VERMONT MONITORING COOPERATIVE

ULTRAVIOLET-B MONITORING PROGRAM

FINAL REPORT

to the

Air Pollution Control Division

Department of Environmental Conservation
Agency of Natural Resources
Waterbury, VT 05671

by

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Vermont Monitoring Cooperative Research Report # 4

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SUMMARY

Increasing solar ultraviolet radiation (UV-B) has the potential to harm local and regional human health, agriculture, and natural ecosystems. Although there is considerable evidence that stratospheric ozone depletion is occurring in northern temperate latitudes, there are few measurements of ground-level UV-B fluxes in this region. In order to monitor UV-B levels and to support basic research on plant and ecosystem responses to a changing environment, the Vermont Monitoring Cooperative (VMC) has initiated a UV-B monitoring program, as described in this report. This work has been supported by the Vermont Department of Environmental Conservation (VT DEC), Air Pollution Control Division through a grant to the University of Vermont (UVM) to study the state of the science of UV-B monitoring and to develop a UV-B monitoring program.

In July, 1993, we installed a Yankee Environmental Systems UVB-1 pyranometer at the top of the VMC forest canopy research tower at the Proctor Maple Research Center (405 m elevation) on Mt. Mansfield. The data from the UV-B pyranometer complements the extensive meteorological monitoring already conducted at the site by the VMC. Continuous UV-B monitoring data are recorded as fifteen minute averages to a data logger. These data are converted to total UV-B irradiance (in watts/m^2), sunburn (erythemal) dose rate (in effective watts/m^2), Minimum Erythemal Dose (MED) rates, and plant dose rates (in effective watts/m^2). *A Guide to UVB-1 Data Processing using UVBOUT.XLT* (Appendix 2) describes the data conversion procedure. This document also presents data Quality Assurance and Quality Control (QA/QC) procedures. UV-B data will be archived at the University of Vermont with other VMC data. They will be made available to VMC cooperators and other state and regional organizations who request them. Depending on decisions of the proposed NESCAUM (Northeast States for Coordinated Air Use Management) UV-B monitoring sub-committee, the data may also be gathered into a regional data base including UV-B data from across the northeast.

This final report provides a brief background discussion of the issues surrounding solar UV-B, summarizes the specific objectives of the Vermont UV-B monitoring program, details the procedures of the monitoring program, and provides some examples of the output data.

BACKGROUND

Ultraviolet-B (UV-B) radiation can harm human as well as plant and animal health (Urbach 1989, Coohill 1989). Radiation in this spectral region causes sunburn in humans and skin cancer in laboratory animals (Urbach 1969), can reduce growth rates and photosynthesis in plants (Caldwell 1981), can reduce the productivity of oceanic phytoplankton (Hader 1993), and can damage synthesized organic polymers (Andrady 1993). Potential effects of marked increases in UV-B radiation include increased occurrence of skin cancer (Scotto *et al.* 1988), reduced agricultural yields of some crop species (Teramura 1983, Tevini and Teramura 1989) and changes in the species composition of non-agricultural ecosystems (Caldwell 1977).

Ultraviolet radiation can be divided into four wave bands:

Vacuum UV:	<200 nm
UV-C:	200-280 nm
UV-B:	280-315 (320) nm
UV-A:	315 (320) - 400 nm

Oxygen, ozone, and other atmospheric gases completely absorb vacuum UV and UV-C radiation so these bands do not reach the earth's surface. Large amounts of relatively long-wavelength UV-A reach the earth's surface, but this is of less concern because the biological effectiveness of UV-A is generally less than of UV-B and because the ozone absorption coefficient for UV-A is so low that stratospheric ozone depletion will not significantly alter UV-A transmission. Most of the solar UV-B (which can harm biological systems) is absorbed by the stratospheric ozone layer, but a portion does reach the earth's surface, and changes in stratospheric ozone can significantly alter this.

Since stratospheric ozone is the primary attenuator of solar UV-B, its depletion may cause a corresponding increase in the amount of UV-B radiation reaching the earth's surface (Frederick *et al.* 1989). Increasing tropospheric ozone, aerosols, and particulates, however, also attenuate UV-B, and may partially or fully compensate for thinning stratospheric ozone (Logan 1985, Scotto *et al.* 1988). Although decreasing stratospheric ozone is well-established, increasing UV-B at ground level have been difficult to demonstrate (Scotto *et al.* 1988). A few reports have, however, shown increasing UV-B flux at ground level (Blumthaler and Ambach 1990, Kerr *et al.* 1993), and Dobson spectrometer data (which measure total column ozone thickness based on UV-B levels at the earth's surface) imply increased ground level UV-B. To date, UV-B monitoring has been limited and therefore inadequate to determine the general trends in ground-level UV-B, and the role of tropospheric UV-B attenuators (aerosols, ozone, etc.) adds to the uncertainties. Additionally, relatively little work has been done to assess biological responses to spatial and temporal variations in UV-B dose rates.

Potential threats to local and regional human health, agriculture, and natural ecosystems and the unknown degree of risk prompted the Vermont Department of Environmental Conservation (VT DEC) Air Pollution Control Division (APCD) to establish a UV-B Monitoring Program. The VT DEC APCD awarded a grant to the University of Vermont in 1992 to study the state of the science of UV-B monitoring and to develop a UV-B monitoring program. In this report we present the final results of the past year's work.

OBJECTIVES

The objectives for the Vermont UV-B Monitoring Program as set forth in the VT DEC grant were to:

1) Review the state of the science of UV-B monitoring with respect to local and regional information needs.

2) Develop an action plan for a Vermont UV-B monitoring program consistent with local and national UV-B monitoring needs.

3) Develop written operating procedures for the operation of a UV-B monitoring station, including procedures for quality assurance and quality control of the data.

4) Establish and operate a UV-B monitoring station at the VMC Mt. Mansfield site and a data management and distribution program.

RESULTS

Objective 1: Review the state of the science of UV-B monitoring with respect to local and regional information needs.

