Proposal

Development and Management of the USDA UV-B Monitoring and Research Program

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February 12, 2007

1. Program Overview

The primary objective of the USDA Ultraviolet Radiation Monitoring and Research Program (UVMRP) is to provide information to the agricultural community about the geographic and temporal climatology of UV-B irradiance.

This program was established in 1992 to provide the US Department of Agriculture with the information necessary to determine whether increasing levels of ultraviolet-B (UV-B) radiation have an effect on food and fiber production in the United States. Surface UV-B radiation data is essential to establish the climatology, short-term variability, and possible long-term trends of UV-B radiation. Prior to the establishment of the program only limited information was available to make such assessments and the geographic distribution and quality of this information was insufficient to meet the requirements of the agency (Gibson, 1991; Gibson, 1992).

Within the first two years, an initial network of ten stations was established using UV broadband radiometers, temperature, humidity and surface albedo sensors, plus seven wavelengths of visible radiation from an instrument called the Multi-Filter Rotating Shadowband Radiometer (vis-MFRSR) (Harrison et al., 1994) produced by Yankee Environmental Systems, Inc. (YES). Beginning in 1995, the seven wavelength Ultra-Violet Multi-Filter Rotating Shadowband Radiometer (UV-MFRSR), also produced by YES (Bigelow et al., 1998) was added to each field site. Each MFRSR instrument serves as an intelligent data logging and communications system for all of the measurements taken at a single site. Since that 1992 beginning the network has expanded to 36 stations (see Figure 1).

