Efficacy of Aerosol – Cloud Interactions under Varying Meteorological Conditions

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(Courtesy Magritte)

Motivation

- Cloud dynamical processes such as entrainment mixing may be the primary modulators of cloud optical properties in certain situations.
  - Entrainment of dry air alters the cloud drop size distribution by enhancing drop evaporation. The effect of entrainment mixing and other forms or turbulence are still quite uncertain.
- Cloud dynamical factors and aerosol-cloud interactions should be considered together when evaluating the efficacy of aerosol indirect effects (AIE) as they share interdependent underlying mechanisms.

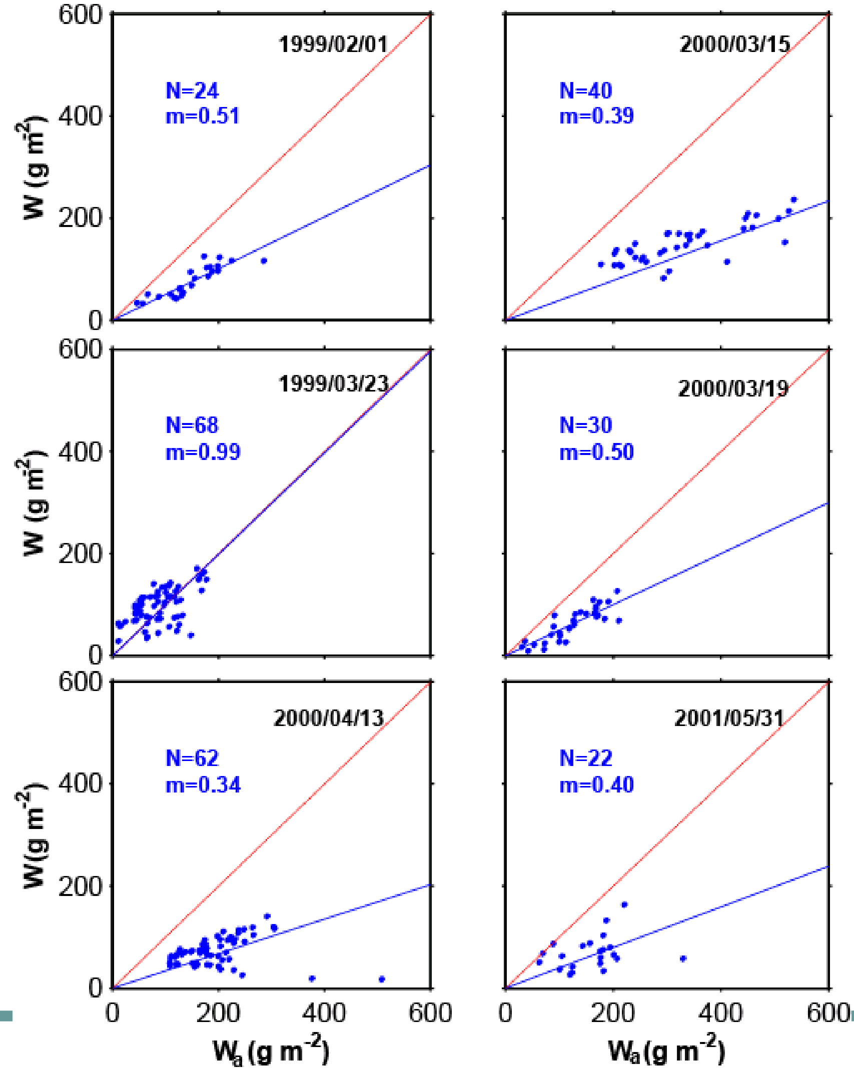
Topics

- Role of Adiabaticity
  - Influence of Adiabaticity on AIE
- AIE with Varying Meteorological Condition
  - Soundings (stability and humidity)
  - Aerosol-Cloud Interactions
- Summary and Issues

Subadiabaticity of Continental Clouds

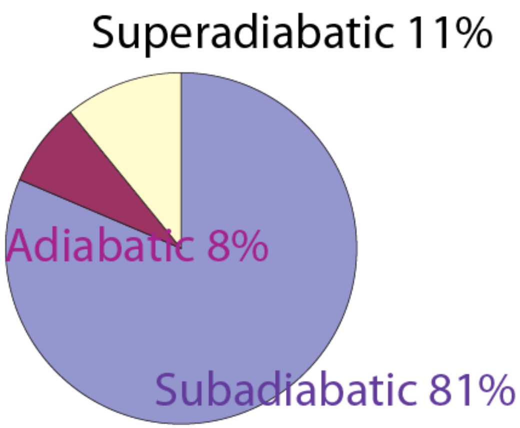
Adiabaticity (α)

