Four Years of Continuous Surface Aerosol Measurements from the DOE/ARM Southern Great Plains CART Site

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Introduction

Continuous measurements of the optical and microphysical properties of aerosol particles have been made at the U.S. Department of Energy's (DOE's) Atmospheric Radiation Measurement (ARM) Program Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site covering the 4-year period from July 1996 through June 2000. The Aerosol Observing System (AOS) is housed in a single trailer at the SGP CART site Central Facility and samples atmospheric aerosols at a height of 10 m above the ground through a large-diameter intake stack. Aerosols are passed from the stack through a manifold and into several sampling lines that deliver sample air to the various instruments. Figure 1 is a schematic of the AOS showing stack, sampling lines, manifold, and instruments. Major upgrades were performed in early 1997 to permit switching between different aerosol size ranges and again in late 1998 with the addition of a second integrating nephelometer to determine the change in light scattering associated with changes in relative humidity.

Aerosol Measurements

Measurements of the microphysical, chemical, and optical properties of atmospheric aerosol particles are made by the AOS. The sample air stream is gently heated when necessary to maintain a sample relative humidity of < 40 percent. A switched inertial impactor system periodically removes particles larger than 1 μm aerodynamic diameter, resulting in $D_p < 1$ μm (submicrometer) and $D_p < 10$ μm aerosol size fractions. Table 1 provides the details of AOS instruments and measurements and shows definitions for all measurement symbols and acronyms. From the primary light scattering and absorption measurements, a number of derived quantities, many of which are important for aerosol radiative forcing estimates, are calculated. These quantities include the aerosol single-scattering albedo, ω_0, the hemispheric backscatter fraction, b, the Ångström exponent, å, the fraction of light scattering attributable to submicrometer particles, R_{sp}, and the aerosol hygroscopic growth factor, f(RH). In addition to our

