Importance of Adiabaticity in Evaluating Aerosol Indirect Effect derived from Ground Based Remote Sensing

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This Study

Several studies demonstrated aerosol indirect effect such as modifications of cloud properties due to aerosols and corresponding changes in shortwave and longwave radiative fluxes.

Some recent studies indicated aerosol indirect effects may not be the primary modulator of cloud optical properties in certain situations. They implied other processes were impacting the cloud optical properties (Kim et al., JGR 2003).

To study these other impacts, we extend a previous study to investigate the role of adiabaticity facilitated by mixing in modulating cloud optical properties.

We quantify the effects of mixing by measuring the ratio of the observed cloud water path to its adiabatic value, (adiabaticity, α).

The screening criteria for relatively homogeneous stratus cloud yield fourteen analysis days (see Fig. 2) from the 3-year (1999 - 2001) data archives.

Motivation

The propensity for layer clouds to maintain sub-adiabatic motivates us to determine analytically the probable impacts of a reduction of liquid water on the cloud optical properties, relative to purely adiabatic clouds without mixing or evaporating drizzle.

Adiabaticity

Examining how cloud optical properties could be influenced by entrainment mixing;

$$\overline{r}_e = \exp(\overline{\sigma}_r^2)\left(\frac{A\alpha\overline{\Gamma}_l\Delta z}{N}\right)^{1/3} \qquad \alpha = \frac{L}{L_a}$$

$$\tau = 2\pi A^{2/3}\left(\frac{\overline{\Gamma}_l^2 N\alpha^2\Delta z^5}{\exp(3\overline{\sigma}_r^2)}\right)^{1/3} \qquad A = \frac{3}{8\pi}\frac{\overline{\rho}}{\rho_l}$$

where σ_r is termed the "dispersion" of the droplet spectrum, Γ_l is vertical variation of the adiabatic liquid water mixing ratio, N is cloud drop number concentration, Δz is cloud thickness, ρ is air density, and ρ_l is density of liquid water.

The above derivation is based on the homogeneous mixing in that properties are impacted by the reduction in liquid water path denoted by α.

From the derivation,

- τ is primarily governed by cloud thickness,
- Adiabaticity is the next most influential factor.
- r_e is found to be equally sensitive to adiabaticity and cloud thickness.