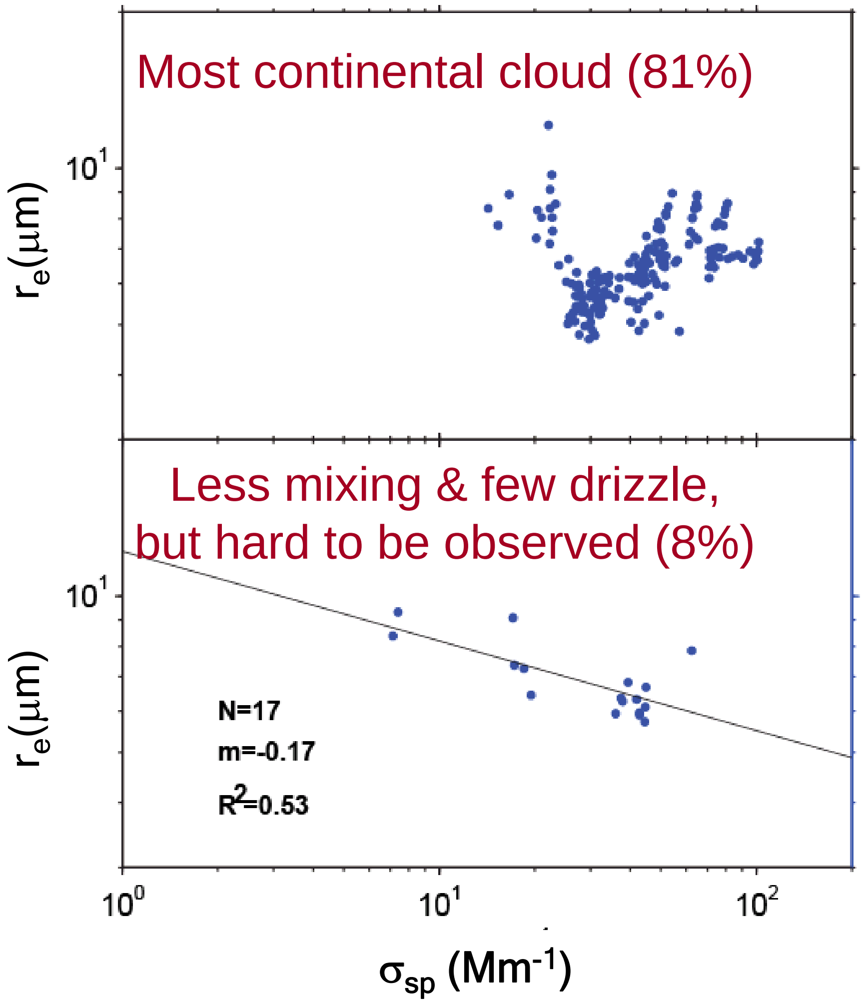
$$\begin{cases} \alpha = \dfrac{W}{W_a} \\ W_a = \dfrac{1}{2}\Gamma_l \Delta z^2 \\ \Gamma_l \cong \dfrac{(\varepsilon + q_s) q_s l_v}{R_d T^2} \Gamma_w \end{cases}$$



(Kim, Miller, Schwartz, Liu, Min, JGR, 2008)

Aerosol-Cloud Interaction with Adiabaticity





Subadiabatic

$0.1 < \alpha < 0.8$

Adiabatic

$0.8 < \alpha < 1.2$

(Kim et al., JGR, 2008)

Aerosol-Cloud Interactions with Varying Meteorological Condition

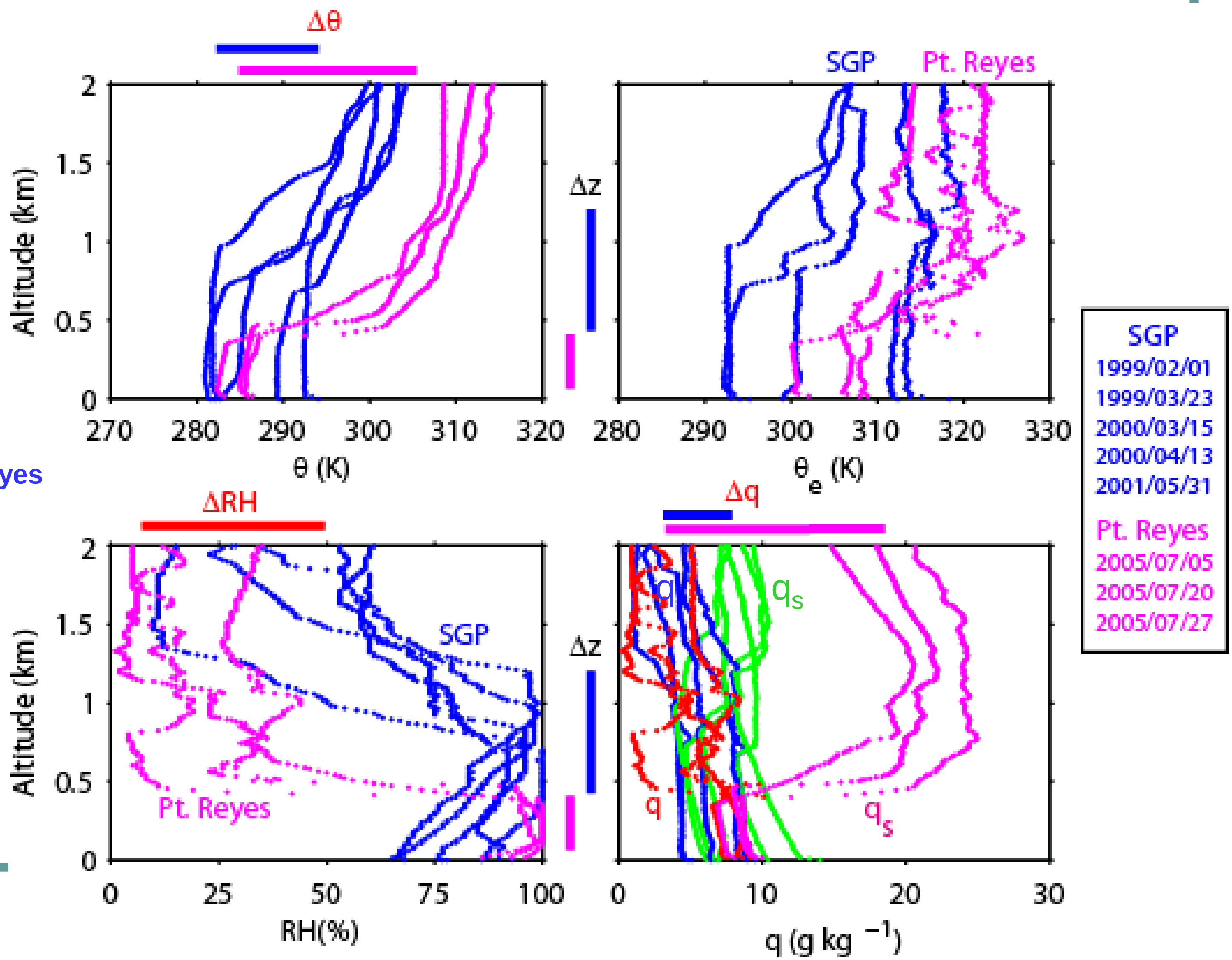
Comparisons of Soundings: SGP vs. Pt Reyes

