Sun and Sky Radiometric Measurements at the CART ARM SGP Site

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Abstract

Cimel sunphotometers/radiometers (CSPHOT) are facility instruments at the three Atmospheric Radiation Measurement (ARM) sites at the Southern Great Plains (SGP) in Oklahoma, Tropical Western Pacific (TWP) in Nauru, and North Slope in Alaska (NSA). Here inferred aerosol optical thickness (AOT) and precipitable water (PW) measurements at the SGP site are compared with measurements using other instruments. Aerosol size distribution derived from direct solar measurements and from the aureole sky brightness measurements are also compared. Results show that the quality of the measurements is high, suitable for modeling of other radiation quantities.

Introduction

A sun/sky scanning radiometer CSPHOT has been operating as a facility instrument at the ARM SGP site since April 1998 (and before that, during intensive operational periods [IOPs]). Since spring/summer of 1999 the instruments have been providing data from the other two ARM sites at the TWP and NSA as well. CSPHOT is also part of AERONET (Holben et al. 1998), a worldwide network of sunphotometers maintained by the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC). Thus, ARM measurements of atmospheric optical properties can be related to those measured elsewhere, thereby providing a global data set for extending applicability of algorithms that are evaluated using measurements at the SGP site.

From direct solar measurements, CSPHOT provides measurement of the atmospheric transmittance to yield apparent AOT and PW. From the sky brightness measurements along the solar almucantar and the solar principal plane, column averaged size distribution is obtained by inverting the solar aureole measurements. Here we illustrate the quality of CSPHOT measurements. Specifically, measured transmittance is compared with that obtained from an independently calibrated and continuously operating Multifilter Rotating Shadowband Radiometer (MFRSR) situated close to the CSPHOT at the central facility. Aerosol size distribution inferred from solar aureole measurements is compared to that retrieved from direct solar extinction measurements. Precipitable water retrieved from transmittance measurements in the 940-nm band is compared with that obtained using radiosondes and Microwave Radiometers (MWRs).

CSPHOT Characteristics

CSPHOT is a silicon detector based, multi-channel, automatic sun and sky scanning radiometer that measures the direct solar irradiance and sky radiance at the surface at pre-determined discrete wavelengths in the visible and near-infrared (IR) to determine atmospheric transmittance and scattering properties. It is an outdoor instrument that is weatherproof and requires little maintenance during periods of adverse weather conditions. It takes measurements only during daylight hours (sun above horizon). Table 1 summarizes CSPHOT characteristics.

Table 1. CSPHOT characteristics.

Detector	Silicon
Number of Filters	8
Number of Collimators	2
Field of View/Aperture	1.2. One has 10 times the aperture of the other.
Solar Scanning	4 quadrant detector.
Sky Scanning	Azimuth and Zenith motors
Frequency of Sun Acquisition.	8 s for 1 scan. Three scans (a triplet) 30 s apart for 1 min. total. Triplets at 0.5 airmass intervals for airmass 5 - 7. 15 min. apart, otherwise.
Frequency of Almucantar Scan	At airmass of 4, 3, 2, 1. 8 times daily.
Frequency of Principal Plane Scan	Hourly 9 a.m. - 3 p.m.
Wavelengths	340, 380, 440, 500, 672, 872, 940, and 1019 nm.
Full-Width Half-Maximum (FWHM)	10 nm; 2 nm for 340, 380 nm.

Theory of Operation

Application of Bouguer's law in conjunction with the Langley plot method of calibration to direct solar measurements yields transmittance directly, without need to calibrate the instrument for irradiance (Halthore et al. 1997a). An accuracy of 0.01 in vertical optical thickness is obtained for calibration at mountain sites such as Mauna Loa where the atmosphere is frequently cloud-free and stable during mornings. Assuming that the components of total extinction - Rayleigh scattering and molecular band and continuum absorption (due to Chappuis ozone bands) are well known, the remaining extinction is attributed to aerosols, the most variable component of extinction in all bands except 940 nm, where water vapor band absorption is important. Thus, water vapor column abundance is inferred from the 940-nm channel (Halthore et al. 1997b) and AOT is inferred from the rest. As explained in an accompanying paper (Halthore et al. 1999), difficulty in reconciling measured and calculated diffuse downward irradiance at the surface has led us to conclude that aerosol light-scattering extinction may have been overestimated by about 0.02 in optical thickness at 550 nm.

