Ultraviolet–B Radiation At Northridge

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Abstract: Data of ultraviolet–B radiation in 1996 at Northridge were derived from a Yankee Environmental Systems UVB–1 pyranometer. Hourly and seasonal variations of ultraviolet–B radiation were presented. Statistical analyses between ultraviolet–B radiation and other weather variables including air temperature, relative humidity, visible–infrared radiation, and precipitation were conducted.

Introduction

Since the discovery of ozone depletion in the stratosphere caused by man–made chlorofluorocarbons (CFCs) in 1974 (Molina and Rowland, 1974), the public have been warned against the possible increase in health risk associated with more penetrations of ultraviolet radiation (UVR) reaching the earth's surface. For this purpose, the US National Weather Service has since 1994 issued non–hour ultraviolet index (UVI) and minute–to–sunburn forecasts as part of their daily weather reports. In order to study the relationship between ozone depletion and ultraviolet–B (UVB) radiation in the Los Angeles area and to verify UVI forecasts, a Yankee Environmental Systems (YES) UVB–1 pyranometer was installed in July 1995 at the California State University, Northridge (CSUN) weather station to monitor UVB radiation. This article presents a preliminary study of mean hourly and seasonal variations of UVB radiation in 1996 at Northridge. Statistical analyses are given of noon–hour (11:30 a.m. to 12:30 p.m. PST) UVB radiation in relation to other weather variables such as visible–infrared radiation, air temperature, relative humidity, and precipitation.

Literature Review

UVR was first classified into three bands, UVA, UVB, UVC, by Saidman and accepted at the Second Congress of Copenhagen in 1932 (Urbach, 1986). UVC, with wavelengths less than 280 nm, is most biologically harmful. Fortunately, it is completely absorbed by ozone and other gases in the upper atmosphere (Berger and Morys, 1992). UVB, of wavelength range 280 nm to 320 nm, is of particular interest because it penetrates through the atmosphere to the earth's surface and is very effective at causing sunburn, skin cancer, eye disorder, and the suppression of immune systems in humans (Passchier and Bosnjakovic, 1987). UVB is strongly absorbed by stratospheric ozone. Small changes in ozone can lead to large changes in UVB radiation that reaches the earth's sur–

face (McKenzie and Bodeker, 1997). Worldwide UVB increases in the past decade are consistent with ozone decreases (Madronich and de Gruul, 1994; Zheng and Basher, 1993). Every one percent decrease in ozone brings an estimated two percent increase in UVB radiation and a three percent increase in nonmelanoma skin cancer per year in the United States (NIH, 1989; Sober, 1976). Increased UVB radiation may also endanger marine organisms in the upper layers of the sea by decreasing algal productivity and damaging various forms of aquatic larvae and other organisms (Smith, 1989; Bidigare, 1989). Sensitive plants often exhibit reduced growth, photosynthetic activity, and flowering when exposed to excessive UVB radiation (Tevini and Teramura, 1989).

UVA radiation, at wavelengths from 320 nm to 400 nm, can produce health damage similar to that of UVB radiation, but is much less effective. For example, UVA radiation is 1000-fold less effective than UVB radiation in producing erythema (skin redness or sunburn), but about 10 to 100-fold more UVA than UVB energy reaches the earth's surface (NIH, 1989).

Therefore, UVA radiation may contribute about 10–20% to the sunburn reaction in summer (Diffey, 1991). UVA radiation is important in the generation of photochemical smog and also degrades many materials such as plastics, paints, and fabrics (McKenzie and Bodeker, 1997).

The first global network of UVB measurements was established in 1973 as part of the Climatic Impact Assessment Program supported by the US Department of Transportation and National Oceanic and Atmospheric Administration (NOAA). Contrary to common belief and more recent findings, Robertson-Berger (RB) ultraviolet meters showed no increase in biologically effective solar radiation, UVB, at ground level from 1974 to 1985, despite decreases in upper stratospheric ozone (Scotto et al. 1988). Small increases in tropospheric absorption by polluting gases or particulates could have offset the increases of UVB radiation due to stratospheric ozone depletion, particularly in densely populated areas (Urbach, 1989). Potential adverse effects of UVB radiation on plants led the United States Department of Agriculture (USDA) to initiate a UVB radiation program in 1992 to provide information on the geographical distribution and temporal trend of UVB radiation. This information is critical to the assessment of potential impacts of increasing UVR on agricultural crops and forests. The USDA has planned to establish a climatological network consisting of 30 to 40 UVB monitoring stations using Yankee Environmental Systems UVB-1 pyranometers to measure UVB radiation (Gibson, 1996). Recently, a number of secondary schools in Los Angeles and the California State University, Northridge have participated in Project Sun to monitor both visible and UV solar radiation using much less expensive Sun pyranometers. Project Sun is directed by the Jet Propulsion Laboratory (JPL) as part of NASA's "Mission to Planet Earth" worldwide education outreach effort (Yanow, 1996).

