Marine Stratus Radiation, Aerosol, and Drizzle MASRAD, MASE

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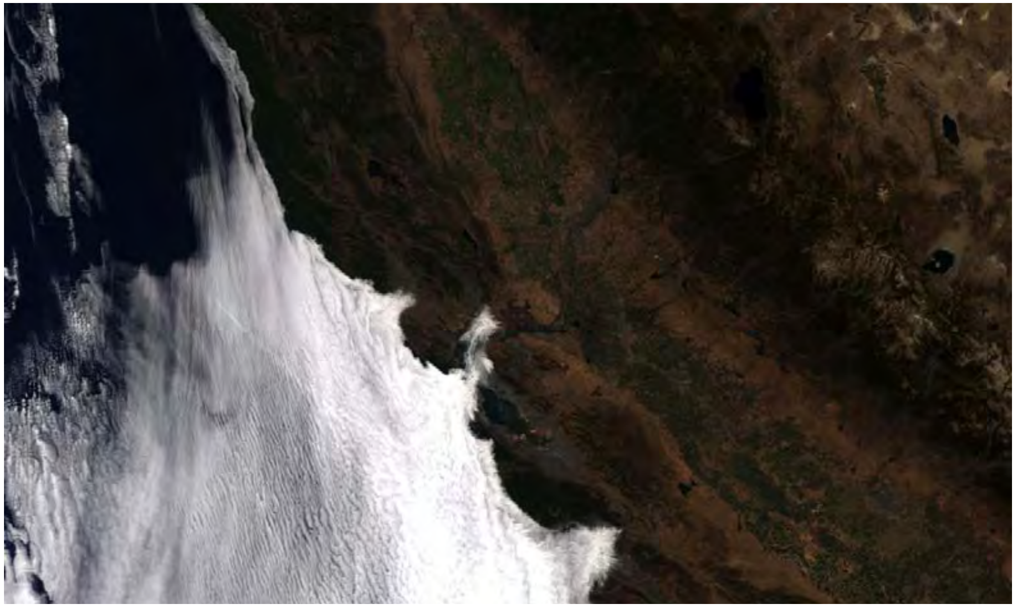
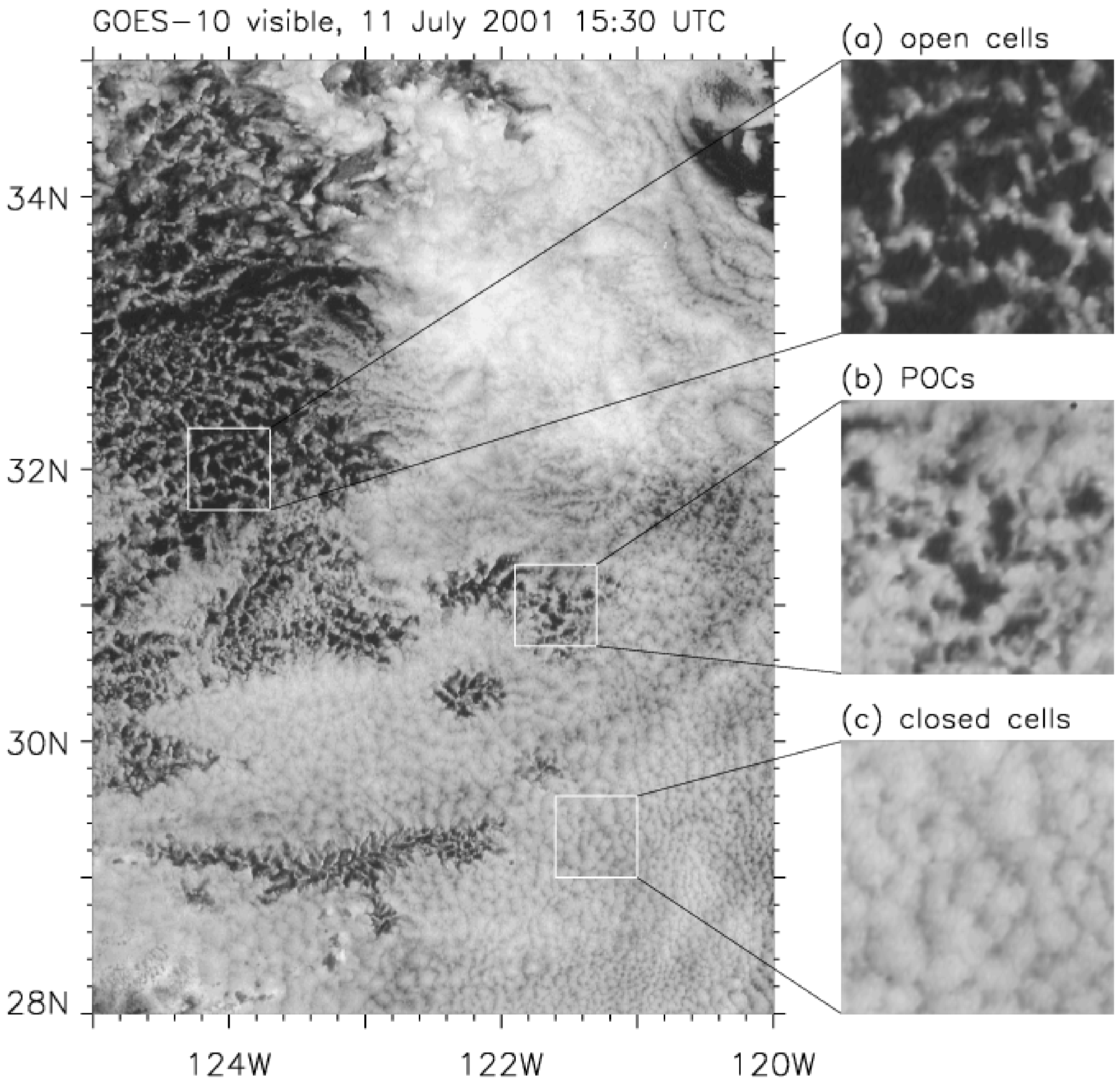
M. Jensen, N. Riemer , J. Ching, L. Berg, A. S. Frisch,
M. Bartholomew, B. Kim, M. Dunn, P. Kollias, B. Albrecht,
…….



Pt. Reyes, California

*PI



Open cells

Pockets of open cells

Closed cells

Motivation:

Strong shortwave cloud forcing (dark underlying ocean)
No compensating longwave forcing

Science Goals

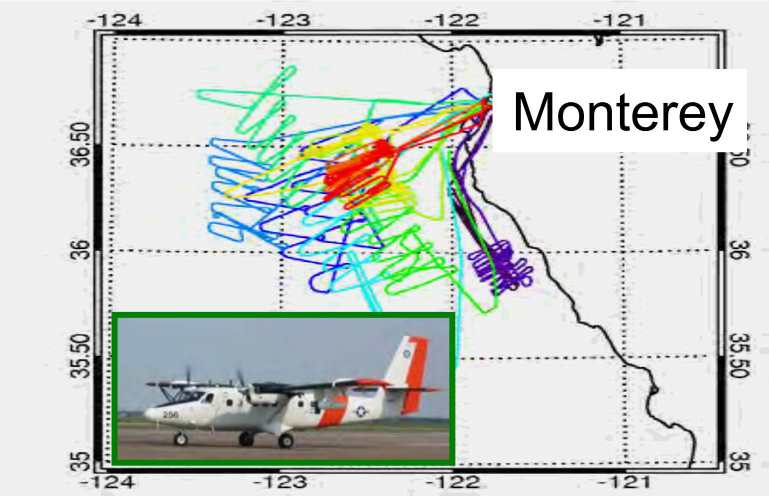
- Aerosol Characterization
- Aerosol ←→ Cloud Interactions in Stratocumulus
  - Effects of aerosol on cloud microphysics, optical properties
  - Effects of clouds on aerosol composition and optical properties
  - Effects of aerosol on the formation of drizzle

Platforms

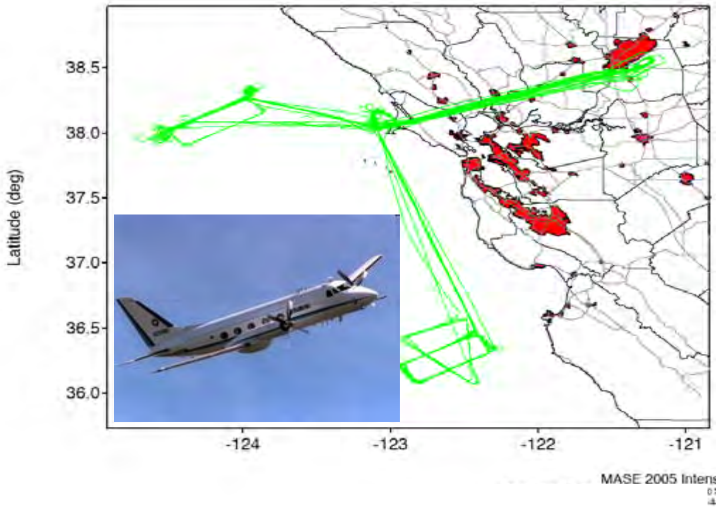
- ARM Mobile Facility (AMF)
- Surface aerosol
- G1
- CIRPAS Twin Otter

March-September

July Intensive



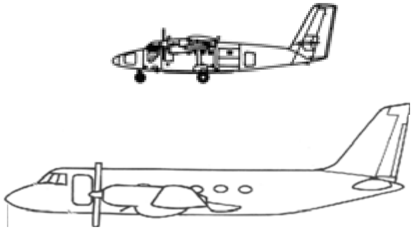
Twin Otter Flight Tracks



G-1 Flight tracks

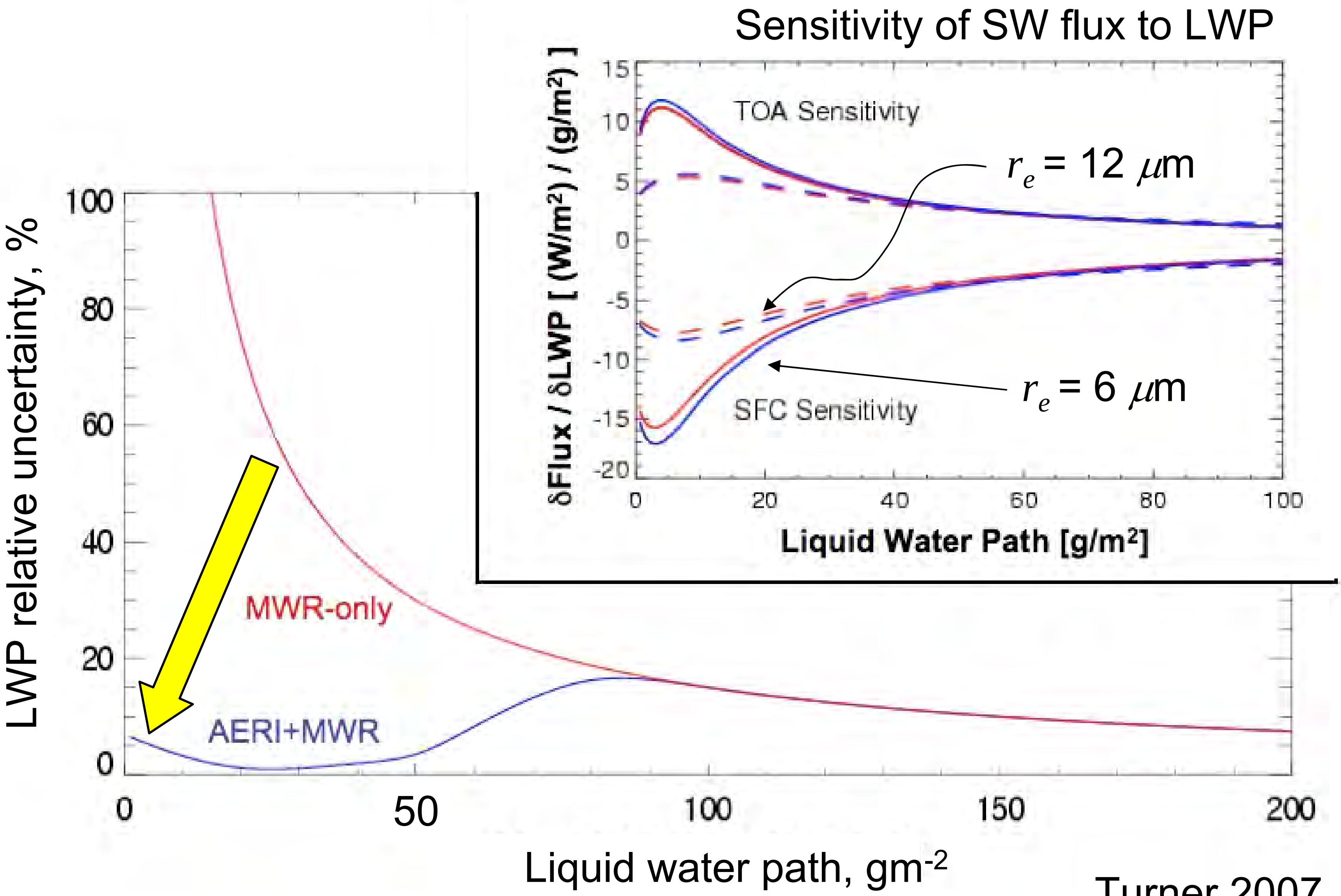
Primary Instrumentation

- ARM Mobile Facility (AMF)
  - Cloud Radar
  - Microwave radiometer
  - MFRSR
  - 2NFOV (narrow field of view radiance)
  - Micropulse lidar
  - Surface aerosol (Size distribution, CCN, light scattering, absorption)
- G1 and CIRPAS Twin Otter
  - Aerosol size, composition, optical properties
  - Cloud, drizzle probes
  - Turbulence
  - Atmospheric State (P, T, RH)
  - Gas phase



