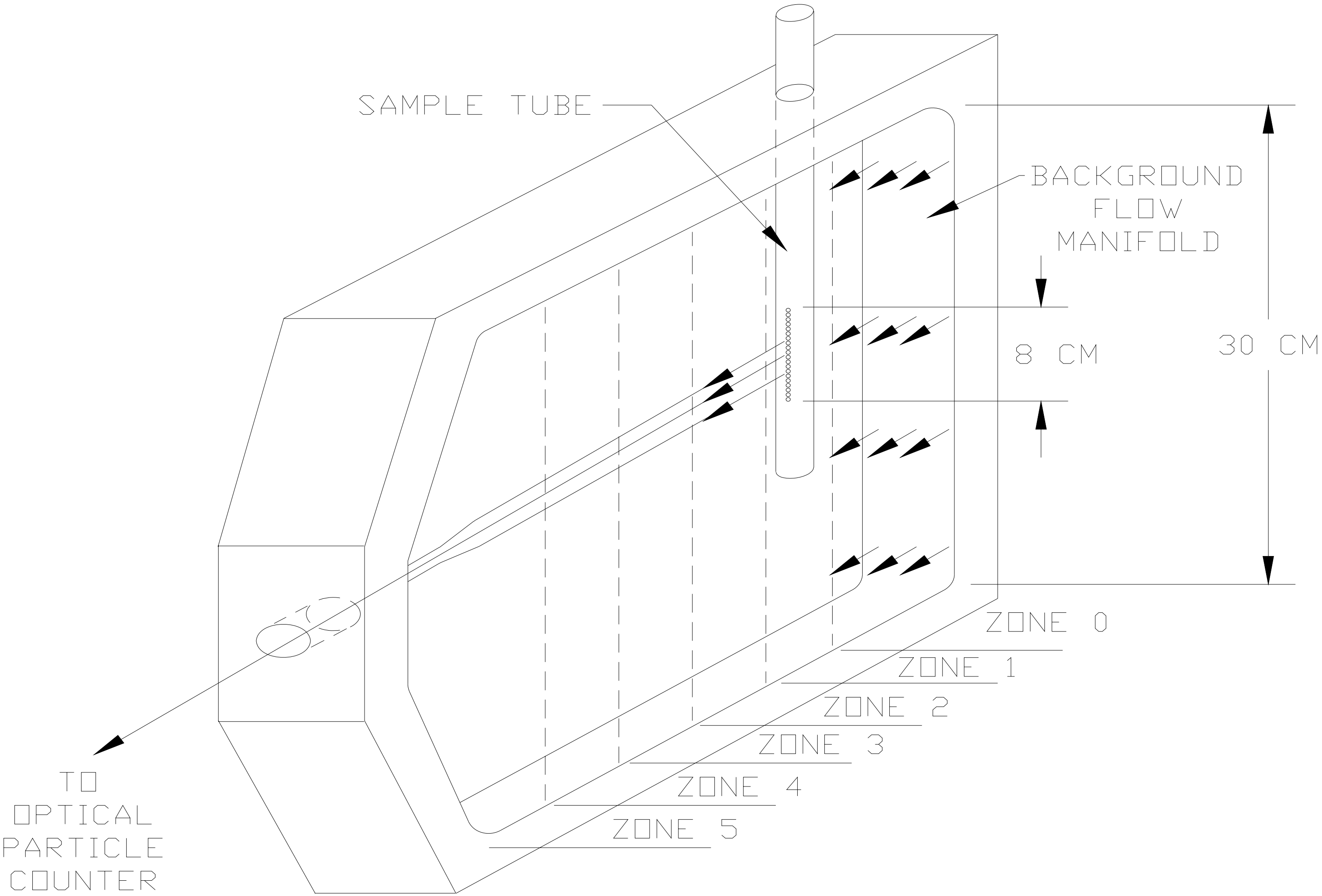
Cloud Condensation Nuclei (CCN)—water-soluble particles that cloud droplets condense upon.
10-1000 nm or 0.01-1 µm or 10^{-6}-10^{-4} cm.

CCN concentrations vary from 1-10^{5} cm^{-3}
CCN determine cloud droplet (5-50 µm) concentrations, which vary from 1-10^{4} cm^{-3}
CCN are amplified by cloud condensation from 10 to 10,000 nm (0.01 to 10 µm). Thousand in size, million in surface area, billion in volume!


SAMPLE TUBE
BACKGROUND FLOW MANIFOLD
8 CM
30 CM
ZONE 0
ZONE 1
ZONE 2
ZONE 3
ZONE 4
ZONE 5
TO OPTICAL PARTICLE COUNTER

DRI Cloud condensation nuclei (CCN) spectrometers.

Produce a field of supersaturations (S) by thermal diffusion of temperature and water vapor between two parallel plates, where cloud droplets grow on hygroscopic sample particles.

More hygroscopic (e.g., larger) particles produce larger cloud droplets.

Continuous flow through the cloud chamber (~30s) then into an optical particle counter (OPC). CCN spectrum is deduced from the OPC droplet spectrum. A calibration curve relates OPC droplet size to particle hygroscopicity (critical supersaturation—S_c).

Calibration is done with nuclei of known composition (e.g., NaCl) and size (differential mobility analyzer—DMA—electrostatic classifier--EC).

Assumes that all CCN with the same S_c regardless of composition (or size) produce the same droplet sizes. Calibration holds only if all chamber parameters (i.e., flows and temperatures) remain constant.

S_c inversely proportional to number of soluble ions. Traditionally CCN plots are cumulative because clouds act cumulatively on the aerosol— all nuclei with S_c < cloud S produce “activated” cloud droplets.

Also previous CCN instruments had too few data points to produce a differential spectrum.
DRI CCN spectrometers have enough data points to produce differential spectra.

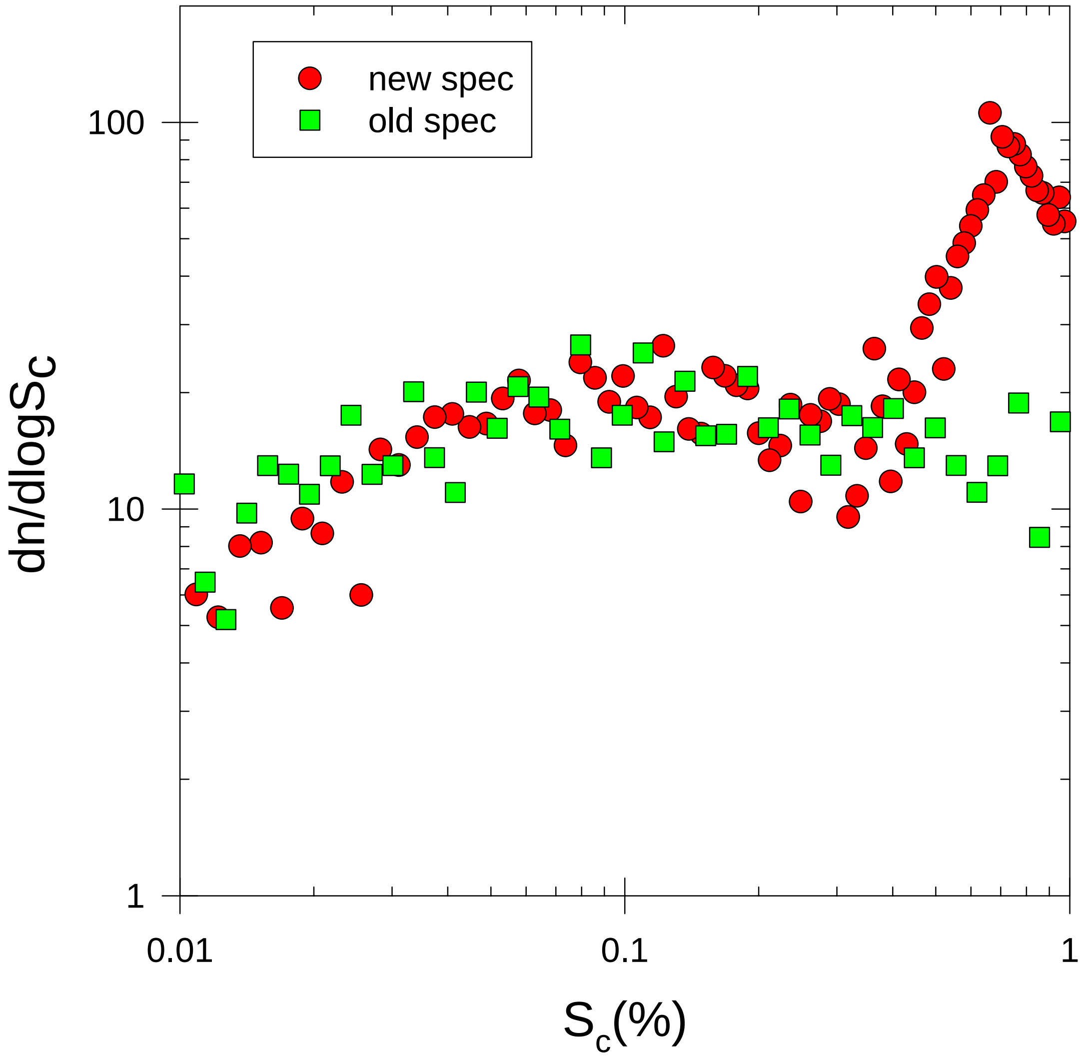
1% S_c -- 25 nm NaCl

0.1% S_c -- 110 nm NaCl

0.02% S_c – 310 nm NaCl

other compositions must have larger sizes for the same S_c.

Dec 10, 2004 1226:00-1228:00 AST (1626:00-1628:00)
C-130 RICO, Antigua 946 mb
CN 194 cm^{-3} CCN @ 1% 47 cm^{-3}



