Development of Rotating Shadowband Spectral Radiometers and General Circulation Model Radiation Code Test Data Sets in Support of the Atmospheric Radiation Measurement Program

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Introduction

This program focuses on the development of spectral versions of the rotating shadowband radiometer (RSR). The RSR is a tool for the simultaneous measurement of total horizontal, diffuse horizontal, and direct normal irradiance. The Atmospheric Radiation Measurement (ARM) Program supports the development of a seven-channel RSR consisting of individual filtered detectors that may be selected (at time of manufacture) in the 350- to 1700-nm range with bandwidths of either 10 or 20 nm, depending on wavelength. Another spectral variant of the RSR is a spectrometer version that contains a 256-channel diode array. This instrument is designed to yield 0.6-nm resolution at 350 nm and 8-nm resolution at 1050 nm.

Besides instrument development and calibration activities, we are collecting a data set at our Albany facility. This data set consists of high quality shortwave and longwave radiation measurements and meteorological variables from the Albany County airport, including upper air observations. The data are for use in testing radiation codes used in global climate models and are provided to those requesting them for their model tests.

In this paper, we discuss the main points of five papers that have been submitted to journals or are conference proceedings within the last year. These include papers describing 1) the seven-channel multifilter rotating shadowband radiometer (MFRSR) (Harrison et al., in press); 2) an objective algorithm for obtaining optical depths without the necessity of human intervention (Harrison and Michalsky 1993); 3) the cosine bench for measuring the cosine response functions of the RSRs and other radiometers (Michalsky et al. 1992); 4) rotating shadowband spectroradiometer progress (Harrison et al., in press); and 5) the effects of Mount Pinatubo on the aerosol above the Oklahoma-Kansas Cloud and Radiation Testbed (CART) site (Michalsky and Larson 1993).

Multi-Filter Rotating Shadowband Radiometer

The MFRSR (see Figure 1) is a ground-based instrument for simultaneously measuring total horizontal, diffuse horizontal, and direct normal irradiance in seven wavelength passbands. At each wavelength, each of the three components of solar shortwave irradiance is measured with the same filter-detector using the shadowband technique.

In this technique, total horizontal and diffuse horizontal irradiance are measured by a pyranometer sensor (one collecting radiation over 2π steradians with a Lambertian response) that is alternately shielded and unshielded from direct solar beam radiation by a metal band. From these two measurements, direct normal radiation is calculated. The band is controlled and the data are acquired and stored by our own data acquisition system. Data are retrieved through either a direct serial connection or a telephone modem.

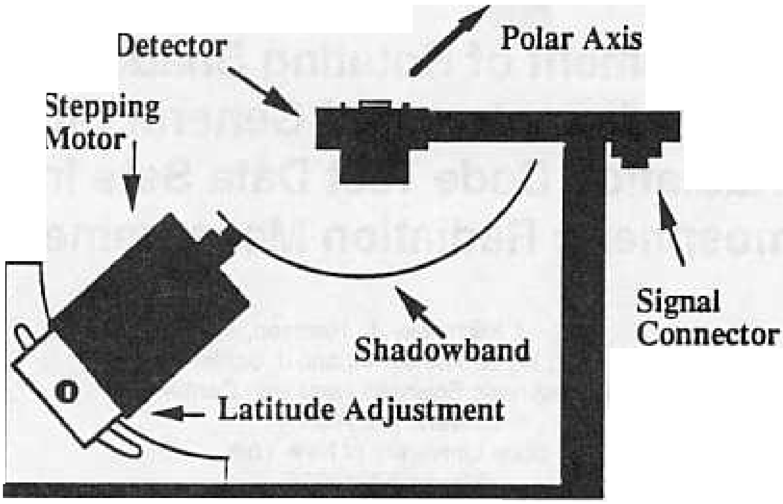

Figure 1. Multi-filter rotating shadowband radiometer.

