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1999 Progress Report: USDA Ultraviolet Radiation Monitoring Program

USDA Agreements # 96-34263-3527, 98-34263-6888, and 99-34263-8506

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INTRODUCTION

The USDA Ultraviolet Radiation Monitoring Program was established in 1993 to provide the US Department of Agriculture with the information necessary to determine if changing levels of ultraviolet light have an effect on food and fibre production in the United States. Prior to the establishment of the program only limited information was available to make such an assessment, and the geographic distribution and quality of this information was insufficient to meet the requirements of the agency (Gibson, 1991; UV-B Monitoring Workshop, 1992). Two different but complimentary actions were taken by the agency to obtain the information necessary to make its assessment. The first solicited proposals for the development of an improved scanning high resolution spectroradiometer and the second action, whose progress is reported in this document, established an ultraviolet radiation monitoring program.

The primary objective of the USDA Ultraviolet Radiation Monitoring Program is to provide information to the agricultural community about the geographic and temporal climatology of UV-B irradiance. Its data is intended to assist scientists in relating changes in stratospheric ozone, cloud cover, and aerosols to changes in ultraviolet light, and to improve the understanding of the factors which control ultraviolet light. Both are critical in assessing the potential impacts of changing UV light on agricultural systems. Since the establishment of the network the data has found use with model developers, human health effects researchers, ecosystem scientists, scientists studying aerosols, and those seeking a ground truth measurement for satellite systems.

The initial network of twelve stations which was established in 1994, has expanded to 28 locations and includes four research sites. Collocations have been established with other federal agencies that collectively define the UV research program of the US Global Change Research Program (Kaye et al., 1999) and also with the long-term Canadian Brewer Network.

All data from the network is captured in on-site data loggers and downloaded over phone lines each evening. Data is made available to the scientific community as well as the general public the next day via the network's World Wide Web site at URL <http://uvb.nrel.colostate.edu>. The network is further described in Bigelow et al. (1998).

ACCOMPLISHMENTS IN 1999

Climatological Network

Changes in Network Size

Two climatological network sites and one additional research site were established in 1999 bringing the total number of monitoring locations in the network to 28. Climatological sites were established at the USDA's Climate Stress Laboratory in Beltsville, MD and at the US Department of Energy's Southern Great Plains ARM site near Billings, OK. In addition, through a collaborative effort with the Desert Research Institute of Las Vegas, NV, a research site was established at the Storm Peak Observatory near Steamboat Springs, CO. The latter site serves as a prototype for cooperative ventures that may eventually help the network "grow" to its original goal of 40 sites. Funding was also secured from NOAA for a full climatological site at Poker Flat, AK. This new site will be an integral part of NOAA's effort to study the effects of ozone and aerosols of Arctic UV. It is expected the Alaska site will be installed in June 2000. It is noteworthy that this will be the first use of a UV-MFRSR in the Arctic.

Current research sites include Table Mountain near Boulder, Colorado, and the Central Plains Experimental Range (CPER) in northern Colorado. A triad of UV-MFRSRs has been established at CPER to work on procedure for transferring calibrations. Due to budgetary pressures research was discontinued and instrumentation was removed from Mt. Lemmon near Tucson, Arizona and Mauna Loa, Hawaii. Climatological data however, is still being collected at the Mauna Loa Observatory.

Instrumentation

Repairs of Vis- and UV- MFRSRs - Since the initiation of the program, repairs to the network's Yankee (YES) shadowband instrumentation has been conducted through the instrument manufacturer, either through warranties or service contracts. Warranties from YES are now expired and the current service contract will lapse on May 1, 2000. A new one year service contract will be implemented one June 1, 2000. Budget restrictions imposed over the past few years have now forced the program to reduce these expenses to a level below which the manufacturer can afford to provide the them. As a result the network has stopped repairing Vis-MFRSRs, relying solely on its existing inventory, and has begun to learn how to repair the most troublesome problems with the UV-MFRSRs. The most sophisticated repair undertaken with our new-found knowledge is the replacement of failed photodiodes in the UV-MFRSRs. Beginning approximately six months after the initial deployment of the UV-MFRSRs, channels started to fail. As of March 15, 2000 there had been 37 channel failure in 25 heads. This is out of a total of 43 instruments. Now that we recognize that these broken channels are the result of failed photodiodes we have begun our own repairs.

One further benefit of doing in-house repairs is that the network no longer needs to incur the expense of a manufacturer's instrument calibration and characterization, previously a condition of any repair done by the manufacturer. Repaired instruments can now be sent directly to the Central UV Calibration Facility (CUCF).

Elimination of low-to-medium frequency noise in the UV-MFRSRs - Periodic oscillations triggered by interference between the VIS- and UV-MFRSRs continue at selected network sites with still no apparent reason. Presently seven sites suffer from the problem. The number of sites affected varies with season and when site instrumentation is changed. The solution to the problem continues to be staggering the sampling

cycles of the VIS-MFRSR and UV-MFRSR by 15 seconds to eliminate the possibility that they are sampling concurrently.

