

Depletion of Total Solar Ultraviolet (TUV) Radiation (260–400 nm) and Erythemal Weighted Solar Ultraviolet (EUV) Radiation by Aerosols Under Clear Sky Conditions: A Case Study from Data Collected at Nakhon Pathom Station in Thailand

Wijittra Kangwanwit Sumaman Buntoung* and Serm Janjai

Faculty of Science, Silpakorn University
6 Rajamankha Nai Rd., Amphoe Muang, Nakhon Pathom, 73000

Received 14 June 2023; Revised 29 January 2024; Accepted 12 February 2024

Abstract

In this work, the depletion of total solar ultraviolet (TUV) radiation and erythemal weighted solar ultraviolet (EUV) radiation by aerosol in clear sky conditions was investigated based on the data collected at Nakhon Pathom station (13.82°N, 100.04°E) in Thailand. Solar spectral ultraviolet radiation was measured by a spectroradiometer (Bentham Instruments Ltd., model DMc150), in addition to aerosol optical depth (AOD) at 340 nm measured by an AERONET sunphotometer (Cimel Electronique, model CE-318). The total ozone column (O₃) retrieved from OMI/AURA satellite data was also used. The data period used in this work were from January 2017–December 2018 at Nakhon Pathom station. The EUV was obtained from the solar spectrum and erythemal weighted action spectrum. A special technique was employed, using UV data calculated from the UVSPEC, a radiative transfer model, to extract the variation of TUV and EUV only as a function of AOD. Equations relating TUV to AOD and EUV to AOD were established. TUV and EUV were found to decrease linearly with the increase of the AOD.

Keywords : Solar radiation; Ultraviolet radiation; Aerosol optical depth; Erythema

* Corresponding Author. Tel.: +668 6161 3292, E-mail Address: buntoung_s@silpakorn.edu

1. Introduction

Solar ultraviolet (UV) radiation is part of the solar spectrum reaching the earth's surface. It has both beneficial and harmful effects on human health. Excessive exposure to solar UV radiation is hazardous for humans. For instance, it can lead to skin cancer, cataracts, and immune system suppression [1]. On the other hand, exposure to solar UV radiation at a suitable level promotes vitamin D synthesis in the human skin [2], strengthening human bones.

Solar UV radiation outside the earth's atmosphere can be divided into UVC (100–280 nm), UVB (280–320 nm), and UVA (320–400 nm) [3]. On entering the earth's atmosphere, UVC is completely absorbed by the earth's atmosphere. A small portion of the UVB and almost all UVA radiation reach the earth's surface. In general, clouds have a strong influence on the solar UV radiation reaching the earth's surface during cloudy conditions. However, during clear sky conditions, aerosols have a significant impact on the solar UV radiation reaching the earth's surface. Deng et al. [4] investigated solar UV radiation in Guangzhou, China, and found that aerosols absorbed an average of 62% of solar UV radiation at 340 nm before reaching the earth's surface. Kim et al. [5] studied the effects of aerosols on solar UV radiation under clear sky conditions in Seoul, Korea, and reported that the attenuation of erythemal UV (EUV) radiation by aerosol is very significant.

Most areas of Thailand have very high aerosol loads [6]. To the best of our knowledge, the effect of aerosols on surface UV radiation has not yet been reported.

Therefore, the objective of this work was to investigate the depletion of TUV and EUV by aerosols using data collected at Nakhon Pathom station (13.82°N, 100.04°E) from January 2017 to December 2018.

2. Materials and Method

2.1 Materials

This work is based on the analysis of four data sets. The first data set contains spectral UV irradiance data obtained from ground-based measurements using a spectroradiometer (Bentham Instrument Ltd., model DMc150) at Nakhon Pathom station (13.82°N, 100.04°E) (Fig. 1) in the wavelength range of 260–400 nm during January 2017 to December 2018. The spectral UV data were recorded every 10 min, which were then averaged to transform it into hourly data. This spectroradiometer was calibrated monthly using a standard lamp. The second data set is AOD, measured at a wavelength of 340 nm. These data were obtained from a sunphotometer installed at the station (Fig. 1) and downloaded from the website of AERONET (<http://aeronet.gsfc.nasa.gov/>). These data were similarly processed to be in the hourly form. The sunphotometer was calibrated annually by AERONET. The third data set is the data on O₃ obtained from the OMI/AURA satellite, downloaded from the website (<https://aura.gsfc.nasa.gov/omi.html>). These data contained relevant daily information for the entire world. The ozone data from the Nakhon Pathom station were used in this work. The fourth data set is the sky image data taken by a sky camera (PREDE, model PSV-100)

installed at Nakhon Pathom station (Fig. 1). It was used to identify clear sky conditions.