Sensitivity of Cloud Property to Adiabaticity

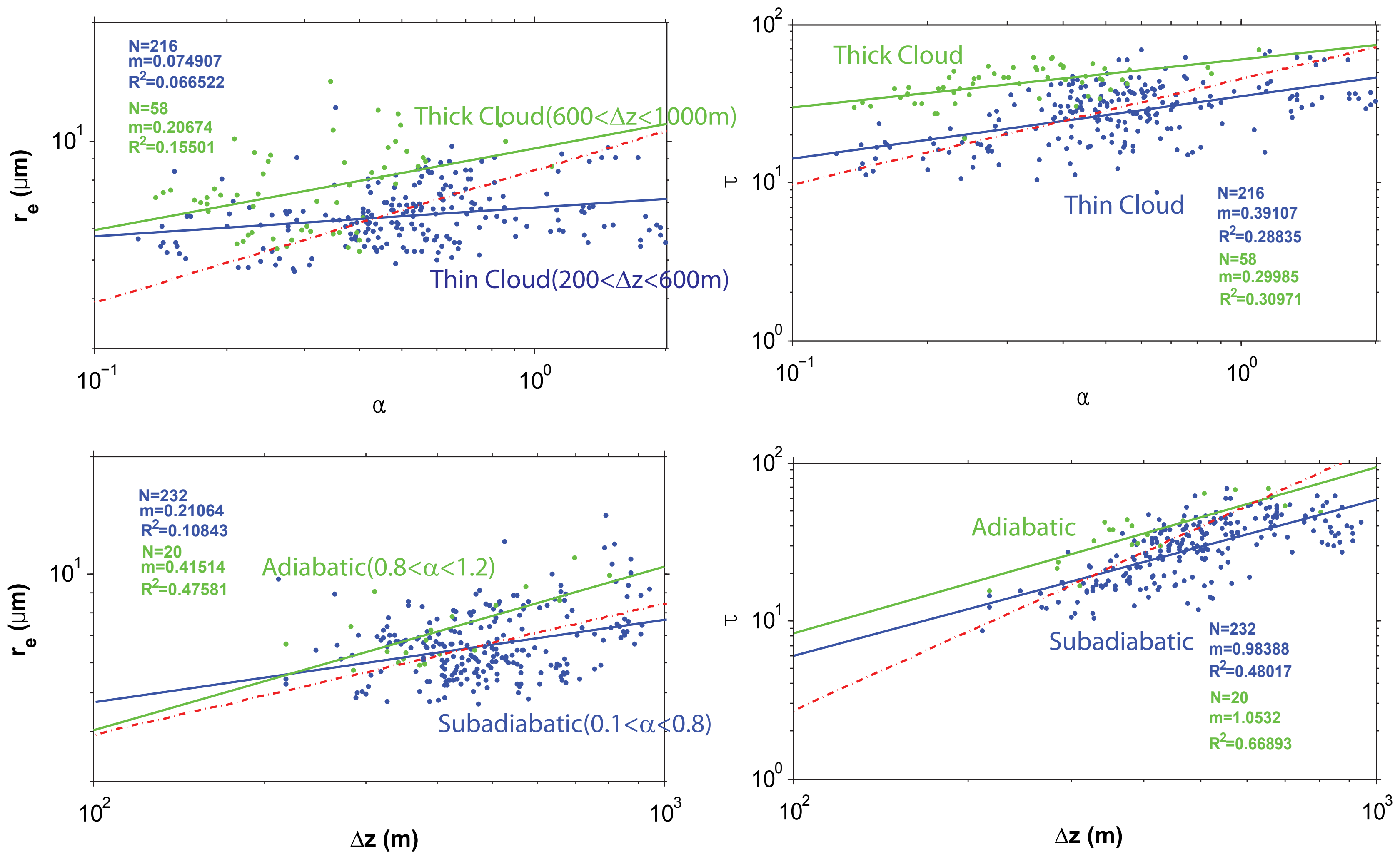


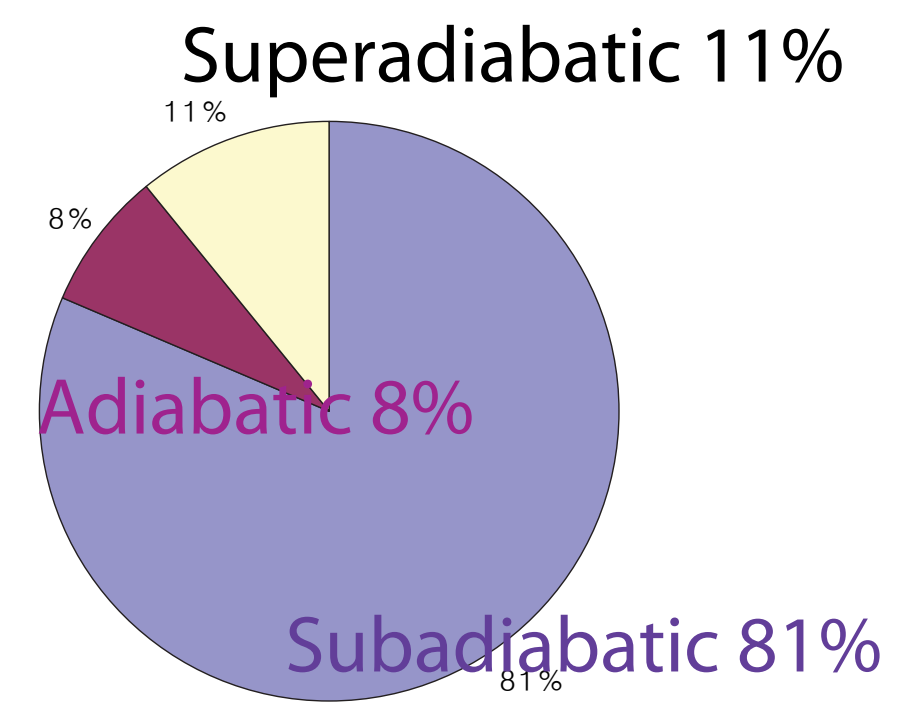
Fig. 1. Effective radius (r_e) as a function of α and Δz (Left), and optical depth (τ) as a function of α and Δz (Right). Red line is based on the analytical derivation.

