Aerosol Microphysical and Optical Properties from Multifilter Rotating Shadowband Radiometers

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Introduction

Multifilter rotating shadowband radiometers (MFRSRs) provide measurements of the total and diffuse solar irradiances at six wavelengths (415, 500, 615, 673, 870 and 940 nm). Direct solar irradiances are inferred by finding the difference between the two measured irradiances, and the direct irradiances are used to derive spectral values of the aerosol optical depth (AOD; Harrison and Michalsky 1994; Alexandrov et al. 2002). Single-scattering albedos (SSAs) can be obtained from diffuse irradiances (Petters et al. 2003).

We propose a simple retrieval technique that can extend the "aerosol capability" of the MFRSR by not only deriving the AOD and SSA, but also the mean particle radius, total number of particles (for an assumed size distribution), and the imaginary refractive index (Kassianov et al. 2005). The retrieval is based on measurements of the direct irradiances at two wavelengths (415 nm and 870 nm) and the diffuse irradiance at 415 nm and requires assumptions regarding the shape of the aerosol size distribution (e.g., a combination of three lognormal distributions), and the real part of the refractive index, as well as an estimate of the surface albedo at 415 nm.

Here we outline the technique and show some results of its application to MFRSR observations performed during the Atmospheric Radiation Measurement (ARM) Program's Aerosol Intensive Operational Period (IOP). Also, we present the validation results of this technique with independent ground-based and aircraft measurements.

Background

The technique consists of three steps that compose an iterative scheme. The first step obtains the aerosol size distribution from the spectral measurements of the direct irradiance (for a given complex refractive index). To reduce the effect of ozone and water vapor contamination, we use wavelengths where ozone and water vapor weakly affect the direct irradiance (415 and 870 nm). The second step determines the effective value of the imaginary refractive index from the diffuse irradiance (for the aerosol size distribution determined during the first step). To reduce the effect of the surface albedo on the retrievals, we select a wavelength where the surface albedo is small (415 nm). The third step determines whether to stop the iterations or not. For a given iteration step, the value of the imaginary refractive index is compared with its previous value. If the relative difference exceeds the given threshold, then we repeat the first and second steps. If not, the iteration is considered to be converged.

The analysis of our initial numerical results shows that accurate retrievals of aerosol characteristics can be achieved. We successfully applied our technique to derive temporal variations of aerosol microphysical properties from ground-based MFRSR measurements performed in an urban region (Kassianov et al. 2005). In addition, we have demonstrated that the MFRSR-derived aerosol properties are in good agreement with AERONET retrievals made also in Mexico City (Kassianov et al. 2005). Below, we show the further validation of this technique with independent, ground-based and aircraft measurements during the Aerosol IOP.

Results

The Aerosol IOP ran from May 5 through May 31, 2003 over the ARM Climate Research Facility (ACRF) Southern Great Plains (SGP) site and provided samples of many variations and types of aerosols, including a few elevated aerosol layers. During the Aerosol IOP, the MFRSR observations were accompanied with independent surface and aircraft observations. The CIRPAS Twin Otter aircraft collected data during 15 days mostly under clear or partly cloudy conditions.

We performed MFRSR retrieval of aerosol for all flight days (clear sky periods). For all retrievals, we used the same assumptions about aerosol model (shape of the size distribution), real refractive index and surface albedo. In particular, we assumed that a rural model (Hobbs 1993) is appropriate. Also, we specify the real refractive index as 1.5 (Dubovik et al. 2002) and the surface albedo as 0.07 at 415 nm (Michalsky et al. 2003). Note the uncertainties in the surface albedo (at 415 nm) affect only weakly the aerosol retrievals (Kassianov et al. 2005).

Here, we present the retrieval results for four flight days: May 9, May 12, May 27, and May 29. These days are characterized by different loading of aerosol and its vertical stratification (Figure 1). For example, these are a few elevated aerosol layers for the first day (May 9); according to the aircraft report one of these layers has high absorption, another has low absorption.

