Testing a Cloud Condensation Nuclei Remote Sensing Method

S. J. Ghan
Climate Physics
Pacific Northwest National Laboratory
Richland, Washington

D. R. Collin
Department of Atmospheric Sciences
Texas A&M University
College Station, Texas

Introduction

Under certain conditions vertical profiles of cloud condensation nuclei (CCN) spectra can be retrieved from ground-based measurements (Ghan and Collins 2003). Surface measurements of the CCN spectrum are scaled by the ratio of the 180° backscatter (or extinction) profile to the surface backscatter (or extinction). The backscatter (or extinction) profile is measured by Raman lidar (RL), and is corrected to dry conditions using the vertical profile of relative humidity (calculated from the absolute humidity measured by RL and temperature measured by atmospheric emitted radiance interferometer (AERI) or radio acoustic sounding system and surface measurements of the dependence of backscatter (or extinction) on relative humidity. This method should be accurate up to cloud base if (a) the aerosol size distribution is independent of altitude, and (b) if the aerosol composition is independent of altitude. The Atmospheric Radiation Measurement (ARM) aerosol-working group is conducting an intensive operational period during May 2003 to test this retrieval method. In the meantime, assumption (a) can be tested using existing in situ measurements of vertical profiles of aerosol size distribution. Vertical profiles of dry backscatter, dry extinction, and CCN concentration are calculated from the aerosol size distribution measured by aircraft on selected days during the Aerosol Characterization Experiment (ACE-2) near the Azores (Collins et al. 2000). The backscatter and extinction profiles are calculated from the Mie theory using Wiscombe's (1979) Mie code, assuming a refractive index of (1.53, 0.0) and a wavelength of 355 nm (the RL wavelength). The CCN concentration is calculated from the Kohler theory using the hygroscopic properties of ammonium sulfate.

Figure 1 shows the CCN concentration at supersaturations S of 0.01%, 0.1%, and 1% plotted versus dry extinction and dry backscatter for each of 4 days during ACE-2. Each point represents a 1-minute average of samples taken between the surface and about 4 km altitude. On all days, the CCN concentration at a supersaturation S of 0.01% (which for ammonium sulfate represents the number of particles with radius larger than 300 nm micron) is highly correlated with dry backscatter. The CCN concentration is not as well correlated with aerosol extinction as it is with backscatter. The CCN concentration at S = 1% (representing the number of particles with radius larger than 14 nm) is not correlated well with backscatter or extinction, particularly on days with a dust layer overlaying a layer

