INFLUENCE OF ATMOSPHERIC STABILITY ON CLOUD DROP EFFECTIVE RADIUS DETERMINED BY GROUND-BASED REMOTE SENSING

BYUNG-GON KIM

GFDL NOAA — PRINCETON UNIVERSITY

(Now at Kangnung University, Korea, bgk@kangnung.ac.kr)

MARK MILLER, STEVE SCHWARTZ

miller@bnl.gov BROOKHAVEN NATIONAL LABORATORY *ses@bnl.gov*

QILONG MIN

UNIVERSITY AT ALBANY
STATE UNIVERSITY OF NEW YORK

min@asrc.cestm.albany.edu

INTRODUCTION

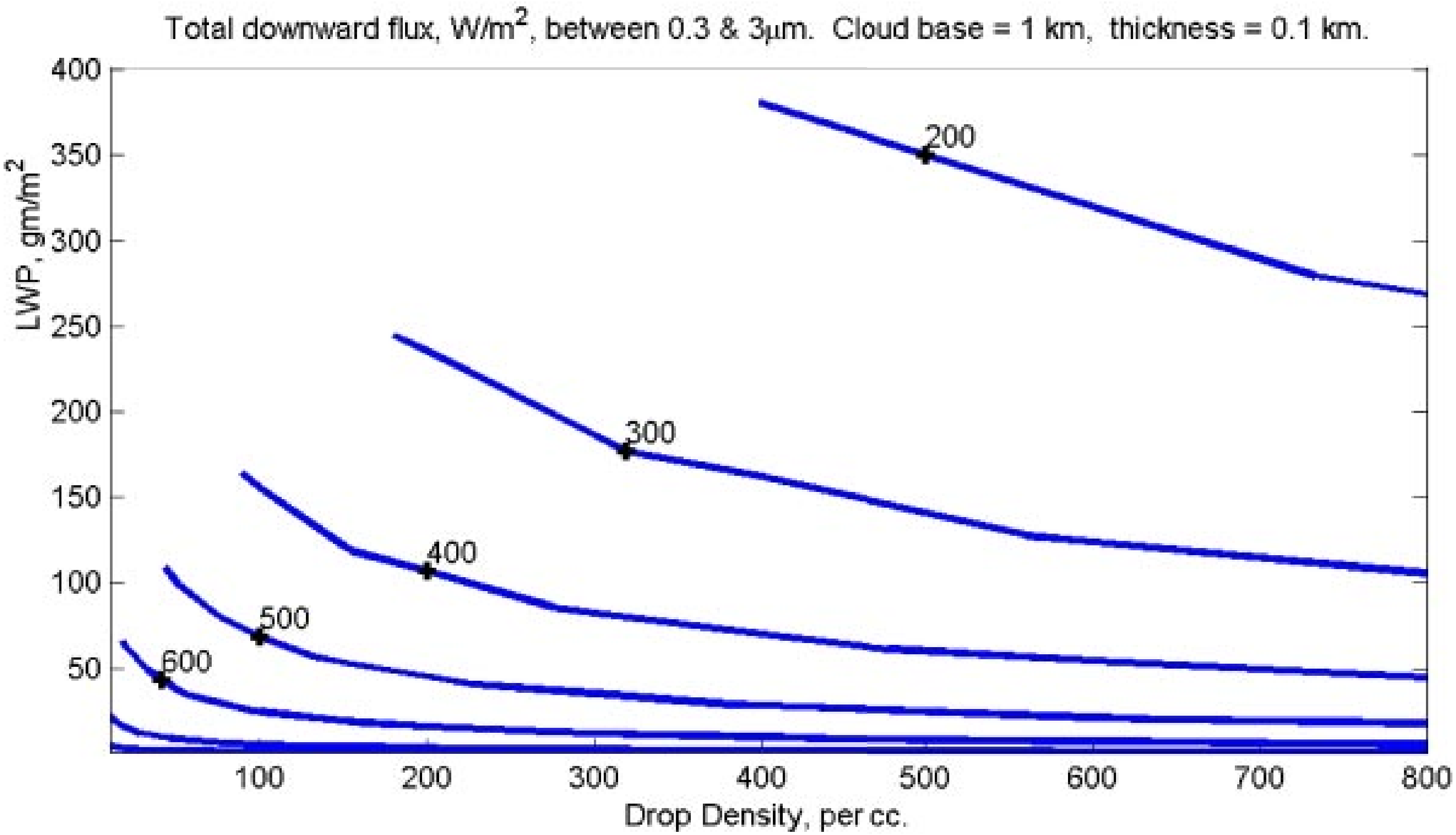
This poster deals with ***aerosol indirect radiative forcing of climate change***, . . .