Stability of the Shadowbands - Over the past few years the network has concentrated on discovering and documenting new ways in which overall shadowband stability could be established. This culminated in the publication of two articles detailing work performed at both the Mauna Loa Observatory and the Central Plains Experimental Range in Colorado (Bigelow and Slusser, 2000; Slusser et al., 2000). In these early efforts concerns focused primarily on the stability of the interference filters. With the switch-over to the US GCRP-CUCF for laboratory more than two years ago and their recent completion of the characterization of about half of the network instrumentation for a second time, the network is now able to investigate and document other sources of possible instability in its instrumentation.

The CUCF has performed 15 repeat filter function characterizations which for the first time puts the network in a good position to see just how stable the spectral response function of each filter is over time. Assuming their wavelength accuracy and repeatability of ± 0.02 nm did not change over time, it can be assumed that all paired differences will reflect true shifts in a channel's spectral response. **Appendix 1a** shows repeat channel response measurements of UV-MFRSR head 386 both performed at the CUCF. The repeatability of this head was the worst of the 15 instruments re-measured. The overall wavelength shift of the filters on all channels except 317 nm is ± 0.1 nm or less. **Appendix 1b** shows the repeated characterizations for head 289, typical of the majority of the re-measured heads. In this case the shifts in channel response are all less than ± 0.05 nm. More repeat measurements will be analyzed to determine the statistics of any observed changes in channel response. This is a profound question to the operation of this network. If the channel responses are stable, in-house calibration becomes feasible using the Langley calibration method and heliostat angular response measurement (see below).

Broadband Meters - The re-calibration of all of the USDA broadband meters by the CUCF was first accomplished in the fall of 1998. However, calibration data for the spectroradiometer used to calibrate the CUCF broadband transfer standards and the documentation of the calibration techniques used were not finalized until nearly a year later. This has delayed the network's re-calculation of all of the network's past and current data from absolute irradiance units to Diffy-weighted irradiances.. This delay has provided an opportunity to draft an article documenting the network's unit conversion rational and the precision and accuracy of the 5 year time series which will result from the conversion. An abstract of the article was submitted and accepted for presentation at the 2000 International Radiation Symposium (IRS) to be held in St. Petersburg, Russia in July of 2000.

Barometers - Barometers have been placed at 6 sites to better correct the effect of air molecules on aerosol optical depth retrievals in the UV. These are sites where NASA has co-located a UVA broadband to help interpret TOMS satellite UV retrievals. Barometers have been installed at Big Bend, TX, Everglades, FL, the Canadian sites of Regina and Toronto, Table Mountain, CO, CPER, CO and at Mauna Loa, Hawaii. A barometer will be installed at Poker Flat, AK.

Smithsonian and Biospherical Spectral Radiometers - As reported previously (Bigelow et al., 1999), collocation and comparisons between USDA climatological instrumentation has been discontinued due to continued budgetary restrictions.

Calibration

The availability and quality of calibrations continued to be a concern of the network in 1999. All calibrations are now performed at the CUCF in Boulder Colorado. At current funding levels, however, the network is concerned that it may no longer afford to send any instrumentation out for third-party calibrations. Due to this concern the network continued to investigate and develop alternate ways of establishing absolute calibrations for its radiometers.

Broadband Calibration - Forty-three broadband meters were calibrated in 1999 by the CUCF which performs absolute, cosine, spectral and erythema characterizations for each instrument each time it calibrates an instrument. However, as previously mentioned (Instrumentation Section), the utilization of this new calibration information has been delayed pending a comparison of annual absolute calibration factors and the availability of data from the 1997 North American Interagency Spectroradiometer Intercomparison. A draft report of the 1997 comparison only became available in March 2000 (Lantz et al., 2000).

Although the recalibrations have been delayed, the utility of the technique was demonstrated when the U.S. Forest Service asked the network to calibrate three YES UVB-1 meters that was intending to use in a joint project between the Rocky Mountain Research Station and Moscow State University (Russia). Because¹ of the carefully documented and compartmentalized steps of the CUCF calibration process the network was able to furnish the USFS with a well documented secondary calibration by simply collocating their instrumentation at the network's Central Plains Experimental Range site in Colorado.

UV-MFRSR Calibration -All 42 UV-MFRSR heads were characterized in 1999 at the CUCF for their spectral response and absolute lamp calibrations. The CUCF however, was still not able to produce reliable cosine characterization by the year's end. A comparison of the spectral responses of several newly characterized heads measured at CUCF and YES revealed a slight bias in wavelength registration of between 0.1 nm and 0.2 nm. This supports previous conclusions of Bigelow and Slusser (2000) when they first addressed the question with only a limited number of heads using YES calibrations. Given the superb wavelength accuracy and repeatability of the CUCF's 1.0 m monochromator, it is suspected that the CUCF spectral characterizations are closer to the truth.

In-House Cosine Response Measurements - Because of the difficulties in obtaining cosine characterizations from the CUCF and our concerns with continued limited budgets, we have begun developing an *in situ* technique for measuring the cosine response of the UV-MFRSR. The prototype consists of a Sun tracker heliostat and a rotating turntable both driven by AC synchronous motors. The UV-MFRSR head is supported on the turntable and driven forward and reverse through 180 degrees. The heliostat uses 2 UV coated mirrors to direct a beam of UV light to the UV-MFRSR's diffuser and the resulting time-stamped voltage outputs of the head are recorded using a standard Yankee data logger. Stray light is eliminated by placing the sun tracker outside of a plastic window while the turn table is inside.