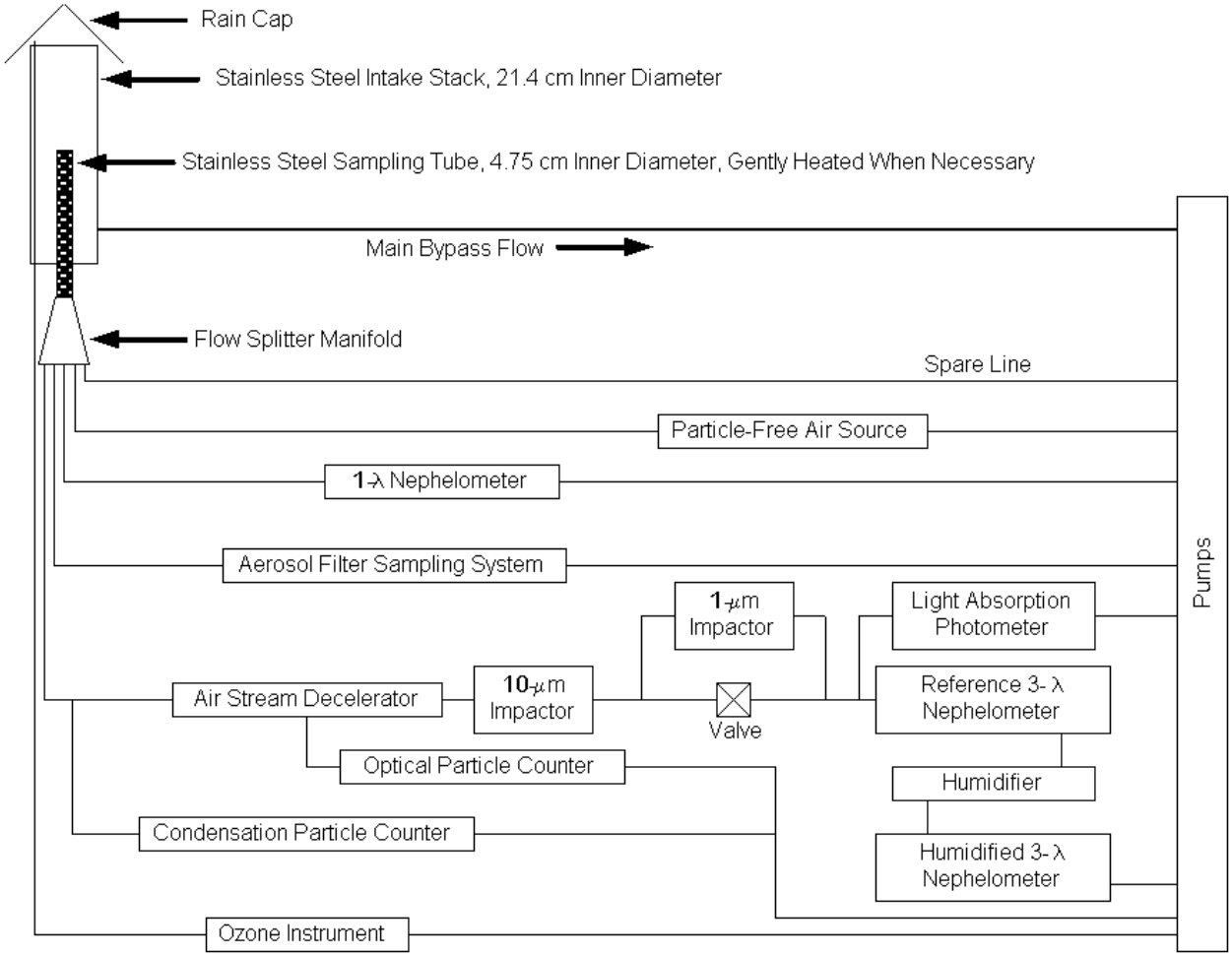

Figure 1. Schematic of the aerosol observing system.

aerosol measurements listed in Table 1, daily filter samples of $D_p < 1$ μm particles are collected and analyzed by researchers at National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratories. This practice permits relating the chemical properties of the aerosols to their optical and microphysical characteristics.

Results

Hourly, daily, and monthly statistics have been calculated that illustrate aerosol variability over a range of time scales. In general, aerosol distributions plotted by day of the week showed little variability from one day to the next, suggesting that day-of-the-week has only a minor influence on the observed aerosol variability. Some parameters, including condensation nucleus (CN) and σ_{ap}, showed appreciably lower values in their distributions on Sunday and Monday than on the rest of the week, possibly from reduced vehicular traffic or less agricultural burning in the area on the weekends. Other parameters showed distribution values for Sunday and Monday that were either slightly lower or nearly identical with those from the other weekdays. Daily and annual aerosol cycles are discussed in following section.

Table 1. Instruments and atmospheric measurements made at the ARM/SGP AOS.

Instrument	Primary measurements	Derived measurements
