Study on the first aerosol indirect effect (AIE-I) using retrievals of cloud drop number concentration for boundary layer clouds from cloud radar

Hongfei Shao

University of Maryland - ESSIC

1) **The importance of obtaining the adiabatic cloud drop number concentration (Nc)**

2) **How to get the adiabatic Nc from cloud radar**

3) **Some interesting results on AIE-I using the adiabatic Nc.**

The first AIE involves a series of processes linking various intermediate variables

Aerosol Mass ➔ CCN (Step 1/2) ➔ Adiabatic Cloud Drop Concentration N_c (1)

➔ Actual N_c (Step 1½) ➔ Cloud Effective Radius (2)

➔ Cloud Optical Depth and Cloud Albedo (3)

Adiabatic N_c is the critical variable that links Step (1) to Step (2)

Measurement of Adiabatic N_c is still missing

Assuming that CCN spectrum in the form of CCN=CS^k (S: supersaturation, C and k a fitting parameters), Twomey derived the following analytical expression:

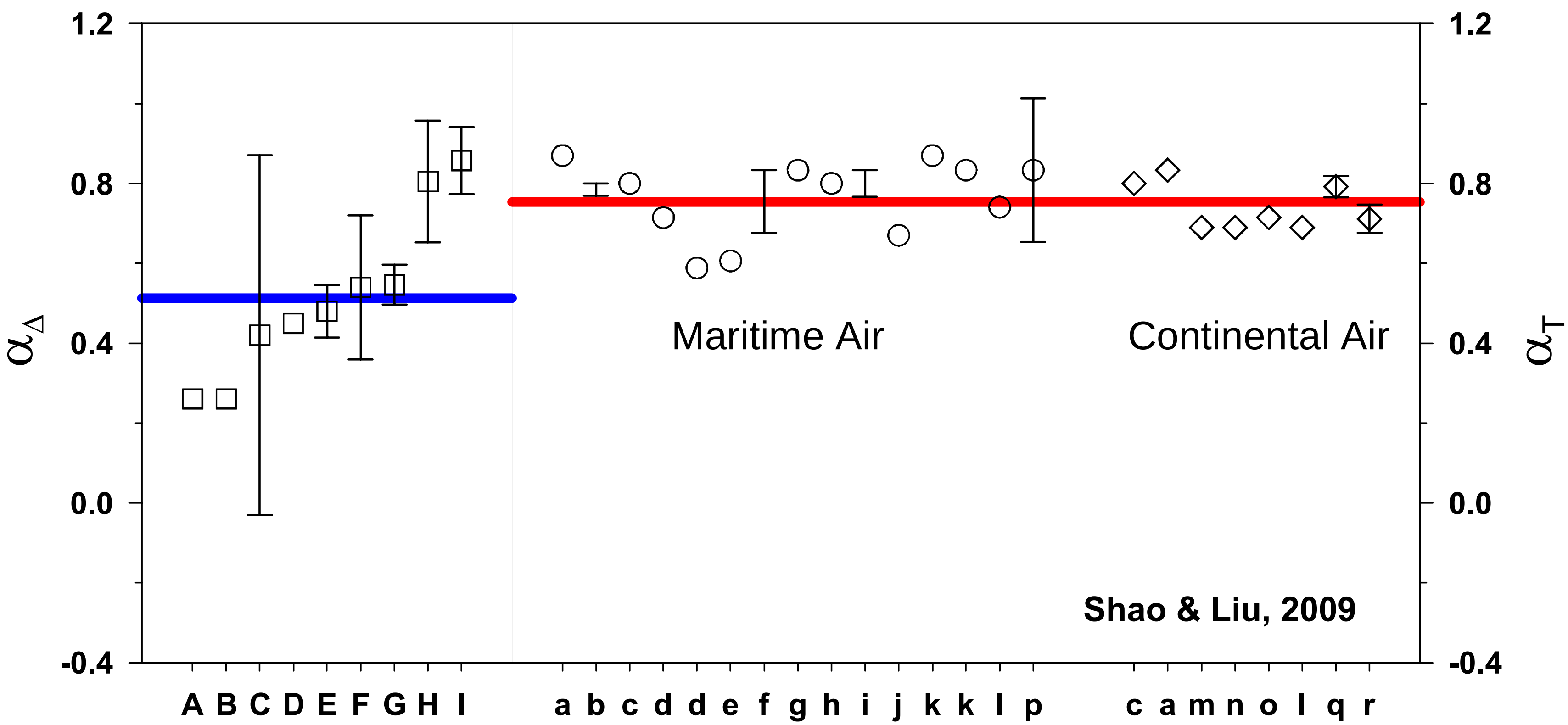
$$N_c^{ad} = (fN_a)^{2/(k+2)} \left[\frac{cw^{3/2}}{kB(k/2,3/2)} \right]^{k/(k+2)}$$

N_c^{ad}: adiabatic Nc
N_a: aerosol number concentration
w: updraft velocity

Twomey then suggested that the first AIE for adiabatic cloud should be:

$$\alpha_T \equiv \frac{\partial \ln N_c^{ad}}{\partial \ln N_a} = \frac{2}{2+k}$$

Comparison Twomey-suggested α_T with in-situ measurement $\alpha_\Delta \equiv \frac{\Delta \ln N_c}{\Delta \ln N_a}$



On average, α_Δ is about half of α_T, but more scattered

According to Twomey's analytical solution:

