A long-term study of aerosol-cloud interactions and their radiative effects

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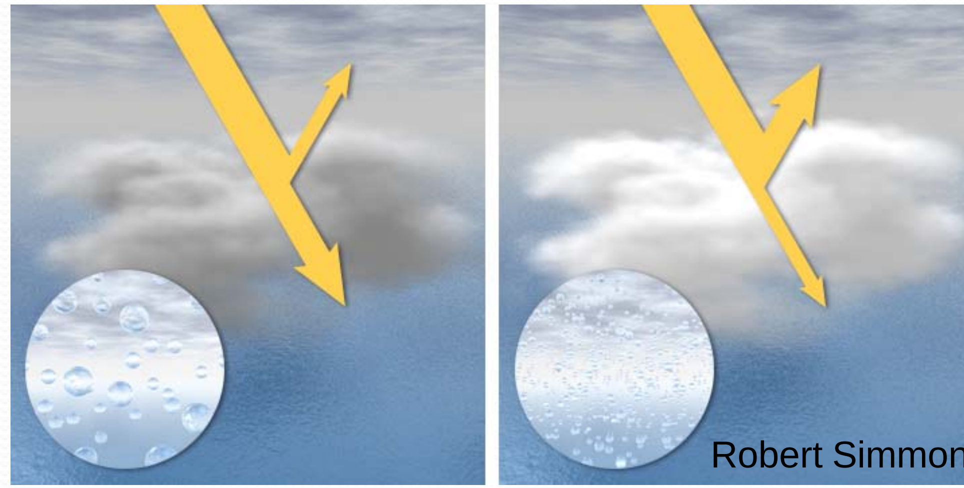
Aerosol-cloud interactions

Less reflective clouds (few large drops)

More reflective clouds (many small drops)



↑ Aerosol conc., N_a

→ ↑ Cloud Condensation Nuclei conc., CCN

→ ↑ Drop conc., N_d

→ All else equal (Liquid water path, LWP)

↓ Drop effective radius, r_e

↑ Cloud optical depth, τ_c

↓

↑ Cloud albedo, A_c

But...

Aerosol, macroscopic cloud properties and dynamics are interconnected → LWP Adjustments

Changes in Cloud Microphysics $\xrightarrow{???}$ Cloud Albedo Change

Goal

Clarify how aerosol and macroscopic cloud properties impact the cloud radiative forcing.

Methodology

- 14-years of coincident ground-based measurements of clouds, aerosol and meteorological properties from SGP ARM deployment.
- Measurements at 1-minute resolution.
- Low non-drizzling clouds (ice crystals and precipitation avoided).

Properties analyzed

RELATIVE CLOUD RADIATIVE EFFECT

$$rCRE = 1 - \frac{F_{all}^{dn}}{F_{clr}^{dn}}$$

Non-dimensional measure for the surface cloud radiative effect.

AEROSOL INDEX

$$A_i = \sigma_{550nm}\text{Å}$$

Proxy for CCN.

PROXY FOR TURBULENCE

$$w'^2 = [w - w_0]^2$$

w_0: mean vertical velocity at the cloud base.

DECOUPLING INDEX

$$D_i = \frac{h_{CB} - LCL}{h_{CB}}$$

Indicates how well-mixed the boundary layer is.