Δθ : Inversion strength above cloud top

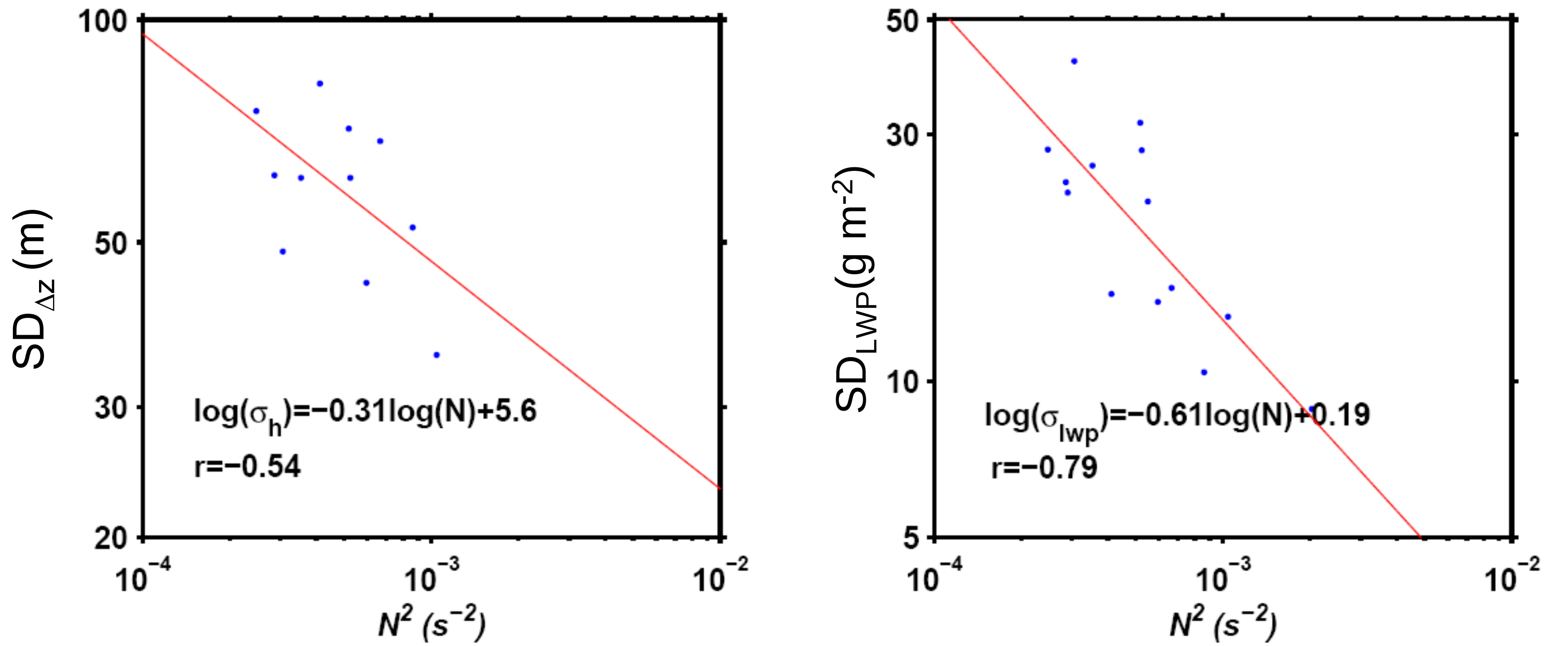
Δq : moisture difference above cloud top