Enhancement of cloud drop number concentration and by anthropogenic aerosols and resultant change in cloud albedo, . . .

Commonly denoted the aerosol first indirect effect or ***"Twomey effect"***).

Numerous studies have demonstrated such modification of cloud properties and have quantified resulting changes in shortwave radiative fluxes.

SENSITIVITY OF DOWNWELLING FLUX TO LWP AND DROP CONCENTRATION



Cloud reflectance is highly sensitive to LWP, and for given LWP is sensitive to cloud drop concentration (or, equivalently, effective radius).

BACKGROUND

We have previously used ground-based remote sensing at the **ARM Southern Great Plains site** of cloud optical depth τ_c by narrowband radiometry and liquid water path L by microwave radiometry ***under complete overcast sky***.

Effective radius: $r_e \approx \frac{3}{2} \frac{L}{\rho_w \tau_c}$

Under assumption that Mie scattering coefficient $Q_e \approx 2$, valid for $r >> \lambda$. In practice an ***iterative method*** is used (*Min and Harrison, JGR, 1996*).

We find ***substantial** (factor of 2) **day-to-day variation in cloud drop effective radius (r_e) that is weakly associated with variation in aerosol loading*** as characterized by light-scattering coefficient at the surface (*Kim et al., JGR, 2003*).

The substantial scatter suggests the importance of ***meteorological influences on cloud drop size***.

MEASURING CLOUD DROP EFFECTIVE RADIUS BY GROUND BASED REMOTE SENSING

Effective radius: Cloud or aerosol property important for radiative transfer

For a homogeneous volume

$$r_e \equiv \frac{\mu_3}{\mu_2} \equiv \frac{\int N(r) r^3 dr}{\int N(r) r^2 dr}$$

For a cloud

$$r_e = \frac{\iint N(r,z) r^3 dr dz}{\iint N(r,z) r^2 dr dz}$$

Cloud liquid water path (LWP) (microwave radiometer)

$$L = \frac{4\pi}{3} \rho_w \int\int r^3 N(r,z) dr dz$$

Cloud optical depth (MFRSR)

$$\tau_c = \iint \pi r^2 Q_e(r) N(r,z) dr dz$$

Mie scattering efficiency

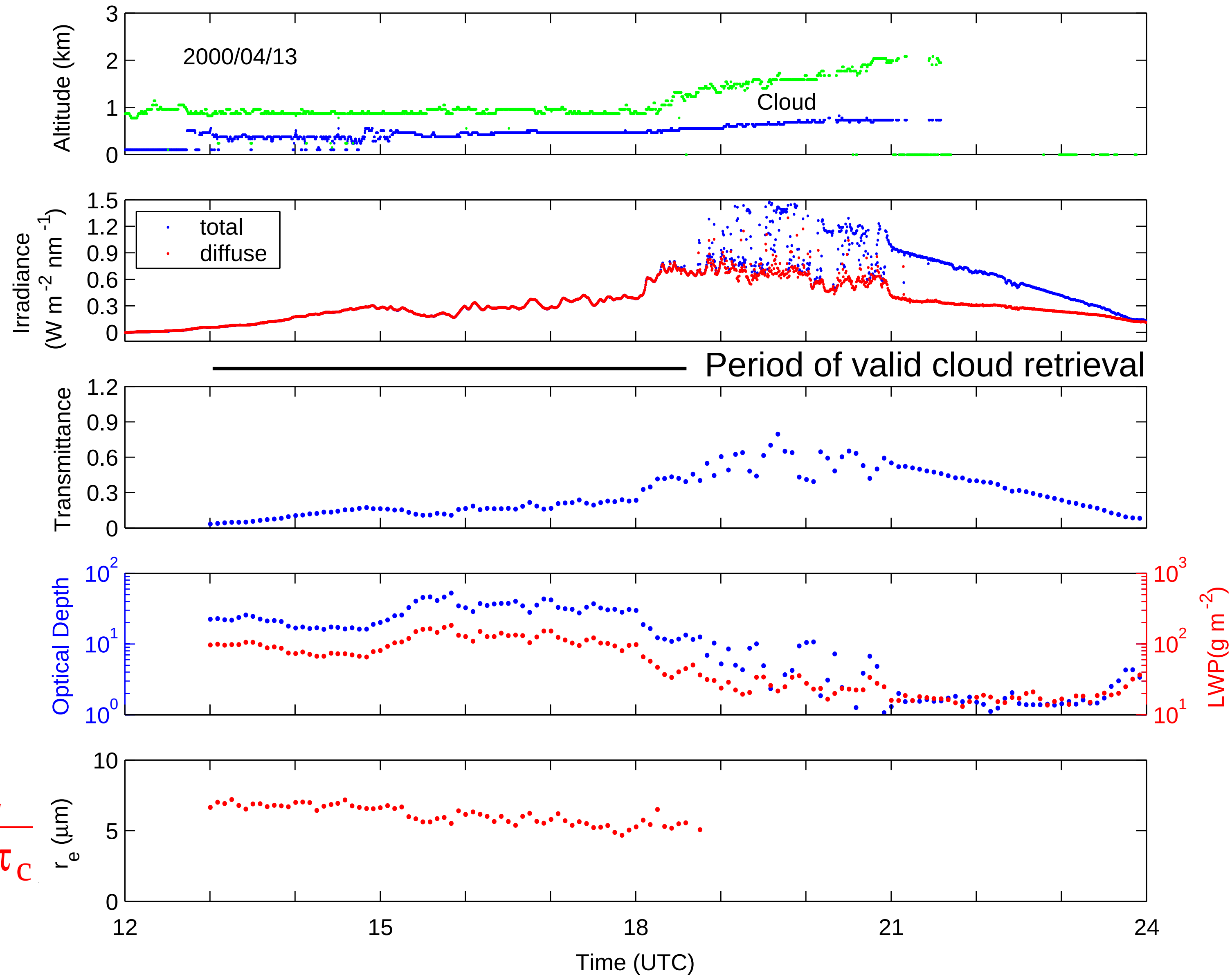
$$Q_e \approx 2 \text{ for } r >> \lambda$$