1. Simultaneous high time resolution CCN spectra

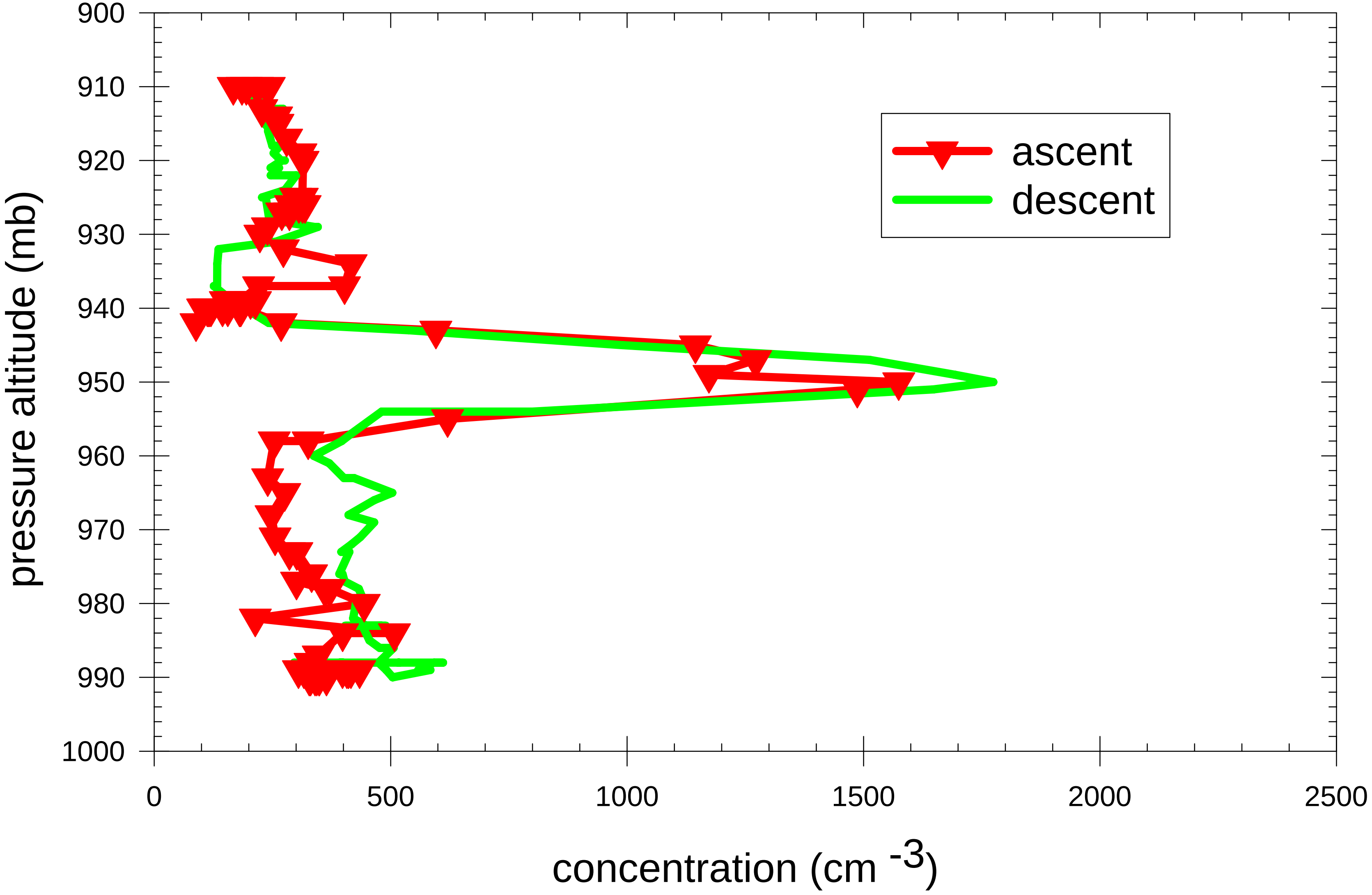
2. Differential CCN spectra

3. Supersaturation (S) range extended below 0.1%.

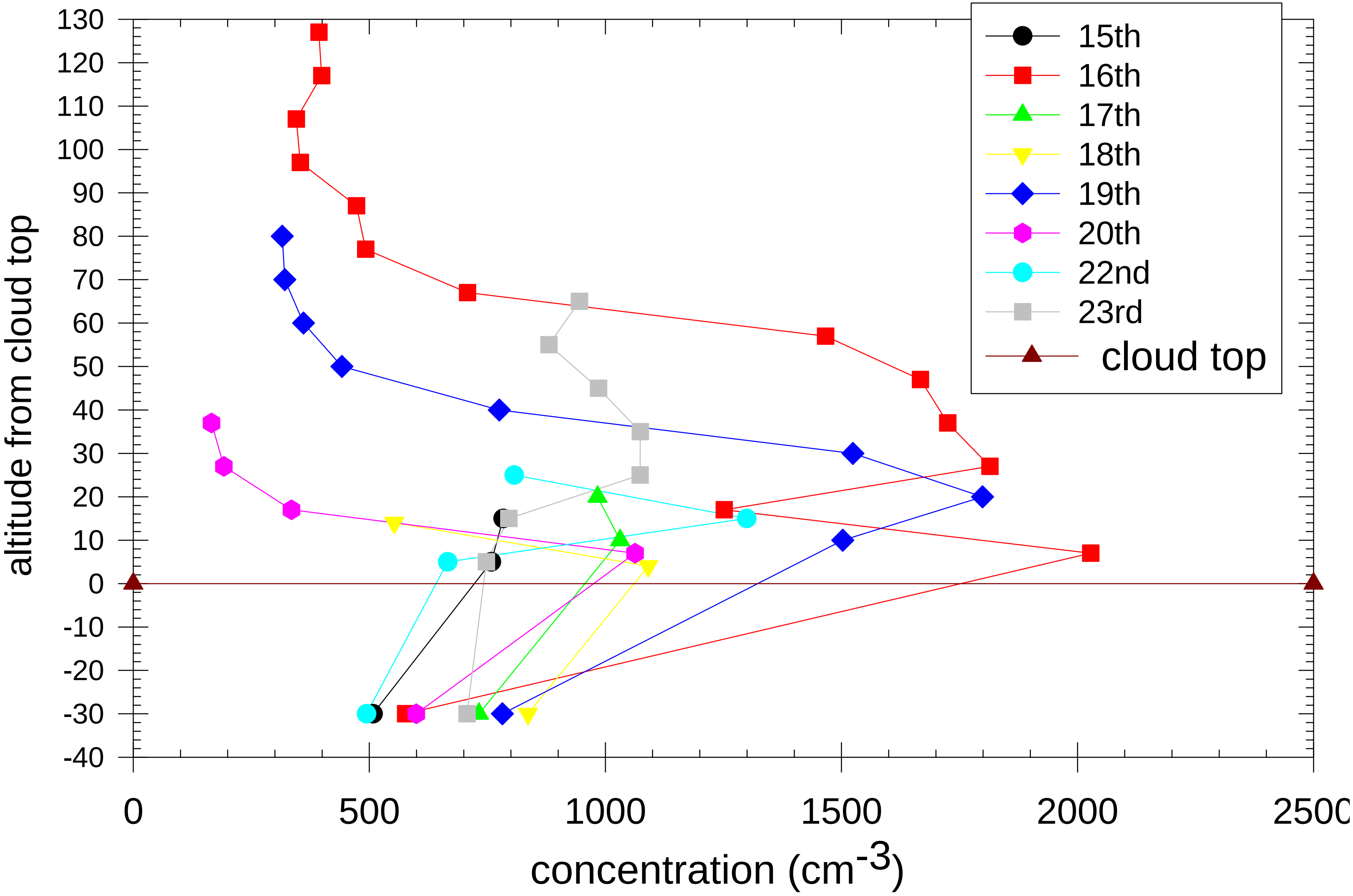
Extension the traditional CCN (Aitken) range below 0.1% to Large Nuclei, is necessary because a large proportion of CCN have S < 0.1%. This is needed because:

- Many clouds have S< 0.1%
- Static closure—aerosol and CCN
- Dynamic closure—CCN and cloud droplets.
- Large nuclei are embryos for precipitation.
- Droplet spectral width.
- Interface with giant nuclei.
- CCN sizes.

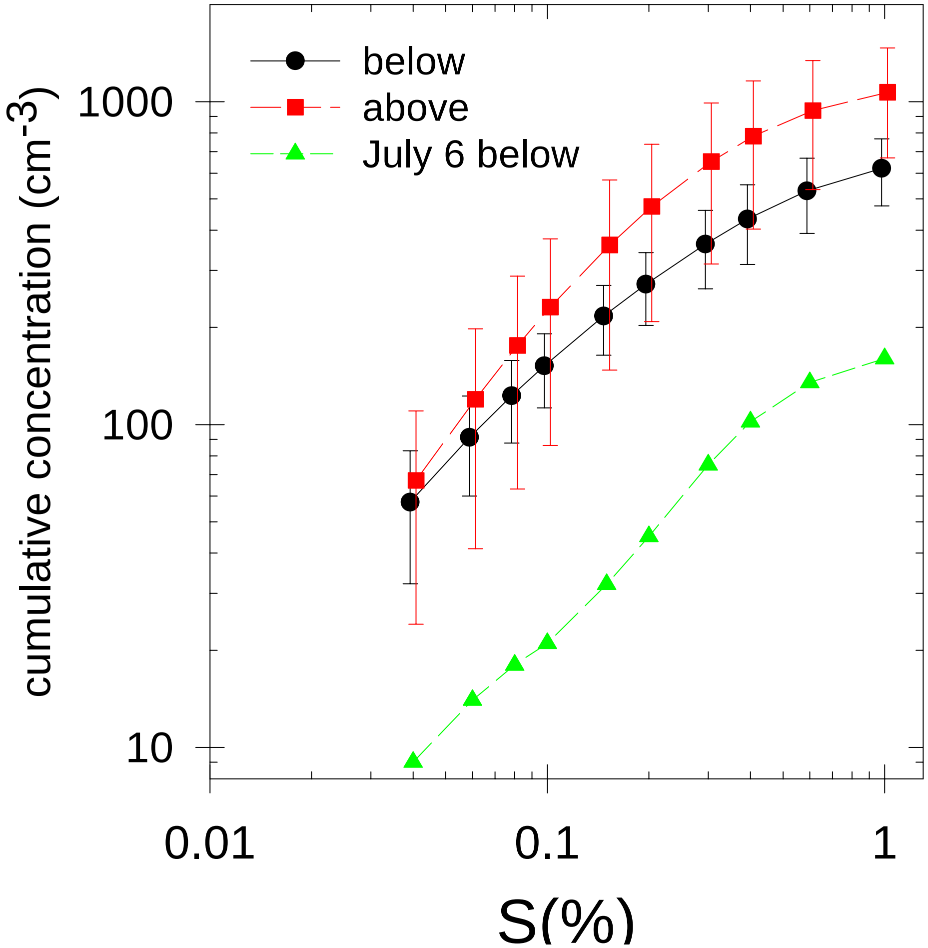
July 19, 2005, 1205-1227 PDT MASE, CCN @ 0.3% S old spectrometer



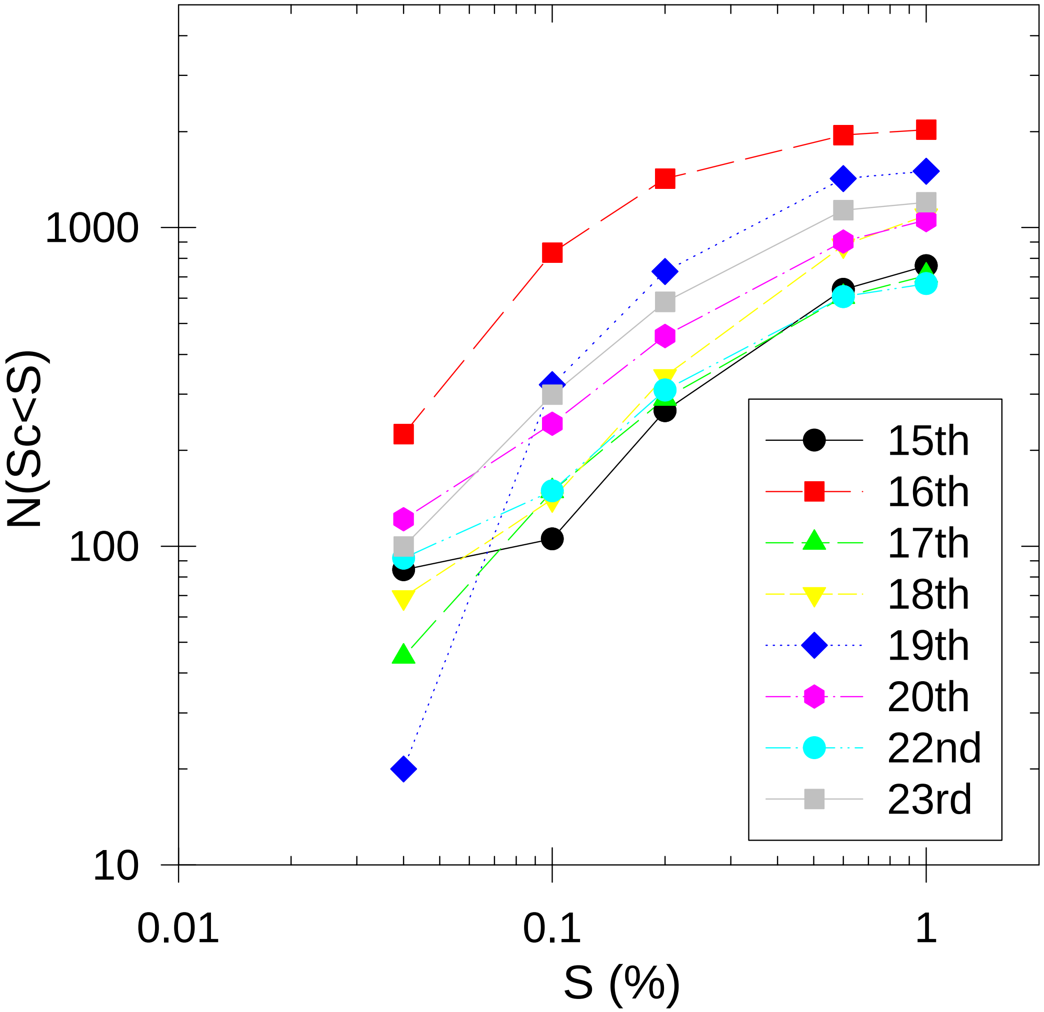
July 15-23, 2005, MASE, CA average within pressure bins
CCN 1% for research area



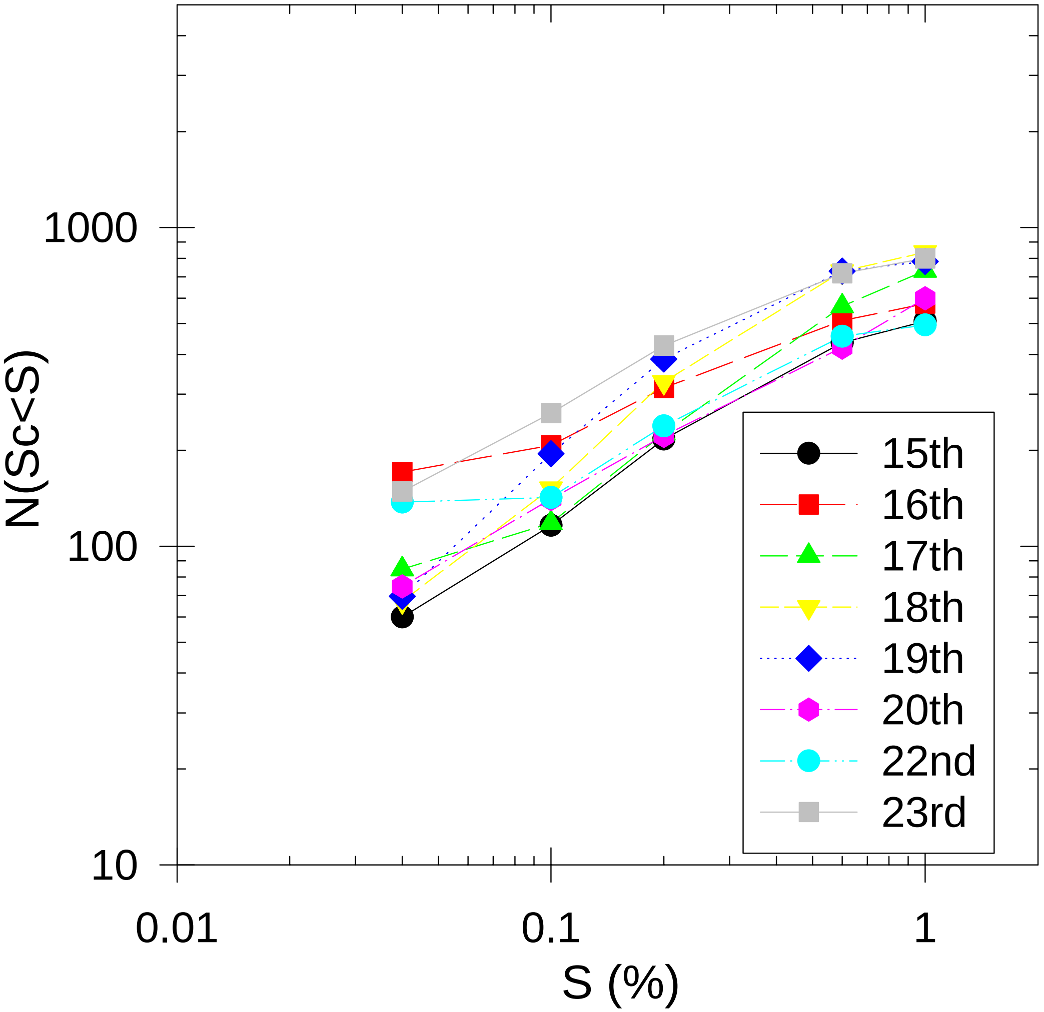
Average spectra below and just above cloud for the eight flights with unbroken polluted low stratus
July 15, 16, 17, 18,
19, 20, 22, and 25
and maritime July 6



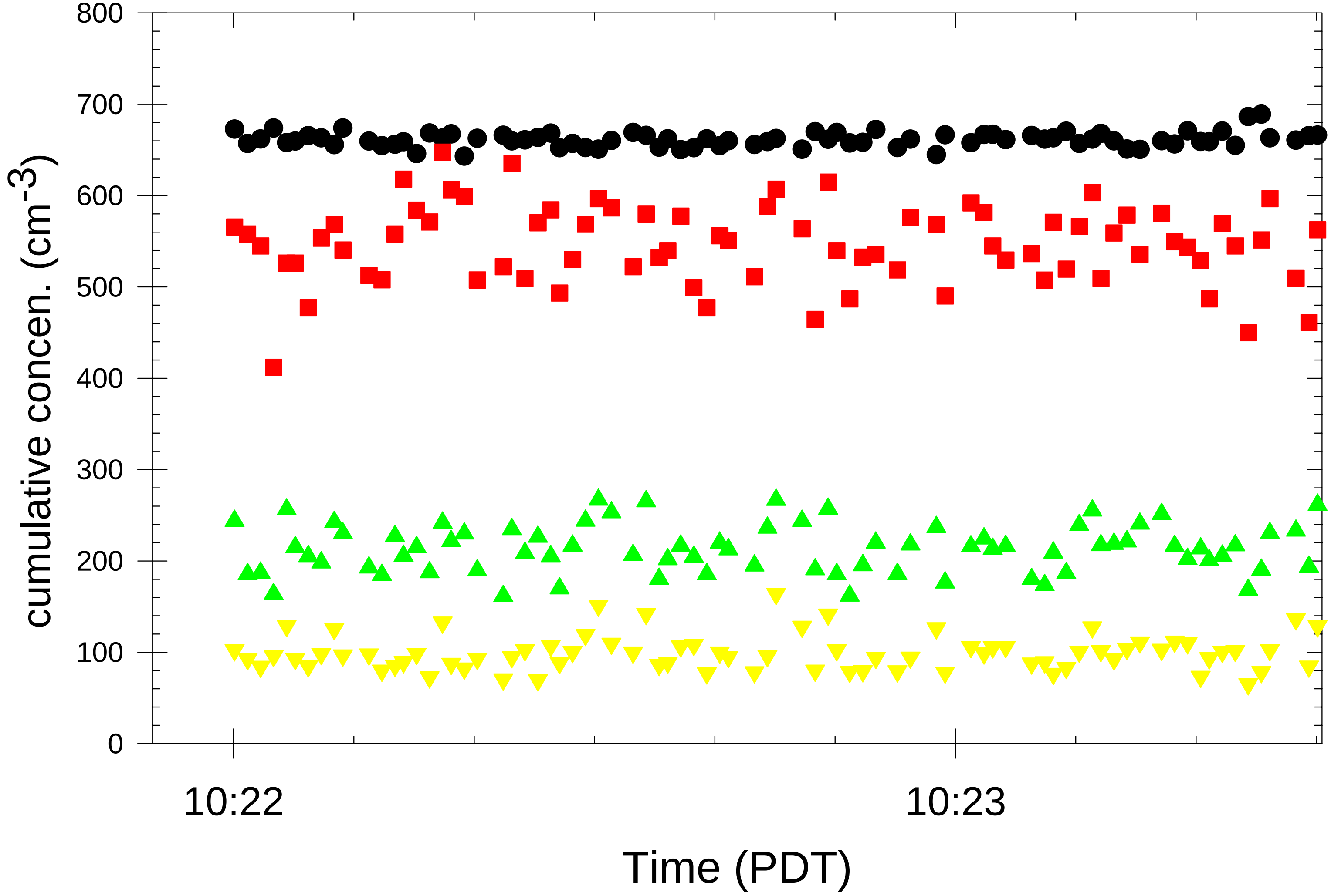
July 15-23 research area; average cumulative spectra just above cloud