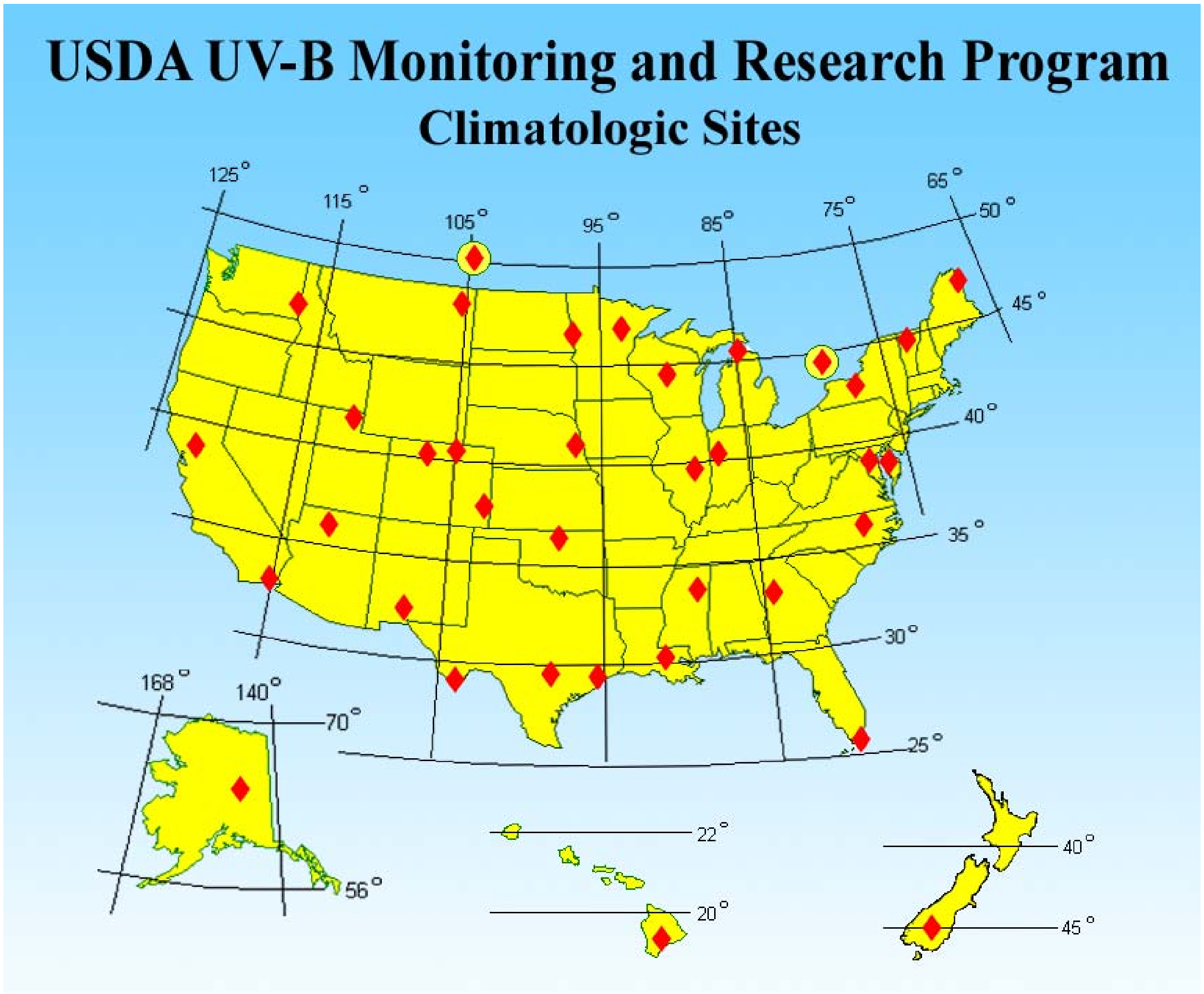

Figure 1: This map shows the location of the 36 climatologic sites in the USDA UV-B Monitoring and Research Program network.

The USDA determined two networks were necessary to meet their objectives (Gibson, 1992): climatologic and research. The climatologic network requires a large number of sites deployed across the U.S. using low-cost sensors to reduce both initial installation and operating costs. The research network requires high resolution spectroradiometers at a limited number of sites. This two-phase approach meets the need for high resolution UV-B spectral and climatologic data over broad geographic regions to support biological effects research. The plan also provides a basis for regional assessment of the potential impacts of UV-B on agriculture, forests, and ecosystems.

1.1 Climatologic Network

The climatologic network:

- Provides information to agriculture, forest, ecosystem, health and material researchers about the temporal and geographical distribution of UV-B irradiance.
- Furnishes ground validation for satellite UV measurements and model estimates of UV-B irradiance, aerosol properties, and column ozone.

- Establishes long-term records of UV-B irradiance necessary to assess year-to-year variability and trends.

To provide an adequate density of measurement sites to establish the climatology of UV-B irradiance, a large network of 30-40 low cost sites, distributed within a grid model, was deployed (see Figure 1). These 36 network sites contain low cost vis-MFRSR, UV-MFRSR and UVB-1 broadband instruments. Each instrument operates continuously in the field with periodic attention from on-site personnel and with control and data collection performed over a phone line from the Program's office in Fort Collins, CO. The UV-MFRSR and vis-MFRSR are each equipped with a rotating shadowband which makes possible the simultaneous measurement of the total horizontal, diffuse horizontal and direct normal irradiances - the latter permitting the use of the Langley calibration method (Slusser et al., 2000). Using a modeling technique developed at SUNY-ASRC (Min and Harrison, 1998), measurements at the seven UV wavelengths can be converted to a continuous spectra from 295 - 400 nm, enabling any action spectrum to be used to weight the spectral data (Gao et al., 2002a; Slusser et al., 2003; Davis and Slusser, 2005). The UV-MFRSR measures seven selected wavelengths in the UV-B and UV-A spectral range (300-, 305-, 311-, 317-, 325-, 332- and 368 nm) employing narrow-band interference filters (2 nm FWHM) and photodiode detectors. Fifty of these instruments are available for deployment throughout the network. We continue to use the very stable UVB-1 broadband meters at each site since much of the historical record is based on broadband meters and they are still widely used by researchers.

Measurements are conducted primarily in rural areas, with particular consideration given to agricultural and forested regions where UV-B response research is already underway. Several sites have been located where spectroradiometers from other agencies are used, which enables us to evaluate both the performance and calibration of our shadowband instruments and broadband meters. These sites include Table Mountain CO, Mauna Loa HI, the Canadian sites of Toronto and Bratt's Lake, and Lauder, New Zealand.

The complete list of our sites is found at http://uvb.nrel.colostate.edu/UVB. Calibrated data is available on our Web site within 24 hours, including data back to January 1, 1997.

1.2 Research Network

The NRI Competitive Research Grants Office of USDA-CSREES and this program supported the development, under the direction of Dr. Lee Harrison at SUNY Albany, of six high resolution U-1000 spectroradiometers (Harrison et al., 2002) to measure UV-B radiation. These instruments have a wavelength range of 280-400 nanometers, a band pass of 0.1 nm and out-of-band stray light rejection of 10^{-10} (Gibson, 1991). Development work was completed in 1998 and the first instrument was deployed that November at the Central UV Calibration Facility's (CUCF) Table Mountain site near Boulder, CO. A second unit, with the support of USDA Agricultural Research Service, was deployed at the ARS site in Beltsville, MD in May 1999. A third was deployed at the

DOE / ARM site near Billings, OK at the end of 1999. The fourth instrument was installed in Fort Collins at the end of 2002. Due to a lack of resources, we have recently shut down the latter three instruments and there are no plans for deploying the remaining two spectroradiometers.

