Instantaneous UV Index and Daily UV Dose Calculations

Instantaneous UV Index

Brewer spectrophotometers in the NOAA-EPA Brewer Network measure total horizontal irradiance at 154 wavelengths ($\Delta\lambda$=0.5nm) over the 286.5nm-363.0nm spectral range. The irradiance is calibrated in mW/m^2/nm. The UV Index is defined as follows:

$$UVI = \frac{1}{25\frac{mW}{m^2}} \int_{286.5nm}^{400nm} I(\lambda) \cdot w(\lambda) d\lambda$$

where the weighting function for erythema is given as

$$w(\lambda) = \begin{cases} 1 & 250 < \lambda \le 298 \\ 10^{0.094\cdot(298-\lambda)} & 298 < \lambda \le 328 \\ 10^{0.015\cdot(139-\lambda)} & 328 < \lambda \le 400 \\ 0 & 400 < \lambda \end{cases}$$

after A. F. McKinlay and B. L. Diffey (1987).

Note 1: Because of the 1/25 coefficient the UVI is dimensionless.

Note 2: The McKinlay-Diffey definition has a discontinuity at 328nm. However minor, this seems to be an oversight.

Note 3: Weighting functions other than erythema could be used (see Biospherical web site). The formulas that follow can easily be modified to accommodate other action spectra.

For $\lambda\le363$ *UVI* is calculated using the measured irradiance and for $\lambda>363$ it's estimated:

$$UVI = UVI_{\lambda\le363} + UVI_{\lambda>363}$$

The UVI$_{\lambda>363}$ amounts to less than 10% of the total UVI and often it is a much smaller fraction (see Figure 2 in Lantz et al. 1999).

To calculate the first component we use the trapezoid rule of integration:

$$UVI_{\lambda \leq 363} = \frac{1}{25}\left[\frac{1}{2}\sum_{i=0}^{152}\left(I(\lambda_i)\cdot w(\lambda_i) + I(\lambda_{i+1})\cdot w(\lambda_{i+1})\right)\cdot(\lambda_{i+1} - \lambda_i)\right]$$

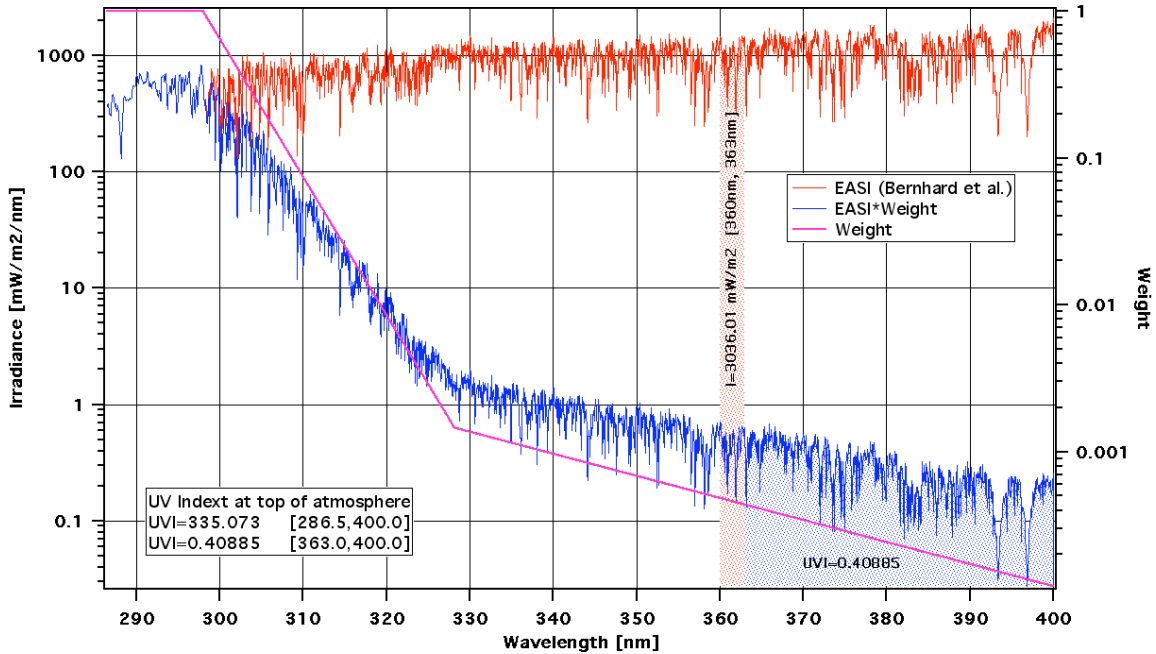where $\lambda_i = 286.5 + 0.5*i$ for $i=0$ to 153.

Figure 1. Exo-atmospheric sun irradiance (EASI) with applied erythema weighting and values of calculated UVI in 363nm-400nm and irradiance integral in 360nm-363nm.