Figure 2 shows some MFRSR-derived aerosol properties for selected days. There is a significant variability of AOD for these days (Figure 2a). For example, the AOD obtained for May 27 (AOD~0.3) is nearly three times larger than AOD for May 12 (AOD~0.1). The retrieval works quite stable under low optical depth conditions (May 12) and strong vertical variability (May 9 and May 27). One can easily notice a few sharp spikes on the temporal series of the MFRSR-derived aerosol properties (e.g., May 9 and May 29). These spikes are mostly associated with cloud effects on diffuse (May 9) and direct (May 29) irradiance. Note the hemispherically cloud free (clear sky) periods are the optimal conditions for the retrieval. Since we selected relatively cloud-free periods (hemispherical sky cover ~0.1 and less), the observed cloud effects are quite rare (Figure 2). The hemispherically cloud-free (clear sky) periods were specified using the algorithm of Long and Ackerman (2000).

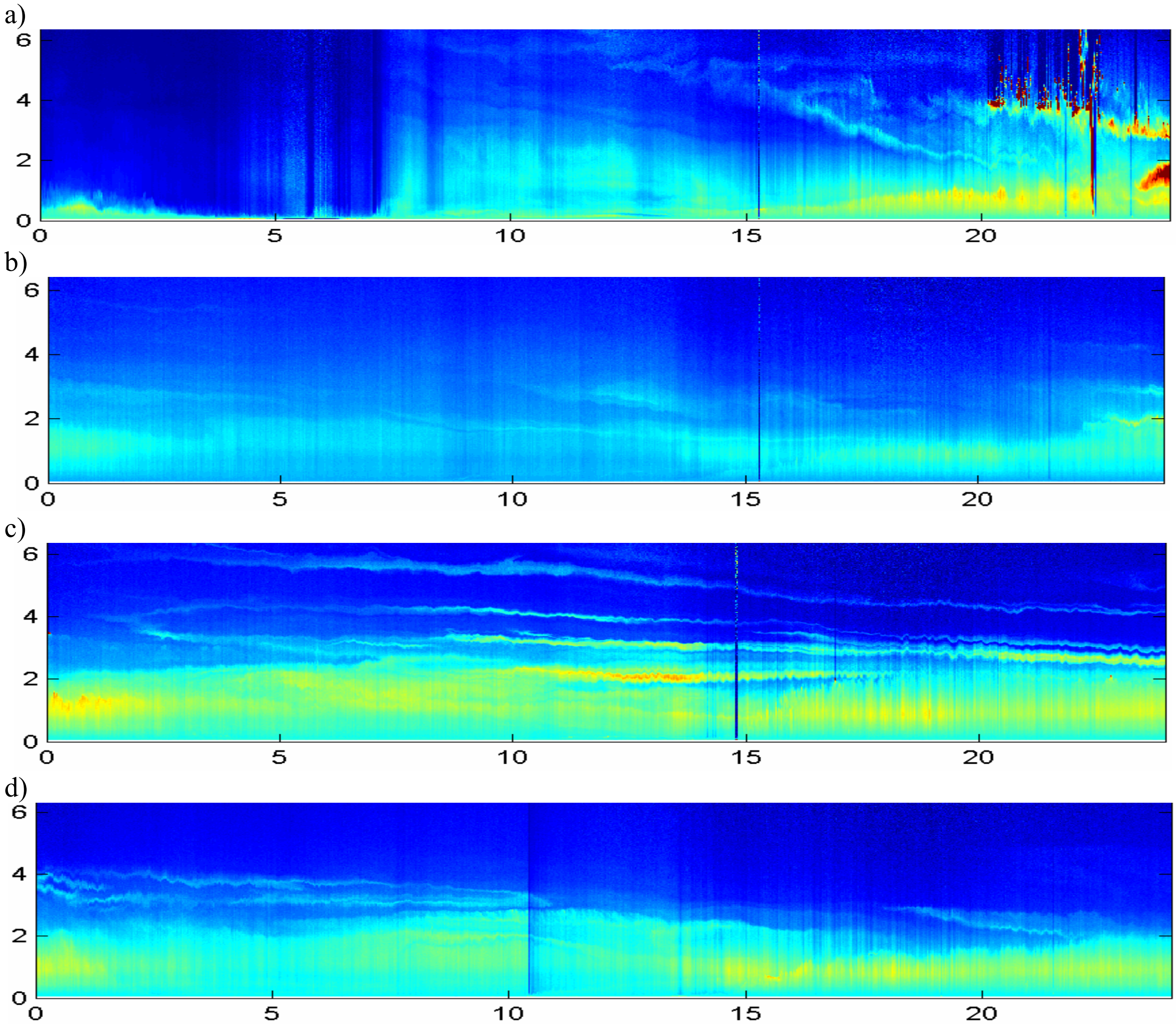

Figure 1. Two-dimensional images of micropulse lidar backscatter for May 9 (a), May 12 (b), May 27 (c), and May 29 (d); horizontal axis – time (UT), vertical axis – altitude (km). Blue and yellow colors represent low and high backscatter, respectively.

