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ACTINIC FLUX AND IRRADIANCE MEASUREMENT AT STORM PEAK LABORATORY, COLORADO

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1. Introduction

Irradiance and actinic flux are important parameters that characterize atmospheric radiation. While irradiance is a measure of the energy flux of photons through the atmosphere the actinic flux is the spherically integrated photon flux at any point in the atmosphere. Actinic flux, not irradiance, is required to calculate photolysis rate parameters for air chemistry.

The use of a diode array spectral radiometer equipped with integrating hemispherical collector to make measurements of actinic flux was tested at the Desert Research Institute's Storm Peak Laboratory in Colorado (Borys and Wetzel, 1997) on a winter day with clear sky conditions.

The measured irradiance and actinic flux are compared to calculations made with the TUV4.2 model (Madronich et. al., 1998). The modeled irradiance and actinic flux have similar temporal patterns to measured values but there are significant differences that may be attributed to the reflection of radiation from the snow surface as well as model specifications and instrument calibration.

Section 2 describes the method of comparison between irradiance and the actinic flux. The use of the TUV4.2 model and the calibration of the spectrometers are also discussed. The results for irradiance and actinic flux are shown in Section 3. And conclusion and discussions are provided in Section 4.

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2. Method

The measurement period was conducted on a clear day, January 16, 2002. An actinic flux sensor with 2π hemispheric diffusive glass dome was positioned normal to the surface. The spectrometer measures the radiance energy as a number of signal counts. Using the calibration data the raw data are converted to the number of photons per unit area, unit time, and unit wavelength.

2.1 Irradiance vs. Actinic Flux

The irradiance (E) is defined as radiant flux density that is received on a flat surface and expressed as:

$$E(\lambda) = \int_{\varpi} L(\lambda,\theta,\varphi)\cos\theta d\omega \qquad (1)$$

where $L(\lambda,\theta,\varphi)$ is the extraterrestrial solar radiance, $cos\theta$ is the zenith angle (i.e., the angle between surface normal and incident solar beam). Solid angle is given as ω. The unit of irradiance is $W/m^2/nm$.

According to the Madronich (1987), the actinic flux (photons/cm/s/nm) is the total amount of spherically integrated light entering a volume of space and it is what causes a molecule to photolyze in the atmosphere. The importance of this conceptual difference between irradiance and actinic flux is evident when one applies radiant energy to photo-dissociation rate for atmospheric gases.

$I(\lambda)$ is the spectral actinic flux. $I(\lambda)$ is obtained from spherically integrated radiance,

$$I(\lambda) = \int_{\omega} L(\lambda,\theta,\varphi) d\omega \qquad (2)$$

where the integration is carried out over the solid angle, $\omega = 4\pi$ and $L(\lambda,\theta,\varphi)$ is the extra-terrestrial solar radiance at the zenith angle (θ) and the azimuthal angle (φ).

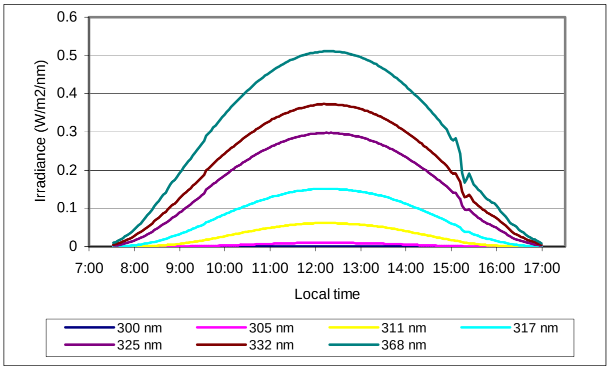

Figure 1. Measured irradiance (W/cm²/nm) on January 16, 2002.

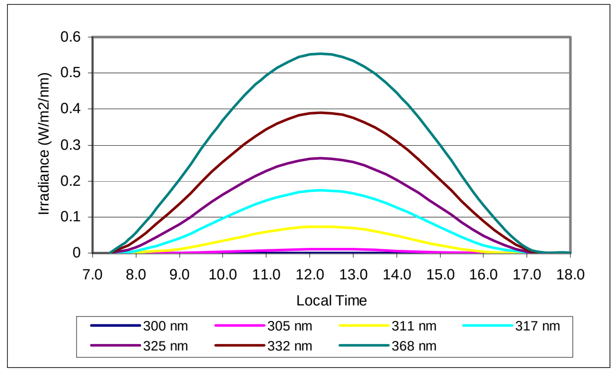

Figure 2. Simulated irradiance (W/cm²/nm) on January 16, 2002.

2. 2 Irradiance And Actinic Flux In The Model

The irradiance measurement at SPL is for the upper hemisphere (2π). Irradiance is given in equation (3),

$$E(\lambda) = F_E(\lambda) \times \frac{\{E_{DIR}(\lambda) + E_{DN}(\lambda)\}}{D(\lambda)} \qquad (3)$$

where λ is wavelength, $F_E(\lambda)$ is the extraterrestrial radiance in the unit of photons/cm^2/$d\lambda$. E_{DIR} and E_{DN} are irradiance of direct solar beam and down-welling diffusive light, respectively. These values are given as fractions of F_E (λ). The equation of the irradiance calculation is divided by wavelength interval, D(λ) to obtain irradiance for the wavelength of the averaged energy.