AMF results

Some New Techniques: LWP retrievals

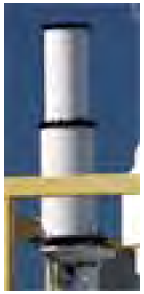


Sensitivity of SW flux to LWP

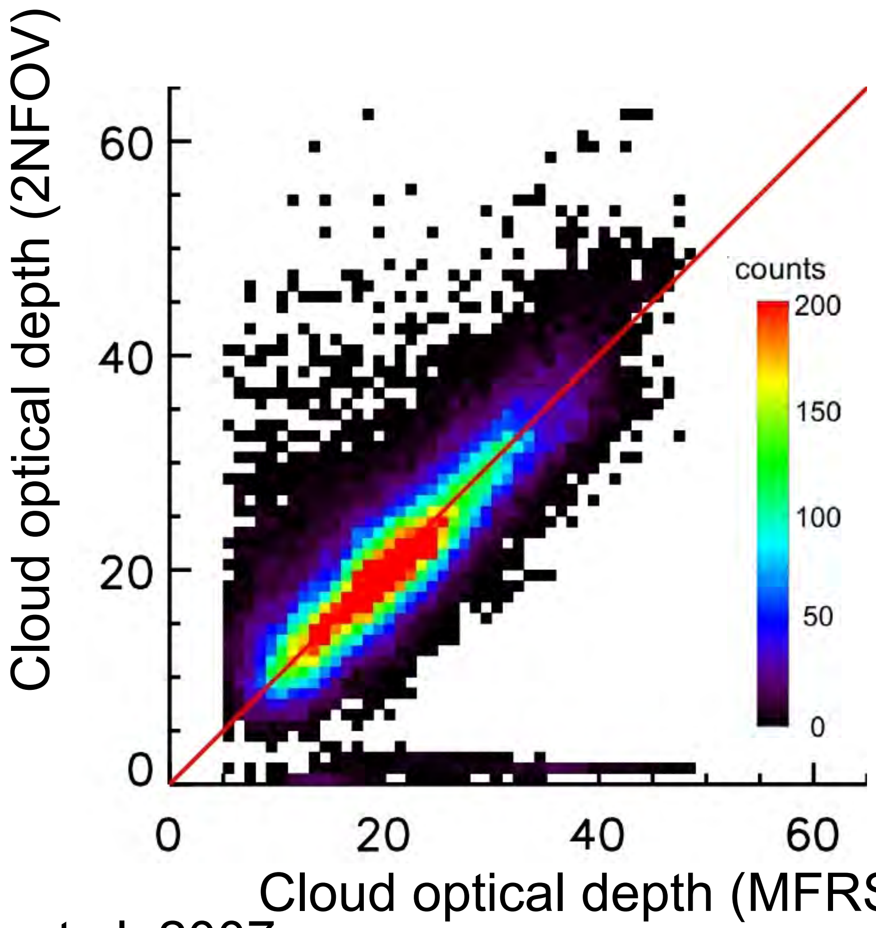
Turner 2007

Some New Techniques:
Cloud Optical Depth

Comparison of Cloud Optical Depth for overcast skies



2NFOV



2NFOV:

- *Fast response*
- *Narrow field of View*
- *Good for broken cloud fields*

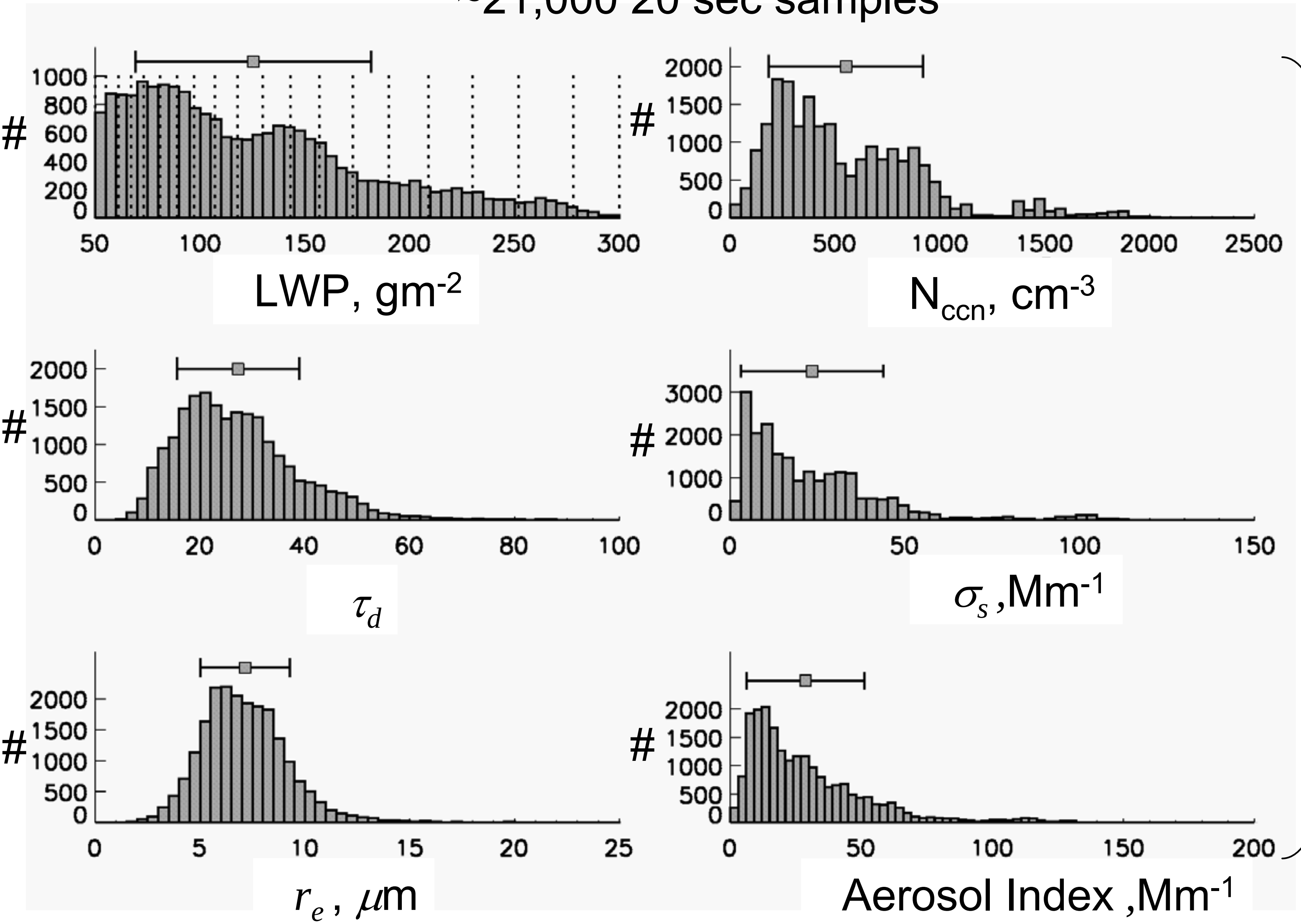
MFRSR

Chiu, Marshak et al. 2007

Overview of AMF results

~21,000 20 sec samples

Cloud microphysical parameters



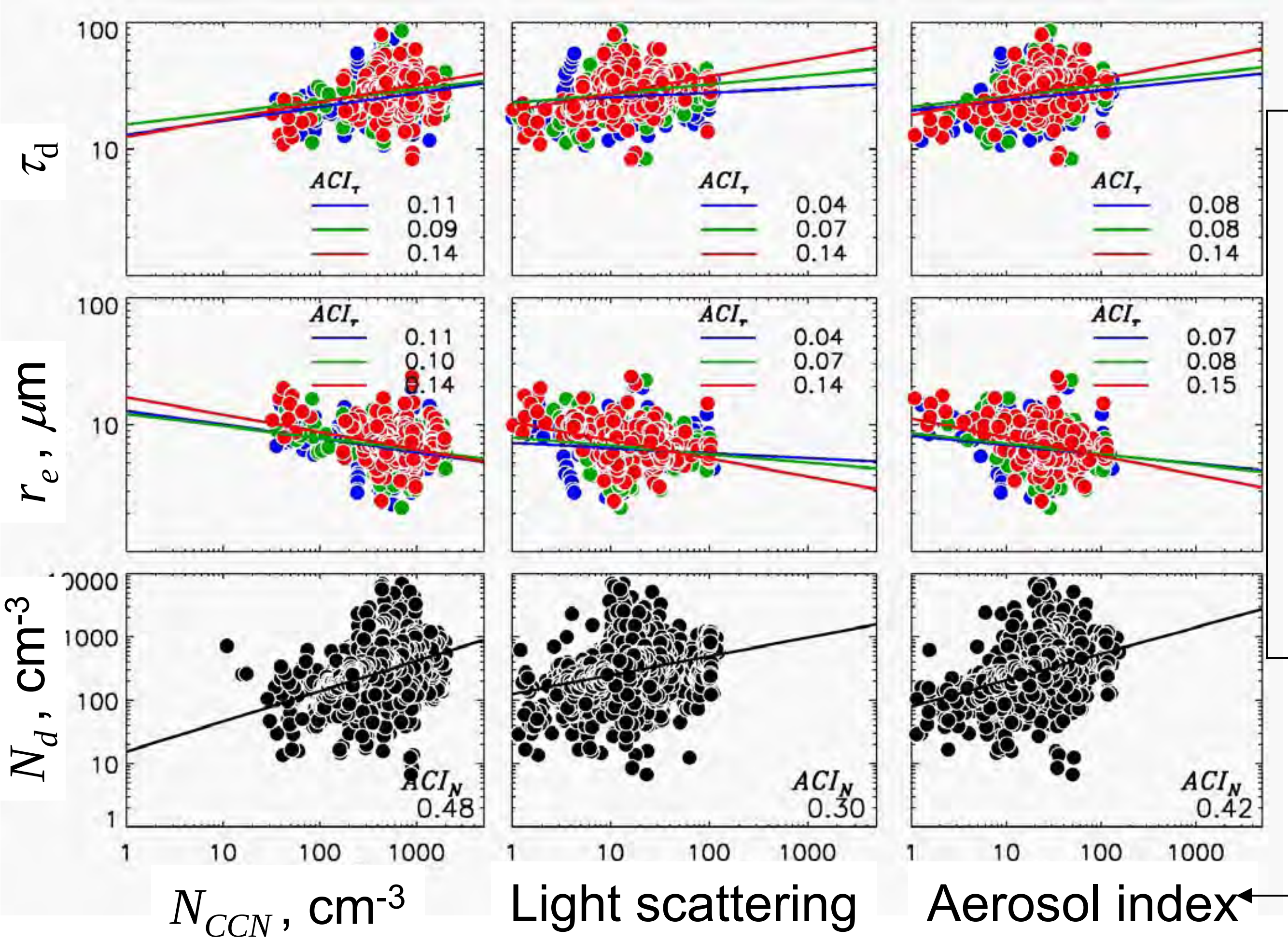
Aerosol Parameters

McComiskey et al. 2009

See also Bartholomew and Miller: joint PDFs

Aerosol-Cloud Interactions

McComiskey et al. 2009



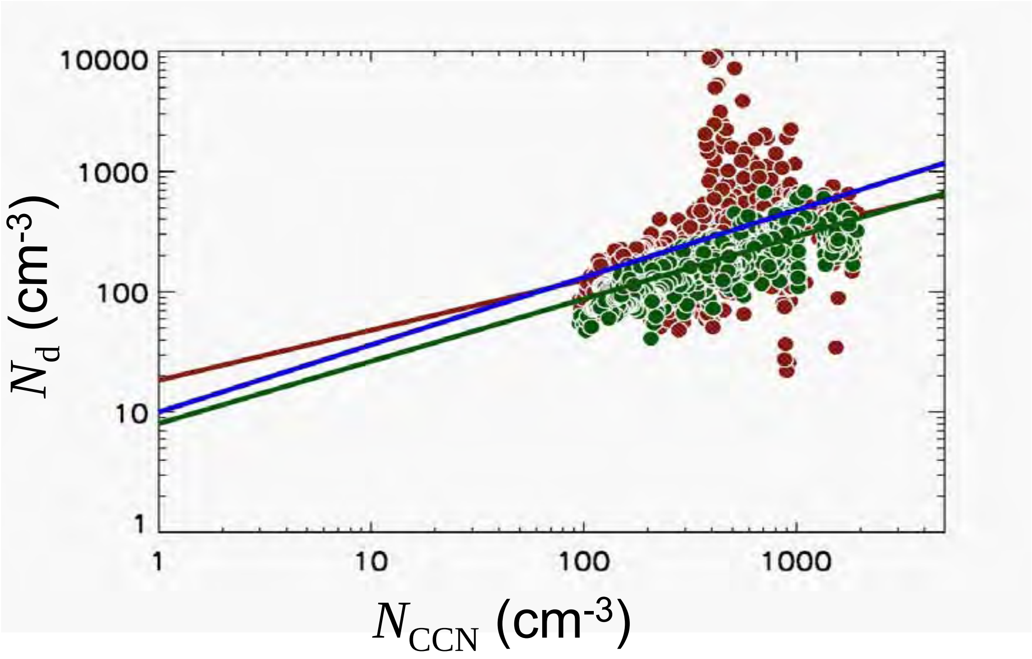
← α = aerosol parameter

- *Consistent measures of μphysical response to changes in aerosol*
- *Aerosol index is good CCN proxy*
- *Light scattering is less sensitive*

🟦 $107 < \text{LWP} < 118$ gm^{-2}
🟩 $118 < \text{LWP} < 130$ gm^{-2}
🟥 $130 < \text{LWP} < 143$ gm^{-2}

$$ACI = \left.\frac{\partial \ln \tau_d}{\partial \ln \alpha}\right|_{LWP} = -\left.\frac{\partial \ln r_e}{\partial \ln \alpha}\right|_{LWP} = \frac{1}{3}\frac{d \ln N_d}{d \ln \alpha}$$

Comparison of different N_d retrievals

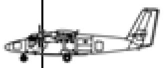


ACI

🟥 0.52, adiabatic

🟩 0.43, Twomey

🟦 0.56, MASE



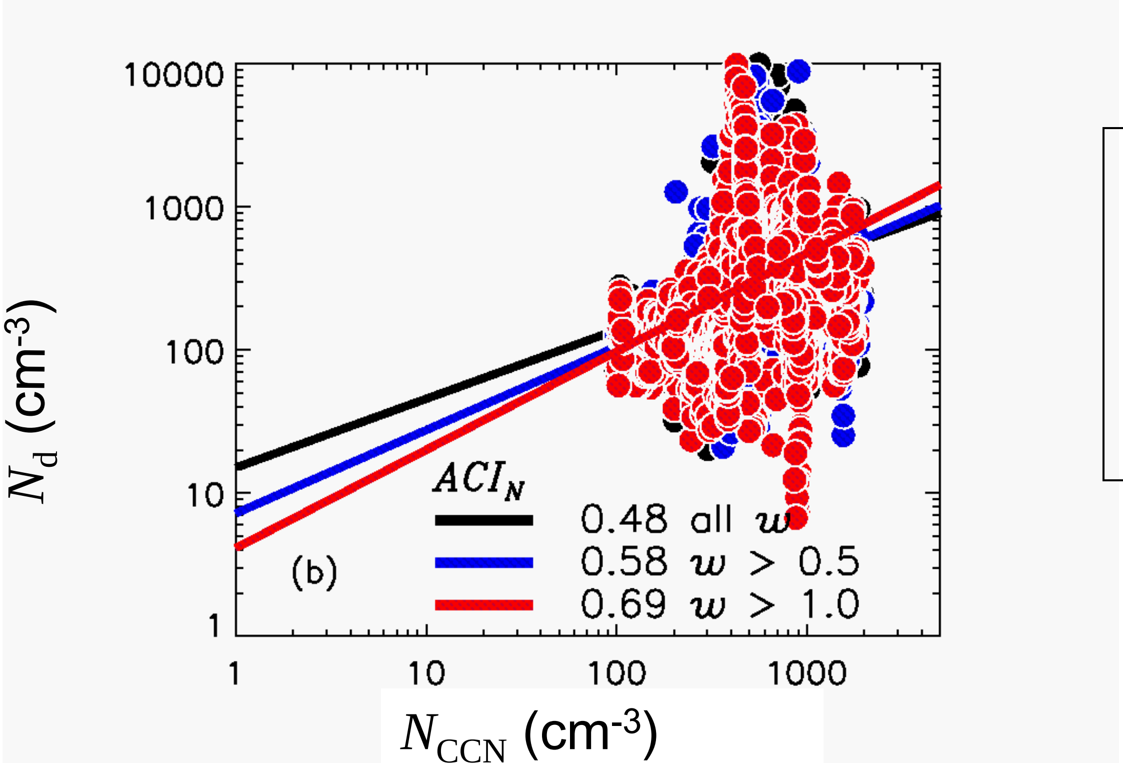
McComiskey et al. 2009

$$ACI = \left.\frac{\partial \ln \tau_d}{\partial \ln \alpha}\right|_{LWP} = -\left.\frac{\partial \ln r_e}{\partial \ln \alpha}\right|_{LWP} = \frac{1}{3}\frac{d \ln N_d}{d \ln \alpha}$$

$$N_d\big|_{adiabatic} = C(T,P)\tau_d^3 LWP^{-2.5} = f\left(\tau_d, LWP, T, P\right)$$ ← Adiabatic approximation

$$N_d\big|_{Twomey} = c^{1-[k/(k+2)]}\left[\frac{2\alpha^{3/2}V^{3/2}}{\beta k G^{1/2} c k B\left(3/2, k/2\right)}\right] = f\left(c,k,w,T,P\right)$$ ← Twomey parameterization