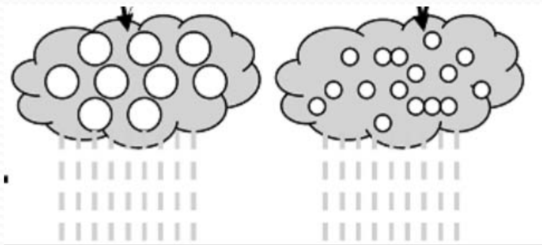
LOWER TROPOSPHERIC STABILITY

$$LTS = \theta_{700hPa} - \theta_{surface}$$

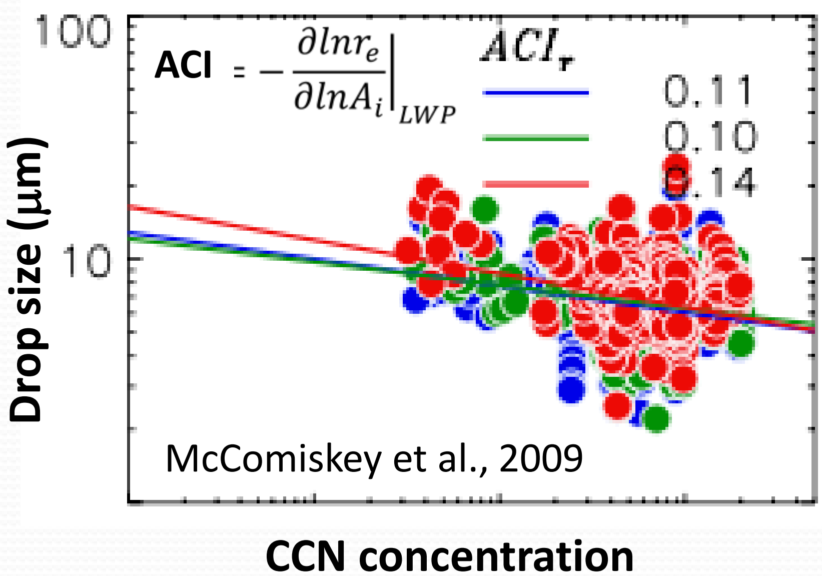
Related to the strength of the capping inversion. θ is the potential temperature.

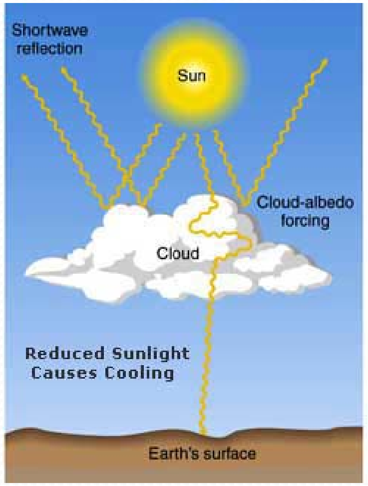
Previous approaches vs. New approach

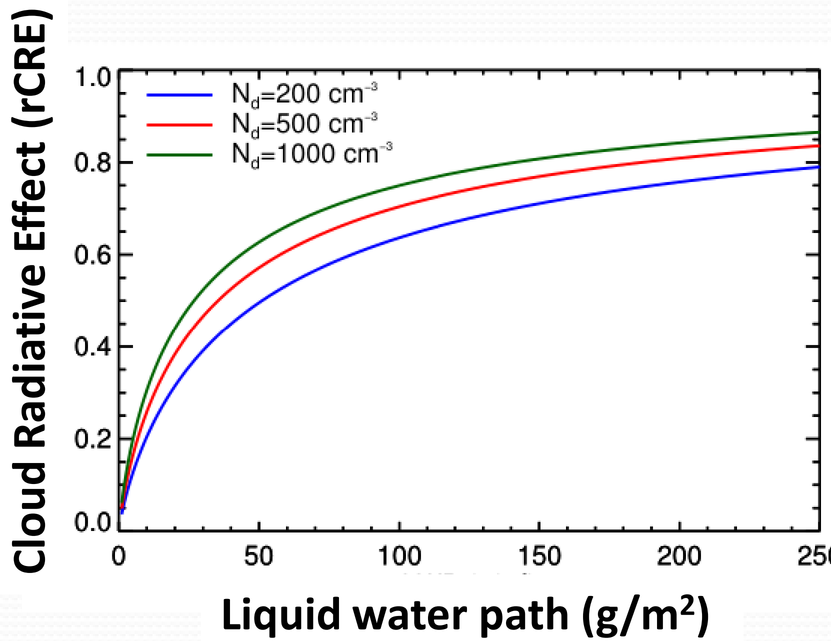
Microphysical responses vs. SW Radiative responses



Unperturbed Cloud | **Drop Conc. (constant LWP)**







How do different properties influence the rCRE?

