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Determination of daily total ultraviolet-B in a subtropical region (Upper Egypt): An empirical approach

Mahmoud El-Nouby Adam *

Quality Assurance Unit (ALI), King Saud University, Riyadh 11491, Saudi Arabia
Faculty of Science (Physics Department), South Valley University, Qena 83523, Egypt

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ABSTRACT

Given the fundamental role played by ultraviolet-B (UVB) and due to the lack of long-term measurements of its magnitude, the present work has established an empirical approach to estimate daily total UVB in all sky conditions (UVB_d). Data from eight years (2000–2007) of UVB_d and daily total global solar radiation (G_d) have been used. For both variables, the dataset used was examined, and a relationship between these two quantities was developed. In addition, the variation of daily clearness indices of UVB and global solar radiation, G (K_{tUVB} and K_t respectively) was determined. K_t was introduced to determine UVB_d. This variable can be considered as an atmospheric modulator of the maximum values of UVB_d (under clear-sky conditions, UVB_{0d}). The relationship between UVB_d and the product of UVB_{0d} and K_t ($UVB_{0d}{}^*K_t$) was parameterized. The significance and performance of this empirical approach have been evaluated with the aid of several statistical analysis procedures. The results show that the modeling index (d) and the coefficient of modeling efficiency (ME) were 0.99 and 1 respectively. In addition, the root mean square error (RMSE), the mean bias error (MBE), and the mean absolute error (MAE) were 8%, −0.3%, and 6%, respectively. Datasets for a new time period from Qena and another location (Aswan) were used to validate the proposed approach. The results of this empirical approach were satisfactory, with a correlation coefficient of 0.98 between measured and estimated values of UVB_d for both sites.

1. Introduction

The amount and spectral distribution of solar radiation have impacts on terrestrial ecosystem productivity and health. The variability of cloud physical characteristics, ozone, and aerosols changes the spectral distribution of solar radiation at the Earth's surface (Grant and Slusser, 2005). The most energetic photons of solar radiation that reach the Earth's surface are in the ultraviolet (UV) wavelengths. UV covers the wavelength range of 100–400 nm (Guarniere et al., 2004). According to biological responses, UV can be divided into three bands: UVA (315–400 nm), UVB (280–315 nm), and UVC (100–280 nm). Although the UVB radiation band represents only a small fraction of extraterrestrial solar radiation (Iqbal, 1983), it accounts for 80% of the harmful effects of exposure to the Sun (Cañada et al., 2007). Therefore, understanding the spatial and temporal availability of UVB near the Earth's surface is significant for a wide range of disciplines, for example, forestry, agriculture, and oceanography (Zerefos and Bais, 1997; He et al., 2002), as well as for air pollution and human health (Diffey, 1991; Lü et al., 1996). Juzeniene et al. (2011) reported on the beneficial and damaging effects of UVB on terrestrial ecosystems and materials. The effects of UVB on human skin are varied and widespread. UVB induces skin cancer by causing mutations in DNA and suppressing certain activities of the immune system. In addition, Caldwell et al. (2003) and Mpoloka (2008) have reported that UVB has a wide range of impacts on terrestrial plants, including effects on plant height,

* Faculty of Science (Physics Department), South Valley University, Qena 83523, Egypt.
E-mail address: el_nouby.adam_svu@yahoo.com.

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leaf area, shoot biomass, activity of secondary metabolisms, and pathogen infection.

The technologies to measure UVB at the Earth's surface have been traditionally expensive, and stations measuring this spectral band in Egypt are few and sparse. These stations are located at Aswan (23.3°N, 32.8°E), Qena (26.2°N, 32.7°E), Hurgada (27.23°N, 33.8°E), El-Arish (31.1°N, 33.8°E), and Rafah (31.2°N, 34.2°E) (Basset and Alamodi, 2006). In addition, when measured data are available, the series tend to cover medium or short time periods. Consequently, it is desirable to have tools to estimate UVB values from other more commonly and routinely measured radiometric or climatological variables. Antón et al. (2009) mentioned that radiative-transfer and empirical methods are useful tools for estimating the UV band as a part of the solar spectrum. Although radiative-transfer approaches need information about meteorological variables which are not commonly measured at ground-based stations, the empirical approaches are developed by simple expressions with the available meteorological variables in each location as independent variables. By analogy with the UV case, in this study, an empirical approach has been developed to estimate UVB at the Earth's surface. The independent variables introduced in this empirical approach are used to characterize the atmospheric modulation of UVB. It has been noted in the literature (Jacovides et al., 2009; Adam, 2013a) that changes in UVB are due to variations in certain geometric factors and atmospheric compounds. The atmospheric compounds that show the strongest influence on UVB are ozone, aerosols, and clouds. However, because of the complexity of the interaction between UVB and atmospheric compounds, a number of UVB empirical approaches have focused on the relationship between UVB and a single variable. Estimates of UVB values from global solar radiation (G) have been introduced by several authors, such as Webb and Stefen (1986), Basset and Korany (2007), and Robaa (2008) (for daily totals) and Kudish and Evseev (2000) and Adam et al. (2013) (for hourly totals).

