CHARACTERIZING CCN SPECTRA TO INVESTIGATE THE WARM RAIN PROCESS

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The objective of the RICO (Rain in Cumulus over the Ocean) project was to characterize shallow precipitating Caribbean cumulus clouds. These clouds are known to be ubiquitous over most of the tropical oceans and understanding them is vital to the estimation of the global heat, radiation and moisture budgets. In the broadest sense, studying the nature of the trade wind cumulus from the microphysical scale to the large scale with particular emphasis on the onset of precipitation was one of the most important objectives of RICO.

The properties of environmental aerosol are known to affect the dependence of trade-cumulus on microphysical and radiative processes. At the microphysical/cloud scale, the measurement of aerosol, CCN in particular is very critical to the evaluation of all hypotheses that explain the onset of precipitation. The best way to describe the cloud forming properties of aerosols is from their activity spectrum. This activity spectrum is defined by the number of particles per unit volume that are activated to become cloud droplets as a function of supersaturation (Rogers and Yau 1989). The DRI CCN spectrometers produce such activity spectra by increasing supersaturation field in a diffusion cloud chamber. These spectra enable the comparison of cloud formation in a controlled environment (inside the cloud chamber) with that of the atmosphere by comparisons of CCN spectra with the actual cloud droplet concentration. In theory, CCN spectra provide all information that is needed about aerosols to predict and determine their effects on clouds such as changes in cloud albedo and precipitation efficiency. It is suggested that if the CCN number concentration matches the cloud droplet concentrations(N_c), then the effective S (S_{eff}) of the cloud can be determined (Hudson and Yum 2001). Thus, CCN measurements enable us to study the effects of aerosols on the cloud microphysical properties and isolate them from complex cloud dynamic processes.

During RICO, aerosol measurements were made by the two DRI CCN spectrometers to analyze their distribution and properties. Use of two instruments ensured redundancy and enabled in-flight calibrations without interrupting ambient measurements. These instruments have the advantage of the extension of the traditional CCN (Aitken) range below 0.1% to include Large Nuclei which is necessary because a large proportion of CCN have S < 0.1%. Large Nuclei may be embryos for precipitation and also provide interface with Giant Nuclei measurements. CCN measurements are very challenging and somewhat controversial. Hence, comparisons of two CCN spectrometers operating at different supersaturation (S) ranges (Figure 1) suggest validity of CCN measurements over the full extended S range. These measurements include more than 180 flight hours from 19 flights over a two month period in the western Atlantic near the northeastern corner of the Antilles (Antigua and Barbuda) in December and January (2004-5).

During 17 of these flights there were two hours of subcloud measurements at constant altitudes. Table 1 shows a partial list of averages and standard deviations of the total particle (CN) and CCN concentrations at three supersaturations (S). Concentration of ambient CCN (Cloud Condensation Nuclei) as compared to CN (Condensation Nuclei) determines the proportion of aerosols that can be activated at low supersaturations typical in natural clouds. Thus, the cumulative CCN concentration measured against the total CN concentration in a cloud is a measure of the relative efficiency of a cloud to nucleate particles that grow into droplets. Table 1 also shows major variations in the total concentrations and standard deviations. This implies that even in clean maritime air there is some significant day-to-day variability in concentrations, which seems to be related either to wind velocity or to cloudiness. It seems to suggest long- range transport of continental aerosol. Indeed vertical profiles (Figure 2) suggest that cloud scavenging in the middle levels, where there were usually cumulus clouds reduced CCN and CN

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concentrations. Measurements of the sizes of CCN and volatility measurements suggest that the maritime CCN in RICO are composed of completely soluble material, which is consistent with ammonium sulfate or NaCl measurements (Fig.3) and with Hudson and Da(1996). Volatility measurements suggest that most CCN in the boundary layer are not NaCl. CCN are even more volatile at higher altitudes (even less NaCl). Preliminary analysis of the RICO data shows low concentrations of CCN near the surface (Fig. 4) which is characteristic of clean maritime air. Figure 4 also validates the measurements by showing good agreement between data from the two instruments. Comparisons with recent field projects in more polluted air (MASE-California) showed that CCN in clean maritime air have smaller size ranges as compared to polluted air (Hudson and Mishra, 2006).

