In Situ Aerosol Profiles Over the Southern Great Plains CART Site

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Introduction

The importance of aerosol particles for climate forcing is recognized, but the magnitude of their contribution is uncertain. Particles may have an influence of the same magnitude but in the opposite direction as greenhouse gas forcing (IPCC 1996). However, because they can settle out, particles tend to have shorter atmospheric lifetimes than greenhouse gases. This results in vertical, horizontal, and temporal gradients in aerosol particle concentrations. These spatial gradients correspond to regional rather than global aerosol forcing effects. In addition, the chemical, physical, and optical characteristics of aerosols can be much different than the global average. These characteristics are easily influenced by local and regional sources and perturbations, including urban areas, fires, dust, and sea salt. This leads to further spatial and temporal inhomogeneity.

Long-term surface measurements of aerosol optical properties have been made at a variety of sites (Delene and Ogren 2001; Koloutsou et al. 2000; Sheridan et al. 2000a; Veefkind et al. 1996). In addition, short-term vertical measurements of aerosol optical properties have also been made during intensive field campaigns (Schmid et al. 2000; Sheridan and Ogren 1999, Sheridan et al. 2000b; Kotchenruther et al. 1999; Remer et al. 1997). However, further characterization of the vertical distribution of aerosol optical properties on a long-term basis over an instrumented surface site is needed to adequately assess the utility of surface in situ aerosol measurements for climate change research.

Vertical distributions of aerosol optical properties were measured over the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site using the light aircraft, Cessna C172N. The aircraft flew 133 profile flights between March 2000 and March 2001 to obtain a statistically representative data set of in situ aerosol vertical profiles. For each profile flight, the Cessna flew nine level legs over (or near) the U.S. Department of Energy (DOE)/CART site. The legs were flown at altitudes of 467, 610, 915, 1220, 1525, 1830, 2440, 3050, and 3660 m asl and flights were made several times each week.

Instrumentation on the aircraft was similar to that at the surface SGP site (elevation 315 m asl) so measurements at the surface and aloft could be easily compared. Measured parameters included total light scattering (σ_{sp}), hemispheric backscattering (σ_{bsp}), and absorption (σ_{ap}) coefficients. Derived parameters included single scattering albedo ($\sigma_{sp}/(\sigma_{sp}+\sigma_{ap})$), backscatter fraction (σ_{bsp}/σ_{sp}), and the wavelength (λ) dependent Ångström exponent ($\ln(\sigma_{sp,1}/\sigma_{sp,2})/\ln(\lambda_2/\lambda_1)$).

Figure 1 shows scatter plots of extinction ($\sigma_{ext} = \sigma_{ap} + \sigma_{sp}$) and single scattering albedo for the lowest level flight leg versus those at the surface. There is agreement between the lowest level leg and surface extinction data (Figure 1a), indicating that submicrometer aerosol (predominantly scattering aerosol) in the 150 m above the surface is well mixed. The comparison is not quite as good for single scattering albedo (Figure 1b). This is due to measured differences in absorption between the surface and the lowest flight level. These observed differences appear real because side-by-side tests of the two particle soot absorption photometers (PSAPs) show good agreement (within 8%). Comparison of other derived properties at the lowest flight level with surface properties are excellent for backscatter fraction and green-blue Ångström exponent, but less so for the green-red Ångström exponent.

