Aerosol Optical Depth Estimates Based on Nephelometer Measurements at the Atmospheric Radiation Measurement Program Southern Great Plains Site

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Introduction

The scattering of shortwave radiation by anthropogenic aerosols during clear-sky conditions, termed direct aerosol forcing, has been estimated to be roughly 1 W/m^2 on a global annual average and may be as high as 50 W/m^2 locally and instantaneously near source regions (Schwartz, 1996). The extent of the direct aerosol forcing effect at a given time and place depends primarily in the aerosol optical depth, τ as well as on other factors including the solar zenith angle, aerosol upscatter fraction, and the single scatter albedo (ratio of light scattering to total extinction). The aerosol optical depth at a given wavelength (τ_λ) can be written as the integral with height to the top of the atmosphere *(toa)* of the aerosol extinction coefficient, $_{bext,p}$:

$$\tau_\lambda = \int_0^{toa} b_{ext,p}(\lambda, z)\, dz \qquad (1)$$

where $b_{ext,p}$ is the sum of the aerosol extinction (b_{ap}) and scattering (b_{Sp}) coefficients. The objectives of this research are to use nephelometer measurements of the scattering coefficient to estimate the aerosol optical depth at a specific wavelength (530 nm), and to compare these results with optical depths measured by a Multi-Filter Rotating Shadowband Radiometer (MFRSR) and Cimel Sun Photometer. This comparison will used to determine if all of the key parameters related to aerosol optical depth are being measured at the SGP ARM site.

Radiation and Aerosol Measurements

Here we present data for April 19, 1994 during the SGP ARM Intensive Operations Period (IOP). This date was chosen due to the relatively high aerosol loading (b_{Sp} ranging from 30 to 140 Mm^{-1}) and cloud-free conditions. Figure 1 shows the total and diffuse solar irradiance measured by the broad-band channel of the MFRSR. In Figure 2 the aerosol optical depth

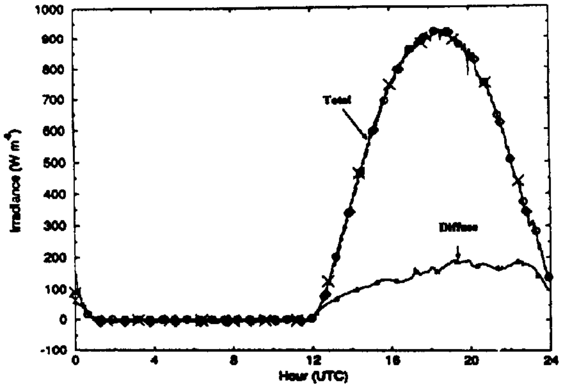

Figure 1. Broadband (400 µm-1000 nm) downwelling total and diffuse solar irradiance measured by MFRSR on April 19, 1994 at the SGP ARM site.

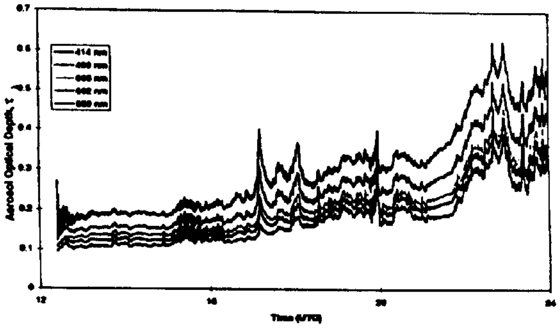

Figure 2. Aerosol Optical Depth (τ_λ) estimated from MFRSR data for April 19, 1994.

as a function of wavelength (τ_λ) for several wavelengths from 414 nm to 859 nm are estimated using MFRSR data. These MFRSR aerosol optical depths are compared with Cimel sun photometer optical depths in Figure 3 at 18:00 on April 19. The aerosol optical depth measurements are in close agreement for the two instruments, as shown by the power law regressions of the data which yield slopes (α values) of 0.080 +/0.04 for the MFRSR and 0.081 +/- 0.08 for the sun photometer. This establishes the validity of using the MFRSR to instantaneously measure τ_λ. Figure 4 shows α values estimated from instantaneous MFRSR data. The α parameter provides a rough estimate of the aerosol particle size, and as a decreases the particle size distribution shifts towards larger particles. The mean α value is 0.78, which suggests that roughly 50 % of the light scattering comes from coarse particles reater than 1 µm (Ogren and Bodhaine, 1994).

