

Article

Mathematical Assessment of Aerosol Impact on the Diffuse-to-Global Ratio of Solar UV Radiation

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Abstract

This study is devoted to investigating the effect of aerosols on solar UV radiation. In the ultraviolet range, scattering processes are dominant and lead to a substantial contribution of diffuse UV radiation to the global UV irradiance. The paper introduces a method for estimating solar UV Index. The proposed method is first compared with other UV Index estimation methods and is subsequently applied to examine the influence of aerosols and ozone on solar UV radiation and on its diffuse component. Human skin exposure to diffuse solar UV radiation can be potentially harmful to health.

Keywords: ultraviolet radiation; global UV Index; diffuse UV Index; aerosols; spectral model; erythral action spectrum function

MSC: 86A10

1. Introduction

Ultraviolet (UV) solar radiation accounts for less than 9% of the total solar energy at the top of Earth's atmosphere, and most of it is absorbed before reaching the surface [1]. The fraction that does reach the ground, though small, has significant effects on human health, contributing to skin aging, skin cancer, and eye damage. Solar UV radiation is classified into UV-C (100–280 nm), UV-B (280–315 nm) and UV-A (315–400 nm). While UV-C is entirely absorbed by the atmosphere, primarily by ozone [2–4], and most of the UV-B is also absorbed, a small and variable fraction still reaches the Earth's surface. UV-A is only weakly absorbed and accounts for roughly 95% of the UV radiation reaching the surface.

The UV Index, which weights the spectral UV irradiance by the erythral action spectrum, is the most widely used measure to inform the public about UV exposure risks [5]. Although monitoring the UV Index is important, direct measurements remain limited. Commercial instruments exist but require frequent calibration, and most meteorological stations do not routinely record this parameter [6]. Consequently, real-time UV Index data are typically obtained from satellite-based estimates, providing global coverage but only approximate local conditions. For example, Ref. [7] compares ground-based UV Index measurements with corresponding values derived from OMI/Aura. Given the lack of direct UV radiation measurements, there is an interest in developing UV irradiance models that use global horizontal irradiance, optical atmospheric mass, and ozone concentration as parameters input [8].

Solar UV radiation is strongly influenced by scattering processes in the atmosphere. As a result, its diffuse component, radiation originating from directions outside the solar



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disk, plays a dominant role at the surface compared to the direct component, which comes directly from the solar disk [9]. In the visible spectrum, under clear-sky conditions, solar radiation is dominated by its direct component, with the diffuse component having much lower intensity. Differently, in the UV spectral band diffuse irradiance can account for at least 50% of the total UV irradiance on a horizontal surface [10]. Diffuse solar radiation results from two physical processes affecting incoming radiation as it passes through the atmosphere, namely Rayleigh scattering and aerosol scattering. With over two-thirds of Earth's surface covered by oceans, marine aerosols, primarily sea salt particles generated by oceanic phytoplankton, constitute the main aerosol type globally. Windblown dust from desert regions is the principal source of continental aerosols [11]. In recent decades, the relative contribution of urban aerosols has steadily increased, driven by industrial processes, transportation, and other anthropogenic activities. This means that a high UV Index can be reached even in shaded areas. The health risks associated with diffuse solar UV radiation (for example, in the shade under a beach umbrella) are often underestimated, as this radiation is invisible to the human eye.

This study addresses a knowledge gap: the quantitative, global assessment of aerosol effects on the diffuse-to-global UV ratio. The objectives are to (i) theoretically assess the contribution of diffuse UV radiation to global UV levels, (ii) develop a method for estimating the UV Index, (iii) investigate how aerosol type and concentration influence the UV Index, with particular emphasis on its diffuse components, and (iv) validate the theoretical findings against measurements from six different locations worldwide.

2. Diffuse UV Radiation in the Solar Spectrum

In this section, the components of the solar spectral irradiance at ground level will be calculated using a spectral model, and then the UV-domain irradiance components will be quantified through the UV Index components.

The UV Index is defined as the solar erythemal irradiance (which considers the erythemal action spectrum as a weighted function of the solar UV irradiance) multiplied by $A = 40 \text{ m}^2/\text{W}$, in order to have values from 0 to 20.

$$UVI = A \int_{280}^{400} B(\lambda) G(\lambda) d\lambda \quad (1)$$

$B(\lambda)$ is the erythemal action spectrum [5], a function of wavelength defined by

$$B(\lambda) = \begin{cases} 1 & \lambda \in [250; 298] \text{ nm} \\ 10^{0.094(298-\lambda)} & \lambda \in [298; 328] \text{ nm} \\ 10^{0.015(139-\lambda)} & \lambda \in [328; 400] \text{ nm} \end{cases} \quad (2)$$

The solar spectral irradiance $G(\lambda)$ will be calculated using a spectral model.

The model used is the Leckner spectral model [12], which estimates the three components of solar spectral irradiance at ground level under clear-sky conditions: direct, diffuse, and global. The Leckner model accounts for five attenuation factors affecting solar radiation as it passes through the Earth's atmosphere: ozone absorption, water vapor absorption, absorption by the mixed gases, Rayleigh scattering, and aerosol scattering. Corresponding to each attenuation factor, a specific atmospheric transmittance is defined.

The transmittance due to ozone absorption is defined by

$$\tau_{O_3}(\lambda) = \exp(-m l K(\lambda)) \quad (3)$$

where λ the wavelength, $K(\lambda)$ [cm^{-1}] the ozone absorption coefficients [12], l [$\text{cm} \cdot \text{atm}$] the total column ozone content and m the optical atmospheric mass.

