Dust Properties Derived from Multi-Filter Rotating Shadowband Radiometer Data in Niamey

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Introduction

One of the key uncertainties in the earth's radiation balance is the effect of dust on radiative fluxes (aerosol radiative forcing), which in turn affects climatic processes on both planetary and local scales (e.g., Intergovernmental Panel on Climate Change 2001; Sokolik et al. 2001). Since Saharan dust is one of the main sources of dust over the globe, its radiative effect has long been the subject of intensive studies. Recently, the ARM Mobile Facility (AMF) was deployed to Niamey, Niger, to participate in a large field campaign directed at elucidating the radiative effect of Saharan dust (http://www.twppo.lanl.gov/internal/pages/siteinfo_amf_niger.html). Since aerosol radiative forcing is a function of aerosol optical depth (AOD), single-scattering albedo (SSA), and asymmetry parameter (AP), there is a critical need to estimate the temporal/spectral variability of the aerosol optical properties.

We study this variability using ground-based measurements of downwelling spectral irradiances provided by the multi-filter rotating shadowband radiometer (MFRSR) at the AMF. Previously, we developed a retrieval technique that can give a means for simultaneous and consistent retrieval of optical (e.g., SSA) and microphysical (e.g., effective radius) properties from measured MFRSR spectral irradiances (Kassianov et al. 2005). Here we apply an updated version of this technique to derive properties of Saharan dust in Niamey from MFRSR observations under a variety of conditions (e.g., clean, dust storm). To eliminate the effect of clouds, only clear-sky periods are considered.

Observations

Comprehensive ground-based AMF measurements include total sky imager (TSI) fractional sky cover, normalized micro pulse lidar (MPL) backscatter, and solar broadband and spectral irradiances (both direct and diffuse components). The latter are measured at five wavelengths (415, 500, 615, 673, 870 nm) by the MFRSR. Surface AMF measurements are accompanied by satellite observations. In particular, we apply data from the moderate resolution imaging spectroradiometer to estimate the surface albedo (both spectral and broadband) over the AMF site in Niamey and in the surrounding area.

The field campaign provides samples of many types of aerosol and clouds. Since the MFRSR retrieval is applicable mostly for hemispherically cloud-free periods, we start with identification of these periods. To select them, we use a combination of data sets collected in Niamey from February to March 2006. The main data stream for such selection includes broadband measurements of downwelling surface fluxes. The algorithm of Long and Ackerman (2000) was applied to the broadband measurements to identify cloud-free periods. In addition, clear-sky conditions are evaluated against TSI images and MPL backscatter. Such evaluation can be performed for clean periods (AOD ~ 1 and less). Large aerosol loading associated with dust storm (March 7-9) restricts the use of these two instruments (TSI and MPL): dust almost completely blocks direct light from the sun (Figure 1) and attenuates the MPL signal (Figure 2).

Figure 1. Examples of TSI images for clean day (left) and dust storm (right).