Whence

$$r_e \approx \frac{3}{2} \frac{L}{\rho_w \tau_c}$$

GROUND BASED REMOTE SENSING OF CLOUD PROPERTIES

North Central Oklahoma, April 13, 2000 – Local time = UTC - 6



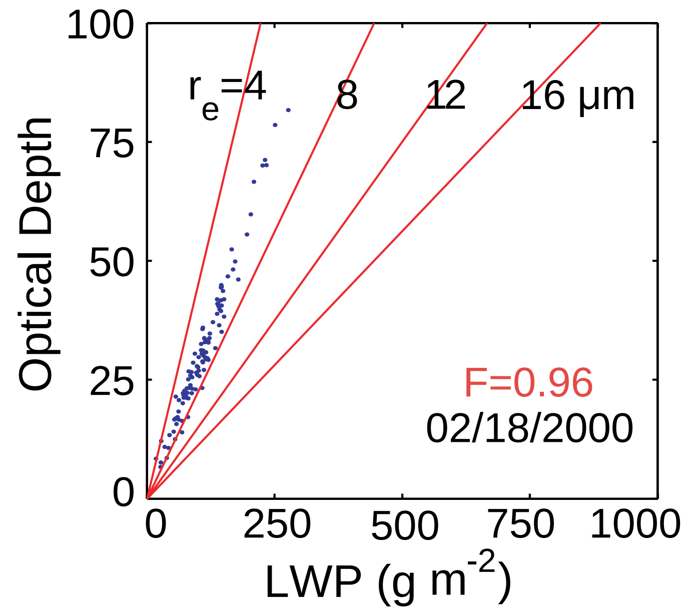
$$r_e \approx \frac{3}{2}\frac{L}{\rho_w \tau_c}$$

Kim, Schwartz, Miller, and Min, JGR, 2003

CLOUD OPTICAL DEPTH VS. LIQUID WATER PATH

Southern Great Plains, 2000

$$\tau_c \approx \frac{3}{2}\frac{L}{\rho_w r_e}$$



Kim, Schwartz, Miller, and Min, JGR, 2003

Optical depth is highly correlated with and strongly dependent on liquid water path.