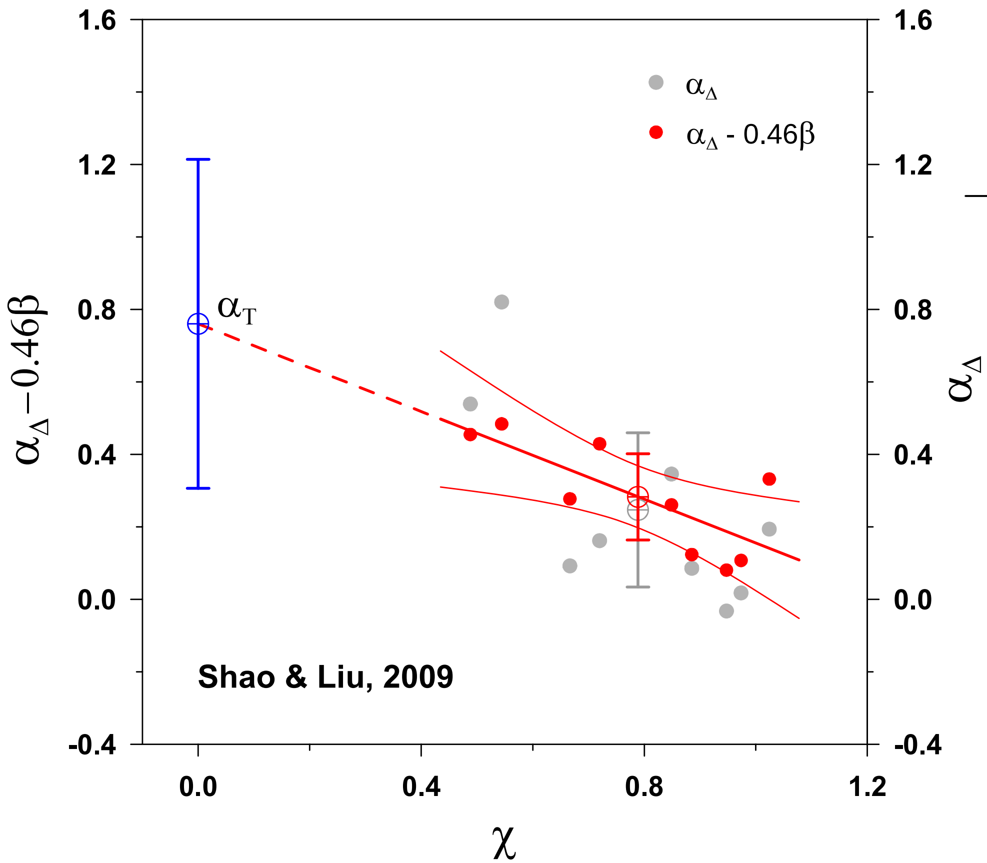
$$N_c = \varepsilon (fN_a)^{2/(k+2)} \left[\frac{cw^{3/2}}{kB(k/2,3/2)} \right]^{k/(k+2)}$$

This discrepancy between α_Δ and α_T may arise from changes in:

1) Aerosol activation efficiency, 2) Cloud adiabaticity and 3) Updraft velocity

$$\alpha_\Delta = \alpha_T + c_1 \frac{\Delta \ln f}{\Delta \ln N_a} + c_2 \frac{\Delta \ln \varepsilon}{\Delta \ln N_a} + c_3 \frac{\Delta \ln w}{\Delta \ln N_a}$$

If the cloud adiabaticity influence (β) is removed, the difference between α_T and α_Δ can be mostly explained by the change in aerosol particle size.



$\chi \equiv \frac{\Delta \ln A}{\Delta \ln N_a}$ **A: Angstrom exponent**

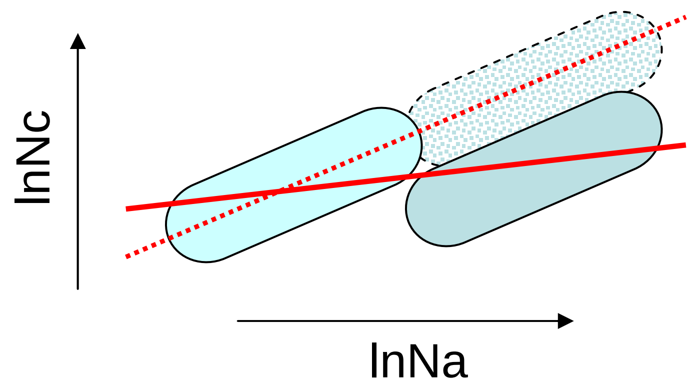
$$\alpha_\Delta - 0.46\beta = \alpha_T - 0.6\chi$$

$$\alpha_\Delta^{ad} \equiv \frac{\Delta \ln N_c^{ad}}{\Delta \ln N_a} \approx \alpha_T - 0.6\chi$$

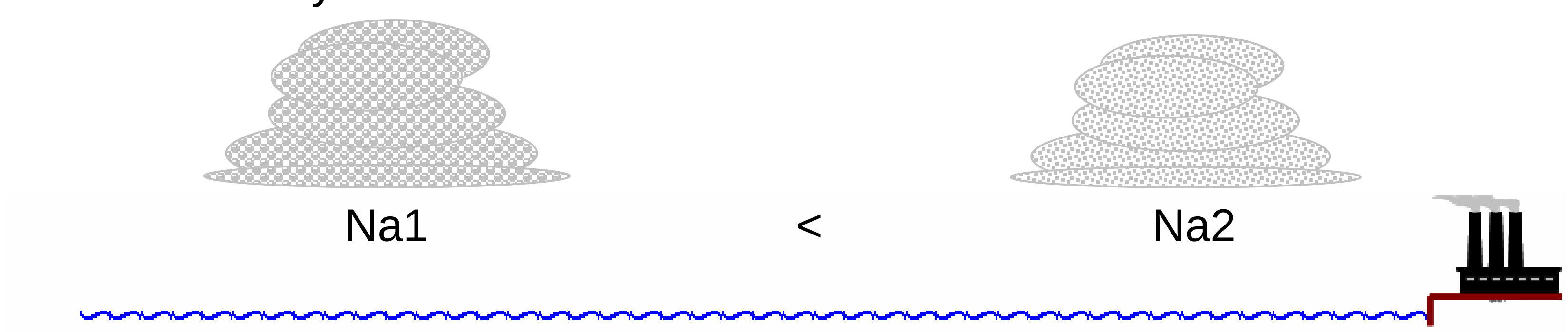
The first AIE for adiabatic cloud is NOT Twomey-suggested α_T