ΔRH : RH difference between SGP & Pt.Reyes

Δz : cloud thickness



LWP Variability Suppressed by the Stability

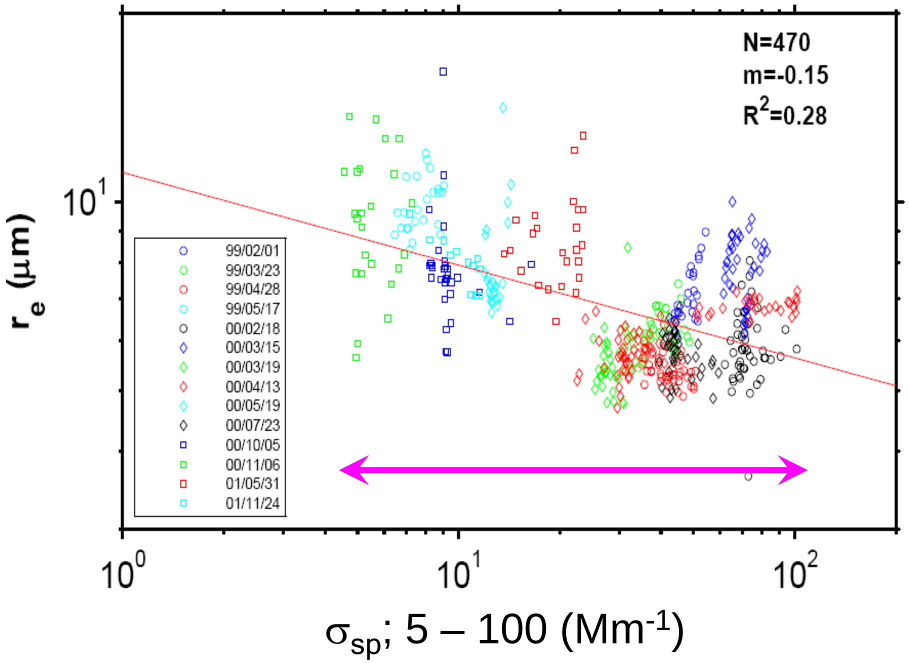


-The variability in cloud depth (Δz) and LWP exhibits significant negative correlation with N^2; suggesting suppression of turbulence by the vertical static stability reduces the cloud variability, which could eventually facilitate aerosol-cloud interactions.

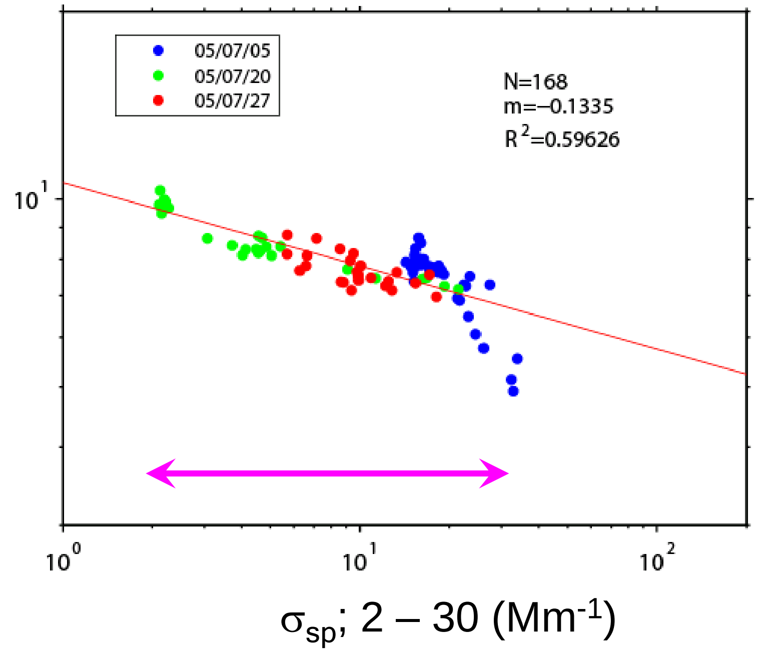
(Kim, Klein, Norris, JGR, 2005)

Efficacy of Aerosol-Cloud Interactions

SGP (1999 – 2001; 13 days)



Pt. Reyes (2005; 3 days)



- Aerosol loading and its variations at Pt Reyes are smaller than SGP, and with also less variation of r_e.
- It could help facilitate aerosol-cloud interactions over Pt. Reyes on the ensemble cloud scale and a single cloud scale also.