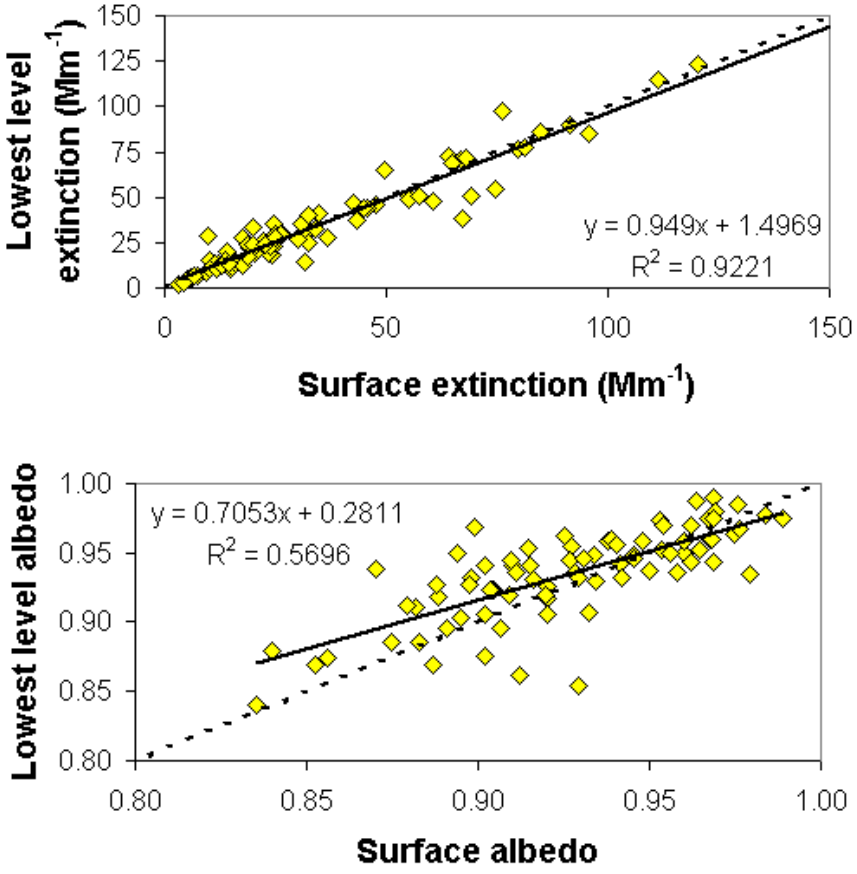

Figure 1. Scatter plots of lowest level leg versus surface measurements; (a) extinction and (b) single scattering albedo.

Figure 2 shows the medians and ranges (as indicated by percentiles) of aerosol optical properties (at standard temperature and pressure, low relative humidity, particle diameter <1 μm) obtained at the surface and during vertical profiling flights. The line in the center of the box represents the median, while the edges of the box give the 25th and 75th percentiles, and the whiskers are the 5th and 95th percentiles. Median absorption and scattering coefficients vary up to a factor of 3, while the medians for derived aerosol properties (single scattering albedo, backscatter fraction, Ångström exponent) are much less variable (less than 10% variation). Figure 2 suggests the median values of absorption and scattering tend to decrease with altitude from the surface upward. Such behavior is expected as distance from the ground-based sources of aerosol particles increases. The median values of the derived properties do not display a functional dependence with altitude.