Current instrumentation for UV-B monitoring falls into two categories: broadband and spectral scanning instruments. Broadband instruments respond to the entire UV-B spectrum (280-320 nm) in the same manner as "average" Caucasian human skin (the erythemal response). As with human skin, the spectral response of the instrument extends into the UV-A spectrum (320-400 nm). Although several studies have reported trends in ground-level UV-B based on broadband data, the UV-B research community has reached a consensus that these instruments are not suitable for long-term status and trend analysis where data must reveal changes of less than 5% per decade (Gibson 1992).

Broadband data are useful, however, for spatial and temporal studies of biologically effective UV-B irradiance (i.e., radiation that affects biological processes) and for examining relationships between UV-B levels and atmospheric environmental conditions (cloudiness, photosynthetically active radiation, aerosols and tropospheric ozone).

More explicit uses for data from this instrument could include:

A) Providing a sun-exposure health index. In keeping with their original design purpose, broad-band instruments can be used to determine when UV levels may pose a human health risk.

B) Determining relative levels of biologically effective UV that occur in the field during various stages of plant and animal life cycles, and in support of research on physiological and morphological adaptations to higher levels of radiation.

C) Assessing the correlations between ground-level UV-B and atmospheric pollutants such as total aerosols or ozone.

D) Determining spatial variation in relative UV-B levels (e.g., between the VMC site and the Howland, ME site) to support the above studies.

In the 1970s several Robertson-Berger (RB) UV-B broadband meters were deployed in North America in a federal effort to monitor UV-B trends, but the value of the twenty years of data provided by these instruments has been questioned since instrument calibration was not constant (J. DeLuisi, pers. comm.), the instruments were generally located at airports which may have higher levels of UV-B attenuating pollutants (Scotto *et al.* 1988), and these instruments cannot detect small trends (<5%) in UV-B levels. In addition, the RB meter is not temperature controlled and the meter's response changes as a function of ambient temperature (0.5-0.8%/°C), although this may be unimportant in temperate latitudes; The output of the RB meter (half-hourly "counts") is not listed with time or date, thus assigning dates and times to each data point can be problematic. Finally, there is little enthusiasm to continue the RB Network program, data processing takes a long time, and no calibration coefficient is confidently known for the instrument.

On the positive side, recent analysis of RB meter data has shown that spectral response functions are basically stable and that calibration and temperature effects could not by themselves explain the observed data trends (Booker and Fiscus 1994). One of these meters continues to record data at the Burlington International Airport; we intend to use output from this instrument in the QA/QC portion of our UV-B monitoring program.

Although conceptually similar to these older RB meters, the latest generation of broadband meters have solved some of these shortcomings. For example, they have incorporated temperature control systems into their designs, have improved spectral responses, and have improved data logging capabilities. Competing companies currently offering state-of-the science broadband UV meters selling for around $5,000 include:

Yankee Environmental Systems (Turners Falls, MA, USA), Solar Light Co. (Philadelphia, PA, USA), VITAL Technologies (Ontario), and International Light Co. (Massachusetts).

The other principal type of UV-B monitoring instrument is a scanning spectral radiometer which detects with high-precision the energy received at discrete wavelengths across the spectrum of interest. This type of instrument provides the best information for detecting long-term trends in UV-B, for understanding the factors controlling surface UV-B fluxes, and for calibrating other UV-B monitoring instruments such as the broadband instruments (Gibson 1992).

Under a grant from the USDA UV-B monitoring program, Lee Harrison and associates have developed a scanning spectral radiometer that meets the rigorous instrumentation requirements of the developing USDA UV-B monitoring program. The prototype instrument is currently being tested by NIST. The USDA plans to deploy 10 of these instruments in a national network by 1995. This instrument is not appropriate for the Vermont monitoring program because it is expensive (>$100,000) and technically difficult to operate, requiring the support of technical staff well-trained in radiation physics.

It is generally agreed that no suitable intermediate between these two instruments currently exists. The USDA is strongly encouraging development of alternative instrumentation that provides more rigorous information than the broadband instruments, but is less expensive than the spectral radiometers, yet are reliable, stable, and accurate. These instruments could take the form of scanning monochromators or instruments measuring several fixed wavelengths (Gibson 1991). Dave Correll (see Appendix 1) is currently directing development of a multi-wavelength filter radiometer at the Smithsonian Institution, as is the Swedish group under Ulf Wester (Science and Policy Associates 1992).

Additional information about the current status of the development of broadband UV-B monitoring instruments and monitoring approaches can be found in our Interim Report to the VT DEC (Scherbatskoy and Sanderson 1993).

Objective 2: Develop an action plan for a Vermont UV-B monitoring program consistent with local and national UV-B monitoring needs.

With the above background in mind, we identified an action plan as described in our interim report to the VT DEC (Scherbatskoy and Sanderson 1993). In the following section, specific actions taken in accordance with the plan are discussed.

A) *Action planned:* Submit a proposal to the USDA UV-B monitoring program to consider the Vermont Monitoring Cooperative (VMC) Mount Mansfield site as a potential climatological site for their UV-B monitoring network (climatological sites will initially have broadband meters and later convert to multi-wavelength meters). We propose that USDA establish this site at the summit of Mount Mansfield.

Action taken: This application was submitted 4/19/93. In late August the USDA Site Selection and Measurements Committee chose 13 sites for initial placement of broadband meters. The VMC site was not among the thirteen chosen, although two regional sites were chosen at a University of Maine site (Howland, Maine), and a Cornell University site (Geneva, NY). The USDA proposes to eventually place 30 multi-wavelength filter radiometers throughout the U.S. The VMC Mount Mansfield site has been retained as a potential site.

B) *Action Planned:* Purchase a Yankee Environmental Systems (YES) UVB-1 ultraviolet pyranometer and begin surface UV-B measurements at the VMC monitoring site at the Proctor Maple Research Center at 400 m elevation on Mount Mansfield by June 1993.

Action taken: In June 1993 we purchased a YES UVB-1 broadband pyranometer for the Mt. Mansfield VMC site. The instrument was fully operational by the end of July, 1993. See Objective 4 below.

C) *Action planned:* Cooperate with NESCAUM to organize a UV-B subcommittee in the Monitoring and Assessment Committee in order to coordinate regional UV-B monitoring efforts.