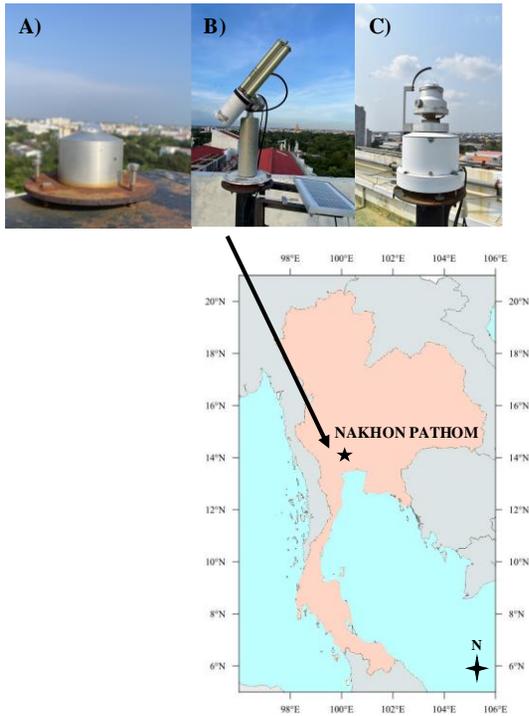


Fig. 1 The location of the station and the instruments installed at the station. A) input optics of the spectroradiometer, B) sunphotometer, and C) sky camera

2.2 Method

2.2.1 The effect of aerosol on TUV

In this work, TUV, the total solar radiation including UVA and UVB (260–400 nm), was calculated using the following equation.

$$TUV = \int_{260 \text{ nm}}^{400 \text{ nm}} i_{\lambda} d\lambda \quad (1)$$

where

TUV = total solar ultraviolet radiation (W/m^2)

i_{λ} = spectral UV irradiance ($W/m^2/nm$)

λ = wavelength (nm)

The method used for investigating the effect of aerosol on TUV can be summarized as follows. First, the data from the sky camera were used to identify the clear sky conditions at the station for the TUV, AOD, and O_3 data to be analyzed during the clear sky period. Then, the spectral UV data for clear sky conditions were integrated over the wavelength range of 260 to 400 nm to obtain the hourly TUV data. A plot of these data against AOD is presented in Section 3. Finally, a special technique employing UVSPEC [7], a radiative transfer model, was used to extract the dependence of TUV on AOD. The calculation is done using the following expression.

$$UV(z_{ave}, AOD, O_{3,ave}) = UV_{meas}(z, AOD, O_3) \frac{UV_{model}(z_{ave}, AOD, O_{3,ave})}{UV_{model}(z, AOD, O_3)} \quad (2)$$

$UV_{meas}(z, AOD, O_3)$ is the TUV measured as a function of the actual solar zenith angle (z), aerosol optical depth (AOD), and the total ozone column (O_3). $UV_{model}(z, AOD, O_3)$ is the TUV from the UVSPEC at the actual conditions of z , AOD and O_3 . $UV_{model}(z_{ave}, AOD, O_{3,ave})$ is the TUV from the UVSPEC, where

AOD is the actual aerosol optical depth, and z and O_3 were set to constants equal to the average values of z and O_3 respectively ($z_{ave}=43^\circ$ and $O_{3,ave}=261$ DU) from all the data sets used in this study. In equation (2), the terms $UV_{model}(z, AOD, O_3)$ and $UV_{meas}(z, AOD, O_3)$ cancel each other, leaving TUV as a function of AOD ($UV(z_{ave}, AOD, O_{3,ave})$). Then, $UV(z_{ave}, AOD, O_{3,ave})$ or in this case, TUV is plotted against AOD at 340 nm ($AOD_{340\text{ nm}}$) and presented in Section 3.