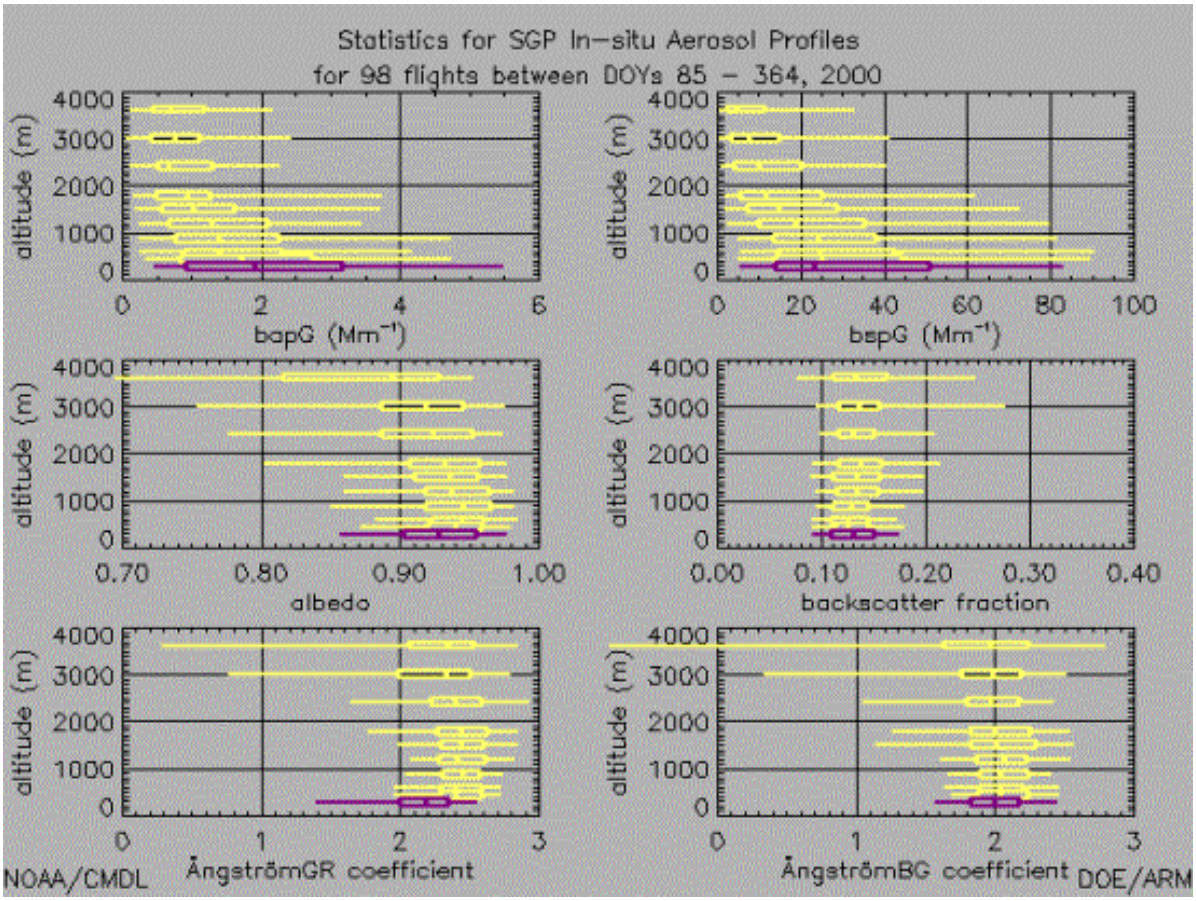

Figure 2. Statistical plots of aerosol optical parameters with altitude. The line through the middle of the box represents the median or 50th percentile; the edges of the box represent the 25th and 75th percentiles and the ends of the 'whiskers' represent the 5th and 95th percentiles. The yellow data are aircraft measurements, while the pink data are surface measurements. (DOY is Day of Year; bapG is the absorption coefficient at 550 nm; bspG is the scattering coefficient at 550 nm.)

More indicative of the overall variability of the aerosol are the ranges of the parameters, as indicated by the percentiles in Figure 2. Absorption and scattering can differ up to 2 orders of magnitude between flights and even between individual levels of the same flight. The derived properties, while still

displaying a range of values, vary at most by an order of magnitude (i.e., green-red Ångström, level 3660 m) but more commonly by less than a factor of 2. The parameter ranges display different tendencies with height. Scattering and absorption coefficients become less variable at higher altitudes due to consistently low concentrations of aerosol particles. Derived properties become more variable with altitude for a similar reason: low concentrations of aerosol particles result in more noise when calculating the values of these parameters.

Despite the statistical consistency with altitude shown in Figure 2, the correlations between column average and surface values are lower than correlations between lowest flight level and surface values. Figure 3 shows scatter plots of column average extinction and column average single scattering albedo versus surface values. Differences in absorption coefficients measured between the surface and lowest flight level are the major contributor to poor correlations in single scattering albedo. These results suggest that surface aerosol measurements may not be representative of the column average on any given day.

