Correction of UVS-AB-T UV Radiometers Using a Radiative Transfer Model

DONG XIA
Dongguan Meteorological Bureau, Dongguan, China

HAOBO TAN
Institute of Tropical and Marine Meteorology, China Meteorological Administration, Guangzhou, China

LING CHEN, WEIQIANG MO, AND ZHIYANG YUAN
Dongguan Meteorological Bureau, Dongguan, China

SI GAO
Key Laboratory of Meteorological Disaster, Ministry of Education, Nanjing University of Information Science and Technology, Nanjing, China, and Department of Atmospheric, Oceanic and Earth Sciences, George Mason University, Fairfax, Virginia

(Manuscript received 9 October 2013, in final form 13 December 2013)

ABSTRACT

Observation of UV radiation is of major importance to human health and to the calculation of photochemical reaction rates. However, the sensitivity of UV radiometers decays because of equipment aging. A correction method is therefore proposed by using a decrement formula that is approximately a quadratic function of time and is obtained by fitting the clear-sky observation data from an aged UVS-AB-T UV radiometer with the data simulated by the Tropospheric Ultraviolet and Visible (TUV) radiative transfer model. The corrected data from the older radiometer are verified by the data from another newer radiometer on selected clear-sky days. The results show a high correlation and a low bias between the radiometers, and the mean of the corrected data from the older radiometer is 94.5% of that from the newer radiometer. After a long time of use, the decrement of the observation data would increase dramatically and errors of the data after correction would still be significant. In Dongguan, China, a recommendation is made that a UV radiometer should not be used for more than 5 years when the decrement rate reaches 50%.

1. Introduction

UV radiation from the sun covers the wavelength range 100–400 nm and is divided into three bands: UVA (315–400 nm), UVB (280–315 nm), and UVC (100–280 nm) (WMO 2008). All UVC and approximately 90% of UVB radiation is absorbed by ozone in the atmosphere; thus, the UV radiation reaching the earth’s surface is largely composed of UVA with a small UVB component. UV radiation (280–400 nm) has a significant impact on human health, crops, and ecosystems. It plays a helpful role in the formation of vitamin D by the skin, but it plays harmful roles in impairing photosynthesis in plants and causing sunburns, cataracts, skin aging, skin cancer, and immunosuppression (e.g., D’Orazio et al. 2013). UV radiation also provides activation energy to photochemical reactions (Dickerson et al. 1997).

According to erythemal effects of UV radiation (McKinlay and Diffey 1987), the UV index was introduced and adopted to represent its risk level on human health (e.g., Burrows et al. 1994; Austin et al. 1994). As people are paying more attention to the impact of UV radiation, observation and forecasting of UV radiation have recently been carried out at many scientific research institutions and meteorological departments around the world after installation of UV radiometers. However, the observation data decay when equipment aging occurs over time, mainly due to the degradation of sensors and the pollution on the diffusing disk (Tan et al. 2008).
Currently, there is no national standard for calibrating solar UV irradiance in China. The imported UV radiators cannot be used after a certain period unless they are sent back to the manufacturers of origin overseas for recalibration.

In this study we propose a simple and economical method to correct an aging UV radiometer. After comparison of the observation data from the UV radiometer and the data calculated from the Tropospheric Ultraviolet and Visible (TUV) radiative transfer model, we analyze the decrement characteristics of the observation data and obtain a decrement formula, and then the data corrected by the formula is verified by a newly installed UV radiometer.

2. Model and data

Two UV radiometers used in this study are both UVS-AB-T radiometers manufactured by Kipp & Zonen. They were installed in Banling National Basic Meteorological Station (station 59289; 22.967°N, 113.733°E) in Donguan, which is a city in the Pearl River delta of south China. The distance between the two instruments is approximately 2 m. The station is located in Dongguan Botanical Garden. There are only green plants, such as fruit trees, garden plants, and grass, within a 1-km radius, and it is far from the downtown and roads. The UVS-AB-T radiometer measures both UVA and UVB. We focus on UVA, since it is the major component of UV radiation at the surface. The two instruments were installed in December 2007 (hereinafter radiometer A) and in May 2010 (hereinafter radiometer B) and were run operationally in January 2008 and July 2010, respectively. UVA observation data used in this study are 1-min average measurements on clear-sky days. First, the clear-sky days are identified by naked-eye observation; then, when there are sudden dips in UVA irradiance, those days are discarded.