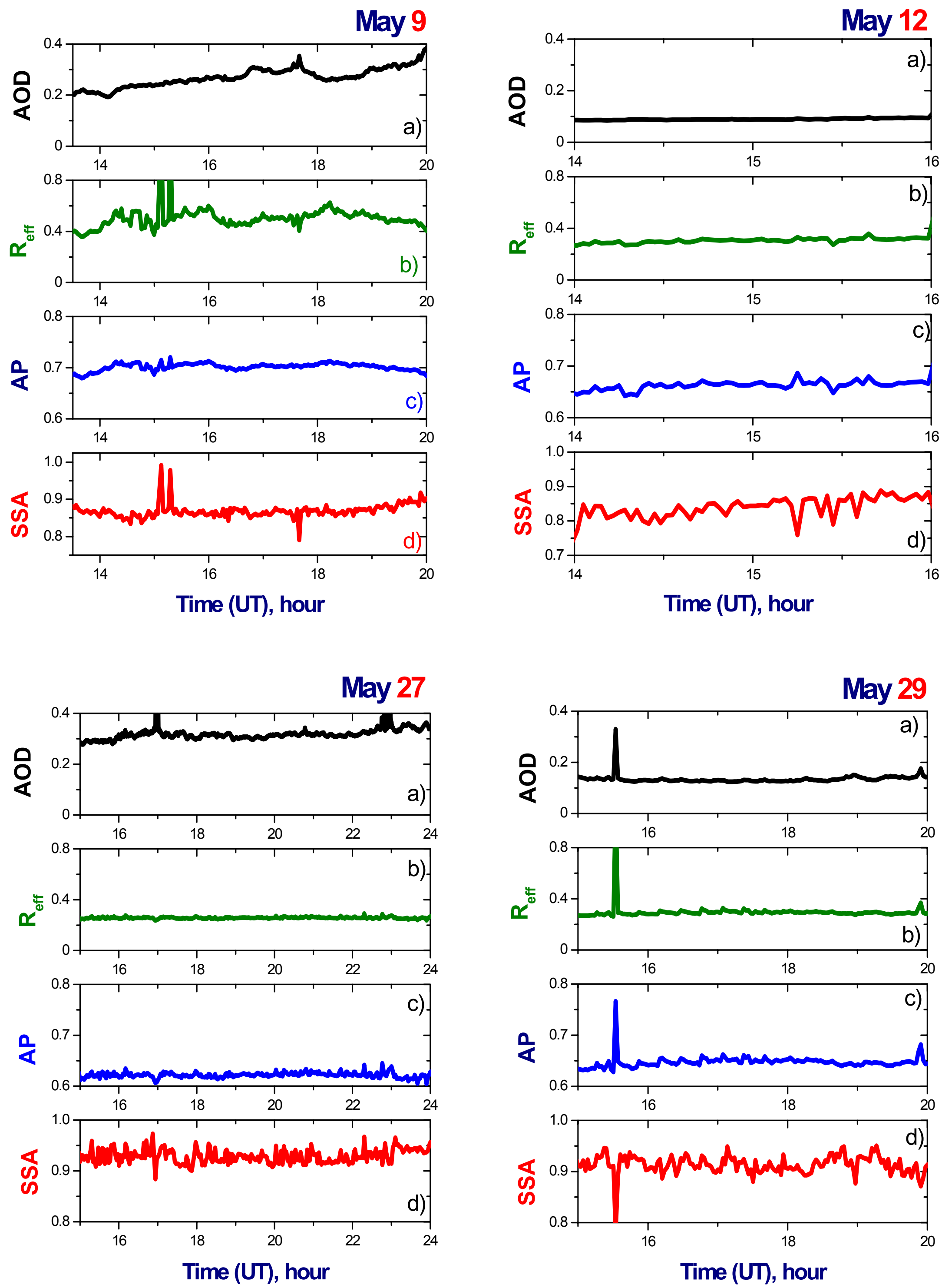

Figure 2. Time series of derived AOD (a), effective radius of particles (b), asymmetry parameter at 500 nm (c), and SSA at 500 nm (d).

To evaluate the technique, the MFRSR-derived properties (single-scattering albedo) are compared with other retrievals (surface and aircraft data) from the Aerosol IOP. Because the particular emphasis of the Aerosol IOP was placed on the role of the aerosol absorption (or SSA), we compare MFRSR-derived SSA (column) with independent surface and aircraft retrievals (Figure 3). Both the derived size distribution of aerosol particles and imaginary refractive index were used to calculate the SSA. The derived values of SSA are consistent with independent retrievals: the relative difference between aircraft and column values is within 7% (Figure 3). The sampling issues and vertical stratification of aerosol may be responsible for some differences between the derived values. We plan to perform a similar comparison for the effective radius of particles and the asymmetry parameter.