Action taken: At the April, 1993 NESCAUM meeting a proposal was advanced to form a UV-B subcommittee to achieve the following objectives:

> (1) Serve as a resource group for NESCAUM members. By maintaining a current list of members with telephone numbers and addresses, NESCAUM members will know who to contact in other states for answers to questions about instrumentation, methodology, data handling, etc.
>
> (2) Coordinate efforts at the state level. Members can benefit from each other's efforts while working together to formulate data collection methods and QA/QC procedures. The subcommittee can also insure comparability of instrumentation.
>
> (3) Determine how UV-B data will be used and by whom, promote sharing of these data, and provide a larger, more consistent UV-B data base.
>
> (4) Facilitate exchange of ideas about the purpose and direction of the monitoring programs in the northeast.

This proposal was generally well-received, but subsequent action on the proposal has been lacking, probably for two reasons. First, many NESCAUM states are struggling to cope with budget shortfalls and UV-B is not currently a high priority for investment. Second, the science of UV-B monitoring is still rapidly evolving, and several NESCAUM members have indicated a hesitancy to become involved in a technically uncertain and rapidly changing monitoring program.

Despite this, the Maine Department of Environmental Protection (DEP) and VMC have pursued the objectives of this committee in an informal, yet productive, manner.

D) *Action planned:* Remain in contact with other UV-B researchers to keep informed of and evaluate changes in this field. Past and planned UV-B monitoring efforts are currently undergoing extensive evaluation, particularly in terms of instrumentation. We anticipate this to be a fast changing field for at least the next year.

Action taken: We remain fully abreast of all literature pertaining to UV-B monitoring and related subjects (e.g., biological effects). We have developed an extensive bibliography of UV-B books, articles, and reports. that includes the most recently published items. We also have frequent contacts with UV-B researchers in Maine, North Carolina, New Zealand, the USDA, and elsewhere.

We hope to attend a NIST-sponsored conference in February that will address advantages and disadvantages of all available instruments for UV-B monitoring. This conference should further enhance our ability to make the UVB-1 pyranometer data relevant to issues in Vermont and New England.

E) *Action planned:* Keep abreast of progress in the USDA and other UV-B monitoring programs. The Ontario provincial government, the EPA, other states, and several academic institutions have established or are considering UV-B monitoring programs.

Action taken: A number of initiatives are underway, and are summarized here. As mentioned above, the USDA did not chose the VMC Mt. Mansfield site for their network, but it remains in consideration for future participation. To date, only three of the sites chosen have been equipped with instrumentation. The USDA project coordinator (Jim Gibson) has not yet proposed how non-selected sites may participate in the network.

The Maine DEP has been monitoring UV-B with a YES UVB-1 pyranometer since the spring of 1993. We are in frequent contact with Paul Nichols and Andy Johnson, the facilitators of Maine's program.

The Canadian national monitoring program, under the direction of Jim Kerr, has ten sites monitoring UV-B with Brewer spectral radiometers. Kerr plans to publish the results of three years of data from the Toronto site that appears to show a significant increase in UV-B radiation reaching the ground.

Two sites (in Idaho and Kansas) have been selected for the NOAA SURFRAD network under the direction of John DeLuisi. These sites will provide UV and broadband solar direct and total radiation measurements as well as other ancillary measurements.

The proposed EPA network, under the direction of Bill Barnard, was on the verge of awarding a contract for instruments for the network, but the negotiations around that contract were canceled and a new RFP is to be issued soon.

F) *Action planned:* Experiment with radiative transfer models to assess their ability to duplicate our monitoring results. These models may eventually be useful for developing UV-B climatological information using satellite data.

Action taken: The Bjorn-Murphy radiative transfer model we currently use predicts the output of the UVB-1 meter well (within about 30% on sunny days). However, it is generally agreed that it does not provide a substitute for direct surface measurements because too much remains unknown about the atmospheric factors that affect UV-B irradiance. This model will be used in our research on sources of UV-B attenuation and in performing QA/QC checks on our data.

Objective 3: Develop written operating procedures for the operation of a UV-B monitoring station, including procedures for the quality assurance and quality control of the data.

a) Operating Procedures.

Data collection methods and QA procedures for a variety of current monitoring programs are well-standardized at the VMC site. Data from the UVB-1 pyranometer are recorded on the Campbell 21X datalogger along with extensive meteorological data also measured on the tower at the VMC Mt. Mansfield site. A minimum of two times per week a technician at the site downloads these data into a computer file. The file is loaded into a standardized spreadsheet with columns for date/time and each variable in the file. The UV-B data are then loaded into another standardized spreadsheet that calculates total UV-B radiation and effective dose rates for human erythema (sunburn) and plant damage.

b) Quality Assurance/Quality Control.

QA/QC procedures include routine maintenance of the pyranometer, re-calibration of the instrument every two years, and comparison of the pyranometer's output with both radiative transfer model output and Burlington Robertson-Berger data. The details of the QA/QC program are included in *A Guide to UVB-1 Data Processing Using UVBOUT.XLT* (Appendix 2).

Objective 4: Establish and operate a UV-B monitoring station at the VMC Mt. Mansfield site and a data management and distribution program.

A YES UVB-1 pyranometer has been installed at the top of the VMC forest canopy research tower where extensive meteorological monitoring (including PAR and total solar radiation) is conducted. The instrument is mounted 22 m above the ground, 6 m above the top of the forest canopy. We began collecting data on July 28, 1993. The instrument output (in millivolts) is sampled by a Campbell 21X data logger every minute and recorded as fifteen minute averages. Monthly data sets are converted to total UV-B irradiance (in watts/m^2), sunburn (erythemal) dose rate (in effective watts/m^2), Minimum Erythemal Dose (MED) rates, and plant dose rates (in effective watts/m^2) through multiplication by conversion factors. The details of the data manipulation are included in *A Guide to UVB-1 Data Processing Using UVBOUT.XLT* (Appendix 2).

Raw data, converted data, and summary data will be archived at the University of Vermont with other VMC data. They will also be made available to VMC cooperators and other state and regional organizations that request them. Depending on decisions of the proposed NESCAUM UV-B monitoring sub-committee, the data may also be gathered into a regional data base including UV-B data from across the northeast.

