

**Final Report for Grant NAG5-12920 (Drexel Project Number 230049)**

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This grant is an extension of Grant NAG5-8929 (Drexel Project Number 230026), resulting from extensions necessary to meet changing science objectives as described in the final report for NAG5-8929, a copy of which is attached.

The instrument configuration resulting from NAG5-8929 has remained basically intact. Cosine response measurements conducted by James Slusser's group at Fort Collins, Colorado, in support of the proposal for Aura ground validation mentioned in the final report for NAG5-8929, indicated that there was significant light leakage to the detector through the sides of the nylon housing. This was easily remedied by machining a removable opaque collar (made from the dark same grey rigid plastic plumbing tubing as the collimating tube) that fits around the detector collar.

Also during this grant period, data logging procedures were established for the UV-A instrument, to record irradiance before, during, and after an Aura overflight. This is required in order to compare spatial and temporal variability as required for ground validation of data products derived from the Ozone Monitoring Instrument (OMI). Standalone 12-bit loggers from Onset Computer Corporation (the U12 series), which were not available at the start of these projects, makes possible relatively inexpensive logging for these instruments at a usable resolution.

Up to 100 UV-A radiometers are available as a result of this grant. The final configuration and disposition of these instruments, including the final version of a GLOBE protocol for using the instruments, currently depend on action taken on the Aura ground validation proposal submitted in 2004. A copy of that proposal is attached.

## **Improving Aura/OMI UV Retrievals Through Spatially Dispersed Measurements Within OMI Footprints**

### **Abstract**

The need for spatially distributed measurements within OMI footprints, to support estimates of UV radiation at Earth's surface in the presence of aerosols and clouds, is well established and clearly stated as a high-priority Aura validation requirement. This project will use a combination of existing high-quality and inexpensive instruments, including those already developed for use by the NASA-sponsored GLOBE environmental science and education program.

Each of several project field sites will include a central reference site, where high-quality instrumentation is already in place. Initially, these sites include NASA/GSFC, the National Renewable Energy Laboratory in Golden, Colorado, and a USDA UV-B monitoring site in Seguin, Texas. Dispersed observing sites will be established at schools (and possibly other places) around the reference site, under the supervision of project personnel, other scientists, and university faculty.

Measurements at the dispersed sites include UV-A irradiance at 372 nm, total solar irradiance, aerosol optical thickness at 372, 505, and 625 nm, water vapor, cloud type and cover, and sky conditions. For the purpose of gaining an improved understanding of spatial variability within an OMI footprint, instruments do not require inherently high radiometric accuracy. An aggressive ongoing program of intercomparisons and calibration against instruments at the reference site will help to ensure data quality.

Much of the data required for the project will be collected by teachers and students. The project management and implementation model takes advantage of the GLOBE Program's highly developed training models and sophisticated online capabilities. Project investigators and collaborators bring considerable experience to bear on the challenges of developing successful scientist/teacher/student partnerships in which each partner assumes responsibility for part of the project implementation.

## **1. Project Description**

### *1.1 Introduction*

Global increases in UV-A and UV-B fluxes due to anthropogenic chlorine releases and, in some regions, decreases in average cloudiness form the basis for concern about UV fluxes at Earth's surface. An increased global understanding of UV fluxes is a goal of Aura's Ozone Monitoring Instrument (OMI). OMI UV products include spectral irradiance at 305, 310, 324, and 380 nm, and 290-400 nm erythemally weighted UV (for producing a UV human exposure index). The UV retrieval algorithms have their origins in the TOMS UV algorithms developed by NASA/GSFC and are based on use of a radiative transfer model whose input parameters will be derived from OMI measurements over a ground pixel that covers a relatively large area (13x24 km at nadir). Previous validation studies with ground-based UV spectrometers have demonstrated that the TOMS UV data successfully reproduce year-to-year fluctuation and long-term changes of UV radiation, although with +10%-20% summer time bias in many locations in North

America and Europe, and negative bias in the presence of snow. In addition, sub-pixel cloud variability results in ~20% noise in comparison with ground-based UV time series that are essentially point measurements. The summertime bias was attributed to aerosol absorption in the boundary layer, and wintertime bias to the inability to separate between cloud and snow reflectance using only TOMS radiances.

The modeling of ground-level UV radiation from space-based measurements in the absence of snow, clouds, and aerosols, and taking into account the effects of ozone, solar zenith angle, and altitude, is a well-understood problem [Krotkov *et al.*, 1998; Krotkov *et al.*, 2003; Nick, more citations here?]. Based on radiative transfer models, it has been estimated that the accuracy of modeled UV surface irradiance under clear skies can be as good as 6.5% at 380 nm [Kroon and Brinksma, 2004; Krotkov *et al.*, 2003]. However, real atmospheres nominally contain both clouds and aerosols and therefore constitute the default conditions under which OMI UV retrievals must operate. Surface UV irradiance  $E$  is related to clear-sky irradiance through a derived cloud/aerosol transmittance factor:

$$E_{\text{actual}} = E_{\text{clear}} C_T$$

Although several methods have been suggested for estimating  $C_T$  in the presence of clouds and aerosols [Ahmad, Bhartia, and Krotkov; 2004; Krotkov *et al.*, 2003; Krotkov *et al.*, 1998; Krotkov *et al.*, 2001; Nick, insert additional citations you think are important and add to References below], all are hampered by the fact that estimation of these effects “is based on a single observation of atmospheric conditions over a ground pixel that covers a relatively large area” Kroon and Brinksma [2004]. (The nadir-viewing OMI footprint is nominally 13x24 km.)

