2000 Progress Report: USDA Ultraviolet Radiation Monitoring and Research Program

USDA Agreements 98-34263-6888, and 99-34263-8506

James Slusser and Wei Gao, Natural Resource Ecology Laboratory and CIRA
Colorado State University, Fort Collins, CO 80523

January 2001

1. Introduction

The USDA Ultraviolet Radiation Monitoring and Research Program was established in 1992 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 called for the establishment of an ultraviolet radiation monitoring program and the second solicited proposals for the development of an improved scanning high resolution spectroradiometer.

The primary objective of the USDA Ultraviolet Radiation Monitoring and Research 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 agriculture and human health effects researchers, model developers, 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 30 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 by 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).

1.1 Staff Changes

After 7 years of service to the UVB Monitoring and Research Program and over 15 years to the National Atmospheric Deposition Program, David Bigelow died on June 15, 2000 after a valiant struggle against cancer. His contributions to UV science are gratefully acknowledged and will be remembered. This change brought the program to a 7.5 FTE staffing level at the close of 2000.

2. Growth of the Network

Three new climatological network sites were established in 2000 bringing the total number of monitoring locations in the network to 30. Climatological sites were established at Poker Flat, AK and Starkville, MS. Funding was 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 on Arctic UV It was installed in September 2000. This is the first use of a UV-MFRSR in the Arctic. A new site was installed in September in Starkville, MS. Data from the site in MS will be used in collaboration with the research of Dr. K. R. Reddy of Mississippi State University who is studying UV effects on cotton. Data will also be used by Remote Sensing Technology Center to provide accurate information to support Precision Farming. In addition, through a collaborative effort with the Desert Research Institute of Las Vegas, NV, a research site that was established last year at the Storm Peak Observatory near Steamboat Springs, CO which was made a climatological site this year.

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 procedures for transferring calibrations.

3. Instrumentation

Retrofit of failing photodiodes - Beginning approximately six months after the initial deployment of the UV-MFRSRs, in 1998, channels started to fail. As of December 31, 2000 there had been 47 channel failures in 28 heads. This is out of a total of 215 channels in 43 instruments. Thus 22% of the possible channels have failed while 65% of the heads have had at least one channel failure. It was determined that the cause of failure was unstable GaP photodiodes. Therefore the network has contracted with YES to retrofit all 43 heads using more stable Si photodiodes in place of GaP photodiodes. The contract includes a one year warranty. The first retrofit has been accomplished and the filter functions measured by CUCF are "the best ever". All the heads from the field will receive a closing calibration from CUCF before retrofitting and the heads will receive a second CUCF calibration after retrofitting before being fielded.

Stability of the UV Shadowbands - Over the past few years the network has concentrated on determining the shadowband's radiometric stability. 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) have been published. The research has been focused primarily on the stability of the interference filters. With the switch-over to the US GCRP-CUCF for our calibration laboratory more than three years ago and their recent completion of the characterization of all of the network instrumentation for at least the second time, the network is now able to statistically investigate and document the stability of the filter functions and the radiometric calibrations of its instrumentation.

The CUCF has performed 34 repeat filter spectral response functions (SRFs) and absolute response characterizations which allows the statistical assessment of the instruments' stability. Since the CUCF's wavelength measurement accuracy and repeatability is better than ± 0.02 nm and does not change over time (Slusser et al., 2000), all paired differences reflect real shifts in a channel's SRF. **Appendix 1a** shows the statistics of repeat channel SRF measurements of 34 UV-MFRSR performed at the CUCF during 1999 and 2000. The median shift in SRF ranged from 0.018 to 0.036 nm with a standard deviation (S.D.) of between 0.061 to 0.103 for the 7 channels. This is a profound result to the operation of this network. Since the SRFs are so stable, in-house calibration becomes feasible using the Langley calibration method and heliostat angular response measurement (see below). **Appendix 1b** shows the repeated absolute response characterizations of 34 UV-MFRSR performed at the CUCF. The median shift in absolute response was 3.69% to 6.40% with a S. D. from 9.22% to 10.76% for the 7 channels.

Another gauge of overall instrument stability which does not require the instrument to be pulled from the field, is using the Langley method to track voltage intercepts (Slusser et al., 2000; Bigelow and Slusser, 2000). We have automated the Langley analysis software to easily track the time series of voltage intercepts for each channel of each head. The slope of each regression indicates the drift over that period of time. A set of these stability plots now accompanies each head as it is sent down to CUCF for re-calibration. Each set of plots (7 per head) contains values for a single head deployment at a given site.

The Langley method of radiometric stability checks works best at sunny, non turbid sites typical of the Western US. For instance at CPER there were 151 hits at 368 nm over 14 months shown in Table 1 below. It is significant that the average drift here for all 7 channels was 1.6%. Figure 1 shows the time series from late 1999 until late 2000 for the 368 nm channel at CPER. The drift in this channel is negligible. One of the most cloudy sites in the network is Vermont, shown in Table 2, which had 47 hits at 368 nm over 15 months. The average drift here, neglecting the 300 nm channel where there were very few hits, was 8.4%. **Appendix 2** shows histograms of the drift per year of all 42 heads. We are investigating possible causes of drift, including soiling of the diffuser (below).

Table 1: CPER Langley Intercept Time Series Results

Channel (nm)	300	305	311	317	325	332	368
hits	49	120	132	147	149	146	151
drift	2.6%	3.8%	4.2%	0.7%	-0.1%	2.7%	0.1%
S.D. of mean	1.9%	0.7%	0.6%	0.5%	0.4%	0.4%	0.4%

Table 2: Vermont Langley Intercept Time Series Results

Channel (nm)	300	305	311	317	325	332	368
hits	5	19	32	34	41	48	47
drift	-13.2%	3.3%	-7.7%	-11.0%	-11.0%	-9.1%	-8.5%
S.D. of mean	15.7%	2.2%	1.5%	1.5%	1.5%	1.3%	1.0%

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) S. D. of the mean of repeated Langley intercept values (V_O) ranged from 0.6% at 300 nm to 0.2% at 368 nm. The precision values of V_O shown in Table 1 are from CPER for data taken between October 1, 1999 and November 30, 2000. The precision of V_O values at CPER ranged from 1.9% at 300 nm to 0.4% at 368 nm, nearly as good as those obtained at MLO and comparable to the precision obtainable from repeated lamp calibrations using the same lamp. These data clearly demonstrate that high precision can be obtained at other than high elevation, pristine sites.

Quartz domes- Repeat lamp calibrations and Langley intercept time series indicate rather steep declines in the responsivity of heads located at a few places (e.g. El Centro, CA). Inspection of the heads have revealed soiled diffusers. To study this problem we have measured the transmission of the teflon diffusor and then placed it in the field at El Centro. Later transmission tests should show if dirt has caused the transmission to be reduced. If this is the case, quartz domes will be affixed to heads going to dusty climes.

Stability of the Broadband UVB Meters - The re-calibration of all of the USDA broadband meters against the CUCF triad was first accomplished in fall 2000. However, calibration data for the spectroradiometer used to calibrate the CUCF broadband transfer standards was not finalized in 2000. 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. The stability of the broadbands as judged against the triad is very good with the median shift in center wavelength of 0.48 nm **(Appendix 3a)** and the median change in scale factor for 30 instruments of 0.47% with a S.D. of 0.39% **(Appendix 3b)**.