The transmittance associated with water vapor absorption is given by

$$\tau_w(\lambda) = \exp\left(\frac{-0.2385 \text{ mw}K_w(\lambda)}{(1 + 20.07 \text{ mw}K_w(\lambda))^{0.45}}\right) \quad (4)$$

where $K_w(\lambda)$ [cm^2g^{-1}] denotes the water vapor absorption coefficients [12] and w [cm^{-2}g] is the total column water vapor content.

The transmittance associated with mixed gases absorption is given by

$$\tau_g(\lambda) = \exp\left(\frac{-1.41 \text{ m}K_g(\lambda)}{(1 + 118.3 \text{ m}K_g(\lambda))^{0.45}}\right) \quad (5)$$

where $K_g(\lambda)$ km^{-1} is the absorption coefficients associated with mixed gases [12].

The transmittance associated with Rayleigh scattering is given by

$$\tau_R(\lambda) = \exp\left(-0.008735 \cdot \lambda^{-4.08} \text{ mp}/p_0\right) \quad (6)$$

where p is the atmospheric pressure and p_0 the normal atmospheric pressure. $\tau_R(\lambda)$ is a continuous function of wavelength.

The transmittance associated with aerosols attenuation is given by

$$\tau_a(\lambda) = \exp(-m\beta\lambda^{-\alpha}) \quad (7)$$

Here, α is the Ångström exponent, and β is the turbidity coefficient; together, they define the properties of aerosol content in the atmosphere. The Ångström exponent is a measure of aerosol particle size [13], and the turbidity coefficient is proportional to the aerosol's concentration. The function $\tau_a(\lambda)$ is also a continuous function of wavelength.

The Leckner model calculates the direct normal solar spectral irradiance at ground level by applying the product of the transmittances to the solar spectral irradiance at the top of the atmosphere $G_{ext}(\lambda)$:

$$DNI(\lambda) = G_{ext}(\lambda) \cdot \tau_R(\lambda) \cdot \tau_{O_3}(\lambda) \cdot \tau_g(\lambda) \cdot \tau_w(\lambda) \cdot \tau_a(\lambda) \quad (8)$$

The diffuse irradiance is evaluated as:

$$G_d(\lambda) = \gamma \cdot G_{ext}(\lambda) \cdot \tau_w(\lambda) \cdot \tau_g(\lambda) \cdot \tau_{O_3}(\lambda) \cdot (1 - \tau_R(\lambda) \cdot \tau_a(\lambda)) \cdot \cos(\theta_z) \quad (9)$$

In this equation, $\gamma = 0.5$ represents the downward fraction of the scattered radiation, as in a pure Rayleigh atmosphere, and θ_z is the zenith angle.

Finally, the global solar spectral irradiance on a horizontal surface is obtained by summing the horizontal projection of the direct normal component and the diffuse component:

$$G(\lambda) = DNI(\lambda) \cdot \cos(\theta_z) + G_d(\lambda) \quad (10)$$

The spectral model described allows the calculation of any UV solar spectral irradiance necessary for the assessment of the UV Index. The spectral irradiance in Equation (1) may represent any of the UV components—direct, diffuse, or global—and, correspondingly, the direct UV Index, diffuse UV Index, or global UV Index will be evaluated.

It is well known that Rayleigh scattering is more pronounced at shorter wavelengths and therefore in the UV range [14]. However, the scattering of solar radiation by aerosol particles is enhanced in UV, as illustrated in Figure 1. This figure shows the specific atmospheric transmittance associated with aerosol scattering, i.e., the attenuation of solar

radiation due to scattering by aerosols. The spectral transmittance due to aerosol scattering, defined by Equation (7), is represented for various parameter combinations (the Ångström turbidity coefficient (β) and Ångström exponent (α)) describing the properties of atmospheric aerosols. The two groups of three curves correspond to distinct turbidity conditions: a low turbidity value ($\beta = 0.1$), characteristic of a clean atmosphere, and a high turbidity value ($\beta = 0.5$), associated with an enhanced aerosol load in the atmospheric column. In both groups, lower transmittance is observed in the left side of the figure, indicative of enhanced scattering in the ultraviolet range. Each group consists of three curves: one for coarse aerosols ($\alpha = 0.3$), one for mixed aerosols ($\alpha = 0.9$), and one for fine aerosols ($\alpha = 1.5$). In both groups the scattering is particularly pronounced for fine aerosols ($\alpha = 1.5$), such as those of urban-industrial origin. The wavelength of $1 \mu\text{m}$ represents a turning point, with fine aerosols contributing predominantly to scattering at shorter wavelengths, while coarse aerosols dominate scattering at longer wavelengths. Both Rayleigh scattering and aerosol scattering are significant in the ultraviolet range, resulting in a substantial contribution of diffuse spectral irradiance to the global irradiance in this domain. Therefore, it is essential to characterize the global UV Index, and especially the diffuse component, in relation to atmospheric aerosol content. In particular, both the type (represented by the Ångström exponent α) and the concentration (characterized by the turbidity parameter β) of aerosols strongly influence the scattering of UV radiation. Higher concentrations of scattering aerosols or aerosols with smaller particle sizes (higher α) enhance the scattering of solar UV radiation, leading to an increase in the diffuse fraction of the UV Index. Consequently, accurate characterization of the diffuse UV component requires consideration of both aerosol type and load in the atmosphere.