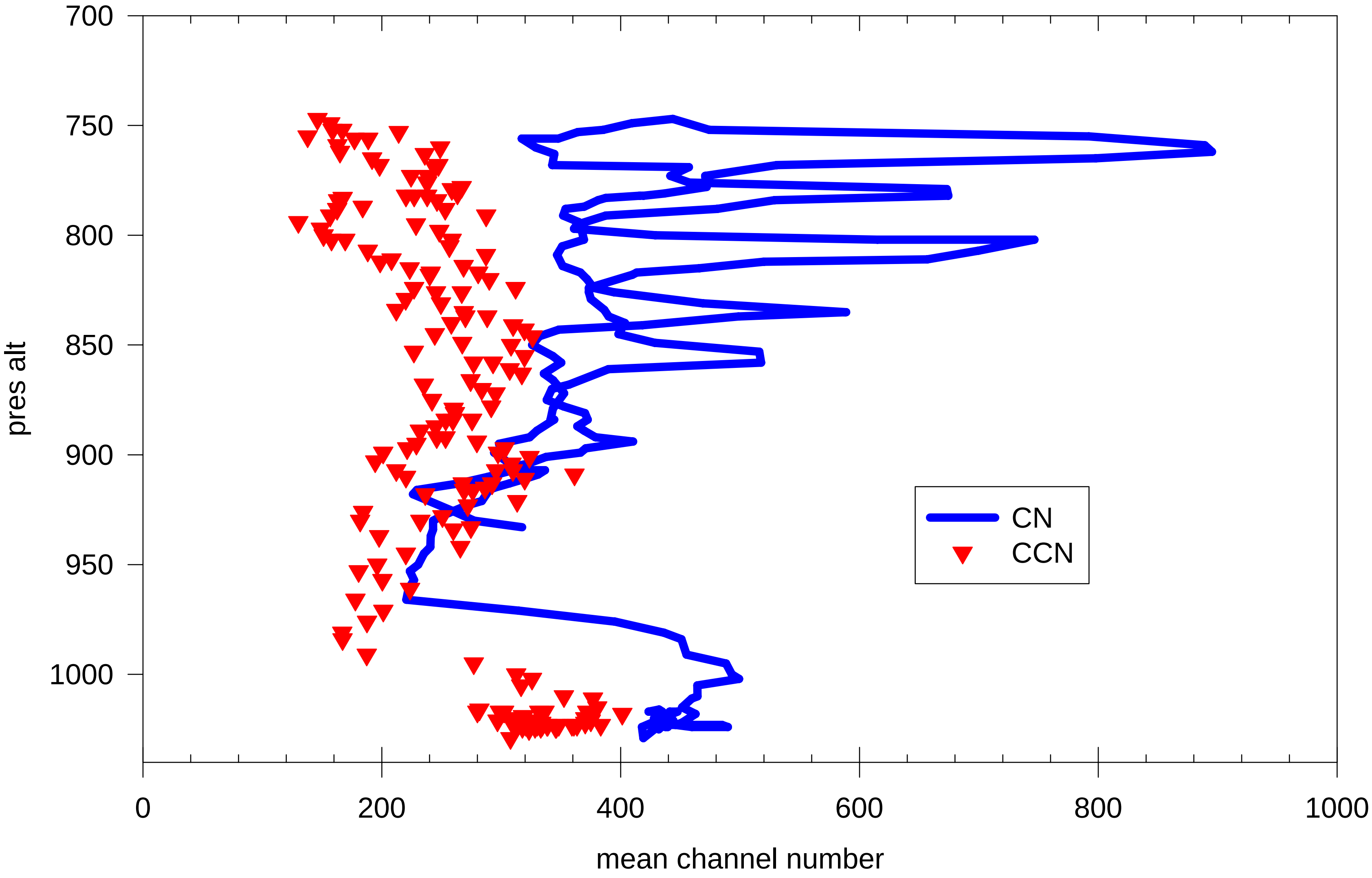


July 15-23 research area; average cumulative spectra below cloud



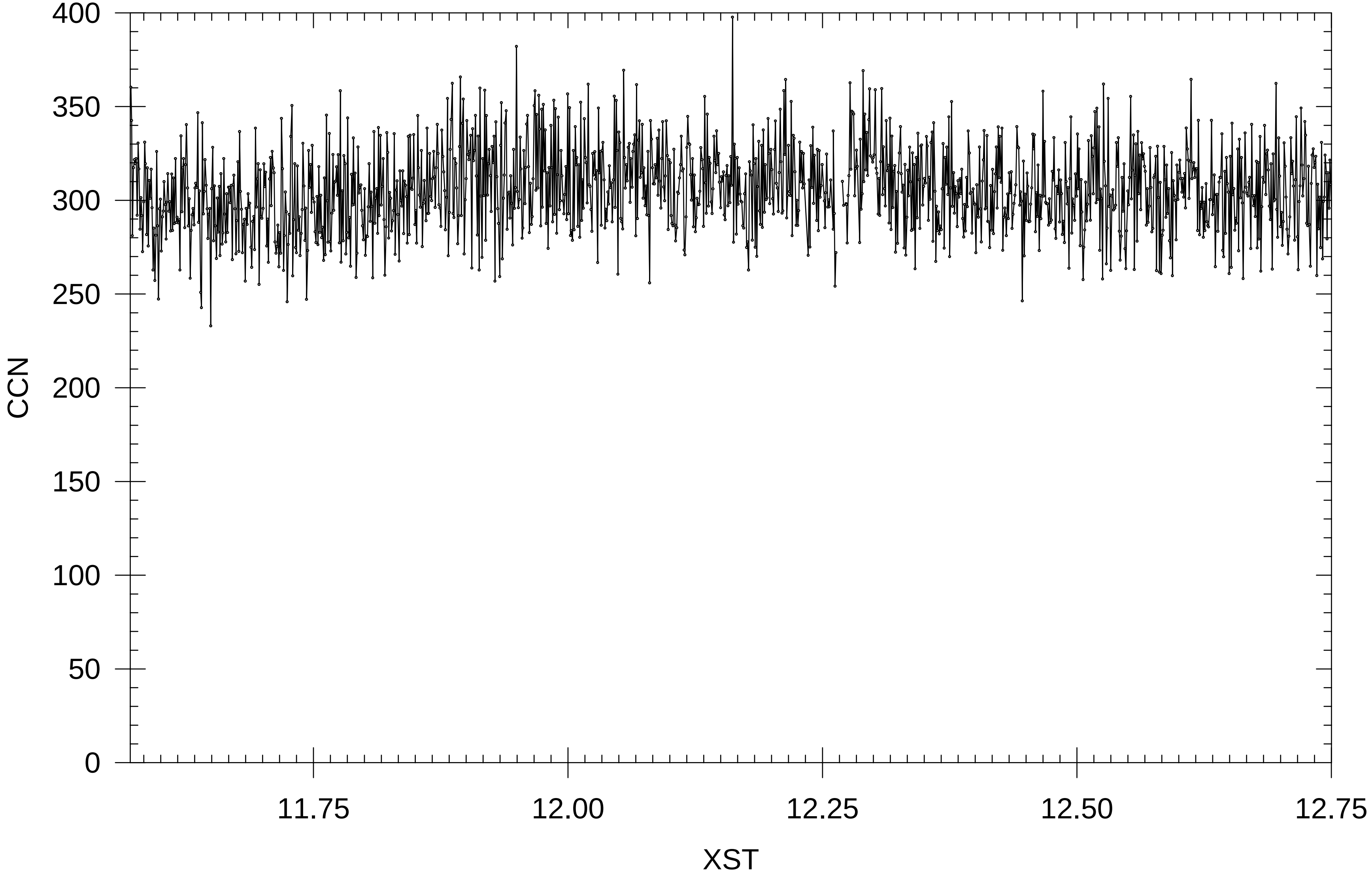
July 23, 2005


800
700
600
500
400
300
200
100
0
cumulative concen. (cm^{-3})
10:22
10:23
Time (PDT)