Reduce the effectiveness of aerosol particles as CCN by 1) suppressing the maximum supersaturation and 2) by changing the aerosols' physicochemical properties

$$\alpha_{\Delta}^{ad} \equiv \frac{\Delta \ln N_c^{ad}}{\Delta \ln N_a} \approx \alpha_T - 0.6\,\chi$$



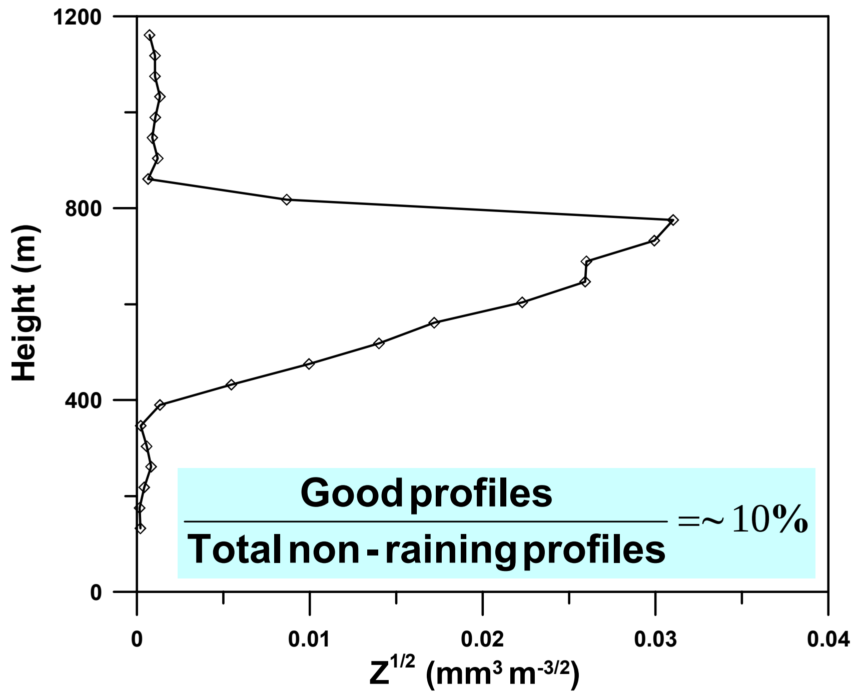
Activation efficiency: f1 > f2

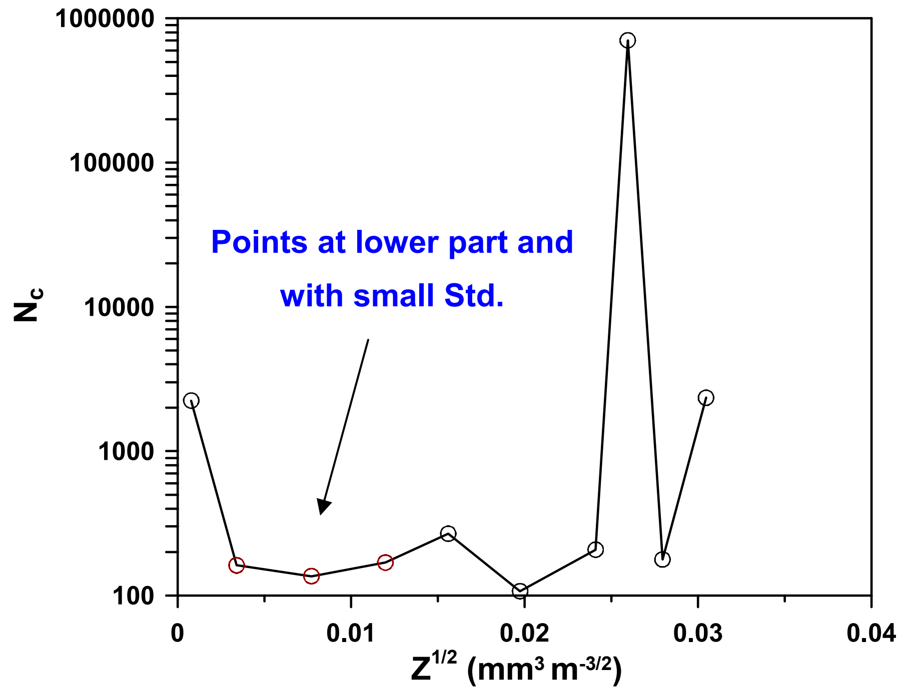


Assuming that liquid water content increases adiabatically with height (H) yields