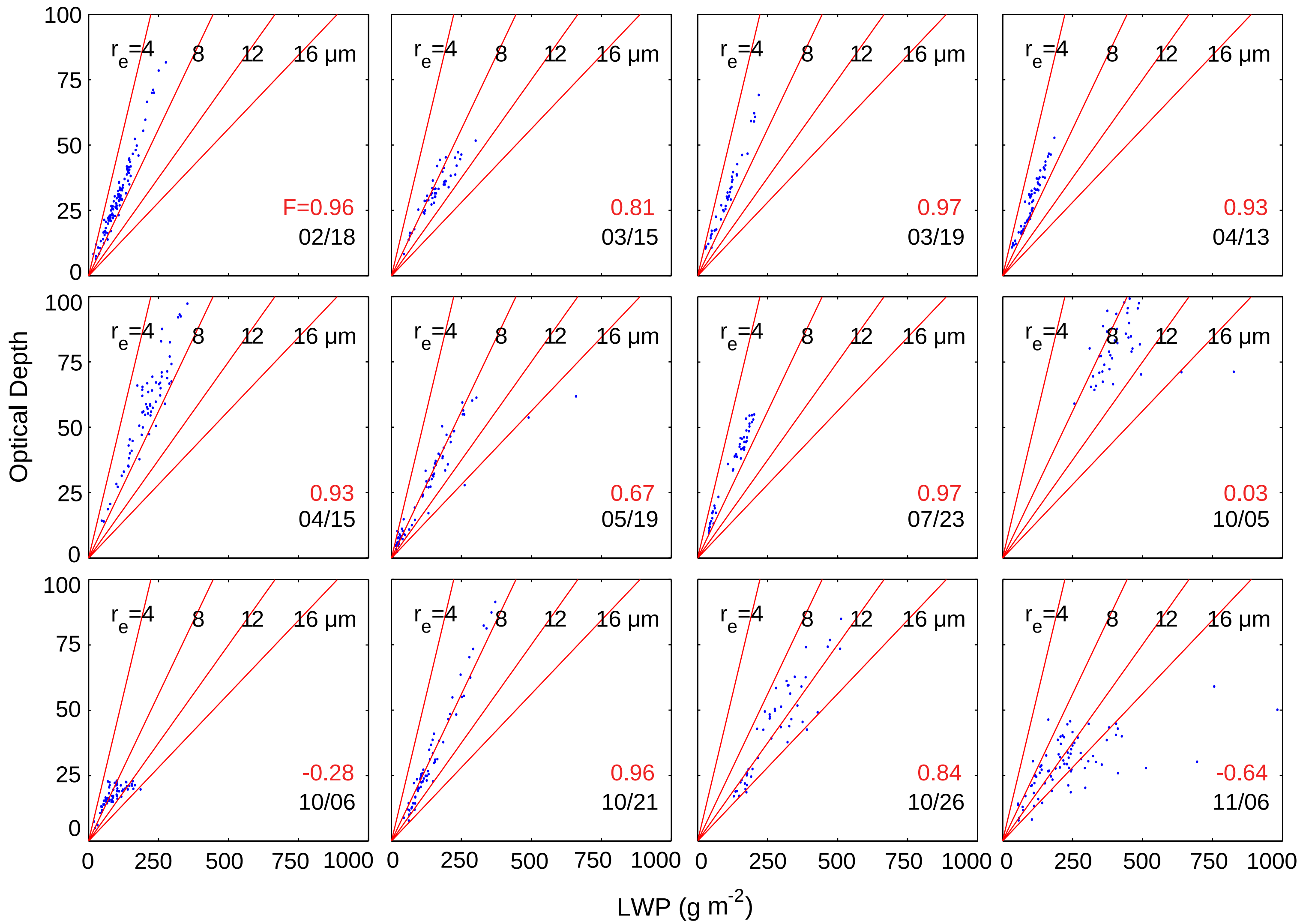
Tight cluster of points about a diagonal line through the origin is indicative of constant effective radius over the day.

Slope is inversely proportional to effective radius.

F, fraction of variance accounted for by regression = 96%.

CLOUD OPTICAL DEPTH VS. LIQUID WATER PATH

Southern Great Plains, 2000

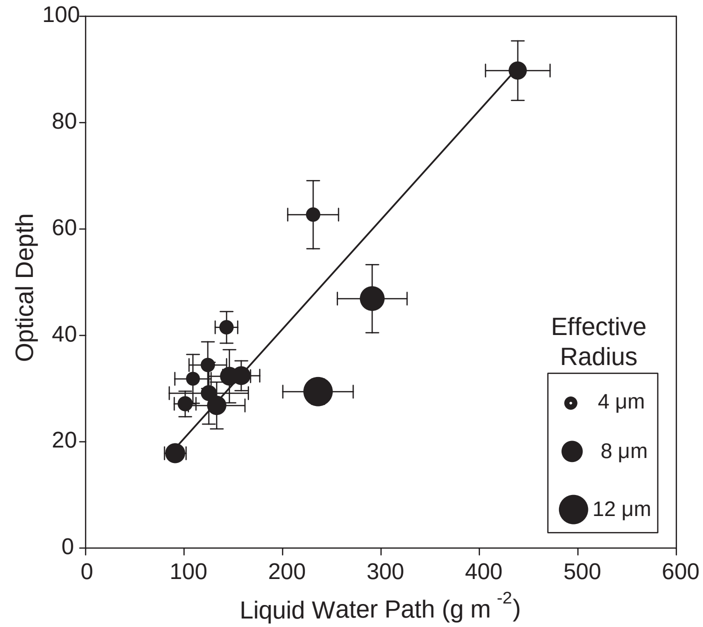


Kim, Schwartz, Miller, and Min, JGR, 2003

F, fraction of variance accounted for by regression, mainly > 80%.