August 28, 2007 Christmas Island, PASE
1527-1543 XST

August 28, 2007, new spec C-130
PASE Christmas Island



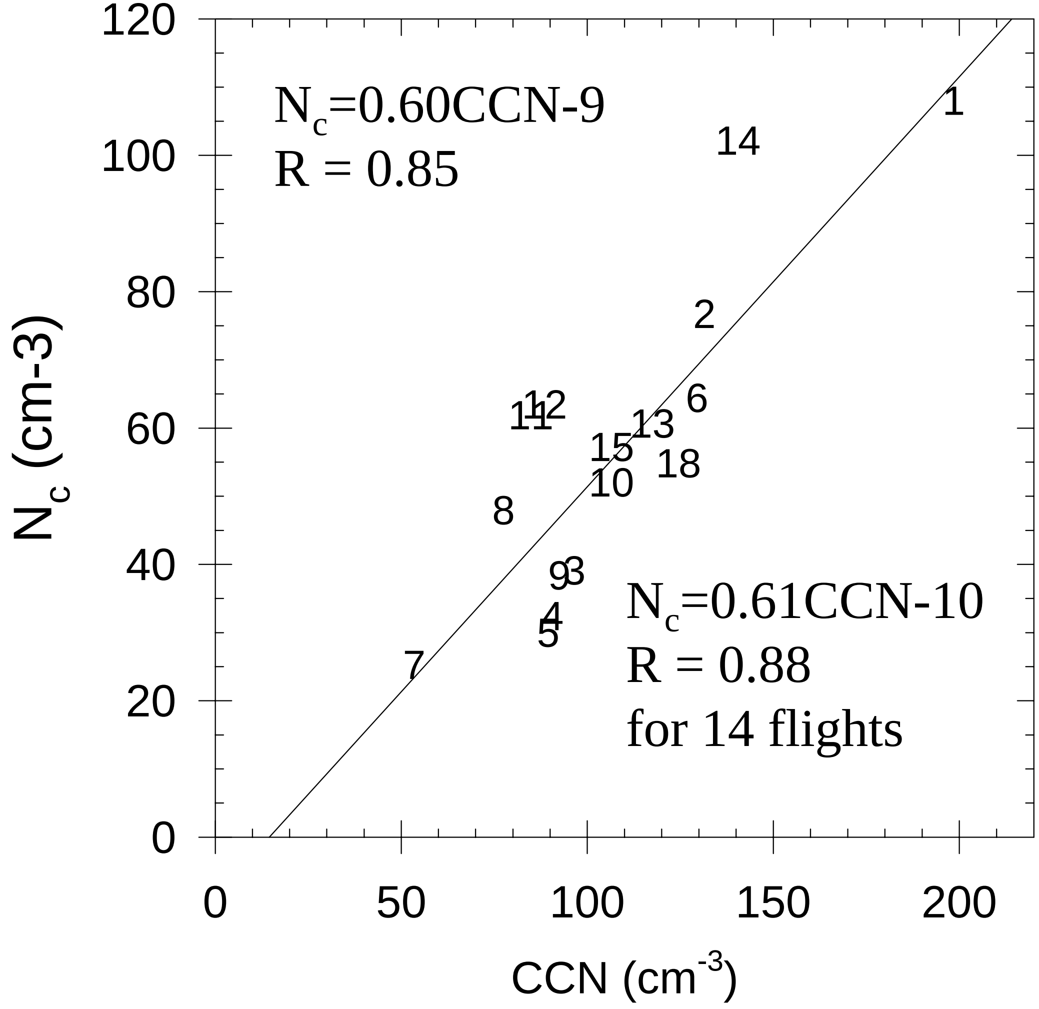
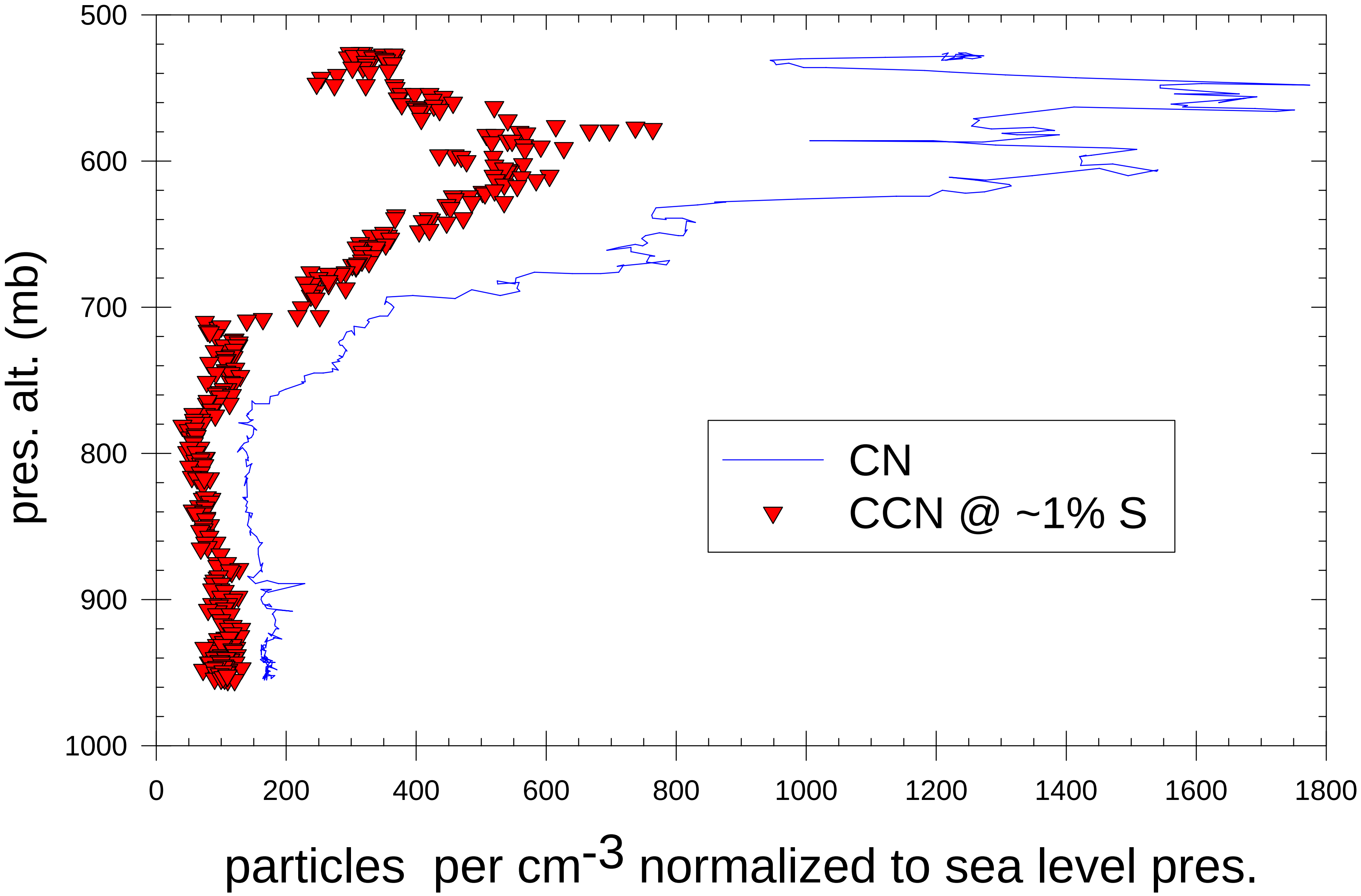
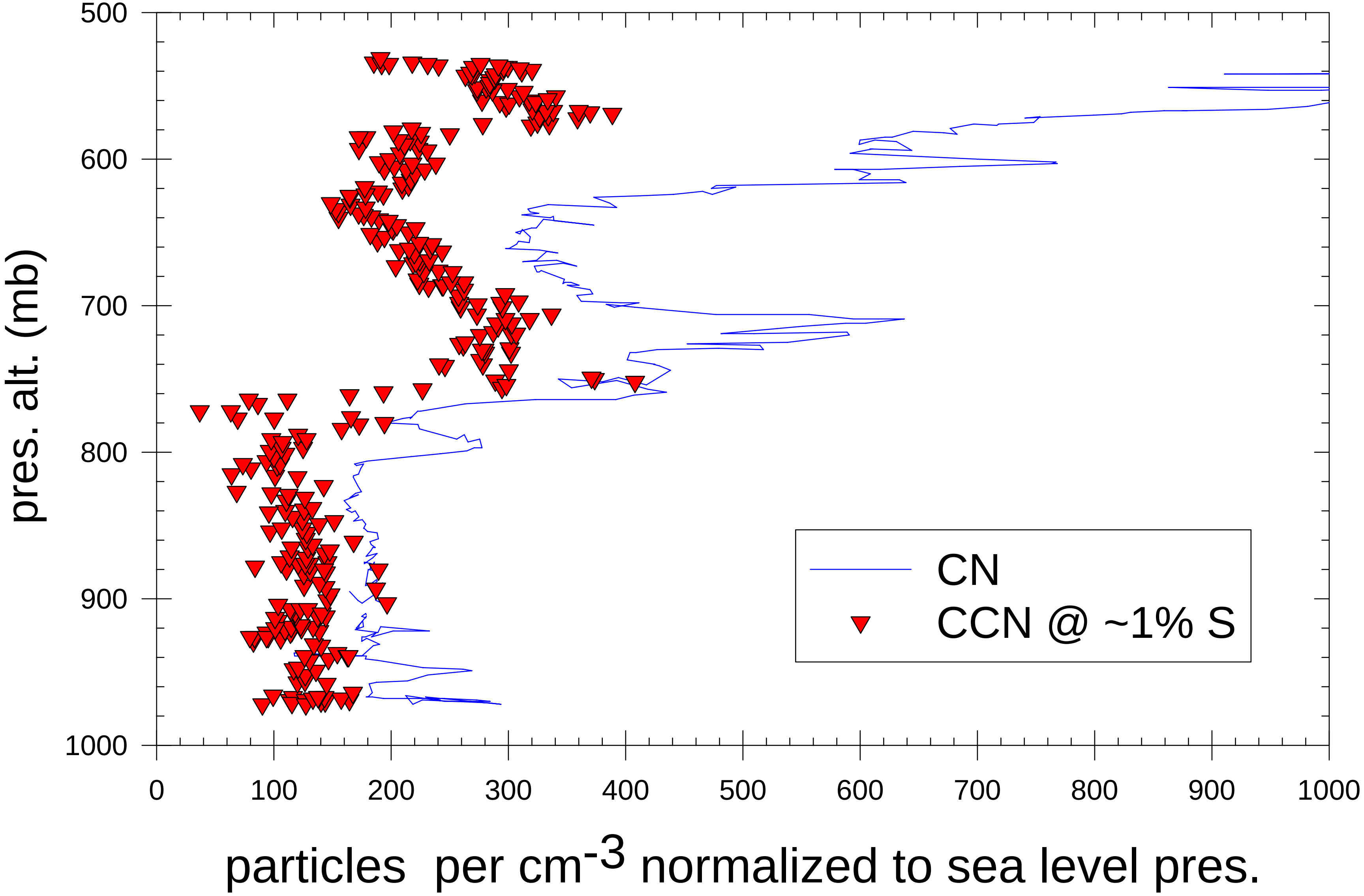


Figure 1. Average total (>2.4 µm) FSSP droplet concentrations (Nc) measured during each flight within the 600-900m altitude range and FSSP LWC > 0.1 gm-3 against the average 100m altitude CCN concentrations at 1% S for each flight. Data points are plotted as the flight number (Table 1). All of the 17 flights considered here except RF17 (J19) had clouds within this altitude range. The linear regression line, equation and correlation coefficient (R) is shown as well as the linear regression and R for only the same 14 flights considered by HM7 (excluding RF4 and 11 [D10 and J7]).

January 16, 2005, RICO, Antigua
at 1621-1635 GMT initial full descent



January 11, 2005, RICO, Antigua
at 2115-2128 GMT final ascent



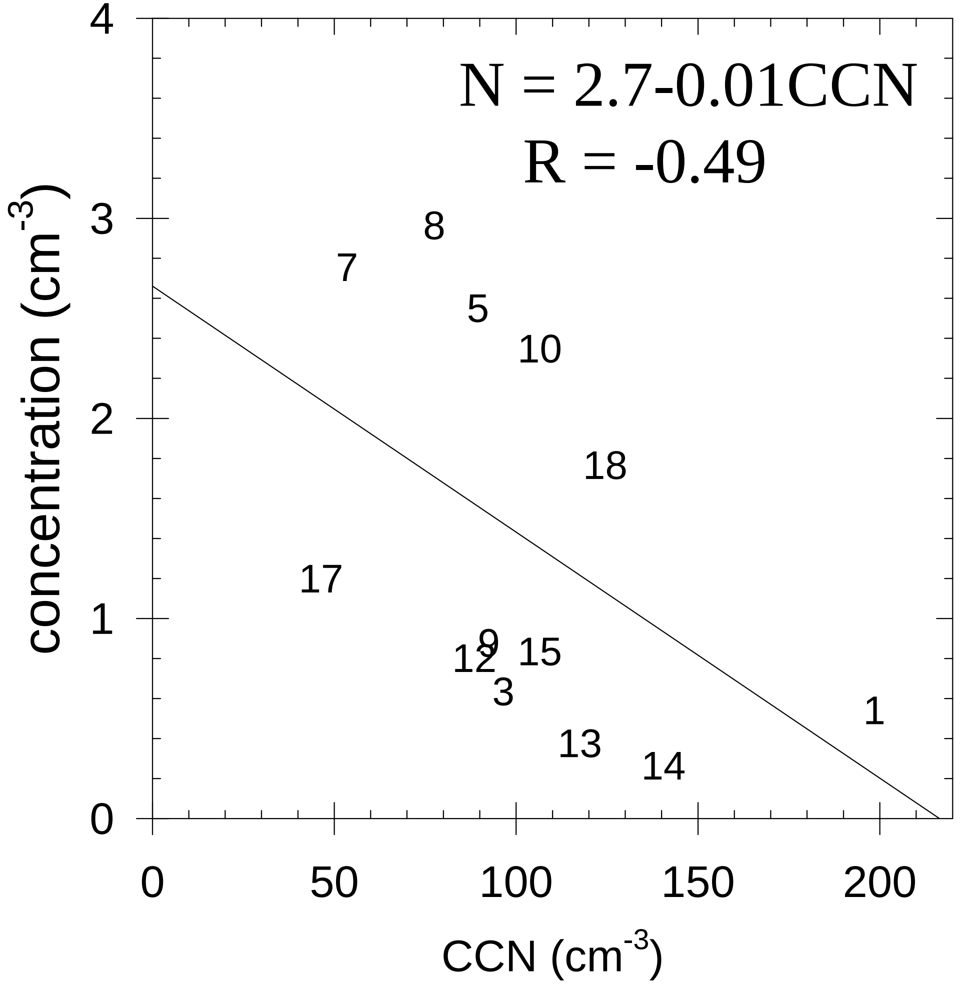
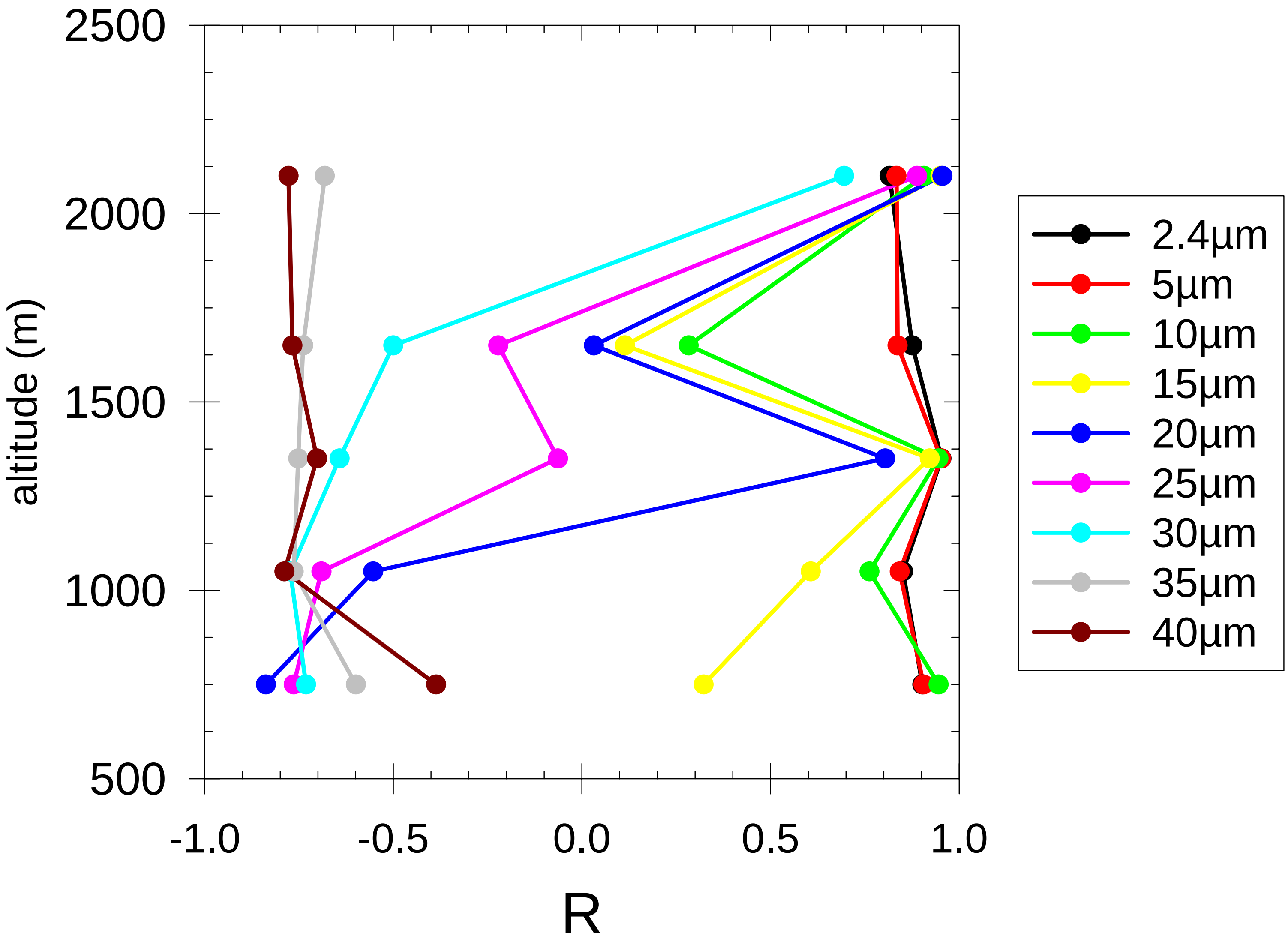


Figure 7. As Fig. 4 but for 1500-1800m altitude and 35 µm diameter. If only RF1, 5, 7, 8, 10 and 18 are considered R is -0.97. R for the other seven flights in this figure is -0.93.