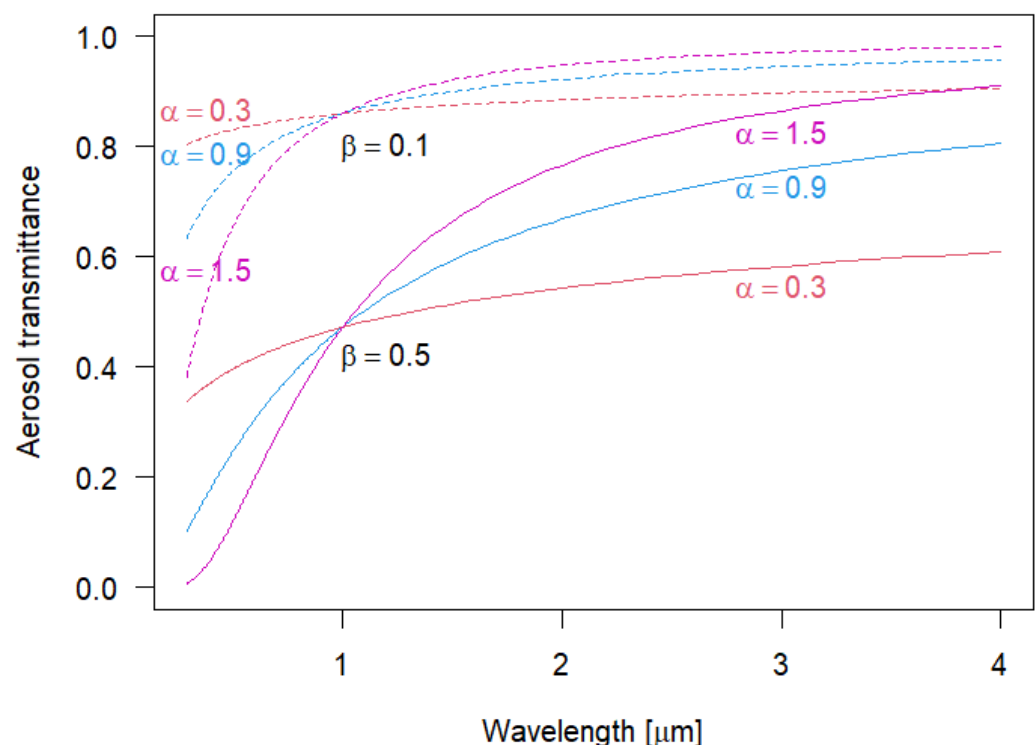


Figure 1. Spectral transmittance associated with aerosol scattering calculated using the Leckner model for two values of Ångström turbidity coefficient ($\beta = 0.1$ for clean conditions, and $\beta = 0.5$ for turbid conditions), as well as three values of Ångström exponent ($\alpha = 0.3$ for coarse aerosol, $\alpha = 0.9$ for mixed aerosol and $\alpha = 1.5$ for fine aerosol). All cases assume optical atmospheric mass $m = 1.5$.

3. Data and Methods

The method proposed in this study for evaluating the UV Index components is carried out in three steps: (1) optical atmospheric mass, ozone, water vapor, and aerosol optical depth data are downloaded from the AERONET network [15] for the selected location and time period; (2) the atmospheric parameters obtained in the previous step are used as input variables in the Leckner model equations (Equations (3)–(10)) to estimate the diffuse spectral solar irradiance and the global spectral solar irradiance under clear-sky conditions; (3) using Equations (1) and (2), the diffuse UV Index and the global UV Index are calculated based on the corresponding spectral irradiances computed in step two and restricted to the ultraviolet range. Prior to applying this UV Index calculation method, the results of the method were compared with established estimates from TEMIS and OMI.

The Tropospheric Emission Monitoring Internet Service (TEMIS), developed by KNMI within an ESA project, has provided ultraviolet (UV) radiation products since 2003 through its web portal [16]. The data are generated in near-real time on a $0.5^\circ \times 0.5^\circ$ grid from satellite observations of global ozone, supplemented over Europe with cloud information. The erythemal UV Index (UVI) is derived following the International Commission on Illumination (CIE) action spectrum for erythema [5] and represents clear-sky conditions at local solar noon. One UVI unit corresponds to 25 mW m^{-2} . In addition, TEMIS provides daily forecasts of ozone and UVI up to eight days in advance.

The Ozone Monitoring Instrument (OMI) is a nadir-viewing UV–VIS imaging spectrograph aboard NASA’s Aura satellite, launched in July 2004 as part of the Earth Observing System. Operating in the 264–504 nm spectral range with a resolution of 0.42–0.63 nm, OMI provides daily global coverage through a 2600 km swath and a nominal ground footprint of $13 \times 24 \text{ km}^2$ at nadir. Among its Level 3 products, the erythemal UV Index (UVI) at local solar noon [17] is available as the OMUVBd dataset, distributed via NASA GES DISC [18].

Using the proposed UV Index calculation method, the noon UV Index in July 2023 was computed for two locations: Boulder (United States) and Hohenpeissenberg (Germany). For the same locations and period, UV Index data were also extracted from the TEMIS and OMI databases. The three datasets for both locations are presented in Figure 2.