Earlier studies reflected a wide range of hourly or daily values for the UVB/G radiometric ratio, varying from 0.02% to 0.8% for different locations (Feister and Grasnick, 1992; Ilyas et al., 1999; Cui et al., 2008). Barbero et al. (2006) and Jacovides et al. (2009) mentioned that part of this variability can be explained by the strong spectral dependence of the atmospheric transmittance of the solar spectrum on the traversed optical air mass, which causes differential behavior of incoming solar UVB and G. Therefore, the empirical approaches relating UVB and G become site-specific, and the value of UVB/G for hourly or daily values cannot be used as a reference for UVB climatology. The use of this ratio for estimating UVB from measured G should be restricted to the particular site where it was obtained. According to Martínez-Lozano et al. (1994) and Barbero et al. (2006), the effect of the site and its climatology on the relationship between UV and G can be reduced by using the clearness index K_t. In addition, Foyo-Moreno et al. (1999, 2007) considered K_t as a modulator of the maximum values (under clear-sky condition) of UV and erythemal ultraviolet (UVER). By analogy with the UV and UVER cases, this study proposes an empirical approach to estimating UVB_d using two independent variables (UVB_{0d} and K_t). K_t can be considered as an atmospheric modulator for UVB_{0d}. It includes the attenuating effect of clouds and aerosol load (Moreno et al., 2013), and the attenuating effect of ozone is included in UVB_0.

Therefore, the first objective of this study is to evaluate the fluctuations in both UVB_d and G_d at Qena to examine the collected data which are to be used to develop an approach for estimating UVB_d. The second is to develop an all-weather empirical approach to estimate UVB_d at ground level. The significance and performance of the proposal approach will then be evaluated with the aid of several statistical analysis procedures.

2. Data

2.1. Measurements

The site of this study is located at South Valley University (SVU), Qena, Egypt (26.2°N, 32.75°E, and 96 m above mean sea level). Adam (2013a) reported that Qena is the capital city of Qena governorate, which has three million inhabitants according to a 2006 estimate. The city itself has 220,000 inhabitants (2009 estimate) and an area of 1800 km^2 and is situated on the east bank of the Nile in the southern part of Egypt between the western and eastern deserts. In addition, Robaa (2008) mentioned that Qena lies within the subtropical region and that its terrain is semi-desert. The climate of Qena is characterized by a hot season from March to September and a cold season from October to February.

Daily values of UVB and G were obtained from the South Valley University Meteorological Research Station (SVU-MRS) for the period from 2000 to 2007. In addition, data of cloudiness were collected through this period. The SVU and the Egyptian Meteorological Authority (EMA) have established this station. SVU-MRS is defined as an urban site. The EMA was responsible for the follow-up of quality system of the Egyptian monitoring network. The scientific advice and the instrument calibrations for SVU-MRS are provided by the EMA. The instruments are calibrated yearly against the World Radiometric Reference (WRR) maintained at Davos, Switzerland (WRC, 1985, 1995). The absolute accuracy of calibration is ±3%–4% (El-Metwally, 2004). Adam (2013a) reported that the Model UVB-1 Ultraviolet Pyranometer (No. 960842, Yankee Environmental Systems Inc.) has been used to measure the total irradiance from 280 to 320 nm. The sensitivity of this instrument is 1.97 μV/Wm^{-2} over the total UVB irradiance, and its response time is approximately 0.1 s. It works over an ambient temperature range of −40 °C to +40 °C. The cosine response of this instrument is ±5% for 0°–60° SZA. The departure from the ideal cosine response exceeds 10% beyond 60° SZAs (Bigelow et al., 1998). In addition, the Precision Spectral Pyranometer (PSP-No. 16317IS, Eppley Laboratory Inc.) has been used to provide precise measurements of total irradiance from 295 to 2800 nm. The sensitivity of the sensor is 9 μV/Wm^{-2} of total irradiance, and its response time is 1 s. The temperature dependence of the PSP is approximately ±1% over the ambient temperature range of −20 °C to +40 °C. The cosine response of the instrument is ±1% from normalization 0°–70° SZA and ±3% 70°–80° SZA.

The Combilog Datalogger (No. 1020, TH., and Friedrichs & Co.) was used to record hourly integral irradiance (irradiation integrated in 1 h) values of UVB and G. The observations of both variables were carried out from Sun-rise to Sun-set. The daily values is provided by using the daily irradiation hourly values of UVB and G (the irradiation integrated in a part of the hour near both Sun-rise and Sun-set was considered). These daily