To obtain the second component we assume that the irradiance in 363nm-400nm range can be estimated with a scaled exo-atmospheric solar irradiance (EASI). The scaling factor k is obtained using [360nm, 363nm] integration of EASI. This covers the last $n=6$ intervals of the Brewer UV scan:

$$k = \frac{\int\limits_{360nm}^{363nm} I(\lambda)d\lambda}{\int\limits_{360nm}^{363nm} EASI(\lambda)d\lambda} = \frac{\frac{1}{2}\cdot\sum_{i=147}^{152}(I(\lambda_i) + I(\lambda_{i+1})\cdot(\lambda_{i+1} - \lambda_i)}{\int\limits_{360nm}^{363nm} EASI(\lambda)d\lambda}$$

where

$$\int\limits_{360nm}^{363nm} EASI(\lambda)d\lambda = 3036.01\frac{\text{mW}}{\text{m}^2}$$

and

$$UVI_{\lambda>363} = k\cdot UVI_0$$

and

$$UVI_0 = \frac{1}{25\,\frac{mW}{m^2}} \int_{363nm}^{400nm} EASI(\lambda) \cdot w(\lambda)d\lambda = 0.408852$$

In the above calculations that resulted in coefficients 3036.01 and UVI0=0.408852 we used the high resolution EASI derived by Bernhard et al. (2004). The calculations are illustrated in Figure 1:

Note 4: The accuracy of this extrapolation has not been formally evaluated. However we believe that the resulting errors should be very small. In the *UVI* files we report the measured fraction of *UVI*

$$MF_{UVI} = UVI_{\lambda \leq 363} / UVI$$

Daily UV Dose (DUVD)

The UV index (UVI_{scan}) is calculated for every scan (*scan=1,..,N*) during a day. For each scan we assign time calculated as the second moment:

$$T_{scan} = \frac{\sum_{i=0}^{153} t_i^{scan} \cdot I^{scan}(\lambda_i) \cdot w(\lambda_i)}{\sum_{i=0}^{153} I^{scan}(\lambda_i) \cdot w(\lambda_i)}$$

where t_i^{scan} is time when the irradiance at λ_i is measured.

Note 5: To calculate the T_{scan} the times t_i^{scan} have to be in the same units and no rollover due to day or year change can be permitted.

If in a given day there were *N* scans taken, then we have *N* pairs (T_{scan}, UVI_{scan}) for *scan=1,…,N*. This series of pairs has to be appended in front with a pair (T_0, *0*) and at the end of the series with (T_{N+1}, *0),* where T_0 and T_{N+1} are defined as times of the sunrise and sunset, respectively.

In Figure 2 we show *UVI* calculated for clear sky cases when the sun was below the horizon (SZA=91°-97°). For SZA=91° UVI <0.01. For this reason we believe that a sufficient degree of precision is obtained with T_o=*Sunrise_Time* and T_{N+1}=*Sunset_Time.* The times T_0 and T_{N+1} are calculated with an ephemeris algorithm for apparent, i.e., including refraction, sunset and sunrise times.
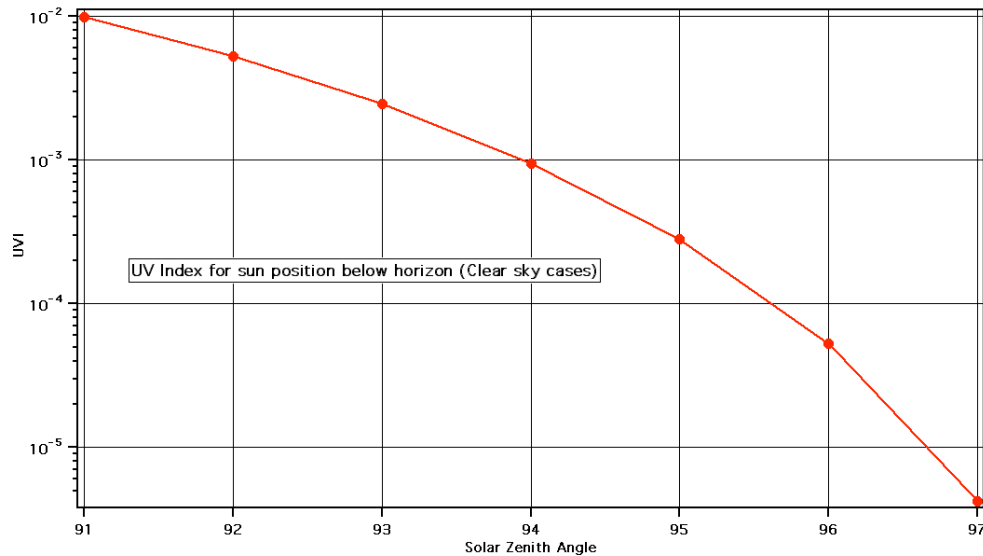
Figure 2. UV index calculated for clear sky cases using TUV code for sun below the horizon.