CLOUD OPTICAL DEPTH VS. LIQUID WATER PATH

Southern Great Plains, 2000, aggregated by days



Kim, Schwartz, Miller, and Min, JGR, 2003

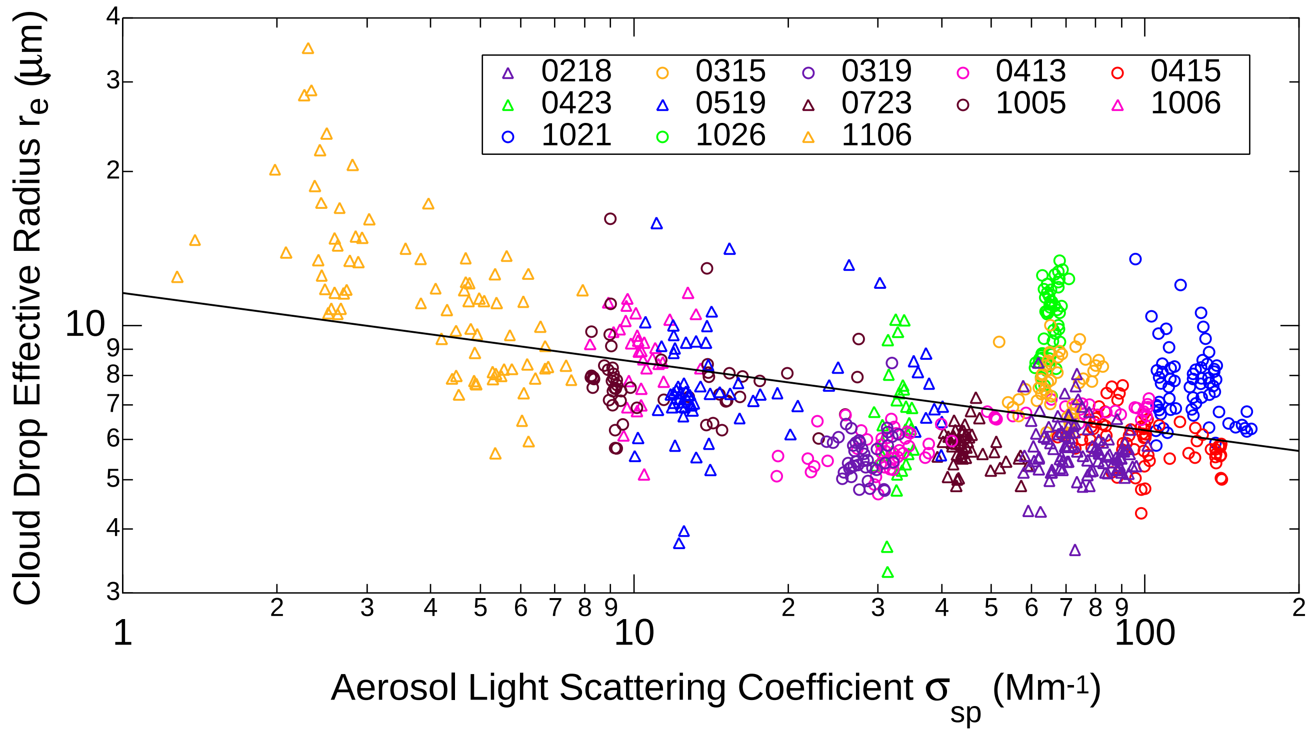
Fraction of variance accounted for by regression, 74%.

Days with smaller radii have a greater optical depth for a given LWP.

CORRELATION OF CLOUD DROP EFFECTIVE RADIUS AND AEROSOL LIGHT SCATTERING COEFFICIENT

Southern Great Plains

All 13 days in 2000 meeting complete overcast criterion; $R^2 = 0.24$



Kim, Schwartz, Miller, and Min, JGR, 2003

CONCLUSIONS FROM PRIOR INDIRECT EFFECT STUDY AT SGP

The dominant influence on cloud optical depth τ_C is Liquid Water Path (LWP). LWP accounts for 63% of the variance in τ_C over the entire data set and up to 97% of the variance on a given day.