Method

In July 1995, the Department of Geography at CSUN established on campus an automatic weather station including a Yankee Environmental Systems UVB-1 pyranometer and a Li200X pyranometer. The former is a broadband one channel instrument measuring total UVB radiation at wavelengths from 280 nm to 320 nm (one channel with band width of 40 nm). The latter, also a broadband instrument, measures visible light and short-wave infrared radiation at wavelengths from 400 nm to 1100 nm. A broad band pyranometer measures total energy within a band wider than 10 nm [UVB, UVA, and visible radiation]. By contrast, a spectroradiometer measures a narrow band of energy with a band width 10 nm or less. UVB radiation at the CSUN weather station is obtained by the following equation:

$$\text{UVB} = 0.001 \times 2 \times 1.97 \times (\text{CR10 voltage output}) = 0.00394 \times (\text{CR10 voltage output})$$

where the factor 0.001 converts millivolts to volts; 1.97 is a calibration constant in unit of $w/m^2/volt$ (YES, 1997); and the factor 2 transfers voltage readings from UVB-1 sensor to the Campbell Scientific CR10 datalogger which outputs the UVB energy in unit of millivolts. UVB measurements are taken every 3 seconds. The other measurements of the weather station include air temperature, wind, atmospheric pressure, and precipitation. Hourly values of average, maximum, and minimum for each weather variable are stored in a module of a Campbell Scientific datalogger and can be displayed on Excel spreadsheets on an IBM computer screen via modem. The real time data can be accessed by the public through a voice phone line (818-677-5628). Macintosh software programs of Statview and Delta Graph are employed to perform statistical analyses and create graphs for the illustrations in this study.

Discussion

Figure 1 shows hourly variations of UVB radiation in January, June, July, and December 1996 at Northridge. UVB radiation was highest in July and lowest in December. In June and July, measurable amounts of UVB radiation occurred between 6 a.m and 7 p.m. PST. In the morning hours, UVB radiation in June and July were almost equal. In the afternoon, hourly UVB radiation in July slightly surpassed that in June. Mean hourly UVB radiation varied from 0.04 w/m^2 at 6 a.m. to 3.2 w/m^2 at noon in both June and July. UVB radiation from 10 a.m. to 4 p.m. in winter was much weaker than in summer The noon-hour UVB radiation was 0.7 w/m² in December and 0.9 w/m² in January in contrast to 3.2 w/m² in both June and July. December UVB radiation slightly exceeded January UVB radiation in early morning hours, but was markedly lower from late morning through afternoon. About 86% of daily UVB radiation in summer and 95% in winter occurred between 10 a.m. and 4 p.m. The National Weather Service and the EPA have advised the public to restrict outdoor activities during those hours when the UVB radiation is most intense (EPA, 1994).

Figure 2 shows monthly variations of the noon-hour mean, maximum, minimum, standard deviation, and coefficient of variation of UVB radiation. Monthly noon-hour means of UVB radiation varied from 0.7 w/m² in December to 3.2 w/m² in both June and July as also shown in Figure 1. The noon-hour maxima of UVB radiation ranged from 3.7 w/m² in May and July, with a slight drop to 3.6 w/m² in June, to 1.1 w/m² in January and December. The noon-hour minima of UVB radiation spanned from 0.1w/m² in December to 2.1 w/m² in both June and July. The plunge of noon-hour minimum UVB radiation in August was perhaps caused by the passage of clouds over Northridge on August 15, 1996. In April and May, the range of UVB radiation was about 2.9 w/m², the highest of the year.

In terms of monthly standard deviations of UVB radiation, the period February through May was characterized by the highest value in the year. However, coefficients of variation of UVB radiation showed more clearly the influence of seasonal weather patterns on the UVB variability. The coefficient of variation is defined as the ratio of monthly standard deviation to monthly mean UVB radiation and is unitless. The advantage of expressing variability by coefficient of variation is that it is not affected by extreme mean values as is standard deviation. The coefficients of variation of UVB radiation show distinctly a higher variability in winter than in summer. Southern California weather is more variable in winter than in summer. Summer weather is more monotonous with the predominance of land and sea breezes from day to day (Keith, 1980), accounting for a very low coefficient of variation of 0.1. By contrast, winter is a rainy season and weather is more variable. Cyclonic or frontal systems and Santa Ana winds frequently interrupt the weather regime of land and sea breezes, reflected in a high coefficient of variation of UVB radiation of 0.4.