Comparison of CSPHOT and MFRSR Inferred AOT

In Figure 1a, AOT inferred from direct sun observations of CSPHOT and MFRSR are compared for three days in 1998 with low, medium, and high AOTs. CSPHOT is calibrated at NASA GSFC by comparing its response to another sunphotometer, which was calibrated at Mauna Loa, Hawaii; uncertainty is estimated at ±0.01. MFRSR was calibrated on-site at the SGP site by obtaining zero-intercepts for many clear days for which the Langley plots were straight and the corresponding optical thicknesses were low; a selection of the best intercept was made by examining mean and median values for each channel. Uncertainty is estimated to be ±0.02. In Figure 1, MFRSR depicts systematic variability late in the afternoon perhaps due to improper shadowing because of misalignment.

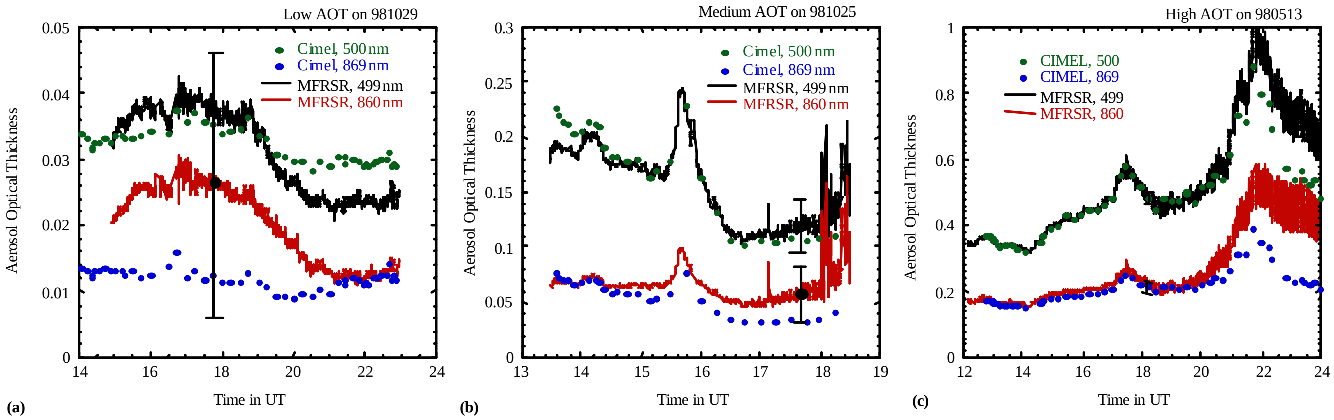

Figure 1. Apparent AOT is compared for three days of low, medium, and high turbidity for two channels of CSPHOT and MFRSR. Notice the varying size of the error bars in these figures, which represent the estimated uncertainty in MFRSR measurements of ±0.02. The agreement between the instruments is good showing that the in situ calibration of MFRSR may have been better than ±0.02. Some MFRSR traces, show systematic effects particularly in the afternoon perhaps due to improper shadowing.

Aerosol Size Distribution

Three inversion methods for aerosol size distribution are compared as column averaged number size distributions in Figure 2 for the low, medium, and high AOT cases. Nakajima's method inverts the aureole sky brightness to determine phase function and size distribution. Sky brightness measurements are obtained by CSPHOT in the radiometer mode by scanning in the Solar almucantar and in the Solar principal plane. Radiance calibration is performed by using an integrating sphere at NASA. The other two methods - a smoothness constrained non-negative least squares (SCNNLS) method (Liu et al. 1999) and Twitty's method - determine size distribution by inverting the wavelength dependence of AOT. Aureole brightness is more sensitive to larger size particles as can be seen more clearly in volume size distribution (Figure 2) with Nakajima's method giving more larger size particles than the other two