2500
2000
1500
1000
500
altitude (m)
-1.0
-0.5
0.0
0.5
1.0
R
2.4μm
5μm
10μm
15μm
20μm
25μm
30μm
35μm
40μm

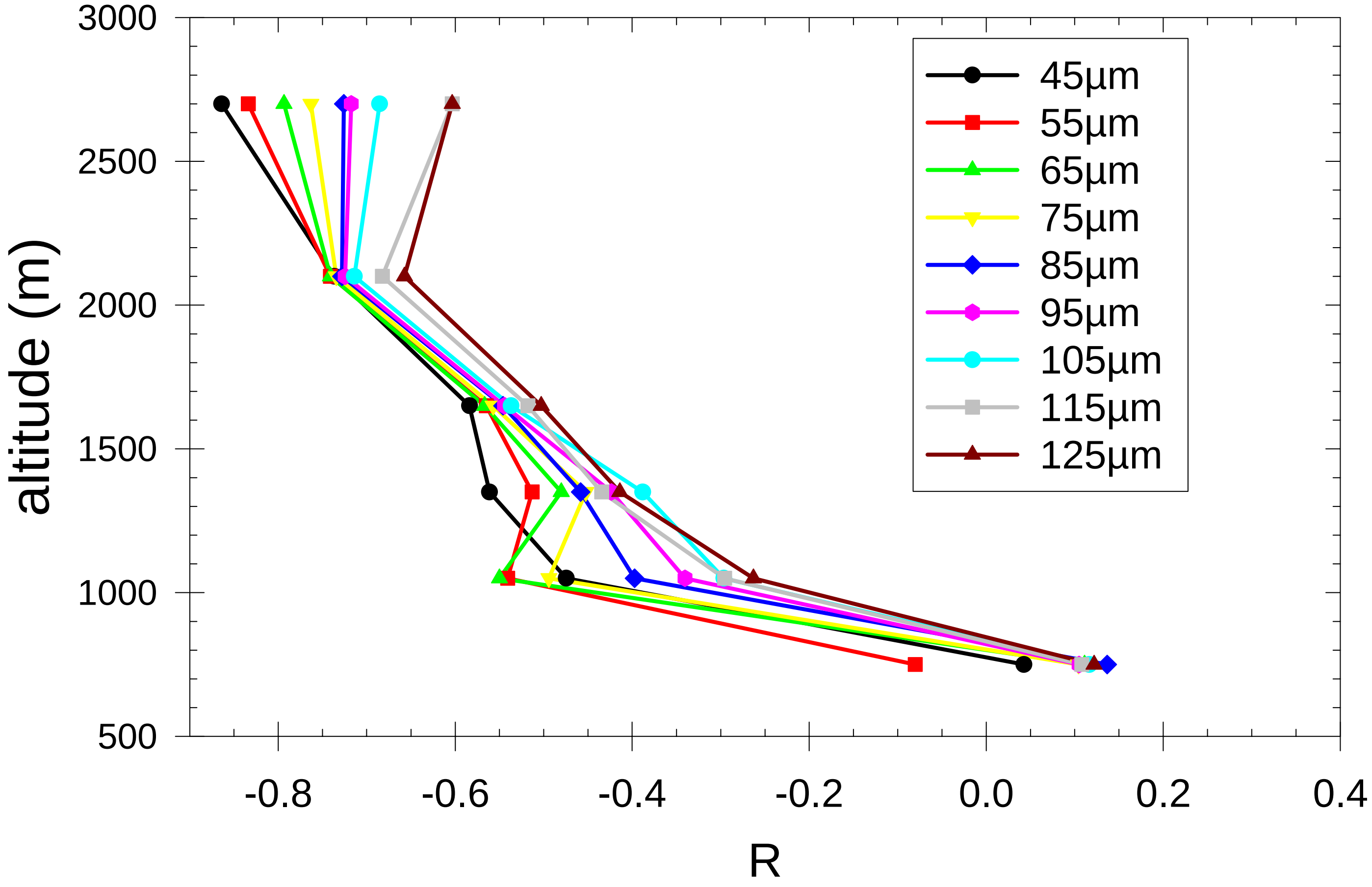


Figure 11. As Fig. 5A but for drizzle drops measured by the 260X probe. This includes all flights with data in each altitude band. This mean different numbers of flights and different flights at the various altitudes. 600-900m—16 flights (no RF17; same flights as the cloud data at this altitude noted in Fig. 5A caption); 900-1200m—15 flights (no RF13 or 17; same as cloud data noted in Fig. 5A caption); 1200-1500m—15 flights (no RF6 or 17; there was one more data point for the cloud data for this altitude as there was cloud data for RF17); 1500-1800m—13 flights (no RF2, 4, 6 or 17; this differs from the cloud data, which did have RF17 data but not RF11); 1800-2400m—12 flights (no RF2, 4, 6, 9, or 15; this is one more than the cloud data because there is drizzle data at this altitude for RF12); 2400-3000m—6 flights (no RF2, 4, 5, 6, 8, 9, 10, 12, 14, 17 or 18; the same flights as the cloud data at this altitude).

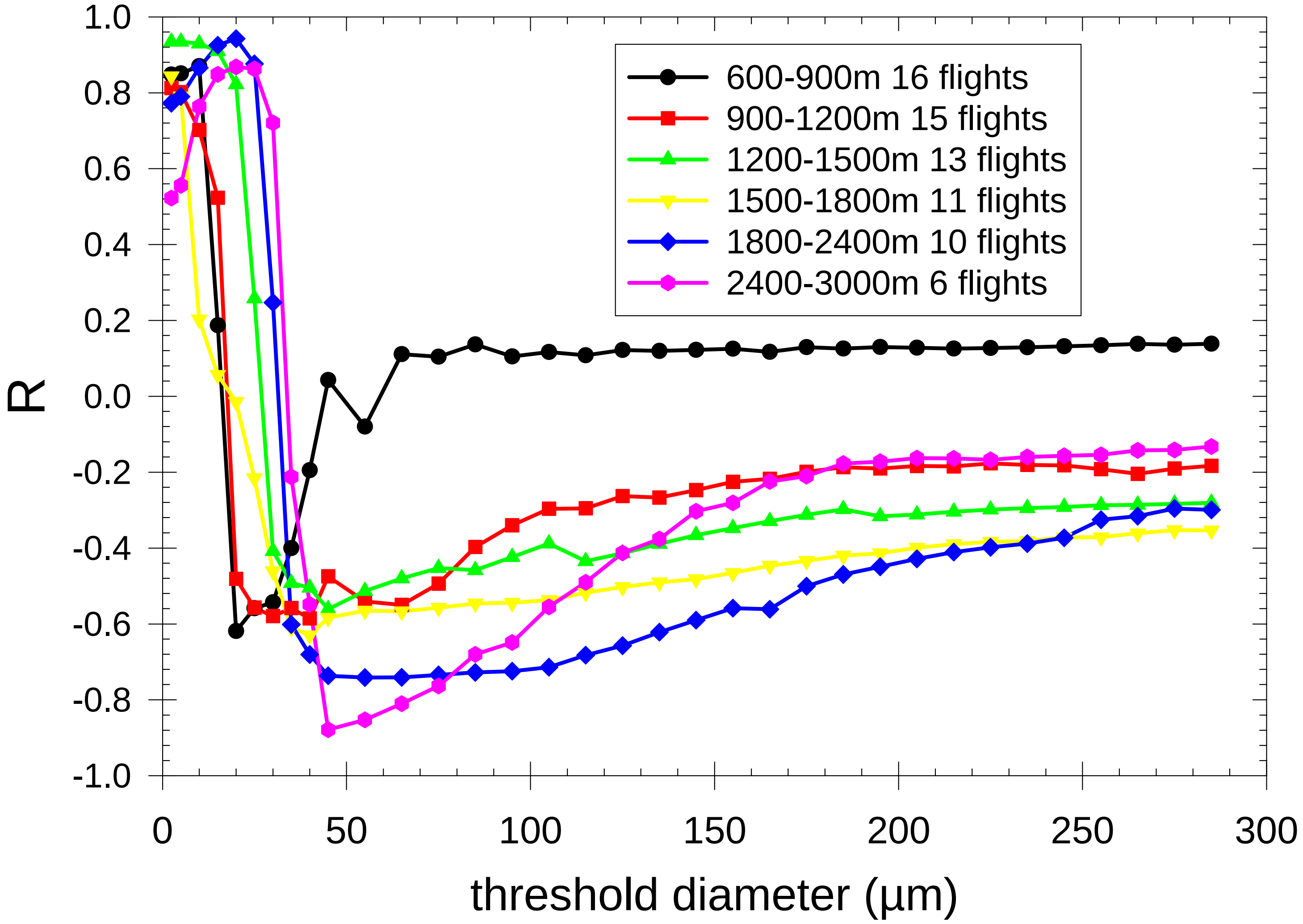


Figure 12. Correlation coefficients (R) for 1% S CCN at 100m altitude versus cumulative drop(let) concentrations above various size thresholds within the specified altitude ranges. This is the same data displayed in Figs. 5A and 11 but here displayed for each altitude band as a function of drop(let) sizes. As in those other figures the flights considered varied with altitude range and this may cause biases. The number of flights in each altitude range is shown in the legend.

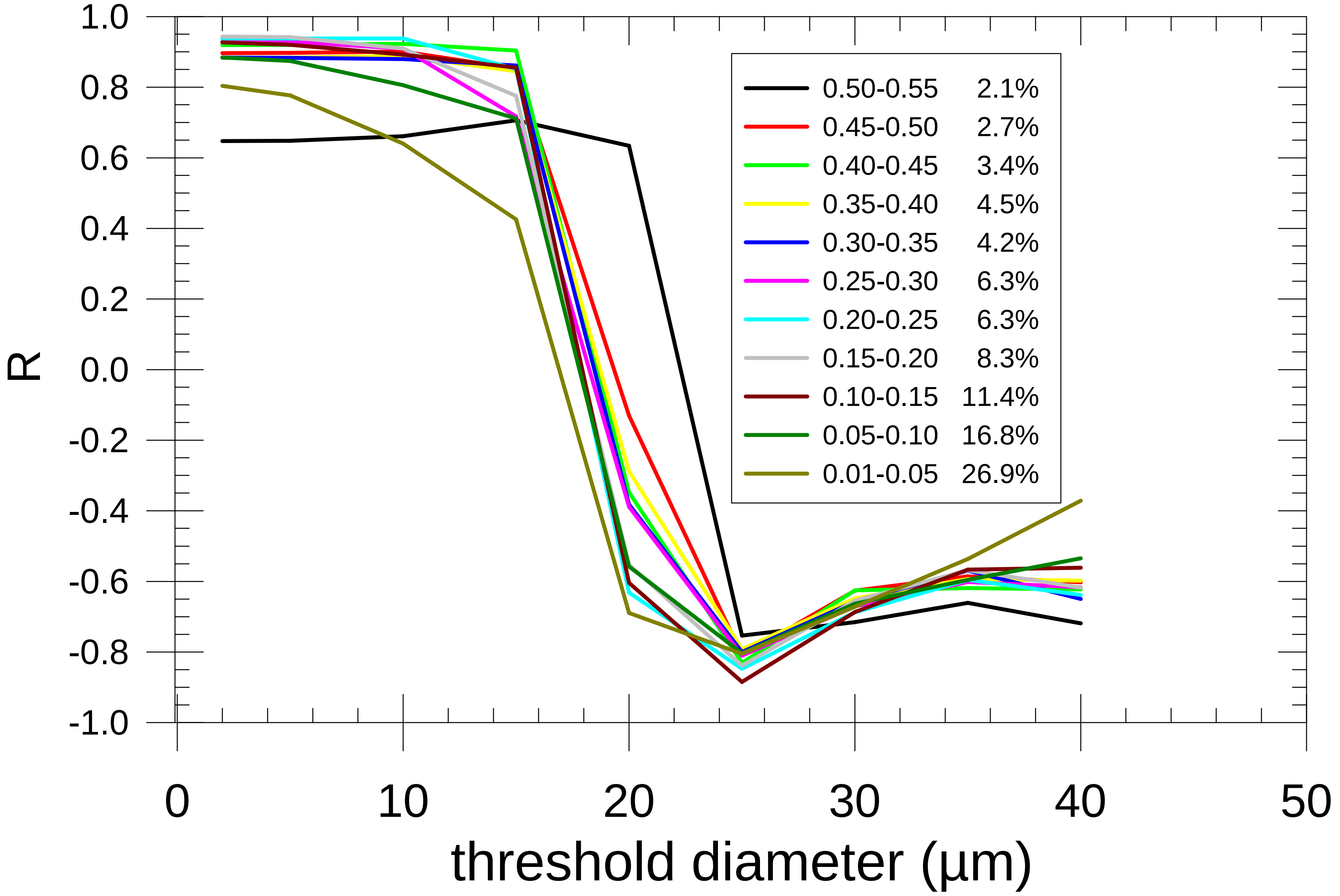


Figure 16. As Fig. 14, but for 900-1200m altitude range. There are also eleven flights with data in these LWC intervals. But the flights are different from the flights in Fig. 14. Here RF2, 3, 11, 13, 14 and 17 (D8, D9, J7, J12, J14 and J19) are excluded. With the higher altitude more LWC intervals are available; 7.1% have LWC > 0.55 gm^{-3}.

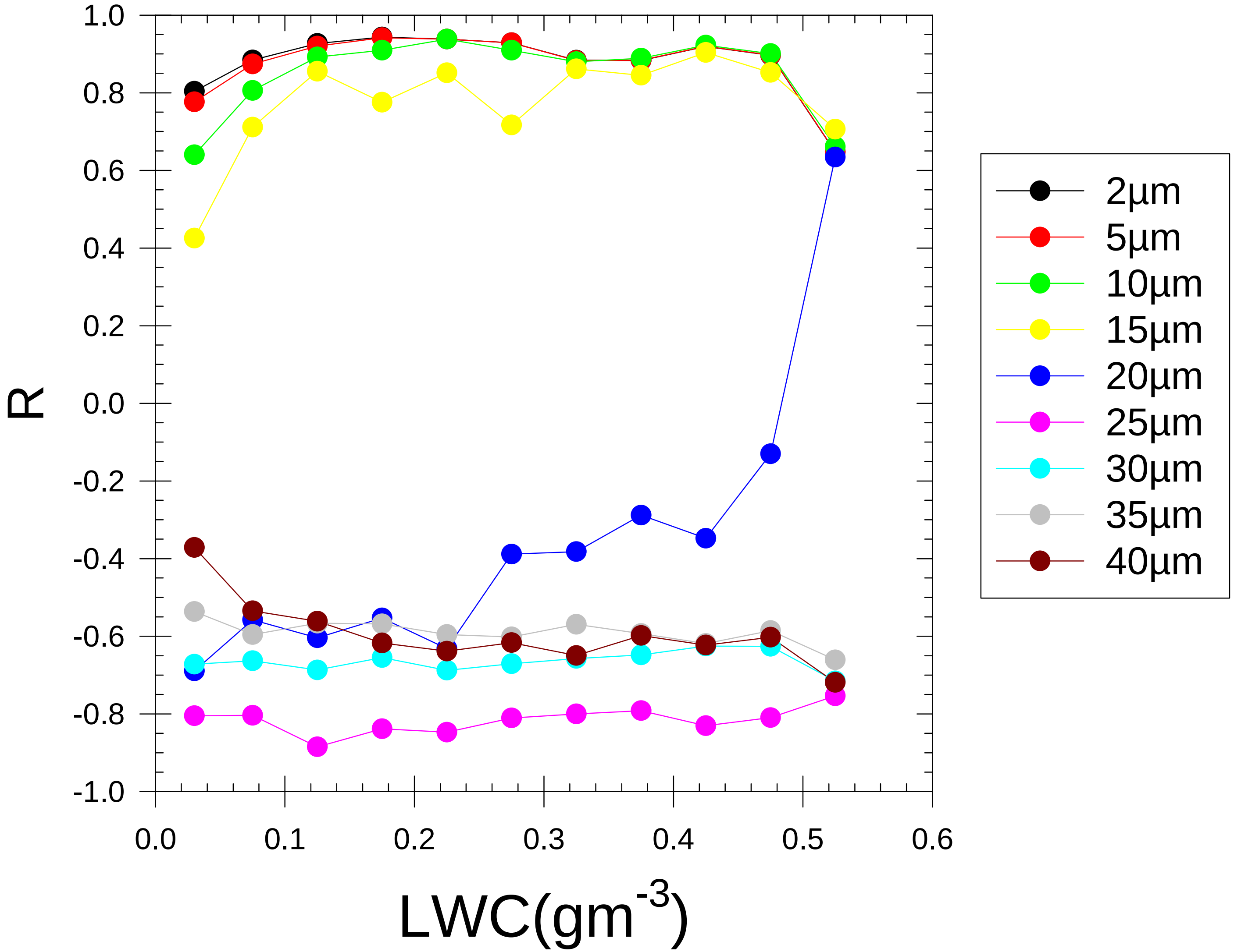


Figure 17. As Fig. 15 except that the data are from the 900-1200m altitude range. This is the same data shown in Fig. 16.