Effective radius r_e varied little on a given day but varied substantially (5.6 ± 0.1 to 12.3 ± 0.6 µm) from day to day.

Aerosol light scattering coefficient at the surface accounted for ~24% of the variance in r_e in the entire data set .

THIS WORK

Here we examine ***key meteorological variables*** that may contribute to variation in r_e.

The ***mixing height*** is determined by the vertical potential temperature gradient determined by radiosonde.

Potential temperature: $$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

where p_0 = standard pressure, typically 10^5 Pa

and $\kappa = R / c_p \approx 2/7$

The ***Brünt-Väisälä frequency***, the (angular) oscillation frequency of a parcel of air following vertical displacement in a system initially at rest, is determined as the square root of the product of gravity and potential temperature gradient.

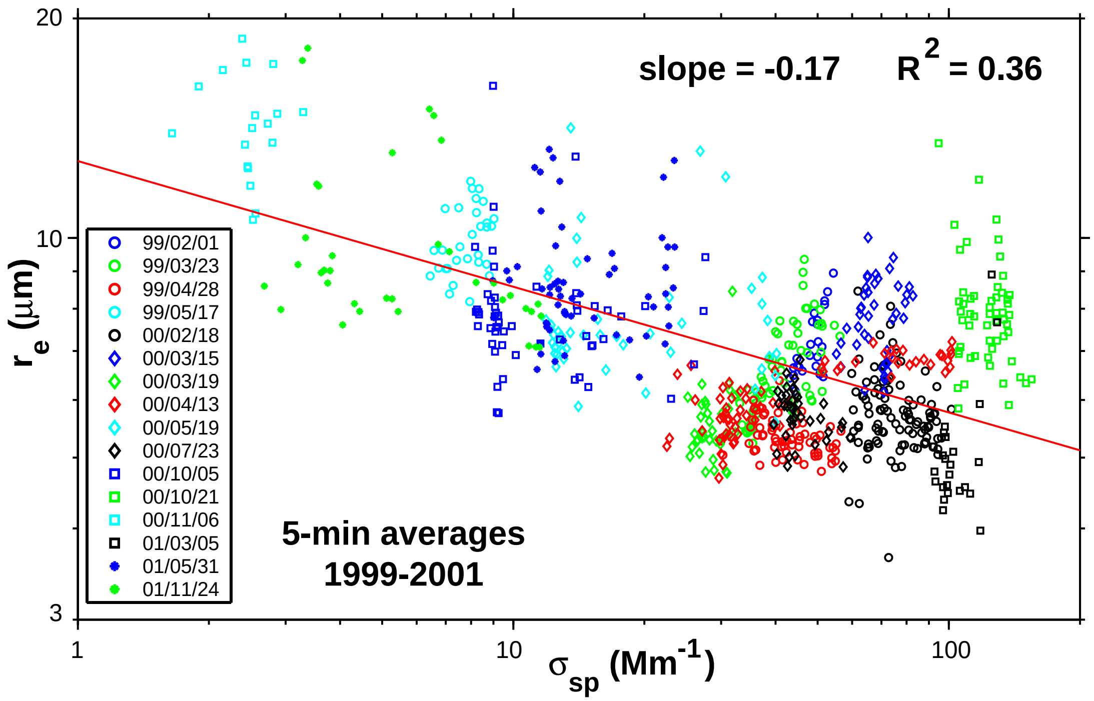
Brünt-Väisälä frequency: $N_{\mathrm{BV}} = \left[g \frac{d \ln \theta}{dz} \right]^{1/2}$