Summary of SGP and MASE

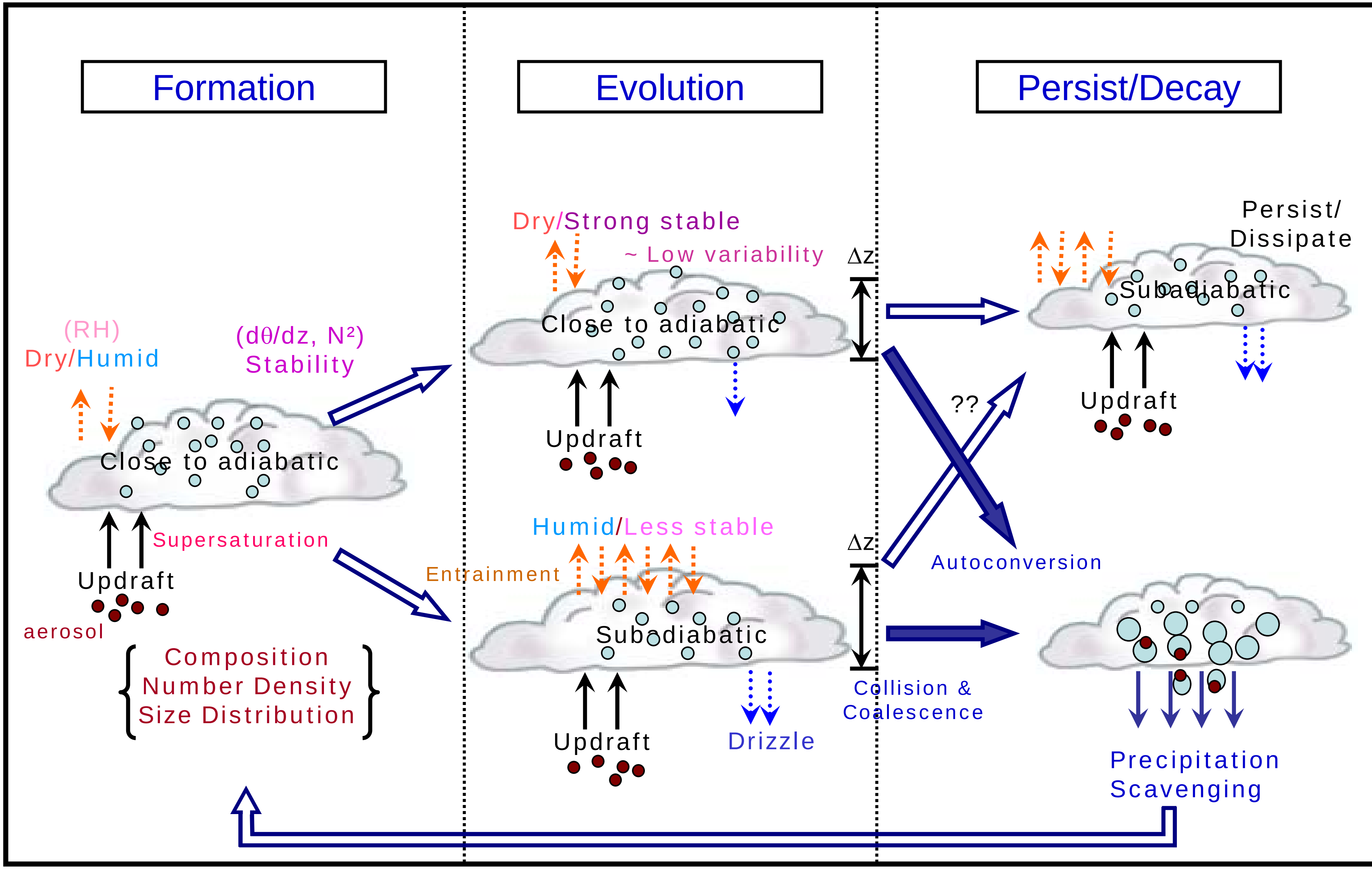
	Cloud Depth(m)	LWP (gm^{-2})	r_e (μm)	σ_{sp} (Mm^{-1})	N (s^{-1})	α	RH (%)	IE
SGP[$] (1999-2001)	200-800	180-1000	5.6-10.2	5.0-100	1.0-2.7	0.3-0.5	30-70	0.15-0.17 (R^2<0.5)
MASE Pt. Reyes[@] (2005.7.15-27)	200-300	40-150	6.0-10.5	2.0-30	2.5-3.1	0.6-0.8[%]	10-30	0.13 (R^2=0.6)
Monterey[#] (2005.7.2-17)	200-500	20-90	5.8-10.6					

[$] Kim et al.(JGR, 2008) SGP mostly remote sensing for 1999-2001.

[@] Daum et al.(JGR, 2008) Pt. Reyes remote sensing & [%]MASE DOE-G1 for 2005.7.15-27.

[#] Lu et al. (JGR, 2007) MASE(CIRPAS) for 2005.7.2-17.

Liquid Stratiform Cloud-Aerosol Interactions



- Different mechanism determining the cloud optical properties in a given situation.
- Aerosol-induced cloud processing driven by varying meteorological environment.
- Limitations on measurement: not process-following, just end results.

Summary

- AIE is more discernible with the segregation by adiabaticity
- The consistent and thin stratus clouds at Pt. Reyes are close to adiabatic in structure than those at SGP because of the stronger static stability above cloud top, which inhibits entrainment mixing of the dry air above.
- These clouds likely exhibit increased efficacy of aerosol-cloud interactions since they form in a much more homogeneous meteorological environment (low variability in LWP).

