Aerosol Optical and Microphysical Characteristics Retrieved from Observations During ARESE

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Introduction

During the Atmospheric Radiation Measurement (ARM) Enhanced Shortwave Experiment (ARESE) in October 1995, the Institute of Atmospheric Physics, Russian Academy of Sciences, obtained aureole and extinction measurements. The aureole measurements were inverted to the size distributions of the coarse dispersed aerosol in a single scattering approximation (Golitsyn et al. 1997). In the present study, multiple scattering is taken into account. Optical thickness was added to the input parameters of the inverse problem. The size distributions obtained were used for the shortwave flux computations.

Retrieval of Aerosol Micro-structure from Measured Aureole Sky Brightness

In the small-angle approximation of multiple light scattering (Belov et al. 1984), the intensity of scattered light is given by

$$I(\varphi) = I_0 \exp(-\tau m) \int J_0(p\varphi)(\exp(mD(p)) - 1) p\,dp \qquad (1)$$

where

- I_0 = solar intensity at the upper boundary of the atmosphere
- τ = optical thickness
- m = airmass
- J_0 = Bessel function of zero order
- D(p) = Hankel transform of the directed scattering coefficients D(φ)
- D(φ) = phase function normalized to the optical thickness.

The Hankel transform of the normalized intensity $I_n(\varphi) = I(\varphi)/(I_0 \exp(-\tau m))$ gives

$$mD(p) = Ln(I_n(p) + 1)) \qquad (2)$$

where

$$I_n(p) = \int J_0(p\varphi) I_n(\varphi) \varphi\, d\varphi \qquad (3)$$

Directed scattering coefficients can be found from Equation 2 using the inverse Hankel transform as

$$D(\varphi) = \int J_0(p\varphi) D(p) p\,dp \qquad (4)$$

This approximation does not take into account scattering at large angles because we must cut the measured intensity at some angle φ^* when computing the integral in Equation 3. Another difficulty of using the small-angle approximation of the multiple scattering is the necessity to know the detailed angular course of the phase function at small angles. During the ARESE, the aerosol loading in the atmosphere was rather small, and scattering outside the aureole region was determined mostly by molecular scattering.

We chose the following scheme of derivation of the single scattering and retrieval of the aerosol size distributions. First, a diffuse irradiance due to molecular scattering was calculated using Monte Carlo simulations. Second, we subtracted it from the measured intensity and the inverse problem was solved for obtained data. Third, we calculated the detailed angular dependencies of the phase functions and applied the near-forward approximation to calculate the ratio of multiple to single scattering for all measured wavelengths and scattering angles. Finally, the single scattering characteristics were inverted to the aerosol size distributions.

The procedure was checked by Monte Carlo computations. In Figure 1, the measured intensity (curve 1) is compared with that recovered by Monte Carlo calculations (curve 2) for retrieved single scattered intensity (3). For example, we chose

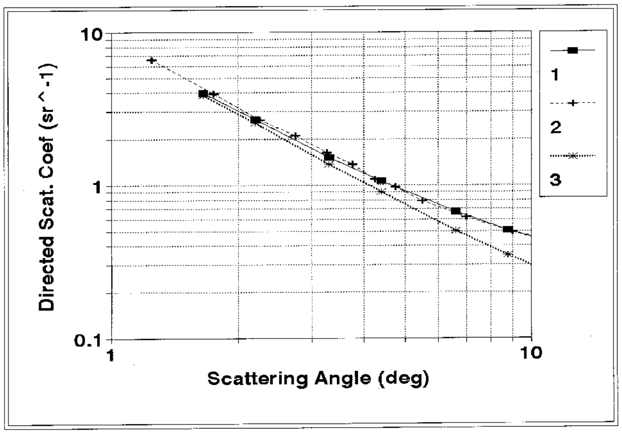

Figure 1. Retrieval of the single scattering from the observed aureole brightness.

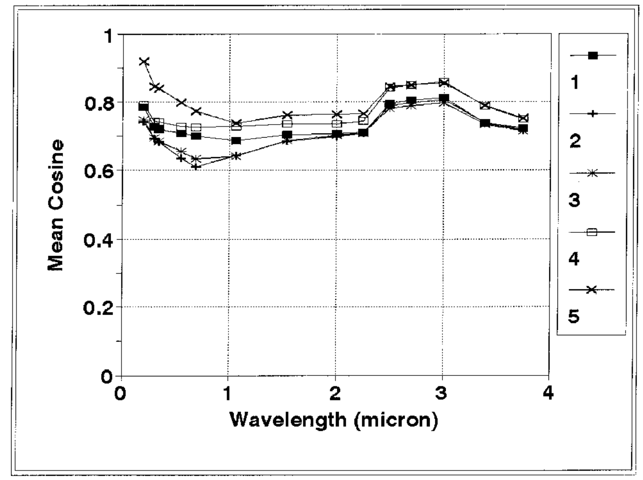

Figure 2. Spectral behavior of the mean cosine of the phase function recalculated for size distributions retrieved from the extinction and aureole measurements during ARESE. October 8 (1), 10 (2), 12 (3), 13 (4), 14 (5).

chose the situation with the greatest input of multiple scattering among our entire data set (wavelength - 0.46 µm, airmass - 3.4, and optical thickness in the direction of the Sun more then 1). Usually the effect of the multiple scattering did not exceed 20% to 30%.

