, yielding a preferable day on 13 Jan 2003. Since the diffuse ratio (the diffuse shortwave irradiance divided by the total shortwave irradiance) is sensitive to small changes in both diffuse and direct shortwave components, an identification of measured data of clear sky periods is simply provided by applying the normalized diffuse ratio variability test (Long and Ackerman 2000.) together with an elimination of early morning and late evening periods when solar zenith angles are greater than 80^{o} on average. The obtainable data is normalized by a power law function of the cosine of solar zenith angle:

$$D_n = D_i / \mu_0^b \qquad (1)$$

where D_i is the downwelling diffuse ratio shortwave, D_n refers to the normalized diffuse ratio shortwave, μ_0 is the cosine of solar zenith angle, and b is a constant (b =-0.5, the average value of b obtained from the polynomial fit of the data plotted between diffuse ratio and μ_0 during the studied periods). The deviation data in terms of normalized irradiance were excluded from the clear sky periods with an assumption of the presence of clouds and temporal variations in haze or sub-visual cirrus. The valid minimum number of identified clear sky measurements is set at 120 (Long and Ackerman 2000). So a process of retrieval algorithm for the measured direct solar irradiance data of daily clear sky periods is able to perform properly for clear day.

The algorithm provides retrieval AODs together with a simultaneous determination of the instrumental calibration constants via Langley analysis at 870 nm channel from direct solar irradiance data set. Since the measured direct solar irradiance can be represented in the form (User Guide 2000) :

$$I = CI_0 \exp(-\tau m) \tag{2}$$

Here τ is the total atmospheric column extinction optical depth, I_0 is the top of atmosphere solar intensity, C is the correction factor used as calibration coefficient, and m is the air mass relative to unit air mass in zenith direction with a common air mass formula (User Guide 2000) :

$$m = 1.0/[\cos(el) + 0.50572(96.07995 - el)] \tag{3}$$

Here *el* is the elevation in degrees. If $\tilde{\tau}$ is the non-calibrated optical depth which is equal to ($\ln I_0 - \ln I)/m$, while the retrieval $\ln I_0$ has been done via Langley plot of $\ln I$ versus *m* of non-calibrated equation :

$$\ln I = \ln I_0 - \tilde{\tau} m \tag{4}$$

In order to remove the Rayleigh scattering before AODs retrieval, we use τ_{Rayleigh} of 0.0151 determined from

$$\tau_{Rayleigh} = 0.008569\lambda^{-4}(1 + 0.0113\lambda^{-2} + 0.00013\lambda^{-4})\frac{P}{P_0} \tag{5}$$

where λ is the wavelength in micrometers, P (1008.80 mb) is the site pressure relative to sea level pressure P_0 (1013.25 mb). And from Eqn 2 and Eqn 4, it can be shown that

$$\tilde{\tau} m = \tau_a m - \ln C \tag{6}$$

From the Langley plot of $\tilde{\tau}\, m$ (after Rayleigh term is removed) versus air mass *m* (not greater than 2.5 in this work), the calibration constant and the atmospheric column AOD (τ_a) are obtained.

Empirical fit for clear sky

A form of simple power law equation used as empirical fit for clear sky irradiance (Long and Ackerman 2000) is

$$Y = a\mu_0^b \qquad (7)$$

where Y is the clear sky diffuse ratio and a and b are regression coefficients which are subsequently determined, so the good data for diurnal cycle of clear sky irradiance can be retrieved. To monitor a reliability of the empirical fit, the above data for clear sky was used for a retrieval of the atmospheric column AOD and compared to the former one.

Finally, all retrieval algorithms for the atmospheric column AOD were repeated with measured data of 10 consecutive days, whether they are clear or cloudy skies.

RESULT AND DISCUSSION

Since 13 Jan 2003 data was investigated as a clear sky day with its results presented in Fig 1 - 3(a). It can be seen in Fig (2b) and (2c) accompanied by Eqn 6 that the slopes of both lines are atmospheric column AODs which all show good agreement. As a result, the procedure of clear sky fit is reasonably reliable. The daily regression coefficients of an empirical fit for clear sky diffuse ratio and a 10-day period in January 2003 of the atmospheric column AODs are given in Table 1 and plotted in Fig 4. Fig 3(b) shows time series of another good fit of direct normal irradiance on 17 Jan 2003 when it was a cloudy day. Furthermore, we can observe from Fig 4 that the retrieval AOD from a fitting of good clear sky data corresponds mostly to another one from measured data with the absence of cloud in a 10-day period. Hence the retrieval AODs in the cloudy day under these conditions is validated. From a 10-day Langley plot of $\tilde{\tau}\, m$ versus m as in Eqn 6, the MRF-7 instrumental calibration coefficients are provided as 1.002 ± 0.005 (from experimental data), and 1.001 ± 0.003 (from the clear sky fitting).

Table 1 A daily archive of regression coefficients (*a* and *b*) for the clear sky diffuse ratio of 10 days with the atmospheric column AODs and calibration coefficients (C).