$$\frac{dH}{d\sqrt{Z}} \propto \sqrt{N_c}$$

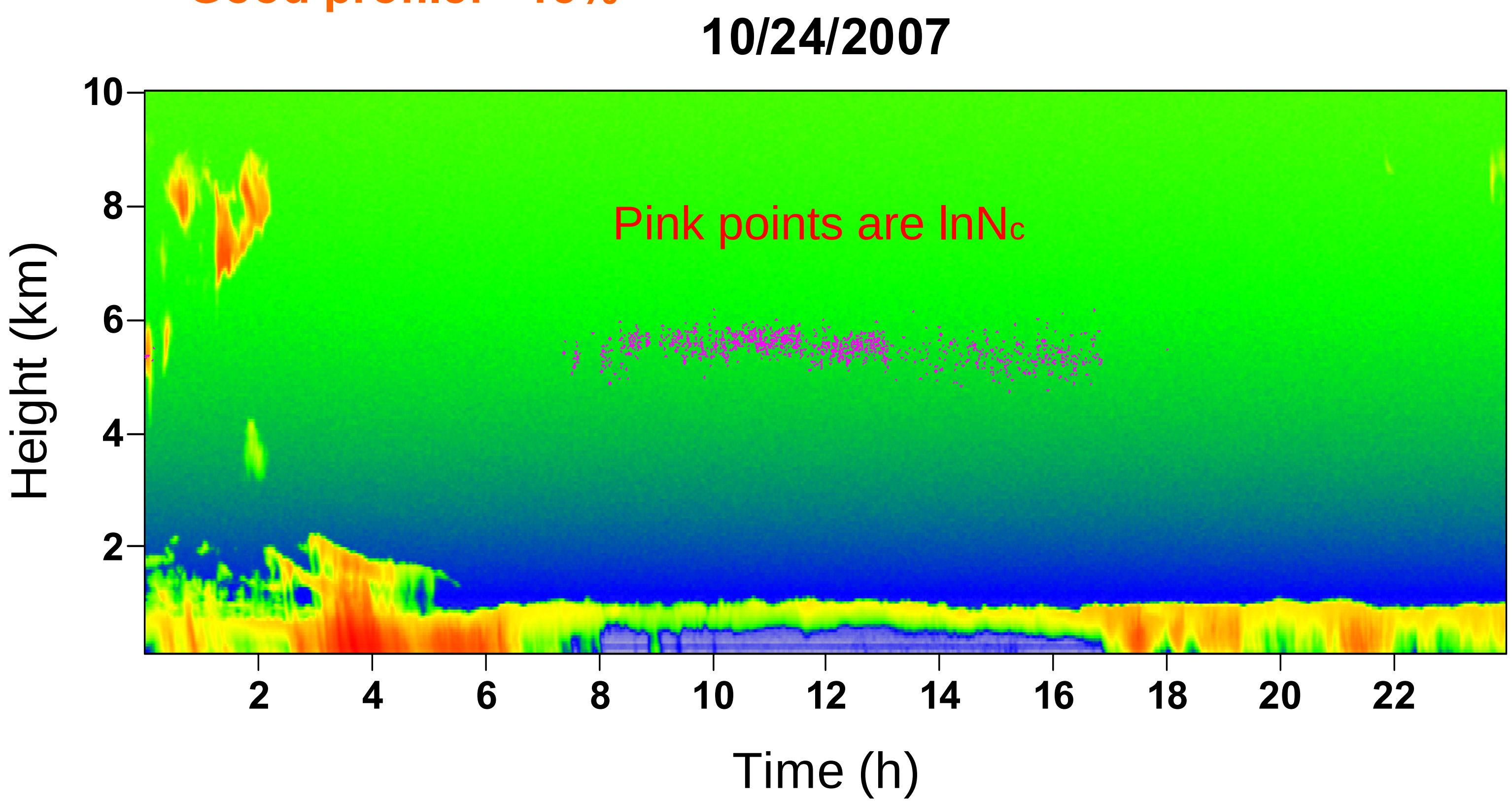
Radar Reflectivity (Z)



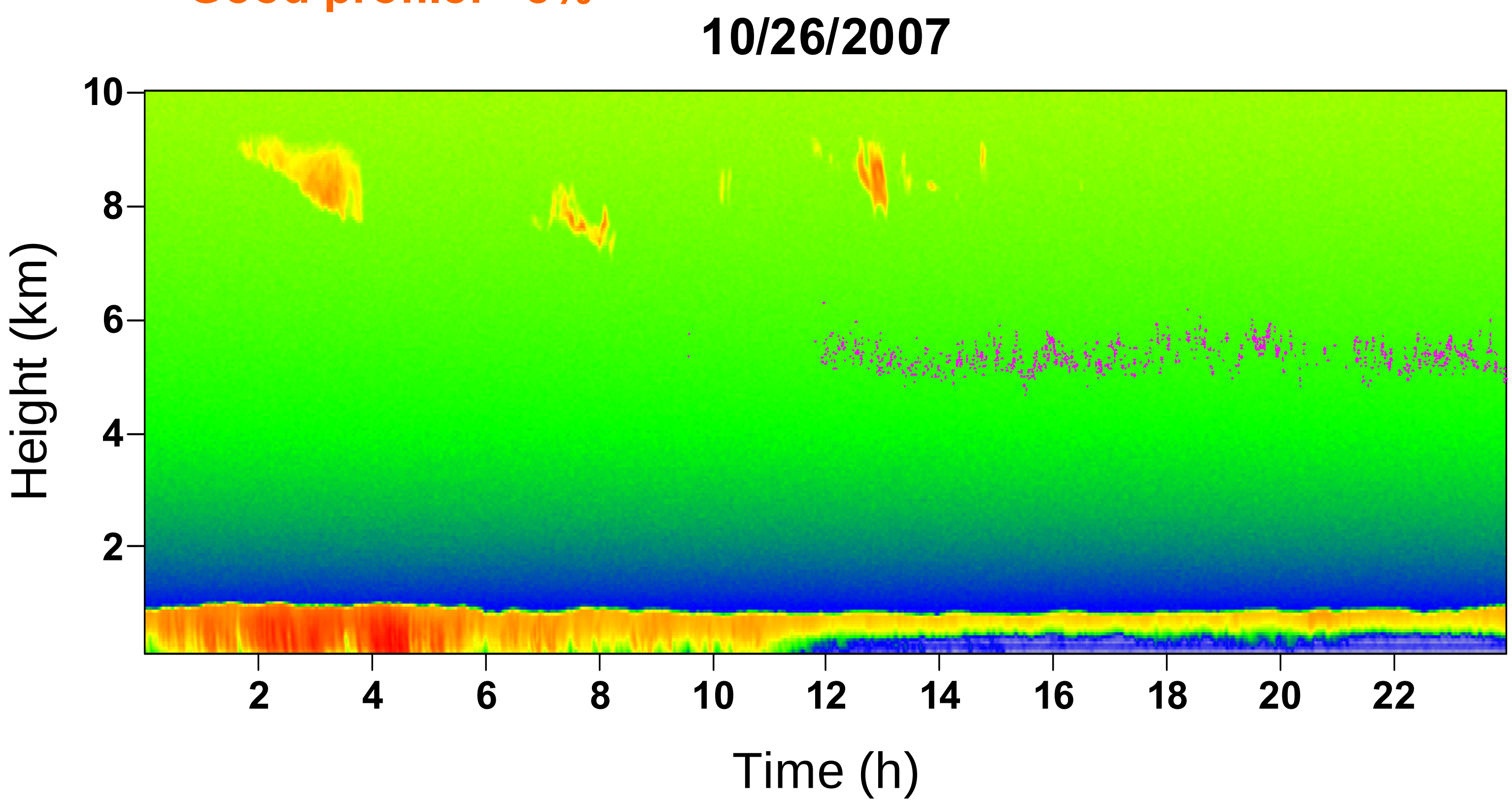


1) no integrated quantity being used
2) no multi-layer clouds problem
3) insensitive to entrainment evaporation at cloud top
4) N_c is close to its adiabatic value (so it can be related to CCN spectrum directly)