Barometers - Barometers have been placed at 7 sites to better correct the effect of molecular scattering on aerosol optical depth retrievals in the UV. These are sites where NASA has co-located a UVA broadband to interpret TOMS satellite UV retrievals. Barometers have been installed at Big Bend TX, Everglades FL, Table Mountain and CPER CO, Mauna Loa HI, and Poker Flat AK, and the Canadian sites of Bratt's Lake and Toronto.

Repairs of Vis-MFRSRs - Due to the lower priority of the Vis-MFRSRs and their inherent instability (Bigelow et al., 1998), the network has stopped regularly repairing them. A few repairs have been performed by PPNL but largely we are relying on existing inventory.

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. Work has begun in collaboration with the Smithsonian Institution and NIST to include the 6 USDA SR-18s in a Material Degradation Network. Data from the SR-18s will be polled every week, checked for quality at Smithsonian, and then made available on the Web for general use.

3.1 Calibration

The availability and quality of calibrations continued to be a major concern in 2000. All calibrations are now performed at the CUCF in Boulder CO. In order to increase our confidence in all calibrations and improve precision and accuracy, the network continues to develop alternate methods of establishing absolute, angular and spectral characterizations for its radiometers.

Broadband Calibration **-** Each of the 43 broadband meters were calibrated in 2000 by the CUCF which performs absolute, cosine, spectral and erythema characterizations for each instrument. However, the utilization of this new calibration information has been delayed pending a completion of the 2000 absolute calibration factors. A report of the 1997 North American Interagency Spectroradiometer Intercomparison has been submitted (Lantz et al., 2000).

UV-MFRSR Calibration **-** All 42 UV-MFRSR heads were characterized during 2000 at the CUCF for their spectral response and absolute lamp calibrations. The CUCF has produced its first cosine characterization and will soon make this a part of the routine calibration.

In-House Cosine Response Measurements **-** Because of the difficulties in obtaining cosine characterizations from the CUCF and our concerns with different measurement strategies, we continued development of an *in situ* technique for measuring the cosine response of the UV-MFRSR. The prototype consist 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 two 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 turntable is inside.

The first series of tests using single readings each lasting 3 seconds produced measurements at 2° intervals. Intervals of 1° 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 was presented along with preliminary results at the European Geophysical Union's annual meeting held in Nice, France in April 2000.

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).

3.2 Quality Assurance

Most of the work done in the area of quality assurance in 2000 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.

Appendix 4 shows the QA coding criteria for all USDA data. These flags are attached to the data record in a separate column to qualify the quality of the data.

We have begun to screen voltage intercepts by visually examining plots of values produced by Langley regression (Slusser et al., 2000). If the time series is anything but flat or with a slight trend or slope, that channel is flagged. Each set of plots (one per wavelength) contains values for a single head deployment at a given site. Voltage intercepts are being screened for all ultraviolet sites and for those visible sites in which data users have expressed interest. The purpose of the screening is three-fold: a) to improve the quality of data products (e.g., aerosol optical depths) we provide to data users which depends on a current voltage intercept; b) to help to identify data that is of questionable quality due to past equipment failures or other problems at a site and c) to monitor recent equipment status to afford more timely repair.

Completeness - The network continues to maintain a high degree of data capture (**Appendix 5**). In 2000 the median number of 3-minute measurements captured by VIS-MFRSRs at network sites was 99.1%. This compares with 97.6% in 1999, 97.5% in 1998. The third full year of UV-MFRSR operation resulted in a median of 99.2% of the 3-minute data being captured compared with 99.1% in 1999. Notable departures from the median occurred at Storm Peak (87.2%) where icing problems on the band caused considerable down time.

Comparability -The network continues to maintain collocations with both the Canadian Brewer Network (2 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 was presented by Edmund Wu at the Quadrennial Ozone Symposium in Sapporo, Japan in August 2000 entitled "A medium-length comparison of erythemal UV irradiance measurements". The extended abstract is included. This study compared erythemal irradiance measured by the USDA UVB1 and the Canadian UVB1 and the Brewer Mk IV. The agreement between each of the three instruments was within ±2% for solar zenith angles (SZAs) from 25° to 50°.

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 such as NASA's CIMEL.

3.3 Network Data Users

Total UVB Web site access increased by 65% during 2000. Educational site traffic increased by 51%, while federal agencies traffic decreased by 14%. However, a total of 1642 gigabytes of UVB project data were delivered via FTP to federal agencies during 2000, an increase in traffic of 18%. International traffic increased by 34%, representing 70 countries, a slight increase over the 67 countries the previous year. The majority of traffic (91%) comes from .com (52%), .net (21%), and .edu (18%), while the remaining comes from .gov (5%), .us (2%), .mil (1%) and .org (1%).

4. Research Activities

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

4.1 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 HI (3.4 km elevation) were compared to calibrations made at CUCF 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 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 ±5.5 % at 300 nm to ±2.4% at 368 nm. For all channels calibrated with CUCF lamps the estimated uncertainty was ±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, probably due to changing ozone during the Langley event.

4.2 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 30 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 attached and will submitted to the *Journal of Geophysical Research* (Slusser, J. R.., O. Torres, J. R. Herman, G. Scott, and J. . Deluisi,

2000. Smoke from Mexican Fires Characterized from USDA UV-MFRSR Ground Based and NASA TOMS Satellite Measurements (in preparation).)

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 Vuilleumeir et al. (2001) "Variability in Ultraviolet Total Optical Depth during the Southern California Ozone Study (SCOS97)" is about to be published in *Atmospheric Environment* summarizing the work.

As a follow-up to the SCOS97 study, a UV-MFRSR and Vis-MFRSR pair of radiometers were placed in Houston to study air quality. We are collaborating with Dr. Richard Shetter of the National Center for Atmospheric Research to investigate the effect of pollution aerosols on tropospheric chemistry. Dr. Nels Laulaninen of the Pacific Northwest National Laboratory (DOE) Atmospheric Chemistry Program will also be collaborating with us to analyze the data. In addition we will test our ability to retrieve actinic fluxes by comparing actinic spectra retrieved using the Min and Harrison (1998) model in conjunction with the TUV radiative transfer model (Madronich, 1993).

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 radiative characteristics will be possible. Results were presented at the American Association of Aerosol Research meeting held in St. Louis in November, 2000.

4.3 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 SZA < 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 HI and the Canadian sites of Bratt's Lake and Toronto (Gao et al., 2000). 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, and 1.001 in Regina between Julian date 160 and 250.

4.4 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 CO and Mauna Loa HI. Erythemal doses are generally within ±5% for all SZA < 75°. 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 CA, and Pullman WA. More comparison are in progress (Gao, W., J. R. Slusser, and B. Olson. Comparison of Synthetic Spectra Retrieved from the UV Multi-filter Rotating Shadow-band Radiometer with Collocated Brewer Spectral Measurements. (in preparation) and will be presented at the Society of Photo-Optical Instrumentation Engineers UV Meeting in San Diego in July 2001.