2.2.2 The effect of aerosol on EUV

EUV or erythemal weighted solar ultraviolet radiation, which is more closely related to the biological effects of solar UV radiation than UVB, was obtained from the convolution of the solar UV spectrum and the erythemal action spectrum, proposed by McKinlay and Diffey [3], as follows.

$$EUV = \int_{250\text{ nm}}^{400\text{ nm}} i_\lambda R_{E\lambda} d\lambda \quad (3)$$

where

EUV = intensity of erythemal weighted solar ultraviolet radiation (W/m^2)

i_λ = spectral UV irradiance ($\text{W}/\text{m}^2/\text{nm}$)

$R_{E\lambda}$ = erythemal response (-)

λ = wavelength (nm)

The method described in Section 2.2.1 was used to examine the effect of

aerosol on EUV. The results are shown in Section 3.

3. Results and discussion

3.1 Effect of aerosol on TUV

The direct plot of total solar UV radiation against AOD under clear sky conditions is shown in Fig. 2. Significant scatter is observed in the data points for both years due to the effects of the solar zenith angle and ozone.

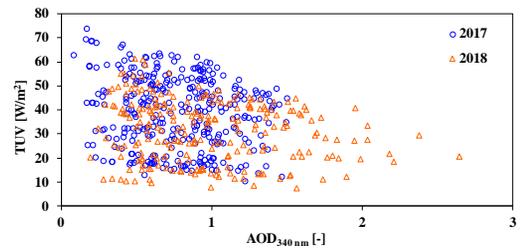


Fig. 2 Direct plot of the total solar ultraviolet radiation data from the Bentham spectroradiometer (TUV) against aerosol optical depth at 340 nm ($AOD_{340\text{ nm}}$) for 2017 and 2018.

A plot of TUV, as a function of only AOD at 340 nm, a constant solar zenith angle (43°), and a constant total ozone column (261 DU), as calculated from equation (1), is shown in Fig. 3.

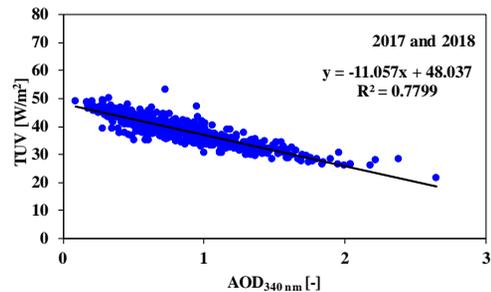


Fig. 3 Plot of TUV as a function of AOD against aerosol optical depth at 340 nm

($AOD_{340\text{ nm}}$) with the solar zenith angle fixed at 43° and the ozone column fixed at 261 DU.

A linear equation was fitted to the graph in Fig. 3, giving us the following equation.

$$TUV = -11.057AOD_{340\text{ nm}} + 48.037; R^2 = 0.7799 \quad (4)$$

where

TUV = total solar ultraviolet radiation (W/m^2)

$AOD_{340\text{ nm}}$ = aerosol optical depth at wavelength 340 nm (-)

R^2 = determination coefficient (-)

Relatively less scatter is observed in the data points for 2017 and 2018 (Fig. 3) because the values of z and O_3 are fixed, and only the effect of AOD on the total solar UV radiation is manifested. It is also observed from Fig. 3 that the TUV radiation for 2017 and 2018 has a linear relationship with the AOD. In other words, the TUV decrease linearly with the increase of the AOD. This may be due to the fact that the increase in the AOD increases the depleting agents of the UV in the atmosphere, thus decreasing the surface UV. This result confirms the result of the research work of Deng et al. [4].

3.2 Effect of aerosol on EUV

Similarly, a direct plot of EUV against AOD is shown in Fig. 4. Although the values of EUV are lower than TUV, a significant degree of scatter is observed due to the effect of the solar zenith angle and ozone.

After filtering out the effects of the variation of the solar zenith angle and ozone column using equation (2), the plot between EUV and AOD is shown in Fig. 5.