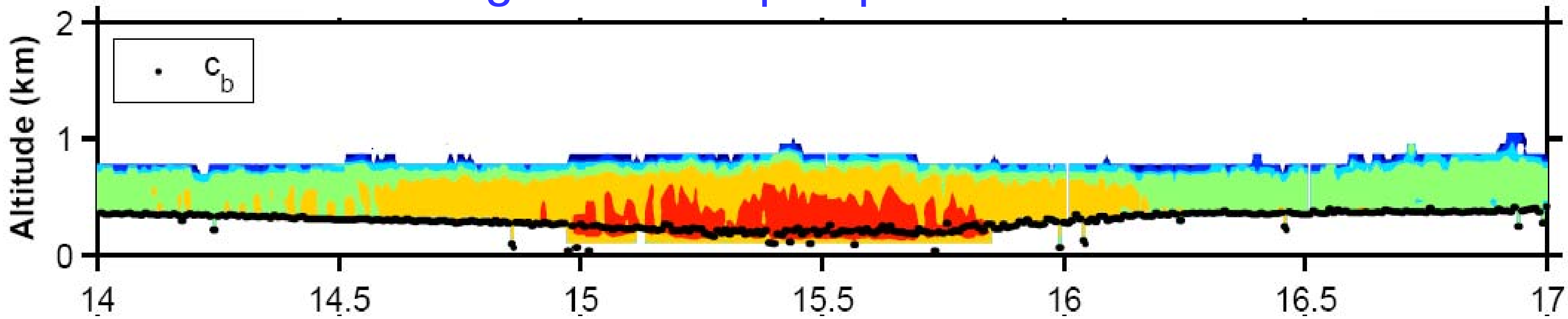
Issues

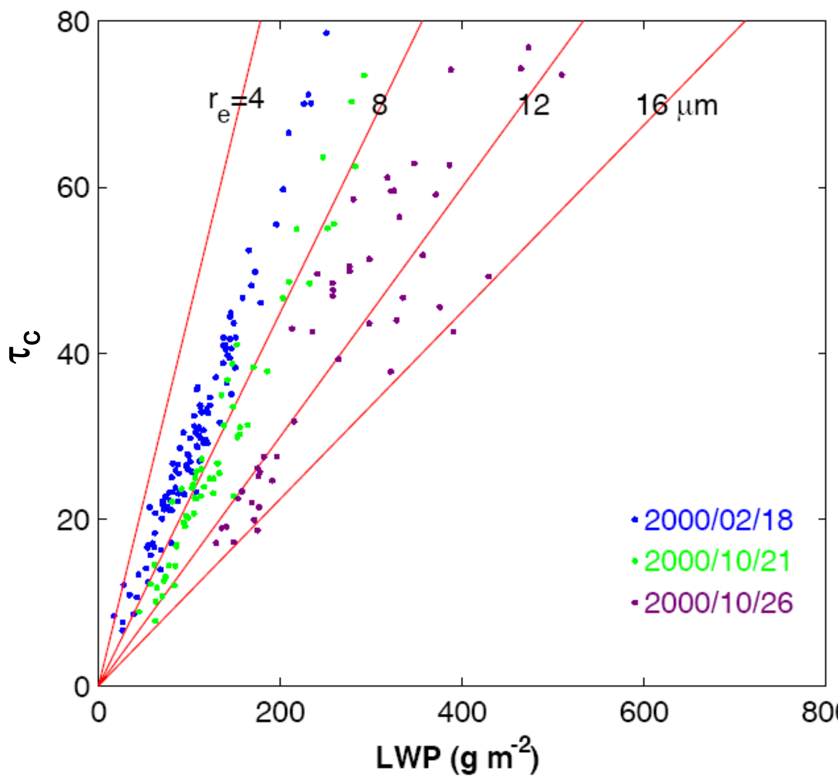
- Observation limitation and artifacts: not process-following, just end results
- All mechanisms are dependent with each other. A full analysis and relevant reasoning will be possible with the segregation of adiabaticity.
- Still uncertainty in estimating the adiabaticity.
  - Overestimation of Pt. Reyes clouds with low LWP.
  - Soundings are most valuable for understanding the meteorological environment.
- No considerations on the dispersion effect.
- Further analysis may enable more accurate assessments of this key variable.

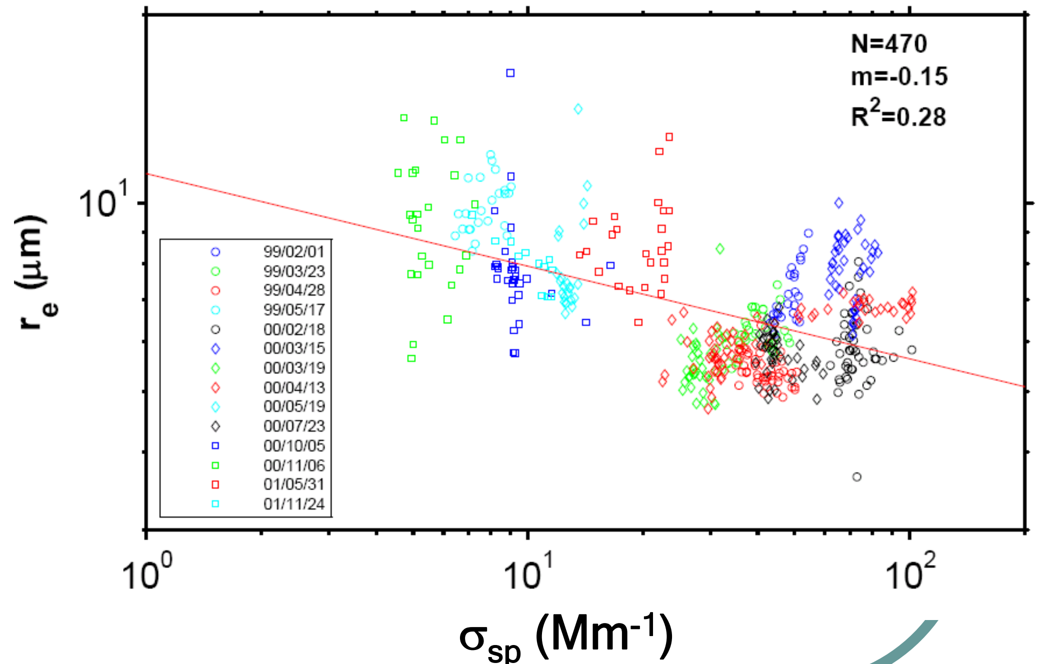

Snow Mountain at Gangnung
Thank you !!!