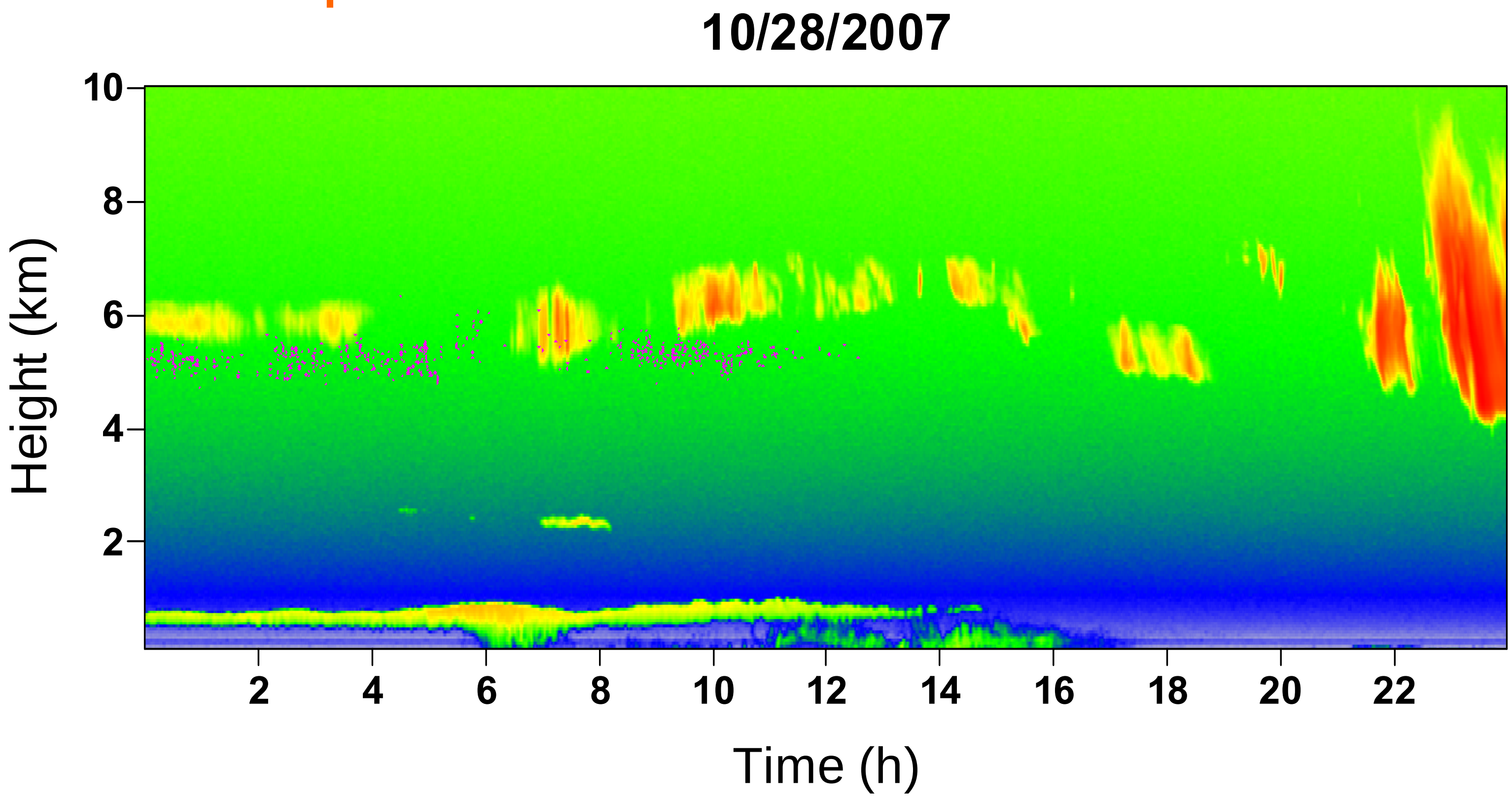
Good profile: ~15%



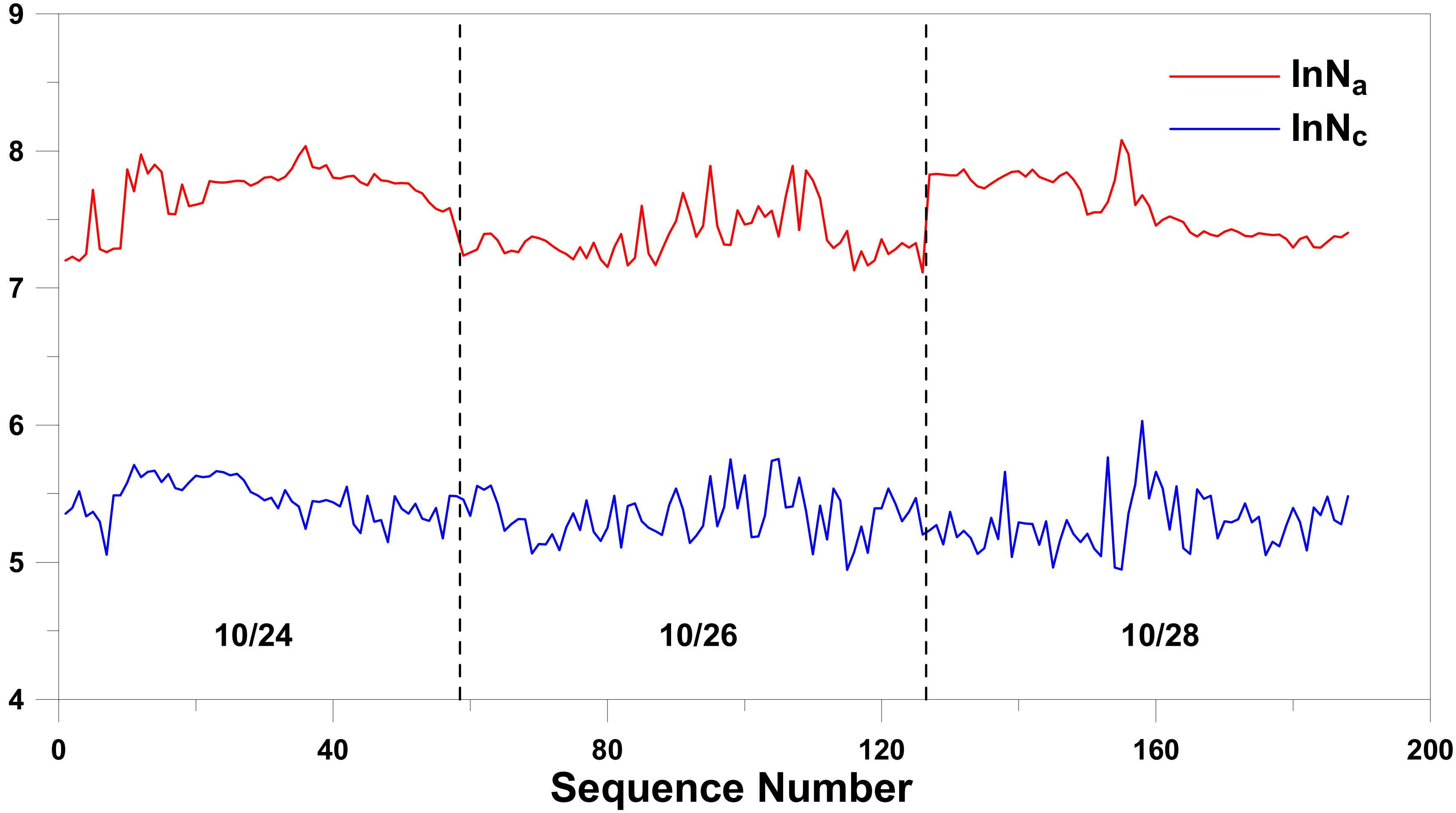
Good profile: ~8%



Good profile: ~8%



Average over 5 min



Aerosol observation system → N_a + N_c derived from WACR

CCN spectrum parameters (k and f)

Angstrom exp.