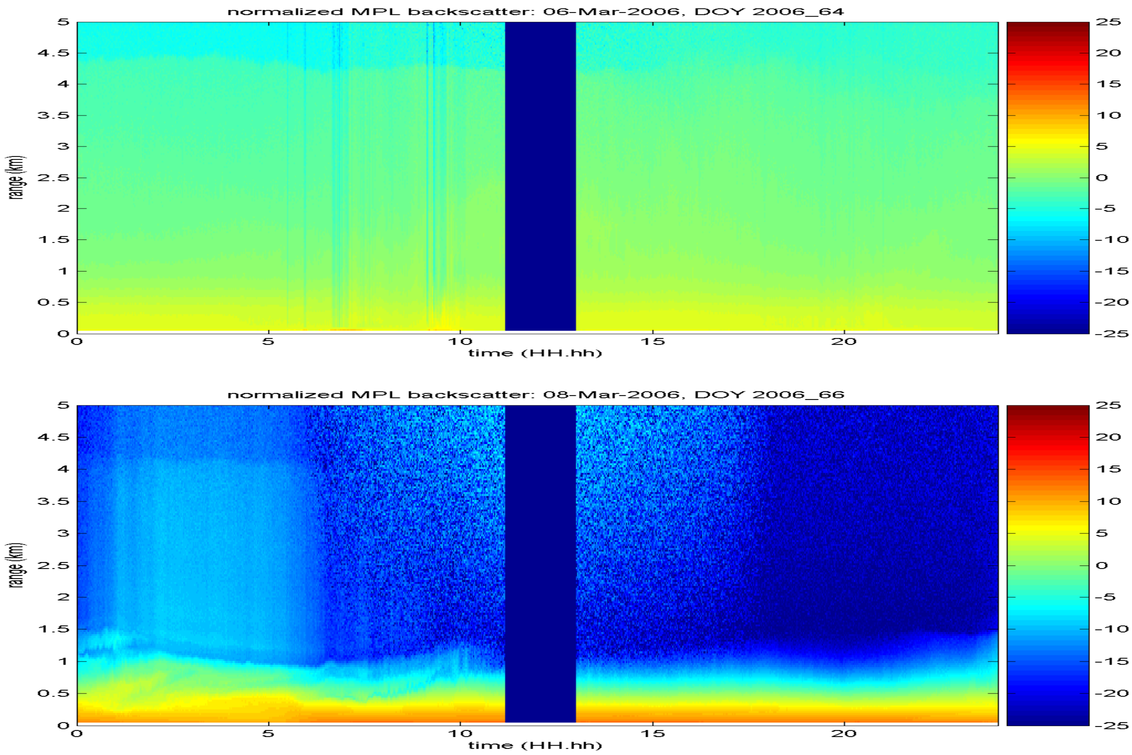

Figure 2. Examples of normalized MPL backscatter for clean day (top) and dust storm (bottom).

Approach

We retrieve aerosol optical properties for mostly hemispherically cloud free periods (hemispherical fractional sky cover ~0.1 and less) by using an updated version of MFRSR retrieval (Kassianov et al. 2005). The retrieval requires assumptions regarding the size distribution, the real refractive index and the spectral values of the surface albedo. We assume that size distribution is described by combination of two lognormal distributions (e.g., Dubovik et al. 2002) and the real refractive index equals to 1.55 (e.g., Sokolik and Toon 1998). The wavelength dependence of the surface albedo is obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) data. The spectral values of albedo are scaled to match the AMF broadband albedo measurements.

There are two basic steps to this retrieval. The first step is the estimation of the particle size distribution. The wavelength dependence of the AOD (or direct irradiance) is used for such estimations. The assumed size distribution has six parameters (three for each mode). The scheme assesses four parameters that represent the integral and mean radius of each mode (both accumulation and coarse), respectively. These parameters are iterated to match the spectral dependence of the AOD. The second step is to estimate the spectral values of imaginary refractive index (for a given size distribution). These values are iterated to match the spectral dependence of the ratio of the diffuse to the direct irradiances (diffuse-to-direct ratio).

Results

For clean days, the typical values of the AOD at 0.5 μ are in the range 0.2-0.6 (Figure 3, top row), compared with 0.05-0.2 at the Southern Great Plains site (Michalsky et al. 2001), indicating higher aerosol loading in the Niamey. Also, from Figure 3 one can conclude that for clean days the temporal variations of AOD are relatively small. The opposite is true for days associated with dust storm (March 7-9). For example, the AOD increased about sevenfold during March 7-8 (from 0.5 to 3.4). As a result of significant aerosol loading, direct light from the sun is strongly attenuated (Figure 1). Interestingly, the color of the sky changes from blue to reddish (Figure 1).

Figure 3 illustrates the spectral variability of AOD as well. It is well known that the wavelength dependence of AOD is an indicator of particle size: large contribution of small particles is responsible for a large decrease of AOD with wavelength and vice versa (e.g., Stephens 1994). Since the spectral variability is relatively small (Angstrom exponent is 0.8 or less for the majority of cases), it suggests that the contribution of large particles is substantial. For clean days, the MFRSR-derived values of the effective radius are in the range from 0.5 to 1.2 μ. During dust storm, these values can reach 3 μ (at initial stage of storm).

Let us turn from the AOD to the SSA (Figure 3, middle row). Retrievals for both clean and storm days suggest that dust from Sahara is blue-absorbing aerosol with strong spectral dependence: values of SSA at 0.415 μ are much less than those at 0.87 μ. Such wavelength dependence of the SSA can be attributed to some types of dust (e.g., Sokolik and Toon 1999). In particular, different types of clays (e.g., kaolinite) may have similar spectral behavior of SSA in the visible region (0.4-0.8 μ). For the infrared region (8-12 μ), a mix of two clays (kaolinite and hematite) can reproduce collocated and coincident observations of the Atmospheric Emitted Radiance Interferometer in Niamey (D. Turner, personal communication). It should be noted that an aircraft study in Senegal (September 2000) showed a weak spectral dependence of SSA (Haywood et al. 2003). Since the dust burden may have a complex spatial and temporal pattern, optical properties of dust observed in Niger and Senegal may be different.

To validate the MFRSR retrievals, we perform radiative closure experiments. The MFRSR-derived optical properties (AOD, SSA, and AP) of dust (Figure 3) and available spectral and broadband values of the surface albedo are used as input for two radiative transfer models, namely, SBDART (Ricchiazzi et al. 1998) and SHDOM (Evans 1998). The output of these models is broadband fluxes. The calculated fluxes are compared with those obtained from surface observations (not shown). The calculated diffuse fluxes fit observations reasonably well (~10%); for direct fluxes this agreement is better (~3%). Difference between model calculations and observations can be attributed to uncertainties of the surface albedo, measurements, and model/retrieval assumptions. Given these uncertainties and assumptions, the model results agree reasonably well with observations. This suggests that the MFRSR-derived optical properties are not too far off the mark.