OTHER ISSUES

1) Funding was available to continue this project through November, 1993. Financial support (approximately $1,800 annually) to continue this work will be needed for equipment calibration, field technical support, QA/QC, and data management. Alternative sources of support need to be identified. Annual operating costs for a monitoring site would include 10% FTE technical support for maintenance and data processing, and for re-calibration of the instrument every two years.

2) Long-term plans. It is our intention to continue monitoring UV-B at this site to (a) measure status and trends, and (b) support related environmental and biological research. There are a number of groups in Vermont and in other regions who are potentially interested in obtaining and using these data. As it is a stated goal of the VMC to facilitate the sharing and use of data such as these, we intend to actively collaborate with these groups in the long-term monitoring of solar UV-B. If better or cheaper technology become available we would adopt these methods in order to continue to accomplish our goals in this program.

ACKNOWLEDGEMENTS

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REFERENCES

Andrady, Anthony L. 1993. *Polymer materials, in UV-B Radiation and Ozone Depletion: Effects on Humans, Animals, Plants, Microorganisms, and Materials.* Manfred Tevini, ed. 1993. Lewis Publishers. Ann Arbor, MI.

Blumthaler, M. and W. Ambach. 1990. Indication of increasing solar ultraviolet-B radiation flux in alpine regions. Science 248:206-208.

Booker, F.L and E.L. Fiscus. 1994. Measurement and modeling of UV-B irradiance. *In: Climate Change and Rice International Symposim,* 14-18 March 1994, Los Bamos, Philippines; International Rice Research Institute, publ.

Caldwell, M.M. 1977. The effects of solar UV-B radiation (280-315 nm) on higher plants: implications of stratospheric ozone reduction. *In: Research in Photobiology* (A. Castellani, ed.) Plenum Publishing, New York.

Coohill, Thomas P. 1989. Ultraviolet action spectra (280 to 380 nm) and solar effectiveness spectra for higher plants. *Photochem. Photobiol.* 50(4):451-457.

Frederick, J.E., H.E. Snell, and E.K. Haywood. 1989. Solar ultraviolet radiation at the earth's surface. *Photochem. Photobiol.* 50(8):443-450.

Gibson, J.H. 1992. *Recommendations of UV-B measurement workshop (1992): Criteria for the Status-and-Trends Monitoring of Ultraviolet (UV) Radiation.* Colorado State University, Fort Collins, Colorado.

Gibson, J.H. 1991. *Report of UV-B measurement workshop: Justification and Criteria for the Monitoring of Ultraviolet (UV) Radiation.* Colorado State University, Fort Collins, Colorado.

Hader, Donat-P. 1993. *Effects of enhanced solar ultraviolet radiation on aquatic ecosystems, in UV-B Radiation and Ozone Depletion: Effects on Humans, Animals, Plants, Microorganisms, and Materials.* Manfred Tevini, ed. 1993. Lewis Publishers. Ann Arbor, MI.

Kerr, J.B. and C.T. McElroy. 1993. Evidence for large upward trends of ultraviolet-B radiation linked to ozone depletion. Science 262:1032-1034.

Logan, Jennifer A. 1985. Tropospheric ozone: seasonal behavior, trends, and anthropogenic influence. *J. of Geophys. Res.* 90(D6):10,463-10,482.

Scherbatskoy, T and J Sanderson. 1993. *Vermont ultraviolet-B monitoring program - interim report to the VT DEC, April 12, 1992.* University of Vermont, Burlington.

Science and Policy Associates, Inc. 1992. *Proceedings of the UV-B Monitoring Workshop: A Review of the Science and Status of Measuring and Monitoring Programs, 10-12 March 1992.* Sponsored by the Alternative Fluorocarbons Environmental Acceptability

Study and the Cooperative State Research Service, USDA. Science and Policy Associates, Inc.; The West Tower, Suite 400; 1333 H Street, NW; Washington, DC.
Scotto, Joseph, Ferald Cotton, Frederick Urbach, Daniel Berger, and Thomas Fears. 1988. Biologically effective ultraviolet radiation: surface measurements in the United States, 1974-1985. *Science* 239(4841):762-764.
Teramura, A. 1983. Effects of ultraviolet-B radiation on the growth and yield of crop plants. *Physiol. Plant.* 58:415-427.
Tevini, Manfred (ed.). 1993. *UV-B Radiation and Ozone Depletion: Effects on Humans, Animals, Plants, Microorganisms, and Materials.* Lewis Publishers. Ann Arbor, MI.
Tevini, M. and A.H. Teramura. 1989. UV-B effects on terrestrial plants. *Photochem. Photobiol.* 50(4):479-487.
Urbach, F. (ed.). 1969. *The Biological Effects of Ultraviolet Radiation.* Pergammon Press, New York.

APPENDIX 1

USEFUL CONTACTS

(Note: an extensive list of UV-B workers is included in *UV-B Monitoring Workshop* (Science and Policy Associates, Inc. 1992))

Dr. Bill Barnard
AREAL (MD-75)
U.S.EPA
Research Triangle Park, NC 27711
Tel: 919-541-2205 Fax: 919-541-4609
Note: Directing EPA UV monitoring efforts.

Dr. David Correll
Environmental Research Center
Smithsonian Institution
P.O. Box 28
Edgewater, MD 21037
Tel: 301-261-4190 Fax: 301-261-7954
Note: Developing a multi-wavelength spectral radiometer.

Dr. Jerry Cotton
Tel: 301-713-0295
Note: First recipient of Robertson-Berger network data.

Dr. John DeLuisi
NOAA/Environmental Research Laboratories
Office of Atmospheric Research
325 Broadway
Boulder, Colorado 80303
Tel: 303-713-0295 Fax: 303-497-6290
Note: Directing NOAA's SURFRAD network. Involved with RB network for many years and still works with broadband data.

Dr. Bronick Dichter
Yankee Environmental Systems
101 Industrial Road
P.O. Box 746]
Turners Falls, MA 01376
Tel: 413-863-0200
Note: The best person to talk to at YES about the UVB-1 pyranometer.

John Ferguson
National Weather Service/Burlington
Tel: 862-9883
Note: Ships Burlington RB data to Jerry Cotton. At our request Cotton will authorize him to send us the data first.