The daily UV dose is calculated as an integral of UV index over the daylight time:

$$DUVD = \int_{T_0}^{T_{N+1}} UVI(t)dt$$

We perform the calculations again using the trapezoid rule that results in the following formula:

$$DUVD = \frac{1}{2}\sum_{j=0}^{N}\left(UVI_j + UVI_{j+1}\right)\cdot\left(T_{j+1} - T_j\right)$$

Note 6: The daily UV dose is in UV Index hours (UVIh) if the units of T_j are hours. To convert UVIh units to kJ/m^2, units that are commonly used to express DUVD, the result from the last equation has to be multiplied by the factor: 0.09=25*3.6/1000

Note on data preparation

UVI and *DUVD* values are being calculated starting with the lowest level of calibrated UV irradiance data, i.e., "101" level. These data are not screened for spikes and no stray light correction was applied. Additionally, no errors in dark counts were evaluated to eliminate a possibility of negative irradiance values at very short wavelengths. For this reason each scan prior to *UVI* and T_j calculations is filtered. The largest wavelength (if it exists) λ_{max} for which irradiance $I_j(\lambda_{max}) \leq 0$ is found. Then for all wavelengths $\lambda \leq \lambda_{max}$ we set $I_j(\lambda)=0$.

Examples

101 level daily UX file was processed according to the equations outlined above. The results are in the following figure.
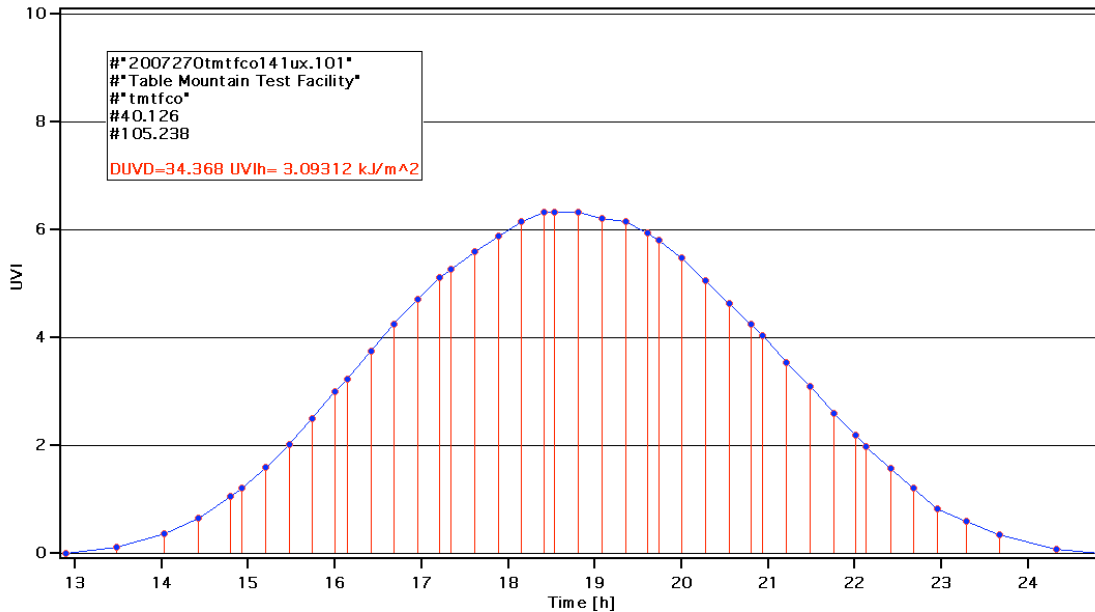

Figure 3. UVI at Table Mt. on 2007-09-27 from Brewer#141

References

McKinlay, A. F. and B. L. Diffey (1987) in *Human Exposure to Ultraviolet Radiation: Risks and Regulations*, ed. W. F. Passchier and B. F. M. Bosnajakovic, Elsevier, Amsterdam, 1987, pp. 83–87.

Action spectra: http://www.biospherical.com/nsf/Version2/description-Version2-Database3.html

Lantz, K. O. P. Disterhoft, J. J. DeLuisi, E. Early, A. Thompson, D. Bigelow, and J. Slusser, "Methodology for Deriving Clear-Sky Erythemal Calibration Factors for UV Broadband Radiometers of the U.S. Central UV Calibration Facility," *J . Atmos. and Ocean. Tech*. **16**, 1736-1752, 1999.

Bernhard, G., C.R. Booth, and J.C. Ehramjian, "Supplement to Version 2 data of the National Science Foundation`s Ultraviolet Radiation Monitoring Network: South Pole," *J. Geophys. Res*. **109**, D21207, doi:10.1029/2004JD004937, 2004.