The first series of tests using single readings each lasting 3 seconds produced measurements at 2 degree intervals. One degree intervals were also obtained by simply changing the table rotation speed. Presently we are working to reduce noise in the system through both mechanical improvements to the system, and statistical methods. A description of this new technique will be presented along with preliminary results at the European Geophysical Union's annual meeting held in Nice, France in April of 2000.

¹ This project compares UV measurements in and out of the city of Moscow and examines plant phenological cycles in relation to UV exposure.

VIS-MFRSR Calibration - As in previous years and due to budget cuts these instruments are no longer calibrated. With increased support it would be possible to use the Langley method to calibrate them *in situ* (Slusser et al., 2000).

Quality Assurance

Most of the work done in the area of quality assurance in 1999 focused on the completion of network shadowband quality assurance documentation (Bigelow and Slusser, 2000; Lantz et al., 1999; Slusser et al., 2000) and preparation for the recalculation of broadband absolute irradiance values to Diffey-weighted irradiance values. No re-evaluations of network precision or accuracy were undertaken although techniques for establishing error budgets were strongly pursued.

Completeness - The network continues to maintain a high degree of data capture (See **Appendix 2**). In 1999 the median number of 3-minute measurements captured by VIS-MFRSRs at network sites was 97.50%. This compares with 97.5% in 1998, 96.9% in 1997 and nearly identical to the number captured in 97.6% in 1996. The second full year of UV-MFRSR operation resulted in a median of 98.97% of the 3-minute data being captured compared with 98.6% in 1998.. Notable departures from the median occurred at Table Mountain (74.5%), and Storm Peak (93.0%) where research projects required that the instruments be removed for extra calibration work.

Precision - Studies at Mauna Loa and the CPER in Colorado (Slusser et al., 2000; Bigelow and Slusser, 2000) estimated UV-MFRSR precision through the repeated use of the Langley technique. At Mauna Loa (MLO) standard deviations of the mean of repeated Langley intercepts (V_o) ranged from 0.6% at 300 nm to 0.2% at 368 nm. An unpublished precision study of V_o values shown in Table 1 was undertaken at Pawnee for data taken during an exceptionally clear period between May 1 and September 30, 1999. These data clearly demonstrate that high precision results can be obtained at other than high elevation, pristine sites. The precision of V_o values of 1.4% at 300 nm and 0.6% at 368 nm was nearly as good as those obtained at MLO.

Table 1: Precision study of Langley voltage intercepts performed at CPER May 1-Sept 30, 1999

Nominal Wavelength (nm)	Standard Deviation of the Mean (%)	Number of Good Langleys
300	1.40	38
305	1.00	56
311	0.78	58
317	0.97	61
325	0.75	64
332	0.78	64
368	0.59	66

Comparability -The network continues to maintain collocations with both the Canadian Brewer Network (3 sites) and with the US EPA sponsored Brewer Network (2 sites). A comparison of USDA broadband irradiances to Brewer data at the Bratt's Lake Observatory, Canada will be presented by Dr. Bruce McCarthur at the Quadrennial Ozone Symposium in Sapporo, Japan entitled "A medium-length comparison of erythemal UV irradiance measurements."

A comparison of aerosol optical depths retrieved from the VIS-MFRSR with those measured in the NASA sponsored AERONET programs was published in *Geophysical Research Letters* (Schmid et al., 1999) indicating that a well calibrated Vis-MFRSR can retrieve aerosol optical depths to within 0.01 compared with other well calibrated sun photometers.

Data

Network Data Users - Users of our Web site included hits from 41 federal agencies, 260 universities, and 66 countries. Numerous collaborations (below) have resulted from the easy access to our data.

Research

Research at the UVB Program was focused on six areas: Langley calibrations, retrieving aerosol properties, ozone retrievals, and synthetic spectra verification, comparison of UV-MFRSR UV measurements with satellite and model retrievals, and a study of long term UVB broadband time series. A number of publications resulted from this work.

Langley Calibrations

Accurate calibration of UV ground-based radiometers is crucial in identifying trends in UV radiation, developing UV climatologies, and quantifying the amount of shortwave radiation absorbed by clouds and aerosols. The Langley method of calibrating UV multi-filter shadow-band radiometers (UV-MFRSR) is explored in a paper by Slusser et al. (2000). This method has several advantages over the traditional standard lamp calibrations: radiometer signal level is optimal during the Langley event, the Sun is a free, universally available and very constant source (to within <0.5% between 300 nm and 400 nm over the 11-year solar cycle) and nearly continual automated field calibrations can be made for each Langley event. Difficulties arise as a result of changing ozone optical depth during the Langley event and the breakdown of the Beer-Lambert law over the finite filter band-pass since optical depth changes rapidly with wavelength. The Langley calibration of the radiometers depends critically upon the spectral characterization of each channel and on the wavelength and absolute calibration of the extraterrestrial spectrum used.