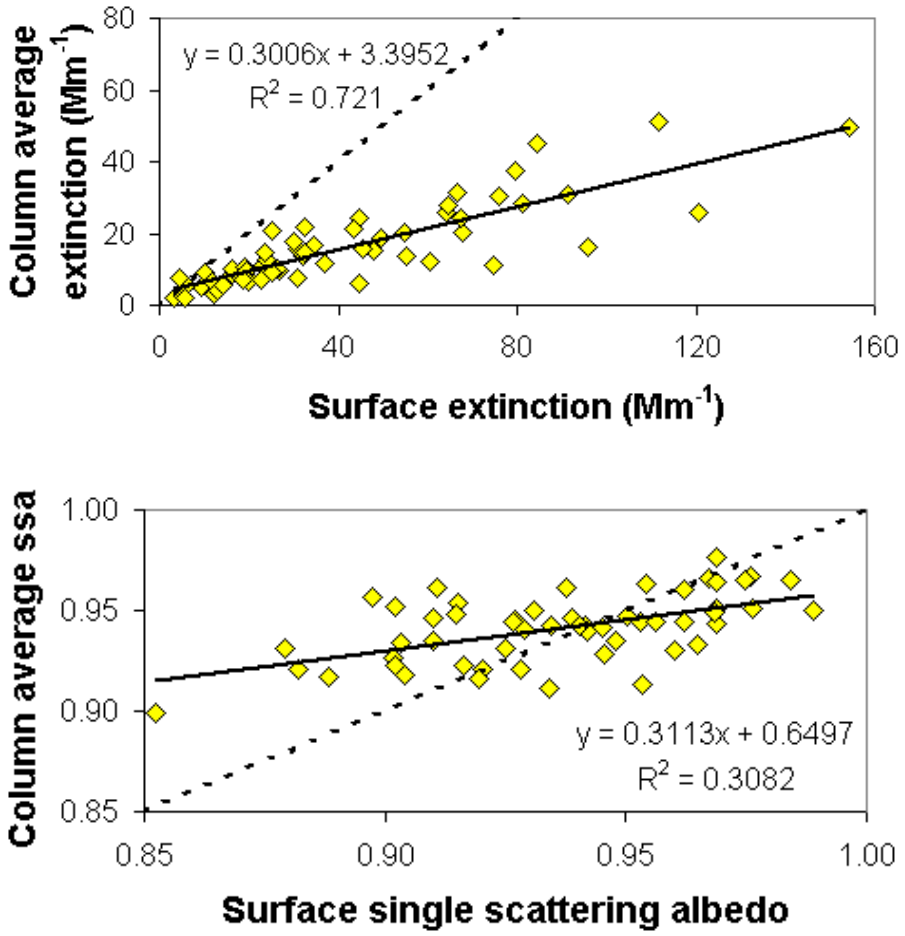

Figure 3. Scatter plots of column average aerosol optical properties versus surface aerosol optical properties; (a) extinction coefficient (R^2 = 0.92 if line forced through origin) and (b) single scattering albedo (R^2 = 0.46 if line forced through origin).

Measurements from the profile flights can also be compared with measurements by remote sensing instruments located at SGP (i.e., the Cimel sun/sky radiometer and the multi-filter rotating shadowband radiometer [MFRSR]). Comparison of Aerosol Optical Depth (AOD) (Figure 4) calculated from aircraft measurements with AOD obtained from the remote sensing instruments shows fair correlation (R^2 ~ 0.4 Cimel, R^2 ~ 0.8 MFRSR), although the aircraft AODs are lower than those derived from the radiation instruments. After incorporating corrections for supermicrometer, upper tropospheric and stratospheric aerosol particles, correlations between the aircraft in situ and remotely sensed AODs are much stronger (R^2 ~ 0.97 Cimel, R^2 ~ 0.87 MFRSR), although the aircraft AOD is consistently lower than the Cimel and MFRSR AODs.