Role of Updraft Velocity



ACI

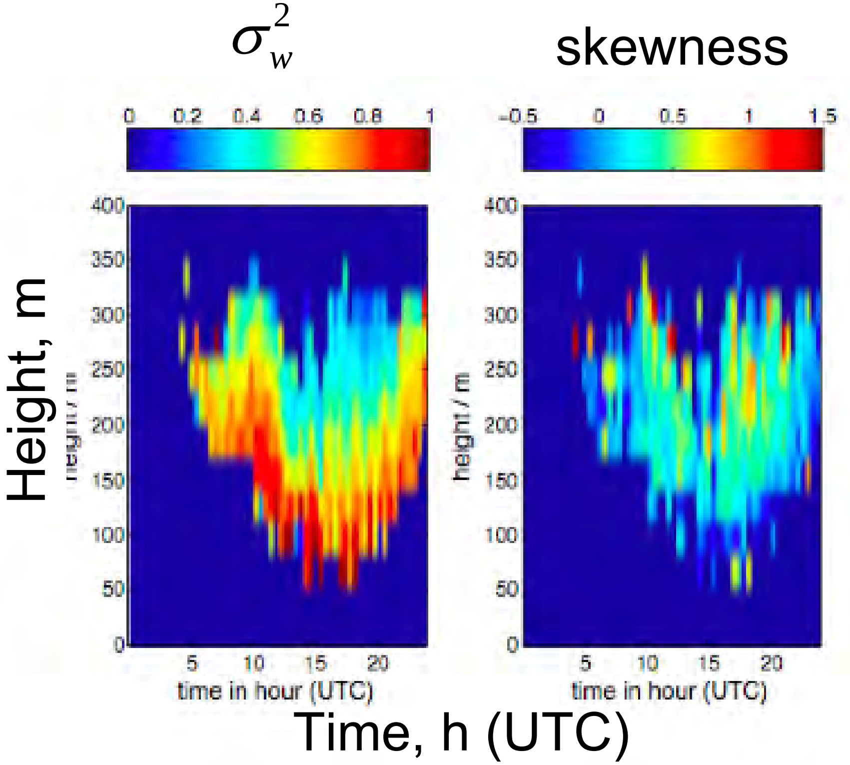
- ▬ 0.48, all w
- ▬ 0.58, w > 0.5 m/s
- ▬ 0.69, w > 1.0 m/s

$$ACI = \left.\frac{\partial \ln \tau_d}{\partial \ln \alpha}\right|_{LWP} = -\left.\frac{\partial \ln r_e}{\partial \ln \alpha}\right|_{LWP} = \left.\frac{1}{3}\frac{d \ln N_d}{d \ln \alpha}\right|$$

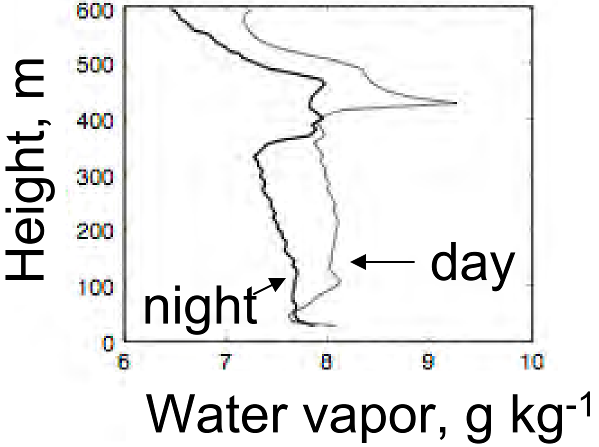
McComiskey et al. 2009

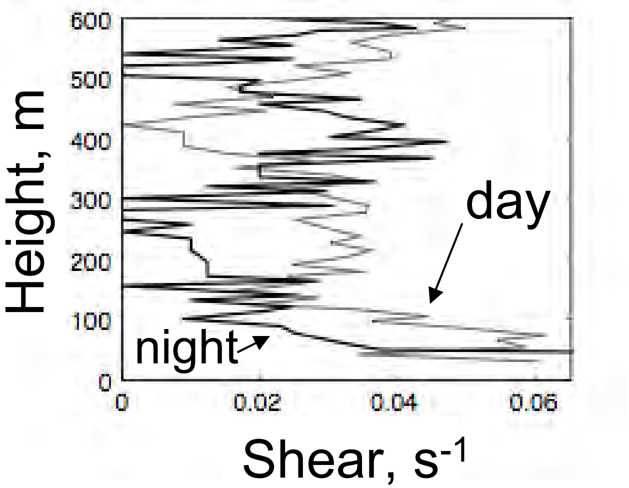
Turbulence Measurements

Doppler Radar (W-band)



July 5 2005



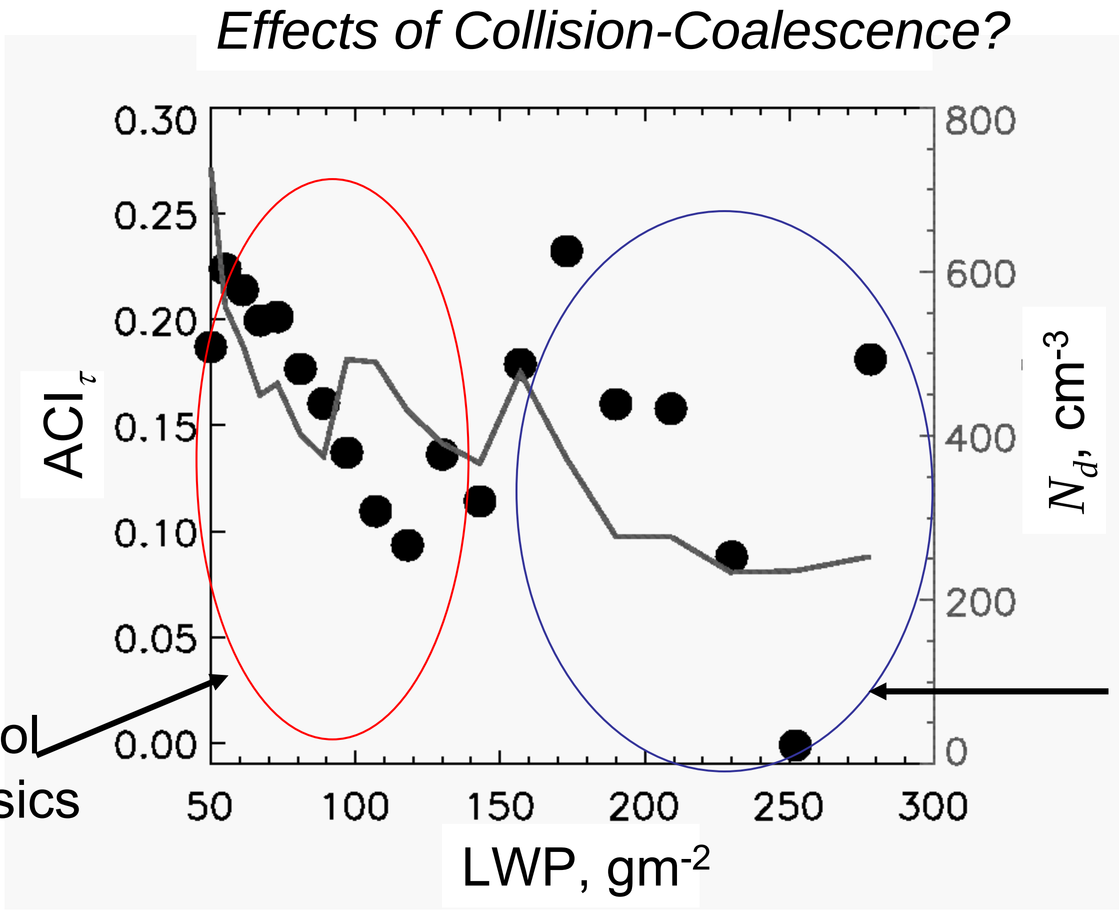


Variance decreases with height;

In-cloud turbulence driven by wind shear and surface fluxes, not radiation

Ching, Riemer et al.

Dependence on Liquid Water Path



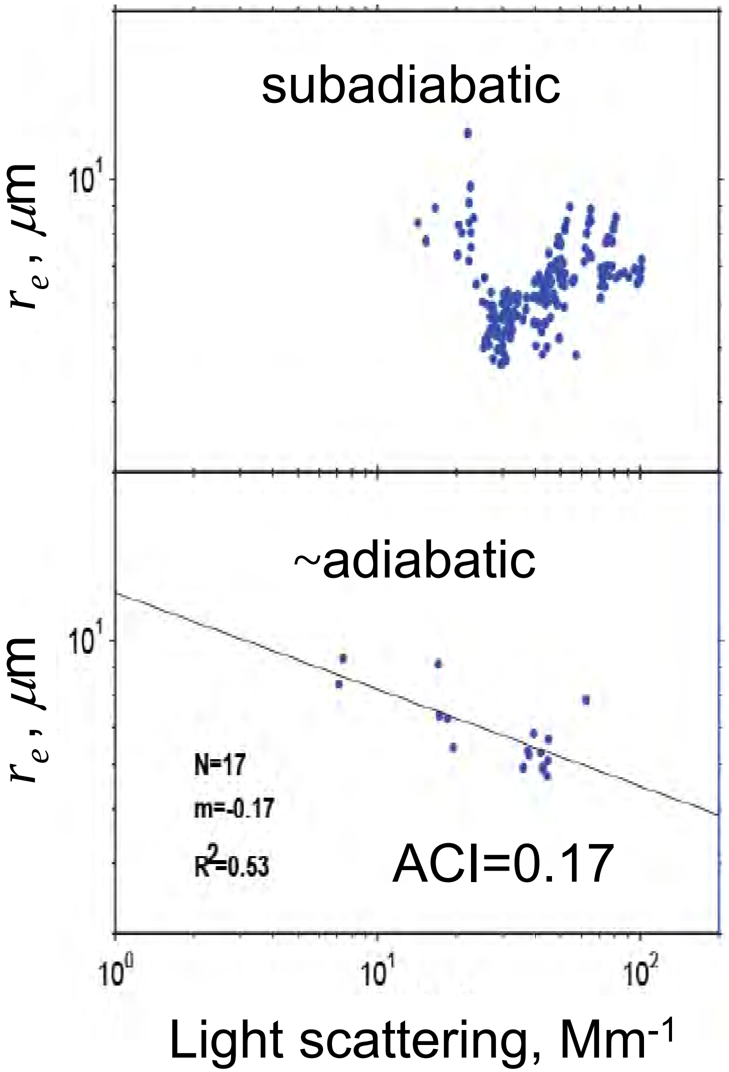
Effect of aerosol on cloud μphysics

Effect of precipitation on aerosol

McComiskey et al. 2009
Kim et al., 2008

$$ACI = \left.\frac{\partial \ln \tau_d}{\partial \ln \alpha}\right|_{LWP} = -\left.\frac{\partial \ln r_e}{\partial \ln \alpha}\right|_{LWP} = \left.\frac{1}{3}\frac{d \ln N_d}{d \ln \alpha}\right|$$

Role of Adiabaticity

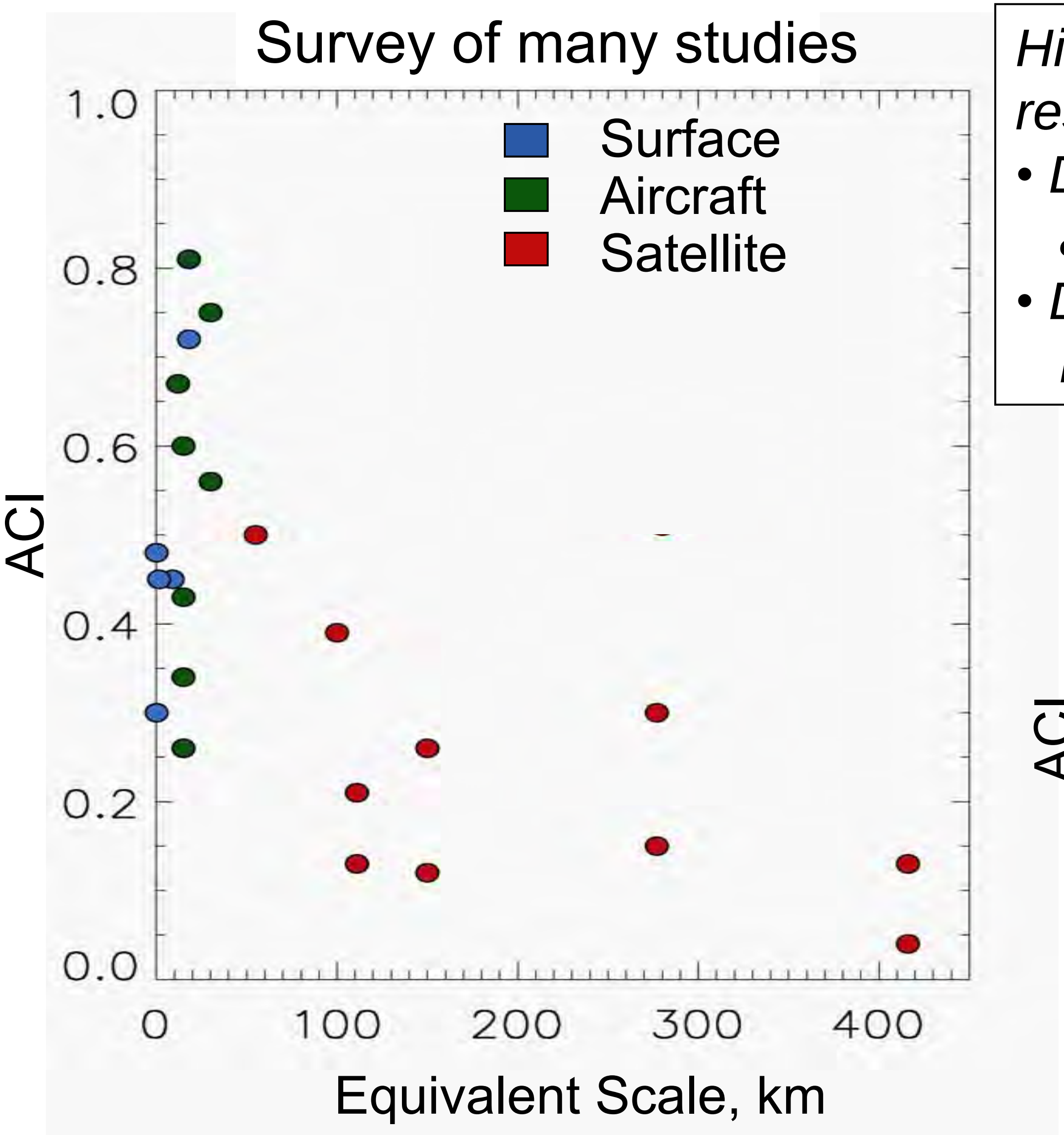


Adiabatic clouds tend to have higher microphysical response to aerosol perturbations