Results of Langley calibrations made over a period from January 1 through September 30, 1998 for two UV-MFRSRs at Mauna Loa, Hawaii (3.4 km elevation) were compared to calibrations using two National Institute of Standards and Technology (NIST) traceable lamps. The objectives of this study were to compare Langley calibration factors with those from standard lamps and to compare field-of-view effects. The two radiometers were run simultaneously: one on a Sun tracker with a collimated full field of view of about 2.0° and the other in the conventional shadow-band configuration. After 2 months the positions of the radiometers were switched. After another 2 months the radiometers were left in place but the field-of-view for the tracker radiometer was narrowed to 1.5°. Both radiometers were calibrated May 15, 1998 at the CUCF in Boulder,

Colorado with two secondary 1000-W lamps. The spectral response functions of the channels were measured at the CUCF on October 15, 1998. Over a 9 month period the ratio of Langley to lamp calibration factors for the 7 channels from 300 nm to 368 nm using the shadow-band configuration ranged from 0.948 to 1.025. The estimated uncertainty in the Langley calibrations ranged from $\pm 5.5\%$ at 300 nm to $\pm 2.4\%$ at 368 nm. For all channels calibrated with CUCF lamps the estimated uncertainty was $\pm 1.6\%$. Thus for each channel of the two radiometers the agreement between the two methods was within the combined uncertainties of the two methods. Differences between the Langley and lamp calibration factors were much larger at shorter wavelengths using the Langley tracker results. The rest is probably due to changing ozone during the Langley event.

Aerosol Properties

Aerosols are suspended atmospheric particles in the solid or liquid phase excluding cloud droplets or precipitation. These particles are of critical importance to the hydrological cycle because they provide condensation sites upon which cloud droplets form in slightly supersaturated air. In addition aerosols scatter and absorb solar radiation, changing the amount of UV reaching the earth's surface as well as modifying the heating of the atmosphere. The USDA UV-B Monitoring Network has the capability to report optical depths, a measure of the total aerosol loading, at 28 sites across the continental U.S. Each of the sites of the UV-B Monitoring Network is equipped with both a UV-MFRSR and a Visible-MFRSR which by measuring the direct beam return the total optical depths on clear days at a total of 13 wavelengths from 300 nm to 940 nm. This constitutes the largest U.S. network of ground-based aerosol optical depths and thus provides atmospheric scientists with a unique data set with which to constrain their models which quantify precipitation processes, aerosol and cloud formation, and global warming.

The UV-B Monitoring Network is working with the NASA -TOMS group to study the Mexican smoke event of May 1998. By observing the Sunlight transmitted through the smoke plume at several different wavelengths, the physical properties of the smoke may be constrained. By measuring the direct to diffuse ratio the absorption properties of the smoke may be inferred using a radiative transfer model. The NASA-TOMS satellite provides extensive spatial coverage of the smoke from above. Taken together these two data sets will provide new information on the smoke. The results are the subject were presented at the AMS Sun Photometer Workshop in June 1999 and will be in a paper in progress (Herman et al., 2000).

The Southern California Ozone Study (SCO97) involved a whole suite of chemical, optical, and meteorological measurements taken in an effort to understand the causes of urban tropospheric pollution in the Los Angeles basin. Two USDA UV-MFRSRs were loaned to the experiment to determine UV irradiances and aerosol optical depths. One was placed atop Mt. Wilson and the other in urban Riverside. The attached paper by Vuillemeir et al. "Variability in Ultraviolet Total Optical Depth during the Southern California Ozone Study (SCOS97) has been submitted to *Atmospheric Environment* summarizing the work.

We are also working with Dr. Sonia Kreidenweis of the CSU Atmospheric Science department to characterize the radiative and chemical properties of aerosols at Big Bend, TX, part of the National Park Service IMPROVE Visibility Network. By combining chemical and optical properties of the aerosol, a more complete picture of aerosol characteristics will be possible. Results will be presented at the American Association of Aerosol Research meeting to be held in St. Louis in November, 2000.

Ozone Retrievals

Column ozone has been retrieved by Slusser et al. (1999) under all sky conditions at Table Mountain, Colorado (40.177°N, 105.276°W) from global irradiances of the UV-MFRSR 332 nm and 305 nm channels (2 nm FWHM) using lookup tables generated from a multiple scattering radiative transfer code suitable for solar zenith angles up to 90°. The most significant sources of error for UV-MFRSR column ozone retrievals at solar zenith angles of < 75° are the spectral characterizations of the filters and the absolute calibration uncertainty together yielding an estimated uncertainty in ozone retrievals of ±4.0%. Using model sensitivity studies it was determined that the retrieved column ozone is relatively insensitive (< ±2%) to typical variations in aerosol optical depth, cloud cover, surface pressure, stratospheric temperature, and surface albedo.

For five months in 1996-97 the mean ratio of column ozone retrieved by the UV-MFRSR divided by that retrieved by the collocated Brewer was 1.024 and for the UV-MFRSR divided by those from a nearby Dobson was 1.025. The accuracy of the retrieval becomes unreliable at large SZA > 75° as the detection limit of the 305 nm channel is reached and due to overall angular response errors. The UV-MFRSR advantages of relatively low cost, unattended operation, automated calibration stability checks using Langley plots, and minimal maintenance make it a unique instrument for column ozone measurement.

Direct Sun column ozone has been retrieved under all sky conditions in Mauna Loa, Hawaii, Toronto, Ontario and Regina, Saskatchewan. The mean ratio of column ozone retrieved by the UV-MFRSR divided by that retrieved by the collocated Dobson was 0.969 in Mauna Loa between Julian date 150 and 270 in 1999. Comparisons were also made with Brewers in Canada. The ratio of column ozone retrieved by the UV-MFRSR divided by that of a Brewer was 1.022 in Toronto between Julian date 120 and 240 in 1999 (shown in Figure 1), and 1.001 in Regina between Julian date 160 and 250.