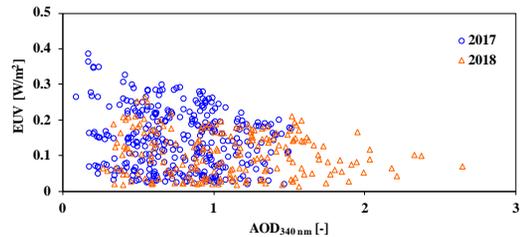


Fig. 4 Direct plot of the erythemal solar ultraviolet radiation data from the Bentham spectroradiometer (EUV) against aerosol optical depth at 340 nm ($AOD_{340\text{ nm}}$) for 2017 and 2018.

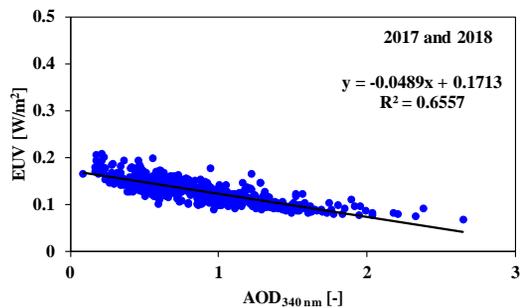


Fig. 5 Plot of EUV as a function of AOD against aerosol optical depth at 340 nm ($AOD_{340\text{ nm}}$) with the solar zenith angle fixed at 43° and the ozone column fixed at 261 DU.

A linear relationship between EUV and AOD was obtained from the graph plotted in Fig. 5 as shown below.

$$EUV = -0.0489AOD_{340\text{ nm}} + 0.1713; R^2 = 0.6557 \quad (5)$$

where

EUV = erythema-weighted solar ultraviolet radiation (W/m^2)

AOD_{340nm} = aerosol optical depth at wavelength 340 nm (-)

R^2 = determination coefficient (-)

This result helps to confirm the work of Kim et al. [5].

4. Conclusion

The depletion of TUV and EUV due to aerosol at Nakhon Pathom station in Thailand was investigated. TUV and EUV decreased linearly with the increase of the AOD. The findings from this work corroborated previously reported work from other parts of the world.

5. Acknowledgments

The author and co-authors of this paper would like to thank the Faculty of Science, Silpakorn University for supporting the research work and for providing financial support to Ms. Wijitra Kangwanwit, a research assistant (SCSU-STA-2565-01). We are also grateful to NASA, USA for aerosol optical depth data and ozone data.

6. References

- [1] R. P. Gallagher and T. K. Lee, "Adverse effects of ultraviolet radiation: a brief review," *Progress in Biophysics and Molecular Biology*, vol. 92, no. 1, pp. 119-131, 2006.
- [2] M. F. Holick, "Sunlight, UV radiation, vitamin D, and skin cancer: How much sunlight do we need?," *Advances in Experimental Medicine and Biology*, vol. 1268, pp. 19-36, Sep. 2020.
- [3] A. F. McKinlay and B. L. Diffey, "A reference action spectrum for ultraviolet-induced erythema in human skin," in *Human Exposure to Ultraviolet Radiation: Risks and Regulations*, D. Passchler and B. Bosnjakovic, Eds. Amsterdam: Elsevier, 1987, pp. 83-86.
- [4] X. Deng, X. Zhou, X. Tie, D. Wu, F. Li, H. Tan, and T. Deng, "Attenuation of ultraviolet radiation reaching the surface due to atmospheric aerosols in Guangzhou," *Chinese Science Bulletin*, vol. 57, pp. 2759-2766, May. 2012.
- [5] W. Kim, J. Kim, S. S. Park, and H. K. Cho, "UV sensitivity to changes in ozone, aerosols, and clouds in Seoul, South Korea," *Journal of Applied Meteorology and Climatology*, vol. 53, no. 2, pp. 310-322, 2014.
- [6] S. Janjai, M. Nunez, I. Masiri, R. Wattan, S. Buntoung, T. Jantarach, and W. Promsen, "Aerosol optical properties at four sites in Thailand," *Atmospheric and Climate Sciences*, vol. 2, no. 4, pp. 441-453, Oct. 2012.
- [7] B. Mayer, G. Seckmeyer, and A. Kylling, "Systematic long-term comparison of spectral UV measurements and UVSPEC modeling results," *Journal of Geophysical Research: Atmospheres*, vol. 102, no. D7, pp. 8755-8767, Apr. 1997.