4.5 Radiometric Stability

A paper published evaluates the stability of the Ion-Assisted-Deposition (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 each instruments' I_o 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 IAD filters are much more stable than the filters in VIS-MFRSR's as reported by Bigelow et al. (1998).

4.6 Comparisons of UV-MFRSRs with TOMS and Radiative Transfer Model

We have compared irradiances from a UV-MFRSR at Table Mountain CO 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 and TUV retrievals was presented at the SPARC Meeting in Mar del Plata, Argentina in November, 2000. Clear sky retrievals at NM and OK agreed to within ±4% of the TUV model and the satellite retrievals. More extensive comparisons including all sky conditions will be presented at the SPIE Meeting in July 2001.

4.7 Spectrometer Research Network

Six high resolution U-1000 1.0 m double spectrometers have been developed by Dr. Lee Harrison of SUNY Albany. The first has been completed and installed at the NIST / NOAA research site on Table Mountain CO. This instrument has been operating since December 1998 and the performance has been good although there has been a steady decline in responsivity. The instrument resolution (0.1 nm), out-of-band rejection, wavelength accuracy and repeatability, and cosine response exceed the specifications of any spectrometer available today. Unlike the Brewer, the instrument is tightly temperature controlled, making it extremely reliable for short periods of time directly following a calibration. Data from the instrument is being used to calibrate the triad of UVB-1 broadbands used to calibrate the 42 USDA UVB1s. The second instrument was installed at the DOE Central Plains ARM CART site near Billings, Oklahoma in September, 1999. The third instrument was sited at the Agricultural Research Service Climate Stress Laboratory at Beltsville Maryland in November 1999. As a result of budget pressure, there are currently no plans to deploy the remaining three instruments. Budget constraints make even the routine operation of these 3 instruments problematic. Currently only the Table Mountain CO instrument has been calibrated. NASA has expressed interest in the data to validate their retrievals, in particular at wavelengths shorter than 305 nm. NASA is also interested in the magnitude of Raman scattering which can be addressed with U-1000 due to its narrow resolution.

4.8 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”, a four-year time series at 10 USDA sites is analyzed to determine the influence in solar zenith angle, column ozone, and clouds on seasonal and year-to-year variability in UV irradiances. One conclusion is that variations in cloud cover contribute more than variations in column ozone in the observed year-to-year changes in UV irradiances.

4.9 Other Cooperative Research

In addition to the more formal collaborations noted above the network is often asked to participate in or contribute to other projects. While in general we believe these collaborations to be of benefit to the network technology, we must choose these opportunities with care so as not to overextend our resources.

5. Agricultural Effects Research

The decrease in stratospheric ozone has prompted renewed efforts in assessing the potential damage to plant and animal life due to enhanced levels of solar UV-B radiation . The effect of UV-B enhancements on plants includes reduction in yield and quality, alteration in species competition, decrease in photosynthetic activity, susceptibility to disease, and changes in plant structure and pigmentation. The enhanced UV-B radiation generally has negative impacts on growth, yield and quality of some crop plants such as soybean, winter wheat, rice, sorghum, cotton and corn. A wide range of UV impact research problems on agriculture have been addressed by the Program. We have developed extensive collaborations and interactions with researchers in agricultural, natural resources, and science communities.

5.1 The Three-dimensional (3-D) UV Radiation Canopy Transfer Model

The distribution of UV-B radiation varies with different vegetative canopies. Tree canopies often have large natural openings between crowns, whereas incomplete row crops have wide spaces between rows of vegetation. Urban environments consist of complex 3-D arrangements of trees and buildings. Obviously, an advanced 3-D radiation model which considers anisotropic sky radiance penetrating through heterogeneous canopies is needed to evaluate UV-B radiation loading in many plant canopies. We have completed the development of this much-needed 3-D UV radiation model with our research partners, Dr. Richard Grant at Purdue University and Dr. Gordon Heisler at the USDA Forest Service. Tests of the model accuracy were made using field measurements in an open canopy apple orchard and in a closed canopy of maize for cloudless sky conditions. Measured and predicted values of UV-B canopy transmittance generally agreed well. The largest differences between measured and modeled UV-B transmittance occurred at high solar zenith angles. This was partly due to the decreasing ratio of direct beam to diffuse sky radiation with increasing solar zenith angle. This model can be used to assess the UV-B irradiance below dispersed canopies (agricultural crops, orchards, and trees in urban areas) given initial sky conditions and canopy composition and structure where the individual crown can be described as an ellipsoid. Sky radiance distributions for use in the model are available for clear and overcast conditions. Additional testing would be needed to determine the applicability of the model for partly cloudy conditions. Results of this research were presented in American Society of Agronomy 2000 annual meeting held in Minneapolis in November. The attached paper by Gao et al., "A Geometric UV-B Radiation Transfer Model Applied to Agricultural Vegetation Canopies" has been accepted for publication in *Agronomy Journal*.

5.2 Effects of UV-B Radiation on Cotton Growth, Development and Physiology: Experimentation and Model Development

This work addresses our long-term goal of understanding the interactive effects of environmental factors including UV-B radiation on cotton growth, development and yield. The objectives of this study are to test the hypothesis that elevated UV-B radiation will modify the response of transpiration, respiration, carbon acquisition, development, reproduction and yield of cotton, and to understand the physiological, anatomical and phenological basis of these effects. This study will use an internationally unique system of daylight chambers that allow the growth of row crops under complete control of microclimate and atmosphere, with simultaneous precise monitoring of water, carbon, and nitrogen balance throughout the experimental period of the crop. We intend to incorporate the effects of UV-B radiation effects into a physiologically-based crop model, GOSSYM/COMAX, to be used for impact analysis in the fourteen Southern contiguous states cotton cropping regions of the U.S. This research effort is ongoing in cooperation with the research group of Dr. K. Raja Reddy at Mississippi State University.

5.3 Evaluation of the influence of epicuticular waxes on the optical properties of leaves, stalks, and canopies of a range of Sorghum cultivars

This work will provide understanding as to the leaf characteristics that cause UV-B leaf reflectance, give useful information in the estimation of the UV-B reflectance of any plant leaf given the characteristics of the leaf surface, and assist in the understanding of how Sorghum thrives in low latitude areas where UV-B irradiance is high. This research activity is ongoing in cooperation with the research group of Dr. Richard Grant at Purdue University.

5.4 Evaluation of the impact of heliotropism on the reported susceptibility of various soybean cultivars

The research will provide greater understanding of the risk of soybean to enhanced UV-B effects, and can also lead to a means of providing potential UV-B impact maps across the soybean growing region for various cultivars based on current and historic USDA UV-B monitoring measurements. This research activity is ongoing in cooperation with the research group of Dr. Richard Grant at Purdue University.

5.5 Integrating plant biochemical and phytochemical responses to incident levels of solar UV-B radiation

This work will provide evaluation of short-term plant responses to UV-B such as leaf development, foliar chemistry (photosynthetic and putative UV-screening phenolics) and level of DNA dimers produced in plants developing under contrasting UV-B environments. These responses will be linked with ambient UV-B fluxes obtained from the USDA UV-B monitoring network. The research results could also lead to further understanding about the mechanisms of UV-B responses. Tested plants include soybean, cucumber, and melons. This research activity is ongoing in cooperation with the research group of Dr. Joseph Sullivan at the University of Maryland.