Table 1 shows monthly variations of both noon-hour visible-infrared and UVB radiation in 1996 at Northridge. Visible-infrared radiation reached a minimum of 406 w/m² in December to a maximum of 937 w/m² in June. The ratio of UVB to visible-infrared radiation in-

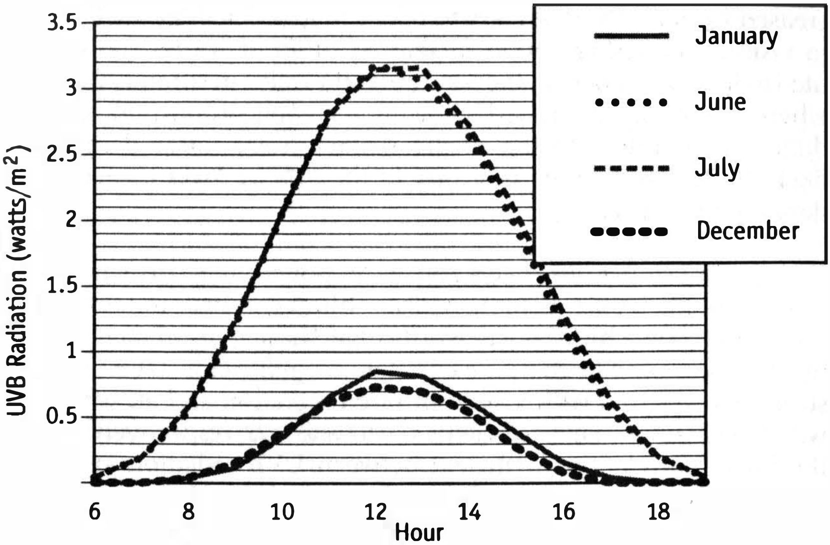

FIGURE 1. Hourly variations of mean UVB radiation in 1996 at Northridge.

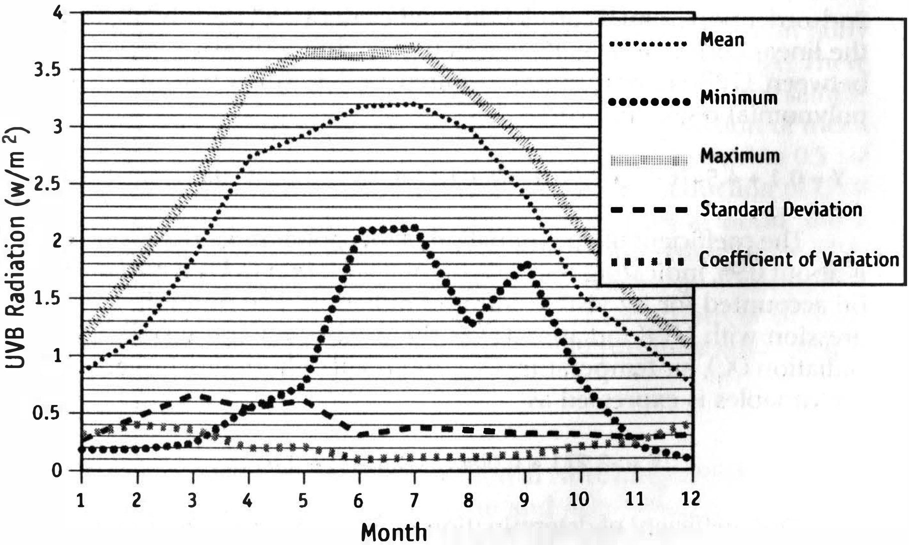

FIGURE 2. Monthly variations of mean, minimum, maximum, standard deviation, and coefficient of variation of noon-hour UVB radiation.

creased from 0.17% in January to 0.35% in July. The higher ratio of UVB to visible-infrared radiation in summer than in winter can be attributed to less cloud cover in the San Fernando Valley in summer (Keith,1980) where Northridge is located, allowing a greater proportion of UVB radiation penetrating to the earth's surface. Solar infrared radiation is likely to be absorbed by moisture in the marine layer associated with daytime sea breezes.