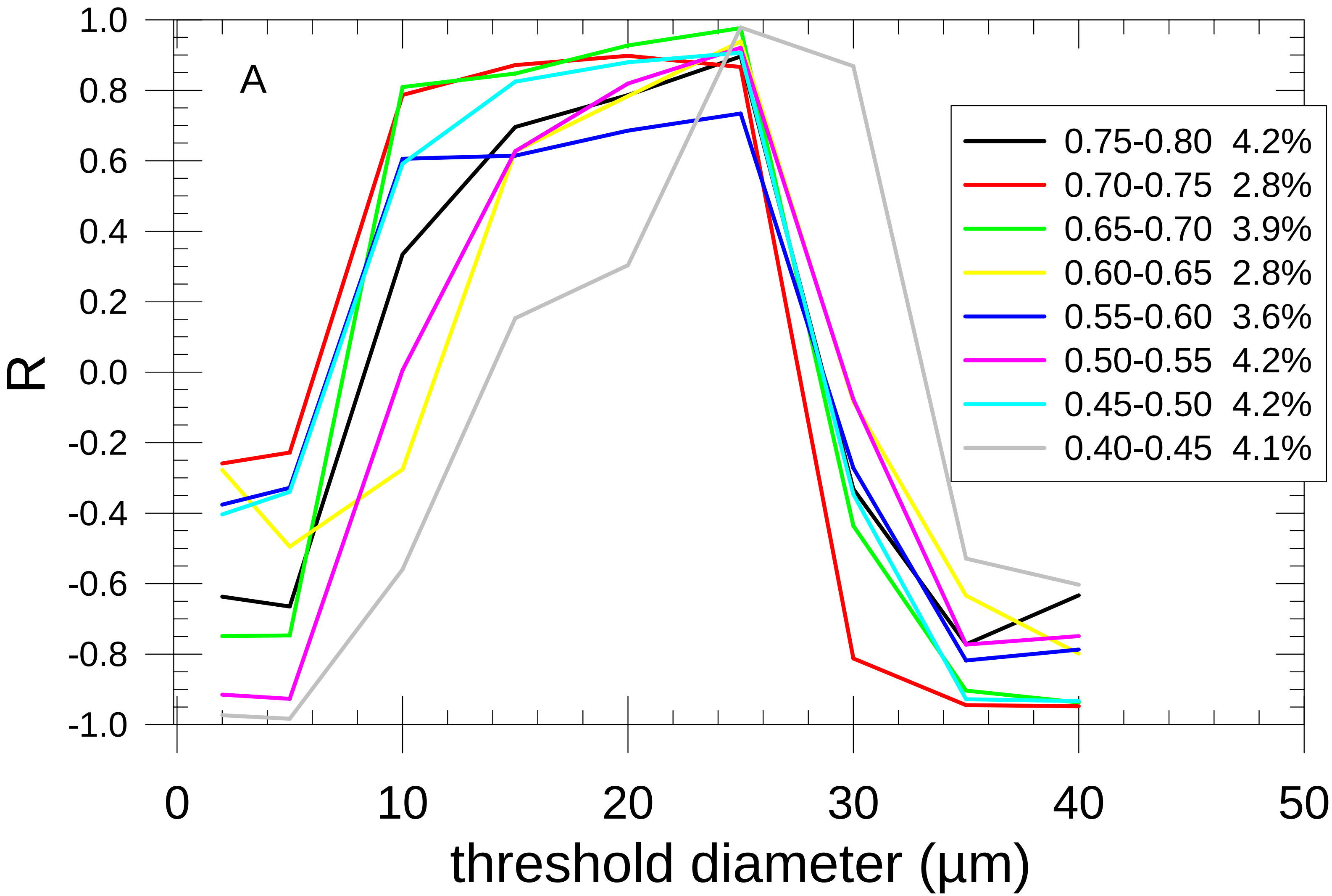


Figure 20. As Fig. 18 but for 2400-3000m altitude. Only four flights; RF1, 11, 13 and 15; 16% exceeded 0.80gm^{-3}. The 0.25-0.30 gm-3 interval with 5.8% of the data is not shown because it did not have data from all four flights.

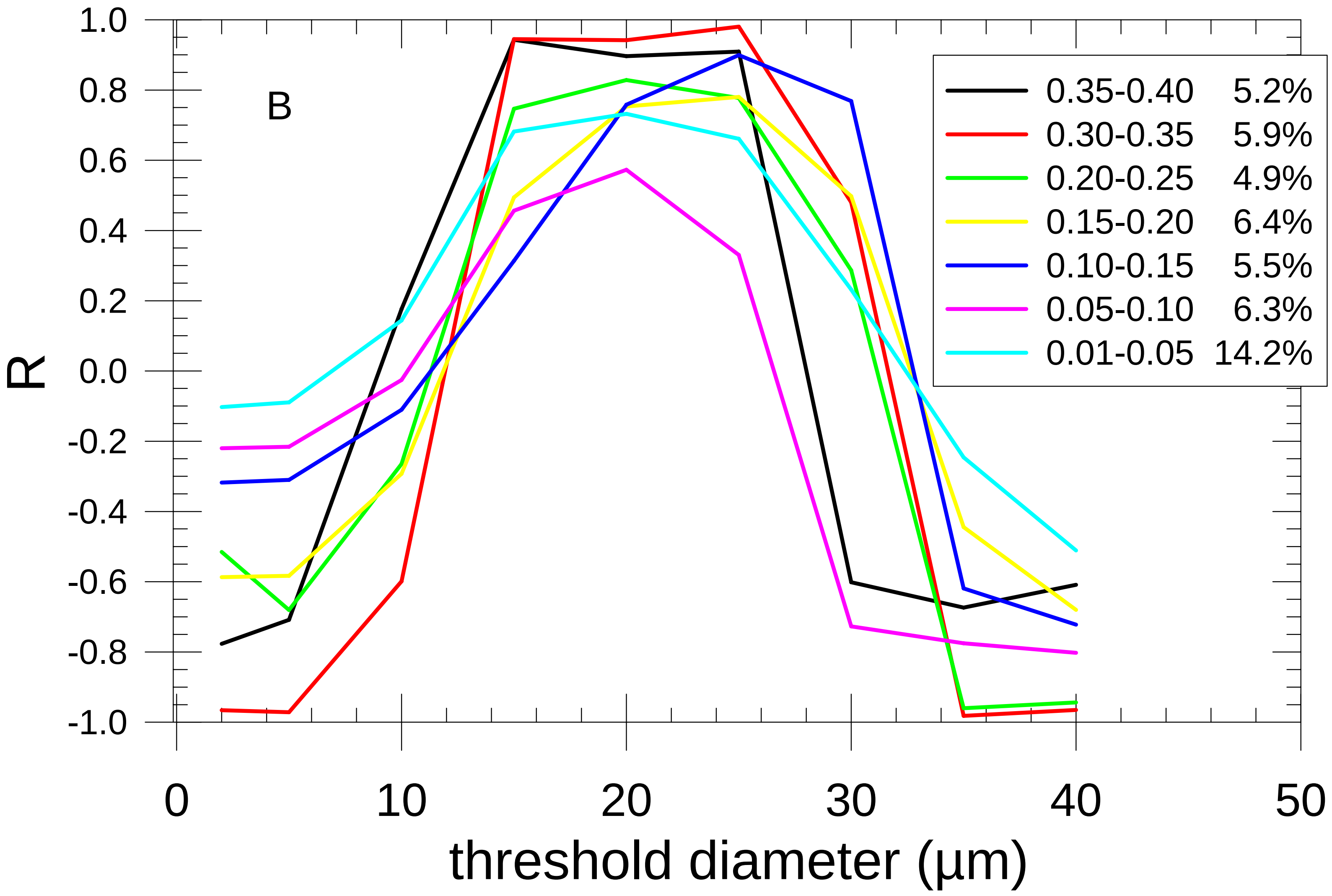

B
R
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
10
20
30
40
50
threshold diameter (µm)
0.35-0.40 5.2%
0.30-0.35 5.9%
0.20-0.25 4.9%
0.15-0.20 6.4%
0.10-0.15 5.5%
0.05-0.10 6.3%
0.01-0.05 14.2%

Figure 20B.

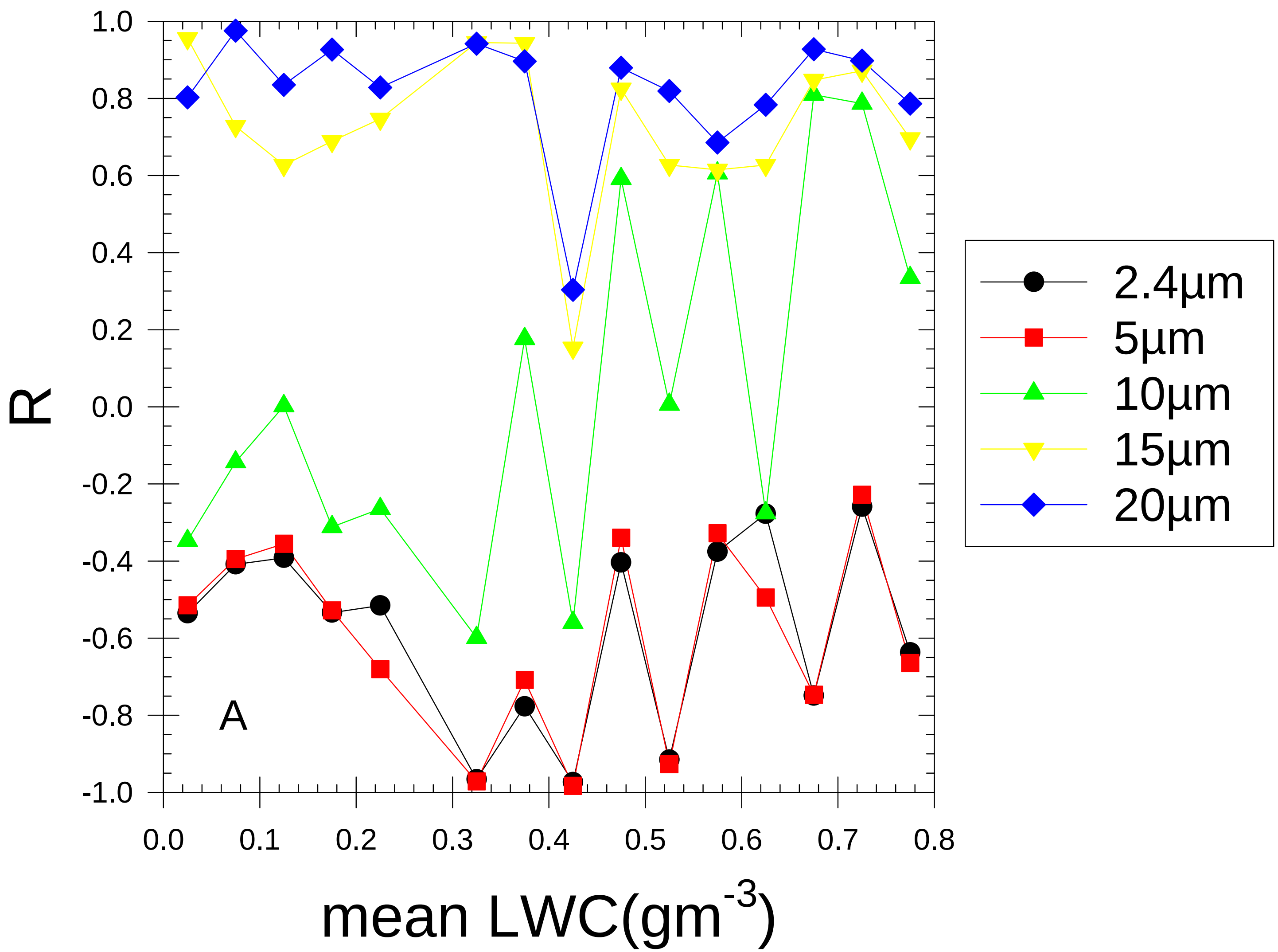


Figure 21. As Fig. 19 but for 2400-3000m. Same data as in Fig. 20.

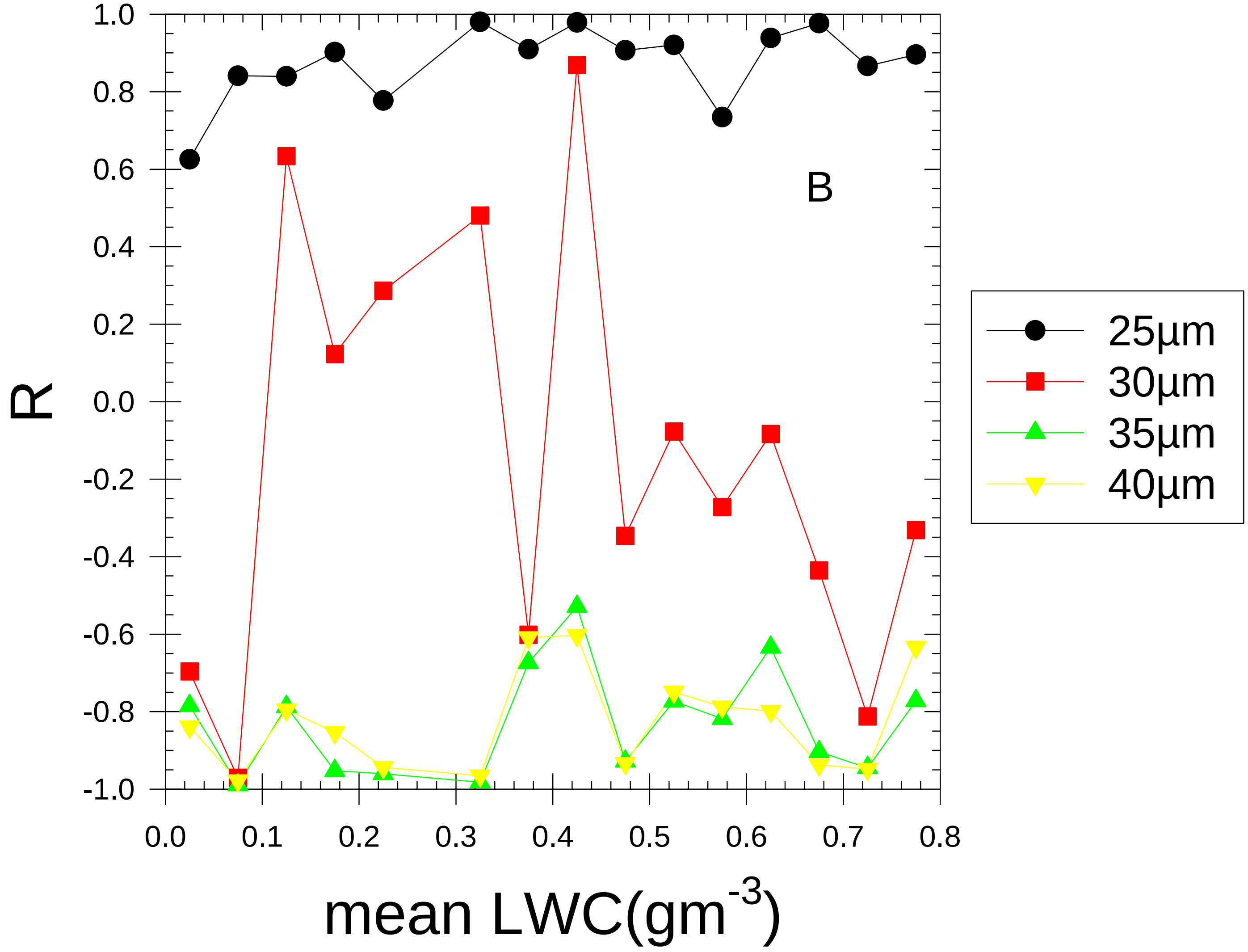

1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
R
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
mean LWC(gm^{-3})
B
25µm
30µm
35µm
40µm

Figure 21B.