where g = gravitational constant

RESULTS

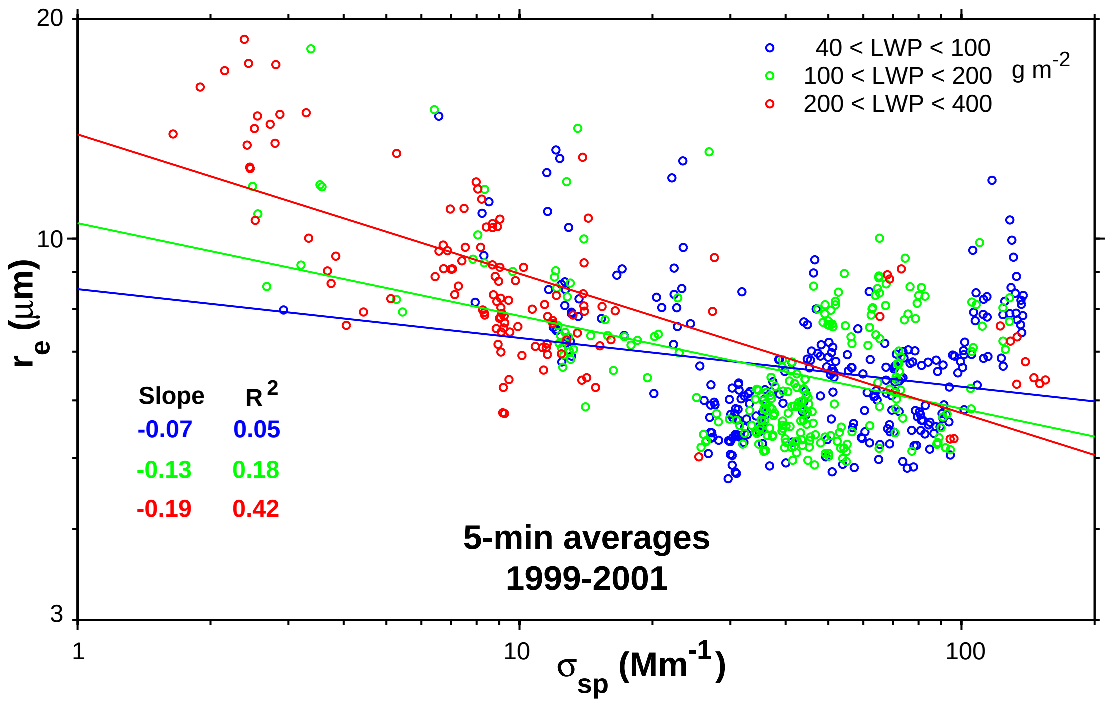
CORRELATION OF CLOUD DROP EFFECTIVE RADIUS AND AEROSOL LIGHT SCATTERING COEFFICIENT

Southern Great Plains, 1999 - 2001, 16 days



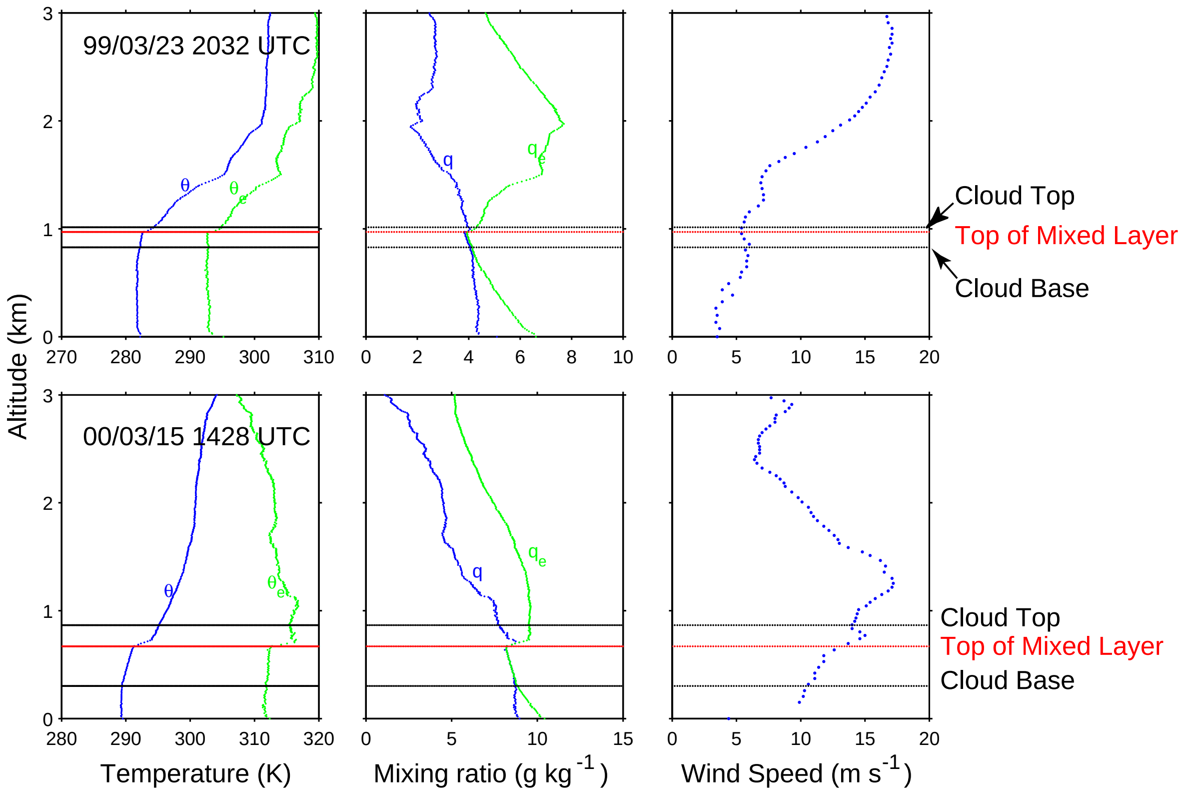
CORRELATION OF CLOUD DROP EFFECTIVE RADIUS AND AEROSOL LIGHT SCATTERING COEFFICIENT