Table 2 shows linear and 2nd-order polynomial correlation coefficients among UVB radiation, visible-infrared radiation, air temperature, and relative humidity at Northridge. Noon-hour data on 363 days in 1996 were used to compute correlation coefficients. UVB radiation is strongly correlated with visible-infrared radiation and air temperature with linear correlation coefficients of 0.92 and 0.72, respectively. Although the linear correlation coefficient between UVB radiation and relative humidity is statistically significant, the value (–0.37) is not impressively high. Moisture does not absorb UVB radiation, but a high relative humidity may be accompanied by the presence of clouds that reduces UVB radiation reaching ground level. This is reflected by a moderate negative correlation coefficient. The 2nd-order polynomial correlation coefficient between UVB radiation and relative humidity is –0.51, a marked improvement over the linear correlation coefficient. Therefore, the relationship between UVB radiation and relative humidity is better described as polynomial than linear. The polynomial relationship also holds between UVB and visible-infrared radiation as evidenced by a 2nd-order polynomial correlation coefficient of 0.97, slightly higher than the linear correlation coefficient of 0.92. Figure 3 shows a very good fit between UVB (Y) and visible-infrared radiation (X) with a 5th-order polynomial regression curve:

$$Y = 0.1 + 4.547E\text{-}4X + 2.001E\text{-}5X^2 - 7.474E\text{-}8X^3 + 1.022E\text{-}10X^4 - 4.458E\text{-}14X^5$$

The coefficient of determination of this polynomial regression curve is about 0.94, indicating that 94% of total variation in UVB radiation can be accounted for by visible-infrared radiation. The multiple linear regression with UVB radiation (Y) as the predictand and visible-infrared radiation (X_1), air temperature (X_2), and relative humidity (X_3) as predictor variables is expressed as

$$Y = -2.271 + 0.004X_1 + 0.048X_2 + 0.014X_3.$$

The coefficient of determination of this regression equation is about 0.92, a value slightly lower than that of the 5th-order polynomial regression equation with only one predictor variable, namely, visible-infrared radiation.

Table 1. Monthly variations of mean noon-hour UVB and visible-infrared radiation and the ratio of UVB to visible-infrared radiation.

Month 1996	UVB radiation watts/m²	Visible-infrared radiation watts/m²	UVB/Visible-infrared (%)
1	0.85	491.80	0.17
2	1.17	522.00	0.22
3	1.86	707.60	0.26
4	2.74	878.00	0.31
5	2.93	883.60	0.33
6	3.18	937.00	0.34
7	3.20	904.00	0.35
8	2.98	881.50	0.34
9	2.39	807.20	0.30
10	1.53	672.00	0.23
11	1.14	557.30	0.21
12	0.74	406.00	0.18

Table 2. Correlation coefficients among temperature, relative humidity, visible-infrared, and UVB radiation. Numbers in parenthesis are 2nd-order polynomial correlation coefficients. Others are linear correlation coefficients.

	Temperature	Relative Humidity	Visible-infrared	UVB
Temperature	1			
Relative Hunidity	-0.60	1		
Visible-infrared	0.67	-0.55	1	
UVB	0.72 (0.74)	-0.37 (-0.51)	0.92 (0.97)	1

Figure 4 shows mean hourly variations of UVB radiation on rainy days and on fair-weather days in December 1996 at Northridge. There were 9 rainy days in December 1996 providing a sufficiently large sample to compute mean UVB radiation on rainy days. The reduction of mean hourly UVB radiation on rainy days reached about 0.3 w/m^2 to 0.5 w/m^2 between 11 a.m. and 2 p.m.. However, the percent reduction of UVB radiation on rainy days attained a minimum of 40% at noon and a maximum of about 80% from 2 p.m. to 4 p.m. The reduction of UVB radiation on rainy days was not significantly related to mean hourly intensity of precipitation. The hours with higher reductions of UVB radiation did not occur during the hours of higher precipitation intensity.

Conclusion

The mean noon-hour UVB radiation at Northridge varied from 0.7 w/m^2 in December to 3.2 w/m^2 in June and July 1996. The detectable UVB radiation in both early morning and late afternoon hours was 0.4 w/m^2. The maximum noon-hour UVB radiation was 1.1 w/m^2 in December and 3.7 w/m^2 in July. There was a much lower daily noon-hour