TSI Model 3563 three-wavelength, backscatter/ total scatter integrating nephelometers, operated at both low (< 40%) and variable (~ 40-90%) relative humidity	Total scattering and hemispheric backscattering coefficients (σ_{sp} and σ_{bsp}) from $D_p < 1$ μm and $D_p <$ 10 μm particles at 450, 550, and 700 nm.	Hemispheric backscatter fraction, $b = \sigma_{bsp}/\sigma_{sp}$ Ångström exponents, $å = -\log[\sigma_{sp}(\lambda_1)/ \sigma_{sp}(\lambda_2)]/\log[\lambda_1/\lambda_2]$ Single scattering albedo, $\omega_0 = \sigma_{sp}/(\sigma_{sp} + \sigma_{ap})$ Submicrometer scattering fraction, $R_{sp} = \sigma_{sp\ (1\text{-}\mu m)}/ \sigma_{sp\ (10\text{-}\mu m)}$ at 550 nm Hygroscopic growth factor, $f(RH) = \sigma_{sp(RH=85\%)}/\sigma_{sp(RH=40\%)}$
Radiance Research Model M903 single wavelength integrating nephelometer	Total scattering coefficients from particles, σ_{sp}, at 545 nm	
Radiance Research Model PSAP particulate light absorption photometer	Light absorption coefficient (σ_{ap}) from $D_p < 1$ μm and $D_p < 10$ μm particles, at 550 nm[(a)]	Single scattering albedo, ω_0, at 550 nm
TSI Model 3010 condensation nucleus counter	Total particle concentration over the range 0.01-3 μm diameter (CN)	None
Particle Measuring Systems Model PCASP-X optical particle spectrometer	Particle concentration in each of 31 size ranges between 0.1-10 μm	Particle size distributions (number, surface area, volume, mass)
Dasibi Model 1008-RS ozone monitor	Ozone mixing ratio	None

(a) PSAP instrument uses 565 nm incident radiation to determine the absorption coefficient. These data are corrected to 550 nm through the use of the calibrations found in Bond et al. (1999).