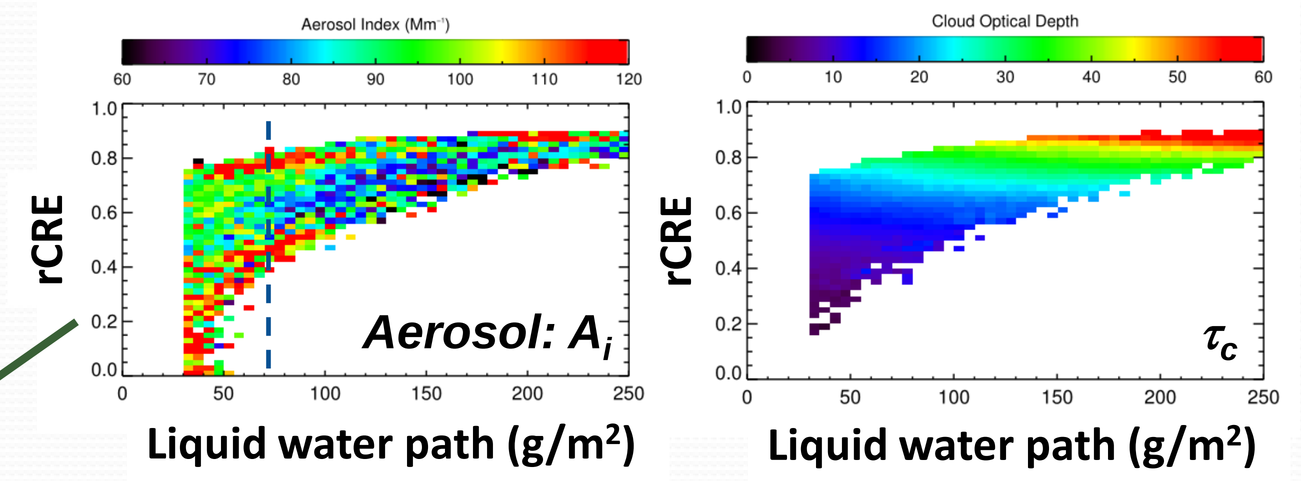
Southern Great Plains (SGP)

rCRE vs. LWP

At Fixed LWP:

Weak trends with A_i

in both directions.



Sena et al., ACPD, 2016

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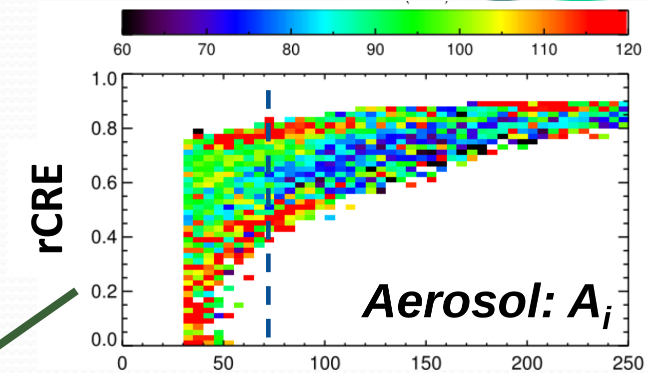
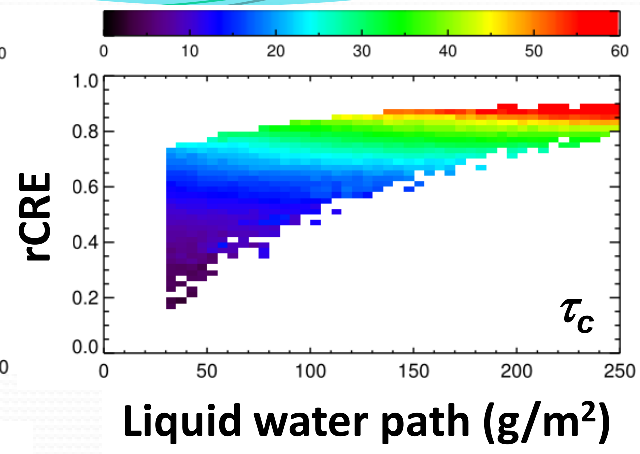
2 cloud regimes:

- Low f_c; High w'^2
- High f_c; Low w'^2





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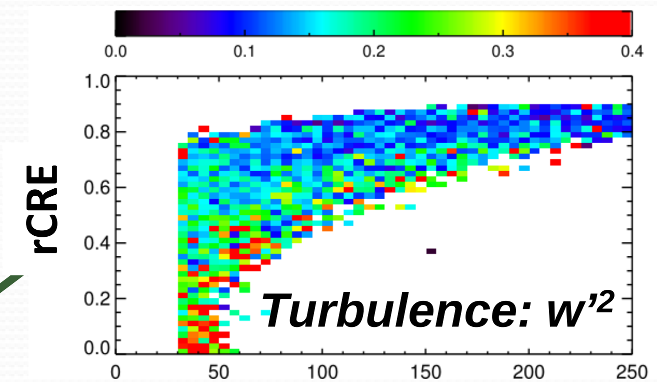