5.6 UV, abiotic and biotic components of production and decomposition in shortgrass steppe: interactions with CO_2 enrichment

This work will investigate the effects of UV and moisture on decomposition and address an important UV plus CO_2 interaction. We intend to assess UV effects on decomposition of plant tissues and fibre qualities, and assess the effects of UV in very wet, average, and very dry years on the decomposition of shortgrass steppe vegetation. This research activity is ongoing in cooperation with the research group of Dr. Daniel Milchunas at Colorado State University.

6. Publications and Conference Presentations

The project produced numerous publications during 2000 and early 2001. Six articles were published in peer reviewed journals and two more were submitted. A total of 16 presentations were made at 10 different venues.

6.1 Publications

Bigelow, D.S. and J.R. Slusser, 2000. Establishing the Stability of Multi-filter UV Rotating Shadowband Radiometers, *J. Geophy. Res., 105*, 4833-4840.

Frederick, J. E., J. R. Slusser, and D. S. Bigelow, 2000. Annual and Interannual behavior of solar ultraviolet irradiance revealed by broadband measurements *Photochem. Photobiolgy 72(4)*, 488-496. .

Gao, W., J. R. Slusser, J. Gibson, G. Scott, D. S. Bigelow, J. Kerr, and B. McArthur. 2000. Direct-Sun Column Ozone Retrieval by the UV Multi-filter Rotating Shadow-band Radiometer and Comparison with Those from Brewer and Dobson Spectrophotometers. *Appl. Opt.* (Accepted)

Gao, W., R.H. Grant, G. M. Heisler, and J. R. Slusser. 2000. A Geometric UV-B Radiation Transfer Model Applied to Agricultural Vegetation Canopies. *Agronomy Journal.* (accepted)

Gao, W., R.H. Grant, G. M. Heisler, and J. R. Slusser. 2000. Modeling Ultraviolet-B Radiation in a Maize Canopy. *Agricultural and Forestry Meteorology.* (In preparation)

Gao, W., J. R. Slusser, and B. Olson. Comparison of Synthetic Spectra Retrieved from the UV Multi-filter Rotating Shadow-band Radiometer with Collocated Brewer Spectral Measurements. (in preparation)

Gao, W., J. R. Slusser, S. Madronich and G. Scott. Validation of the Tropospheric Ultraviolet and Visible Radiation Model Using USDA UVB Surface Measurements. (in preparation)

Gao, W., Y.F. Zheng, J.R. Slusser. Impact of Enhanced Ultraviolet-B Radiation on Cotton Yield and Quality. (in preparation)

Grant, R.H., G. M. Heisler, W. Gao, and M. Jenks. 2000. Ultraviolet Leaf Reflectance of Common Urban Trees and the Prediction of Reflectance from Leaf Surface Characteristics. *Remote Sensing Environment.* (Submitted)

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*).

Heisler, G. M. R.H. Grant and W. Gao. 2000. Ultraviolet Radiation in Tree Shade. *Journal of Arboriculture.* (submitted)

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 (submitted *J. NIST*)

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., 105*, 4841-4849.

Slusser, J. R., O. Torres, J. R. Herman, G. Scott, and J. Deluisi, 2000. Smoke from Mexican Fires Characterized from USDA UV-MFRSR Ground Based and NASA TOMS Satellite Measurements (in preparation).

Vuilleumier, L., R. A. Harley, N. J. Brown, J. R. Slusser, D. Kolinski, and D. S. Bigelow. 2001. Variability in Solar Ultraviolet Irradiance during the Southern California Ozone Study (SCOS97) *Atmos. Environ. 35(6)*, 1111-1122.

Zheng, Y. F., W. Gao, J.R. Slusser, and C. H. Wang. Yield Formation of Winter Wheat in Response to Enhanced Solar Ultraviolet-B Radiation. (in preparation)

6.2 Conferences and workshops

Slusser, J. Cooperative Institute for Research in the Atmosphere / National Park Service, Colorado State University, “Retrieving Aerosol and Cloud Properties from USDA Shadowband Radiometers”, Fort Collins CO, February 2000.

Durham, W., J. Slusser, D. Bigelow, European Geophysical Society, “Using the sun as a UV calibration source”, Nice, France, April 2000.

Gao, W.,Association of American Geographers, “Performance of the COTTAM and CERES-Rice Crop Models in the Southeastern US: Yield Response to Different Climate Change Scenarios”, Pittsburgh PA, April 2000.

Slussser, J., Co-chair of Second Front Range UV Workshop at National Center for Atmospheric Research, “Aerosol Properties in the UV”, Boulder CO, May 2000.

Gao, W., J. Slusser, J. Gibson, G. Scott, D. Bigelow, J. Kerr, and B. McArthur, the Second Front Range UV Workshop at National Center for Atmospheric Research, “Direct-Sun Column Ozone Retrieval by the UV-MFRSR and Comparison with Those from Brewer and Dobson Spectrophotometers” Boulder CO, May 2000.

Slussser, J., UVB Health Effects Workshop, “Factors Affecting UVB Transmission Trough the Atmosphere”, Steamboat Springs CO, July 2000.

Gao, W., UVB Health Effects Workshop, “UV Waveband Solar Irradiance in Different Vegetation Canopies: Measurements and Modeling”, Steamboat Springs CO, July 2000.

Gao, W., UVB Health Effects Workshop, “Spectral Radiative Properties of Various Tree Species in Ultraviolet Wavelengths and the Impacts on Irradiance Modeling and Measurement”, Steamboat Springs CO, July 2000.

McArthur, L. J. B., J. Slusser, E. K. Wu, and D. Bigelow, Quadrennial Ozone Symposium, “A medium-length comparison of erythemal UV irradiance measurements”, Sappora, Japan, August 2000.

Slusser, J., N. Laulainen, and D. Bigelow, American Association for Aerosol Research, “Single Scattering Albedo from Direct to Diffuse Technique”**,** St Louis MO, November 2000.

Hand, J., S. Kreidenweis, J. Slusser, W. Gao, and G.Scott, American Association for Aerosol Research, The Relative Contributions of Accumulation and Coarse Mode Particles to Aerosol Optical Depth and Their Effect on the Spectral Variation of the Ångstrom Coefficient During BRAVO, St Louis MO, November 2000.

Slusser, J. R., J. R. Herman, W. Gao , N. Krotkov, G. Labow, Stratospheric Processes And their Role in Climate, “Comparisons of USDA UV-MFRSR UV irradiance measurements with TOMS satellite retrievals and DISORT under various cloud and aerosol conditions”, Mar del Plata, Argentina, November 2000.

Gao, W., R. H. Grant, G. M. Heisler, and J. R. Slusser, Stratospheric Processes And their Role in Climate, UV Impacts Workshop, “A Geometric UV-B Radiation Transfer Model Applied to Agricultural Vegetation Canopies”, Mar del Plata, Argentina, November 2000.

