Introduction

The purpose of the Data Workshop was to focus on the use of climatological data by terrestrial and aquatic biologists studying UVB effects on plants and animals and to define the needs of the biological effects community in terms of data presentation (summaries, weighting functions, etc.). The workshop included seven invited scientists whose research encompasses the interactions and response of aquatic and terrestrial systems to UVB radiation, two USDA CSREES program officers, and Colorado State University program staff (see attached list of participants).

Since 1992, the USDA UVB Monitoring Program has been designing and implementing a network to provide climatology and trends data of UVB irradiance in the U. S. The current network now has 26 sites (see web site - http://uvb.nrel.colostate.edu/) with plans for 30-40. The primary instrumentation for measuring UV irradiance is a seven channel interference-filter UV Multi Filter Rotating Shadowband Radiometer\(^1\) (UV-MFRSR) making total horizontal irradiance measurements nominally at 300, 305, 311, 317, 325, 332, and 368 nm. These filters have a bandpass of 2 nm and therefore approach the spectral resolution of some spectroradiometers. In addition, this instrument employs a shadowbanding technique which permits the determination not only of total horizontal irradiance but also the diffuse and direct normal component. The direct normal irradiance is the value of the sun only (no diffuse) as if the instrument were tilted so that the detector was normal to the sun. Other measurements at each site include a visible seven channel filter instrument (VIS-MFRSR)\(^1\) similar to the UV instrument described above but making six measurements in the range of 400-940 nm with a seventh broadband channel (350-1100 nm) and a broadband UV meter (UVB-1)\(^1\).

A climatological network will provide information on the spatial characteristics and temporal of UV irradiance on a national scale and will be a source of data for the evaluation long-term trends. The USDA network now supplies calibrated UV irradiance data from both the UV-MFRSR and the broadband UVB-1 as well as calibrated visible irradiance data from the VIS-MFRSR to scientists and the public worldwide. The irradiance data, which are in the form of three minute averages, can be viewed on program web pages as daily or weekly plots for each monitoring site and can be downloaded as an ASCII file. The broadband data are now presented as irradiance in “instrument units” (watts/m\(^2\)). (The broadband data will soon be CIE weighted). The USDA

\(^1\)Yankee Environmental Systems, Inc.
believes that such information is of importance to US agriculture and, in general, for assessing potential impacts of increasing UVB on terrestrial and aquatic ecosystems.

We have questioned whether or not the current three minute average data serves the needs of the biology community. Currently the primary use of the network data has been by the atmospheric science community in studies of aerosols (visible data), support of atmospheric modeling, and validation of satellite-based determinations of surface UV irradiance. There have been only limited requests for data from the biological community. Thus, we believed there was a need to focus on how climatological data will be used by the terrestrial and aquatic biologists studying the UVB responses of plants and animals. The workshop participants, consisting of terrestrial and aquatic biologists, were able to define products that we need to develop, suggested how they should be delivered to the user, and defined the required uncertainty limits.

**Workshop Recommendations**

Recommendations of the workshop participants addressed spectral bandwidth, averaging times, spectral weighting, daily doses, reporting units for UVB (290-320 nm), UVA (320-400 nm), and PAR\(^2\) (400-700 nm), UVB/UVA/PAR ratios, and finally acceptable uncertainty limits. It was agreed that in addition to UVB, the data output should include UVA and PAR. While PAR is not directly measured, there is a broadband channel on the VIS-MFRSR which has a spectral response from approximately 350-1100 nm. We believe it will be possible to convert the measurement of this channel to PAR with reasonable accuracy. The following details these recommendations and discusses the action to be taken by the monitoring program.

**Spectral Bandwidth**

- **Recommendation:** While the network provides broadband (Yankee UVB-1) data, there was a consensus that broadband data did not meet the needs of the aquatic and terrestrial response research. Narrowband (2 nm FWHM) data from the shadowband UV-MFRSR should be modeled at 1 nm resolution to create continuous spectral data. The continuous spectral data can then be weighted with selected action spectra and daily doses derived (see following sections).