They occur much more rarely

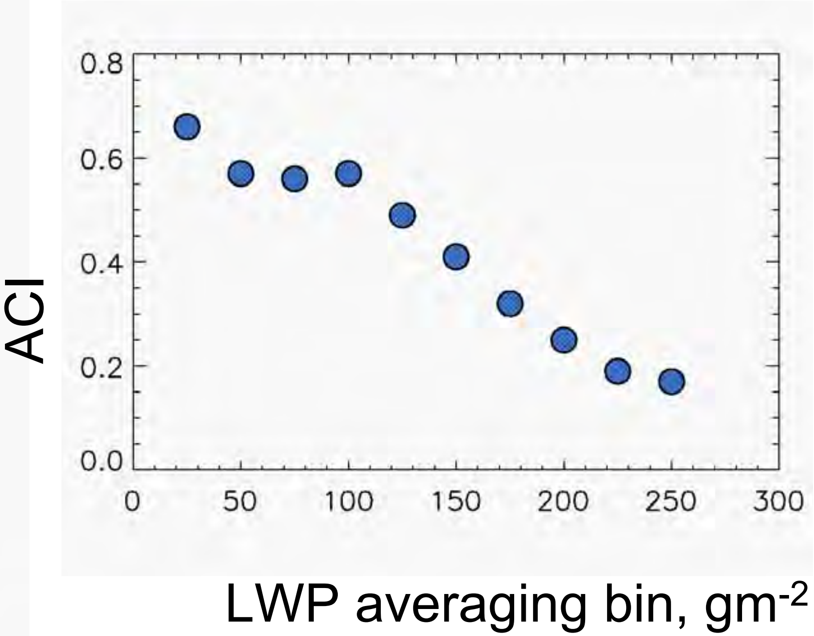
Kim et al., 2008

Response to Scale



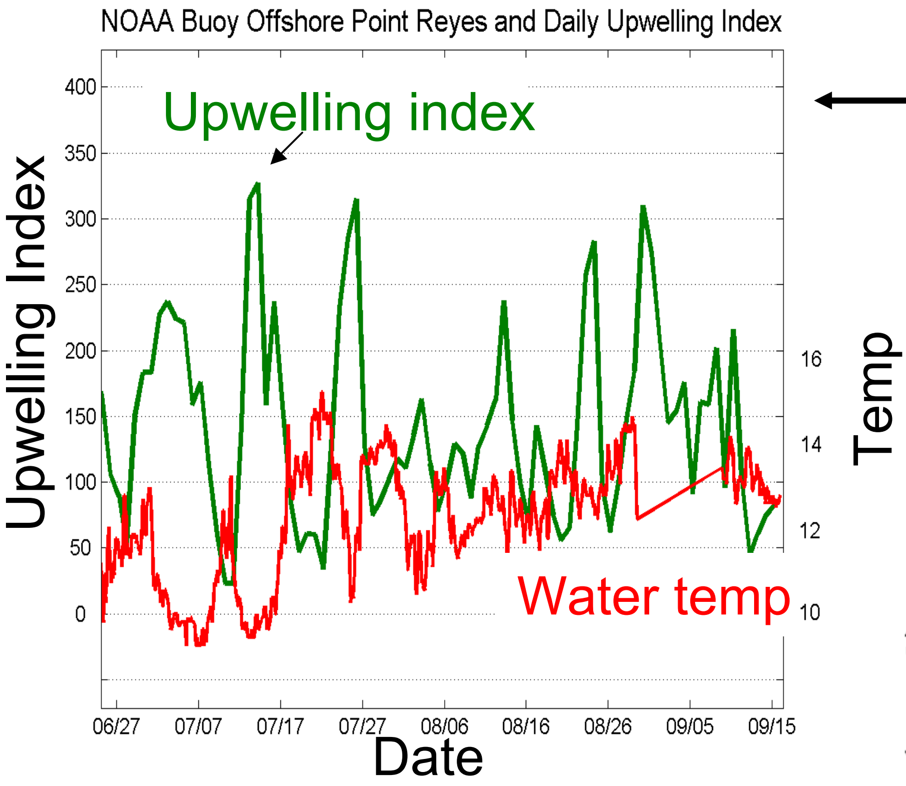
High spatial variability in LWP results in:

- *Decrease in ACI with increasing averaging length scale*
- *Decrease in ACI with increasing LWP bin size*



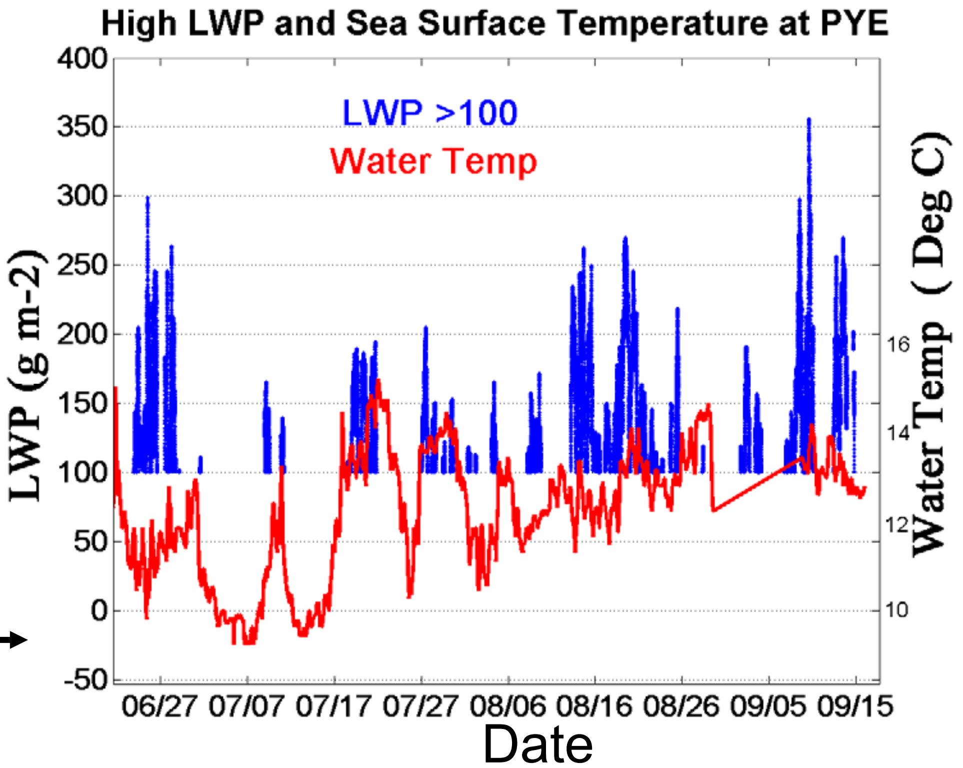
McComiskey et al. - Poster

Meteorological Controls


NOAA Buoy Offshore Point Reyes and Daily Upwelling Index

Upwelling brings colder water to surface

LWP increases as SST increases


High LWP and Sea Surface Temperature at PYE

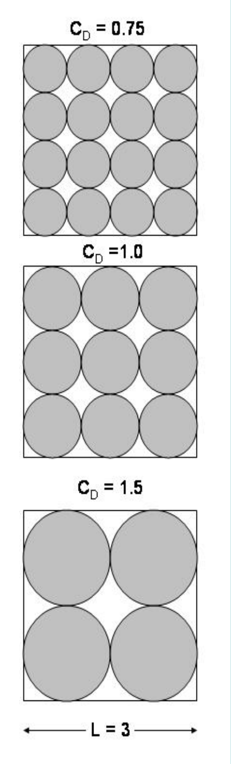
Dunn et al.

Marine Boundary Layer Cloud Macroscale Structure

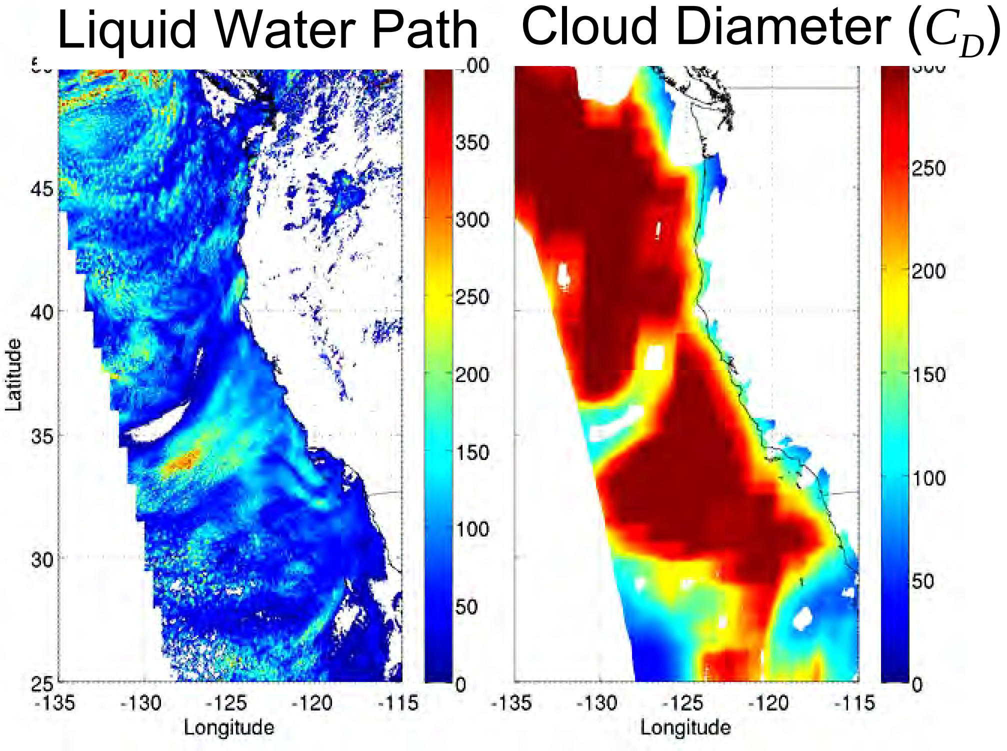
Effective Cloud Diameter (C_D)

$$C_D = \frac{4\sum_{i}^{N} A_i}{\sum_{i}^{N} P_i}$$

- A=cloud area
- P= cloud perimeter
- N=# of cloud elements



C_D offers a simple measure of MBL cloud organization



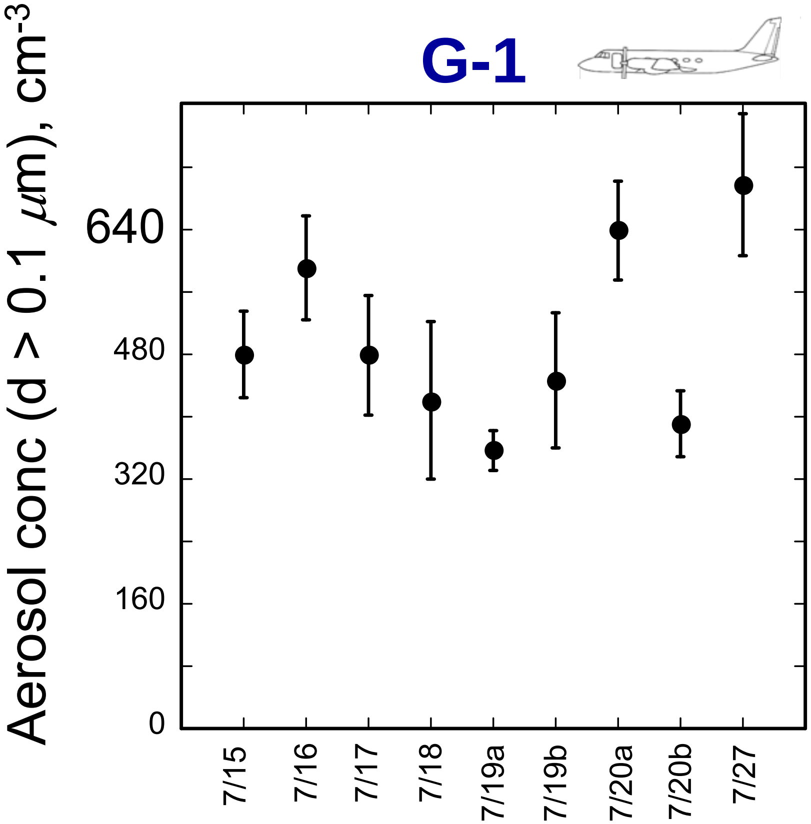
Liquid Water Path

Cloud Diameter (C_D)