Current plans call for the maintenance of one reference site at Table Mountain, CO, using two high resolution scanning spectroradiometers, the U-1000 and a Ultra-Violet Rotating Shadowband Radiometer (UV-RSS). In addition, one of the Smithsonian Institution's SR-18 scanning spectroradiometer instruments is collocated here. Operation of these instruments, as well as on-site support and data acquisition, is performed by CUCF personnel (with technical support from SUNY Albany), funded by a sub-contract from the UVMRP.

A new approach to calibration of the UV-RSS was developed in 2006. The data from three years of deployment were used to generate new Langley plots that are corrected for both ozone and pressure. Aerosols can now be retrieved for all wavelengths down to 300nm.

High resolution spectral data is required to:

- Establish an absolute calibration reference for all US Global Change Research Program and international UV measurement programs.
- Provide calibrations for the other USDA UV-B broadband instruments.
- Provide the highest precision at the shortest wavelengths (most sensitive to changes in column ozone) for detecting possible long-term trends in UV-B irradiance.
- Validate synthetic spectra.

1.3 Quality Assurance and Calibration

A critical issue in the establishment of the monitoring program, and one that plagued previous efforts to monitor UV-B radiation, is the accurate and frequent characterization of the radiometric, spectral, and angular responses of the instruments. Because of the high quality radiation measurement programs conducted by the NOAA/ARL labs in Boulder, CO, this group was selected to construct a calibration facility under the direction of Dr. John DeLuisi and Patrick Disterhoft. This calibration facility is supported by the USDA (by subcontract to NOAA), and NOAA. To assure the highest possible quality, NIST is providing radiometric standards, technical guidance and oversight. NOAA operates the field site on Table Mountain, north of Boulder, CO. The Table Mountain site was the location for the North American Spectroradiometer Intercomparison held in June 2003.

In support of our QA/QC program, we have established a research site at CSU's Christman Field in Fort Collins. The site's proximity to the UVMRP office makes it ideal to replicate, diagnose, and solve sensor problems that occur at the network's other sites. In addition, this site permits us to evaluate new sensor technology for comparison with our existing instruments, and serves as a secondary outdoor calibration facility.

1.4 Data Management

The UV-B spectral data and ancillary measurements are stored in a data logger at each site. Current protocol for sampling frequency is every 20 seconds for the UV-MFRSR and 15 seconds for the vis-MFRSR. Data are stored as three minute averages, then downloaded nightly. A data management system has been designed to access, validate with extensive quality checks, and archive this information in a form which is readily retrieved and accessible to users with a variety of scientific and policy interests. This system employs a freeware relational data base management program (MYSQL). Calibrated erythemal UV-B broadband and calibrated total horizontal, diffuse and direct normal measurements at seven wavelengths in the UV and six in the Visible are available the next day as plots and data files from our Web site http://uvb.nrel.colostate.edu/UVB. Calibrated UV and visible irradiances are available using either the CUCF-determined lamp factors or the Sun-derived values of the Langley method.

Since many users do not require three minute data, the following information will soon be made available as standard data products on our web site:

- Hourly averages for each wavelength.
- Daily dose for each wavelength.
- Daily maximum for each wavelength.

The following products were added to our web site in 2006:

- Daily Langley plots and voltage intercept time series.
- Daily average column ozone.
- Synthetic spectra.
- Weighting of spectra with selected action spectra.
- Daily average total aerosol optical depths.
- History of deployment of each instrument plus its calibration factors

2. Progress Report

2.1 Significant events and accomplishments from 2006:

- Dr. Jim Slusser attended the EPA Star UV-B meeting in Boulder in November and presented a paper titled *A History of the USDA UV-B Network.*
- Dr. Barry Lefer from University of Houston visited with UV-B staff in November to discuss Houston's measurements. Dr. Lefer is PI with Dr. Slusser as co-PI of an EPA funded study of Houston's pollution aerosols and UV-B.

