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A model for calculating the depletion coefficient of solar illuminance by aerosols

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Abstract

Aerosols are small particles suspended in the atmosphere, and they affect the depletion of solar illuminance. The ability of aerosol in depleting solar illuminance can be quantified in terms of depletion coefficient (D_{aer}). In this work, a model for calculating D_{aer} is presented. To formulate the model, 6S radiative transfer model was used to calculate D_{aer} by varying aerosol optical depth (AOD) and air mass (m_a). Then the model relating D_{aer} with AOD and m_a was obtained. To investigate its performance, the model was used to calculate aerosol depletion coefficient at two solar radiation monitoring stations in Thailand and the results were compared with the measurements. It was found that the values of the coefficient calculated from the model and those obtained from the measurements were in reasonable agreement.

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Keywords: depletion of solar illuminance, aerosol optical depth, solar illuminance

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1. Introduction

Aerosols are small solid particles or liquid droplets suspended in the atmosphere [1]. They play an important role in the Earth's radiative budget and affect the depletion of solar illuminance by scattering and absorbing processes. The ability of aerosols in depleting solar illuminance can be quantified in terms of aerosol depletion coefficient. This coefficient is an importance input parameter of satellite-based solar illuminance models. However, the exiting approach for calculating this coefficient is complicated [2]. Therefore, the object of this work is to developed a simple empirical model for calculating depletion coefficient of solar illuminance by aerosols.

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2. Methodology

The depletion coefficient of solar illuminance by aerosols (D_{aer}) is defined as follows:

$$D_{aer} = \frac{E_{clean} - E_{turbid}}{E_{clean}} \tag{1}$$

where E_{clean} is hourly solar illuminance under cloudless sky without aerosol and E_{turbid} is hourly solar illuminance under cloudless sky with aerosol load indicated by aerosol optical depth.

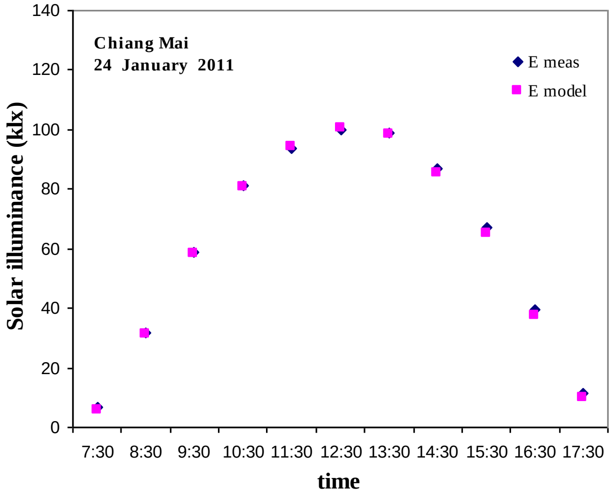
In general, E_{clean} and E_{turbid} can be calculated by using a radiative transfer model. However, the use of radiative transfer model to calculate D_{aer} directly from Eq.(1) is relatively complicated and time consuming. In this work, instead of using a radiative transfer model directly, the model was employed to generate the values of D_{aer} under various values of atmospheric parameters. Then the results were used to formulate an empirical formula relating D_{aer} to various atmospheric parameters. In this work the 6S radiative transfer model was selected to generate the value of D_{aer} .

The 6S radiative transfer model (second simulation of the satellite signal in the solar spectrum) has been documented by Vermote et al. [3]. This model was designed to compute the reflectance at satellite due to backscattering of solar radiation in the ground-atmosphere system, assuming a cloudless atmosphere. In addition, 6S model can be used to calculate all components of clear sky solar radiation at any levels of atmosphere and at any wavelength intervals. Therefore, it can be used to calculate the solar illuminance, which is a part of solar spectrum, by using spectral condition in visible region (380-770nm) and the CIE photopic response. The 6S model includes analytical descriptions of the absorption by aerosol particles and atmospheric gases (H_2O, O_3, O_2 and CO_2), describes the scattering by gas molecules (Rayleigh scattering) and aerosols (Mie scattering). The main input parameters of the model are solar zenith angle, precipitable water, total column ozone and aerosol optical depth at 550 nm. The main output parameters of the model are the direct and diffuse transmittances on sun-ground and ground-satellite paths and the reflectance or radiance at satellite level. For more details of the 6S model can be seen in ref. [3].

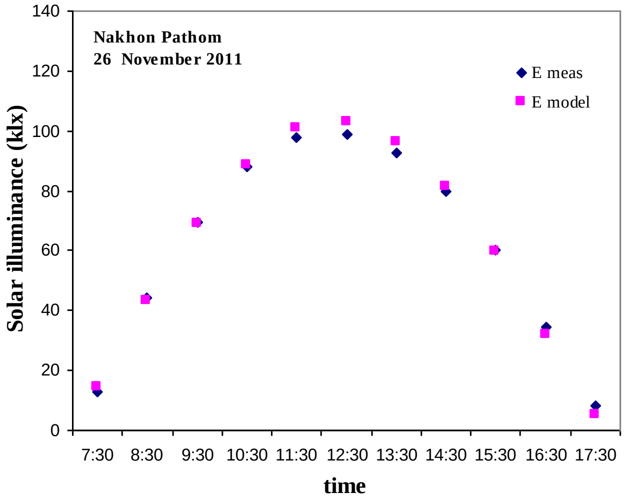
Before using 6S model, it was tested against measured solar illuminance data on cloudless day at two solar radiation monitoring stations in Thailand, namely Chiang Mai (18.78°N, 98.98°E) and Nakhon Pathom (13.82°N, 100.04°E). A sample of comparison is shown in Fig. 1.