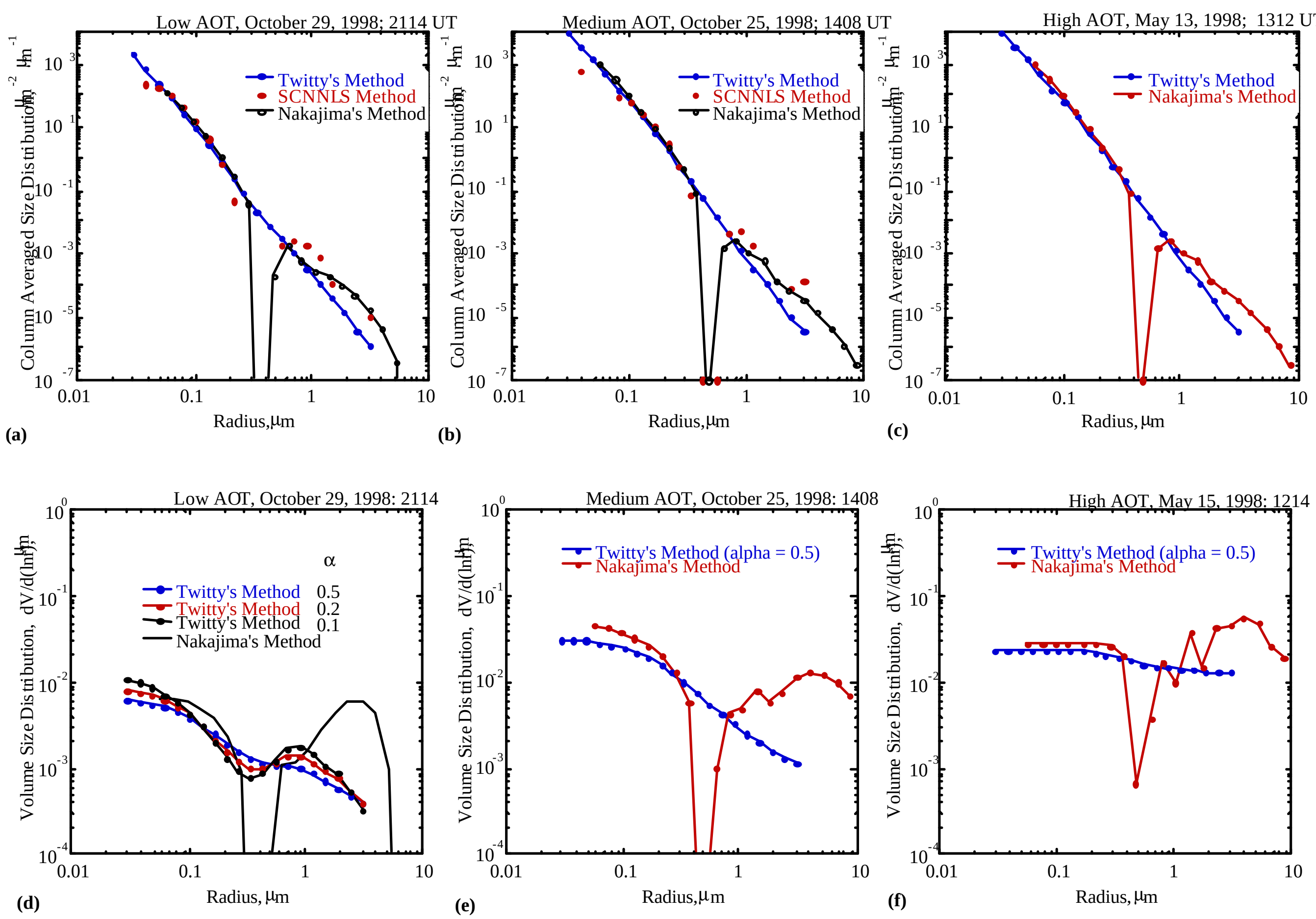

Figure 2. Size distributions derived from extinction measurements using Twitty's method and a smoothness-constrained non-negative least squares (SCNNLS) method are compared with that obtained from solar aureole measurements (Nakajima's method). In all cases, a refractive index of 1.45 - 0.005i, is used. Low, medium, and high AOT cases are shown in these six figures corresponding to the same cases as in Figure 1. (a) through (c) depict column averaged number size distribution (dN/dr) in μm^{-2} μm^{-1}. (d) through (f) depict column averaged volume size distribution (dV/d(lnr)) in μm^{-1} . The parameter α is used to smooth the size distribution in Twitty's method; a value of 1.0 corresponds to perfect smoothness; 0, none. Note that aureole brightness is sensitive to larger size particles.

methods. The effect of smoothing by a parameter α in Twitty's method is also seen in Figure 2. Thus, column averaged aerosol size distribution derived from extinction and sky brightness measurements are consistent with each other.