Gao, W., R. H. Grant, G. M. Heisler, and J. R. Slusser, American Society of Agronomy Annual Meeting, "An Introduction of USDA UV-B Radiation Monitoring Program and A Radiation Transfer Model for Open Canopies in the UV-B Waveband ", Minneapolis MN, November 2000.

Gao, W., American Society of Agronomy Annual Meeting,"Cotton and Rice Yields Change with the Future Climate in the Southeastern US", Minneapolis MN, November 2000.

Gao, W., Natural Resource Ecology Laboratory, Colorado State University, "Modeling and Measurement of Ultraviolet Irradiance in Vegetation Canopies ", Fort Collins CO, November 2000.

7 Recommendations for Future Work and Five Year Plan

7.1 Recommendations

Calibration and instrument stability will continue to be major areas of concern in 2001 and beyond. It will be difficult to support the CUCF and SUNY Albany in addition to the various UVB agricultural effects subcontracts. In response to the direct request from Congress that we supply more of our data to agricultural effects researchers, we will support several of these efforts. Wherever possible we will pursue strategies that increase our independence from costly CUCF calibrations. During FY 2002 the UVB Monitoring and Research Program will:

- Continue the development of *in-situ* techniques that establish reliable calibrations for its instrumentation. The recently implemented Langley calibrations allow the network to gain independence from expensive calibration facilities as well as track stability. If it can be demonstrated that the filters are stable, repeat spectral calibrations will be no longer required. 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.

- Develop procedures for calibrating the broad bands with Fort Collins staff at CPER. The physical setup is in place to accommodate 6 broadbands. Assuming it takes one week for a calibration transfer, the entire fleet of broadbands could be completed in 2 months

- Continue to fund the calibration of all of its instrumentation at the CUCF in Boulder CO during FY 2002.

- Continue UV agricultural impact studies.

NASA has funded a 2/3 time 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 available manpower limits 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 we will:

- Compare UV retrievals for several sites where NASA has expressed particular interest. Include USDA data, TOMS and standard UV radiative transfer models.

- Work with NASA to develop the first US UV climatology.

- Provide ground-truth (UV, aerosol optical depths, and column ozone) for existing and new NASA satellites.

- As time permits compare USDA measurements with the Canadian and US-EPA Brewer Networks. This will establish a firm relationship between the principle North American USCRCP ground-based satellite based UV monitoring programs.

To complete the original design of 30-40 stations the network will need to establish partnerships with local research and monitoring programs

- 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 4**).

- Old data (back to January 1, 1998) should be coded when time permits

7.2 Five Year Plan

During the next five years the UVB Program will continue its leadership in providing quality UV data to interested users, especially to agricultural effects researchers. The first requirement is that we have good data. To accomplish this goal we will continue efforts at improving calibrations of the UV-MFRSR and broadbands as well as implementing QA and QC of all our data. To further this goal we will continue research of the Langley method and support of the CUCF. The CUCF has become the world's premier UV calibration facility and should be given our continued support. We will cooperate with Yankee to keep open a fall-back calibration option should potential budget restrictions ever make CUCF unaffordable. We will keep on evaluating the single diode array spectrometer (UV-RSS), available from

Yankee, for possible purchase. The UV-RSS is a single prism array spectrometer which retrieves the entire spectrum simultaneously but may suffer from stray light contamination at wavelengths shorter than 305 nm. The SUNY 1.0 m double scanning spectrometer is promising but has not yet established sufficient stability to warrant unconditional 5 year support. Nor have compelling scientific objectives for the data of the 1.0 m instrument been identified. The instrument is a scanning device that has superb stray light rejection and wavelength accuracy. Therefore we will evaluate its continued support on a year-to- year basis.

We will continue work with the NASA TOMS group to help them to improve their satellite based UV retrievals. TOMS UV retrievals also form an important QC check on our data. This collaboration will involve research the role of clouds, aerosol optical depth, and aerosol single scattering albedo on UV transmission. This collaboration will lead to the first US UV climatology which is one of the major goals of the USDA UVB Monitoring Program. New satellites such as the Triana Mission will allow continuous retrievals of UV instead of the once per day TOMS overpass, thus improving the ability of satellite UV retrievals for the UV climatology.

Where appropriate we will continue our support of research in agricultural responses to increased UV. The criteria for selecting potential projects to support are: cutting edge crop research on economically and politically important crops; researchers with outstanding publication records.

We are in a unique and fortunate position to lobby Congress, which specifies the funding levels for our Program . We consult regularly with them on what they perceive our priorities should be. As a direct result of the feedback we received from key Congressional aides during 2000, we commenced the support of four subcontracts that investigate the response of agricultural plants to UV. This resulted in a restoration of $434,000 of previously cut funds.

8 References

Bigelow, D.S. and J.R. Slusser. 1998 Interim Report: USDA Ultraviolet Radiation Monitoring Program, 1999. Natural Resource Ecology Laboratory, Fort Collins, CO.

Bigelow, D.S. and J.R. Slusser, 2000. Establishing the Stability of Multi-filter UV Rotating Shadowband Radiometers, *J. Geophy. Res., 105,* 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, C0 80523, 21 pp.

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.

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., 16,* 1736-1761.

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.*, *26,* 2725-2728.

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.*, *105*, 4841-4849.

Slusser, J. R. and Bigelow, D. S. 1999 Interim Report: USDA Ultraviolet Radiation Monitoring Program, 2000. Natural Resource Ecology Laboratory, Fort Collins, CO.

Slusser, J. R., J. R. Herman, 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).