Altitude range (m)	Mean altitude (m)	Mean LWC FSSP (gm^{-3})	Mean LWC 260X (gm^{-3})	total LWC (gm^{-3})	Adiab. LWC (gm^{-3})	Mn/Ad LWC
2400-3000	2660±150	0.34±0.18	0.22±0.10	0.56	2.69	0.21
1800-2400	2010± 70	0.33±0.16	0.09±0.05	0.42	1.80	0.23
1500-1800	1612± 87	0.29±0.10	0.04±0.03	0.33	1.25	0.26
1200-1500	1358± 74	0.25±0.08	0.02±0.02	0.27	0.96	0.28
900-1200	1049± 77	0.18±0.05	0.01±0.01	0.19	0.57	0.33
600- 900	798± 33	0.10±0.02	0.01±0.01	0.11	0.24	0.46

Table 3. Altitude ranges, means and standard deviations of, measured mean flight-averaged altitudes for LWC > 0.01 gm-3 for flights considered for correlations within the various LWC bins in Figs. 14-21 and text, mean LWC for these flights, adiabatic LWC at the mean altitudes, ratio of mean LWC to adiabatic LWC.

1. Regular ambient measurements. Change integration time (1s) and sample flow rate for better statistics but spectra may suffer
1. CCN measurements invalid in cloud so need to separate data.
    A. Splashing artifact
    B. Interstitial measurement—CCN not within droplets, but where is the cutoff?

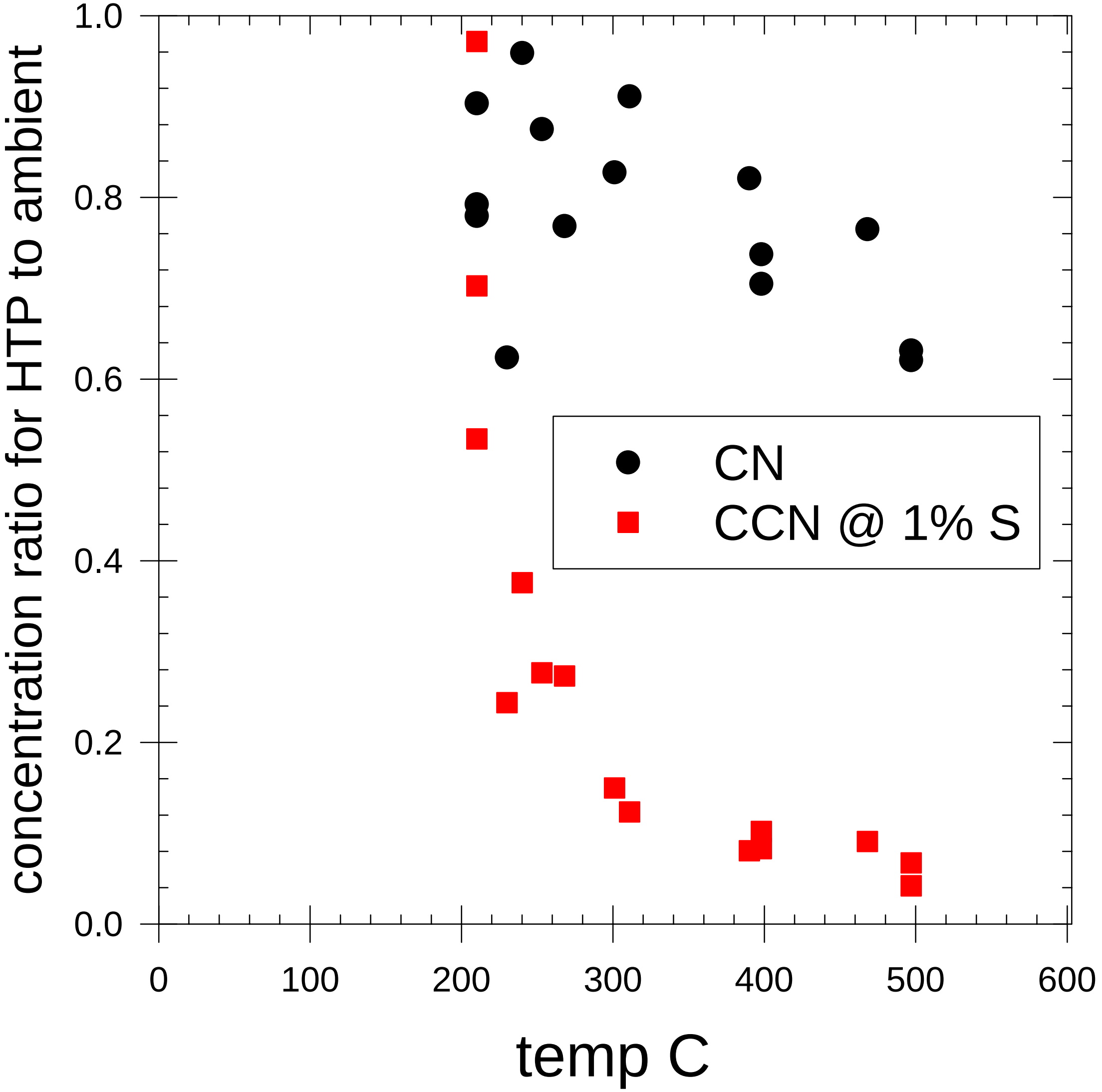
3. Calibrations—usually done in flight (in cloud) because instrument is very sensitive to changes. Confidence in data. Can be done on ground before or after flight but conditions can be different—esp. Temp.
    Can bring cal particles in conductive plastic bags.

4. Volatility measurements--~chemistry—NaCl for sure 600-800C.
    CN/CCN comparison for clean or polluted air—less volatile substances are usually less soluble—ammonium sulfate is both soluble and volatile 200C.

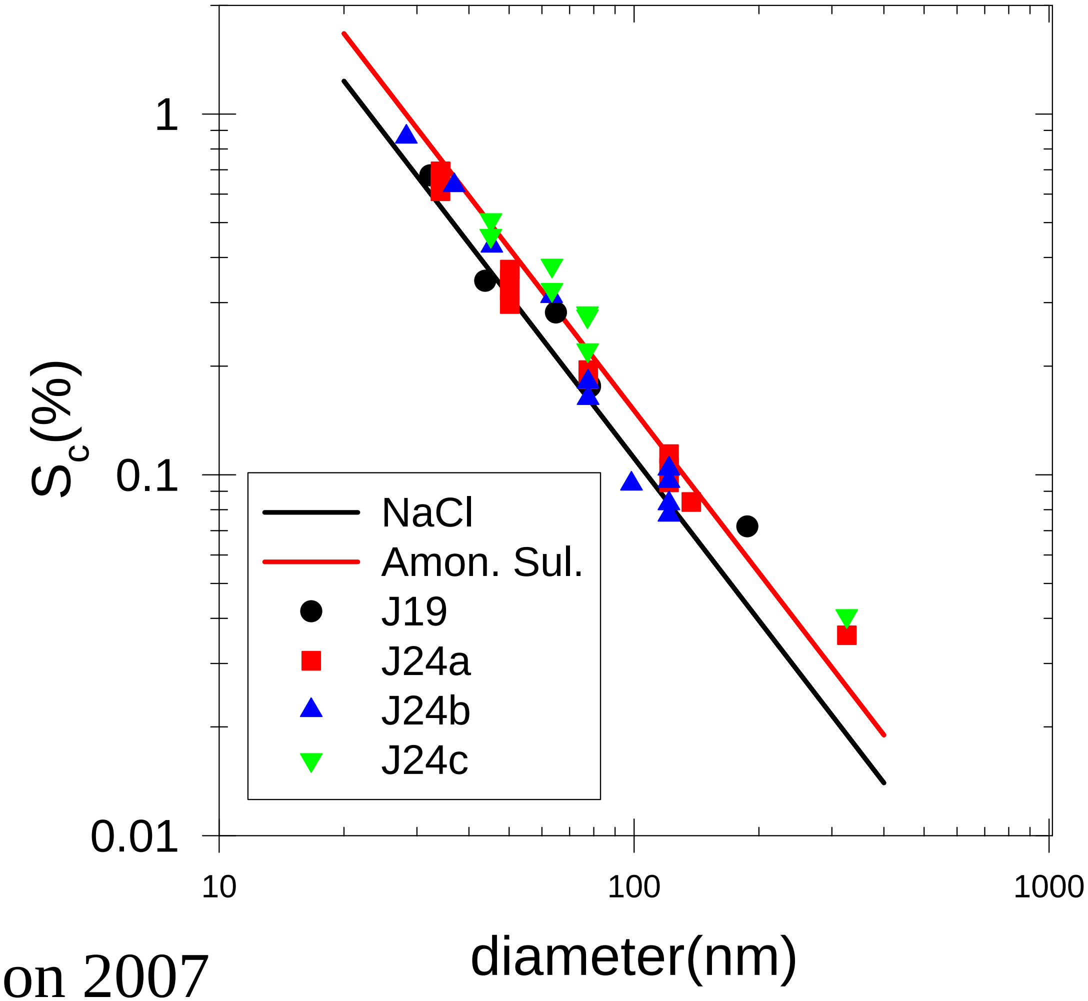
5. Size/S_c measurements—CCN size. Larger CCN are less soluble usually polluted air mass. But PASE measurements may contradict this.

6. May do surface measurements with other instruments.
    Continuous, comparisons, Size/S_c, students.

July 22, 2005, 1042-1303
High Temperature Processor
@ 955-976 mb



Particle critical Supersaturation (S_c)
versus dry particle diameter
January 19 and 24, 2005
RICO Eastern Caribbean near Antigua
low altitude