Daily Aerosol Cycles (July 1996 to June 2000)

Statistical distributions of hourly-average, $D_p < 10$ μm aerosol data collected over the 4-year period and grouped by hour of the day are presented in Figure 2. The ends of the boxes, the ends of the whiskers, and the shorter line across each box represent the 25th and 75th percentiles, the 5th and 95th percentiles, and the median, respectively. The mean is represented by the longer line with ends extending well beyond the sides of the box. The distribution at the far right of each plot represents all hourly data, and the median line for that distribution is drawn across the entire plot. The vertical line at 1800 Universal Time Coordinated (UTC) is for local noon (1200 Central Standard Time).

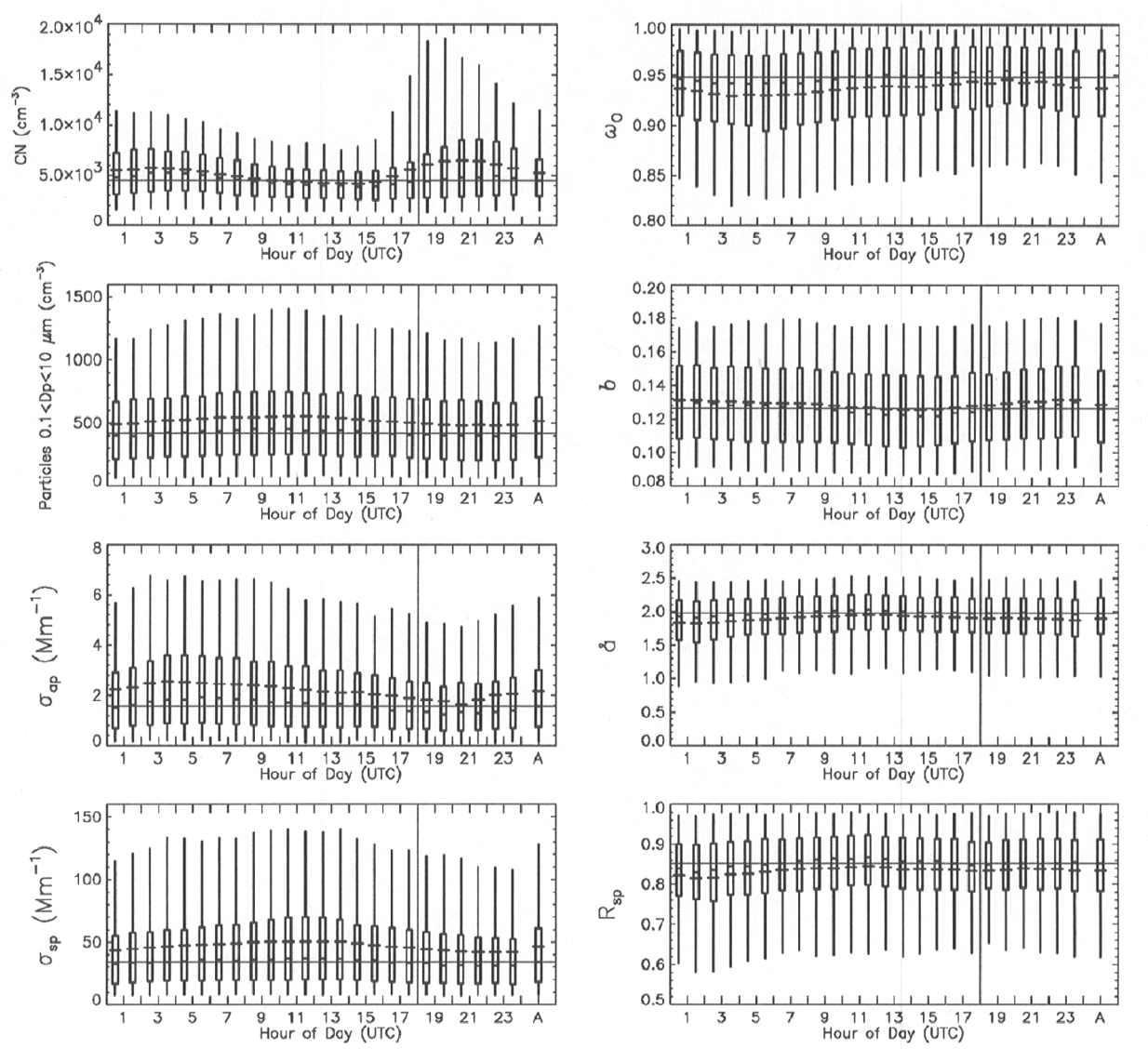

Figure 2. Statistical distributions of hourly-average, D_p < 10 μm aerosol data collected over the 4-year period and grouped by hour of the day.

A strong daily cycle was observed for total particle number, with the large peak in CN occurring during local afternoon. A different (albeit subtle) cycle was found for OPC counts (particles between 0.1 and 10 μm diameter) and σ_{sp}, with peaks between 1000 and 1300 UTC. Finally, σ_{ap} and ω_0 showed inverse cycles, which is expected if variability in σ_{ap} levels is driving the observed variability in ω_0.

Annual Aerosol Cycles (July 1996 to June 2000)

Statistical distributions of hourly-average, D_p < 10 μm aerosol data collected over the 4-year period and grouped by month of the year are presented in Figure 3. The σ_{sp} at a wavelength of 550 nm for the 4-year period showed a median value of 33 Mm^{-1} and was highest in February and August. The