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- Dr. Xinli Wang spent the month of October in Champaign, Illinois working with researchers to build the infrastructure to incorporate a crop model into the regional climate model-Climate Extension Weather and Research Forecasting Model.
- Dr. Wei Gao was the leading editor for *Remote Sensing and Modeling of Ecosystems for Sustainability III* which was published by The International Society of Optical Engineering.
- Dr. Wei Gao was co-editor for a two-volume book *Earth Science Satellite Remote Sensing*, which was published by Tsinghua and Springer.
- Dr. Jim Slusser traveled to Stockholm, Sweden in September to Chair the SPIE Europe Conference: Remote Sensing of Clouds and Atmosphere. He presented a paper written by recent graduate student Tommy Taylor titled *Determining Ozone and Aerosol Optical Properties from UV-RSS.* He also presented *Ultraviolet Ground and Space-based Measurements, Models, and Effects Research* authored by Dr. Peter Kiedron, NOAA. Dr. Slusser also traveled to Hanover, Germany for a meeting with Dr. Gunther Seckmeyer, Institute for Meteorology and Climatology, University of Hanover, a world expert in calibration and analysis of UV-B data.
- Dr. Wei Gao, a SPIE symposia committee member of the International Society of Optical Engineering, chaired the international conference *Remote Sensing and Modeling of Ecosystems for Sustainability III* during the society's annual meeting in San Diego in August. Dr. Gao and his graduate students presented several papers.
- Graduate student Bill Smith is working with Dr. Wei Gao, Dr. Jim Slusser, Dr. Bill Parton, NREL, Dr. Heidi Steltzer, NREL, and Dr. Jack Morgan, USDA-ARS-Rangeland Resources, to study the effects of UV-B and microbial decomposition on aspen leaf litter.
- Dr. Alain Sarkissian, from the Centre National de la Rechirche Scientifique, Verrieres-Les-Buisson, France, visited for the month of August. Dr. Sarkissian is world renowned for his work in trace gas aerosol retrieval of planetary atmospheres. Dr. Sarkissian worked with Dr. Slusser and Roger Tree to test a new short focal length spectrometer that will have direct sun pointing capabilities. He performed thermal, optical and electronic tests to demonstrate the feasibility of using these spectrometers in the field.
- The 36th climatologic site in our network was installed early this month at the University of Houston, Texas. The equipment is owned by UH, as part of a suite of instruments being used by Dr. Barry Lefer for intensive in-situ monitoring and research of Houston's atmospheric pollution. The site is atop one of the 19-story tall residence halls, about midway between downtown Houston and the Port of Houston.
- Dr. Jim Slusser and Dr. Sonia Kreidenweis, Department of Atmospheric Science will be mentoring Ms. Chelsea Corr as she analyzes optical and chemical UV data for the air quality study in Houston, TX. This study will investigate the interactions between UV transmission through a polluted atmosphere and the pollution process itself.
- Andres Hernandez, graduate student of Dr. James Slusser/Michele Gruetter, in Mexico City, Mexico, was in the UV-B lab for most of July, evaluating the results of the NSF project, *Collaborative Research: Impact of aerosols on the photochemistry of Mexico City,* using the data set from the MIRAGE-Mex. Colorado State University provided the Ultraviolet Multifilter Rotating Shadowband Radiometer (UV-MFRSR) to measure the total and diffuse downwelling irradiance at several UV wavelengths to calculate aerosol optical depths during cloud-free conditions.