Identification of Aerosol-Cloud Interaction

Homogeneous Liquid-phase Stratus Cloud





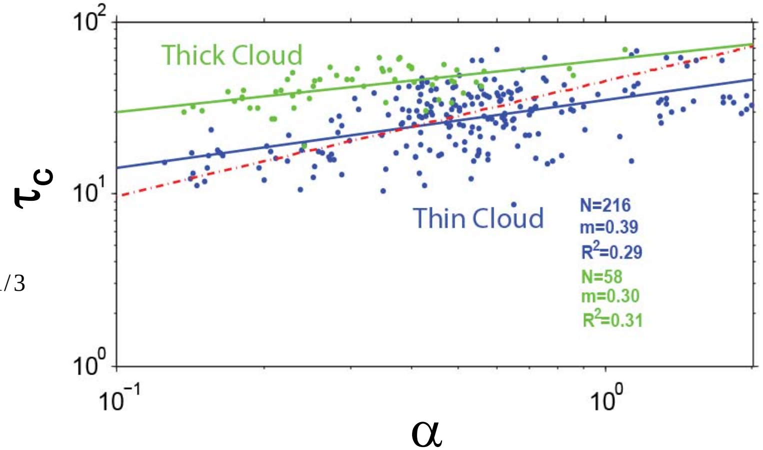


(Kim, Schwartz, Miller, Min, JGR, 2003)

Dependence of τ_c upon α and Δz

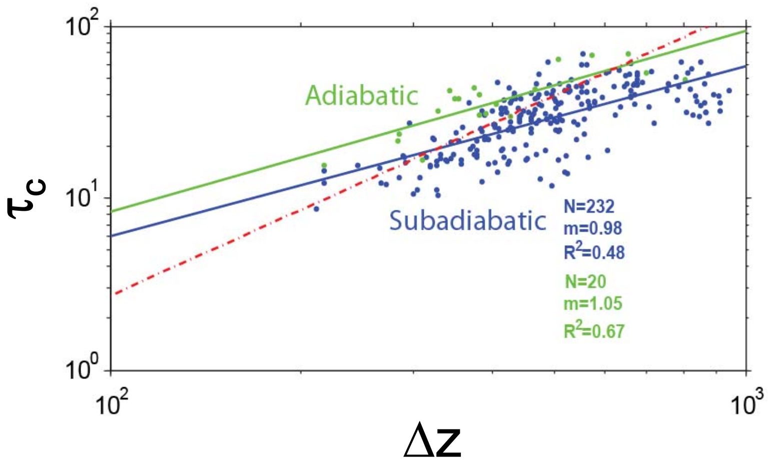
$$\tau_c = 2\pi A^{2/3}\left[\frac{\Gamma_l^2 N_{cd}\alpha^2\Delta z^5}{\exp(3\overline{\sigma_r}^2)}\right]^{1/3}$$

$$A = \frac{3}{8}\frac{\overline{\rho}}{\rho_l}$$



Thick Cloud
600m<Δz<1000m

Thin cloud
200m<Δz<600m

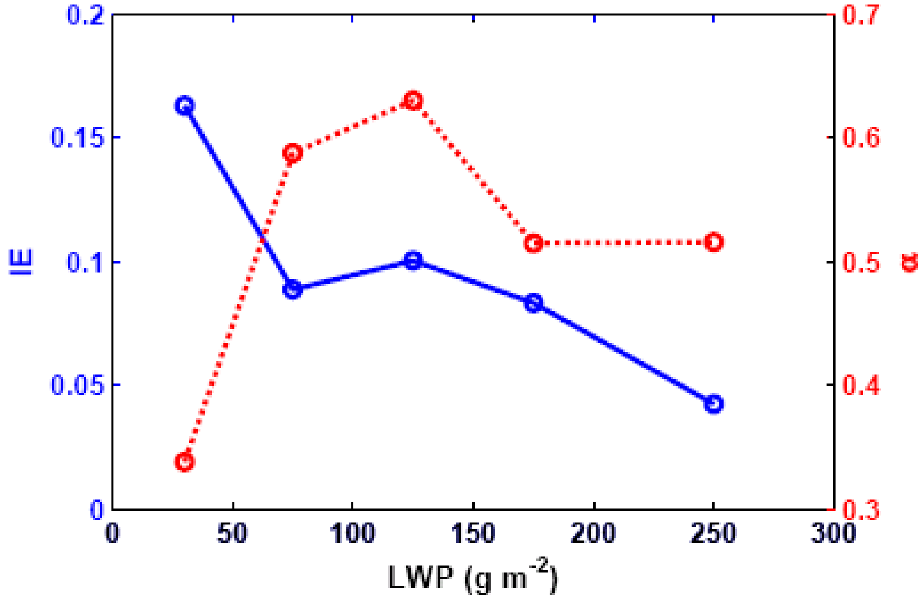


Adiabatic
0.8 < α < 1.2
Subadiabatic
0.1 < α < 0.8

(Kim et al., JGR, 2008)