The comparison results show that solar illuminance calculated by 6S and that obtained from the measurements are in good agreement.

In the next step, the 6S was used to calculate E_{clean} and E_{turbid} for various values of aerosol optical depth (AOD) and air mass (m_a). By substituting the values of E_{clean} and E_{turbid} in Eq.(1), the values of D_{aer} under various values of AOD and m_a were obtained. In the final step, a statistical relation of D_{aer} with AOD and m_a were formulated by using a regression analysis.



(a)



(b)

Fig. 1. The comparison between solar illuminance calculated from 6S (E_{model}) and that obtain from measurements (E_{meas}); (a) Chiang Mai, (b) Nakhon Pathom

3. Result and discussion

From the values of D_{aer} corresponding various values of with AOD and m_a obtained from 6S, it was found that $(1- D_{aer})^{1/ma}$ varied linearly with AOD as shown in Fig. 2.

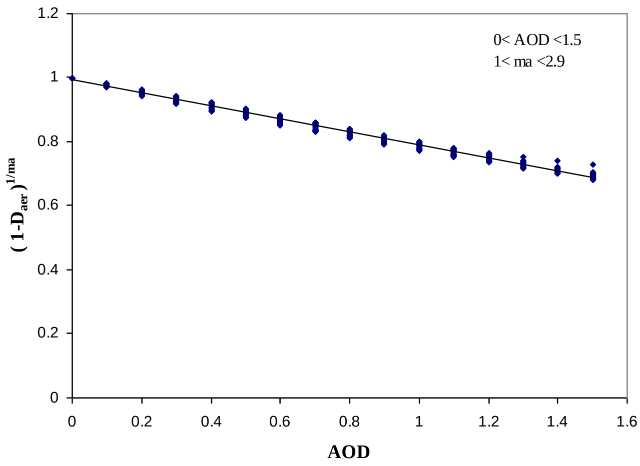


Fig. 2. The relation between depletion coefficient (D_{aer}) and aerosol optical depth (AOD) at different air mass (m_a)

From Fig. 2. the relation between D_{aer} and AOD at any air mass (m_a) can be written as:

$$(1 - D_{aer})^{1/ma} = 0.9941 - 0.2041\mathrm{AOD} \quad (2)$$

or

$$D_{aer} = 1 - (0.9941 - 0.2041\mathrm{AOD})^{ma} \quad (3)$$

To validate the model in Eq.(3), it was used to calculated the values of depletion coefficient ($D_{aer,\ model}$) at Chiang Mai and Nakhon Pathom. At the same time, the values of depletion coefficient ($D_{aer,\ meas}$) were computed from Eq.(1) using the data of E_{turbid} and E_{clean} at these stations. E_{turbid} was obtained from the measurements and E_{clean} was calculated by using the 6S with the input data obtained from measurements. The values of $D_{aer,\ model}$ were plotted against those of $D_{aer,\ meas}$ .The results are shown in Fig. 3.

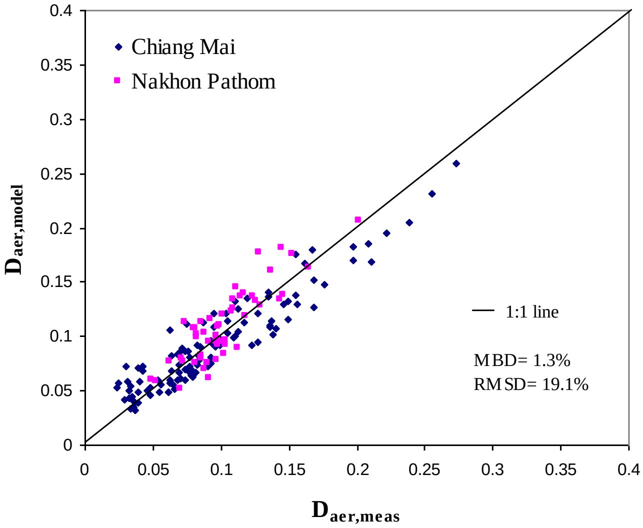


Fig. 3. Comparison between the aerosol depletion coefficient calculated from model ($D_{aer,\ model}$) and that obtained from the measurement ($D_{aer,\ meas}$) at Chiang Mai and Nakhon Pathom

From Fig. 3, the discrepancy between $D_{aer,\ model}$ and $D_{aer,\ meas}$ in terms of the root mean square different (RMSD) and mean bias different (MBD) were 19.1% and 1.3%, respectively. As there are many types of aerosols in the atmosphere, and the types of aerosols were not taken in account in the model, this is likely to be the main cause of the discrepancy. However the accuracy of the model in an acceptable level.

4. Conclusion

In this study, a model for calculating the depletion coefficient of solar illuminance by aerosol was formulated by using 6S radiative transfer model. Then the depletion model was validated against the measurements at two stations in Thailand. It was found that the values of D_{aer} from the model and the measurement are in reasonable agreement, with RMSD of 19.1% and MBD of 1.3%.

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