Jensen et al., 2008

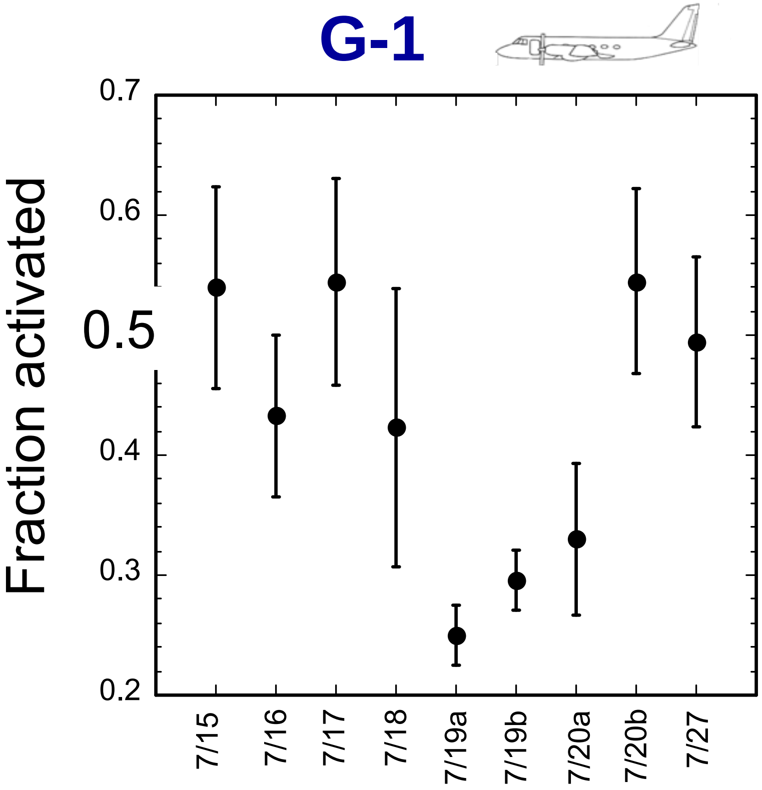
Aircraft Results

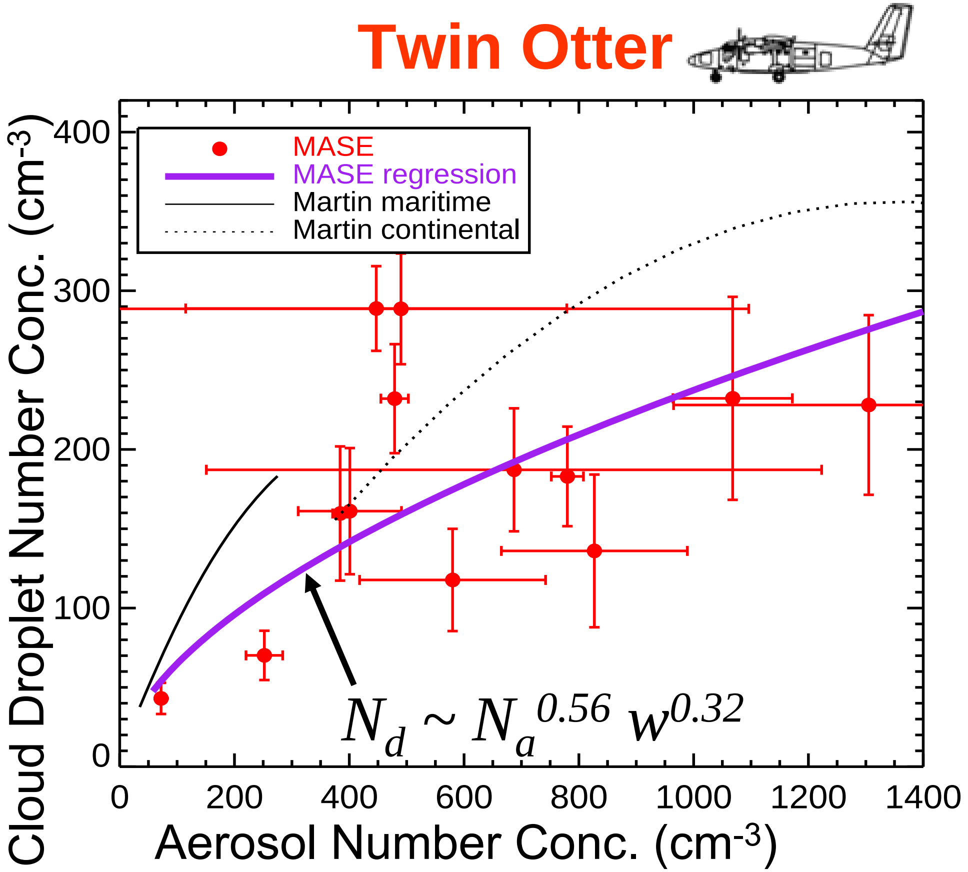
Aircraft: Sub-cloud Aerosol



Polluted conditions!

Aerosol-Cloud Interactions


G-1


Twin Otter

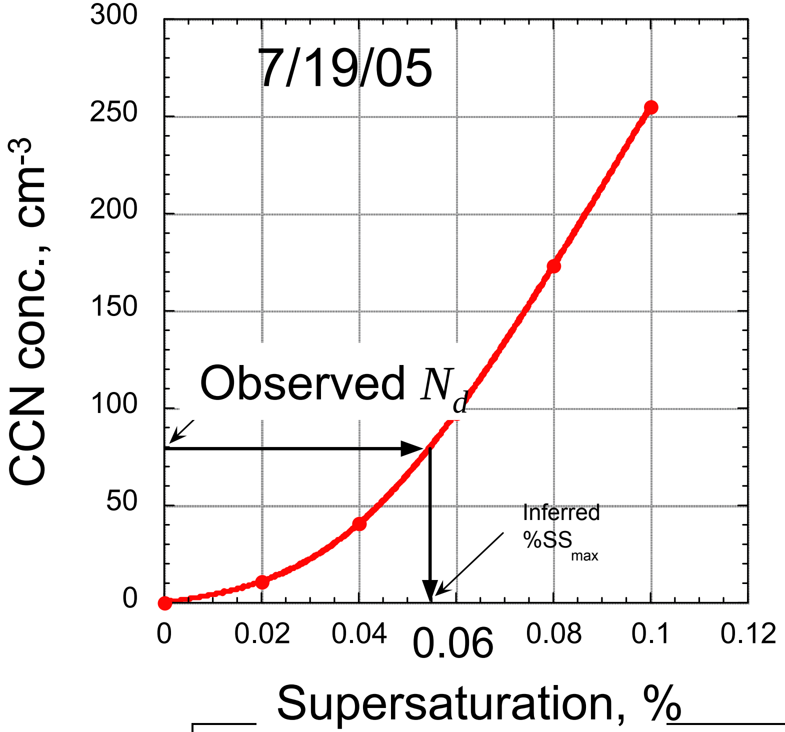
Relatively low activated fractions:
low updraft velocities or coalescence scavenging?

Lu et al., 2008

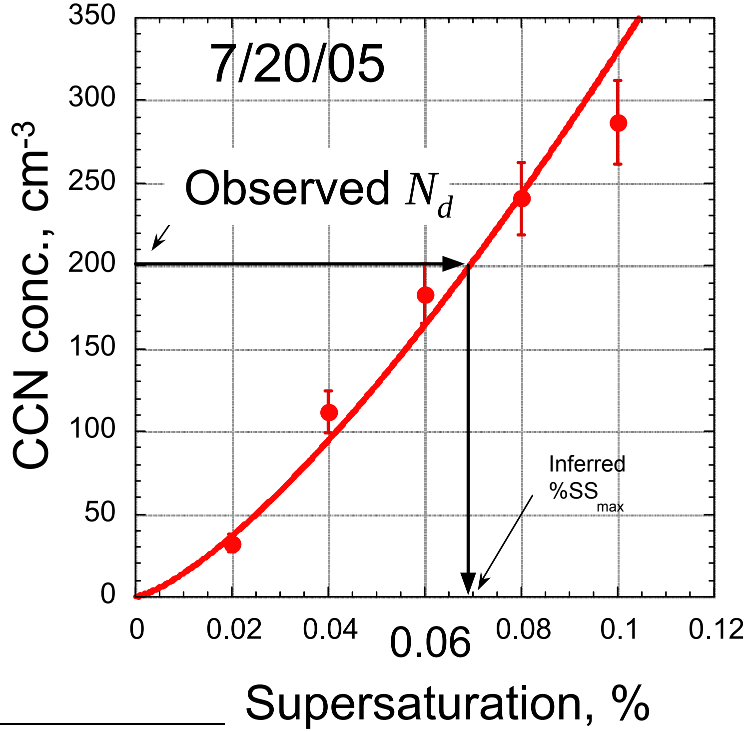
Inferring Supersaturation

Infer by comparing below-cloud CCN spectrum to N_d

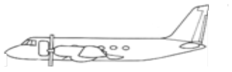
Clean conditions



Polluted conditions

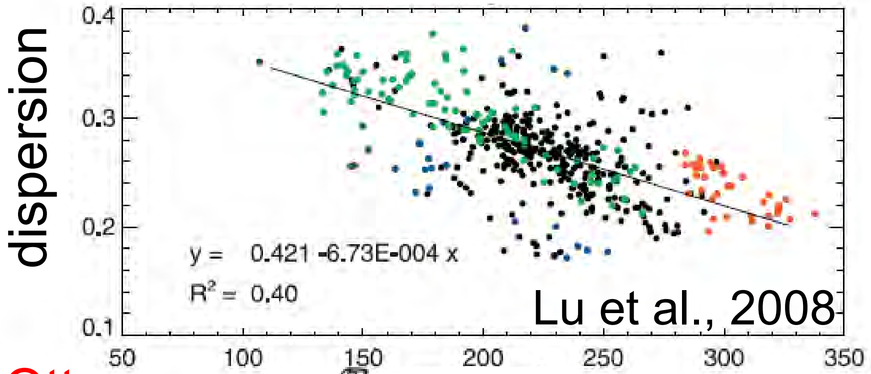


Maximum Supersaturation ~ 0.05 – 0.07%:
(updraft velocities were low)



The Dispersion Effect

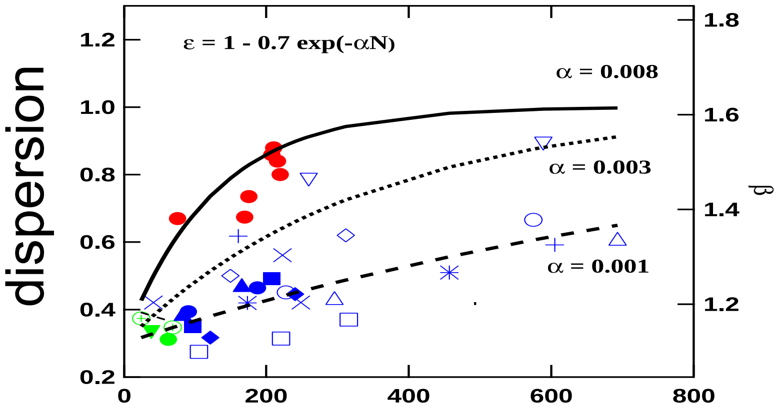
Coalescence-dominated



Twin Otter

N_d

Condensation-dominated



N_d

Dispersion <u>decreases</u> with increasing N_d

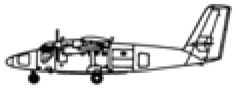
Liu and Daum 2002

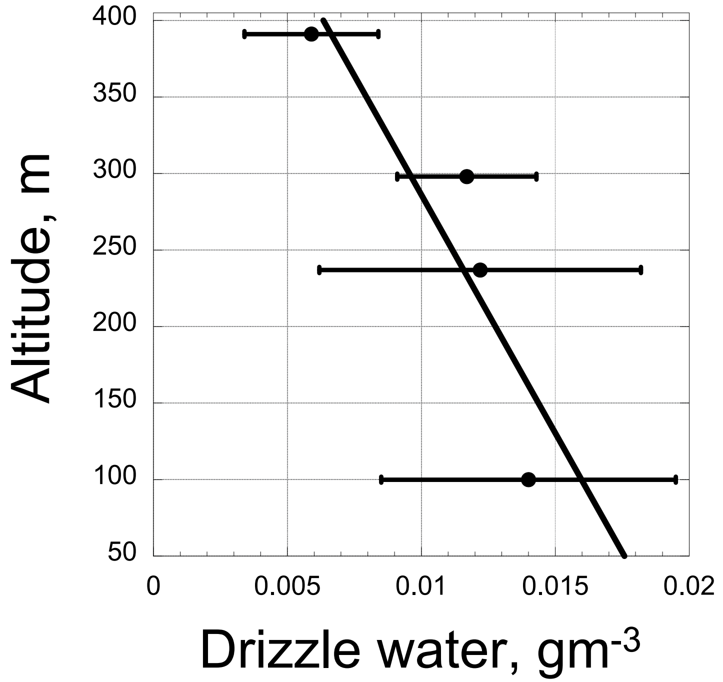
$$S_0'' = S_0'\left[1 + \frac{5}{2}\frac{d\ln LWP}{d\ln N_d} - \frac{d\ln \sigma_d}{d\ln N_d}\right]$$

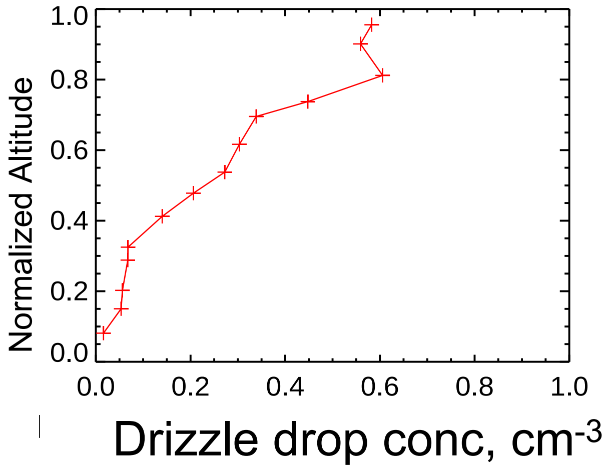
Dispersion effect

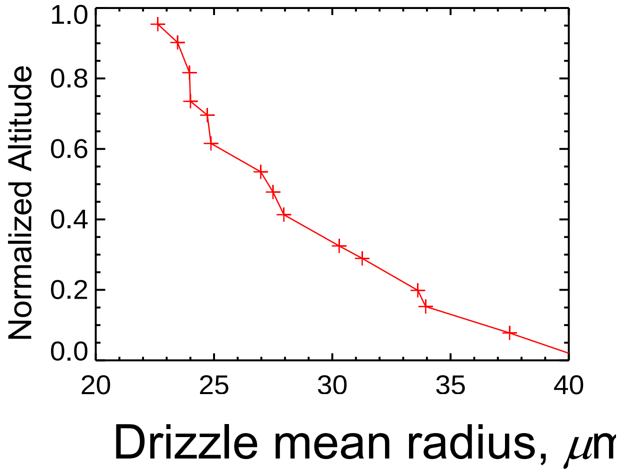
$S'_0 = (1-A)/3$ S'_0 = Albedo Susceptibility at constant LWP