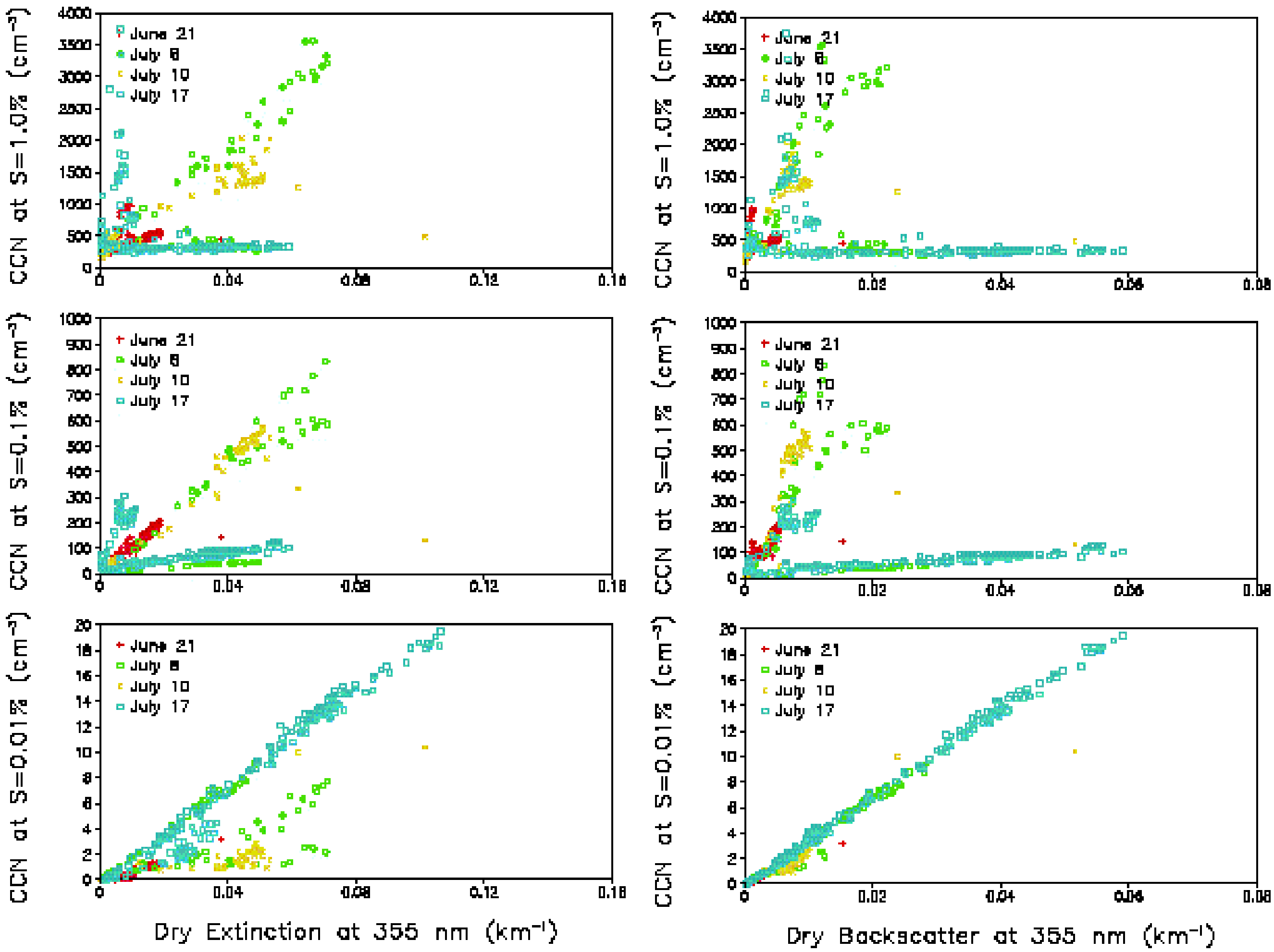

Figure 1. Scatter plot of CCN concentration at supersaturations of 0.01%, 0.1%, and 1% plotted versus dry extinction (left) and dry backscatter (right) at wavelength 355 nm for each of 4 days, during ACE-2. Each point represents a 1-minute average of samples taken between the surface and about 4 km altitude.

dominated by smaller particles. The more robust relationship between backscatter and CCN at S = 0.01% than at S = 1% arise because extinction at 355 nm is most sensitive to particles with radius between 100 and 200 nm (which are not activated at S = 0.01%), while backscatter is most sensitive to particles with radius between 300-500 nm (which are activated at S = 0.01%). The CCN concentration at S = 1% depends on particles down to radius 14 nm, so that particles with radius between 14 and 100 nm can control CCN without influencing backscatter or extinction. If the aerosol size distribution varies with altitude the proportion of particles smaller and larger than 100 nm will vary, which will influence the relationship between backscatter and CCN at S = 1%.

Figure 2 summarizes the relationship between CCN concentration and backscatter or extinction on 11 days during ACE-2. The correlation between CCN concentration and backscatter or extinction is plotted for each day and for seven supersaturations between 0.01% and 1%. Backscatter is consistently