The key points of Harrison et al. (in press) are

- All three components at each wavelength have the same calibration, thus reducing the errors associated with intercomparing results from independent instruments.
- Direct normal measurements can be used for Langley analysis, which produces a determination of the solar constant and, therefore, calibration of all three components. This can be used to track detector stability and provide a comparison to the calibration using the standard light.
- The instrument achieves an accuracy of the direct normal component comparable to a tracking instrument and an accuracy of the total and diffuse components that exceeds commercial pyranometers. These higher levels of accuracy are the result of the improvement in cosine response and because the measured direct component can be corrected for the remaining error in cosine response. Figure 2 illustrates the comparability of the direct. In this figure, the optical depths obtained simultaneously by a tracking MFRSR detector and an MFRSR operated normally are compared. Optical depth is very sensitive to tracking errors, and the results are generally indistinguishable with errors comparable to that obtained when comparing two tracking devices.

Objective Algorithm for Optical Depth Retrieval

The MFRSR instrument is expected to be deployed in large numbers. Each instrument is capable of producing seven direct irradiance plots each day. Each clear morning or afternoon may be subjected to Langley analysis for optical depth and extraterrestrial irradiance calculations. If all 27 MFRSRs are deployed at each CART site, human analysis of the data will be impossible or, at best, costly. Furthermore, Langley analysis is somewhat subjective in that the handling of marginal data may be inconsistent. The objective algorithm developed by Lee Harrison sequentially removes data outside the 2-6 air mass range, data during cloud passages, and data whose residuals are beyond 1.5 standard deviations of a least squares fit to the points that remain. Furthermore, if fewer than one third of the points in the 2-6 air mass range remain or if the standard deviation of the remaining points exceeds a limit, the analysis is terminated.

The key points of Harrison and Michalsky (1993) are

- Such an algorithm is needed to reduce large amounts of data objectively. The algorithm works not only for MFRSRs, but for any tracking sunradiometer.

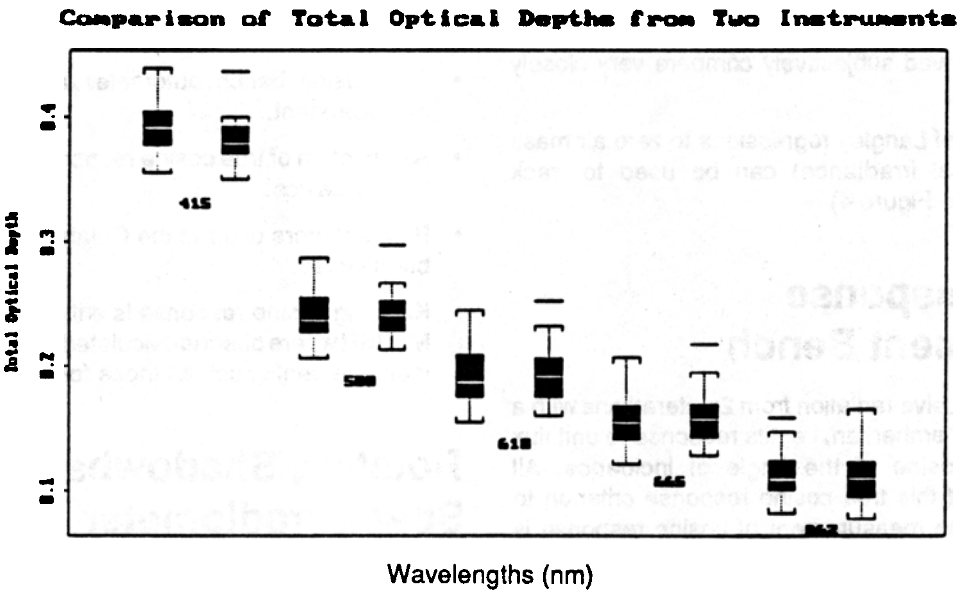

Figure 2. MFRSR and tracking MFRSR detector head optical depth comparison.