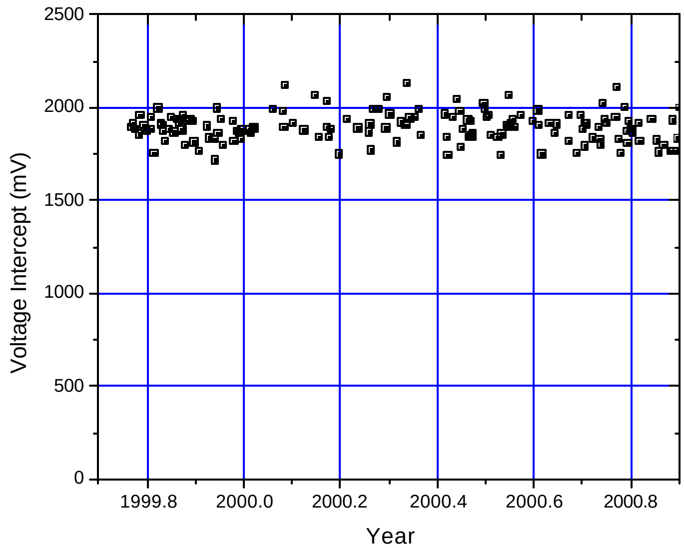
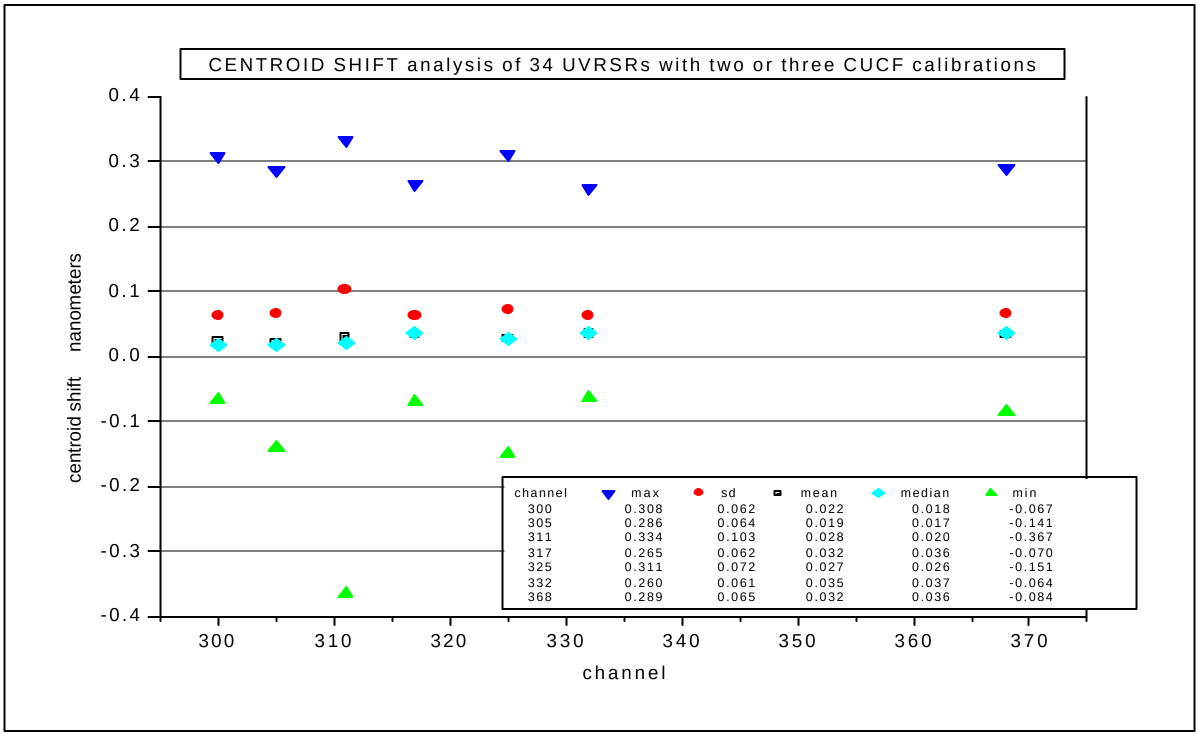
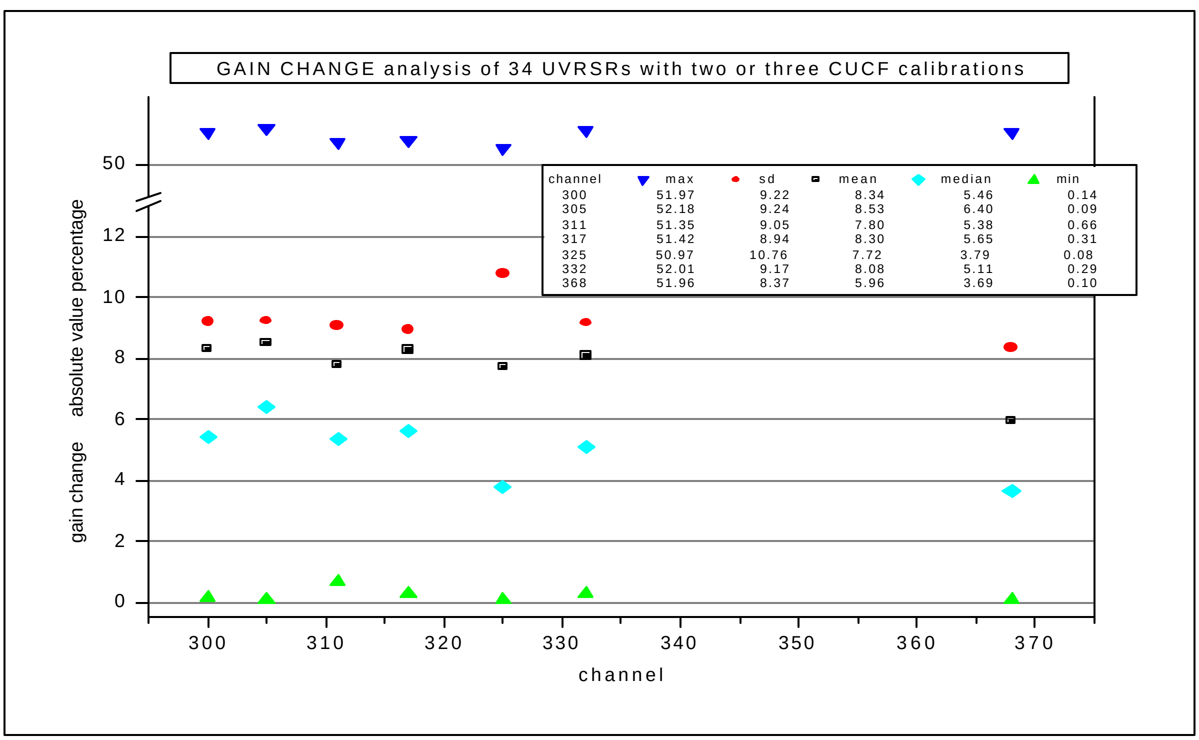


Figure 1: Time series of Langley voltage intercepts for the 368 nm channel at CPER shows excellent stability over 14 months of operation. The drift is <0.2%.

Appendix 1a: Statistics of Wavelength shift for UV-MFRSRs

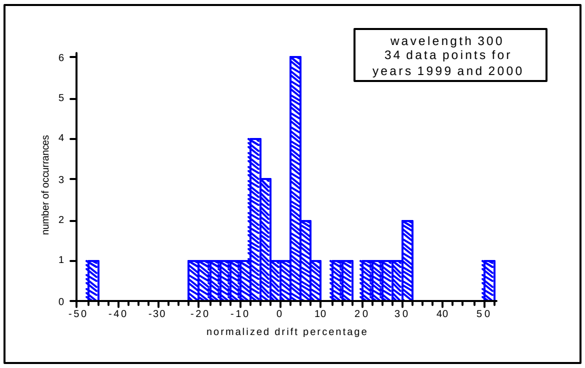


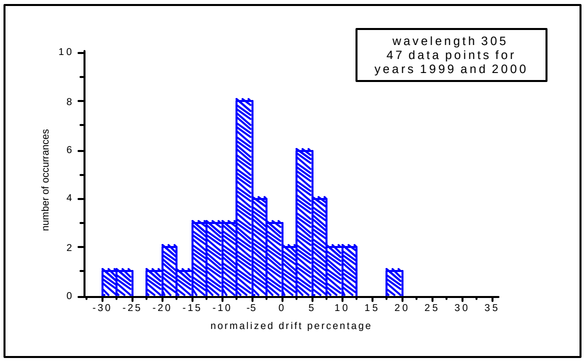
Appendix 1b: Statistics of changes in UV-MFRSR calibration factors.