Date in Jan 2003	*a*	*b*	AOD	C
11th	0.1945	-0.6789	0.2697	0.99998
12th	0.1336	-1.2272	0.3111	1.00003
13th	0.1575	-0.6402	0.1860	1.00002
14th	0.1813	-0.5259	0.1785	1.00005
15th	0.1730	-0.6639	0.2207	1.00005
16th	0.2063	-0.4017	0.1695	0.99996
17th	0.2125	-0.4543	0.1986	1.00481
18th	0.1193	-0.4361	0.1146	0.99998
19th	0.1100	-1.0027	0.2678	0.99996
20th	0.1773	-0.5046	0.1782	1.01704

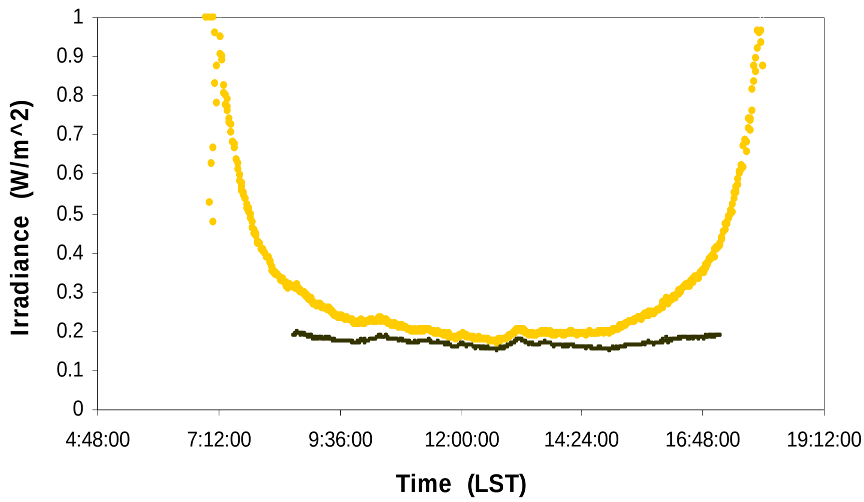
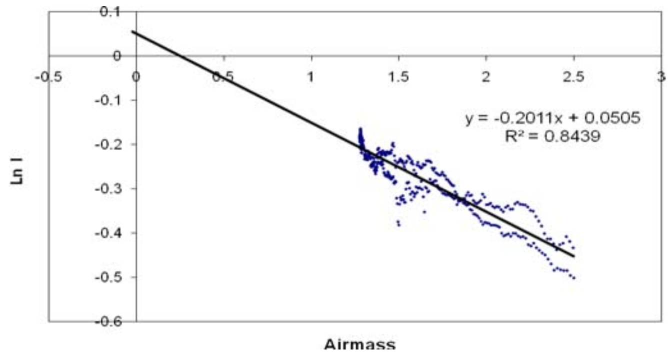
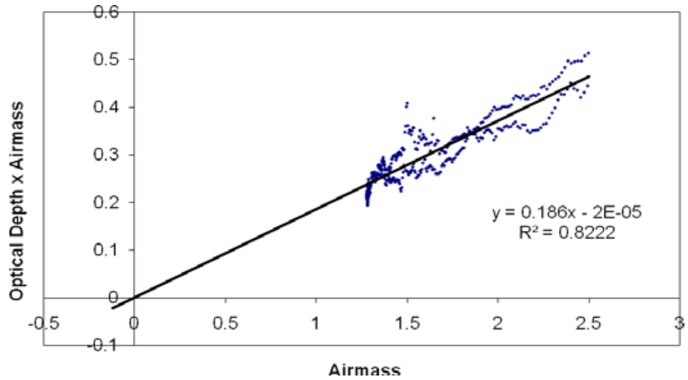


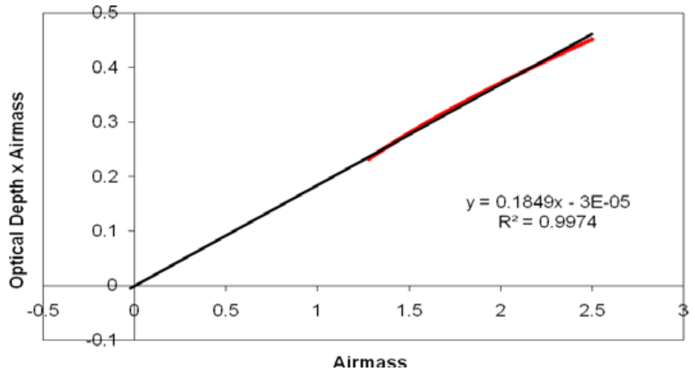
Figure 1 Time series of diffuse ratio (yellow line) and normalized diffuse ratio (black line) on 13 Jan 2003. The identified clear periods are from 8.48-13.02 and from 13.39 – 16.10 local time.