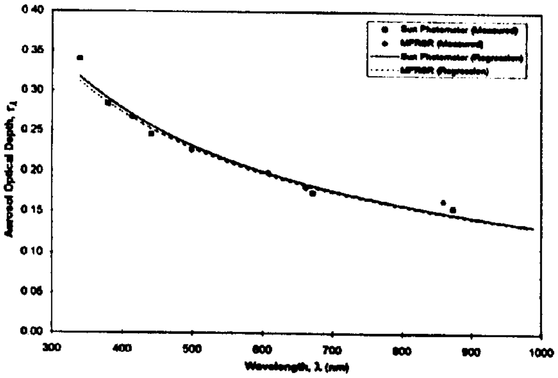

Figure 3. Comparison of aerosol optical depth (τ_λ) measurements by MFRSR and Sun Photometer at 18:00 on April 19, 1994.

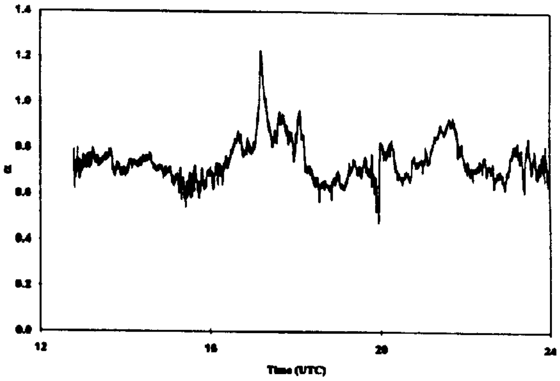

Figure 4. α from MFRSR on April 19, 1994.

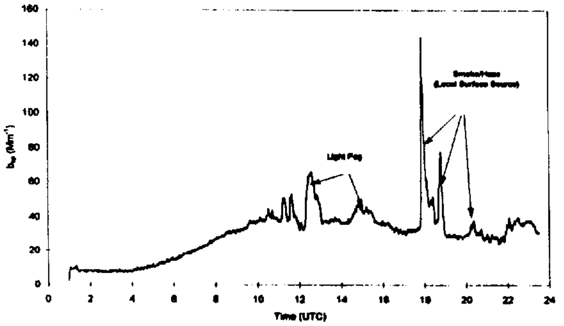

Figure 5. Nephlometer measurements of the light scattering coefficient (b_{sp}) on April 19, 1994.

Figure 5 shows the aerosol scattering coefficient (b_{Sp}) at a wavelength of 530 nm measured by integrating nephelometer at a height of 60 m. The scattering coefficient is typically 40 Mm^{-1} during daylight hours (12 UTC to 24 UTC), with peaks occurring due to fog events (13 UTC and 15 UTC), as well as from local biomass burning plume (18 UTC and 20 UTC).

Comparison of MFRSR and Nephelometer Measurements

Figure 6 compares the nephelometer b_{Sp} versus τ_{499} measured by the MFRSR for the period of the day when the atmospheric surface layer was well mixed (based on potential temperature profiles from radiosonde data) from 17:30 to 20:30. Surprisingly, there is no apparent relationship between b_{sp} and τ_{499}. A further comparison can be made by estimating τ_λ from the nephelometer measurements and comparing that with the MFRSR τ_{499} for the same time period. nder the assumption

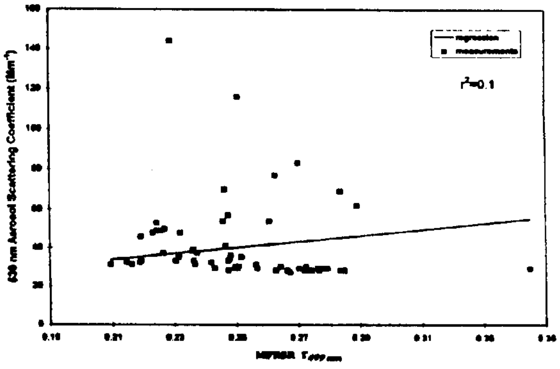

Figure 6. b_{sp} (530 nm) vs. MFRSR $\tau_{499\ nm}$ from 17:30 to 20:30 on April 19, 1994.