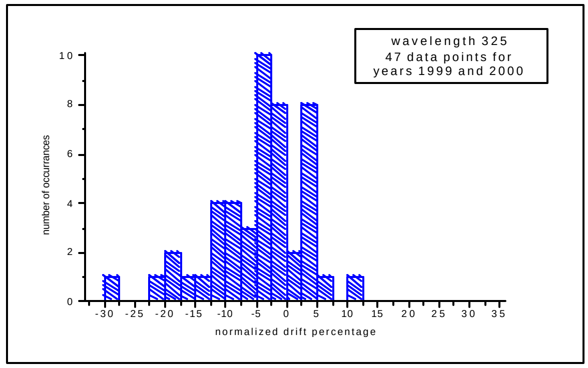


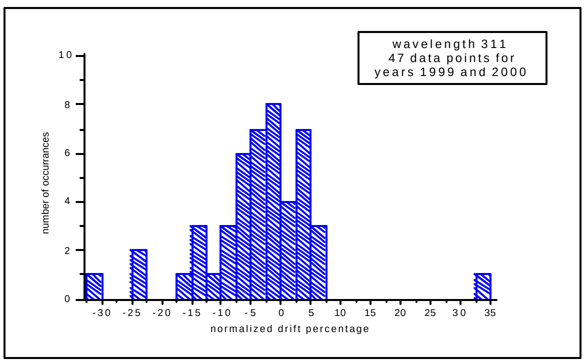
Appendix 2

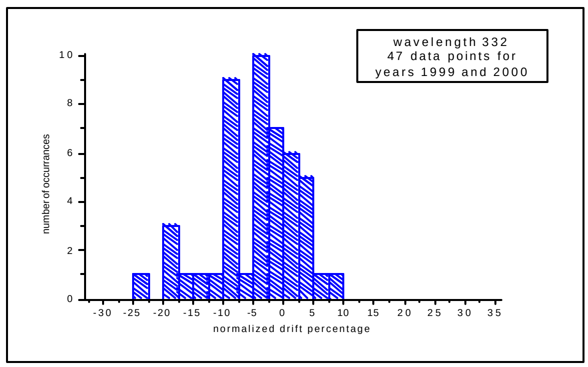
Histograms of UV-MFRSR sensor drift as determined by Langley Plot analysis of all 42 instruments for years 2000 and 1999 (though some extend back to 1998), with data points normalized to one calendar year.