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- Dr. Wei Gao was nominated as an Editor-in-Chief of the Journal of Applied Remote Sensing. His term is for three years. He was also invited to be an advisory board member for the Center for Capacity Building in NCAR.
- Two of Dr. Gao's graduate students, Shuyan Liu and Qifeng Lu, received their Ph.D. degrees in May. Shuyan is working for Beijing Normal University as an assistant professor and Qifeng accepted a job at the China Meteorological Administration as a research scientist.
- Dr. Jim Slusser traveled to Mexico City during March to meet with Dr. Michel Grutter and Andres Hernandez to work on the infrastructure and equipment for a NSF Grant to study pollution in the Mexico City area. Colorado State University's field suite of spectrally-resolved UV radiation instrumentation was deployed for the NSF sponsored MIRAGE-Mex field campaign at three Mexico City "supersite" ground stations. This UV radiation package included instrumentation from Colorado State University and the new site at the University of Houston, who's site operator is Berry Lefer.
- Drs. Jim Slusser, Wei Gao and Xinli Wang attended a workshop on the molecular aspects of plant secondary metabolism in response to UV-B radiation in San Antonio, Texas, February 2-3. The workshop was sponsored by the USDA CSREES and the USDA UV-B Monitoring Program, NREL.
- Dr. Jim Slusser was selected to chair the 11th Conference on Remote Sensing of Clouds and the Atmosphere in Stockholm, Sweden, Sept 11-16. The conference focused on all aspects of remote sensing of clouds and the atmosphere in several planned specialist sessions.
- Dr. Wei Gao attended the SPIE Photonics West 2006 meeting in San Jose, California, Jan. 21-26. Dr. Gao presented papers describing ultraviolet ground- and space-based measurements, models and effects research. The meeting also gave Dr. Gao the opportunity to network with other researchers from around the world. SPIE is the largest international force for the exchange, collection, and dissemination of knowledge in optics, photonics and imaging.
- In conjunction with NASA/Goddard, we are investigating the effect of installing a quartz dome atop the diffuser. A few short-term tests have been conducted at our Christman Field site, and preliminary data show no significant difference with concurrent data from a collocated instrument that did not have a dome.
- Several short-term tests have been conducted at our Christman Field site to investigate the actual variability and stability of the electronic bias, or dark current, in our instruments. When instruments are available they are deployed with a dark cap for continuous monitoring of this bias signal. Preliminary results indicate the bias is stable throughout the day, being little affected by fluctuations in the ambient weather conditions.
- To address the issue of red light leakage we are now using absolute calibration files from the CUCF lab that have been adjusted for this red light leakage (Lantz et al., 2005). In addition, we are investigating future replacement of the Si photodiodes with GaP, or other newer technology, photodiodes. It should be noted that tests of the red light leakage done during our annual maintenance trips to each site showed practically no detectable change in the data, with the exception that a few channels on a few instruments showed less than 0.5% change.
- Based on data from the CUCF lab and NASA/Goddard which shows that the frequency of cleaning of the diffusers has a significant effect on the data, we have instituted a more rigorous routine cleaning regimen with the on-site operators.

• We have begun collaboration with Dr. Katherine Warphea and Dr. Lon Kaufman, University of Illinois at Chicago, to study the UV response i.e. UV photo receptor mechanism, in support of genetic research on agriculturally significant crops. The UV-B program has developed and supplied a specialized UV lamp that allows wavelength-specific irradiation of seedlings to test for genetic impacts.

2.2 Significant events and accomplishments from 2005:

- Re-calibration of all UV field instruments is done on an annual basis by the Central UV Calibration Facility (CUCF) maintained by the NOAA/ARL labs in Boulder, CO. Many repeat characterizations indicate good radiometric stability and allow statistical analysis of stability (Gao et al., 2001; Lantz et al., 2003; Janson and Slusser, 2004; 2005 Technical Report).
- Publication, Bjorn Jonson, of results from our participation in the Norwegian UV filter radiometer intercomparison, in May, 2005.
- Collaborative work continues at Purdue University, the University of Maryland, Utah State University, University of Illinois, Agricultural Research Service (Beltsville, MD), and Mississippi State University to study the response of various agricultural plants and trees to enhanced UV-B and other climate stressors.
- The Langley method of calibration has been successfully applied to UV-MFRSRs to provide an independent measurement in addition to CUCF lamp calibrations. At the NOAA Mauna Loa Observatory in Hawaii, we are able to provide Langley calibrations on all seven channels of the UV-MFRSR (Slusser et al., 2000). Agreement of Langley calibration factors to those from lamps range from perfect agreement to 5% difference, all within experimental uncertainties.
- QA/QC flags for all data back through 1997 have been added to the database, including Langley radiometric stability checks (Bigelow and Slusser, 2000; Janson and Slusser, 2005).
- There has been continued improvement in the accessibility of network data via the World Wide Web. There has been a significant increase in the number of “hits” and more importantly the number of users downloading data via ftp.
- Analysis of a time series of Langley voltage intercepts on three UV-MFRSRs in the field for two years have demonstrated the long-term stability of the instrument to an average of less than 5% per year for all channels (Janson and Slusser, 2004). Repeat spectral characterizations at CUCF have demonstrated the stability of UV-MFRSR filter functions to $\pm$ 0.02 nm.
- Work is underway to construct small spectrometers (Tree and Slusser, 2005b) to augment the UV-MFRSR’s at specific research sites.
- Patrick Disterhoft and CUCF continue the successful operation of the high resolution 1.0 m reference spectroradiometer at Table Mountain, CO (Harrison et al., 2003). Due to lack of resources we have shut down the other three spectroradiometers, located at Billings, OK; Fort Collins, CO; and Beltsville, MD.
- Wei Gao and Jim Slusser along with Drs. Bernhard of Biospherical and Herman of NASA TOMS co-chaired the “UV Measurements, Models and Effects V” sessions at the SPIE Meeting in San Diego, CA in August 2005.