that the aerosol is present primarily in the near surface mixed layer, the aerosol optical depth is estimated from the nephelometer b_{sp} as:

$$\tau_\lambda = \int_0^H b_{ext,p}(\lambda, RH_{ref})\ f(RH)\ dz \qquad (2)$$

where H is the height well mixed surface layer, $b_{ext,p}(\lambda, Rh_{ref})$ is the extinction coefficient of the dry aerosol at a reference RH taken as 40%, and $f(RH)$ is a factor that accounts for the enhanced scattering of aerosols due to hygroscopic growth We take the mixing height as 1000 m (from Radiosonde profiles), and assume that the aerosol is uniformly distributed in the mixed layer, that there is a negligible contribution to the optical depth by absorbing particles (i.e., $b_{ext,p} = b_{sp}$), that nephelometer measurements represent $b_{ext,p}(\lambda, RH_{ref}$, that $f(RH)$ is 1.7 (Charlson et al., 1992), that the nephelometer samples the entire particle size distribution contributing to light scattering (including particles having diameters > 1 µm), and that no evaporation of volatile aerosols occur during sampling. Figure 7 compares τ_{530} estimated with nephelometer data using Equation 2, with τ_{499} measured by the MFRSR The optical depth estimated from the nephelometer is generally a factor of 4 less than the MFRSR τ_{499}. In addition, the smoke/haze signals seen in the nephelometer τ_{530} are not reflected in the MF RSR τ_{499}, evidently because the peak in b_{sp} was from a local aerosol plume.

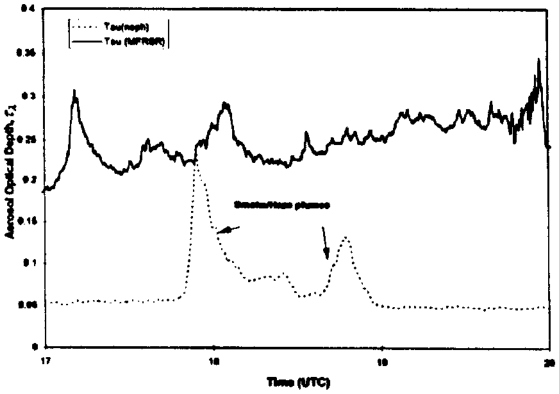

Figure 7. Comparison of AOD measured by MFRSR ($\tau_{499\ nm}$) and estimated from b_{sp} ($\tau_{530\ nm}$).

Possible Explanations for the Discrepancy Between Nephelometer Estimated and MFRSR Measured Aerosol Optical Depths

There are several possible reasons for the underprediction of the aerosol optical depth using nephelometer measurements. Perhaps the foremost point is the lack of knowledge of the vertical profile of the aerosol properties related to light scattering (number concentration and size distribution). Profiles of the aerosol number and size distribution measured during flights over the SGP ARM on April, 21 suggest a significant fraction of light scattering may occur above 1000 m (University of North Dakota Citation Aircraft flight, unpublished data). As previously mentioned, the fraction of light scattering by aerosol particles greater than 1 µm may be roughly 50%. These particles are difficult to sample due to inertial effects, and may account for factor of 2 underestimations in the scattering coefficient. The evaporation of volatile particles (such as ammonium nitrate) may account for a fraction of the discrepancy, although recent lab studies suggest that this effect may be on the order of a 20% decrease in the scattering coefficient (Bergin et al., 1996). It is not expected that absorption by particles significantly contributes to the nephelometer underestimation since the single scatter albedo is most likely greater than 90%.

Recommendations for Future Work

In order to determine if all of the key variables related to direct shortwave radiative forcing by aerosols are being measured at the SGP ARM site it is important to reach closure between measured aerosol properties related to optical depth and direct optical depth measurements. Perhaps the most important issue is to measure the vertical profiles of the aerosol properties related to light scattering. In addition, the aerosol sampling artifacts (loss of large aerosol particles and evaporation of volatile aerosols) must be quantified.

References

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