Actinic flux is given in equation (4),

$$I(\lambda) = F_E(\lambda) \times \frac{\{E_{DIR}(\lambda) + E_{DN}(\lambda) + E_{UP}(\lambda)\}}{D(\lambda)} \qquad (4)$$

where λ is wavelength. $F_E(\lambda)$ is the extraterrestrial solar irradiance in photons/cm^2/$d\lambda$. E_{DIR}, E_{DN}, and E_{UP} are irradiances of direct solar beam, down welling and up welling diffusive radiation, respectively. These values are given as fractions of $F_E(\lambda)$.

2.3. UV Spectral Radiometers

Two UV spectral radiometers were obtained from Metcon, Inc. Each spectral radiometer consisted of a hemispherical radiation collection head and a monolithic monochromator with a 512-pixel diode array detector and spectral resolution of 0.85 nm. The detectors have an extremely fast response time, such that the wavelengths affecting the photolysis rate of nitrogen dioxide could be sampled at frequencies up to 5 Hz. The spectral radiometers were calibrated at DRI before the field measurements. Two calibrations were performed with two 1000w calibration lamps; one was with a NIST-traceable lamp and the other uncalibrated. At SPL the secondary lamp was used to inter-calibrate the spectral radiometers. The irradiance of the uncalibrated lamp was determined from the ratio of the two DRI calibration results. Following the calibration the spectral radiometers were mounted on elevated posts at SPL.

3. Results

3.1 Irradiance

SPL measurement data include radiation a range of UV wavelengths, monitored since March 1999 as part the USDA UVB Monitoring Network (Bigelow et al. 1998). Spectral UV irradiance measurements were used seven channels wavelength (300, 305, 311, 317, 325, 332, and 368 nm).

Irradiances obtained from the TUV4.2 model were compared, and model values were utilized to study the irradiance and actinic flux.

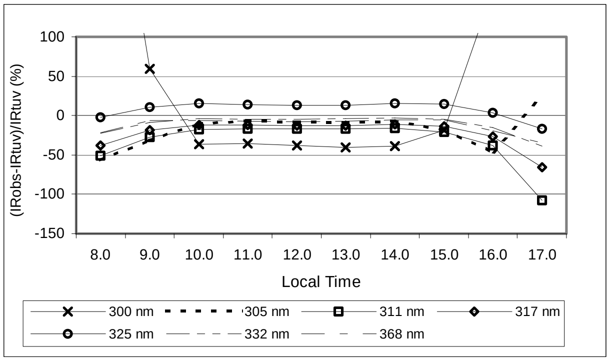

Figure 3. The ratio of simulated irradiance to measured irradiance, expressed at a percentage. Simulations of irradiance assumed surface albedo = 0.9.

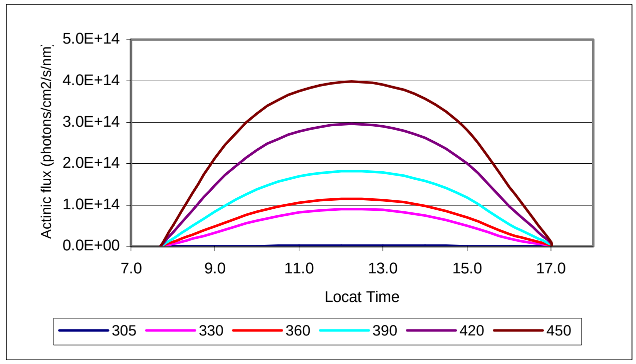

Figure 4. Model calculation of 2π actinic flux on January 16, 2002 for various wavelengths (nm).

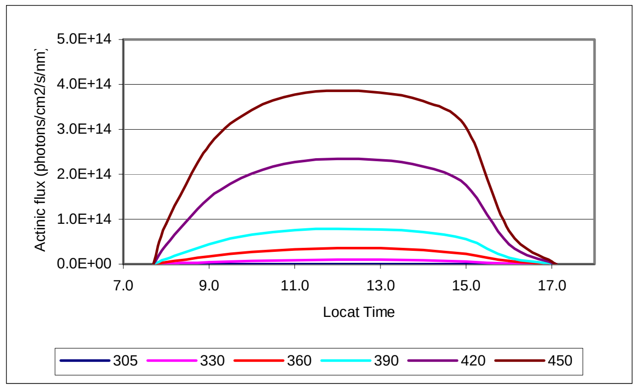

Figure 5. Measured actinic flux with 0.5 second exposure on January 16, 2002.

Figure 1 and 2 show the measured and simulated irradiances at selected wavelengths, respectively. Both irradiance time series show minima at near sunrise and sunset. The longest wavelengths (368 nm) is associated with the largest radiant energy. The sudden drop at 15:20 LT in measured irradiance is caused by blockage by the nearby instrument tower.