The problem of how to derive appropriate surface/atmosphere-dependent values for  $C_T$  is acknowledged specifically in the NRA, which asks for:

(A1) “Assessment of smaller-scale variability... that can remove the need for assumptions about the nature of the horizontal or vertical variability within an Aura observational footprint about the nature of the distribution of a parameter of interest... [including] heterogeneity within the observing scene.”

(A2) “Comparisons of Aura measurements with coincident... measurements [involving] comparison of Aura observations with comparable ones made from the ground...”

(B1) “Comprehensive coincident observation of parameters not measured by Aura.”

(C3) “Models that may be used to improve Aura retrievals, including those that are used for assimilation of radiances as part of retrieval efforts...”

Monitoring the spatial variability of UV irradiance at several locations within even a few OMI footprints is a prohibitively expensive undertaking with high-quality instruments, but can be accomplished in a cost-effective manner by using several identical inexpensive instruments together with a single reference instrument at each site. Such an instrument should have a response limited to the UV-A band in order to isolate

atmospheric effects due to clouds and, possibly, variable aerosols, from effects due to variable ozone absorption.

This approach to validating the Aura UV product has been outlined by Kroon and Brinksma [2004]: “To validate the surface UV irradiance, a combination of existing instrumentation around the globe and special campaigns should be made. In these campaigns, various UV instruments should be distributed within the OMI footprint, to address the effect of sub-pixel variability due to clouds, aerosols, and other local conditions.” Although no source is suggested for the many UV instruments required to accomplish this task, Kroon and Brinksma note that they can be “simple radiometers.”

### *1.2 research goal and questions*

The basic project goal is to validate and improve OMI UV products. With this goal in mind, the project addresses several research questions:

1. What is the nature of the spatial and temporal variability in UV and total solar irradiance within an OMI footprint?
2. How are spatial and temporal variability related? How well does the time average from a single instrument within an OMI footprint represent the spatial average UV value within that footprint?
3. To what extent can a single OMI measurement per day be used to calculate a daily UV dose within a footprint?
4. How well do OMI cloud correction algorithms represent surface UV under various cloud conditions?
5. What are the effects of aerosol absorption on surface UV?
6. What is the relationship between broadband solar irradiance and UV?

Questions 1-4, which are central to understanding the quality of transmittance factors generated by OMI algorithms, can be answered only by using networks of radiometers dispersed within an OMI footprint as proposed. The project addresses question 5 by collecting UV and visible sun photometer data as well as full-sky data at each site within a footprint. Question 6 is addressed through simultaneous UV-A and pyranometer measurements at each site.

### *1.3 Instrumentation and data collection*

To meet the research goal in a cost-effective way, the first project objective is to identify existing sites with high-quality instrumentation that will provide concurrent measurements of aerosols (optical thickness and single scattering albedo) to account for their effects on UV irradiance at Earth's surface. Instruments include YES shadowband radiometers, CIMEL sun photometers used by AERONET, the worldwide network developed and maintained by NASA/GSFC [Holben *et al.*, ??], broadband UV-A radiometers, and spectroradiometers. UV-A measurements are important because UV-A wavelengths lie above wavelengths where ozone absorption is important.

This set of aerosol and UV measurements will allow for UV radiation modeling closure, which is important for determining the causes of surface UV change, which is one of the science goals of the AURA/OMI mission. This improved understanding

contributes directly to the main AURA/OMI science goals considering the significant role of UV irradiance in photochemical processes.

There are several such sites, although some compromises in the locations of such instruments are inevitable. For example, relatively flat and homogenous terrain is favored for at least the initial phases of Aura validation. This implies an unobstructed view of the horizon for full-sky instruments – a constraint that may be better met at some sites than at others.

The critical second objective is to develop appropriate inexpensive instruments to provide the required spatial density of measurements, and a data collection mechanism that is both inexpensive and reliable. **The unique feature of this project is that it will use inexpensive instruments developed for GLOBE and related programs, including a UV-A radiometer developed specifically for EOS/Aura validation (the GLOBE/GSFC UV-A radiometer/sun photometer, GUARS).** These instruments, described in more detail in **Attachment A**, will be deployed around sites with appropriate reference instruments. Nominally, five radiometers will be assigned to each site. One will reside permanently next to the reference instrument, for ongoing performance comparisons. The remaining instruments will be dispersed over the footprint.

The measurements will be datalogged for a minimum of one hour before and after Aura overflights. At least some of the instruments can be used to collect data over a longer time interval. In addition to UV-A irradiance, additional measurements made during the overflights will include total solar irradiance logged at the same time as UV-A irradiance, aerosol optical thickness at 372, 505, and 625 nm, total precipitable water vapor, and basic meteorological parameters. Qualitative observations will be made of cloud amount and type, sky color, horizontal visibility, and any unusual atmospheric conditions. In some cases, sky photographs will be taken.

Data collection will be undertaken by a combination of scientist-collaborators (see **Personnel**, below), and teachers and students, using models for scientist/teacher/student partnerships developed by the GLOBE Program. Data collection protocols are described in **Attachment B**.

#### *1.4 Calibration issues*

Two related calibration issues will be addressed by the project: intercomparisons between CIMEL and shadowband radiometer data and calibrations of the GUARS and related instruments.

Recent work by Krotkov *et al.*, [?? provide reference] has demonstrated some persistent systematic discrepancies between optical thickness calculations at UV wavelenths based on data from these two instruments. The evidence suggests that these problems lie with the shadowband radiometer rather than the CIMEL. Long-term data sets from sites where both instruments are in operation, including sites used for this project, will be studied in order to better understand the discrepancies.

Although a calibration plan has been part of the development process for each GLOBE instrument, this project imposes ongoing and more stringent requirements. Calibration activities will include:

ongoing UV-A irradiance calibrations at the National Renewable Energy Laboratory, Golden, Colorado.