- **Action:** Two models will be evaluated (Min and Harrison\(^3\), 1998, and the TUV model (Madronich - personal communication)) to construct a continuous spectra from the seven wavelengths of the UV-MFRSR. The Min and Harrison model employs all seven wavelengths to reconstruct a continuous spectra while the TUV model employs just two wavelengths to derive column ozone and a third channel outside of the ozone band to

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\(^2\) Photosynthetically Active Radiation

\(^3\) Min, Qilong, and Lee Harrison, 1998. Synthetic spectra for terrestrial ultraviolet from discrete measurements, J. Geophysical Res., **103**, No. D14, 17,033-17039
estimate effective cloud thickness. Both models base their computation on an extraterrestrial solar spectra. It is estimated that the computational time of the TUV model will be less but that the Min model should provide a more accurate spectral representation as well column ozone (clear days only). Both methods will be tested and computational time and error limits evaluated. The method which best meets program needs will be employed to provide continuous spectral output.

**Averaging Times**

- **Recommendation:** It was generally agreed that three minute averages were not important to studies of the response of terrestrial and aquatic systems to UVB irradiance. The recommendation was to create hourly averages. For some aquatic studies fifteen minute averages may be more appropriate (example: studies of response phytoplankton).

- **Action:** The program will initially provide hourly averages in addition to the current three minute averages. In the future, shorter averaging time for some sites may be provided in response to individual user requests.

**Spectral Weighting**

- **Recommendation:** It was generally agreed that the weighting of spectral data with biologically relevant action spectra was desirable. It was also agreed that the widely used CIE action spectra would be most useful in comparing to data provided by other measurement programs. Based on need, other weighting functions should be considered as routine output. It was also suggested that software for applying user selected weighting functions be made available to the data users.

- **Action:** The program will routinely supply CIE weighted broadband data. With the availability of the reconstructed continuous spectral data, action spectra in addition to CIE (Setlow, generalized plant, DNA dimer, etc.) can be applied and made routinely available when there is adequate interest. The need for the routine weighting of the reconstructed spectral data will be evaluated along with the required computational time. The program will also investigate the feasibility of providing software for applying user selected weighting functions.

**Integrated UV Values**

- **Recommendations:** It was agreed that very useful outputs would be the hourly and daily integrated UVB (weighted and unweighted), UVA and PAR.

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4 CIE - human erythemal action spectra sometimes referred to as “Diffey”.
• **Action:** The program will investigate the development of the daily and hourly integrated UVB, UVA, and PAR as a routine output. Consideration will be given to supplying several different UVB weighting functions (see previous section) in addition to CIE for the integrated output.

**Reporting Units**

• **Recommendations:** It was recommended that UVB and UVA irradiances be reported as watts/m² and that hourly or daily integrated values should be expressed as joules/m². PAR values should be expressed as quantum flux in µmoles/sec/m² and integrated values as µmoles/m². A factor to convert quantum flux to energy units (joules) should be supplied.

• **Action:** These units will be adopted.

**UVB, UVA, and PAR Ratios**

• **Recommendation:** It was recommended that ratios of UVB, UVA, and PAR be available.

• **Action:** This information can be derived from the reconstructed continuous spectra.

**Uncertainty Limits**

• Unlike the application of irradiance data for the determination of long-term trends which depends on high accuracy and/or long-term stability, uncertainty requirements of data used for terrestrial and aquatic response studies are much less restrictive. It was agreed that 5-10% uncertainties were acceptable. Uncertainties in current calibration methods, the wavelength stability, stray light rejection in available instrumentation (including spectroradiometers), suggest that it unrealistic to expect uncertainties of less than 3-5%.

The construction of a continuous spectra from the seven wavelength UV-MFRSR data will introduce an additional uncertainty which is yet to be quantified. It is believed that an overall uncertainty of 5-10% is a realistic target.

**Summary**

After reviewing the recommendations of the workshop participants, it is apparent that the ability to construct a continuous spectra from the seven measured wavelengths of the UV-MFRSR is critical. The various products which the committee wished to see available depend on continuous spectral data. As previously discussed, two approaches for producing continuous spectra have been suggested. The feasibility of these two approaches has yet to be investigated. It will be necessary to investigate the uncertainties and the computational time required for each. At this time we believe it will be possible to produce continuous spectra as hourly averages which will make possible the routine calculation of the requested outputs or by providing software which will allow the user to derive them directly from information in our data base.
Workshop Participants

Invited Participants

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Steve Britz, USDA ARS
Thomas Day, Arizona State Univ.
Patrick Neale, Smithsonian Institution
Barbara Prezelin, Univ. California at Santa Barbara
Ann Stapleton, Univ. of Tennessee at Chattanooga
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