Final Report

Spectral and Broadband Shortwave Radiometry and Analysis
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Abstract. This report includes results for the entire period of this award 9 September 2003 through 14 February 2005. Two contributions were in broadband shortwave irradiance measurements. One included conducting the second diffuse horizontal broadband shortwave irradiance IOP to establish a working standard for diffuse horizontal shortwave irradiance, where none exists. The results are summarized in a paper published in the Journal of Geophysical Research – Atmospheres. Another broadband shortwave effort was in the comparison of clear-sky measurements of broadband diffuse and direct irradiance during the May 2003 Aerosol IOP with six radiative transfer models of direct and diffuse irradiance using aerosol and other data inputs carefully measured during the Aerosol IOP. A paper with the results has been submitted to the Journal of Geophysical Research – Atmospheres; it is in review. A third area of research was in spectral radiative transfer model comparisons made using three models and measurements made with the visible rotating shadowband spectroradiometer (RSS) during the first diffuse irradiance IOP in 2001. Besides these contributions that have resulted in papers and/or presentations, the principal investigator (PI) consulted with science team and infrastructure representatives to improve aerosol optical depth measurements and to produce a spectral surface albedo product.

Diffuse horizontal shortwave irradiance

Fifteen pyranometers representing most, active manufacturers of thermopile pyranometers participated in the second diffuse horizontal shortwave irradiance IOP held in October 2003 at the SGP ACRF's central site. This IOP differed from the first in several ways. During this IOP all pyranometers received a simultaneous shade-unshade calibration, which is the best way to calibrate pyranometers for total horizontal irradiance. All instruments were offset corrected, and the offset correction procedure was tested using daytime capping experiments. Shade receiver geometry differences that contribute to irradiance differences still exist, but receiver sizes had a smaller range presenting a smaller problem than in the first IOP.

Eight of the fifteen pyranometers agreed to within 2% for both clear and cloudy conditions. Four of the pyranometers either could not be offset corrected, were excessively noisy, or just did not track the other pyranometers. Three pyranometers agreed with the eight during cloudy periods, but read uniformly high during clear conditions. Attempts to explain this clear-sky behavior of these three included corrections for cosine response, corrections for the differing detector sizes, and corrections for spectral sensitivities. While the corrections were for the generic behavior of the different sensor types it was not specific to the pyranometers in the comparison because that information was not available. The generic corrections improved the agreement by about 1.2 W/m² out of the 3 to 5 W/m² disagreements that the three pyranometers had with the mean values of the eight.

These results are summarized in Michalsky et al. (J. Geophys. Res. Atmospheres, 110, D06107, doi:10.1029/2004JD005265, 2005). Figure 12 in that paper is reproduced here.

This demonstrates how well instruments could agree if instead of using the shade-unshade calibration for pyranometers used to measure diffuse irradiance, a diffuse irradiance standard were adopted. A third diffuse IOP is being considered using a restricted set of the instruments from this second IOP that will be carefully characterized for cosine and spectral response. This will establish the ARM working standard.

Clear-sky closure studies

In May 2003 ARM conducted a comprehensive aerosol IOP at the SGP ACRF. One of the main goals was to achieve closure between clear-sky models and measurements of broadband shortwave diffuse and direct irradiance. There has been considerable effort put forth in the last decade to try to explain why, in particular, direct beam models and measurements agree, but diffuse models are generally higher than measurements by about 10%.

For our closure study we chose 30 clear-sky cases that were screened using three criteria; irradiance plots of direct and diffuse shortwave irradiance, diffuse irradiance at 870 nm from MFRSR measurements that is particularly sensitive to any cloud in the sky, and total sky imager (TSI) images at the times in question. Cases were chosen to represent a range of solar zenith angles, a range of water vapor loading, and aerosol loading that varied from the cleanest that we experience in May to around 0.5 optical depths at 500 nm, or rather turbid conditions.

Six models were chosen for the calculations. The emphasis was on using fairly accessible models with modest to low spectral resolution. The six models chosen were RAPRAD, MODTRAN, SBDART, SBMOD, RRTM-SW, and SMARTS. These models are described in DOE report

DOE/ER/63703-2. The results are summarized in the bar chart above. The average bias errors from measured direct and diffuse irradiance for all 30 cases are denoted by solid green and solid blue bars, respectively. Hence, their appearance above and below zero. These are to be compared to the average direct and diffuse irradiances of 761.5 and 108.6 W/m², respectively. Biases are well below 1% for direct and below 2% for the smaller diffuse irradiance. Further, the biases are in both positive and negative directions. The root-mean-square uncertainties are naturally somewhat large, but remain well below the combined uncertainties in the models and measurements.

The bottom line is that closure seems to have been achieved. The reasons appear to be well-measured inputs to the models and careful irradiance measurements. The earlier studies often assumed what are considered reasonable estimates for inputs without decisive measurements. In particular, a smaller than generally estimated asymmetry parameter and a better determination of spectral surface albedo led to smaller diffuse modeled values than typically would have been determined using estimated values of asymmetry parameter and albedo.

Spectral clear-sky closure studies

During the first broadband shortwave diffuse irradiance IOP in September and October of 2001 a rotating shadowband spectroradiometer (RSS) was deployed for testing purposes. Using three models we compared RSS measurements for the inputs available to us as a first step toward beginning the process of validating models spectrally rather than just in broadband. There is always a concern that in broadband the agreement could result from error cancellation in different portions of the spectral range.

The three models used for the calculations were SBDART, SMARTS, and MODTRAN. The inputs were measured aerosol optical depth, water vapor, and ozone column. Spectral surface albedo was parameterized from the MFRSRs looking up and MFRs looking down. Single scattering albedo and asymmetry parameters were assumed based on climatology for the ARM site, i.e., they were not measured on the specific day.

The figures on the next page demonstrate the agreement/disagreement among the three models and the RSS measurements for the direct (top figure) and the diffuse (bottom figure) for 6 October 2001. The lower plots in the top and bottom figures are differences of models from the measurements. Clearly there are differences in the absorption bands. Some of this may be caused by the wavelength registration of the measurements. In the direct there appear to be portions of the spectrum where models are low and portions where they are high suggesting that in broadband calculations these difference may cancel leading to agreement of broadband models and measurements. In the diffuse the models appear to be high at all wavelengths as is seen in broadband results. These are just the first rudimentary looks at the spectral issues and ultimately ARM intends to implement a QME to perform these comparisons on a continuous basis.

Other contributions

The PI has also contributed to improvements in aerosol optical depth retrievals by developing a cloud-screening algorithm. A parameterized spectral surface albedo product has been developed using downward facing MFR and upward facing MFRSR measurements. These were specifically produced for the 2003 Aerosol IOP data set.

Direct on Day 279 Case No. 1

Diffuse on Day 279 Case No. 1