Drizzle







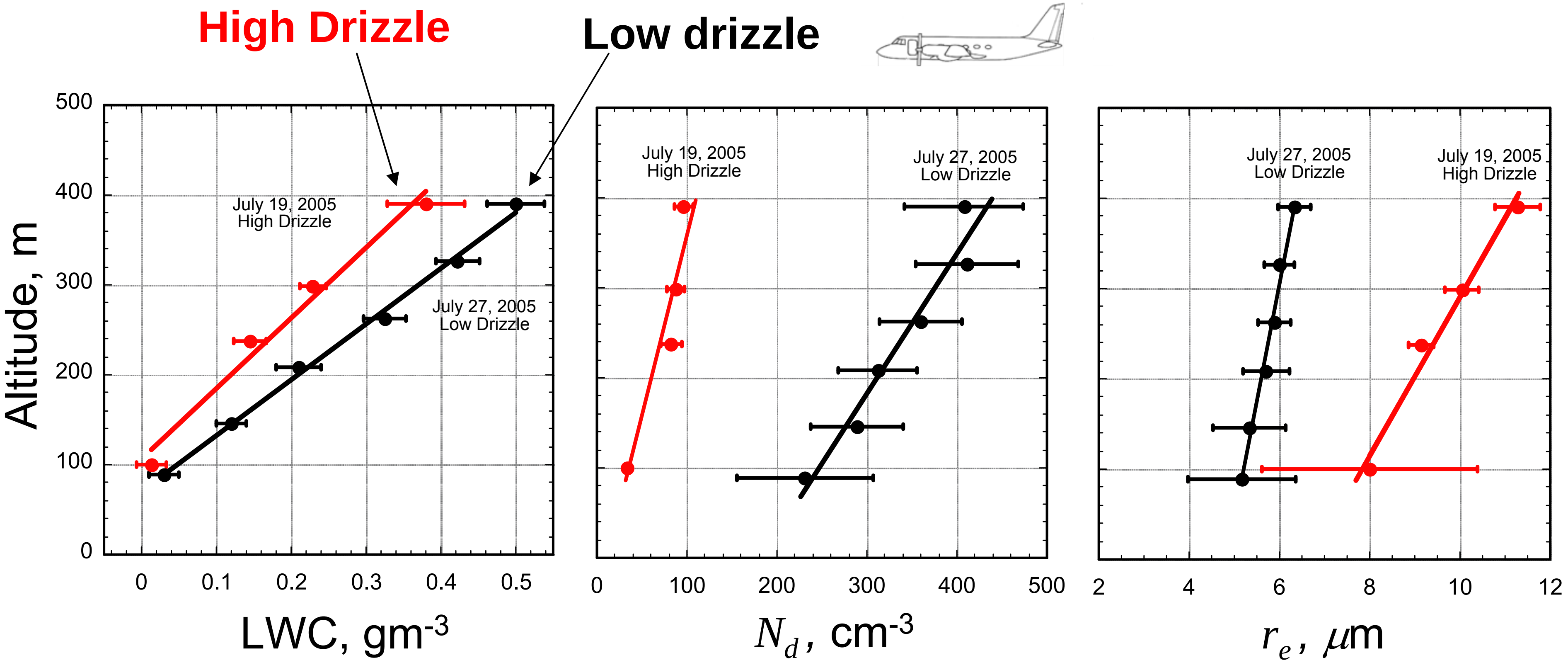


Drizzle embryos are initiated at cloud top where LWC is highest;

Lu et al. 2007

Drizzle drops grow by coalescence as they fall

Drizzle: Contrast Low and High



$$R \propto LWP^{\alpha} N_d^{\beta}$$

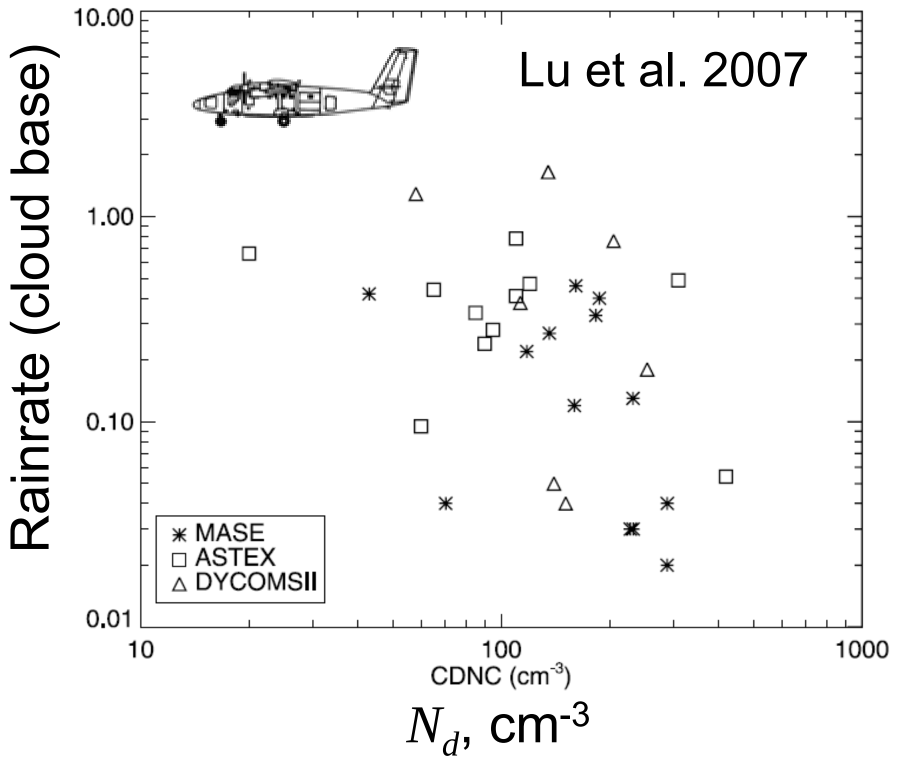
$\alpha \sim 1.5$; $\beta \sim -0.6$

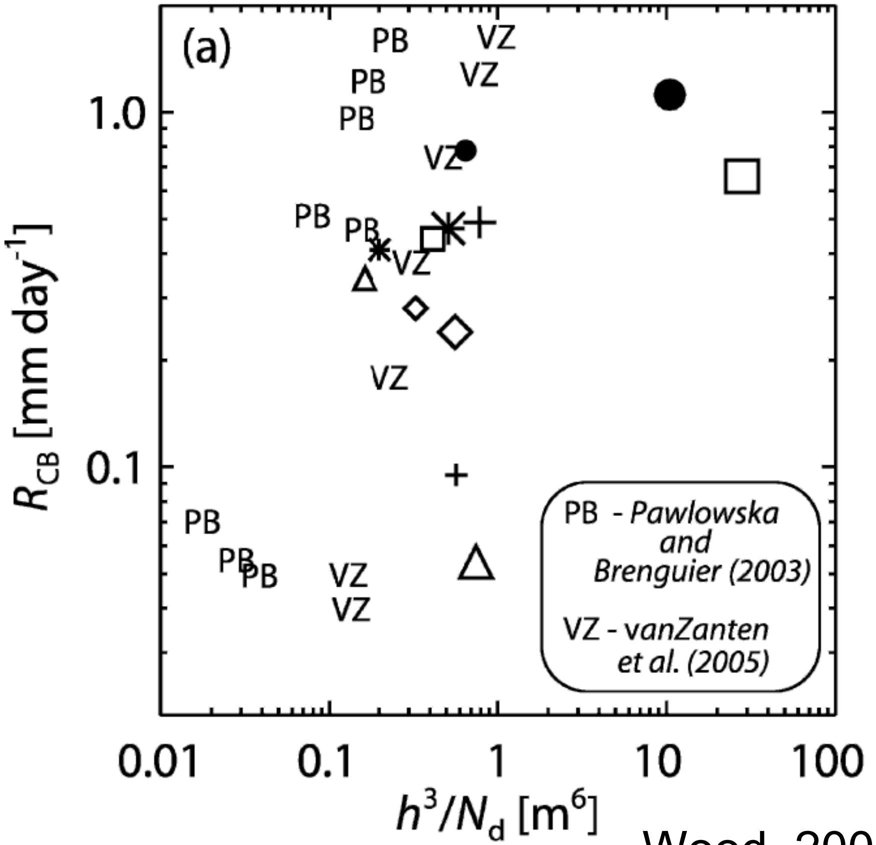
LWC is similar for both cases

High drizzle case: smaller N_d, higher r_e

Daum et al., G1

Drizzle


Lu et al. 2007

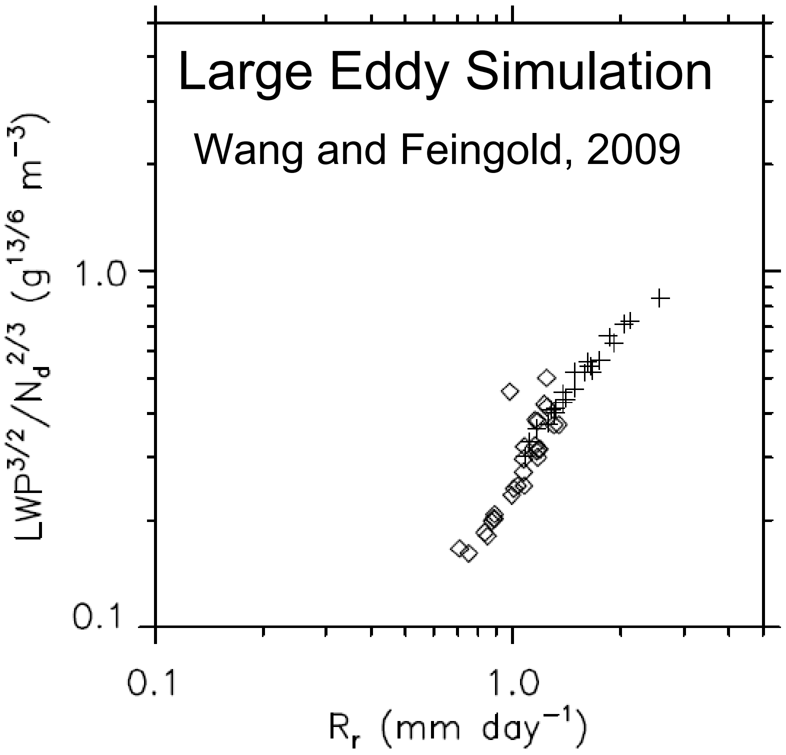

Wood, 2005

$$R \propto LWP^{\alpha} N_d^{\beta}$$

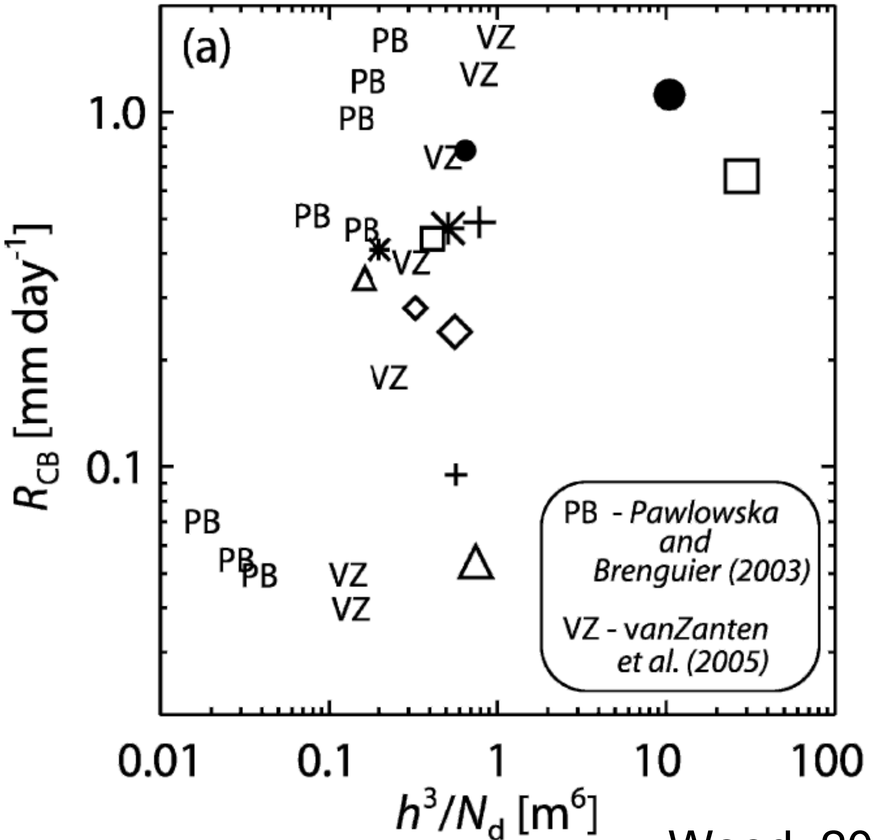
$\alpha \sim 1.5$; $\beta \sim -0.6$

Rainrate is ~ 2.5 x more sensitive to LWP than to N_d

Drizzle


Large Eddy Simulation

Wang and Feingold, 2009



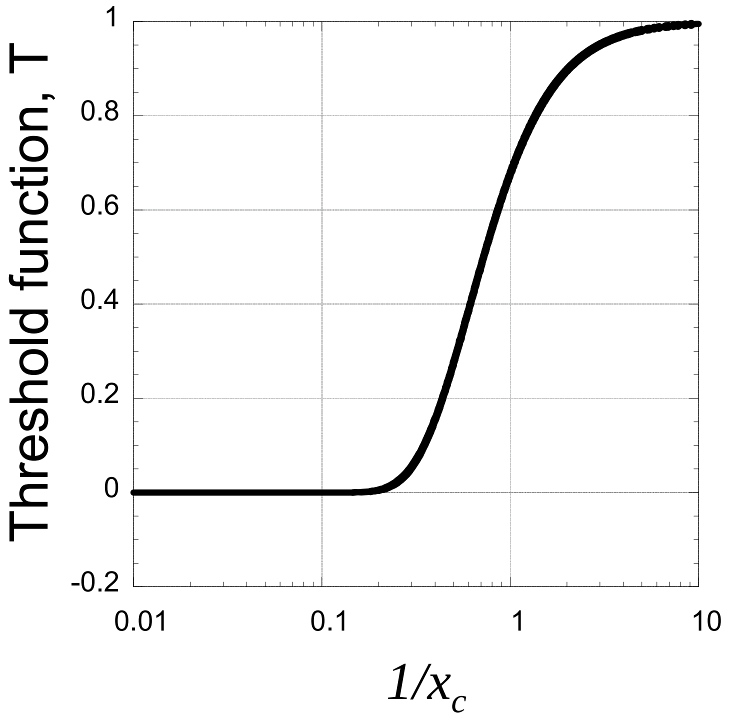
Wood, 2005

$$R \propto LWP^{\alpha} N_d^{\beta}$$

α ~ 1.5; β ~ -0.6

Rainrate is ~ 2.5 x more sensitive to LWP than to N_d

Autoconversion of cloud droplets to drizzle: theory



Autoconversion rate ($g/m^3/s$),

$$P = P_0 T$$

- T *is the threshold function for onset of drizzle.*
- P_0 *is the conversion rate after the onset of the autoconversion process*