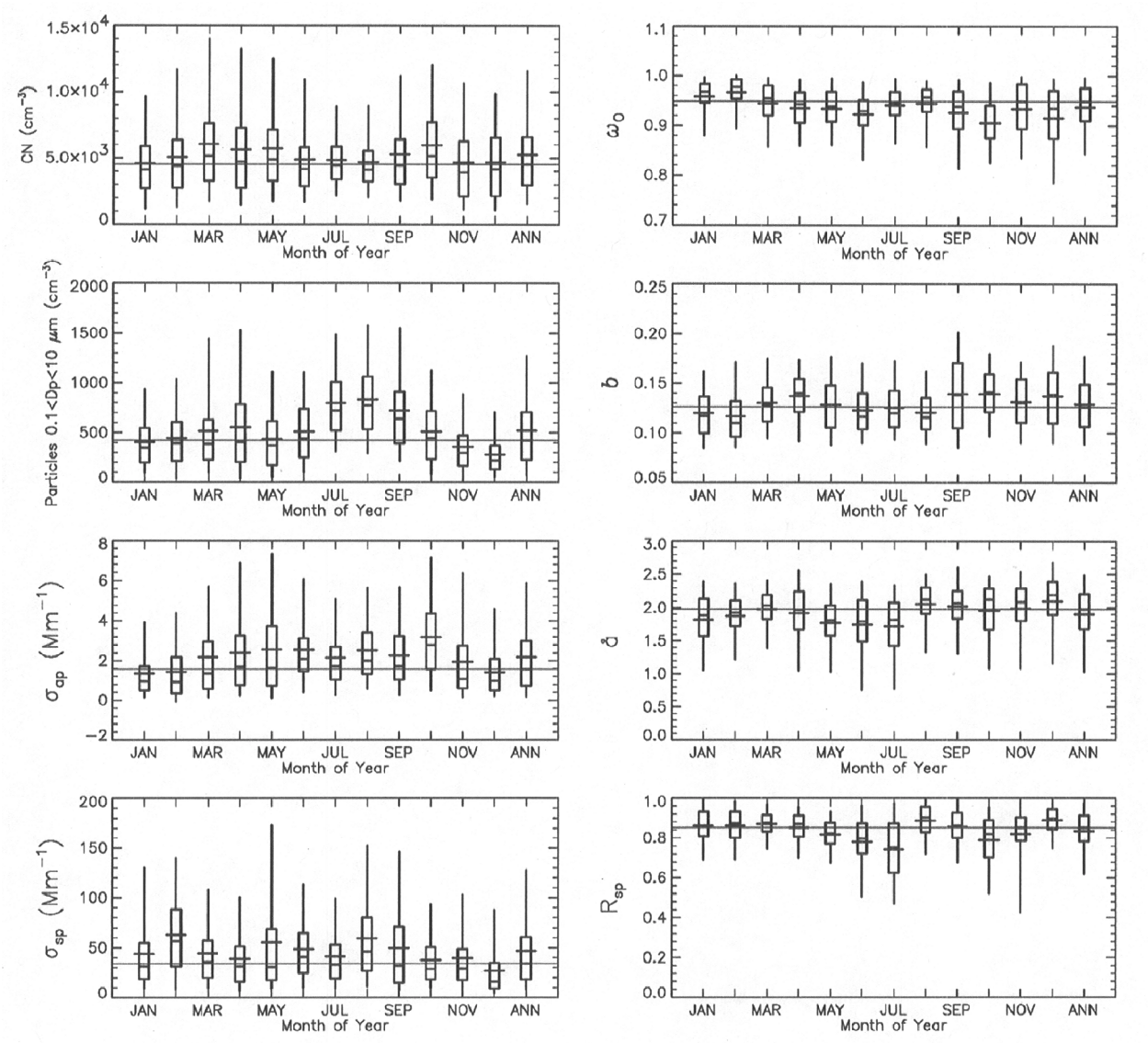

Figure 3. Statistical distributions of hourly-average, D_p < 10 μm aerosol data collected over the 4-year period and grouped by month of the year.

median fraction of aerosol light scattering at 550 nm due to particles < 1 μm aerodynamic diameter was 0.85 over the entire record. The median aerosol light absorption coefficient, σ_{ap}, for the 4-year period was ~1.5 Mm^{-1} and was observed to be highest in late summer and autumn. The σ_{ap} showed an increasing trend of nearly 0.5 Mm^{-1}/yr, possibly due to increased agricultural field burning in the area. The occurrence of an autumn decrease in single-scattering albedo, ω_0, was observed and may be caused by regional-scale agricultural, transportation activities, or seasonal changes in atmospheric flow patterns. The median value for ω_0 over the 4-year period was 0.95, but this value has decreased ~ 1 - 2 percent per year presumably due to increased agricultural burning. Numerous field fires during the second half of 1999 influenced the surface aerosol at the CART site causing substantial variability of aerosol optical properties.

Aerosol Hygroscopic Growth Factor (1999 to 2000)

Statistical distributions of hourly-average, $D_p < 10$ μm aerosol f(RH) data grouped by hour of the day (upper plot) and month of the year (lower plot) for the 2-year period from January 1999 to December 2000 are presented in Figure 4. A weak daily cycle is evident that shows higher f(RH) values during local afternoon and lower f(RH) values at night. No obvious annual cycle was observed during this period. The February minimum and December maximum are likely statistical artifacts related to instrument problems resulting in insufficient humidified nephelometer measurements at these times.

For the year 1999, a study was performed that related the aerosol hygroscopic growth factor, corresponding to a relative humidity increase of 40 - 85 percent, to several probable aerosol types. Figure 5 shows f(RH) frequency distributions for various criteria. The median f(RH) values for all $D_p < 10$ μm and $D_p < 1$ μm aerosol particles were 1.83 and 1.86, respectively. Aerosols that were probably impacted by locally-generated soil dust ($R_{sp} < 0.6$) and smoke from agricultural burning ($\omega_0 < 0.8$) showed much lower f(RH) values, at 1.59 and 1.55, respectively.

Summary

The first 4 years of continuous aerosol optical property measurements at the ARM SGP CART site have produced a wealth of surface aerosol measurements useful in evaluating aerosol radiative forcing. When analyzed statistically over various time scales, numerous aerosol cycles become apparent. Hour-of-the-day and month-of-the-year variability in aerosol properties is typically more statistically significant when related to the entire data set variability than is day-of-the-week variability. Several of the stronger aerosol cycles, including the afternoon rise in CN and the autumn decrease in ω_0, are also apparent at the rural continental aerosol-monitoring site at Bondville, Illinois (Delene and Ogren 2001). The aerosol hygroscopic growth factor showed a median value of 1.83 for $D_p < 10$ μm particles, but was much lower for probable dust- and smoke-influenced aerosols. For a more complete discussion of the aerosol variability over the first 4 years of AOS operation, please see Sheridan et al. (2001).