(2a)

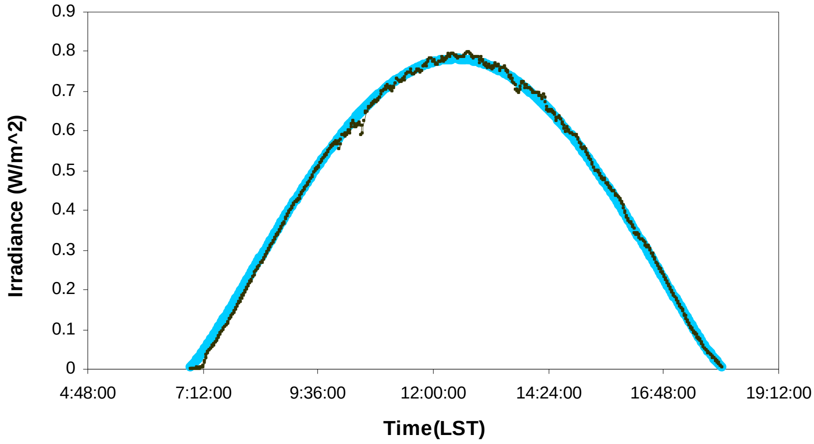


(2b)

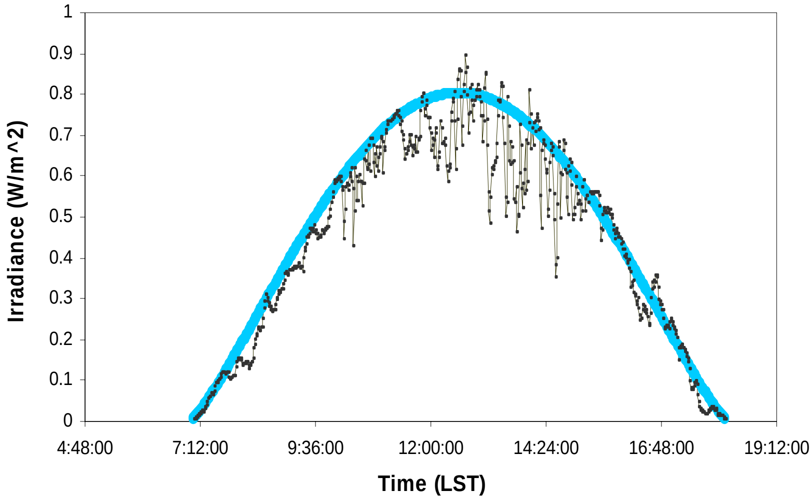


(2c)

Figure 2 Langley plots of identified clear sky period on 13 Jan 2003 for (2a) non-calibrated Eqn 4 and (2b) calibrated Eqn 6. And (2c) Langley plot of good data for clear sky by Eqn 6 on the same day.



(3a)



(3b)

Figure 3 Time series of measured direct normal irradiance (black line) and clear sky fitted data (blue line) on (3a) 13 Jan 2003 and (3b) 17 Jan 2003.

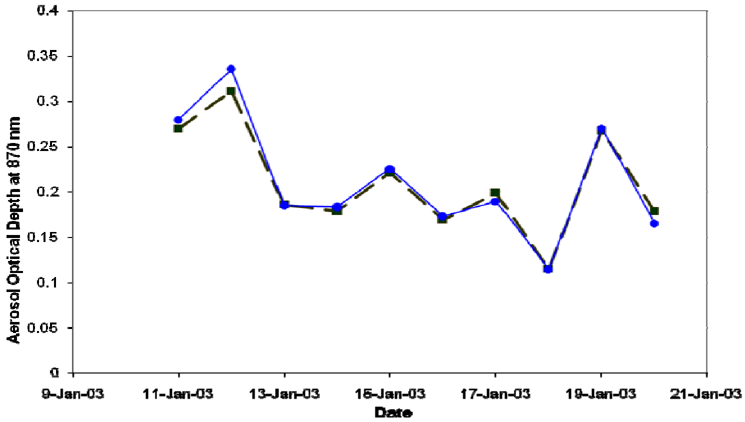


Figure 4 A variation of daily atmospheric column AODs for 10 days (11-20 January 2003) was retrieved from the measured data (dash line) comparing to the clear sky fitted data (solid blue line).

CONCLUSIONS

Results reveal an approved validation of clear sky fitting. Importantly, the daily AOD can be determined without excluding the cloudy days, and then the diurnal varying atmospheric aerosols in that location can be consequently considered except special case of bad whole cloudy days. The feasibility of retrieval algorithms from the MFR-7 data under various conditions is still very challenging for a further study, which will be useful and plays a key role in climatology.

ACKNOWLEDGEMENTS

The authors are grateful to the National Institute of Environmental Studies of Japan and the Department of Geology, Faculty of Science, Chulalongkorn University for supporting all facilities and raw data. Also we express our gratitude to Faculty of Science, Srinakharinwirot University for supporting graduate research scholarship.

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