For most wavelengths except the shortest wavelength of 300 nm, the ratio of the observed irradiance to the modeled irradiance (Fig. 3) is bounded by $\pm 20\,\%$ during the day, and is larger at the morning and late afternoon. It declines in the next two hours. The gradient is most uniform between 9:00 LT and 16:00 LT. At noon, the ratio values of all wavelength, except 300 nm, are in the range between –38.0 and +13.0 %.

For relative differences during the day, two factors need to be considered. One is that the irradiance near sunrise and sunset is more affected by the atmosphere because of the longer path length. The other is that the albedo of the snow is unknown and so that it is difficult to estimate the impact of the reflected light.

3. 2 Actinic flux

A time series of simulated and modeled 2π actinic fluxes for six wavelengths are shown in Figure 4 and 5, respectively.

The flux could be detected at the wavelength of 292 nm throughout the day. The actinic flux increased sharply after sunrise and reached a broad peak by noon. Note that solar radiation for wavelength 290 nm is absorbed by the atmosphere and not detected at the surface.

The peak flux occurs at the maximum solar zenith angle (61.5°), 30 minutes after local time (LT) noon. The actinic flux value at 12:00 LT at wavelength 305, 360, and 420 nm are 2.30E+10, 1.14E+14, and 3.97E+14 photons/cm^2/nm, respectively, from the simulation. The measured actinic flux at noon is 2.96E+10, 3.56E+13, and 3.86E+14 photons/cm^2/nm for the same wavelengths, respectively. It is clear that both measured and modeled actinic fluxes do not agreed well at the lower wavelengths.

The ratio of 2π actinic flux to the corresponding irradiance in the time series is shown in Figure 6. A bimodal shape in the time series is seen through selected wavelengths. The maximum ratio occurs at 7:30 LT and 16:00 LT in most wavelengths and the minimum is at 12:30 LT. By definition irradiance is dependant on solar zenith angle while actinic flux is not. That means at noon, when the zenith angle is smallest, the values are closest. Possible

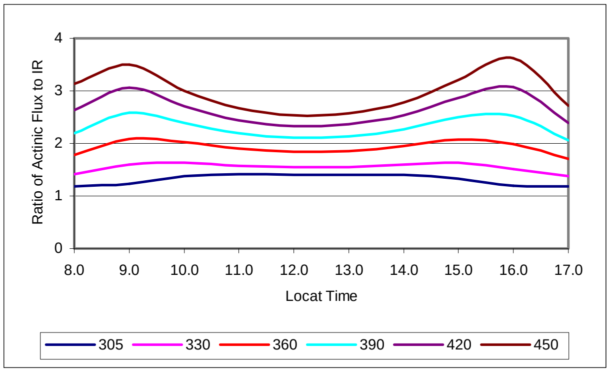

Figure 6. The ratio of simulated 2π actinic flux to simulated irradiance for various wavelengths.

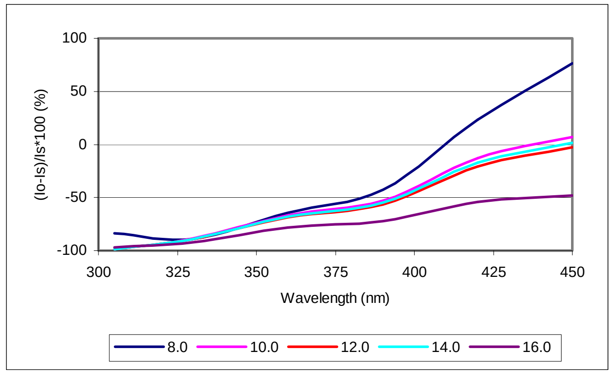

Figure 7. Comparisons of the measured to modeled actinic flux. *Io* is measured actinic flux and *Is* is modeled actinic flux. Each curve is for different hours (LT).

reasons for the bimodal shape are 1) increased scattering by the extended path in the early morning and late afternoon and 2) snow surface reflectivity is higher for lower incident light angle.

A comparison between measured and modeled actinic flux is shown in Figure 7. The values are given as the percent ratio of the measured actinic flux to simulated actinic flux for selected wavelengths.

Each line is a different time of the day. The ratio has large values at lower wavelengths then becomes to agree as wavelength increases. The result indicates that the model consistently overestimates the observed values. The comparison also indicates that better agreement is obtained from the model for the longer wavelengths.

4. Discussion and conclusions

Modeled and measured irradiance and actinic flux on a clear winter day (January 16, 2002) were compared. While irradiance measures the radiant energy on a horizontal surface which depends on the solar zenith angle ($W/m^2/nm$), actinic flux represents radiation reaching a molecule from all directions ($photons/cm^2/s/nm$). For photochemical applications, the value of the actinic flux is more important. As shown in Section 3, modeled UV spectral irradiance and actinic flux have significant differences when compared with measured values in a field comparison experiment at a snow-covered site.

Modeled and measured 2π actinic flux reasonably agree at longer wavelength but there is large difference in short wavelength. The difference in the UV range is a critical characteristic because atmospheric photochemical reactions occur in specific UV wavelength range and in many cases modeled actinic flux values are adopted without verification. It is necessary to measure upwelling diffusive radiation flux from the snow surface.

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