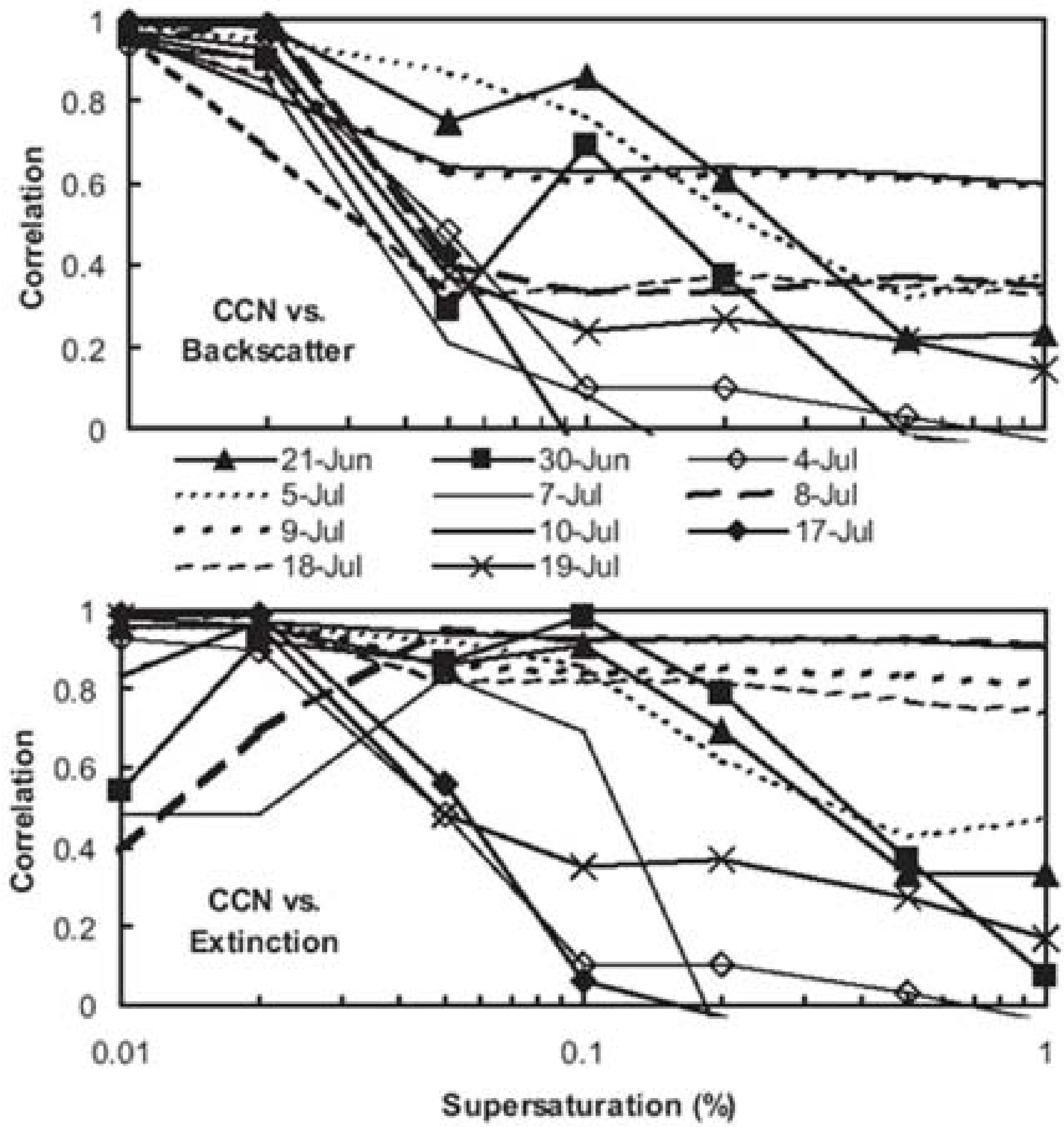

Figure 2. Correlation between CCN concentration and backscatter (top) and extinction (bottom) as functions of supersaturation for 11 days, during ACE-2.

highly correlated with CCN at S = 0.01 and 0.02%, while extinction is poorly correlated on some days. At higher supersaturations backscatter is usually poorly correlated with CCN concentration, but extinction is still well correlated with CCN concentrations on a significant fraction of the days. At S = 0.1% extinction explains at least 80% of the variance on four and at least 65% of the variance on 7 of the 11 days, and at S = 1% it explains more than 80% of the variance on two and more than 55% to 65% of the variance on four of the 11 days. Thus, on many days, the retrieval can provide CCN profiles that are significantly more accurate than estimates from the surface CCN concentration alone, but on other days it cannot.

RL measurements of the extinction/backscatter ratio can be used to quantify how uniform the size distribution is. Figure 3 shows the ratio plotted versus altitude for the same samples as in Figure 1. On July 8 and July 17, the ratio is remarkably uniform between altitudes 1800 and 3700 m. However, the ratio is much larger at the surface, which suggests that the size distribution aloft is quite different from that at the surface. Moreover, since neither extinction nor backscatter is sensitive to particles smaller than 100 nm radius, uniformity of the extinction/backscatter ratio does not necessarily mean CCN concentration can be scaled by the profiles of extinction or backscatter. Extinction and backscatter are unlikely to be useful as proxies for CCN at S = 1% unless the distribution of number is dominated by sizes larger than 100 nm.