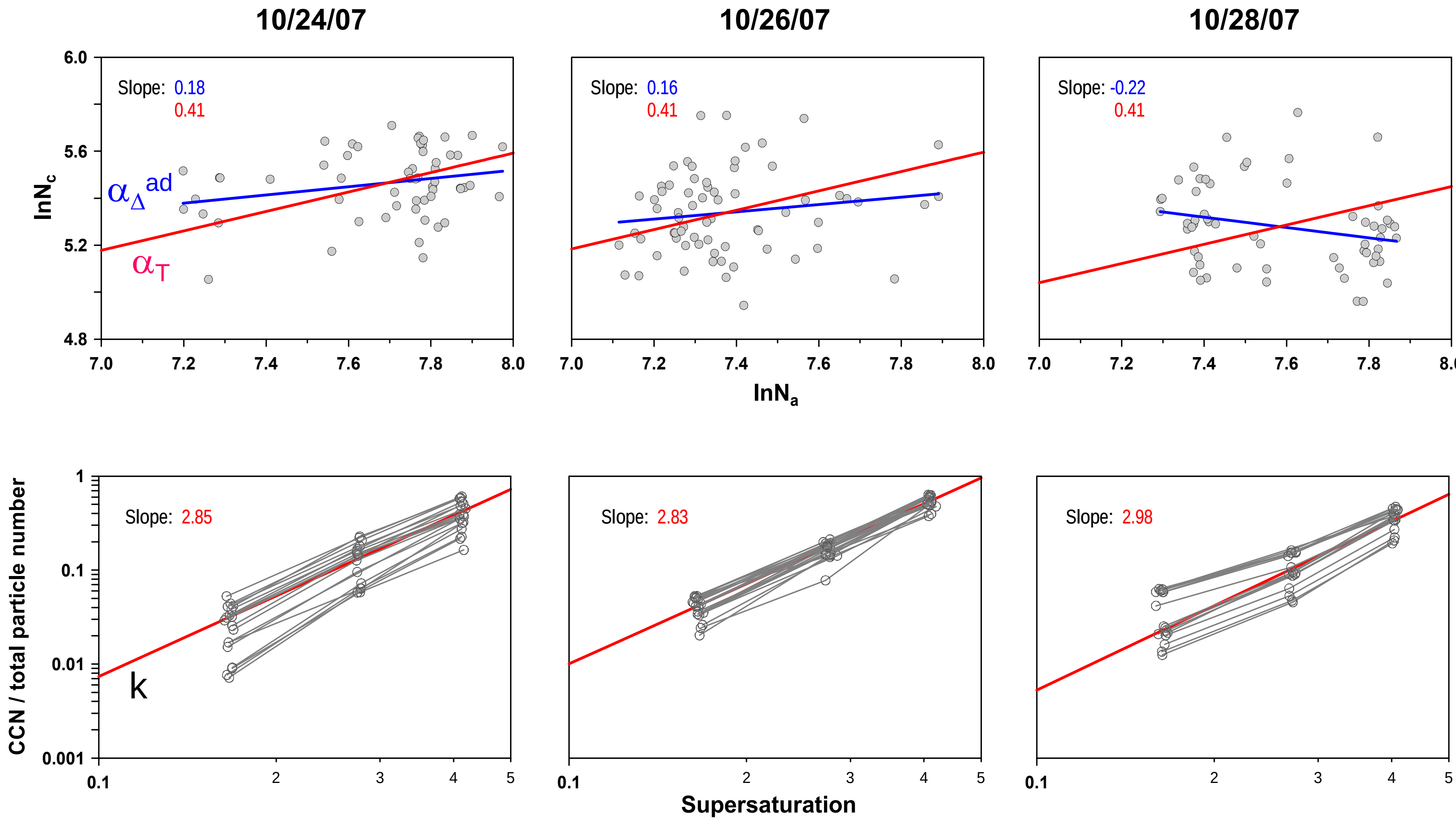
Twomey-suggested AIE-I

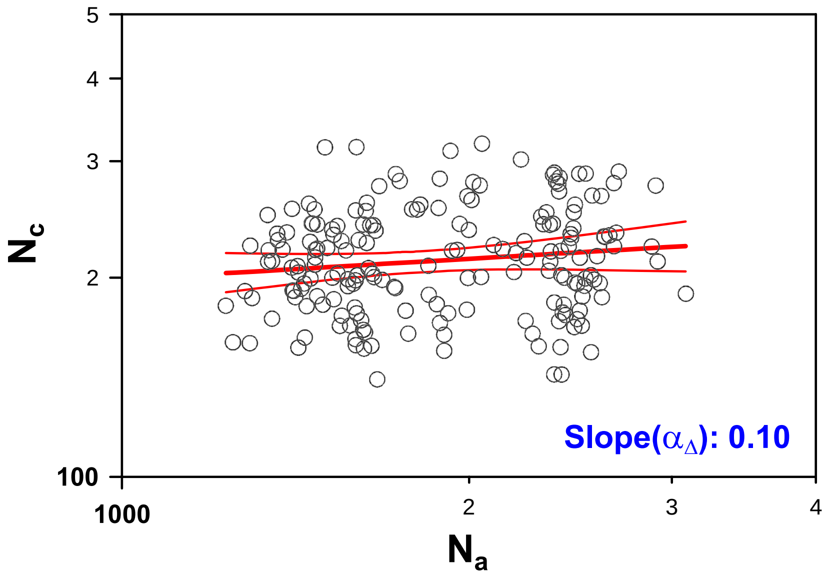
$\alpha_T = 2/(k+2)$

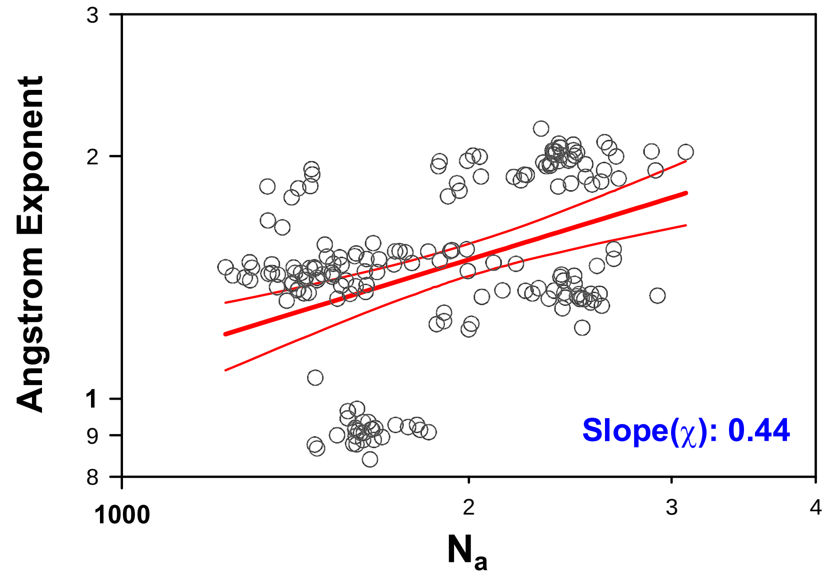
$$\alpha_{\Delta}^{ad} = \alpha_T - 0.6\chi$$

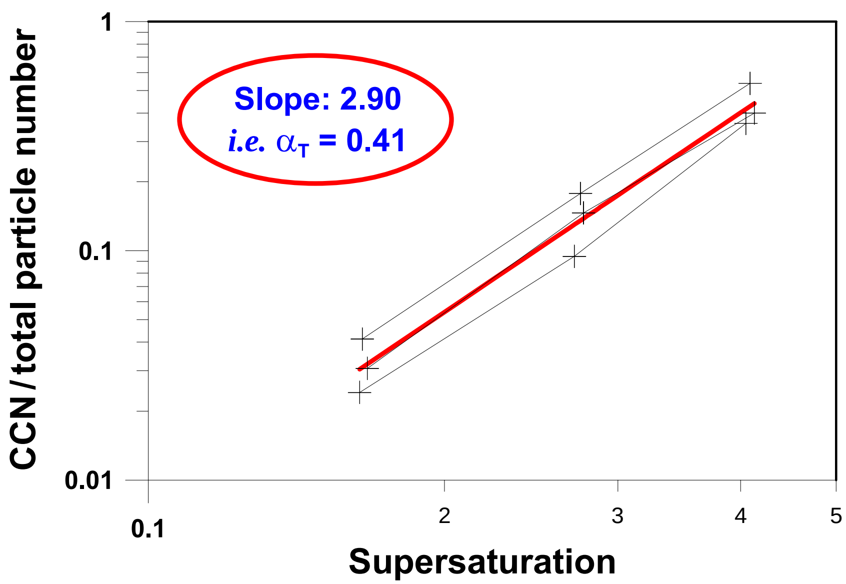
Directly-measured AIE-I

$$\alpha_{\Delta}^{ad} = \frac{\Delta \ln N_c}{\Delta \ln N_a}$$


10/24/07
10/26/07
10/28/07
Slope: 0.18
0.41
Slope: 0.16
0.41
Slope: -0.22
0.41
lnNc
lnNa
αΔad
αT
Slope: 2.85
Slope: 2.83
Slope: 2.98
k
CCN / total particle number
Supersaturation