Dr. Edwin Fiscus
USDA-ARS
North Carolina State University
1509 Varsity Drive
Raleigh, NC 27606
Tel:919-515-3505
Note: Has worked extensively with radiative transfer models. Did a solar spectral scan on Mt. Mansfield in June, 1991 (this data is on a diskette with the other UV-B files).

Dr. Jim Gibson
Director, USDA Ultraviolet Radiation Monitoring Program
Colorado State University/Natural Resource Ecology Laboratory
Fort Collins, Colorado 80523
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Dr. Lee Harrison
Atmospheric Sciences Research Center
SUNY-Albany
Albany, NY 12205
Tel: 518-442-3811 Fax: 518-442-3867
Note: Developed the spectral radiometer for the USDA monitoring network.

Dr. Jim Kerr
Experimental Studies Division
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Tel: 416-739-4626 Fax: 416-739-4281
Note: Directs Canadian national UV monitoring network.

Paul Nichols
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Bangor, ME 04401
Tel: 207-941-4570 Fax: 207-941-4584
Note: Coordinates ME DEP UV-B Monitoring Program.

APPENDIX 2:

A GUIDE TO UVB-1 DATA PROCESSING USING UVBOUT.XLT

Introduction

This paper explains the Excel spreadsheet UVBOUT.XLS which manipulates that solar UV-B data collected by the Yankee Environmental Systems UVB-1 Pyranometer. It also presents recommended Quality Assurance and Quality Control (QA/QC) procedures. The six sections that comprise the paper are:

1) **What does *that* mean?:** explains the terms (mostly column headings) that appear in the spreadsheet.

2) **What UVBOUT does:** steps through the data manipulation performed by the spreadsheet.

3) **How to use UVBOUT:** describes procedures for entering new data into the spreadsheet

4) **Other things you may want to know:** information that may make your life a little easier.

5) **Recommended QA/QC:** suggested ways to assure quality data

6) **The UVB-1 Pyranometer Output:** a short explanation of the numbers that flow from the instrument and how they are made relevant to various biological processes.

1. What does *that* mean?

UVB-1 Output [B57 (column, row)]: A fifteen-minute average of the pyranometer's output based on one-minute samples. Units are millivolts.

Zenith Angle [C57]: The angle between a line perpendicular to the earth's surface at the pyranometer and a line from the pyranometer to the sun. The response of the pyranometer varies as a function of zenith angle so we calculate this angle in order to determine the appropriate correction factor.

Total UV-B Irradiance [B16;D56]: The rate at which UV-B radiation impacts the Earth's surface. The UV-B spectrum is defined as 280-315 nm, but is commonly appears in scientific literature as 280-320 nm. Units are Watts/meter^2.

Parrish Erythema Dose Rate [E56]: The sunburn effective UV-B dose rate for the average white human skin, calculated using the Parrish Erythemal Action Spectrum. Both Parrish (Parrish *et al.* 1982) and Diffey (McKinlay and Diffey 1987) developed a sunburn response spectrum. Parrish's appears here because it yields a higher (more conservative) value for effective sunburn dosage. Diffey's yields a result about 5-6% less than Parrish. Units are Effective Watts/meter^2.

15-minute MED [C18;F58]: A Minimum Erythemal Dose is the amount of UV energy that will turn light-colored skin slightly pink. 15-minute MEDs [F58] displays the number of MEDs received in the preceding fifteen-minute period. Maximum 15-minute MEDs [C18] in the summary table refers to the maximum MEDs received in any one fifteen minute period during the day. 1 MED equals 201±52 Joules/meter^2. In this spreadsheet MEDs were calculated using the Parrish Erythema Dose Rate.

Total MEDs [D18]: The total MEDs received from sunrise to sunset on the given day.

Caldwell Plant Dose Rate [E16;G56]: The plant effective UV-B dose rate, calculated using Caldwell's Generalized Plant Action Spectrum, normalized to 300 nm. Units are Effective Watts/meter^2.

Time of Maximum Total UV-B Irradiance [F16]: The time at which the Maximum Total UV-B occurred on the given day. On most days the Maximum MEDs and Maximum Plant Effective Dose Rate occurred at the same time as Maximum Total UV-B, though rare exceptions do occur.

Criteria [L19] & Crit.time [L22]: These tables are used to construct the Summary Data table. They should not be altered.

Correction Factor: These convert the output of the pyranometer to either Total UV-B or a number that represents the response of a chosen biological system. They are looked up in a table in the CORRFACT.XLM macro (based on Zenith Angle) and then used in the calculation of Total UV-B, Parrish Erythema Dose Rate, and Caldwell Plant Dose Rate. The method of correction factor determination is discussed in the last section of this guide.

2. What UVBOUT does

With inputs of only DATE/TIME and UVB-1 Output (in mV), the spreadsheet works on the data in the steps listed below (in order of execution). The process begins with Table 2 - Complete Data, then proceeds to Table 1 - Summary Data.

a) **Actions performed in Table 2:**

1) In the "Zenith Angle" column the macro function SOLAN calculates the solar zenith angle for the given date, time, and the latitude of the instrument. Solan is located in the macro spreadsheet "SOLALT1.XLM." Latitude (used as an argument in this macro function) is read from the site information at the top of the spreadsheet.

2) Using the calculated zenith angle, the columns entitled Total UV-B, Parrish Erythema Dose Rate, and Caldwell Plant Dose Rate look up the appropriate correction factor in CORRFACT.XLM. The numbers displayed in these columns are the pyranometer output divided by 1000 and multiplied by the correction factor.

3) The 15-minute MED column uses the Parrish Erythema Dose Rate to calculate the total MEDs received over the past fifteen minute interval. (Note: 1 Watt = 1 Joule/sec; 1 MED = 201 J/m^2)

4) Columns I and J (DATE and TIME) separate column A (DATE/TIME) for use in the summary table calculations. These columns must remain intact, with their current headings.

b) **Actions performed in Table 1:**

5) The cell immediately below DATE [A21] reads the first day of the data period from the first cell under DATE/TIME in Table 2 [A60]. The 30 rows below [A22 through A52] are then filled with the ensuing days of the following month.

