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Technical Progress Report

Development of Rotating Shadowband Spectral Radiometers and GCM Radiation Code Test Data Sets in Support of ARM

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Co-Principal Investigators:
Joseph Michalsky and Lee Harrison
Atmospheric Sciences Research Center
University at Albany
State University of New York

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EXECUTIVE SUMMARY

Two tasks are included in the second year of this project. One task continues the collection of high quality data sets for the testing of radiation codes within climate models. The other task involves the development of accurate spectral instruments for the measurement of shortwave radiation. A third task was completed in the second half of the first year of the project and will be briefly summarized.

Completed Task

Existing direct and diffuse shortwave radiation data from Albany, New York, and Golden, Colorado, were merged with National Weather Service hourly meteorological data and 12-hourly upper air radiosonde data from nearby weather stations. These merged files established a preliminary radiation and meteorology data base for the testing of climate model radiation codes. Four seasonally representative months of data were assembled for Albany and one winter and one summer month's data were assembled for Golden. This data base is available to interested modelers.

Data Collection Task

Since it was expected that existing radiation data sets may not be as comprehensive as modelers would like, a second task was begun in the first year to add measurements that more fully describe the radiation environment. Quality control procedures have been developed and applied to the collected data set. Two related programs are using the ARM data set and adding to it thus expanding the data base and making it more useful to all. Again, the data are available upon request.

Instrument Development Task

This task includes the development of two spectral versions of the rotating shadowband radiometer and the careful calibration of each for state of the art accuracy in spectral solar radiation measurements. The multifilter rotating shadowband radiometer was deployed this past fall in a related program and the second version, which incorporates improvements based on our experience in that program, will be completed this spring. This new version will be deployed at the Southern Great Plains Cloud and Radiation Testbed central, auxiliary, and extended sites. The principal mechanical and electronic components of the prototype diode array rotating shadowband spectroradiometer have been built and tested. System integration and software development are beginning. This task is on or slightly ahead of schedule.

DATA COLLECTION TASK

Progress to Date

A modeling team at the Atmospheric Sciences Research Center (ASRC), led by Wei-Chyung Wang, has used pre-ARM radiation and meteorological data that we have merged into a radiation code test data set. They found it useful as a first step, but, as we anticipated, they wanted more data to better describe the radiation environment. Thus, the data collection task was begun to fulfill this need of modelers. During July 1991, following the improvement of the ASRC rooftop electrical wiring and signal cabling, a more comprehensive data collection activity began.

Table I contains the measurements available from the ASRC site that are part of the ARM activity. It also contains measurements that are made as part of other programs that are part of the data collection, quality control, and archiving path, and share in its costs.

The QL in the table refers to the Quantitative Links program in the Environmental Sciences Division of the Office of Health and Environmental Science within the Department of Energy (DOE). IDMP refers to the International Daylighting Measurements Program of the International Illumination Commission. Both programs make use of the ARM data and vice versa. For example, IDMP is collecting visible wavelength data, but most radiation data collected is total shortwave. Algorithms will be developed from these data to convert between total shortwave and visible in order to expand the daylight data base. The QL program measures direct normal radiation at particular wavelengths. This allow us to better characterize the aerosol and clouds for ARM research.

Data collection began in July 1991. Instead of five minute data, as we had specified in last year's report, we are acquiring data every minute. This higher data collection rate should provide a clearer understanding of radiation variability, for example, when trying to understand satellite data. The IDMP and ARM data are collected together at one minute intervals and share a common quality control procedure. The QL data are collected every five minutes according to the protocol of that program.

The calibration of shortwave radiation sensors is based on the Eppley calibration of the normal incidence pyrheliometer (NIP) that is used for direct normal irradiance. The NIP is calibrated at Eppley against an absolute cavity radiometer (ACR), which in turn participates in the World Meteorological Organization (WMO) intercalibrations at Davos, Switzerland, that set the world standard. Calibration is transferred to the global irradiance sensors using the shade-unshade technique, where the global sensor is shaded and unshaded and the difference is equated to the NIP reading multiplied by the cosine of the solar-zenith angle. Once this global sensor is calibrated, it is used to transfer calibrations to other irradiance sensors through side-by-side comparisons.

We have purchased an ACR from Eppley, which will be used to eliminate some of the calibration steps because these additional steps increase error. The NIP will be calibrated by direct comparison with the ACR, and the global horizontal irradiance sensors will be calibrated by the shade-unshade method using the ACR. We will participate with our ACR in the next WMO-sanctioned intercomparison of the world's standard instruments.

TABLE I: ARM & RELATED PROGRAM MEASUREMENTS AT ASRC

Measurement	Instruments	Program
global horizontal irradiance	PSP, CM 11, $NIP \cdot \cos(ZA) + PSP \text{ diffuse(disk)}$, MFRSR, RSR(LI200)	ARM, QL
diffuse horizontal irradiance	PSP+shadowband, PSP+disk, MFRSR, RSR(LI200)	ARM, QL
direct normal irradiance	NIP, MFRSR, RSR(LI200)	ARM, QL
global horizontal illuminance	LI210, RSR(LI210), LMT	IDMP, ASRC
diffuse horizontal illuminance	LI210+shadowband, RSR(LI210)	IDMP, ASRC
direct normal illuminance	LI210+tube, RSR(LI210)	IDMP, ASRC
albedo	PSP, LI200	ARM, QL
infrared	PIR(2)	ARM, QL
global@415,500,610,665, 862,940nm	MFRSR	QL
diffuse@415,500,610,665, 862,940nm	MFRSR	QL
direct@415,500,610,665, 862,940nm	MFRSR	QL
N,S,E,W illuminance	LI210	IDMP
zenith luminance	LI210+tube, UDT+tube	IDMP
ambient temperature	Vaisala	IDMP
relative humidity	Vaisala	IDMP
precipitation	Sierra-Misco	QL

Another critical measurement to radiation code modelers is the downwelling infrared. We took part in a meeting of experts last May and have discussed calibration with many researchers in this field. We are following their advice as closely as possible in collecting and correcting our data set. The results of an intercomparison of infrared instruments last November and December at Coffeyville, Kansas, will further guide our data acquisition and correction.