Left Figure

The relationship between r_e and α, a proxy for mixing, is weak and only slightly dependent upon Δz. Note that the observed mixing does not appear to be homogeneous.

Right Figure

There is a notable increase in τ with an increase in α and distinct segregation in the two cloud thickness populations. Certainly the sensitivity of τ to Δz is greater than that of τ to α.



Relationship of r_e to Aerosol Load

Left figure

A general decrease in r_e is shown with an increase of σ_{sp} (light scattering coefficient) with a slope of 0.15.

Right Figure

Poor correlations of r_e and σ_{sp} in the subadiabatic clouds, and the significant correlation ($R^2 = 0.53$) of r_e and σ_{sp} in the adiabatic clouds are exhibited.

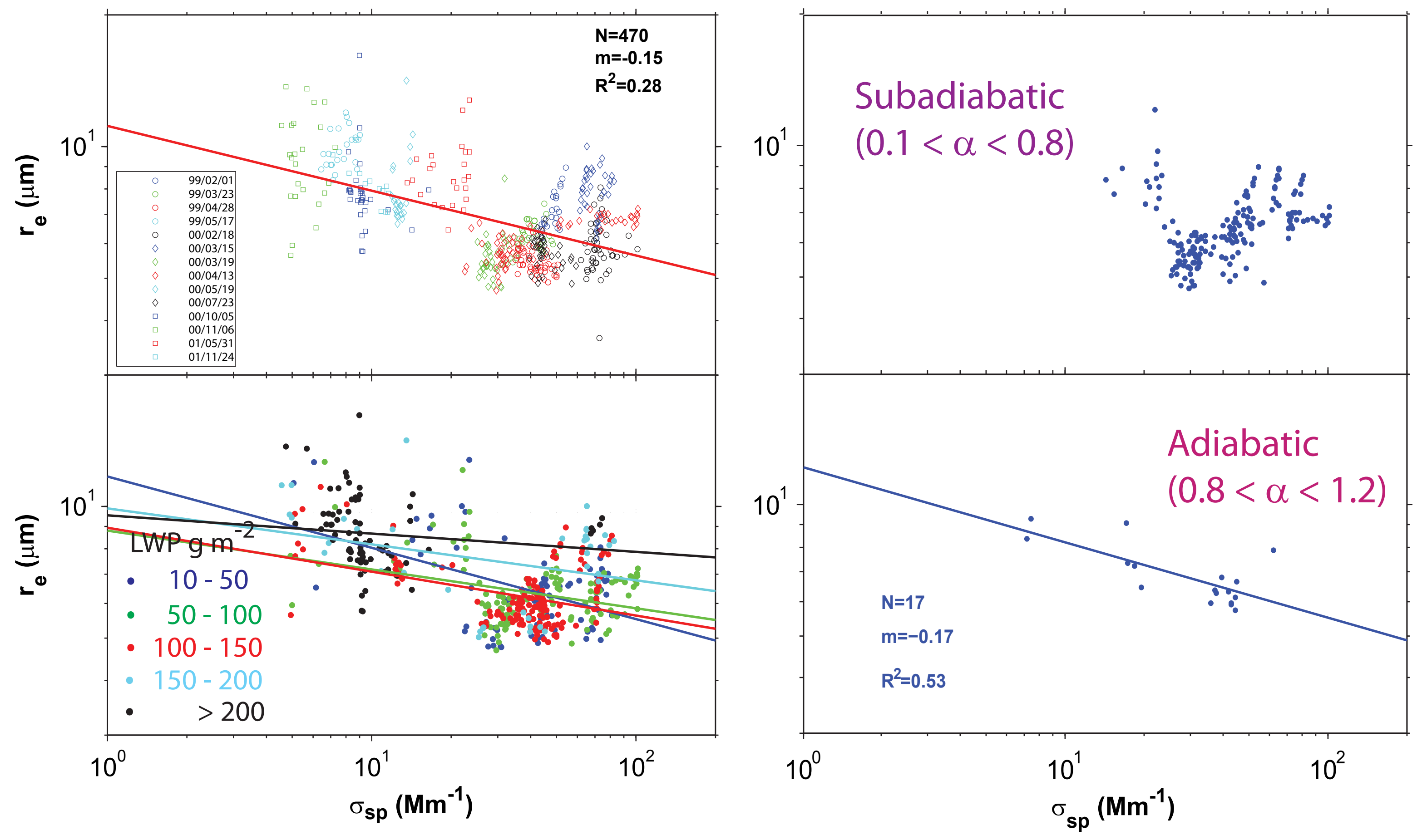


Fig. 2. Scatterplot of r_e vs. σ_{sp} for submicrometer aerosols (Up), and Scatterplot of r_e vs. σ_{sp} for the different LWP classes(Down) in the left figure. Scatterplot of r_e vs. σ_{sp} for the subadiabatic and adiabatic clouds (Right).

Response of r_e to Mixing

$$r_e = \alpha_\beta\left(\frac{\alpha_L}{\alpha_N}\right)^{1/3} r_{ea} \qquad \alpha_x = \frac{x}{x_a}$$

r_{ea} is r_e for an adiabatic cloud, x is a variable being considered, and β is relative dispersion of droplet spectrum.

Potential response of r_e to mixing processes

	Homogeneous Mixing	Heterogeneous mixing/ETEM$		
		Extreme case	Secondary activation	Enhanced growth