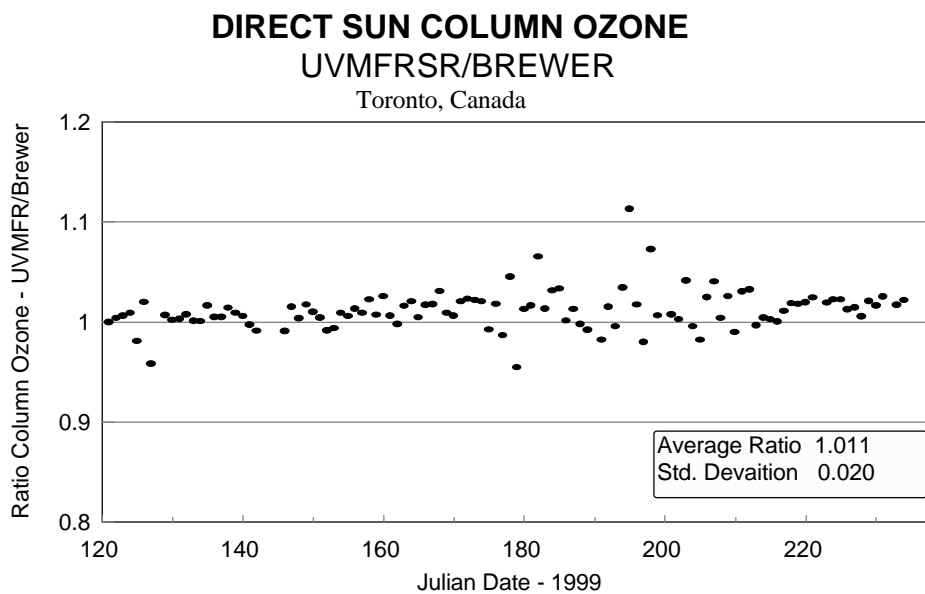


Figure 1: Ratio of UV-MFRSR to Brewer direct Sun column ozone retrievals at Toronto during 1999.

Synthetic Spectra

Plant, animal, and materials effects researchers often want to multiply their particular action spectrum by the spectra measured to estimate damage due to UV. Because of this a study was initiated to use a model to “fill in the pieces” from the 7 channel UV radiometer measurements and construct the entire spectrum. Using the methodology of Min and Harrison (1998) we retrieved a number of synthetic spectra from the 7 channel UV-MFRSR data. We made comparisons of these spectra with spectral measured from collocated spectrometers at Boulder, Colorado and Mauna Loa, Hawaii. Erythemal doses are generally within $\pm 5\%$ for all SZA $< 75^\circ$. A comparison study is in preparation. We provided the synthetic spectra (295nm to 375 nm) to the U.S. Army Laser / Optical Radiation Program with 4 stations as they requested: Geneva, NY; Griffin GA; El Centro of CA, and Pullman WA. More comparison are in progress (Gao et al., 2000)

Radiometric Stability

A paper published in the Journal of Geophysical Research evaluates the stability of the IAD filters used in both prototype and production models of the UV-MFRSR (Bigelow and Slusser, 2000). Based upon an initial examination of a few prototype and production instruments it appeared that there was an approximate 1% per year decline in its instruments' I_0 values due to filter instability. It is unclear as to whether the decline is a result of wavelength shifts or loss of instrument sensitivity. The Ion-Assisted-Deposition (IAD) filters are much more stable than the filters in VIS-MFRSR's as reported by Bigelow et al. (1998).

Comparisons of UV-MFRSRs with TOMS and Radiative Transfer Model

We have compared irradiances from a UV-MFRSR at Table Mountain of Colorado with those from a radiative transfer model (TUV) (Madronich, 1993). Sensitivity tests of the modeled ratio of direct to diffuse irradiances for different aerosol absorption were made for Big Bend of Texas. A comparison of UV-MFRSR irradiances with TOMS satellite UV retrievals is in preparation.

Spectrometer Research Network

Six high resolution spectroradiometers have been developed by Dr. Lee Harrison, SUNY Albany. The first has been completed and installed at the NIST / NOAA research site on Table Mountain, north of Boulder, Colorado. This instrument has been operating since December 1998 and the performance has been excellent. The instrument resolution, out-of-band rejection, slit function, wavelength, and cosine response exceed the specifications of any other instrument available today. A second instrument has been installed at the DOE Central Plains ARM CART site near Billings, Oklahoma in September, 1999. A third instrument has been installed at the ARS Climate Stress Laboratory at Beltsville Maryland in November 1999. A fourth instrument will be sited at CPER. As a result of budget reductions, there are currently no plans to deploy the remaining two instruments. Budget constraints make even the routine operation of these 4 instruments problematic. None of the 3 currently fielded instruments has had enough calibrations to demonstrate radiometric stability. NASA has expressed interest in the data.

Long Term UVB Broadband Time Series

In the attached study by Frederick et al. (2000) "Annual and Interannual Behavior of Solar Ultraviolet Irradiance Revealed by Broadband Measurements" submitted to *Photochemistry and Photobiology*, a four-year time series is analyzed to determine the influence in solar zenith angle, column ozone, and clouds on seasonal and year-to-year variability in UV irradiances.