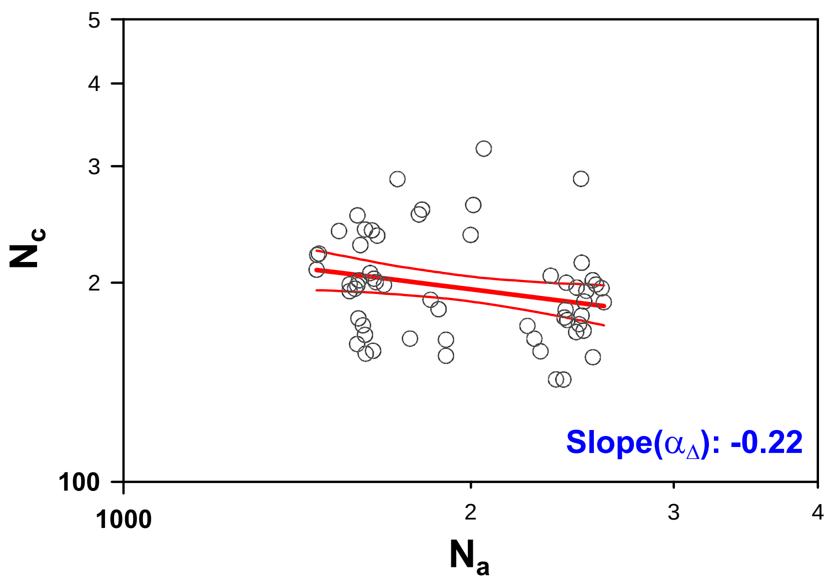


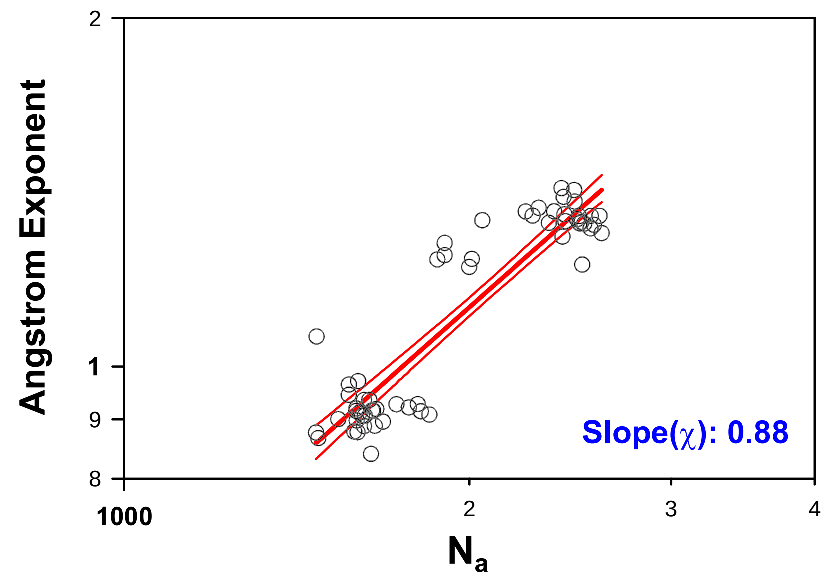


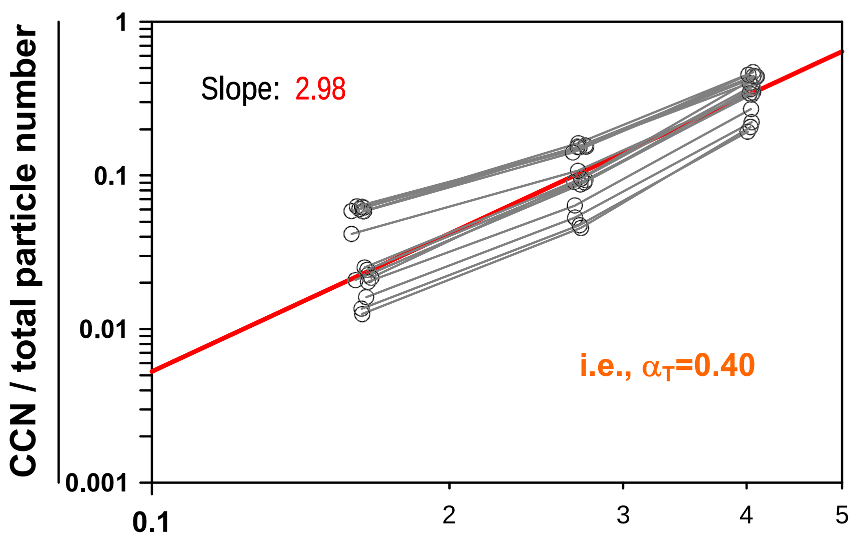


$$\alpha_\Delta^{ad} = \alpha_T - 0.6\chi$$

$$\alpha_T = 0.36$$







$$\alpha_\Delta^{ad} = \alpha_T - 0.6\chi$$

$$\alpha_T = 0.31$$

Our ground-based method corroborates our previous satellite results:

1) Additional aerosols can reduce the efficiency of aerosols to active as cloud condensation nuclei

2) Unlike the semi-direct effect (Hudson and Yum, 1997) and the dispersion effect (Liu and Daum, 2002), this offsetting mechanism takes place at the initial stage of drop formation and can compete the Twomey-suggested AIE-I substantially.

Future work:

1) **Aerosol activation efficiency will be directly related to CCN spectrum parameters k** and **f**.

2) **The response of supersaturation to the change in aerosol number concentration will be examined.**