Southern Great Plains, 1999 - 2001, 16 days, *by LWP*

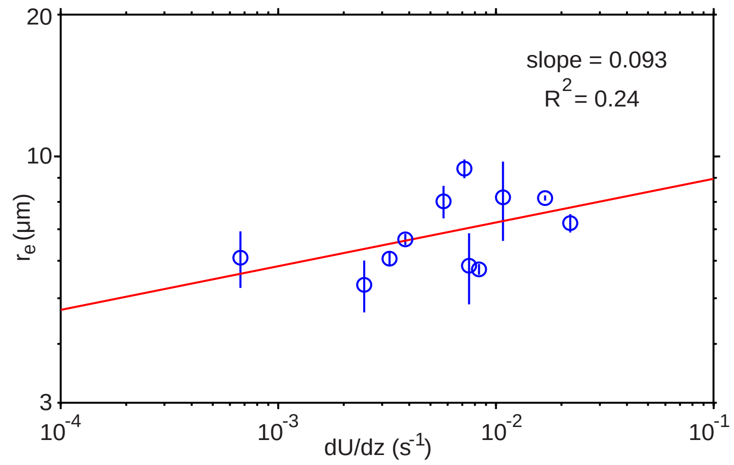


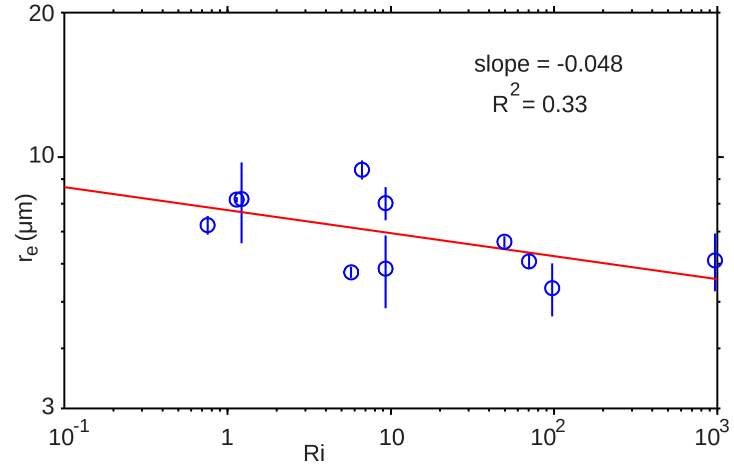
Correlation is greater for higher LWP.

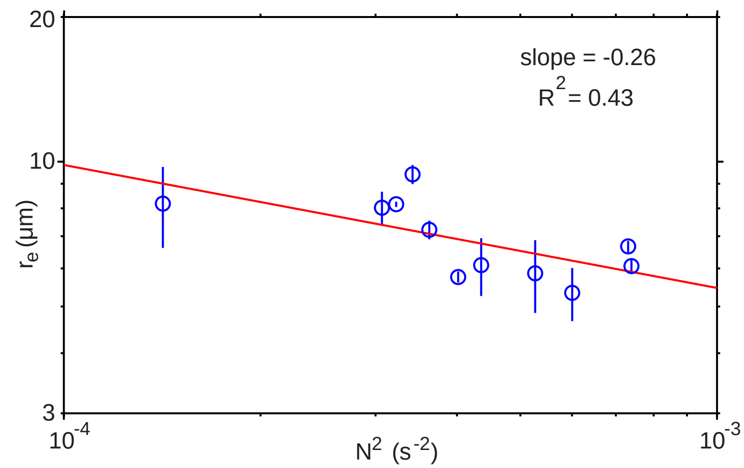
ATMOSPHERIC VERTICAL STRUCTURE



METEOROLOGICAL INFLUENCES ON EFFECTIVE RADIUS







Brünt-Väisälä frequency accounts for 43% of the variance in r_e.

CONCLUSIONS

The analysis indicates a ***correlation of smaller droplets with higher Brunt-Väisälä frequency*** at height above the top of the mixed layer but just beneath the cloud top.

The more stable the inversion, the smaller the droplets.

Such a correlation would result in ***enhancement of the aerosol first indirect effect in situations of highly stable cloud tops.***