- Jim Slusser co-chaired the SPIE Europe "Remote Sensing of Clouds and the Atmosphere X" sessions in Brugges, Belgium in September 2005.
- The UVMRP and GeoResources Institute of Mississippi State University co-chaired the Ecosystem Dynamics and Agricultural Remote Sensing sessions at the SPIE Meeting in San Diego in August 2005.
- The UVMRP edited "Advances in UV Measurements and Models II" Special Section for the *Journal of Optical Engineering.*

We continue to provide program management, research, and coordination of the various subcontracts for the USDA UVMRP. This includes maintenance and establishment of new UV-B monitoring sites, archiving and QA/QC of the data from one high resolution scanning spectroradiometer, continuing development and refinement of both the field measurement and the data management system of the climatological data, including maintenance and expansion of the data dissemination capabilities of the Web site, and developing an integrated impact assessment system that fully couples the Earth climate, ultraviolet-visible solar radiation and crop growth models, as well as assimilating satellite and *in situ* observations, to better understand and ultimately predict climate-crop interactions.

Research efforts continue to be directed toward reducing measurement uncertainties, establishing the quality of the data, and quantifying the factors controlling surface UV-B irradiance. We will continue to refine our UV-B irradiance data "products" for the user community, including aerosol optical depths at 332-, 368-, 415-, 500-, 610-, 665- and 860- nm, column ozone, synthetic spectra, Langley plots, and clear sky detection. In addition, we will continue to support carefully selected subcontracts which investigate the responses of plants and ecosystems to enhanced UV-B and other climate stressors (2005 Technical Report). Finally, we will continue outdoor solar irradiance comparisons through collocation with other federal (NOAA, NASA, NIST, NSF, DOE, and Smithsonian) and international agencies (in Canada, Norway, Germany, and New Zealand) that monitor ultraviolet radiation.

3. Research

3.1 Responses of Agricultural Crops to UV-B and Interacting Stressors: Experiments

Maintaining high agricultural yields is vital to our national economy and security interests. However, changes in the Earth's climate and more frequent extremes in temperature, precipitation, UV-B radiation, air pollution from human activity and forest fires threaten our agricultural productivity by causing stress on plants, livestock, and forests. To serve the needs of agriculture, the UVMRP provides data and technical guidance to the research community and will continue to support UV researchers from seven land-grant universities and one USDA-ARS Phytonutrients Laboratory. These researchers study the responses of agricultural plants, trees, and ecosystems to elevated UV-B radiation and other climate stress factors such as high temperature, nutrient deficit, and drought. Each researcher uses the USDA UVMRP data to establish the ambient level of UV-B radiation.

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In cooperation with Dr. K. Raja Reddy's research group at Mississippi State University we have conducted experiments in computer-controlled growth chambers to test the responses of cotton and corn to increased CO_2, drought, high temperature, and enhanced UV-B radiation. In the following year, we will continue experiments in the growth chambers on cowpea responses to enhanced UV-B levels along with other abiotic stressors. Furthermore, experiments will be conducted to determine cotton crop responses to increased UV-B and UV-A radiation either alone or in combination with other abiotic stressors projected to change in the future climate such as high temperature. This investigation is to study the UV-B effects when combined with UV-A radiation as it is in the real world. The plants will be grown from sowing to a respective growth stage under optimum water and nutrient conditions at different UV-B and UV-A combinations. The UV radiation treatments will be imposed soon after emergence. As growth reductions are not always correlated to the observed reductions at the whole plant-level, we plan to carry out the investigation at both leaf and canopy levels to gain a better understanding of the mechanisms involved in the effects of UV-A and UV-B radiation on cotton growth and development. This study will provide the dataset that can be ultimately used to improve process-level crop models to study the impacts of global environmental change including UV at different scales. Efforts will also be made to validate the model accuracy so that the modified model can be used for global environmental change including UV radiation at different spatial and temporal scales. Based on their known tolerance to specific abiotic stress, plants from several genotypes will be used in these experiments to address genetic components of plant responses to UV radiation and other stressors.