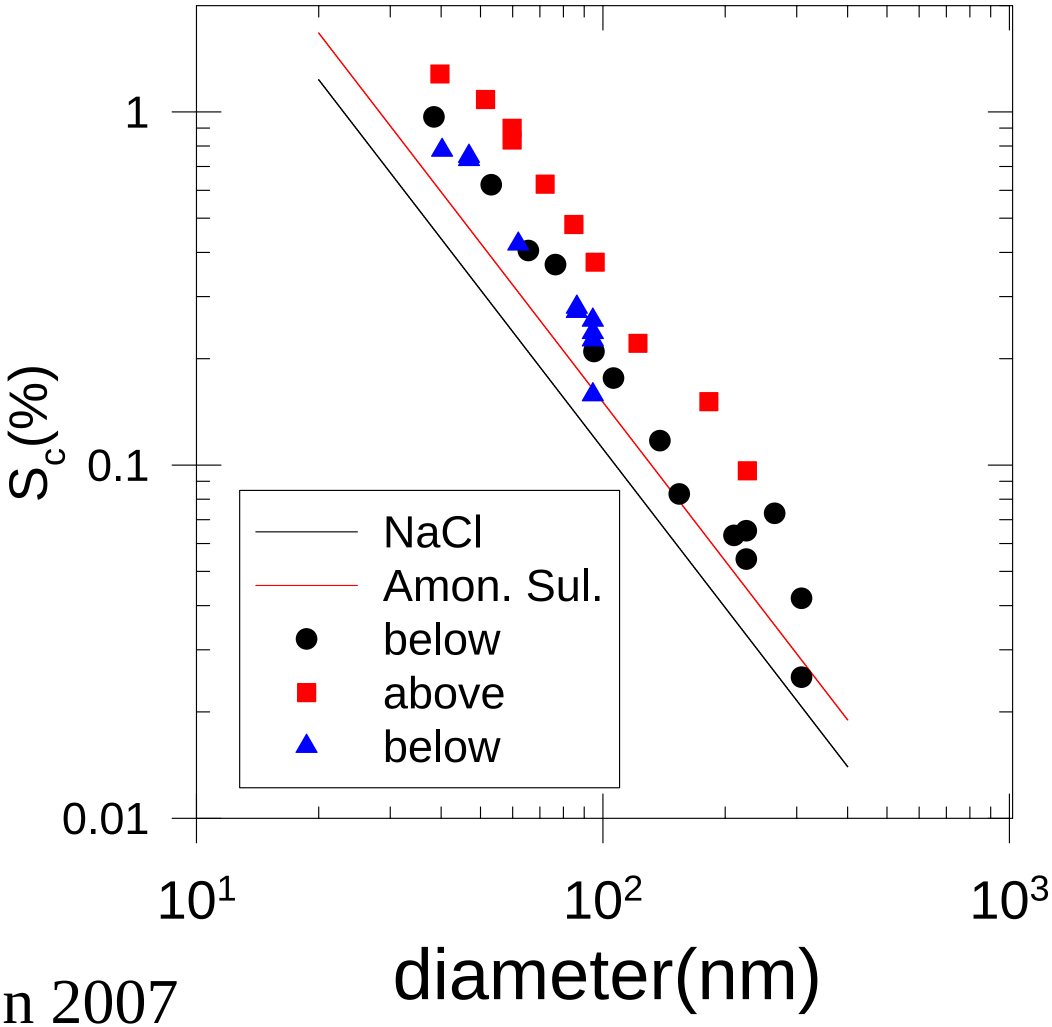
From Hudson 2007

Particle critical supersaturation (Sc) versus dry diameter

July 25, 2005

MASE off the Central California Coast

below and above stratus cloud layer

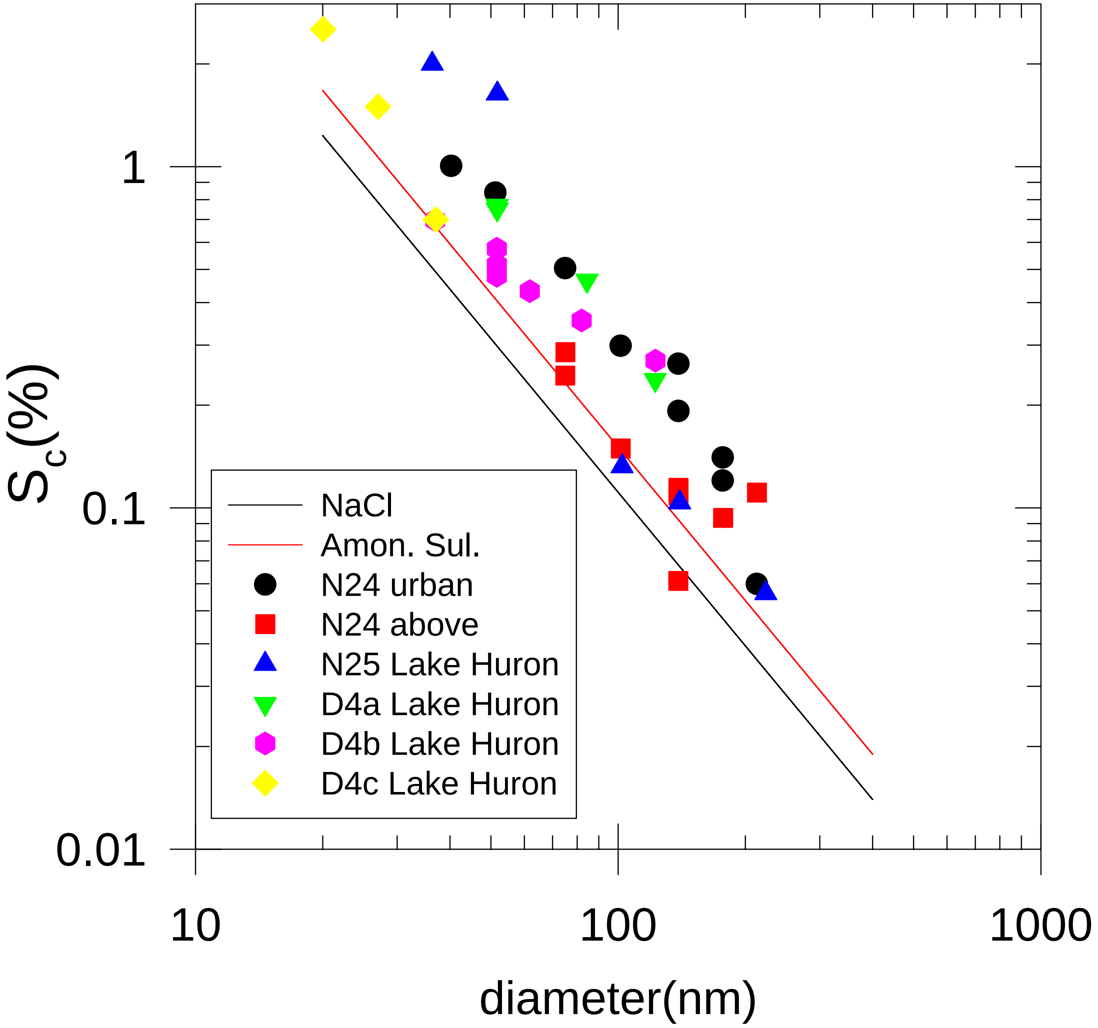


From Hudson 2007

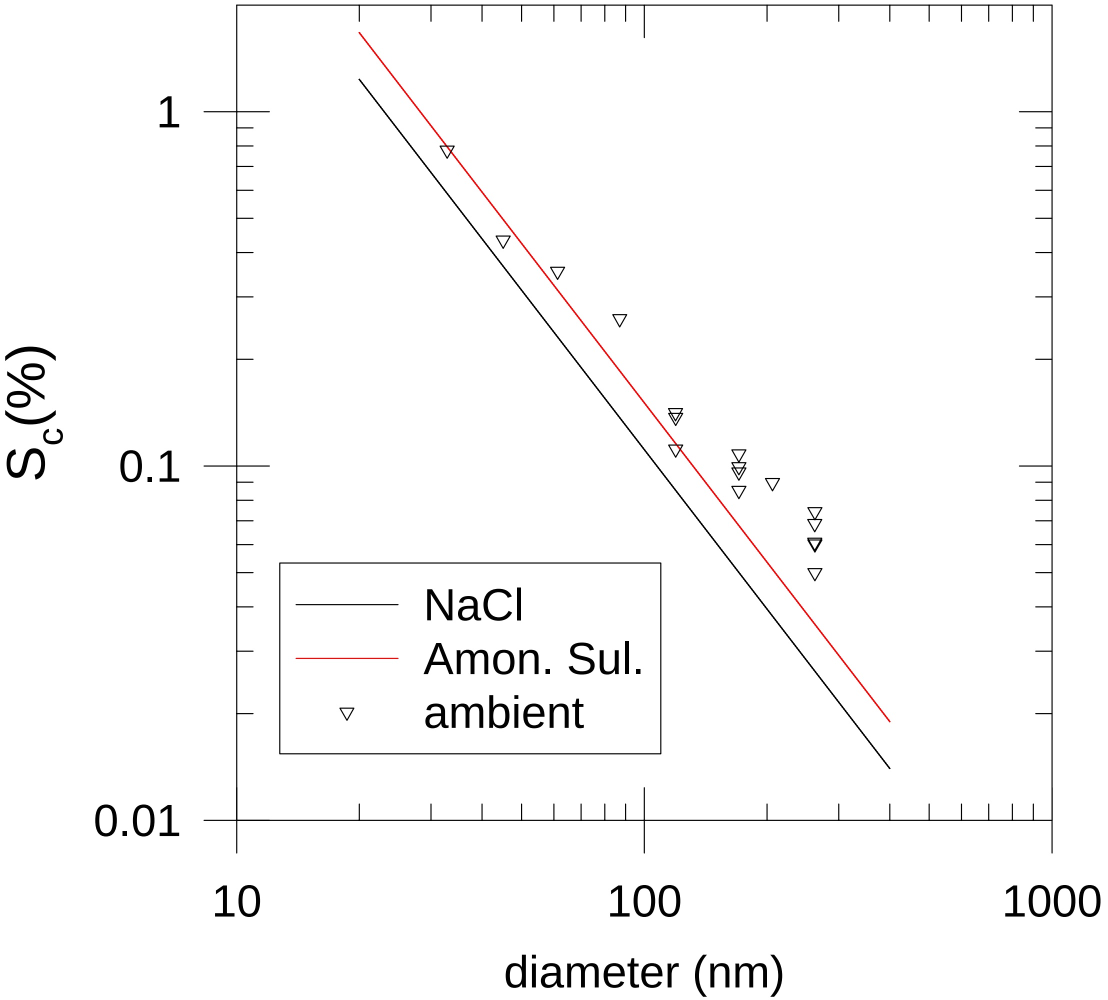
Particle critical Supersaturation (Sc) versus dry particle diameter

Nov. 24 and 25 and Dec. 4, 2003

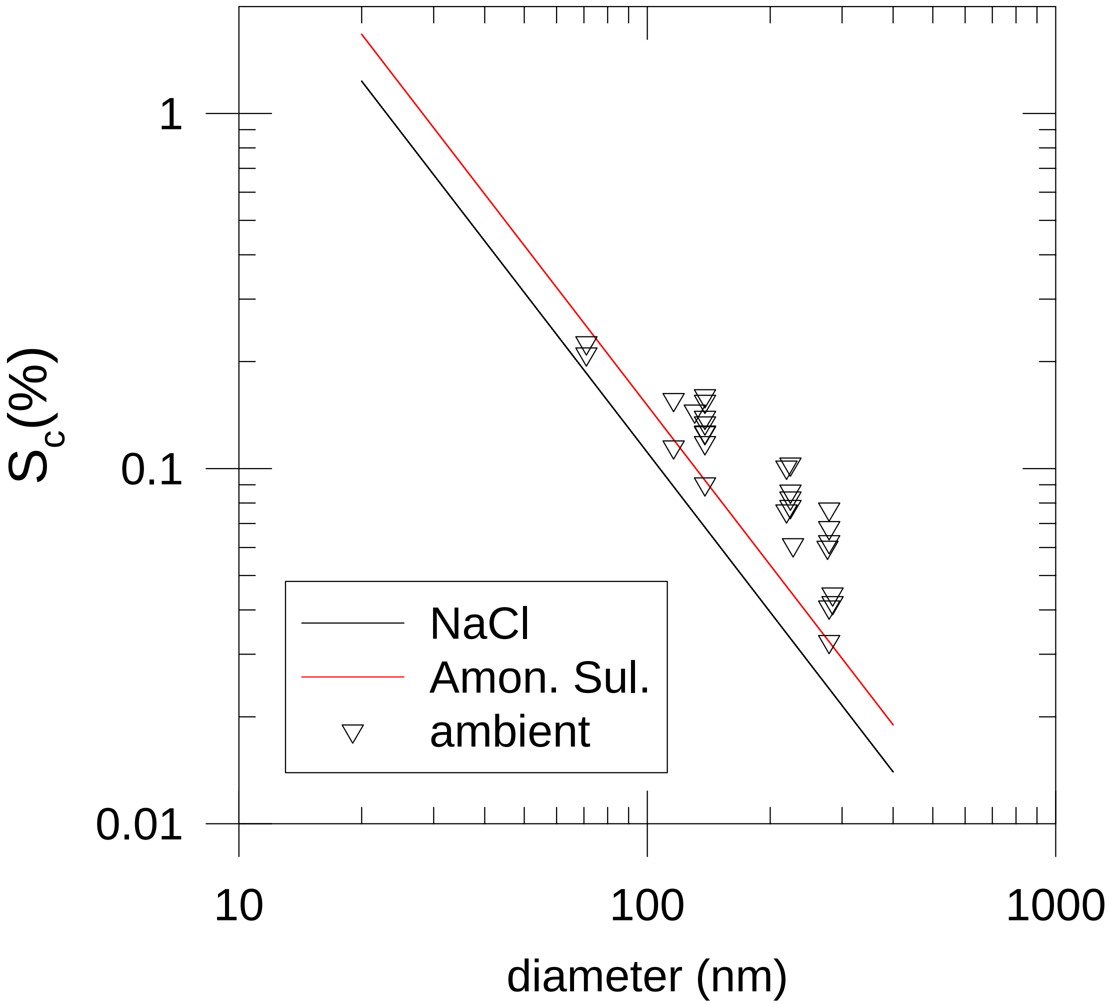
AIRS2 Northeast US



Particle critical Supersaturation (S_c)
versus dry diameter
September 2, 2007 1417-1637 local time
PASE near Christmas Island
low altitude



Particle critical Supersaturation (S_c)
versus dry diameter
Sep 7, 2007 0913-1507 local time
PASE near Christmas Island
low altitude



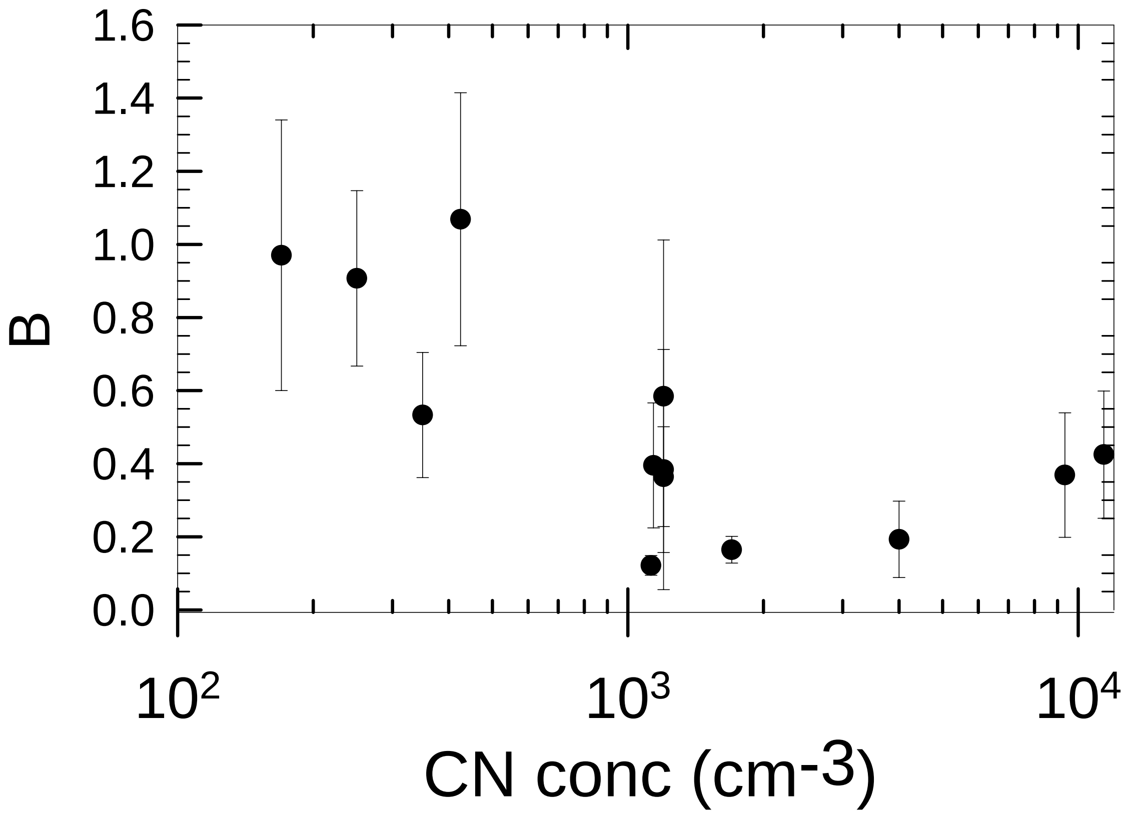


Figure 4. Average and standard deviation of the solubility parameter, B, plotted against the simultaneous average CN concentration during each set of size-S_c measurements.

1. Vertical differences in concentrations—layers above cloud.
2. Is there a low concentration layer right above cloud?
3. Do higher concentrations above get into cloud?
4. Will there be day-to-day variations as in RICO or not as in MASE?
5. CCN-droplet correlations—related to entrainment?
6. Drizzle inverse relationship?
7. Determine cloud S—related inversely to concentration?
   How related to entrainment? Causes underestimate of S.
8. FSSP missing small cloud droplets when S is low? Haze
   versus activated droplets?
9. CCN conc. related to cloudiness—cloud scavenging?
10. Volatility
11. Size-S_c, B related to concentration?