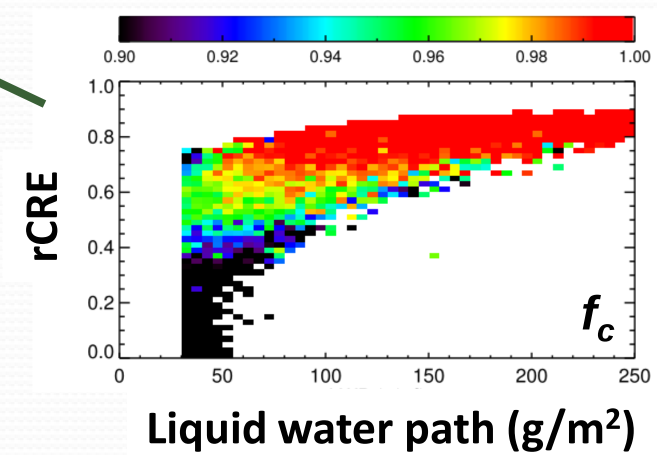

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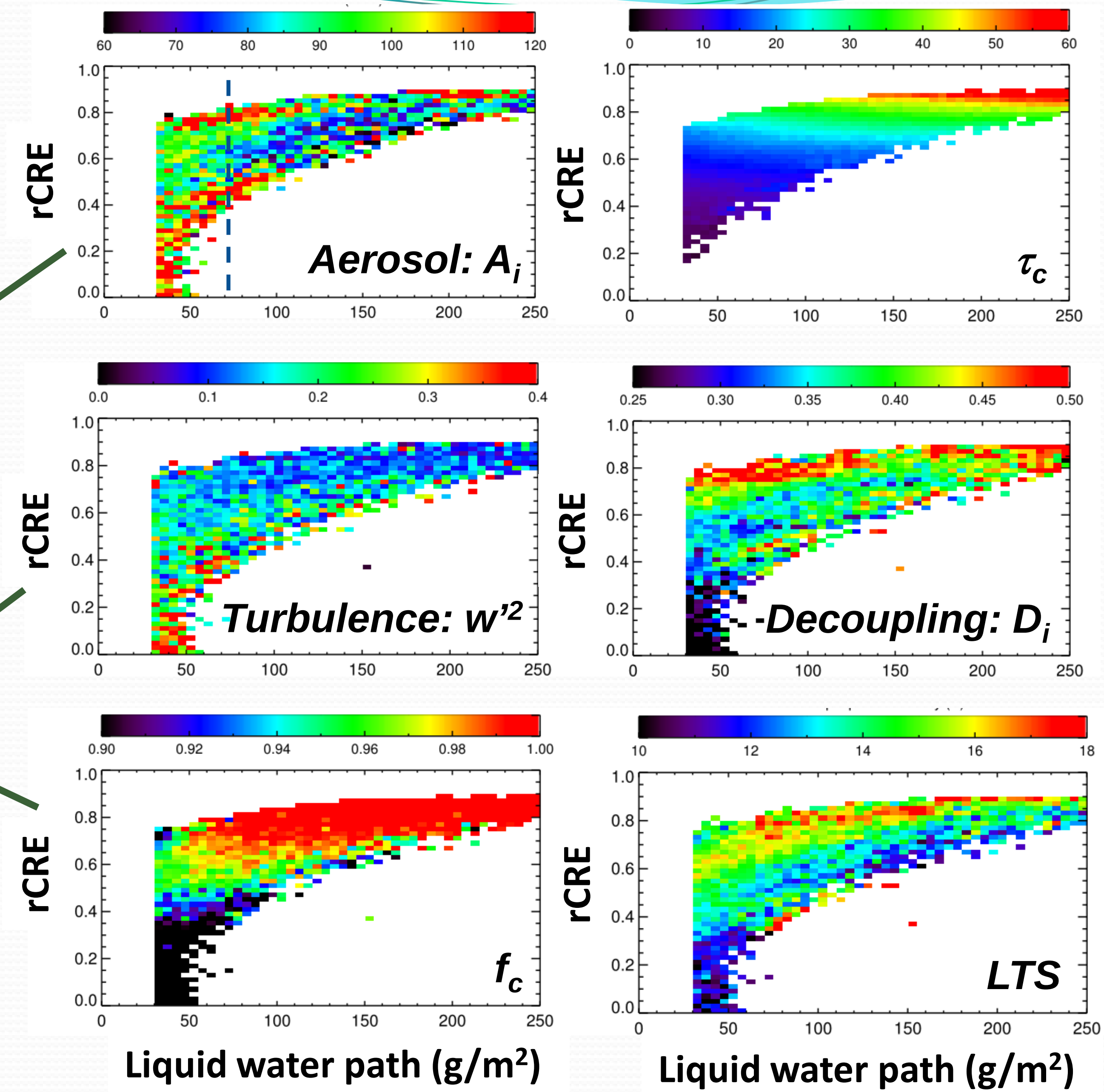
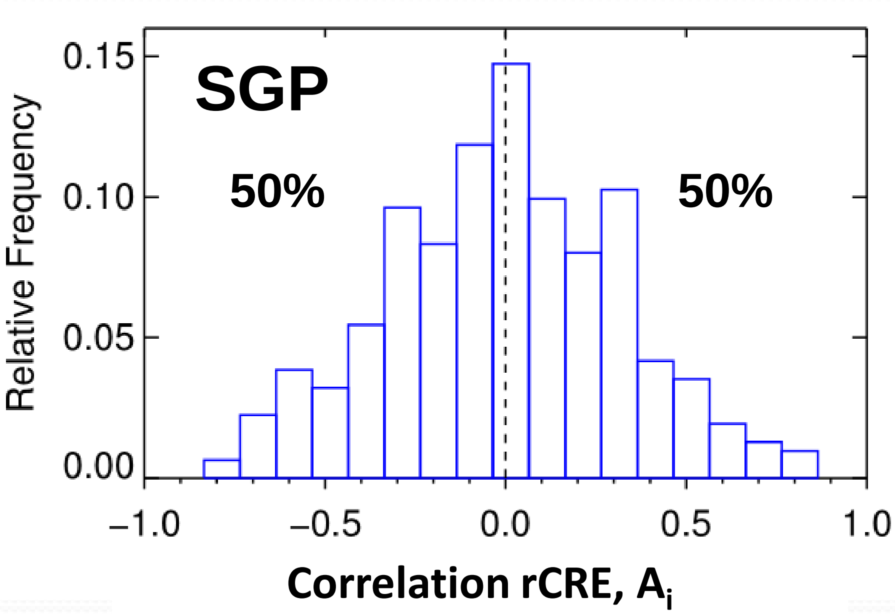