6) Cells [B20],[C20], and [E20] contain EXCEL's Database functions DMAX to calculate the entire data period's maximum 15 minute values for Total UV-B Irradiance, 15-minute MEDs, and Caldwell Plant Dose Rate. [D20] contains the DSUM function and displays the total MEDs for the data period. Though these numbers may be interesting in their own right, this step is performed mainly in preparation for the next.

7) EXCEL's Table function looks up the maximum Total UV-B, 15-minute MEDs, and Plant Dose Rate for each day in column A as well as the total MEDs for each day.

8) Time of Maximum Total UV-B Irradiance [column G in Table 1] displays the time of day corresponding to the maximum Total UV-B. When their is no data this column displays #VALUE!; when the maximum occurred at two different times during the day this column displays #NUM!..

3. How to use UVBOUT

1) Open ZENITH1.XLM, CORRFACT.XLM, and then open UVBOUT.XLT (always open UVBOUT.XLT last). Note that UVBOUT.XLT is an EXCEL template. When you open this template it is preserved on the disc in its original form and with its original title. On the screen you will see a copy of this file which has been given a default name (eg., UVBOUT6.XLS).

2) Before proceeding to the next step, choose the Options menu on the spreadsheet. Choose "Calculations . . .", then Choose "Manual Calculation" and remove the "X" from the box that says "Calculate before saving." This step gives you more control over the spreadsheet and possibly saves some confusion.

3) Open the spreadsheet containing the original data.

4) Highlight the entire DATE/TIME column in the original data (maximum of 3000 rows of data only, no titles!). Choose Copy. Switch to UVBOUT and put the cursor immediately below DATE/TIME in Table 2 [A60]. Choose Paste.

5) Repeat the step 3 for the UVB-1 Output.

6) Press F9 or choose Options/Calculations/Calculate Now.

7) Sit back and wait while you computer churns away. It may take several minutes (8 or more) to work all the way through the summary table. While EXCEL works on Table 2 it displays "Recalc: XXX" in the upper left-hand corner of the display. While it works on Table 1 it displays "Table: 1" in the same place. A cell address appears in this location when all data manipulation is complete. Note: Interrupting the "Table 1" process will send it back to the beginning of the table again.

8) Enter the date and time information at the top of the spreadsheet in the double-line bordered block of cells [B9 through C10].

9) If you desire, copy the Summary Data table into the file that contains all of the daily summaries.

10) Save the spreadsheet under an appropriate filename for the data set.

11) Close All and Exit.

4. Other things you may want to know

1) The program can handle up to 31 days of data. It will simply ignore any data beyond the 31st day. Having fewer than 31 days poses no problems, though you will see plenty of zeros and #VALUE!s in the summary table.

2) The table of Correction Factors in CORRFACT.XLM also contains the correction factors for the Diffey erythemal spectrum and total UV-B from 280-320 nm, and UVBOUT.XLT can easily be altered to calculate irradiance for these other spectra. The reference numbers for all the spectra are:

1 - Total UV-B (280-315 nm)
2 - Total UV-B (280-320 nm)
3 - Diffey Erythemal Action Spectrum
4 - Parrish Erythema Action Spectrum
5 - Caldwell Plant Action Spectrum

These reference numbers, along with the zenith angle, are used as arguments in CORRFACT.XLM macro function. See columns D,E, and G in the data table (Table 2) to understand better how they are used. Note that the UVB-1 output must be divided by 1000 before being multiplied by the correction factor.

3) Since UVBOUT.XLT is a template, you can't edit it if you open the file using normal procedures. If you must edit the template, depress the "shift" key while you open the file. After editing the file be sure to save it as a template file again (by choosing File Type/Template under the Save As heading. I don't recommend inserting or deleting rows or columns in either the Summary Data or Complete Data tables unless you really know what you are doing with EXCEL. All sections of the spreadsheet are linked to each other and fields are based on the current layout. Altering any part of the spreadsheet could disrupt these relationships.

5. Recommended QA/QC

The following procedures should be implemented to assure quality data.

1) Each month the dome of the pyranometer should be wiped clean with a soft cotton cloth and then cleaned with a small amount of ETHYL ALCOHOL. WARNING: **OTHER SOLVENTS HAVE BEEN SHOWN TO LEAVE A UV-ABSORBING FILM AND SHOULD NOT BE USED.**

2) The humidity plug should be checked monthly to assure it has maintained its blue color, indicating that the pyranometer's seals are intact.

3) Each year the electrical connector and associated cable should be inspected for wind-wear, bird or animal damage, or general deterioration.

4) The internal temperature of the pyranometer should be checked monthly by checking resistance on the leads from the thermistor. The UVB-1 provides a Resistance vs. Temperature table. The sensor should maintain a temperature of 45°C.

5) The sensor should be returned to YES every two years for re-calibration. Currently this re-calibration costs $350 and takes a minimum of one week.

6) The Bjorn-Murphy radiation transfer model should be run using actual or estimate ozone levels. UVB-1 results obtained close to noon on a cloudless day should be compared to the output of these models. The model should predict the pyranometer output within 30%, or closer if actual ozone data is used.

7) UVB-1 Results should be compared with the data from the Burlington Robertson-Berger meter in the following manner:

a) Compute half-hour MED values from UVB-1 data.

b) Calculate the ratio of half-hour MED values to the half-hour RB count values from the Robertson-Berger meter.

c) Note how this ratio varies daily and seasonally. Any large changes in the expected variation of this ratio suggest one of the instruments is yielding spurious results. Keep in mind that the RB meter output is temperature dependent, and that assigning data points to a specific time and day may entail some inaccuracy.

6. The UVB-1 Pyranometer Output

The UVB-1 Pyranometer is a broadband meter that is designed to respond to solar ultraviolet radiation as the human skin does. It responds maximally around 300 nm and drops off rapidly as wavelength increases. Its total region of response is about 290-330 nm. The phosphorescent sensor on the instrument responds to UV by emitting visible light that is measured by a photo diode. This diode generates a current that is proportional to the response of the pyranometer's phosphor. This current is the output of the instrument.

Not all biological systems respond to UV in the same manner, nor does the instrument respond exactly as the skin does. Each type of biological system, monitoring instrument, polymer material, etc. has a response that varies across the UV-B spectrum. This response is called an "action spectrum." The pyranometer output must be multiplied by a correction factor unique to each action spectrum in order to obtain an effective dose rate for that system, instrument, or material. Correction factors are calculated empirically by the manufacturer as follows.