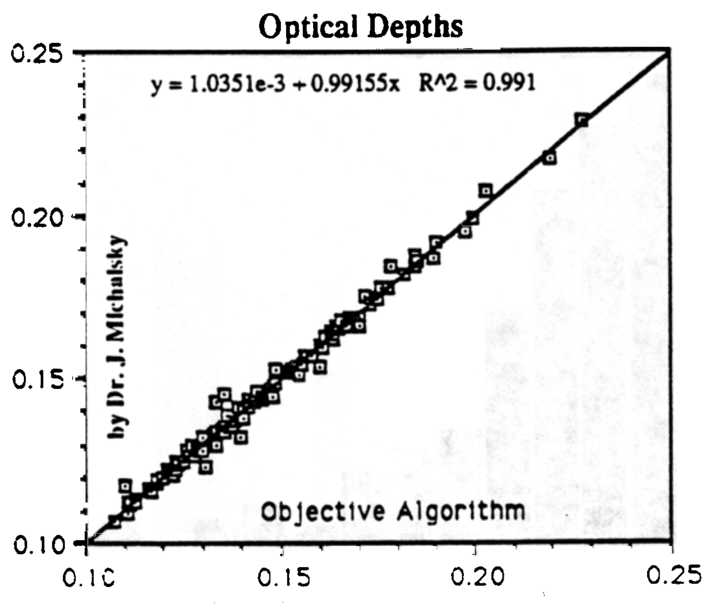

Figure 3. Scatter plot of optical depths determined by the objective algorithm versus subjective analysis.

- Comparisons of optical depths retrieved by this algorithm and those derived subjectively compare very closely (see Figure 3).
- Extrapolation of Langley regressions to zero air mass (extraterrestrial irradiance) can be used to track calibration (see Figure 4).

Cosine Response Measurement Bench

Pyranometers receive radiation from 2π steradians with a response that is Lambertian, i.e., its response to unit flux varies as the cosine of the angle of incidence. All pyranometers fail this true cosine response criterion to some degree. The measurement of cosine response is normally difficult and time-consuming and is performed only at a few angles. A bench to test standard radiometers and the MFRSRs has been constructed to automate these tests. Responses of three Eppley PSP pyranometers used in the CART facilities appear in Figure 5.

The key points of Michalsky et al. (1992) are

- The cosine bench automates an otherwise difficult measurement.
- Assumption of true cosine response is never quite true for any device.
- Pyranometers used at the Oklahoma CART site have been tested.
- Knowing cosine response is critical, especially for the MFRSR where direct is calculated and for high accuracy measurements such as those for ARM.

Rotating Shadowband Spectroradiometer

A second spectral version of the RSR is the 256-channel spectrometer version that we call the rotating shadowband spectroradiometer (RSS). The receiver optics of this version of the instrument are shown schematically in Figure 6.