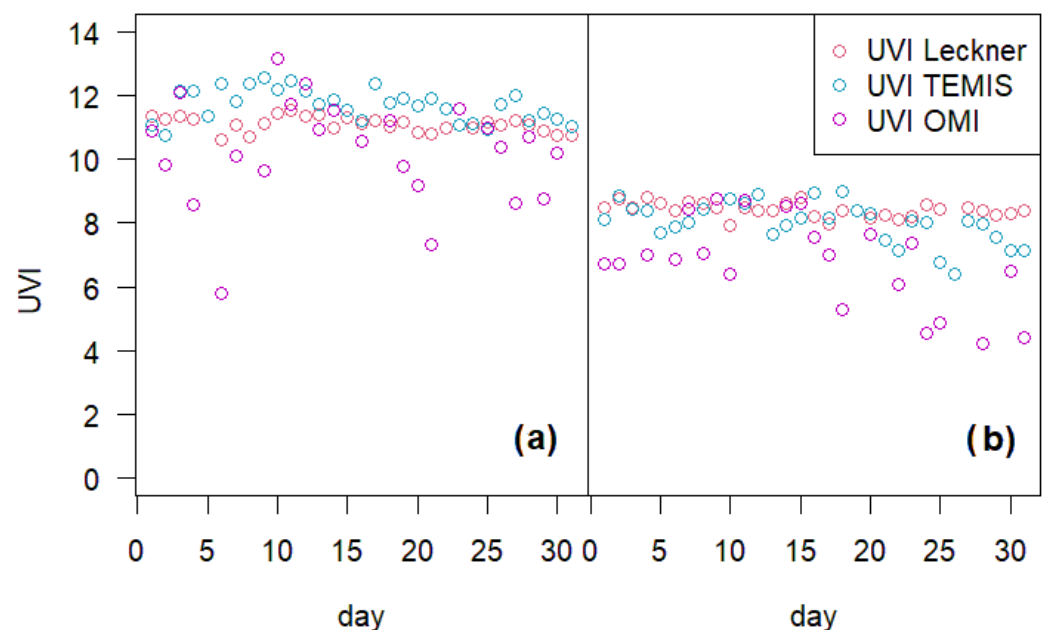


Figure 2. UV Index evaluated using the proposed calculation method based on the Leckner model, and UV Index extracted from the TEMIS and OMI datasets for July 2023, at (a) Boulder, USA, and (b) Hohenpeissenberg, Germany.

A visual comparison of the two figures indicates that the three calculation methods produce reasonably consistent UV Index values, supporting the validity of the proposed approach. Moreover, the results obtained with the proposed method appear to be more closely aligned with those derived from TEMIS. For the Boulder location, the normalized Root Mean Square Error between the UV Index calculated using the proposed method and the UV Index data retrieved from TEMIS is $nRMSE = 6.88\%$, while the normalized Mean Bias Error is $nMBE = -5.20\%$. The same statistical indicators, calculated for the UV Index retrieved from OMI, are $nRMSE = 16.75\%$ and $nMBE = 8.59\%$. The overestimation relative to OMI data and the underestimation relative to TEMIS data can also be visually observed in Figure 2. For the Hohenpeissenberg location, the statistical indicators are $nRMSE = 32.25\%$ and $nMBE = 25.15\%$ when calculated relative to OMI data, and $nRMSE = 8.37\%$ and $nMBE = 3.98\%$ when calculated relative to TEMIS data. For this location, the proposed method for estimating the UV Index overestimates the values relative to both datasets, but once again, the results are closer to those retrieved from TEMIS.

The procedure for comparing the results obtained with the proposed method and those extracted from TEMIS is illustrated in the flow chart in Figure 3.

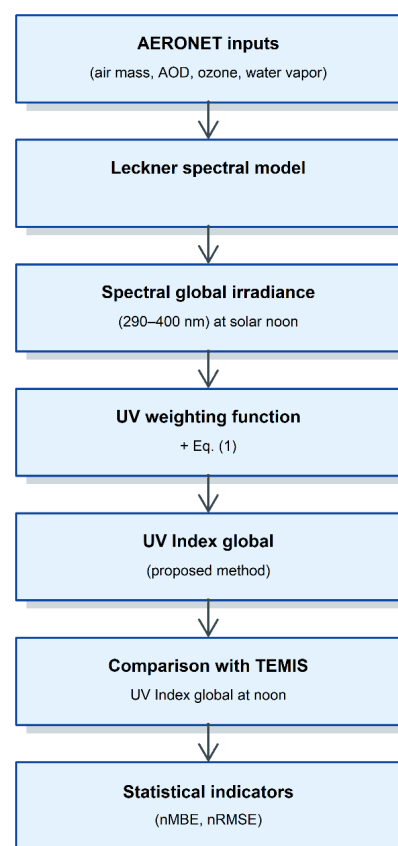


Figure 3. Flow chart of the proposed UV Index estimation method using AERONET inputs, Leckner model calculations, and comparison with TEMIS data ($nRMSE$, $|nMBE|$).

The UV Index data extracted from the two satellite databases, OMI and TEMIS, can also be compared with each other. For the Boulder location, the normalized RMSE is 18.05% and the normalized MBE is -12.79% when comparing OMI data relative to TEMIS. For the Hohenpeissenberg location, the statistical indicators are $nRMSE = 22.68\%$ and $nMBE = -16.31\%$ when calculated OMI relative to TEMIS data.

4. Results and Discussion

The UV Index calculation method, based on the Leckner spectral model, was applied on two levels: (1) a theoretical study addressing the contribution of diffuse UV radiation to global UV radiation as influenced by atmospheric aerosol content, and (2) an applied study using real atmospheric data from locations characterized by significant or distinctive aerosol loads.

The global UV Index is calculated using Equation (1), which incorporates the spectral global irradiance G from the Leckner model. This represents the UV Index communicated to the public as a means of warning about potential health risks. If, instead, the diffuse irradiance G_d from the Leckner model is used in Equation (1), the diffuse UV Index can be derived.