Expected Progress in the Next Year

The calibration will be improved through the process described. Data sets will be provided to modelers as requested.

INSTRUMENT DEVELOPMENT TASK

Multifilter Rotating Shadowband Radiometer

One instrument development task is near completion. The first version of the multifilter rotating shadowband radiometer (MFRSR) was deployed this past fall in the DOE Quantitative Links program. Nine MFRSRs are operating in the northeastern and midwestern U.S. This has given us several months experience with the device in a field setting. Based on these results we have improved the design for the first CART site instruments.

The multifilter instrument has been selected by DOE for the Southern Great Plains Clouds and Radiation Testbed site near Lamont, Oklahoma. It will be deployed at the central site and at auxiliary and extended sites in Oklahoma and Kansas. The experience in the Quantitative Links program has led to an improvement in the cosine response, the temperature control of the filter and amplifier cavity, enclosure layout, and modem selection. The data acquisition and control unit that operates the shadowband will also acquire data from other sensors at each of the CART sites.

The MFRSR contains seven detectors; one is unfiltered and the others have interference filters above them that define 10 nm-wide spectral intervals. Calibration of the unfiltered detector for the measurement of shortwave is via side-by-side comparison with a calibrated secondary standard. The filtered detectors are calibrated using a LICOR 1800-02 Optical Radiation Calibrator. Five of the six filtered detectors' calibrations may be checked by using the Langley technique to derive top-of-the-atmosphere values for the detectors and then equating to the solar spectral irradiance (adjusted for solar distance) at these wavelengths.

A paper on the MFRSR was presented last August at the 1991 Solar World Congress in Denver, Colorado. A more detailed paper describing the instrument is being prepared for a refereed journal. The instrument is receiving widespread attention and several other research groups have asked for replicas of the instrument for their programs. These requests are being handled by Pacific Northwest Laboratory who is constructing the units with our direction.

Diode-Array Rotating Shadowband Spectroradiometer

Excellent progress was made toward development of a 256-channel CCD (charge-couple device) diode array rotating shadowband spectroradiometer (RSS) this past year. A crucial phase is the coupling of the diode array and the analog-to-digital converter (ADC). A printed circuit board was designed and built to control the timing signals needed to start the integration, stop the integration, begin the diode array read-and-convert sequence for all 256 channels and ready the array for the next measurement.

The ADC, after some effort, is showing 15-bit accuracy for single samples and 16-bit accuracy within one standard deviation if sampled four times. Therefore, we have the 16-bit accuracy that was our goal, allowing us the large dynamic range needed for solar spectroscopy with the current spectrometer design.

The next step is to acquire the spectrometer from the Pacific Northwest Laboratory where it was designed (by Harrison) and begin the hardware integration. The software interface was begun in the testing phase of the CCD array and ADC integration and will continue with the hardware integration. We expect to measure solar radiation in a tended mode of operation this summer.

Cosine Response Test Bench

The cosine bench was completed last summer. It is designed to automatically rotate irradiance sensors within a stable light source to measure how well the sensor's response matches that of a true Lambertian receiver. A true Lambertian receiver's response decreases exactly as the cosine of the angle of incidence. The rotating table is controlled by the same data acquisition system used in the rotating shadowband instruments. Samples may be made as often as every 0.25 degrees, however, samples are usually taken every degree from -90 to +90 degrees and back to -90 degrees and this sequence is repeated four times. Since a measurement at each position consists of 16 samples, a total of 22,912 samples are taken to characterize a sensor in one plane. The sensor is rotated 90 degrees to characterize the response in a second plane in order to understand the azimuthal response.

A paper has been accepted for the 1992 American Solar Energy Society meeting in Cocoa Beach, Florida. The paper will describe cosine responses for several of the standard instruments used by solar radiation researchers. A more detailed paper is being prepared that describes these same instruments and compares them with the cosine response of our MFRSR. This will be submitted to a refereed journal this summer.

Many researchers have shown an interest in our cosine bench. We have tested sensors for the National Renewable Energy Laboratory, for the University of Geneva, and we will be responsible for the cosine test of the MFRSRs deployed at the CART sites. We will test other irradiance sensors for the ARM program as requested.

Expected Progress in the Next Year

We will fully integrate the mechanical, optical, and electronic hardware of the RSS into a prototype system. After several months of testing at the ASRC, we will choose a final design for the three instruments we have agreed to build for ARM. The final year will be devoted to developing an absolute spectral calibration system for the careful characterization and calibration of both the MFRSR and the RSS. Our goal is state of the art accuracy approaching 1% for both instruments.

OTHER ARM RELATED EFFORTS

In addition to our own program tasks we have been actively involved in other ARM and DOE activities. We have participated on several review panels for DOE, including participation in the ARM Readiness Review held May 1991 at PNL. We are represented on the science team executive committee. We have contributed to the efforts of NREL to develop a calibration laboratory for ARM. We participated in the science team site visit to the Southern Great Plains central facility to advise on instrument deployment. We have worked with the Oak Ridge National Laboratory group on the development of a scanning radiometer and development of code for the interpretation of the data from that instrument and our rotating shadowband instruments.

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