The UVB-1 Broadband Pyranometer and a Spectrophotometer (that measures radiation wavelength-by-wavelength) are run side by side in unaltered sunlight. Using the spectrophotometer data, total UV-B is calculated for the ranges 280-315 nm and 280-320 nm. The theoretical responses of plants, DNA, human skin, etc. are also calculated by convoluting the actual solar spectrum with the appropriate action spectrum. The result of this convolution is the effective UV-B dose rate (in Watts per meter^2) experienced by the system of interest. The correction factor is the ratio of the theoretical response calculated with actual solar spectral data to the output of the UVB-1 pyranometer. Of course some statistical inaccuracies, as stated in the UVB-1 Instruction Manual, result from this method. The conversions are generally accurate within 5 - 7%.

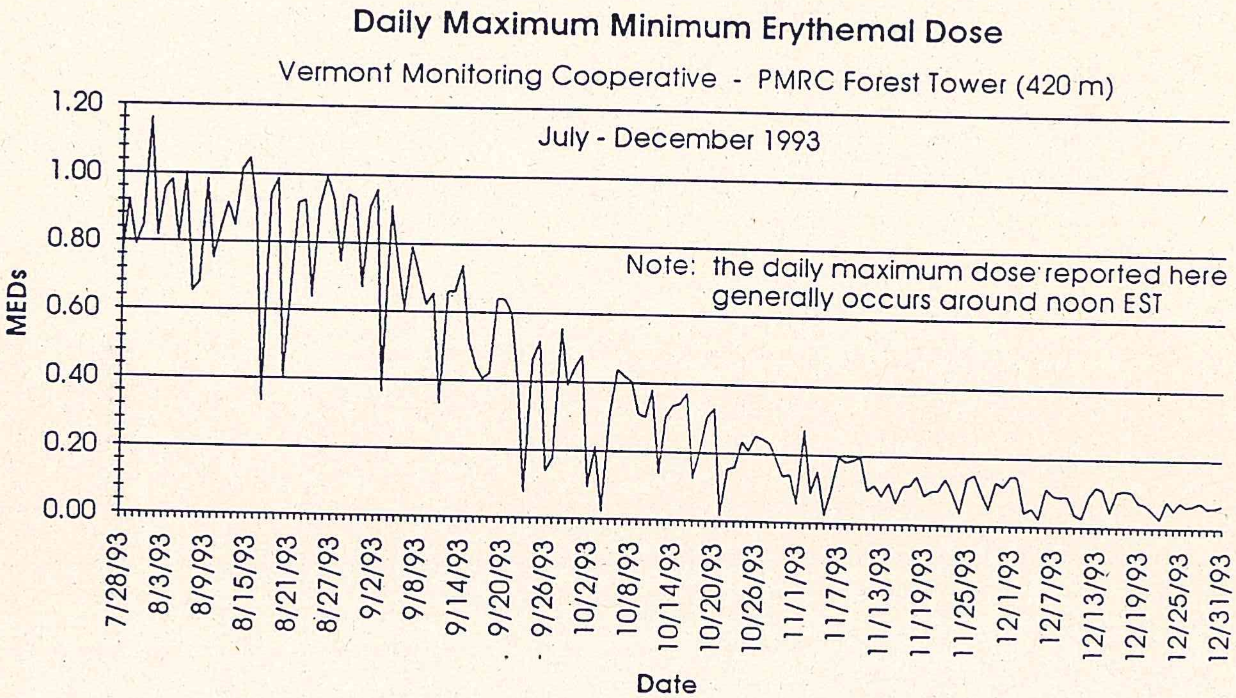
7. Examples of UV-B Monitoring Data from the Program.

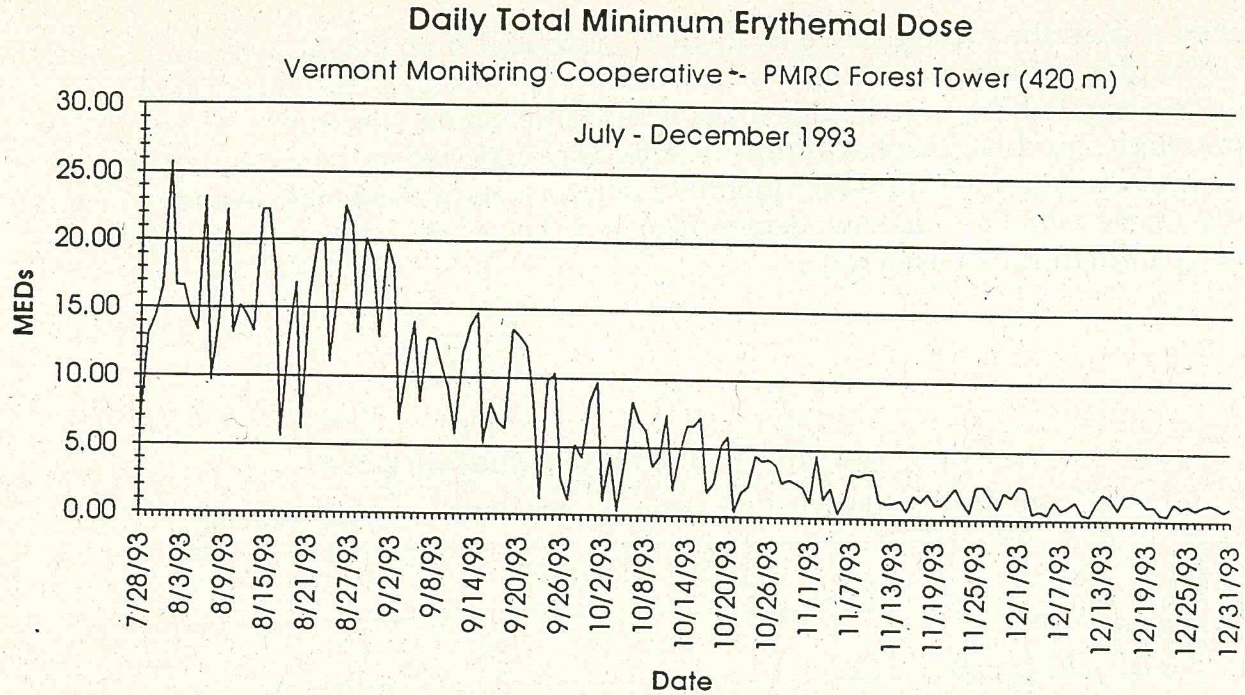
On the following pages are several graphs of the data from the UV-B monitor, providing daily summary data from July through December 1993. Higher resolution data (15 minute averages) are also available for studies requiring this level of detail.