Other Cooperative Research

In addition to the more formal collaborations noted above the network is increasingly being asked to participate in or contribute to more modest projects. While in general we believe these collaborations to be an important benefit and use of network technology it is unclear as to whether budget limitations will allow them to be afforded in the future.

Broad band and temperature data was supplied to the University of Colorado Health Center to help investigate how exposure to sunlight influences cases of sunburn in children.

Broad band and temperature data was supplied to the USDA / APHIS group in Fort Collins to study the effects of UV on the *Brucella* bacteria affecting the Yellowstone, WY bison herd.

Publications/Conferences/Workshops/Meetings

The project significantly increased both the quality and quantity of its publications during 1999 and early 2000. Six articles were published in peer reviewed journals and two more were submitted.

Journal Articles

Bigelow, D.S. and J.R. Slusser, 2000. Establishing the Stability of Multi-filter UV Rotating Shadowband Radiometers, *J. Geophys. Res.* 4833-4840.

Bodhaine, B.A., N.B. Wood, E.G. Dutton, and J.R. Slusser, 1999. On Rayleigh Optical Depth Calculations, *J. Atmos. Ocean. Tech.*, 1854-1861.

Frederick, J. E., J. R. Slusser, and D. S. Bigelow, 2000. Annual and Interannual behavior of solar ultraviolet irradiance revealed by broadband measurements (submitted to *Photochem. Photobiology*).

Gao, W., J. R. Slusser, and Q. Min, 2000. Validation of Synthetic Spectra (in Preparation).

Heath, D. F., and J. R. Slusser, 2000. Assessment of the Radiometric Stability of a Calibration Transfer Standard Spectroradiometer and a Tandem Ebert-Fastie Double Monochromator Against NIST Standards of Spectral Irradiance. Proceedings of NEWRAD 97 Conference, Tuscon, AZ (submitted to *Metrologia*).

Kaye, J.A., B.B. Hicks, E.C. Weatherhead, C.S. Long and J.R. Slusser, 1999. US Interagency UV Monitoring Program Established and Operating. *EOS*, 80 (10), 114-116.

Lantz, K.O., P. Disterhoft, J.J. Deluisi, E.A. Early, A. Thompson, D.S. Bigelow, and J.R. Slusser, 1999. Erythemal Calibration Factors for Yankee and Solar Light UV Broadband Radiometers of the US Central UV Calibration Facility. *J. Atmos. Ocean. Tech.*, 1735-1752.

Lantz, K. O., et al., 2000. The 1997 North American Intercomparison of Ultraviolet Spectroradiometers (in preparation).

Schmid, B., et al, 1999. Comparison of aerosol optical depth from four solar radiometers during the fall 1997 ARM intensive observation period, *Geophys. Res. Letts.*, 2725-2728.

Slusser, J.R., J.H. Gibson, D.S. Bigelow, D. Kolinsky, M. Wanfeng, G. Koenig, and A. Beaubien, 1999. Comparison of Column Ozone Retrievals By Use of a UV Multi-filter Rotating Shadow-band Radiometer with those from Brewer and Dobson Spectrophotometers. *Appl. Opt.*, 38, 1543-1551.

Slusser, J.R., J. H. Gibson, D. Kolinski, P. Disterhoft, K. Lantz and A. F. Beaubien, 2000. Langley Method of Calibrating UV Filter Radiometers, *J. Geophys. Res.*, 4841-4849.

Vuilleumier, L., R. A. Harley, N. J. Brown, J. R. Slusser, D. Kolinski, and D. S. Bigelow. 2000. Variability in Solar Ultraviolet Irradiance during the Southern California Ozone Study (SCOS97) (submitted to *Atmos. Environ.*).

Conferences, etc

Project staff co-organized and presented at 1 scientific workshop, gave 6 seminars and 1 poster.

J. Slusser, Co-chair of Front Range UV Workshop at NCAR, January, 1999.

J. Slusser, University of Denver Physics Department, “Retrieving Atmospheric Properties Using the USDA Ultraviolet Multi-filter rotating Shadow-band Radiometer”, Denver, CO. February 1999.

J. Slusser, Sun Photometer Workshop, “Single Scattering Albedo from Direct to Diffuse Technique”, Madison, WI., June, 1999.

D. Bigelow, Sun Photometer Workshop, “The USDA UVB Monitoring Network”, Madison, WI., June, 1999.

D. Bigelow and J Slusser, American Society of Photobiologists poster, “Broad band UV Long-term time series”, Washington, DC, July 1999.

J. Slusser, CSU / CIRA Atmospheric Science talk, “Aerosol Properties retrieved from USDA UVB Monitoring Network”, Fort Collins, CO, August, 1999.

J. Slusser and D. Bigelow, with M. Bergin, N. Laulainen, American Association for Aerosol Research, “Comparison of Aerosol Radiative Properties Measured at the Surface and Over the Entire Atmospheric Column With Surface Irradiance Measurements at Bondville, IL”, Tacoma, WA. October, 1999.

STAFF CHANGES

After 7 years of service to the UVB Monitoring Program and over 15 years to NADP, Dr. James Gibson retired on April 1, 1999. His contributions to UV science are gratefully acknowledged. One additional staff was hired in 1999 as Dr. Wei Gao joined the project on November 1, 1999 as a Research Associate. These changes brought the project to a 8.5 FTE staffing level at the close of 1999.