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References

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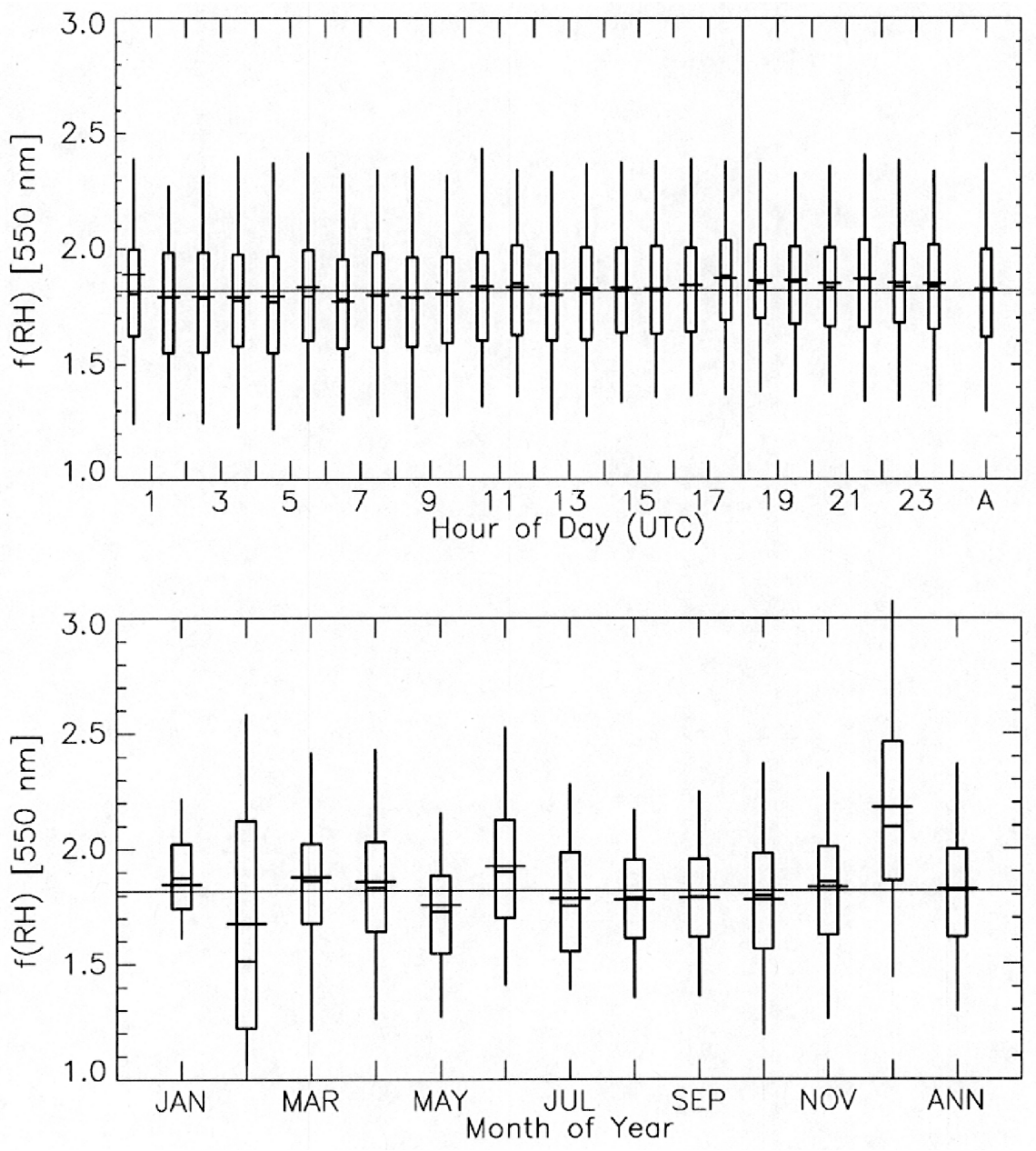

Figure 4. Statistical distributions of hourly-average, D_p < 10 μm aerosol f(RH) data grouped by hour of the day (upper plot) and month of the year (lower plot) for the 2-year period January 1999 to December 2000.