Under clear-sky conditions, global UV radiation and diffuse UV radiation are strongly affected by variations in atmospheric composition, primarily driven by changes in ozone concentration and in the amount and type of aerosols. To investigate the influence of ozone and aerosols on ultraviolet radiation, a reference atmosphere was prescribed by constraining specific parameters. The optical atmospheric mass was fixed at $m = 1.5$, corresponding to a moderate solar zenith angle, while the columnar water vapor content was set to $w = 2 \text{ g/cm}^2$. For the present analysis, Julian day $J = 172$ (day of the year corresponding to 21 June) was selected as a representative summer day. These fixed values provide a controlled framework that isolates the effects of ozone and aerosols, minimizing the variability introduced by other atmospheric constituents. The variation range for the total column ozone was set to $0.2\text{--}0.5 \text{ cm}\cdot\text{atm}$. In Figure 4a, a low turbidity value was chosen ($\beta = 0.1$), representative of a relatively clean atmospheric state. Calculations of the global and diffuse UV Index were performed for two distinct atmospheric scenarios: one characterized by coarse aerosols ($\alpha = 0.3$) and the other by fine aerosols ($\alpha = 1.5$). Compared to coarse aerosols, the presence of fine aerosols in the atmosphere reduces the global UV Index while increasing the relative contribution of the diffuse component. In Figure 4b, with higher atmospheric turbidity ($\beta = 0.5$), the diffuse component dominates, especially in the case of fine aerosols. With respect to atmospheric ozone content, an increase in ozone concentration leads to a reduction in both global and diffuse components of the UV Index.

A study on the effect of ozone layer thickness and aerosols on the global and diffuse UV Index was reported for Livorno, Italy, on 21 June 2015 [9]. The aerosols in this location are predominantly marine. Although the optical atmospheric masses considered in the study are different (namely 1 and 2), the results obtained are not in contradiction with those described in this paragraph.

The theoretical curves in Figure 4 show that high concentrations of fine aerosols can reduce the global UV Index while substantially increasing the relative contribution of the diffuse UV Index component. A look at Figure 1 recalls that fine aerosols enhance scattering in the UV range, which leads to a high proportion of diffuse radiation within the global radiation in this domain.

To validate these theoretical conclusions, measured atmospheric parameters were used as input for the Leckner spectral model, and the resulting spectral irradiances were used to calculate the UV Index components. The UV Index itself was not measured, but it is based on directly measured input data. Thus, measurements obtained in July 2023 from six geographically diverse locations worldwide were analyzed. The sites and their geographical coordinates are presented in Table 1, which also includes statistical information on atmospheric parameters characterizing aerosol type and concentration. All data were retrieved from the AERONET network [15]. In addition to the aerosol parameters, the remaining atmospheric inputs required for the computation of spectral

irradiances using the Leckner model were retrieved from AERONET, namely the total ozone content (I), the total water vapor (w), and the optical atmospheric mass, derived from the solar zenith angle. In this study, AERONET Version 3, Level 2.0 (quality-assured) data were employed. These data incorporate automated cloud-screening algorithms and post-campaign calibration validation, substantially reducing uncertainties in photometric measurements. Consequently, Level 2.0 data were selected to ensure high data quality and consistency, even at the expense of a reduced number of observations [15].

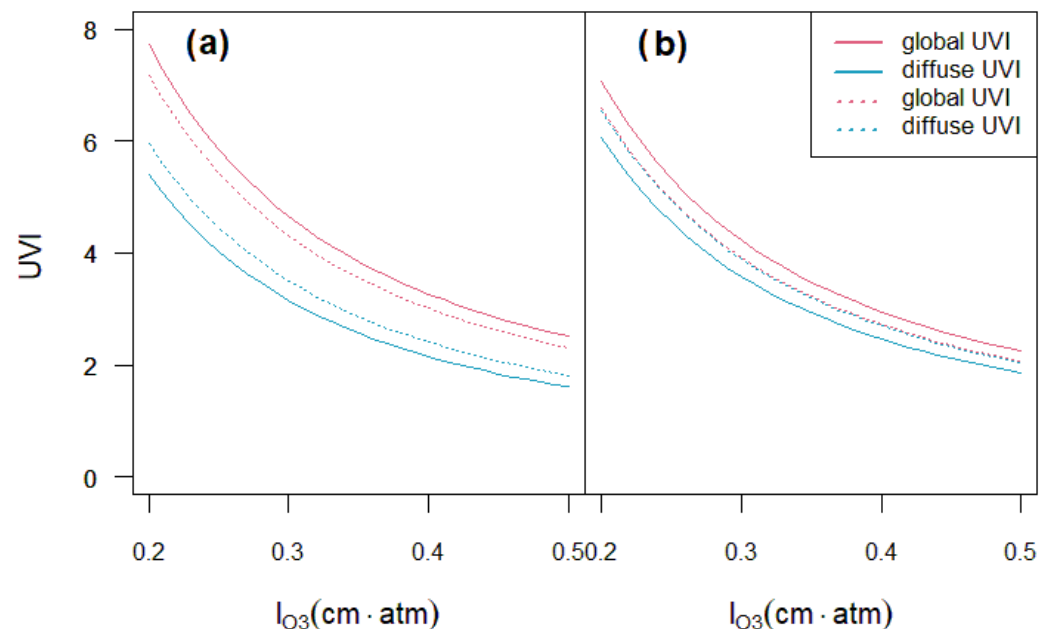


Figure 4. Global UV Index (red) and diffuse UV Index (blue) evaluated using the proposed calculation method. Atmospheric turbidity is 0.1 in (a) and 0.5 in (b). Both figures consider two aerosol types: coarse ($\alpha = 0.3$, solid line) and fine ($\alpha = 1.5$, dashed line).