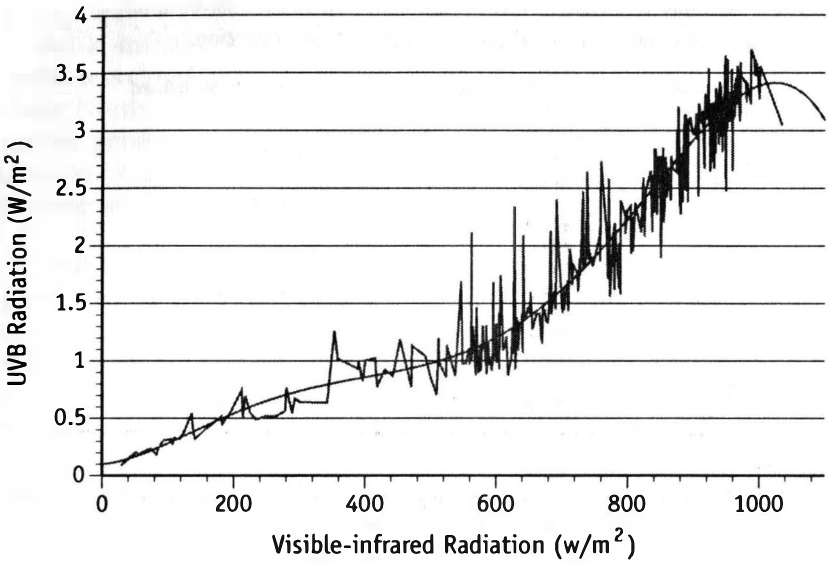

FIGURE 3. The 5th-order polynomial regression between UVB and visible-infrared radiation in 1996 at Northridge.

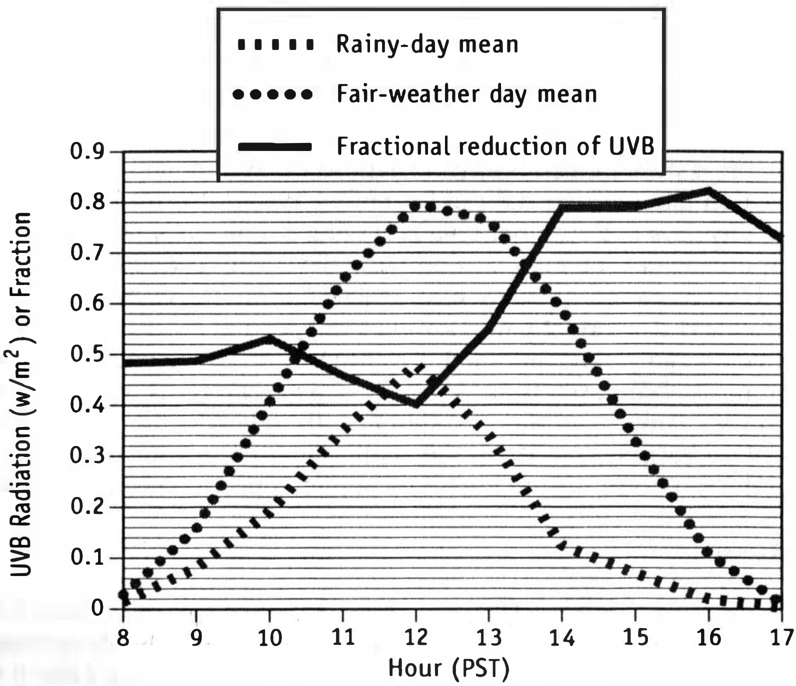

FIGURE 4. Mean hourly UVB radiation on rainy and fair-weather days and the fractional reduction of UVB radiation on rainy days in December 1996 at Northridge.

UVB variability in summer than in winter since summer weather was more monotonous, characterized by the predominance of sea breezes during the daytime.

The noon-hour UVB radiation was significantly correlated with visible-infrared radiation, air temperature, and relative humidity. The relationship between UVB radiation and visible-infrared radiation or relative humidity is polynomial. Rainy days significantly reduced UVB radiation reaching the earth's surface by about 40% to 80% depending on the time of day. However, the reduction of UVB radiation was not determined by the intensity of precipitation.

A research project is planned by the author using the regression equations developed in this study to reconstruct UVB radiation in the past when the data of predictor variables were available in order to determine whether there has been an increase in UVB radiation at Northridge due to stratospheric ozone depletion. The Northridge UVB radiation can be used to compute UVI and minute-to-burn for the purpose of verifying daily forecasts of these two variables in Los Angeles issued by the National Weather Service. Whether UVB radiation is related to surface concentrations of ozone and particulate matters will be addressed in another study. An additional Yankee Environmental Systems UVB-1 pyranometer will be installed in the summer of 1997 in order to find out the reflection of UVB radiation from the earth's surface.

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