RECOMMENDATIONS FOR FUTURE WORK

Calibration concerns and budget pressure will continue to challenge the project in 2000 and beyond. Budget reductions imposed in 1997 and 1998 and sustained in 1999 have resulted in termination of the calibration of the Vis-MFRSRs. It will be increasingly difficult to support both CUCF and SUNY Albany subcontracts. This will result in the eventual choice between calibrations and the continued operation of the three reference 1.0 m spectrometers. Due to the continued uncertain funding of the UVB Monitoring Program in FY 2001 we will:

- ! Increase efforts to develop other *in-situ* techniques that can establish reliable calibrations for its instrumentation. Techniques such as the recently implemented Langley calibration technique allows the network to gain independence from expensive calibration facilities. The triad of UV-MFRSRs at CPER, designed to transfer calibrations to other heads, will be used to explore transfer calibration techniques. The in-house cosine response measurements will

be pursued. If it can be demonstrated that the filters are stable, repeat spectral calibrations will be no longer required. This would free us from depending on the CUCF for any UV-MFRSR calibrations.

- ! Develop procedures for calibrating the broad bands in house, that is with Fort Collins staff at CPER. The physical infra-structure is already in place to accommodate 6 broadbands at once. Assuming it takes one week for a calibration transfer, the entire fleet of broadbands could be completed in 2 months
- ! Continue to fund calibration of its instrumentation at the CUCF in Boulder, Colorado during FY 2001.

NASA has funded a Research Associate to compare our UV measurements with satellite UV retrievals. In addition the network has collected collocated data with 2 sites of the Canadian Brewer Network, and 3 sites of the US EPA Brewer Network. Although budget reductions constrain the amount of time available for analysis, it is of enormous benefit to the networks and the UV Global Change Research Program to know how comparable these networks and instruments are to one another. In addition,

- ! Compare UV retrievals for several sites where NASA has expressed particular interest. Include USDA data, TOMS model, and radiative transfer models.
- ! As time permits compare our measurements with the Canadian Brewer Network and the US EPA Brewer Network. This will establish a firm relationship between the principle North American USCRCP ground-based satellite based UV monitoring programs.

The spatial density requirements of a national UV climatological network can no longer be realized with current funding levels. To complete the original design of 30-40 stations the network will need to establish partnerships with local research and monitoring programs. Without these partnerships no new sites can be accommodated within the network.

- ! Develop and establish a partnership program for those willing to follow network protocols to enable local UV research data to be brought into the network data system.

The longest network record of UV measurements has been collected with broadband meters (Frederick et al., 2000). Recent scientific literature (Bodhaine et al., 1998; Lantz et al., 1999) has demonstrated that ozone and solar zenith angle need to be considered when establishing calibration for this class of radiometers. All 44 of the network's broadband meters have been re-characterized to these new scientific standards.

- ! The erythemal broadband calibration should be applied, first to all new and second to all old data. This will allow most of the historical data in the network to be re-processed thus allowing the previously established 5 year measurement record to continue without interruption.

The network continues to be a leader in providing radiometric data to the scientific community and the public at large. The data however only meets minimal quality standards. A more robust and lasting quality coding system needs to be implemented to ensure data users can have confidence in the quality of all data.

- ! Quality coding should be developed for and implemented with the current data set to elevate the data to a Level II quality product (Gibson et al., 1998; **Appendix 3**).
- ! Old data should be coded when time permits

Budget reductions in 1997 and 1998 that were sustained in 1999 have resulted in the suspension of new site development and calibrations of the auxiliary instruments (humidity and temperature). The calibration of the VIS-MFRSRs have been terminated. The quality and credibility of network data has been diminished by the sustained budget reduction and will continue to degrade if funding is not restored.

- ! Funding should be restored to prevent further deterioration of network data quality and to restore those calibration and collocation activities which enable the network to provide the scientific community with the high quality measurements it deserves.
- ! Funding should be restored to allow continued both CUCF calibrations and operation of the 1.0 m reference spectrometers

REFERENCES

- Bigelow, D.S. and J.R. Slusser. Interim Report: USDA Ultraviolet Radiation Monitoring Program, 1998. Natural Resource Ecology Laboratory, Fort Collins, CO. April 1999.
- Bigelow, D.S. and J.R. Slusser, 2000. Establishing the Stability of Multi-filter UV Rotating Shadowband Radiometers, *J. Geophys. Res.*, 4833-4840.
- Bigelow, D.S., J.R. Slusser, A.F. Beaubien and J.H. Gibson, 1998. The USDA Ultraviolet Radiation Monitoring Program. *Bull. Amer. Meteorol. Soc.*,(79), 601-615.
- Bodhaine, B.A, E.G. Dutton, R.L. McKenzie and P.V. Johnston, 1998. Calibrating Broadband UV Instruments: Ozone and Zenith Angle Dependence. *J. Atmos. Ocean. Tech.*, 916-926.
- Gibson, J.H., D.S. Bigelow and J.R. Slusser. Interim Report: USDA Ultraviolet Radiation Monitoring Program, 1997. Natural Resource Ecology Laboratory, Fort Collins, CO. February 1998.
- Gibson, J.H., 1991. Justification and Criteria for the Monitoring of Ultraviolet (UV) Radiation: Report of the UV-B Measurements Workshop. Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523, p21
- Herman, J.R., J.R. Slusser, and O. Torres, 2000. Physical Characteristics of the Smoke Aerosol from Extensive 1998 Mexican Fires Deduced from TOMS Satellite and USDA Ground Based Spectral Measurements (in preparation).
- Madronich S., *Environmental Effects of Ultraviolet (UV) Radiation*, chapter: UV radiation in the natural and perturbed atmosphere, Lewis Publisher, Boca Raton, pp. 17-69, 1993.
- Lantz, K. O., P. Disterhoft, J.J. Deluisi, E.A. Early, A. Thompson, D. Bigelow, and J. Slusser, 1998.