Table 1. List of the six AERONET sites analyzed in this study, including their geographical coordinates and the statistical values (minimum, maximum, mean, and standard deviation) of atmospheric parameters—Ångström exponent and turbidity coefficient—representative of aerosol type and concentration, for July 2023.

Location	Latitude	Longitude	Counts	Aerosol Parameters							
				Ångström Exponent (α)				Ångström Turbidity (β)			
				Min	Max	Mean	SD	Min	Max	Mean	SD
Bandung	6.88° S	107.61° E	1078	0.474	1.622	1.362	0.206	0.022	0.807	0.125	0.110
Chicago	41.97° N	87.71° W	2028	0.786	1.841	1.6	0.115	0.022	0.556	0.1	0.089
Lecce	40.33° N	18.11° E	2166	0.339	1.868	0.958	0.397	0.022	0.427	0.117	0.081
New York	40.82° N	73.94° W	1081	0.772	1.896	1.678	0.133	0.014	0.507	0.088	0.068
Seoul	37.56° N	126.93° E	515	0.496	1.721	1.336	0.270	0.016	0.602	0.152	0.059
Timisoara	45.74° N	21.22° E	1110	0.389	1.907	1.395	0.271	0.019	0.478	0.080	0.059

Here, we summarize the characteristics of pollution levels and specific features of atmospheric aerosols in the six locations under consideration. In Bandung, Indonesia, air pollution primarily stems from vehicular emissions, releasing CO, NO₂, and fine particulates (PM_{2.5}, PM₁₀), as well as industrial activities emitting SO₂ and other aerosols. The city's basin-like topography and limited green spaces hinder pollutant dispersion, leading to pollutant accumulation [19]. In Chicago, USA, Ref. [20] reports a notable in-

crease in pollution: the number of days with $\text{PM}_{2.5}$ levels exceeding $35 \mu\text{g}/\text{m}^3$ —considered unhealthy—rose from 0 to 11 per year, while days with detectable smoke increased by 81% between 2019 and 2023. In Lecce, Italy, variations in PM_{10} concentrations reflect the combined effects of urban morphology and atmospheric circulation [21]. In New York City, USA, Ref. [22] investigated the short-term effects of $\text{PM}_{2.5}$ on hospitalizations for cardiovascular diseases, considering seasonal and temperature-related modifications and potential heterogeneity across regions. In Seoul, South Korea, transboundary air pollutants originating from China contribute approximately 19% to the weekly average PM_{10} concentrations, with seasonal variations ranging from 12% to 30% [23] (Kim, 2019). Finally, in Timișoara, Romania, Ref. [24] monitored air quality over four days in August 2024, both outdoors and within a central park. Fine ($\text{PM}_{2.5}$) and coarse (PM_{10}) particulate matter were among the parameters measured, with $\text{PM}_{2.5}$ concentrations exceeding the allowable limit of $15 \mu\text{g}/\text{m}^3$ on certain days, even within the park interior.

Figure 5 illustrates the global UV Index, diffuse UV Index, and their difference, as estimated by the proposed method using atmospheric parameters from AERONET for the stations listed in Table 1. The variables are arranged in columns, with each row representing a different location. The contour plots of the UV Index components prove the variations in relation to the aerosol parameters, specifically the Ångström exponent (α) and the turbidity coefficient (β).

It can be observed that fine aerosols with an Ångström exponent greater than 1.2 are present at all six locations. In Chicago and New York, coarse aerosols with an Ångström exponent below 0.6 are not present (the minimum values of α reach 0.786 and 0.772, respectively). Furthermore, in Chicago and New York, the mean Ångström exponent reaches the highest values among all locations, 1.6 and 1.678, respectively. This indicates that these two sites are dominated almost entirely by fine aerosols. In Lecce and Timișoara, aerosol turbidity is the lowest, with β values below 0.427 and 0.478, respectively (see Table 1). Moreover, the variability of aerosol types is the highest in these two locations. In Lecce, the aerosol size distribution reaches its lower limit, with the smallest Ångström exponent ($\alpha = 0.339$), while in Timișoara the opposite behavior is observed, where the highest α value (1.907) indicates the finest aerosol load among the six locations. The large diversity of aerosol types at these two locations is also reflected in the high standard deviation values of the Ångström exponent (0.39 maximum in Lecce and 0.27 in Timișoara). Bandung is characterized by high Ångström exponent values (mean $\alpha = 1.362$) and a medium-to-high turbidity level (mean $\beta = 0.125$). This combination creates a triangular region (approximately defined by $\alpha > 1$) in which the two components of the UV Index appear to be equal. In Figure 5(a1,a2), the two triangular regions share the same colors, whereas in Figure 5(a3), the triangle is shown in a dark color, which denotes a negligible difference between the components from the first two columns.

Notably, in the first two columns showing the global and diffuse UV Index, the right-hand side of the plots displays similar colors, indicating that the diffuse component contributes significantly to the global UV Index. This pattern is also reflected in the third column, where the differences between the two UV Index components are minimal, particularly on the right-hand side of the plots.

The high contribution of the diffuse UV Index to the global UV Index, particularly in the presence of fine aerosols, appears to be confirmed in the presented case studies. To highlight this aspect, Figure 6 shows contour plots of the diffuse UV Index expressed as a percentage of the global UV Index for the same six locations.