Precipitable Water

Water column abundance is estimated by using the Modified Langley technique for extinction in the 940-nm band in which water has a strong absorption (Halthore et al. 1997b). Comparisons of PW with MWR and radiosondes (Figure 3) show that CSPHOT inferred PW is consistent with MWR measurements but not with radiosonde measurements. The reason for the underestimate in radiosonde measurements (if confirmed) needs to be understood.

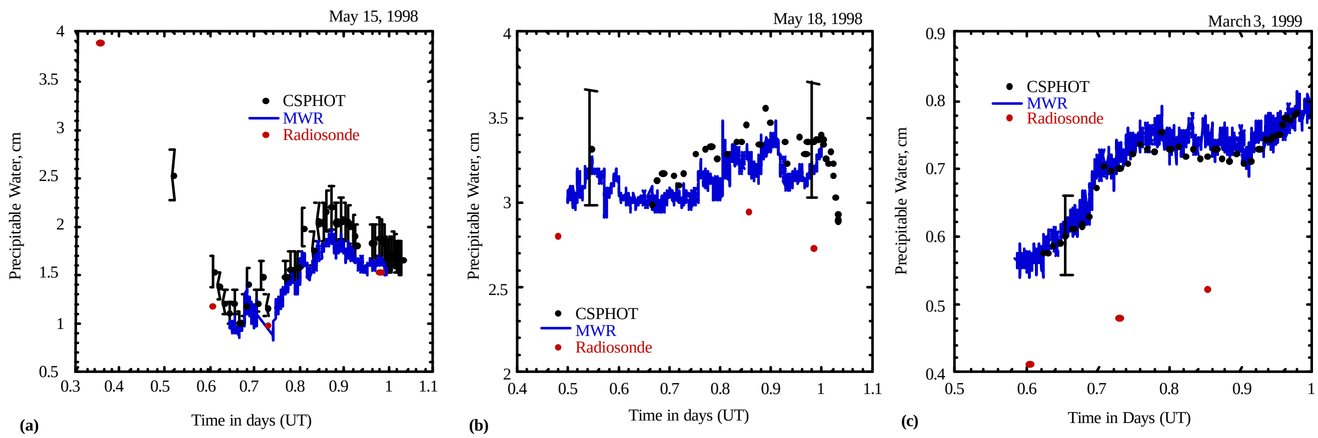

Figure 3. Water vapor vertical column abundance in centimeters of PW obtained on three days from three different instruments - CSPHOT, MWR, and radiosonde - is shown here. The accuracy in CSPHOT measurements is ~±10% and is shown as error bars. Data in the last figure were obtained by a replacement sunphotometer, which was installed at the SGP site to enable CSPHOT to be calibrated at NASA GSFC in comparison with instruments calibrated at Mauna Loa. Some of the data are preliminary and are subject to change.

Conclusions

CSPHOT measurements in 1998 at the ARM SGP site appear to be of high quality and suitable for further calculations of components of shortwave radiation.

Acknowledgments

Major portions of this work were performed under U.S. Department of Energy (DOE) ARM contract (DE-AC02-98CH10886).

References

Halthore, R. N., T. F. Eck, B. N. Holben, and B. L. Markham, 1997b: *J. Geophys. Res.*, **102**, 4343-4352.

Halthore, R. N., S. E. Schwartz, and E. G. Dutton, 1999: This proceedings.

Halthore, R. N., S. E. Schwartz, J. J. Michalsky, G. P. Anderson, R. A. Ferrare, B. N. Holben, and H. M. Ten Brink, 1997a: *J. Geophys. Res*., **102**, 29,991-30,002.

Holben, B. N., T. F. Eck, I. Slutsker, D. Tanre, J. P. Buis, A. Setzer, E. Vermote, J. A. Reagan, Y. J. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak, and A. Smirnov, 1998: *Rem. Sens. Env*., **66**, 1-16.

Liu, Y., P. W. Arnott, J. Hallett, 1999: Particle size distribution retrieval from multispectral optical depth: influences of particle nonsphericity and refractive index. *J. Geophys. Res*. In press.