The research effort by Dr. Rich Grant's group at Purdue University will provide greater understanding of the impact of short term high UV-B exposures on soybean physiology and soybean rust spores. Towards this end, they will evaluate the physiological responses (carbon assimilation and transpiration rates and photosynthetic efficiency) during and after short term UV exposures under both greenhouse and field conditions. They will model the exposure of soybean rust spores in transit from source fields. Little is known about the sensitivity of Asian soybean rust to solar ultraviolet radiation but it is assumed that the spores are inactivated by some amount of solar radiation. Observations have shown that the UV-B exposure would have to be over at least two days to deactivate the spores. However, it is not clear if there is a photo-repair mechanism in the spores that would reduce DNA damage overnight. Consequently, the assessment of the sensitivity of spores to solar UV radiation will be carried out over two-day periods with relatively low irradiance. Experiments will also be carried out to determine the effects of short-term UV-B exposure and leaf wounding on gene expression and accumulation of secondary metabolic compounds in order to explore how the gene expression in Essex cv. (UV-B sensitive) and Williams 82 cv. (UV-B tolerant) when exposed to UV-B differ from that of leaf wounding. In addition, they will enhance the flexibility and adaptability of the UV Radiation Canopy model for impacts assessments.

Dr. Ronald Ryel, along with Mr. Steve Flint and Dr. Corey Burger, at Utah State University will study the optical properties and UV absorbing pigments in leaves to determine the responses to intensity and timing of irradiation. To continue the work with optical properties, UV-absorbing pigments, and UV-stimulated secondary compounds in aspen leaves in relation to UV-induced gene induction, experiments will be conducted to compare optical properties and pigments in plants grown under identical cultural conditions in Hawaii and Logan, Utah. Experiments are planned to determine early belowground development and epidermal transmittance in seedlings exposed to different UV levels and to explore the possible effects of different ultraviolet radiation balances on root nodulation in legumes and how this might alter the nitrogen balance in a mixed non-legume and legume community. These experiments will pioneer the research in these fields since very little is known about the effects of UV radiation on early belowground development in seedlings and root nodulation in legumes. The results will provide useful information essential to better understand the role of enhanced UV radiation in the nitrogen cycle. Finally, they will continue the work toward a synthesis of UV-exclusion data set in the literature and complete any remaining work on publishing materials from the previous contract periods.

Dr. Joseph Sullivan's group at the University of Maryland, together with Dr. Steven Britz's group at USDA Phytonutrients Laboratory, will evaluate the effects of short-term responses to enhanced UV-B radiation of 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 then linked with ambient UV-B, UV-A, PAR, and temperature in order to quantify the role of each in altering plant chemical composition. Agricultural crop species such as soybean and barley will be used in the experiments. Tree species and clover will also be integrated into the studies. Regression analysis will be exploited to partition the response among the various environmental parameters that are being monitored. By allowing plants to develop under a range of environmental conditions and assessing the plants at the same phonological state of development they will be able to separate phonological effects from environmental effects. By evaluating responses over a range of conditions they will be able to determine the importance of each environmental factor by building field dose response to each of these. Studies will be also conducted to determine the contributions of environmental conditions to the variability of nutrition allocation in different parts of the plants.

Dr. John Bassman's group at Washington State University will simultaneously examine the effects of enhanced UV-B radiation on secondary metabolites of various forage species and the concomitant nutritional responses of selected mammalian herbivores. They will investigate the effects of UV-B radiation on secondary chemistry and associated food quality in apple and grape. By exploiting genomic tools, they will study the influence of multiple interacting stress factors on plant response to UV-B radiation to examine (1) How multiple stresses acting in combination with UV-B radiation affect gene expression for enzymes in the phenylpropanoid pathway; (2) How stress-induced changes in gene expression are manifest at subsequently higher levels of biological integration; and (3) What genes are shared between different stressors and which are specific to individual stresses.