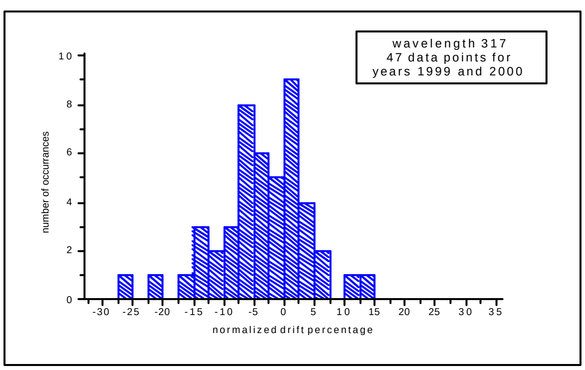


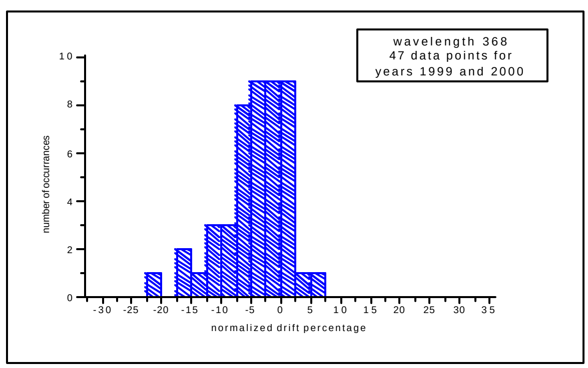




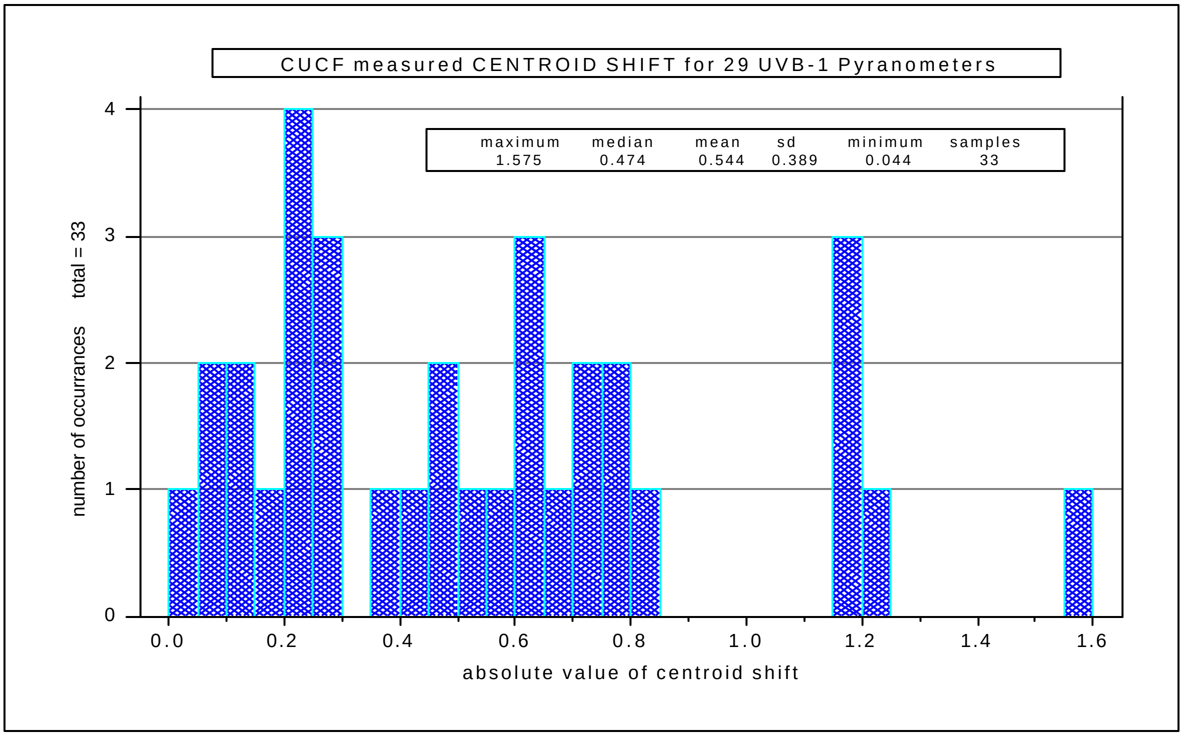




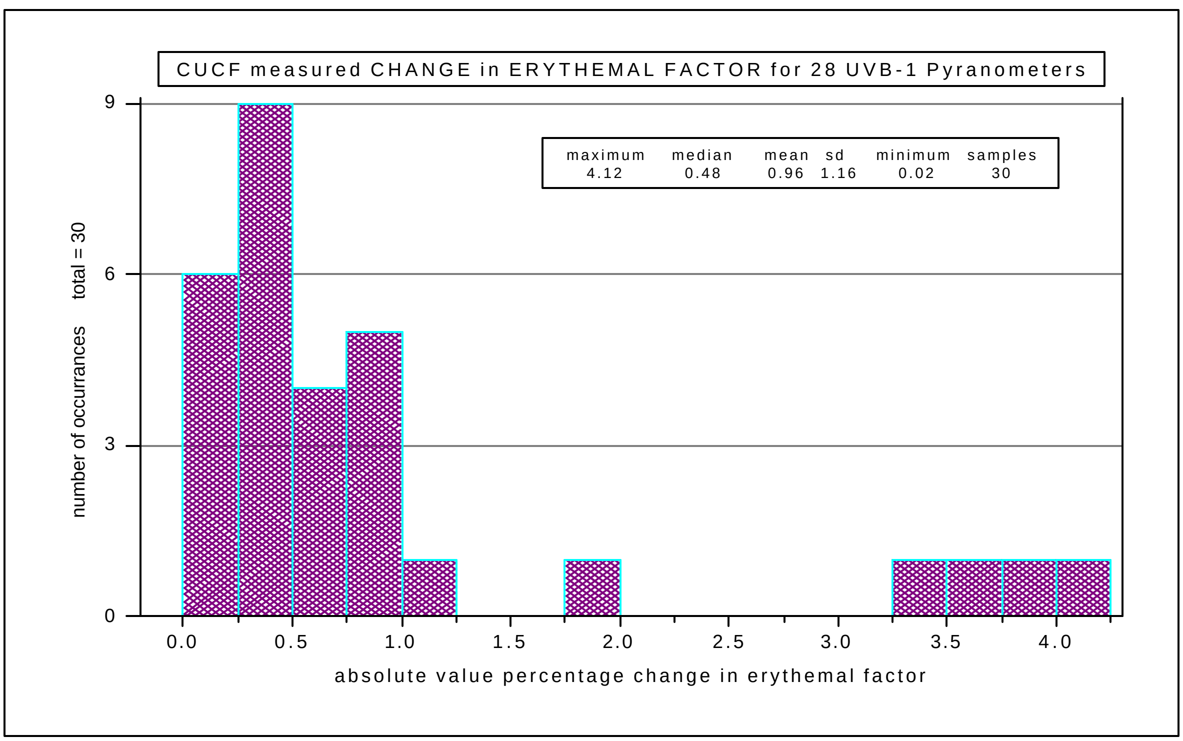




Appendix 3a: Statistics of Wavelength shift for broadbands



Appendix 3b: Statistics of changes in broadband calibration factors.



Appendix 4: Quality Assurance Coding of UVB data records

Data Record Code	Reason	Rule	Type
bt	broadband dome temp problem	dome temp is <= 750 millivolts or dome temp is >= 850 millivolts	aux
at	uva dome temp problem	dome temp is <= 900 millivolts or dome temp is >= 1100 millivolts	aux
hh	humidity high	humidity > 1030 milivolts	aux
hf	humidity failure	humidity < 0 milivolts	aux
tf	air temperature failure	air temp < 2300 millivolts	aux
s[n],n is 1-7 channel	signal saturated for channel n		channel
i[n],n is 1-7 channel	signal interference for channel n		channel
nc[n],n is 1-7 channel	no calibration data for channel n		channel
a[n]	averaging interval is n minutes not 3 minutes		channel
fp	power failure		channel
fe	polling failure		channel
db	board damaged		channel
dd	diffuser damaged		channel
dr	diffuser dirty		channel
dh	head damaged		channel
ba	band alignment problem		channel
bm	band motion problem		channel
tx	timekeeping problem		channel
ma	annual maintenance		channel
mt	troubleshooting maintenance		channel
bd	broadband dark count problem		aux
bz	broadband dome crazed		aux
ad	uva sensor problem		aux
az	uva dome crazed		aux
ed	epply sensor problem		aux
ld	licor sensor problem		aux
sd[n]	solar light n problem		aux
f[n],n is 1-7 channel	channel failure for channel n	one of the total channels at local noon is below 150 mv that channel has failed. If all channels at local noon are below threshold then no failure	channel
bc1	no des_factor in broadbands_calibrations	for this serial_num	aux

bc2	no erythemal coefficients in auxiliary_bb_coeff	for this serial_num	aux
dc	no diffuse correction coefficients in diffuse_cosine	for this serial_num	channel

Appendix 5: Completeness of Level 1 Data Capture for Sites that Operated a Full-Year

Location	Vis- MFRSR (%)						UV- MFRSR(%)		
	1995	1996	1997	1998	1999	2000	1998	1999	2000
Alaska						99.42			98.89
Arizona			90.7	97.1	87.9	93.85	97.7	92.9	96.05
California - Davis	98.8	99.6	98.4	98.9	99.4	99.99	97.9	99.7	100.0
California - El Centro					98.3	99.97		99.79	99.95
Colorado - Pawnee / CPER	98.7	97.2	97.0	99.0	99.5	98.47	74.9	98.2	100.0
Colorado- Steamboat Springs						88.41			87.25
Colorado - Table Mountain							66.3	74.5	99.68
Florida					94.0	99.95		98.0	99.91
Georgia	96.5	98.1	95.8	96.9	97.3	92.66	97.0	97.4	93.05
Hawaii				83.9	98.2	99.12	76.0	96.2	99.73
Illinois	95.2	97.4	93.5	85.2	98.8	99.06	98.6	99.5	99.02
Louisiana			96.9	98.1	97.6	99.29	99.0	99.2	98.82
Maryland – Wye			92.9	98.1	89.6	96.77	99.1	96.5	95 .61
Maryland - Beltsville					98.3	99.31		99.4	99.98
Maine	95.9	94.3	96.2	94.4	97.8	97.8	98.7	99.4	99.71
Michigan	89.9	95.5	93.3	95.5	96.9	99.71	95.7	97.6	97.11
Minnesota			99.4	99.4	95.4	98.94	99.2	98.5	99.05
Mississippi						100.0			100.0
Montana				97.9	95.7	99.06	96.2	99.8	99.99
Nebraska			98.7	96.1	94.1	98.5	99.9	95.5	99.45
New Mexico	98.8	97.6	96.6	92.9	96.5	94.05	99.1	98.5	100.0
New York	97.5	99.0	96.1	98.2	97.4	98.46	99.0	99.1	98.98
Ohio	99.2	99.1	98.0	92.3	96.4	99.92	99.3	99.5	99.71
Oklahoma					97.8	99.30		99.0	98.83
Ontario (Canada)					98.7	99.63		99.1	99.18
Saskatchewan (Canada)				99.1	98.7	97.93	91.5	99.4	98.30
Texas			98.0	99.7	98.7	96.76	99.9	99.9	99.04
Utah	100	98.6	97.3	94.4	97.8	99.97	100	99.0	99.98
Vermont			95.2	98.7	97.1	99.46	96.7	94.4	98.64
Washington	99.5	97.0	96.9	98.6	99.4	99.17	99.7	99.3	99.46
Wisconsin			99.1	86.8	92.4	91.24	97.0	99.4	95.98
Median	98.7	97.6	96.9	97.5	97.6	99.09	98.6	99.1	99.18