References

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Table 1. Concentrations measured during RICO

Date	CN	CCN 1%	CCN 0.1%	CCN 0.04%
Dec. 7	--	220± 60	45±18	12± 8
Dec. 16	385±193	234±203	49±28	15±13
Dec. 17	163± 94	45± 16	20± 8	8± 5
Dec. 19	202± 37	93± 19	56±16	29±12
Jan. 5	297±134	121±107	48±46	27±14
Jan. 7	272±269	100± 64	28±12	12± 8
Jan. 11	194± 73	86± 35	24± 8	8± 4
Jan. 12	193± 19	131± 18	71±11	28± 9
Jan. 14	221± 63	115± 21	54±11	23± 7
Jan. 16	165± 30	83± 20	38±10	15± 6
Jan. 23	281± 28	129± 20	52±12	25± 9
Jan. 24	323± 91	121± 40	36±22	13±11

Average and standard deviaitions of total particle (CN) and cumulative CCN concentrations during low altitude horizontal legs of 1-hour duration.

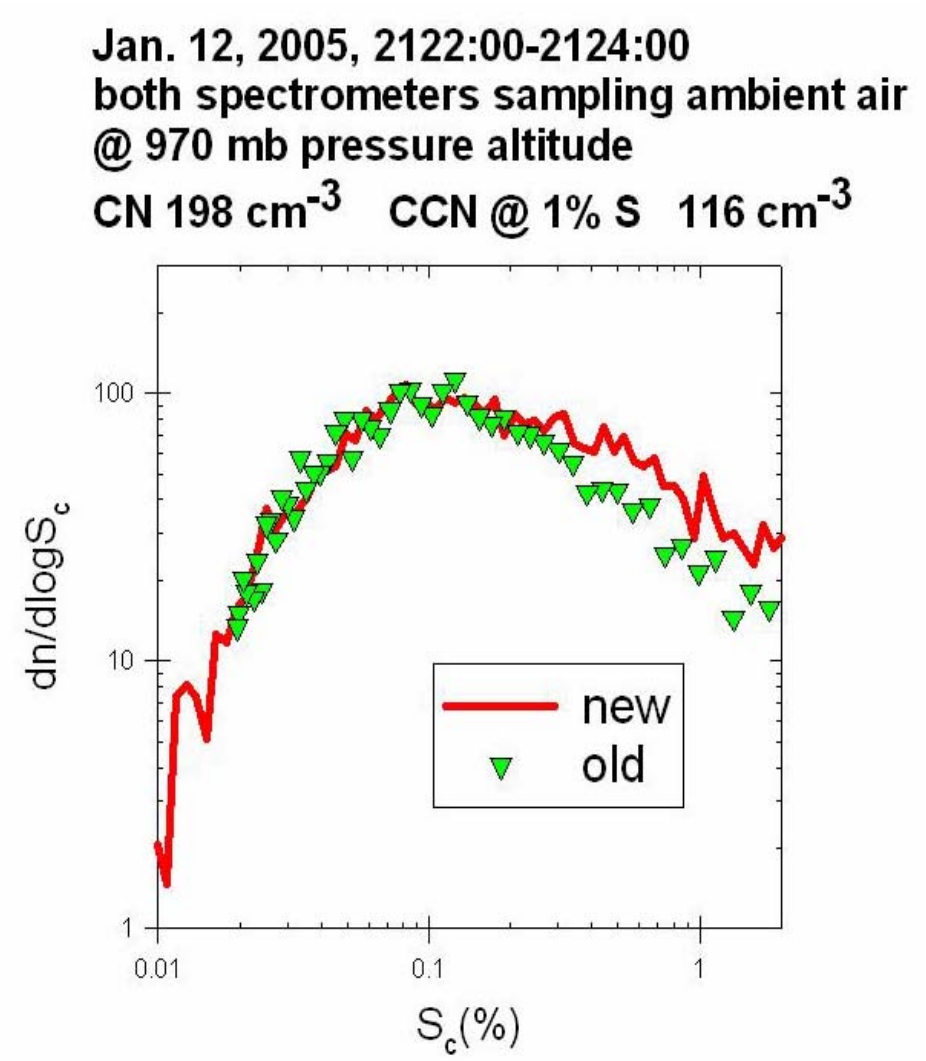

Figure 1: Comparison of CCN spectra from the two DRI instruments over the entire S range (.01%-2%S)

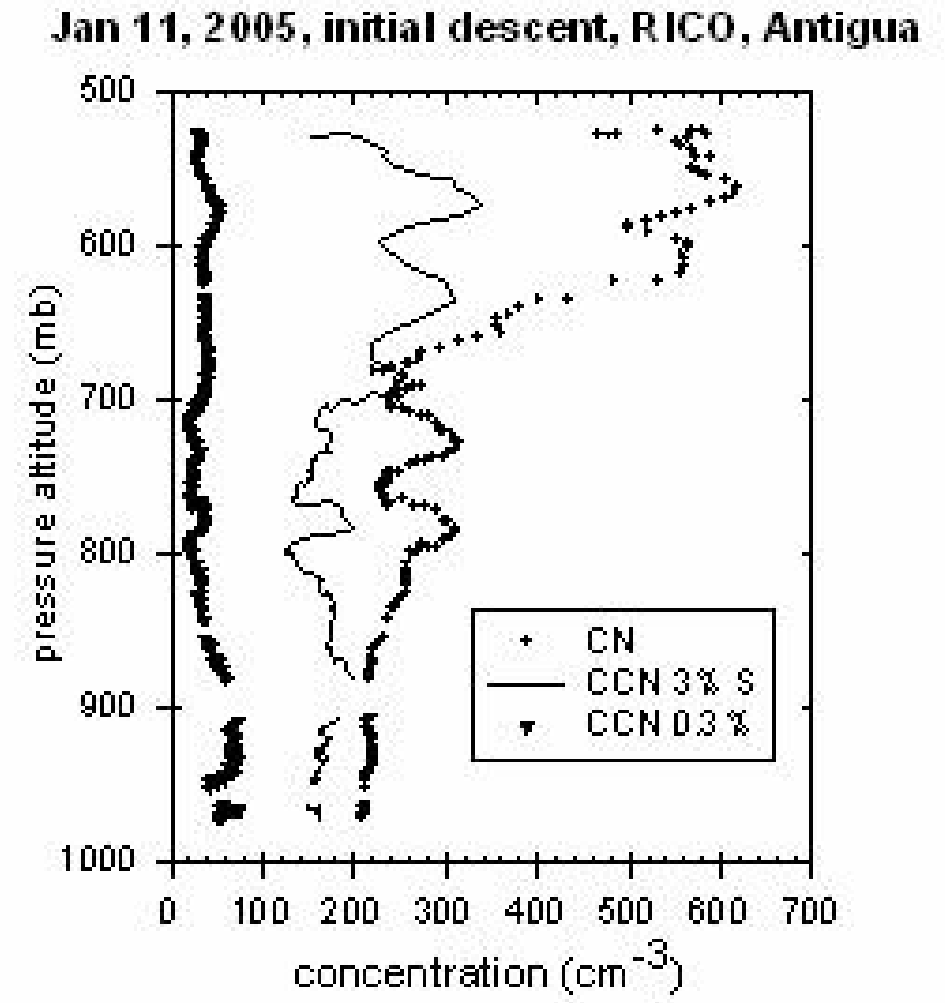

Figure 2: Total particle (CN) and cumulative CCN concentrations during a sounding