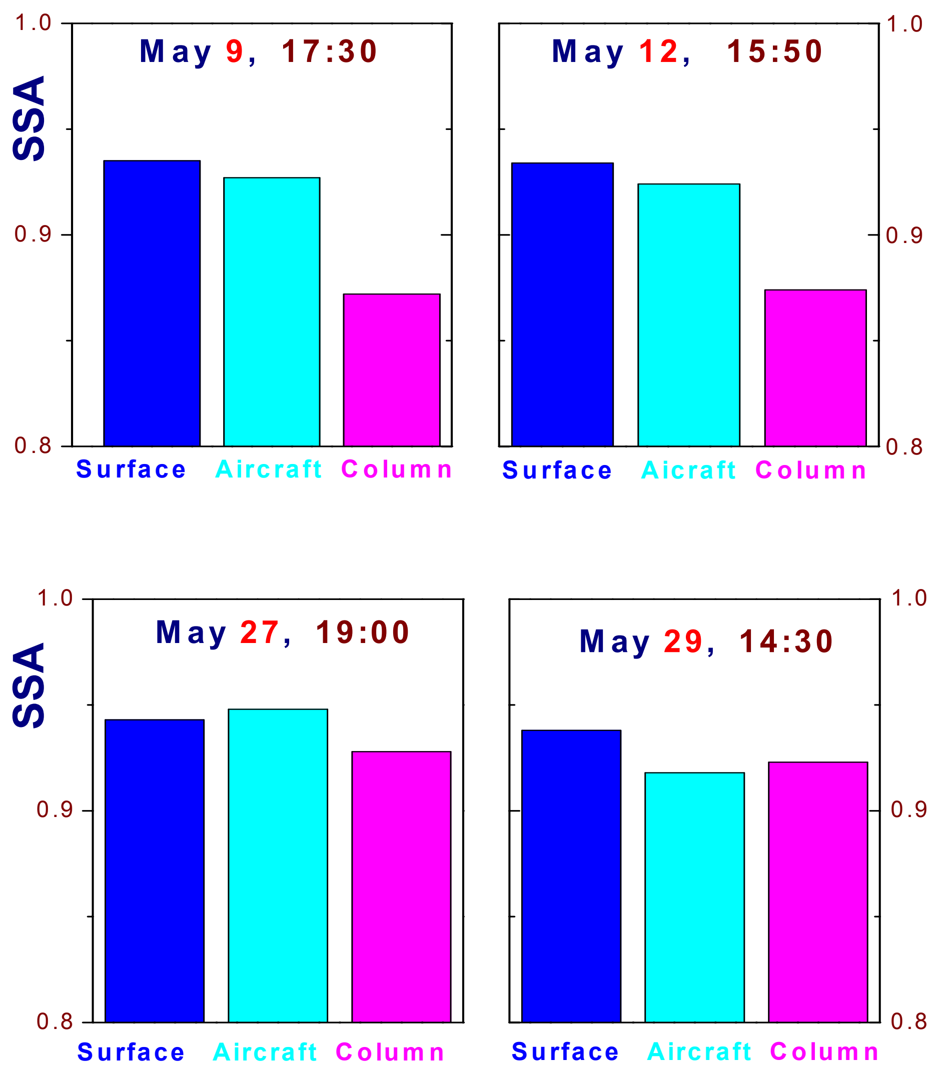

Figure 3. SSA derived from the surface (550 nm), aircraft (530 nm) and MFRSR (500 nm) data.

Discussion

Because this technique relies in part on the diffuse solar radiation scattered by aerosol, any diffuse scattering by clouds is a source of error. Thus, the usefulness of the approach is directly related to the amount of time that the sky is hemispherically cloud-free. An analysis of about nine years of data from the SGP site, shows that significant periods of cloudless sky occur on approximately 30% of all days at the SGP site in Oklahoma. Applying this algorithm to data from the ACRF site in Barrow, Alaska, produces a roughly comparable result. We expect the SGP numbers to be fairly typical of mid-latitude sites.

We think that, in practice, retrievals can be performed with some clouds in the sky as long as those clouds are low on the horizon and have only a very small contribution to the diffuse field. Additional numerical tests and comparison with field data will be carried out in the future to help address this issue.

Summary

MFRSRs are widely deployed over the world. Currently, these radiometers provide routine observations of the spectral AOD and SSA. We propose here a simple retrieval technique that allows for simultaneous retrieval of the mean particle radius, total number of particles (for an assumed shape of the size distribution), and the imaginary refractive index from combined measurements of solar direct and diffuse irradiances.

The technique has been successfully applied to derive temporal variations of aerosol microphysical and optical properties derived from ground-based MFRSR measurements performed during the Aerosol IOP at the ACRF SGP site in May 2003. To validate the technique, four days with different aerosol loading and vertical stratifications were selected. The derived size distribution of aerosol particles and imaginary refractive index were used to calculate the SSA. The MFRSR-derived values of the SSA are in good agreement with those obtained from independent surface and aircraft observations.

We plan to perform a similar comparison for the effective radius of particles and the asymmetry parameter. To better understand the strengths and weaknesses of the technique, we plan to perform additional numerical experiments (e.g., different aerosol types and aerosol optical depths). We intend to assess the impact of clouds (e.g., different cloud fraction and cloud optical depth) and how this would limit the applicability of the retrieval. In addition, we will use available independent aircraft data and ground-based observations to further evaluate this method.

Acknowledgement

This work was supported by the Office of Biological and Environmental Research of the U.S. Department of Energy as part of the ARM Program.

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