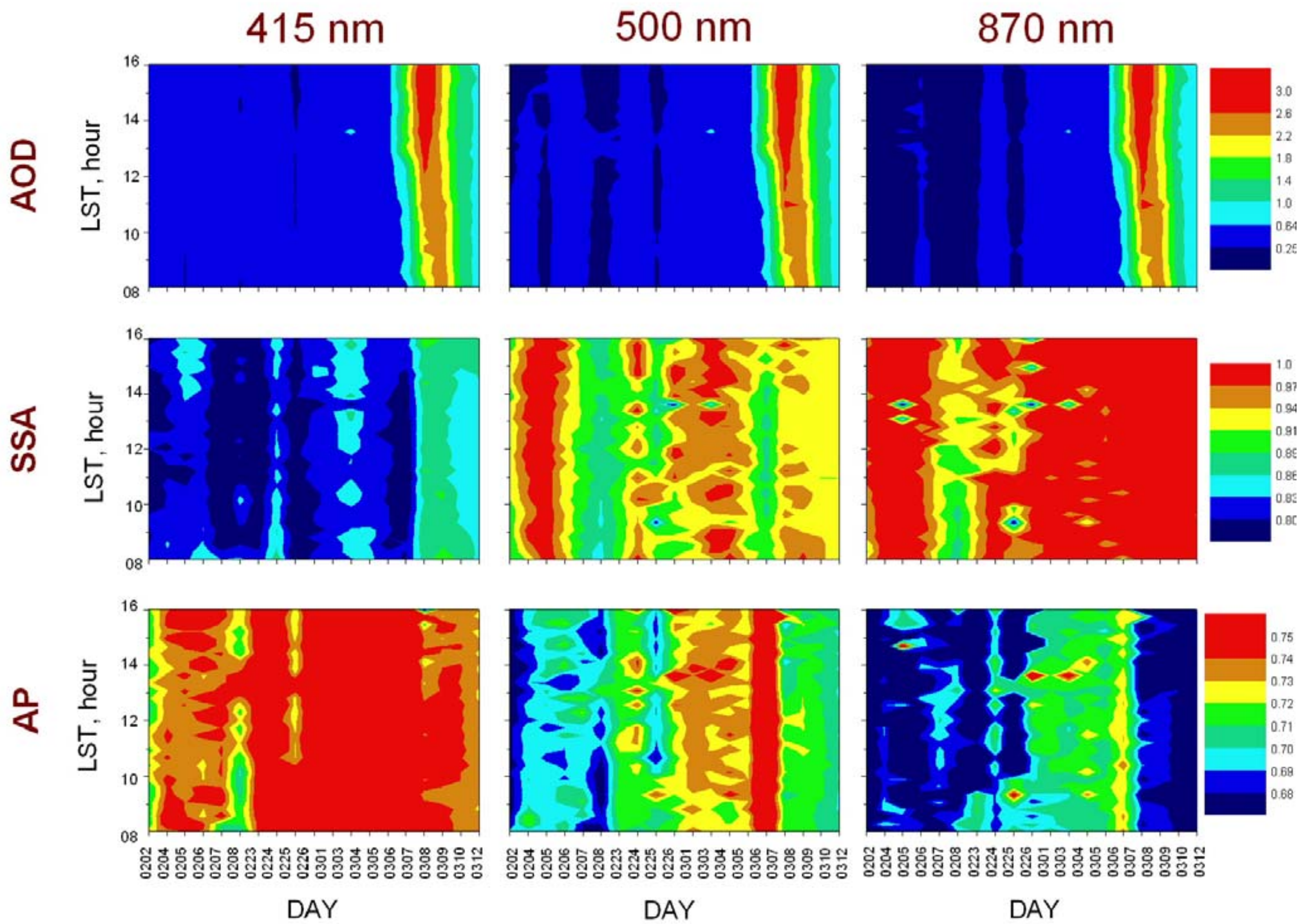

Figure 3. MFRSR-derived optical properties (AOD, SSA, AP) as function of day (horizontal axis) and daytime (vertical axis) for three wavelengths (0.415, 0.5, and 0.87 μ). In this notation, the first two numbers correspond to a month, and last two numbers represent a particular day.

Summary

We estimate the optical properties (AOD, SSA, and AP) of Saharan dust from MFRSR data by using an updated version of our retrieval technique (Kassianov et al. 2005). The AOD evolves strongly during the dust storm (from 0.5 to 3.4). The same is true for the spectral dependence of AOD. The latter is determined mostly by the mean size of aerosol particles. Spectral behavior of SSA suggests that Saharan dust includes various clays, such as kaolinite (blue-absorbing aerosol). To evaluate the performance of the retrieval technique, we perform radiative closure experiments by applying the MFRSR-derived properties of dust. Calculated broadband fluxes are comparable (~ 10%) to those obtained from measurements.

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