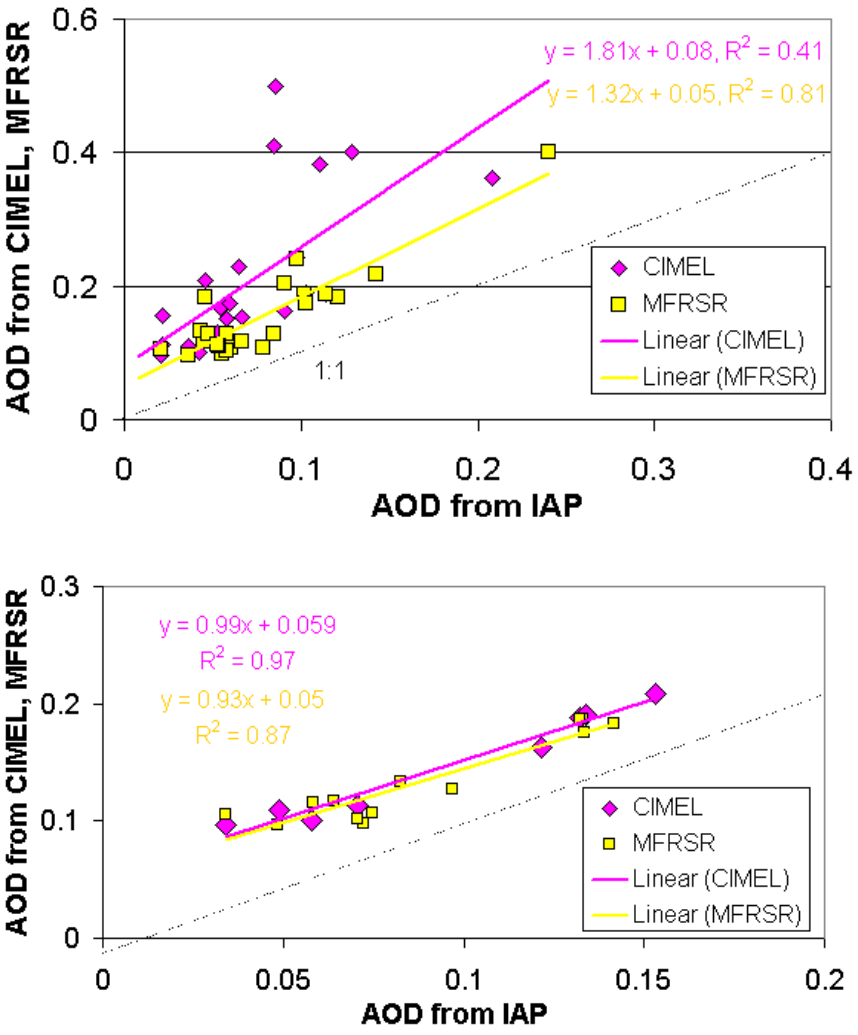

Figure 4. Scatter plots of AOD calculated from the Cimel sunphotometer and MFRSR versus the AOD calculated from in situ aircraft measurements. (a) Aircraft measurements at ambient temperature, pressure, relative humidity; and (b) aircraft measurements at ambient temperature, pressure, relative humidity and adjusted for supermicrometer, upper tropospheric and stratospheric aerosol. Note there are fewer points in Figure 4b because Lidar data did not exist for all the comparison days; for the days without Lidar, the upper tropospheric aerosol could not be adjusted for.

Long-term surface measurements can represent statistical distribution of aerosol properties aloft. However, day-to-day variability between the surface and aloft may not always be captured and causes a poor relationship between surface and column average quantities. Comparison of the in situ and remote sensing instruments shows good correlation for AOD, although the aircraft AOD is consistently lower than that of the remote-sensing instruments.

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