Underlying mechanism	Faster Mixing	Uniform evaporation	Nucleation	Coalescence
α_N and α_L	$\alpha_N=1$	$\alpha_N = \alpha_L$	$\alpha_N > \alpha_L$	$\alpha_N < \alpha_L$
Mixing function	Mixing does not change N but reduce the sizes	Mixing changes L & N proportionally	Stronger mixing results in more droplets,	Stronger mixing results in less but bigger droplets
Response of r_e	Depending on α_β and α_L	r_e independent of α_L	r_e decreases with decreasing α_L	r_e increases with decreasing α_L
Formula	$r_e = \alpha_\beta r_{ea}(\alpha_L)^{1/3}$	$r_e = \alpha_\beta r_{ea}$	$r_e = \alpha_\beta\left(\frac{\alpha_L}{\alpha_N}\right)^{1/3} r_{ea}$	$r_e = \alpha_\beta\left(\frac{\alpha_L}{\alpha_N}\right)^{1/3} r_{ea}$
AIE Effect	?	No change	More AIE effect	Less AIE effect

$ ETEM means Entity Type Entrainment Mixing proposed by Telford (AR, 1995)

Conclusions

The first indirect effect may be observable in clouds with no drizzle or entrainment, which places a severe limitation on observations made in continental clouds.

The difficulty in observing the first aerosol indirect effect in subadiabatic clouds is compounded by the sensitivity of the cloud properties to the mixing process because homogeneous and heterogeneous mixing apparently produce different responses.

Our study emphasizes the role of adiabaticity in evaluating the aerosol indirect effect, and suggests that adiabaticity is a convenient variable for the classification of clouds.