Calculation of the Solar Radiation Fluxes

For the calculations of the shortwave clear-sky fluxes, information on the spectral behavior of the aerosol optical characteristics in the whole shortwave range is needed. Aureole measurements are insufficient for microphysical extrapolation in the wide spectral range because of their weak sensitivity to the submicron fraction of the atmospheric aerosol. In order to enlarge the size range of the retrieved size distributions, we added the results of our measurements of the optical thickness to the input inversion parameters. Size distributions were retrieved in the radius range 0.1 µm - 11 µm.

Another problem of spectral expanding is connected with selection of a spectral model of real and imaginary parts of the refractive index. We used the model of Zuev and Krekov (1986) for aerosols of the dispersion origin. The results of calculations of the spectral course of the mean cosine of the phase function and optical thickness with the Zuev-Krekov model and size distributions retrieved from our ARESE measurements are shown in Figures 2 and 3. The MODTRAN2 radiation code was applied to the calculations of the clear-sky shortwave irradiance. Water vapor profiles from the sondes were included in the computation scheme parallel with our aerosol data. The surface albedo was assumed to equal 0.1.

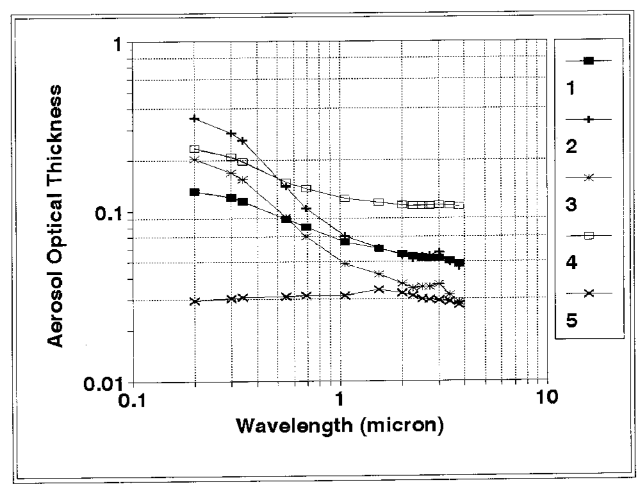

Figure 3. Spectral behavior of the aerosol optical thickness. October 8 (1), 10 (2), 12 (3), 13 (4), 14 (5).

Comparison Between Shortwave Flux Calculations and Observations

The calculated normal direct-beam solar irradiance S, downwelling hemispheric diffuse solar irradiance D, and downwelling hemispheric solar irradiance Q were compared with Baseline Surface Radiation Network (BSRN) observational data. For comparison, we chose the period close to the sonde launching. The measured fluxes were averaged through the 20-min period. Aerosol parameters were taken from the nearest aureole measurement and, if it was needed, corrected for the variations of aerosol optical thickness. The observed and calculated fluxes are compared in Table 1. Index ^{meas} refers to the BSRN data and ^{calc} to the calculated from the extinction and aureole scattering data. The aerosol optical thickness τ is given for a wavelength of 0.55 µm.

In the last three cases (October 10, 14, and 18) the differences between measured and calculated diffuse irradiance are less than 10 Wt/m^2 and much less than on October 3, 4 and 6. The total shortwave irradiance also differs significantly from that calculated for the first three cases. But irradiance S/m + D retrieved from normal direct-beam and diffuse irradiance are within 6 -25 Wt/m^2 of the calculated irradiances. Note that even on October 10, 14, and 18 the differences between measured fluxes Q and S/m + D are of the same order as between measurements and computations. It follows from Table 1 that measured direct irradiance is greater than calculated. One of the possible explanations of such a discrepancy is the input of the scattered light into the finite field of view of the actinometer. The calculated values of the total irradiance for pure molecular atmosphere Q^{mol} are also given in Table 1 to evaluate the aerosol influence on the downwelling fluxes of shortwave radiation.

Table 1. Comparison Between Measured and Calculated Irradiance

Date 1995	10/03	10/04	10/06	10/10	10/14	10/18
Time GMT	20.30	17.30	20.30	20.30	20.30	17.30
M	1.58	1.36	1.60	1.67	1.73	1.48
τ	0.08	0.06	0.06	0.14	0.04	0.12
Q^{meas} wt/m^2	558	736	587	570	585	680
Q^{calc} wt/m^2	624	780	641	554	586	664
Q^{mol} wt/m^2	672	807	675	621	619	724
D^{meas} wt/m^2	78	68	83	93	57	95
D^{calc} wt/m^2	62	94	79	89	66	98
S^{meas} wt/m^2	----	960	908	811	925	863
S^{calc} wt/m^2	859	930	897	778	902	837
S/m+D wt/m^2	----	774	651	579	592	678

Summary

An improved technique of retrieving the aerosol size distributions from combined extinction and aureole measurements was developed. The input of multiple scattered light in the aureole region was taken into account based on the small angle approximation of the radiative transfer equation. The measurement data obtained during ARESE (Lamont, Oklahoma, October 1995) were inverted to the aerosol size distributions in the size range 0.1 µm - 11 µm. Spectral aerosol optical characteristics needed for the shortwave flux computation (optical thickness, absorption, mean cosine of the phase function) were recalculated from the retrieved size distributions. Calculated clear- sky shortwave fluxes were compared with those measured during ARESE.

Acknowledgment

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