The research effort in cooperation with Dr. Xin-Zhong Liang's group at Illinois State Water Survey, University of Illinois at Urban-Champaign is to couple the state-of-the-art mesoscale regional Climate-Weather Research and Forecasting model (CWRF) with the most comprehensive crop growth models to study climate-crop interactions. We will eventually develop an advanced model infrastructure to quantify the impacts of key environmental stress factors, including temperature, moisture, nutrient, UV radiation, CO_2 concentration, aerosols and other air pollutants, on the quality and yields of agricultural crops. In the coming year, we will complete and improve the CWRF inline coupling with two major crop models (GOSSYM for cotton and DSSAT for corn and soybean) and conduct the coupled system verification study on climate-crop interactions. Long-term integrations will be performed to evaluate the system capability in reproducing the historical yields of cotton, corn, and soybean crops. The modeling results will be exploited to develop physical relationships of the final crop yields with the time evolutions of crop growing characteristics and climate conditions during the whole plant life cycle. These relationships will provide important guidance to developing effective applications of satellite and other measurements of vegetation variations for predicting crop yields. We will also improve the NCAR TUV module to better study UV radiative impacts on the crop life cycle and perform model validation against the direct measurements from the USDA/UVB monitoring program.

The research effort by Drs. Katherine M. Warpeha and Lon S. Kaufman is to both quantitate the effects of UV radiation on the development and productivity of soybean (Glycine max) and to determine the efficacy of phenylalanine supplements delivered by exogenous application, or through stable genetic transformation in order to prevent deleterious effects of chronic exposure to increased levels of UV radiation. In the following year, experiments will be conducted to (1) evaluate the changes in the growth habits, seed set and seed nutrition value in soybean varieties currently used by the major US soybean breeders as a result of exposure to low-dose UV radiation; (2) evaluate the ability of exogenously added phenylalanine in preventing the deleterious effects of exposure to UV radiation normally seen as changes in the growth habits, seed set and seed nutrition value in soybean varieties currently used by the major US soybean breeders; and (3) obtain stable transformants of soybean varieties currently used by the major U.S. soybean breeders, expressing various versions of the Prephenate dehydratase (PD) gene and thereby capable of synthesizing increased levels of phenylalanine, and evaluate the ability of these lines to protect themselves from the deleterious effect of increased UV radiation.

3.2 Development and Modification of Crop Models

We will also continue to develop an integrated crop impact assessment system that fully couples the Earth's climate, ultraviolet-visible solar radiation, and crop growth models as well as assimilate satellite and *in situ* observations to predict climate-crop interactions.

It is important to use the ground-based measurements of weather-related parameters in sophisticated computer models to create climate scenarios to simulate how plants stress and how the combinations of UV-B radiation, moisture, temperature, soil nutrients, and CO_2 affect agricultural crop yield and quality. We are coordinating the effort to modify the GOSSYM and DSSAT crop models. The cotton2k crop model will be recoded in accordance with the CWRF framework and be tested. The models will be also validated and calibrated offline using the NARR data and the USDA consensus yield data in the domain of United States. Then, the validated models and calibrated parameters will be coupled with the CWRF climate model to assess the effect of future environmental changes on crops. The coupled CWRF-GOSSYM/COTTON2K-DSSAT versus uncoupled (standalone) CWRF, GOSSYM/COTTON2K and DSSAT runs will be compared with observations to evaluate the contribution of climate-crop interactions to CWRF regional climate and GOSSYM/COTTON2K and DSSAT crop growth simulations. This coupled system can be used to mitigate harmful effects by selecting appropriate management practices, and provide crop yield projections under current weather and future projected climatic conditions. Future plans include integrating remote sensing information into both regional climate model and crop models.

The UVMRP has developed both one-dimensional and three-dimensional UV Radiation Transfer (UVRT) models, which calculates the amount of UV-B radiation passing through a canopy within or below an open vegetation canopy. These UVRT models will be incorporated to Tropospheric Ultraviolet and Visible (TUV) radiation model to establish a complete UV atmospheric/canopy application model system to study UV radiative impacts on the crop life cycle.

We will continue to develop and improve the Geo-Process model, which is based on ecosystem photosynthesis theory (GeoPro Model). The GeoPro model is a terrestrial ecosystem process model to simulate the photosynthesis, autotrophic respiration (RA), allocation of carbon, evaporation (E) and transpiration, water and energy balance of ecosystems by combining the ecological, biogeochemical, phonological, and hydrological processes. The model is developed from several existing models (Biome-BGC, BEPS, Century, and CLM). It includes the radiation transferring module, carbon module, water balance module, and photosynthesis-respiration module. The outputs of this model includes Net Primary Productivity (NPP), Evaportranspiration (ET), Gross Primary Productivity (GPP), Soil Carbon (SC) and Vegetation Carbon (VEGC).

4. Publications

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