The first figure shows the daily maximum MED rate. A MED (Minimum Erythemal Dose) is the amount of UV energy that will turn light-colored skin slightly pink (1 MED equals 201±52 Joules/meter^2). This graph shows the MEDs received in the fifteen minute period during the day when the UV-B dose was maximum (usually around noon). Thus, during August, for example, there were a number of days when one MED was received during 15 minutes. As the sun angle decreased during the fall and early winter, this rate naturally declined. In December, for example, the maximum MED dose never exceeded 0.15 MED.

The second figure totals the MED rate for the entire day. Thus, over the entire daylight period of many days in August, one would accumulate 15-20 MEDs of UV-B if outside in the sun all day. Again, the MEDs drop to a low level in December, as the sun angle becomes very low. A similar figure could be constructed based on any chosen time period of the day, providing, for example, the total dose each day between noon and 2 pm.

The last figure shows UV-B irradiance, the power (in Watts per m^2) of the UV-B radiation for the 15 minute period of each day during which the maximum irradiance occurs. Two measures of irradiance are calculated, as explained earlier: the total effective irradiance, integrated from 280-315 nm, and Caldwell's plant effective dose rate (Caldwell 1977), which is the integrated irradiance weighted for a generalized plant response action spectrum. These measures both show the seasonal decline in irradiance expected as the solar angle decreases in the fall. They provide quantitative information about the absolute intensity of the radiation (effective irradiance) and the possible effects on plant systems (plant effective dose rate).




Daily Total Minimum Erythemal Dose
Vermont Monitoring Cooperative - PMRC Forest Tower (420 m)
July - December 1993
MEDs
30.00
25.00
20.00
15.00
10.00
5.00
0.00
7/28/93
8/3/93
8/9/93
8/15/93
8/21/93
8/27/93
9/2/93
9/8/93
9/14/93
9/20/93
9/26/93
10/2/93
10/8/93
10/14/93
10/20/93
10/26/93
11/1/93
11/7/93
11/13/93
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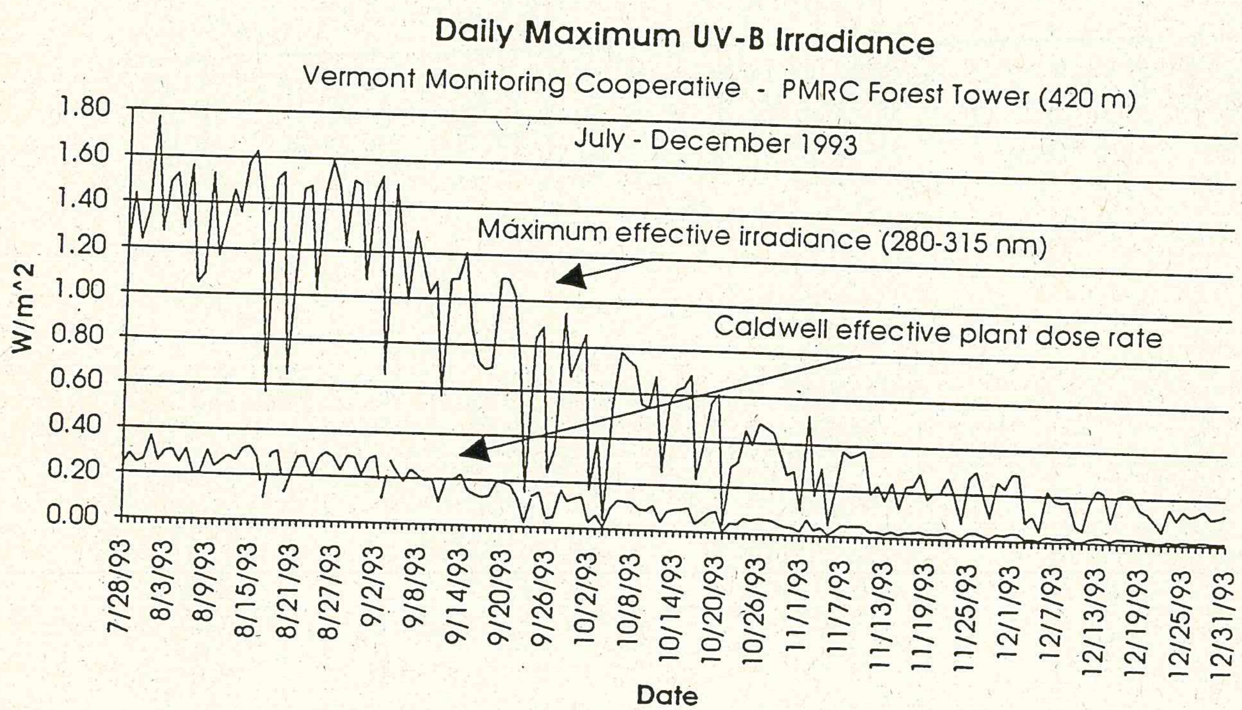
12/19/93
12/25/93
12/31/93
Date


Daily Maximum UV-B Irradiance
Vermont Monitoring Cooperative - PMRC Forest Tower (420 m)
July - December 1993
Maximum effective irradiance (280-315 nm)
Caldwell effective plant dose rate
W/m^2
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
7/28/93
8/3/93
8/9/93
8/15/93
8/21/93
8/27/93
9/2/93
9/8/93
9/14/93
9/20/93
9/26/93
10/2/93
10/8/93
10/14/93
10/20/93
10/26/93
11/1/93
11/7/93
11/13/93
11/19/93
11/25/93
12/1/93
12/7/93
12/13/93
12/19/93
12/25/93
12/31/93
Date