The TUV radiative transfer model (Madronich 1993) was developed at the U.S. National Center for Atmospheric Research and version 4.4 source code was obtained online (http://cprm.acd.ucar.edu/Models/TUV). The wavelength range of the model is 121–750 nm, and the spectral resolution of the solar spectrum is 0.05 nm. The TUV model uses the ozone profile from the U.S. Standard Atmosphere, 1976 and the aerosol profile from Elterman (1968). The input parameters of the model are composed of longitude, latitude, local date and time, column ozone, surface albedo, aerosol optical depth (AOD) at 550 nm, aerosol single scattering albedo, wavelength exponent $\alpha$, surface pressure, and so on. The main output is downward spectral irradiance in a range of wavelength. UVA wavelength range 315–400 nm is specified for the model in this study. UV irradiance calculated by the TUV model shows good agreement with the measurements (Michalsky and Kiedron 2008; Piacentini et al. 2002; Singh and Singh 2004; Srivastava et al. 2006).

AOD at 550 nm is obtained from the Hong Kong University of Science and Technology. Li et al. (2005) modified the Moderate Resolution Imaging Spectroradiometer (MODIS) algorithm to retrieve AOD at 1-km resolution in south China, and the validation shows root-mean-square errors of $\sim0.05–0.01$ compared to sunphotometer observations. Column ozone is taken from 0.25° daily Ozone Monitoring Instrument (OMI) satellite data (Levett et al. 2006). There are two ozone products from OMI. One product is derived using the traditional Total Ozone Mapping Spectrometer (TOMS) algorithm, since it shows less bias (within 0.4% of ground observation; McPeters et al. 2008) than the other product that is derived using a Differential Optical Absorption Spectroscopy (DOAS) algorithm. Clear-sky surface albedo in the UVA region is assumed as 0.02 over vegetation (Feister and Grewe 1995; Chady and Girgzdys 2008). Aerosol single scattering albedo is 0.92, which is the mean in the Pearl River delta retrieved by Xia et al. (2013). The wavelength exponent $\alpha$ in south China is 1.2–1.6 (Tan et al. 2009); the mean value 1.4 is used.

It is noted that the TUV model simulations are instantaneous, while the differences between instantaneous model simulations and 1-min average observations are negligible on clear-sky days. To understand the sensitivity of input parameters on the simulated UVA irradiance and further test our settings of input parameters for the TUV model, model outputs using the aforementioned proposed settings and the adjusted input parameters are compared with observations from radiometer B on seven consecutive clear-sky days from 28 October to 3 November 2010, during which decay of this instrument could be neglected due to a short period of use. There is one value each day due to MODIS AOD data availability, and MODIS on board the Aqua and Terra satellites passes over the meteorological station around midday (between 1000 and 1400 local time) when the UV radiation is close to maximum. The results are shown in Fig. 1. The legends represent observation from radiometer B, and the TUV model outputs use the proposed settings: AOD $\pm 0.1$, surface albedo = 0.1, column ozone $\pm 20$ (Dobson units) DU, wavelength exponent $\alpha = 0.1$, and aerosol single scattering albedo $\pm 0.01$. It is found that AOD and surface albedo have large impacts on UVA irradiance, followed by aerosol single-scattering albedo and the impacts of column ozone and wavelength exponent are relatively small. The biases of model outputs using our parameter settings are within...
0.8% of the observations, indicating reasonable model settings. In the remainder of this paper, the proposed parameter settings are used for the TUV model.

3. Correction method

a. Correction formula

UV radiation that reaches the earth’s surface is composed of direct and diffuse components. Direct component is reduced by Rayleigh scattering, gas (ozone, oxygen, and water vapor) absorption, and extinction by aerosols. The diffuse component consists of UV radiation scattered by aerosols, haze water drops, cloud water drops, and cloud ice particles. To remove the large impact of haze and cloud on surface UV radiation, UV radiation data are corrected on selected clear-sky days only.

The real surface UVA irradiance in a range of wavelength $\lambda$ at a time is $F(\lambda)$, and the UVA irradiance of the TUV model output is $F_m(\lambda)$. We assume that

$$F(\lambda) = F_m(\lambda). \tag{1}$$

The UVA irradiance observed by the aging UV radiometer is $F_{ob}(\lambda)$, and then the decrement rate $D$ at the same time is

$$D = 1 - \frac{F_{ob}(\lambda)}{F_m(\lambda)}. \tag{2}$$

And $D$ is a function of time $t$, defined as

$$D = f(t), \tag{3}$$

where $t$ is the number of months for which the instrument has been in use, and $D$ is the monthly decrement rate.

A total of 72 clear-sky days during the period February 2008 to April 2013 are selected, and only 89 samples of UVA irradiance on those days are available due to limited swath coverage of MODIS. Figure 2 shows the comparison of UVA irradiance calculated from the TUV model and from the observation of radiometer A. There are biases between them, and the observations are lower than the model calculation. Besides equipment aging, the biases may be from two sources. The errors from the model input parameters are the first source. The aerosol single scattering albedo and the wavelength exponent are assumed as constants, although they are variable. However, we cannot obtain accurate values of them due to a lack of retrieval methods. The second source is from the errors of surface observation, since naked-eye observation of clear-sky days cannot entirely remove the impact of haze and cloud on surface UV radiation. The two sources of errors are random; thus, the errors may be randomly positive or negative.