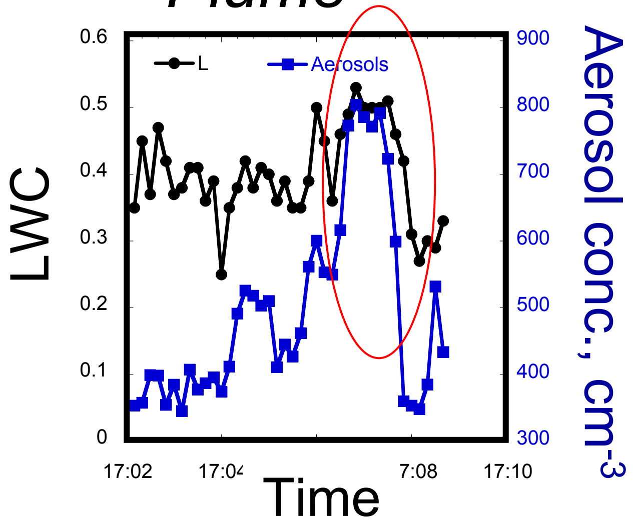
$$T = 1/2(x_c^2 + 2x_c + 2)(1+x_c)\exp(-2x_c)$$

$$x_c = 9.7 \times 10^{-17} N_d^{3/2} LWC^{-2}$$

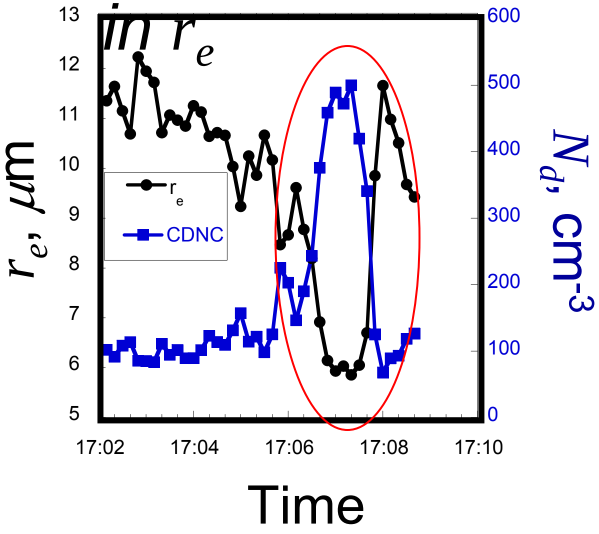
Liu, Daum, McGraw, 2005

Suppression of Drizzle by an Aerosol Plume

Aerosol Plume

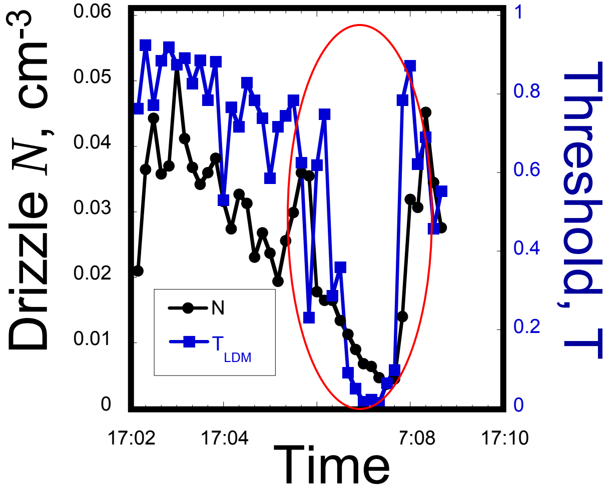


Increase in N_d decrease in r_e



Precip suppression

$T \to 0$

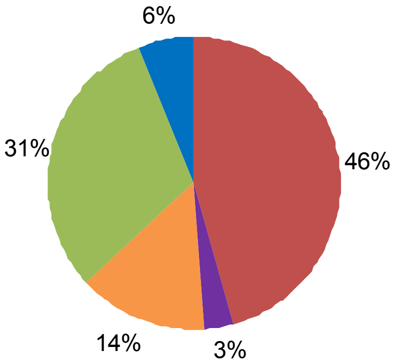


Liu, Daum, McGraw, 2005 **G-**

Aerosol Studies

Composition of Droplet Residuals

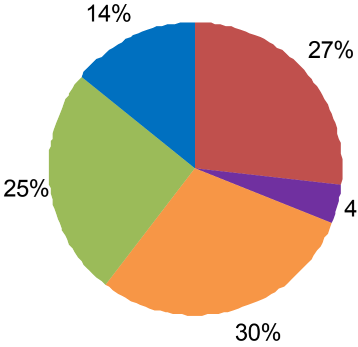
Interstitial
(N=44, Total = 0.65 µg/m3)

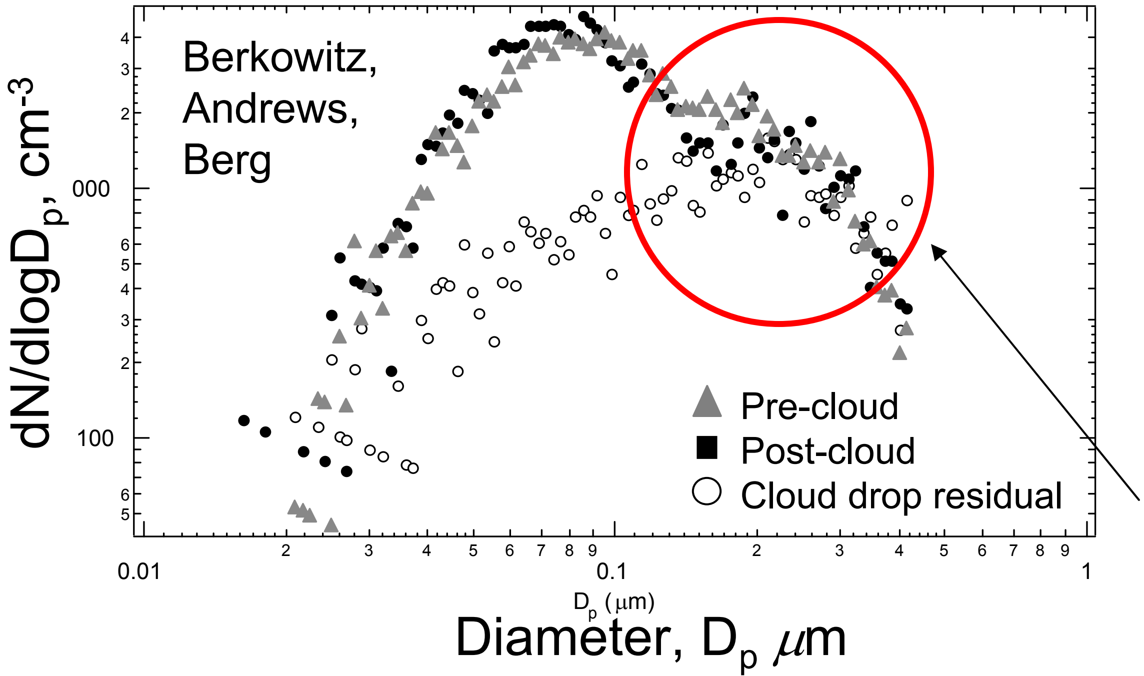


Mass Fractions

Sulfate
Chlorine
Ammonium
Organic
Nitrate

Cloud drop residual
(N=9, Total = 0.26 µg/m3)

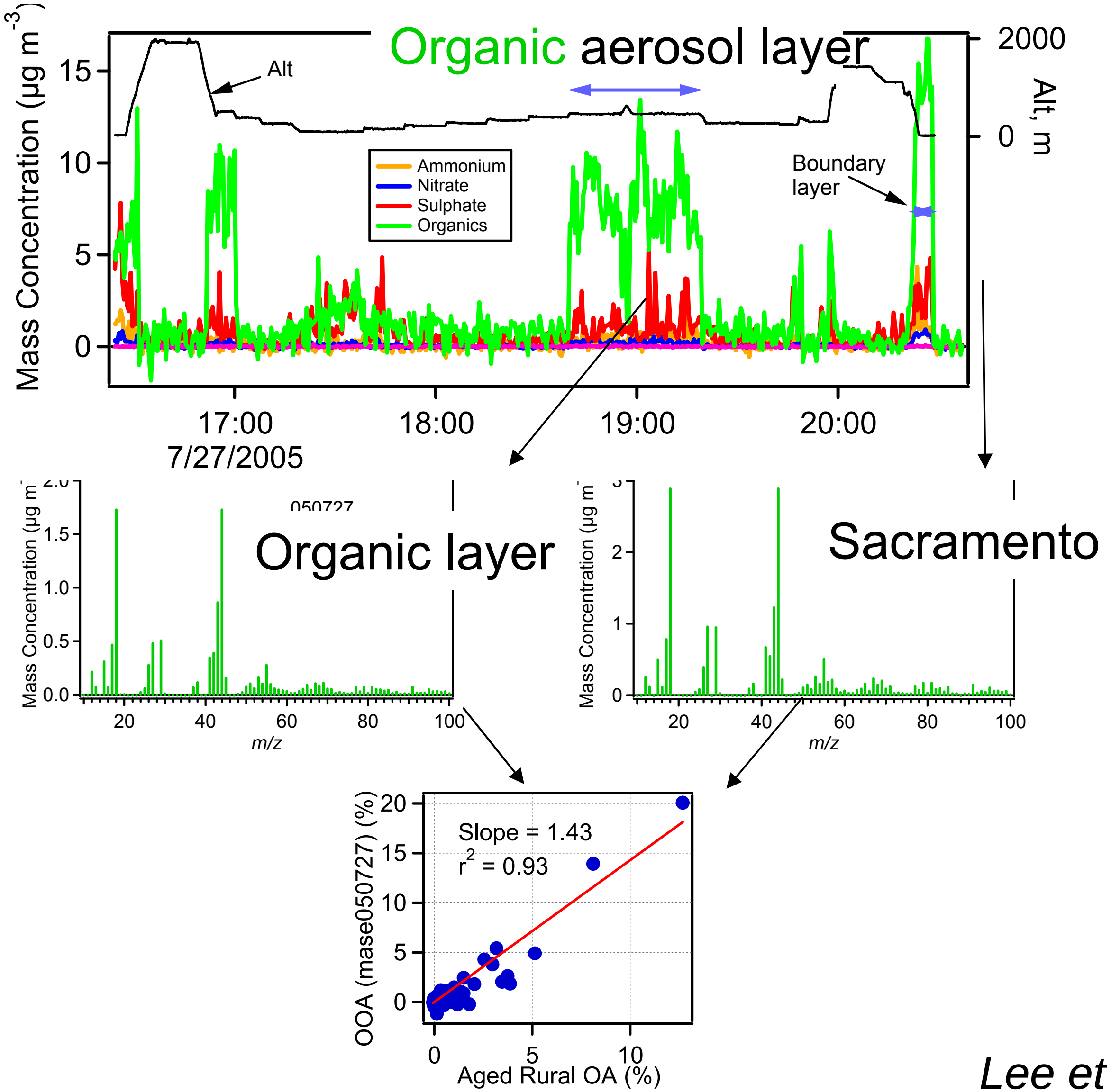




Why do drop residuals have less sulfate, more ammonium and more nitrate? Meteorology vs. cloud chemistry?

Signature of aqueous mass addition on activated particles

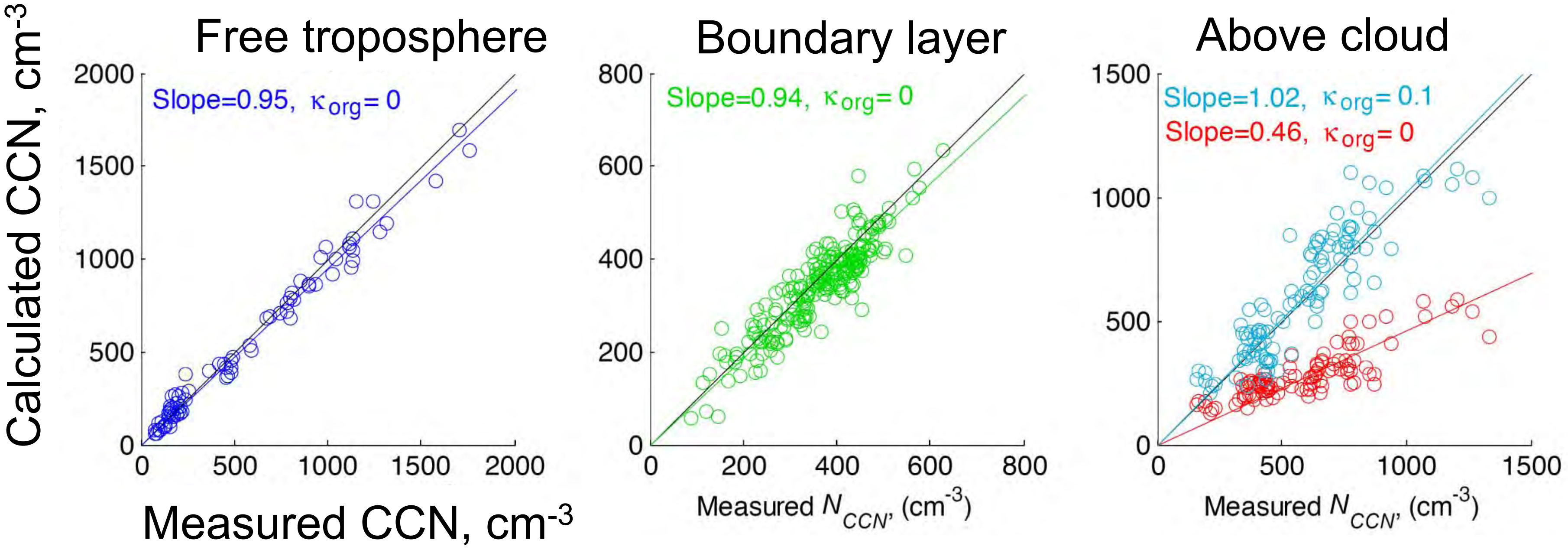
Organic aerosol layer overriding stratocumulus: origin?



- *Organic aerosol layer and boundary layer aerosol over Sacramento are the same: <u>land source</u>*
- *Organic aerosol layer above the stratocumulus is <u>not</u> produced by cloud processing*

Lee et al. G-1

CCN closure



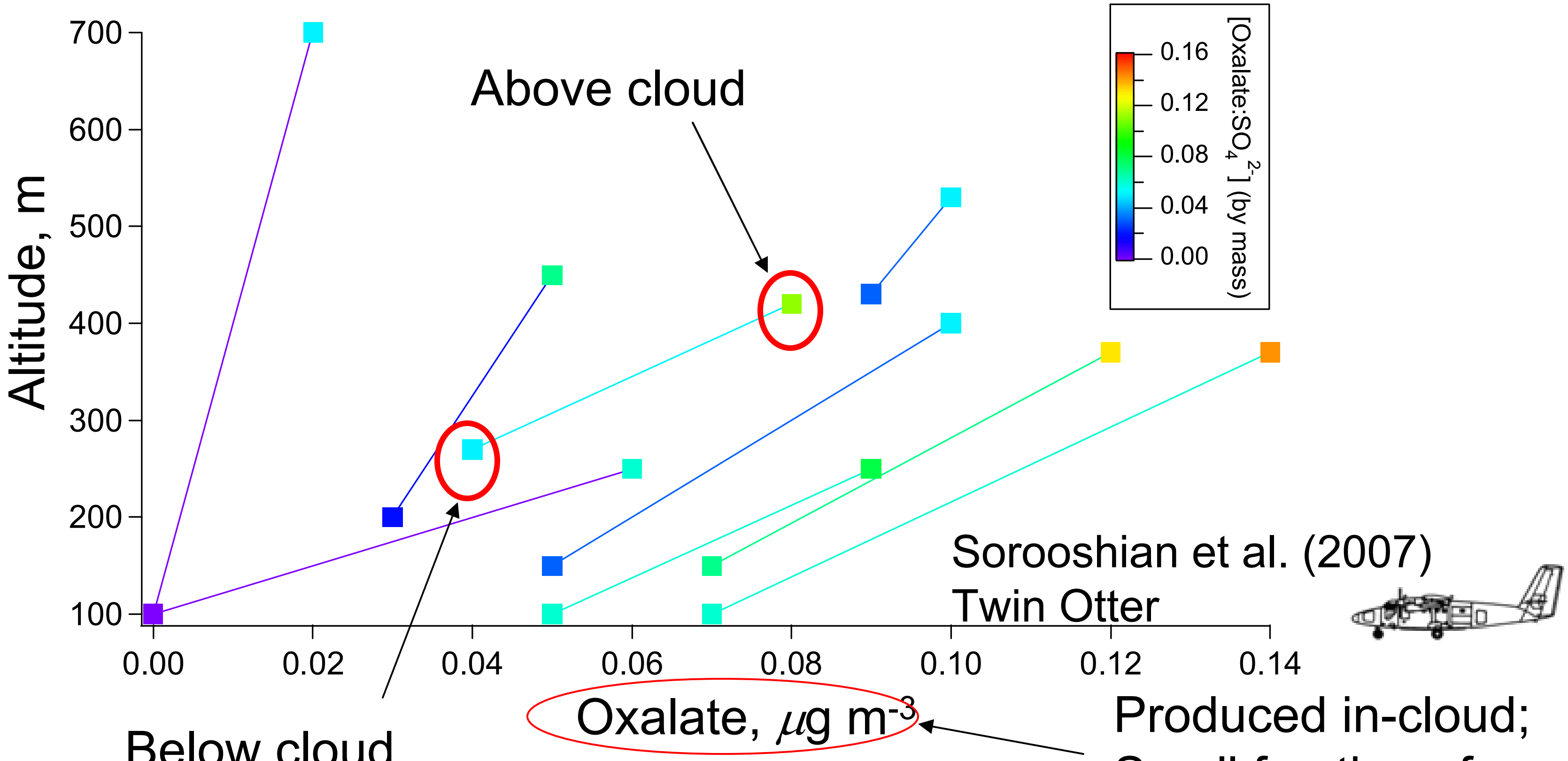
- *Free troposphere and BL: excellent closure (~50% organic)*
- *Above cloud: poor closure unless the hygroscopicity of the large organic fraction is accounted for*

$$S = \frac{D^3 - D_p^3}{D^3 - D_p^3\left(1-\boxed{\kappa}\right)} \exp\left(\frac{4\sigma_w M_w}{RT\rho_w D}\right) \qquad \boxed{\kappa = \sum_i x_i \kappa_i}$$