IE Susceptibility to Adiabaticity & LWP

$IE = -d\log r_e / d\log \sigma_{sp}$



$\alpha = W/W_a$

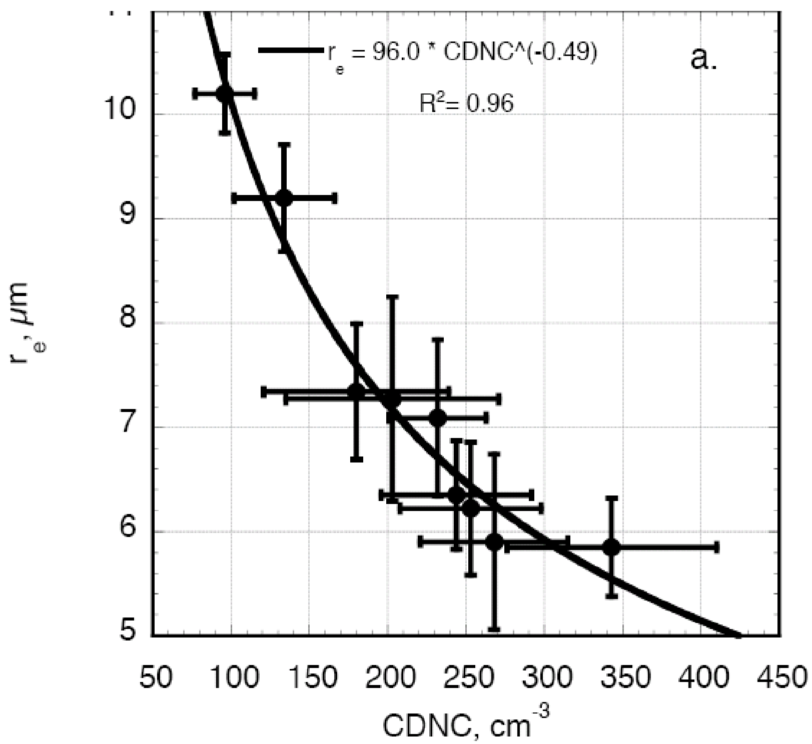
-The thicker clouds of high LWP tend to contain subadiabatic LWP and lower IE values, partly due to larger interacting surface area for the entrainment-mixing processes.

- It could eventually damp aerosol first indirect effect with an increasing LWP.

(Kim et al., JGR, 2008)

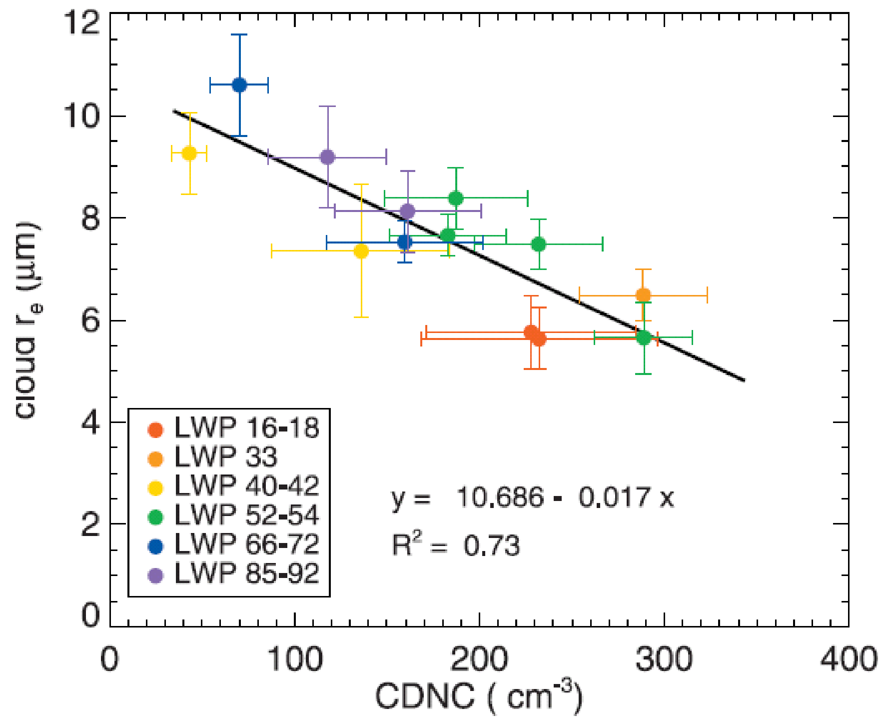
Clear AIE Evidence for MASE

2005.7.15-7.27



Daum et al. (JGR, 2008 in submission)

2005.7.2-7.17



Lu et al. (JGR, 2007)

- A smaller r_e in more polluted clouds at almost steady LWP, a clear aerosol first indirect effect is demonstrated during the MASE period