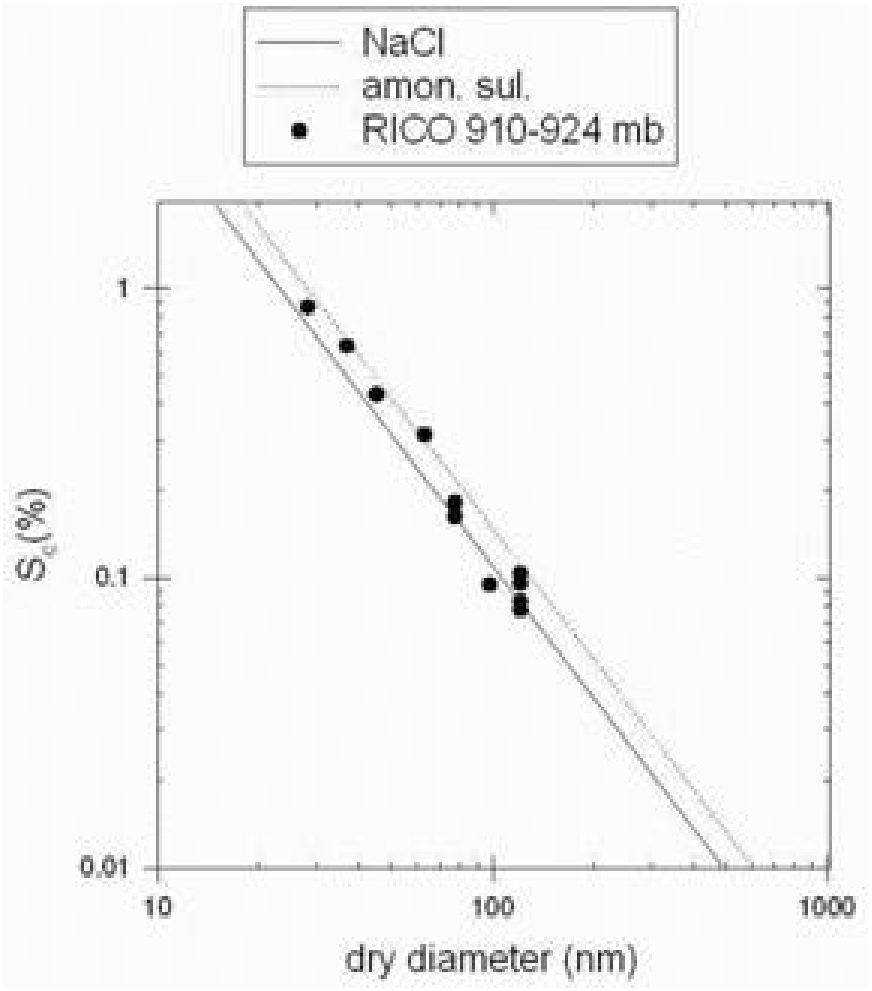

Figure3: Sizes of CCN measured in RICO. Also plotted is the theoretical versus critical supersaturation (Sc) relationship