To reduce the influence of random errors, we calculate the decrement rates from Eq. (2) and then obtain the monthly means before performing a curve fitting. The results are indicated in Fig. 3. It is found that the decrement rate is approximately a quadratic function of time,
This is different from the result of Tan et al. (2008), probably because their study period is shorter and the decrement rate is approximately linear during a shorter period. Decrement tends to increase at a faster rate after a longer working time of the equipment. The radiometer A decayed by 50% over 5 years.

The correction formula is then

\[ F'(t) = F_{\text{ob}}(t)/(1 - 0.0001404t^2), \]

where \( F' \) is the UVA irradiance after correction and \( F_{\text{ob}} \) is the observation of UVA irradiance from the UV radiometer.

**b. Verification**

The data of radiometer A corrected by Eq. (5) are verified by those from radiometer B. Table 1 is a list of 1-min measurements every hour on the hour during the daytime on 57 clear-sky days from July 2010 to December 2012 that were selected for corrections and comparison. Table 2 indicates the mean UVA irradiance of the two radiometers before and after correction. There is only a slight difference between corrected and uncorrected data for radiometer B due to its short time of use. The mean uncorrected irradiance from radiometer A is 67.8% of the corrected irradiance from radiometer A.

**TABLE 1. Number of clear-sky days (parentheses) in each month/ year on which the comparison and corrections are performed.**

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of clear-sky days</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Oct (2), Nov (2), Dec (8)</td>
</tr>
<tr>
<td>2011</td>
<td>Jan (2), Feb (1), Mar (1), Apr (1), May (1), Aug (3), Sep (1), Oct (3), Nov (4), Dec (8)</td>
</tr>
<tr>
<td>2012</td>
<td>Jan (1), Mar (3), May (1), Sep (4), Oct (5), Nov (4), Dec (1)</td>
</tr>
</tbody>
</table>

**Figures**

**FIG. 2.** Time series of UVA irradiance from TUV model simulations (circles) and observations of radiometer A (squares).

**FIG. 3.** Empirical relationship between the decrement rate and the number of months for which radiometer A has been in use. The circles are the raw data, and the solid line is the fitted curve.
B, showing a 32.2% decrement. After correction, the bias between radiometers A and B is 1.29 W m$^{-2}$ and the mean irradiance from radiometer A is 94.5% of that from radiometer B. Figure 4 shows the scatterplot of corrected data from radiometers A and B as well as the linear fit. The correlation coefficient between them is 0.996, and the corrected data from the two instruments agree well with each other. The results suggest that the use value of the instrument can be increased by our correction method.

4. Summary and discussion

Given the fact that we lack independent calibration techniques, and that it is costly and time consuming to send the old UV radiometers back to the manufacturers of origin for recalibration, we propose a simple and economical method to correct UVA irradiance by using a decrement formula that is obtained by fitting the observation data from an aged UVS-AB-T UV radiometer with the data simulated by the TUV radiative transfer model.

By comparing the UVA irradiance calculated from the TUV model with that observed by the older UV radiometer, we find that the decrement rate of the instrument is a quadratic function of time and fits a decrement equation that is then used to obtain a correction formula. The observation data from two UV radiometers are corrected by the correction formula. The mean decrement rate of the older UV radiometer is as high as 32.2% before correction, while the mean of the corrected data from the older instrument is 94.5% of that from the newer instrument, and the two data are highly correlated, suggesting that our correction method can increase the use value of the instruments.

Since the decrement rate is a quadratic function of time, after a long time of use, decrement of the observation data would increase dramatically and errors in the data after correction would still be significant. We recommend stopping the use of the instrument when the decrement rate reaches 50%. The decrement is related to equipment aging as well as local aerosol concentration, thus it varies by locations. In Dongguan, it is recommended that a UV radiometer be used for no more than 5 years.

There may be some errors in our correction method. The main error sources may include the impact of very few clouds and the uncertainties of aerosol parameters, and these errors could have been reduced by data averaging and fitting.

Acknowledgments. This work was supported by the Natural Science Foundation of China (Grant 41375156); the Natural Science Foundation of Guangdong Province, China (Grant S2013010013265); the National Basic Research Program (Grant 2011CB403403); and the Science and Technology Innovation Team Plan of the Guangdong Meteorological Bureau (Grant 201103). SG was supported by NOAA Grant NA11NES4400003.

REFERENCES


Copyright of Journal of Atmospheric & Oceanic Technology is the property of American Meteorological Society and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.