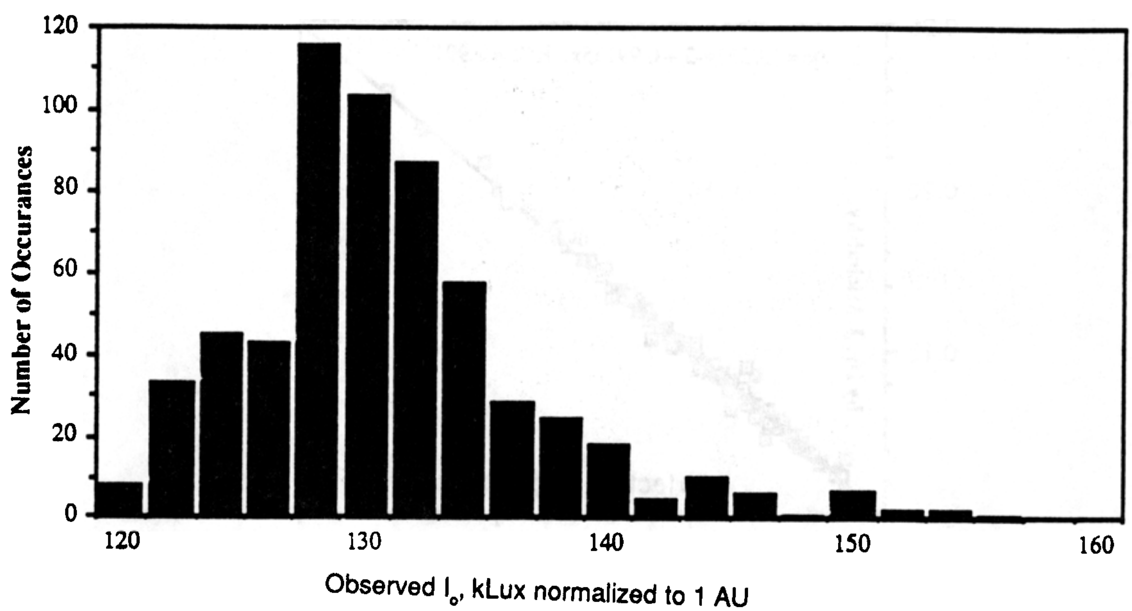

Figure 4. Histogram of I_o's determined by Langley regression for a rotating shadowband photometer.

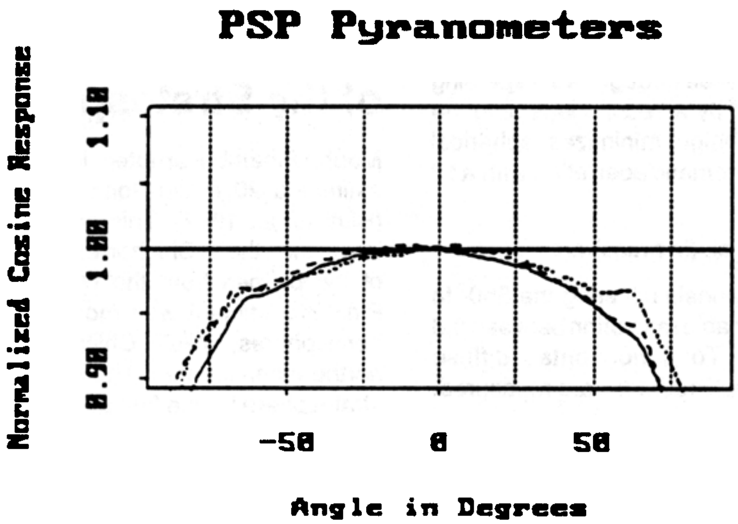

Figure 5. Cosine responses of three different Eppley PSPs.

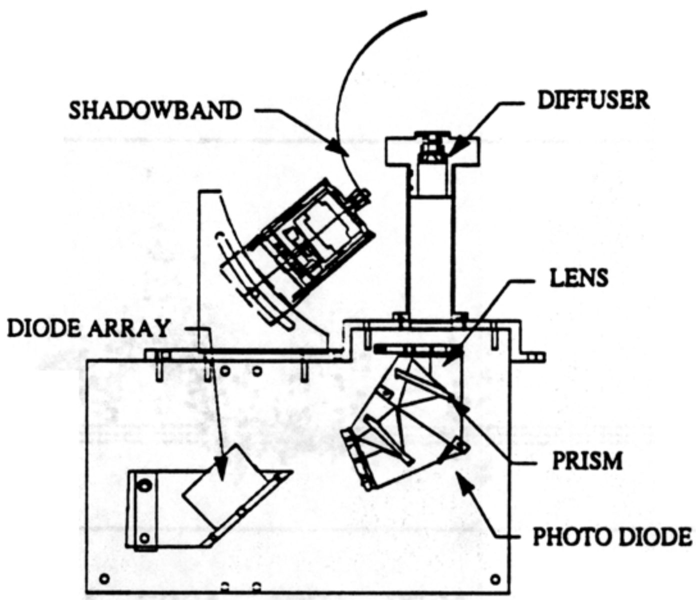

Figure 6. Rotating shadowband spectroradiometer.