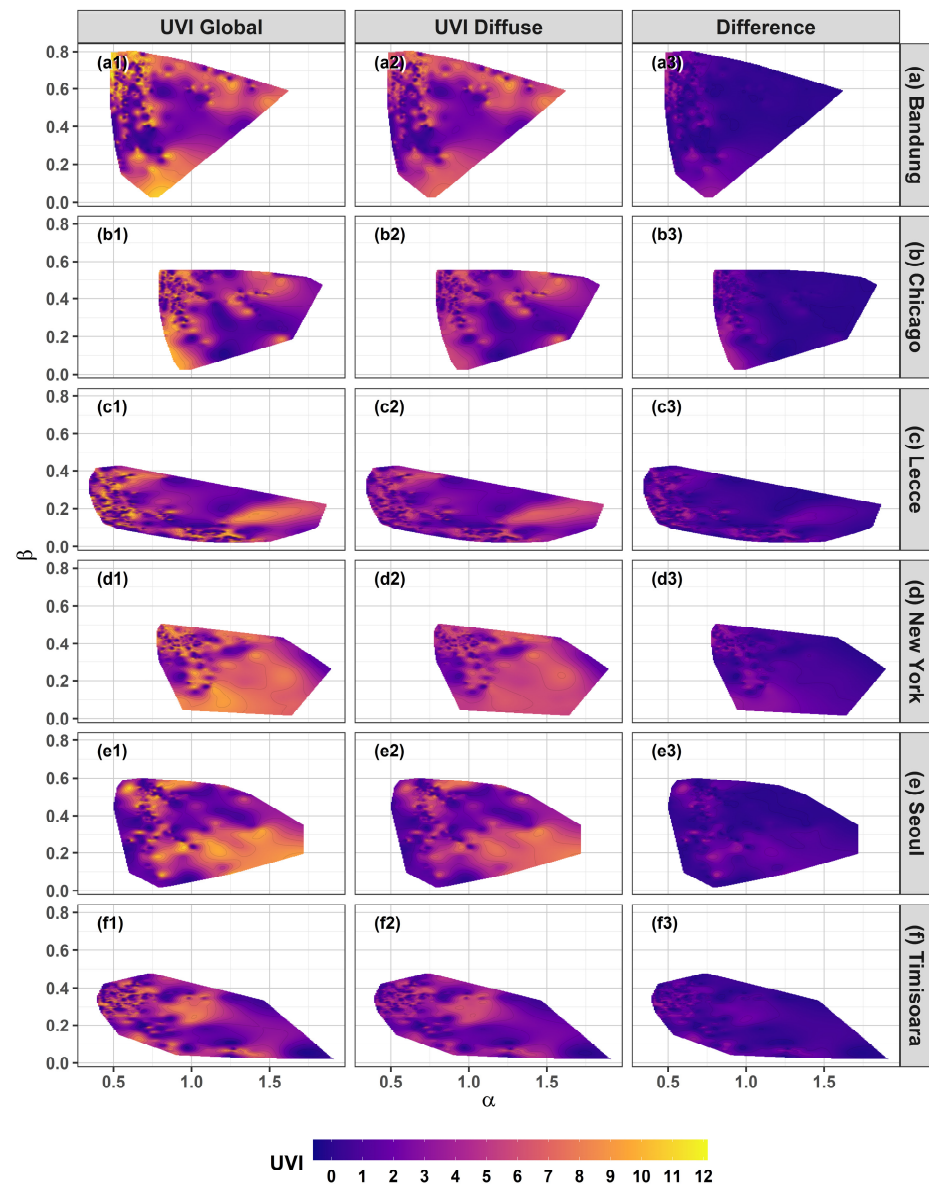


Figure 5. Contour plots of UV radiation derived using the proposed method for the six locations listed in Table 1 during July 2023. Each row corresponds to one location, while the three columns represent (left) the global UV Index, (middle) the diffuse UV Index, and (right) the difference between them (global–diffuse). All contour surfaces are expressed as a function of the aerosol Ångström parameters α (aerosol type) and β (turbidity level). The figure highlights how both aerosol type and concentration modulate the dominance of the diffuse fraction in the ultraviolet domain.

In Figure 6a,b, corresponding to Bandung and Chicago, intense yellow (100%) appears predominantly in regions associated with fine aerosols, where turbidity is also relatively high. In these locations, the diffuse fraction of the UV Index ranges from 57% to 100%. In Figure 6e, corresponding to Seoul, the yellow color is nearly as dominant. For β values below 0.3, the yellow gradually shifts to orange for fine aerosols with α greater than 1.2. At this location, the diffuse fraction reaches both the highest minimum value (58.3%) and the highest mean value (87.7%) among the six locations analyzed. Table 1 shows that the mean turbidity is highest at Seoul ($\bar{\beta} = 0.152$). In Lecce and New York (Figure 6c,d), the lowest mean percentages of the diffuse UV Index are observed, both just below 80% (77.8% and 78.2%). These locations also record the lowest minimum values of the diffuse fraction, 53% and 53.9%, respectively. Lecce exhibits the overall lowest values for the diffuse fraction, with a minimum of 53%, a maximum of 99.8%, and a mean of 77.8%.