κ represents the effectiveness as a CCN
κ = 0: insoluble
κ = 1.1: NaCl

Wang, et al., 2008 G-1

Enhanced organic acid above clouds



Above cloud

Below cloud

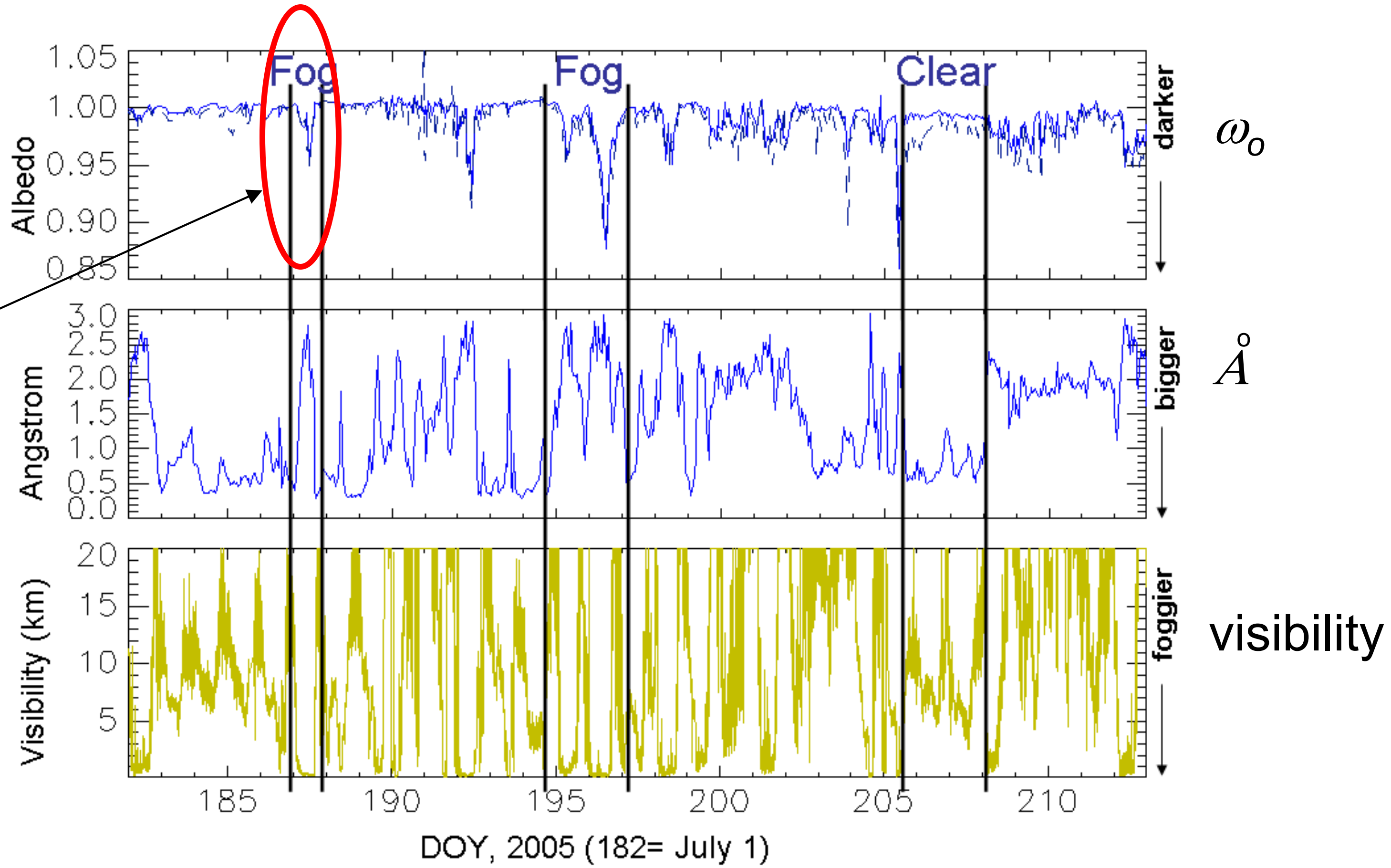
Sorooshian et al. (2007)
Twin Otter

Produced in-cloud;
Small fraction of
total organic

- *Oxalate is produced in cloud;   oxalate:sulfate ratio increases*
- *Entrainment of free tropospheric aerosol also contributes to the organic acid layers*

Aerosol Optical Properties

Properties of drop <u>residuals</u>

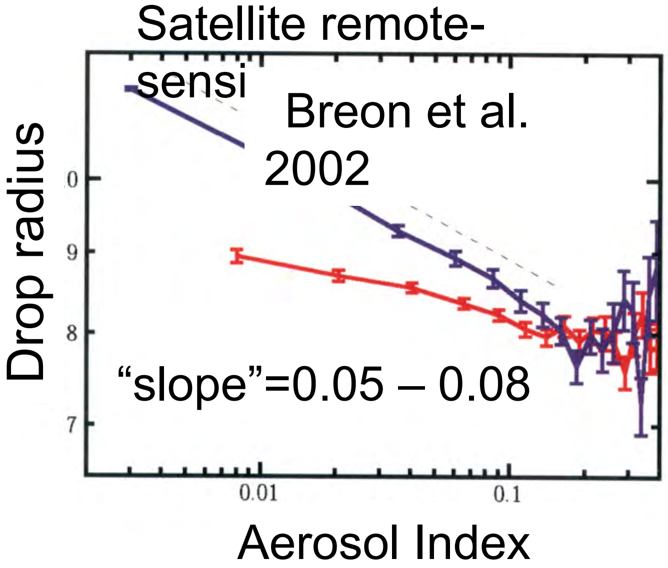


Cloud processing of aerosol → Smaller, more absorbing particles

Berkowitz, Andrews, et al. Pt Reyes

Radiative Forcing Implications

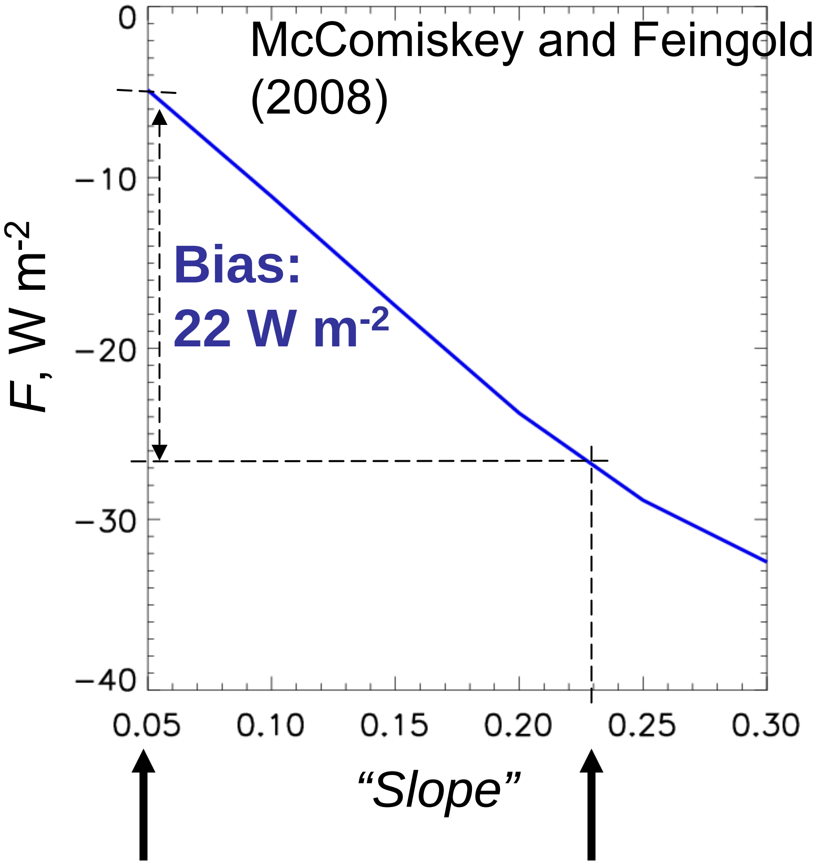
ACI and TOA Radiative Forcing


Satellite remote-sensi

Breon et al. 2002

“slope”=0.05 – 0.08

- *Some GCMs use satellite-derived “slope” to represent aerosol effects on clouds*
- *Errors in slope yield large errors in forcing*
- *Weakest indirect forcing in IPCC (2007) is associated with satellite- derived slopes*


McComiskey and Feingold (2008)

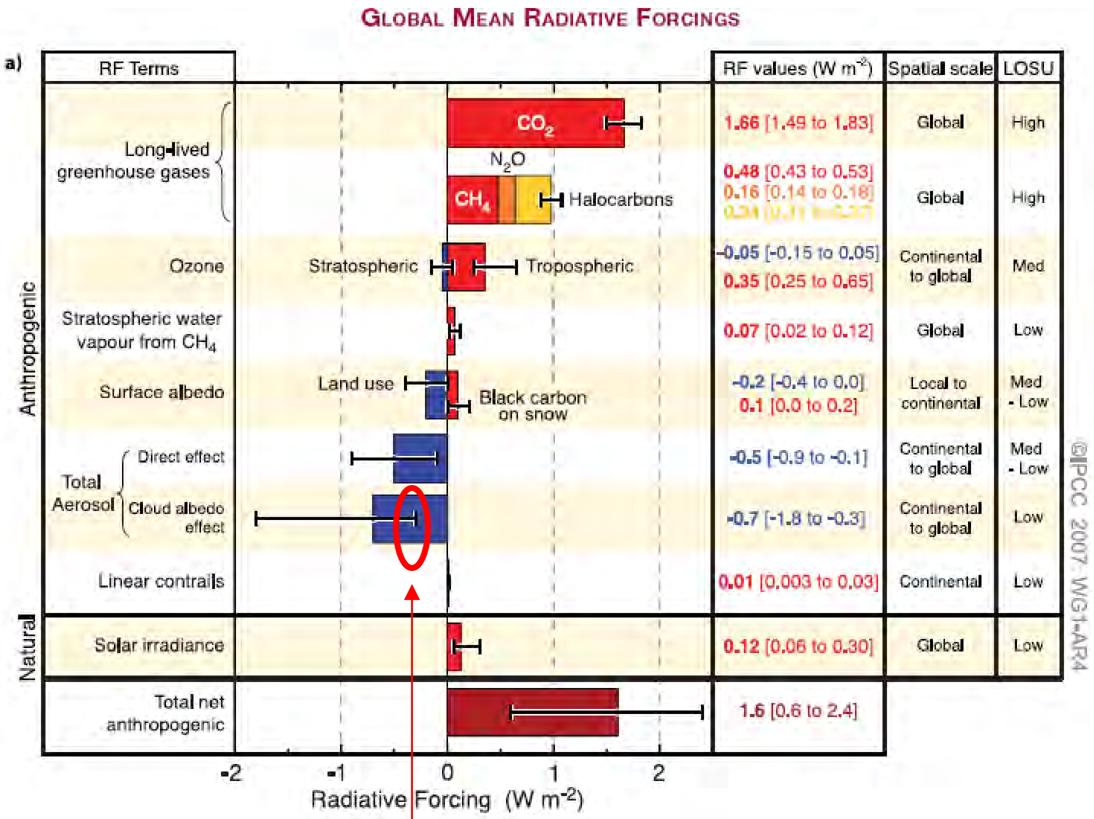
Bias: 22 W m^{-2}

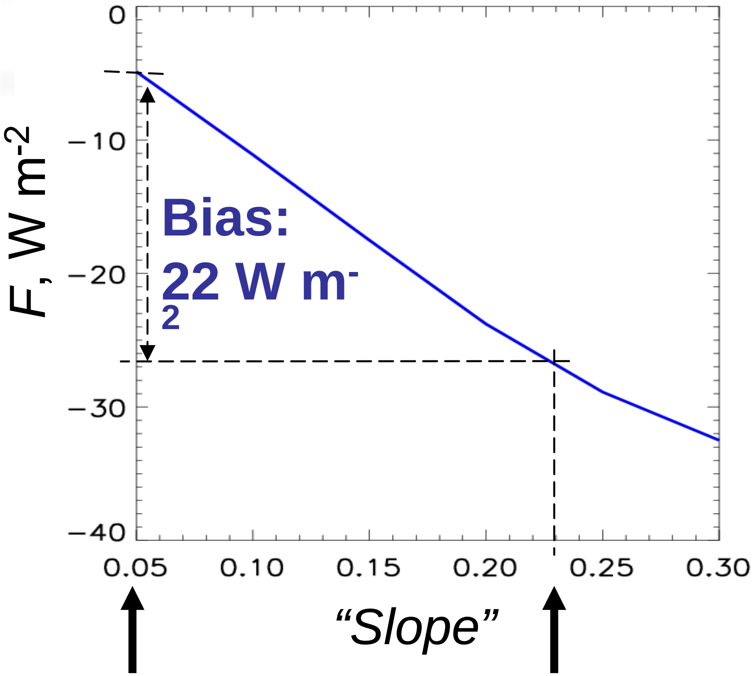
Satellite obs.

In-situ obs.

Flux change resulting from CCN changing from 100 to 1000 cm^{-3};
Diurnal average based on 100% cloud cover

ACI and TOA Radiative Forcing





Satellite obs.

In-situ obs.

Weakest indirect forcing in IPCC (2007) is associated with satellite-derived slopes