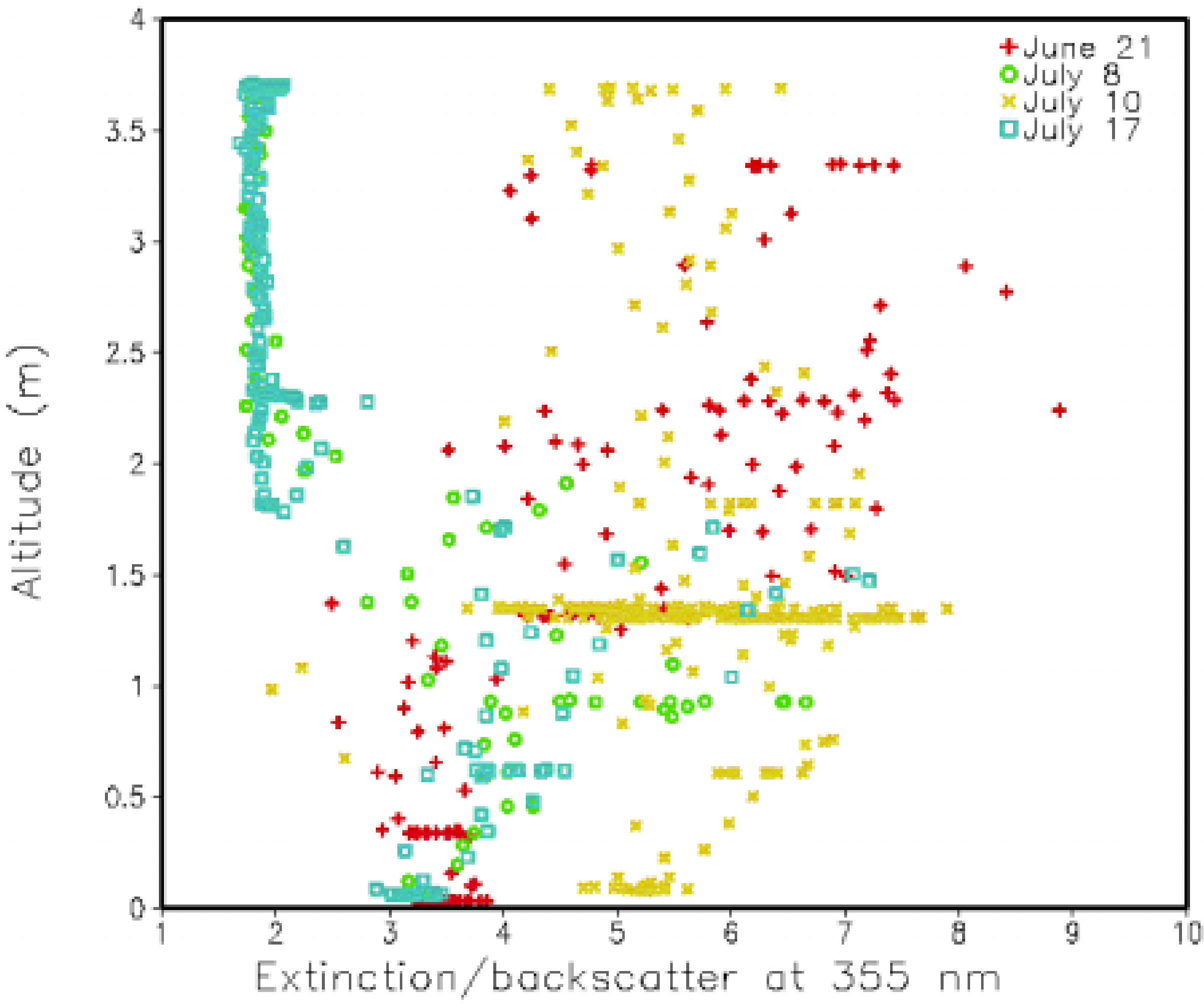

Figure 3. Extinction/backscatter ratio at 355 nm plotted versus altitude for each of 4 days, during ACE-2.

References

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