Interestingly, Table 1 shows that Lecce also has the lowest minimum and mean values of the Ångström exponent α (0.339 and 0.958), indicating the highest coarse aerosol content among the six locations. In Figure 6f (Timisoara), the yellow color appears in regions with a very high Ångström exponent, corresponding to fine aerosols, or in regions with high turbidity and a medium Ångström exponent. The yellow patches present in areas other than those corresponding to high Ångström exponent values and/or high turbidity may result from the contributions of other atmospheric parameters. For example, a high water vapor content affects the asymmetry factor, which in turn influences the fraction of scattered radiation reaching the surface [25]. Across all studied locations, even the lowest values of the diffuse UV Index percentage remain above 53%, highlighting the consistently significant role of diffuse radiation. It is also worth highlighting an important point: even if the UV Index was estimated only on the clear-sky conditions, the fraction of diffuse UV Index always exceeds 53%.

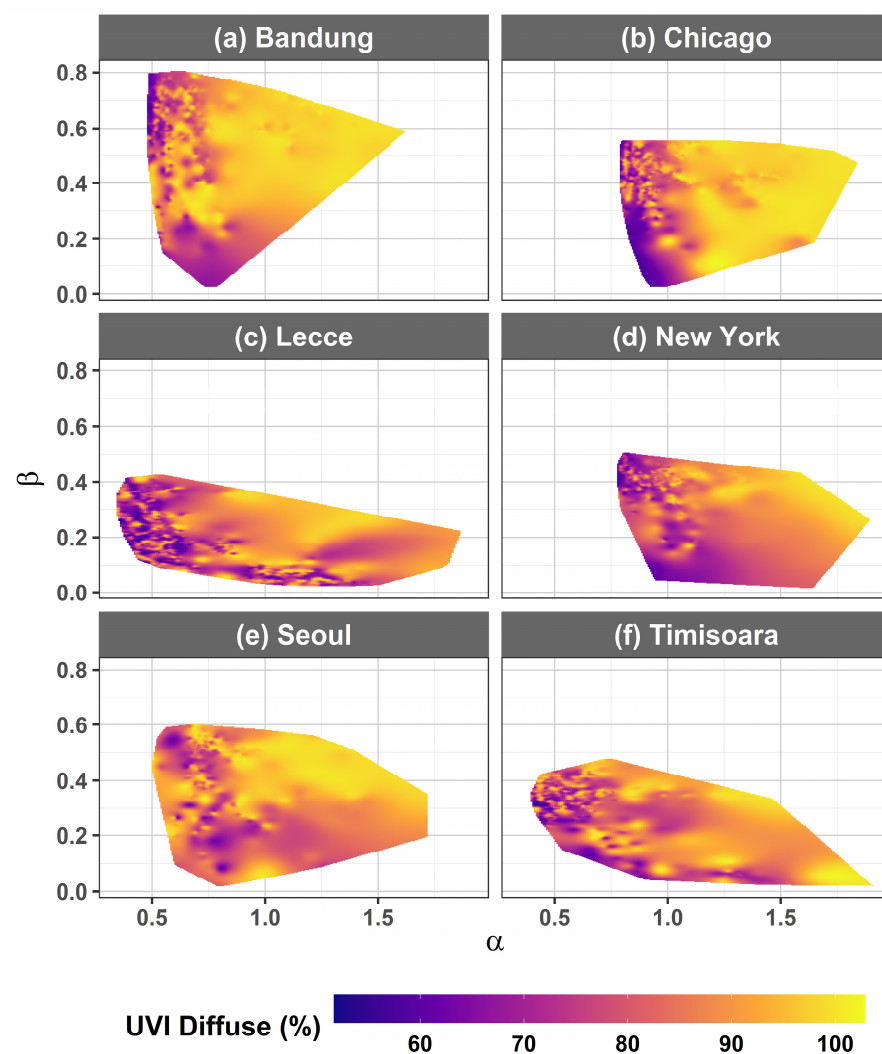


Figure 6. Contour plot of the percentual contribution of diffuse UV Index in global UV Index as a function of aerosol parameters α and β , based on measurements from the six locations listed in Table 1 for July 2023.

5. Conclusions

This study focuses on the impact of aerosols on the contribution of the diffuse UV component to global UV radiation. The UV Index, a quantity familiar to the general public, is used to quantify the UV radiation components. The approach proposed in this study for

computing the global and diffuse UV Index is based on the Leckner spectral model. This model estimates global and diffuse solar spectral irradiance. For model implementation, the required atmospheric parameters (the optical atmospheric mass, the total column ozone content, the total column water vapor content, the Ångström exponent, and the turbidity coefficient) were derived from the AERONET (Aerosol Robotic Network).

The Leckner spectral model characterizes the two fundamental atmospheric scattering processes of solar radiation—Rayleigh scattering and aerosol scattering—by means of two continuous functions that depend on the wavelength of the incident solar radiation. An analysis of these functions indicates that the scattering processes of solar radiation are most pronounced within the ultraviolet region of the spectrum. In particular, the extent of aerosol scattering is highly sensitive to both the aerosol type and its atmospheric concentration. The main result of this study is that diffuse UV radiation constitutes the dominant component of global UV radiation. A minimum diffuse/global fraction of 53% was found in all six locations analyzed. This dominance is further enhanced by the type and concentration of aerosols present in the atmosphere. The result is supported through the estimation of the diffuse/global UV Index. The fraction of diffuse UV Index within the global UV Index increases with increasing atmospheric ozone content, decreasing aerosol particle size (indicated by a higher Ångström exponent), and increasing atmospheric turbidity.

The estimation of the UV Index with the proposed model is limited by access to the input data in the model. Future work will focus on coupling the proposed model with satellite input data, which would make it applicable on a global scale.

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