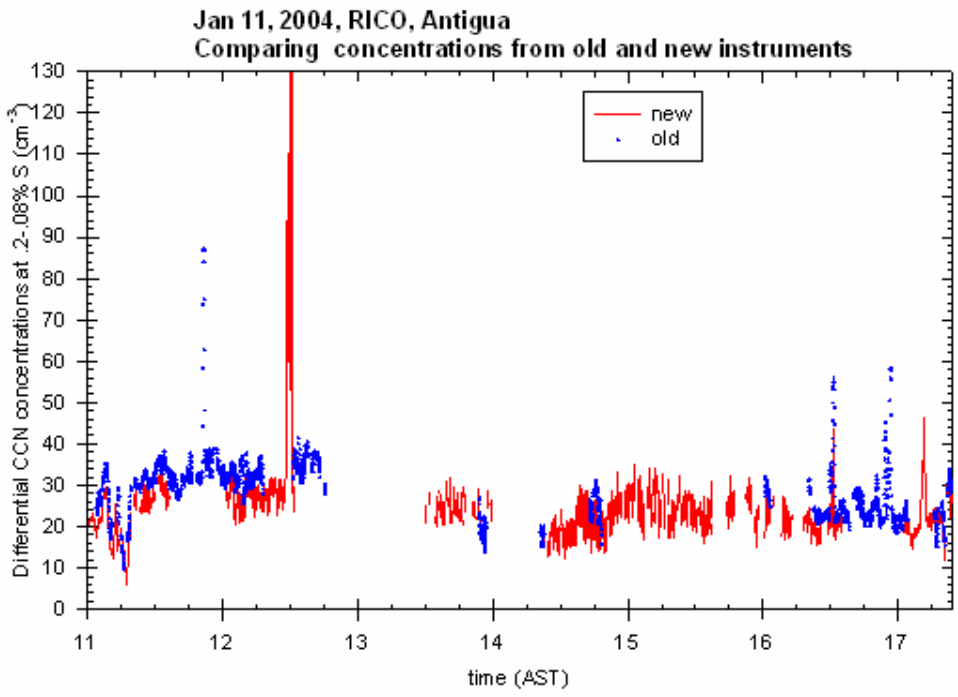

Figure 4a

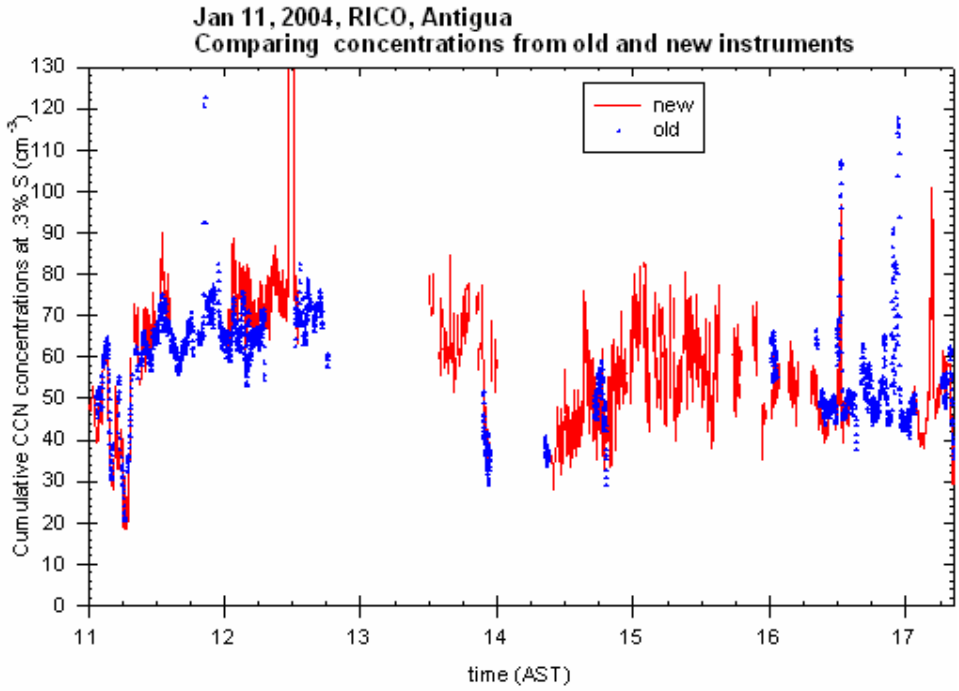

Figure 4b

Figure 4 a, b: Time plots of differential and cumulative CCN concentrations within the same overlapping S range as obtained simultaneously by the two DRI CCN spectrometers each operating over different S ranges. Gaps in the time plots are due to calibration and in-cloud measurements.