Methodology for Deriving Erythemal Calibration Factors for UV Broadband Radiometers of the US Central UV Calibration Facility. *J. Atmos.Ocean. Tech.*, 1736-1761.

Lantz, K. O., et al., 2000. The 1997 North American Intercomparison of Ultraviolet Spectroradiometers (in preparation).

Slusser, J.R., J.H. Gibson, D.S. Bigelow, D. Kolinsky, M. Wanfeng, G. Koenig, and A. Beaubien, 1999a. Comparison of Column Ozone Retrievals By Use of a UV Multi-filter Rotating Shadow-band Radiometer with those from Brewer and Dobson Spectrophotometers. *Appl. Opt.*, 38, 1543-1551.

Slusser, J.R., J.H. Gibson, D. S. Bigelow, D. Kolinski, P. Disterhoft, K. Lantz and A.F. Beaubien, 2000. Langley Method of Calibrating UV Filter Radiometers. *J. Geophys. Res.*, 4841-4849.

Appendix 2. Completeness of Level 1 Data Capture for Sites that Operated a Full-Year

Location	Vis- MFRSR				'99	UV-	MFRSR
	1995	1996	1997	1998		1998	'99
Arizona - Grand Canyon			90.7	97.1	87.9	97.7	92.9
California - Davis	98.8	99.6	98.4	98.9	99.4	97.9	99.7
California - El Centro					98.3		99.79
Colorado - Central Plains	98.7	97.2	97.0	99.0	99.5	74.9	98.2
Colorado - Table Mountain						66.3	74.5
Florida					94.0		98.0
Georgia	96.5	98.1	95.8	96.9	97.3	97.0	97.4
Hawaii				83.9	98.2	76.0	96.2
Illinois	95.2	97.4	93.5	85.2	98.8	98.6	99.5
Louisiana			96.9	98.1	97.6	99.0	99.2
Maryland – Wye			92.9	98.1	89.6	99.1	96.5
Maryland - Beltsville					98.3		99.4
Maine	95.9	94.3	96.2	94.4	97.8	98.7	99.4
Michigan	89.9	95.5	93.3	95.5	96.9	95.7	97.6
Minnesota			99.4	99.4	95.4	99.2	98.5
Montana				97.9	95.7	96.2	99.8
Nebraska			98.7	96.1	94.1	99.9	95.5
New Mexico	98.8	97.6	96.6	92.9	96.5	99.1	98.5
New York	97.5	99.0	96.1	98.2	97.4	99.0	99.1
Ohio	99.2	99.1	98.0	92.3	96.4	99.3	99.5
Oklahoma					97.8		99.0
Ontario (Canada)					98.7		99.1
Saskatchewan (Canada)				99.1	98.7	91.5	99.4
Texas			98.0	99.7	98.7	99.9	99.9
Utah	100	98.6	97.3	94.4	97.8	100	99.0
Vermont			95.2	98.7	97.1	96.7	94.4

Washington	99.5	97.0	96.9	98.6	99.4	99.7	99.3
Wisconsin			99.1	86.8	92.4	97.0	99.4
Median	98.7	97.6	96.9	97.5	97.6	98.6	99.1

Appendix 3: Quality Assurance Coding of UVB data records

Quality Assurance Coding of UVB data records

Data Record Code	Reason	Rule
f[n] n is 1-7 channel	channel failure for channel n	if one of the channels at local noon is below the threshold 150 millivolts or 0.1 w/m ² /m, that channel has had a failure. If all the channels at local noon are below the threshold then no channel failure
s[n] n is 1-7 channel	signal saturated for channel n	
i[n] n is 1-7 channel	signal interference for channel n	
nc[n] n is 1-7 channel	no calibration data for channel n	
a[n]	averaging interval is n minutes not 3 minutes	
fp	power failure	
fe	polling failure	
db	board damaged	
dd	diffuser damaged	
dr	diffuser dirty	
dh	head damaged	
ba	band alignment problem	
bm	band motion problem	
tx	timekeeping problem	
ma	annual maintenance	
mt	troubleshooting maintenance	
bt	broadband dome temp problem	dome temp is <= 40 degrees or dome temp is >= 50 degrees
bd	broadband dark count problem	
bz	broadband dome crazed	
at	uva dome temp problem	dome temp is <= 20 degrees dome temp is >= 30 degrees

ad	uva sensor problem	
az	uva dome crazed	
hh	humidity high	humidity > 103 %
hf	humidity failure	
tf	air temperature failure	air temp < 2300 millivolts
ed	epply sensor problem	
ld	licor sensor problem	
sd[n]	solar light n problem	