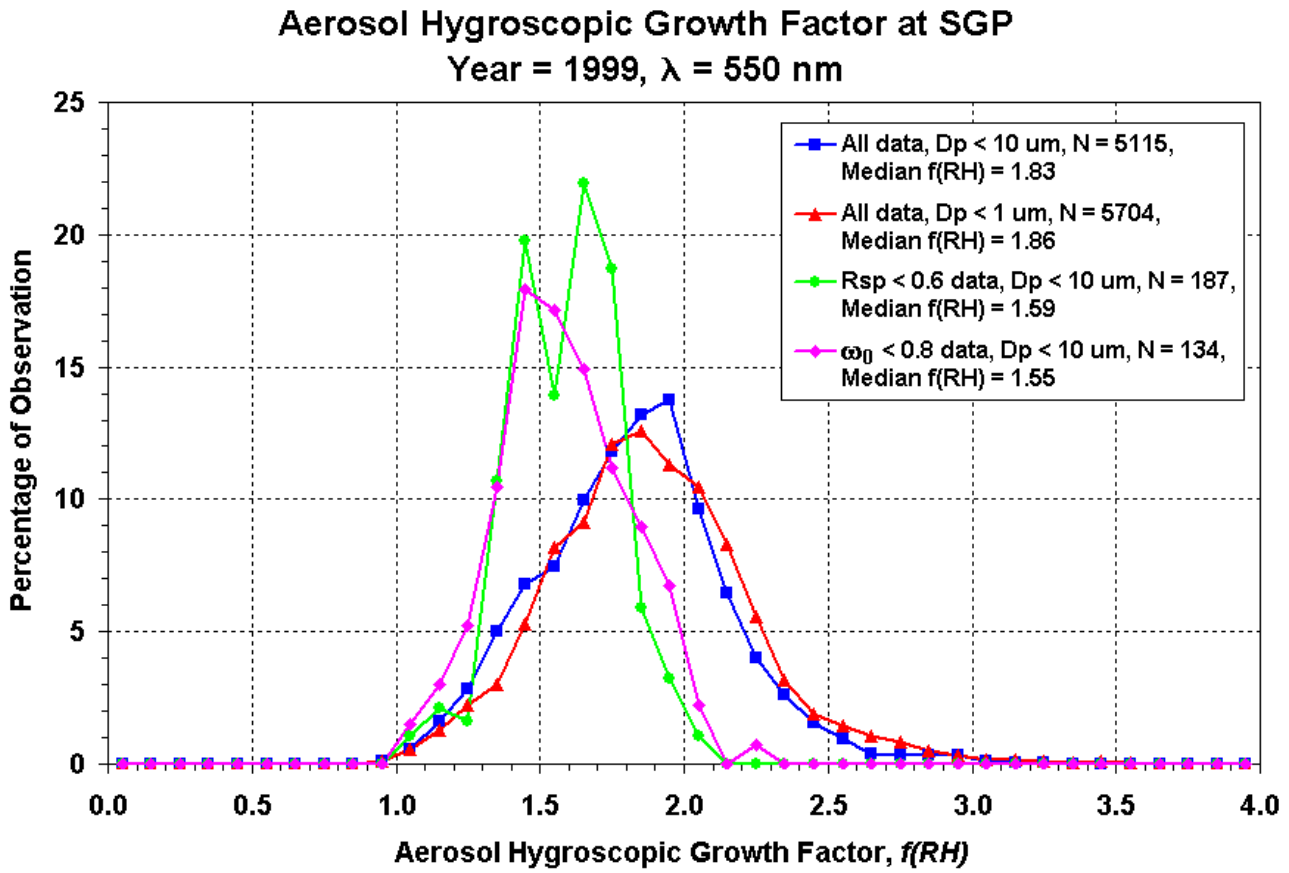

Figure 5. f(RH) frequency distributions for D_p < 1 μm particles, D_p < 10 μm particles, and for aerosols that were probably impacted by locally-generated soil dust (R_{sp} < 0.6) and smoke from agricultural burning (ω_0 < 0.8).