Solar radiation is incident on the Lambertian receiver modeled after the MFRSR receiver. The exit port of this diffuser-integrating cavity is a slit. The light from the slit is collimated by the first lens, passes through two dispersing quartz prisms, and is focused by a second lens onto the diode array. The system design minimizes spherical aberration and corrects for chromatic aberration with a tilt of the detector.

The key points of Harrison et al. (in press) are

- The prototype has 256 channels covering the 350- to 1050-nm spectrum with variable resolution between 0.6 and 8 nm, respectively. Total horizontal, diffuse horizontal, and direct normal irradiance are measured.
- CAD drawings exist for the hardware and electronics.
- All subsystems are performing as expected.
- Much software and hardware integration is needed.
- Substantial effort is needed to achieve 1% accurate calibrations, which are now at 5% to 10%.

Mount Pinatubo Aerosol Perturbation of the Stratosphere

Mount Pinatubo erupted in June 1991, introducing an estimated 20 million tons of SO_2 into the stratosphere (Bluth et al. 1992). This amount was about three times larger than the El Chichon eruption of 1982. The dispersion of the plumes from the two volcanoes differed: Mount Pinatubo effluent was more evenly dispersed between hemispheres, while El Chichon was confined mostly to the northern hemisphere. The Pinatubo aerosol will affect the stratosphere for the first two or three years of operation of the first CART site. Since stratospheric aerosol can be rather uniformly distributed in latitude zones, we may use other measurements in the mid-northern latitudes to estimate the effect over Kansas and Oklahoma. Figure 7 is a plot of stratospheric aerosol above Boulder, Colorado, resulting from the Mount Pinatubo eruption.

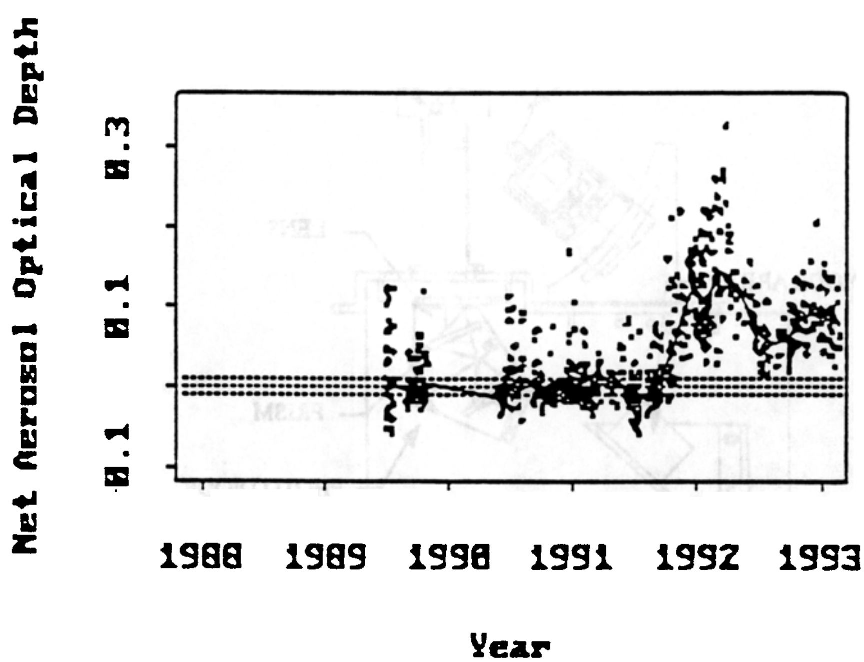

Figure 7. Mount Pinatubo aerosol optical depth as a function of time for Boulder, Colorado, at 555 nm.

The key points of Bluth et al. (1992) and Michalsky and Larson (1993) are

- The stratospheric and tropospheric aerosol contributions may be separated in a ground-based measurement.
- Mount Pinatubo produced about 50% greater optical depth at mid-northern latitudes than El Chichon.
- Spectral data obtained with the MFRSR will allow us to determine some size information through mathematical inversion methods.
- The stratospheric data from other sites will allow us specify the monthly average tropospheric aerosol contribution until Mount Pinatubo aerosol decreases to background levels.

References

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