Aerosol vs. LWP signals on rCRE

Distributions of daily correlations

$\rho_{rCRE,Ai}$



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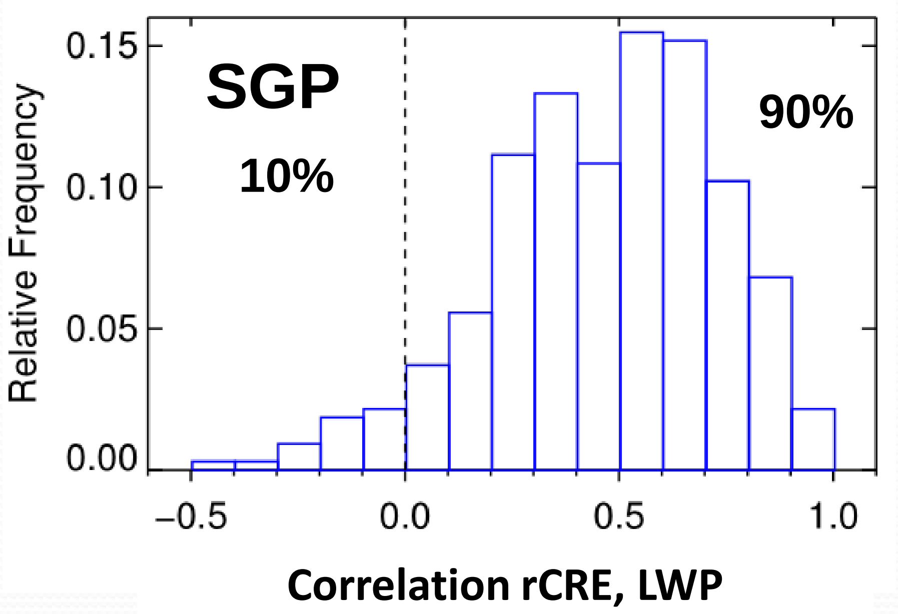

Mean: 0.00 $\pm$ 0.02

Mean: 0.46 $\pm$ 0.02

At least 25 observations per day. N = 323 days

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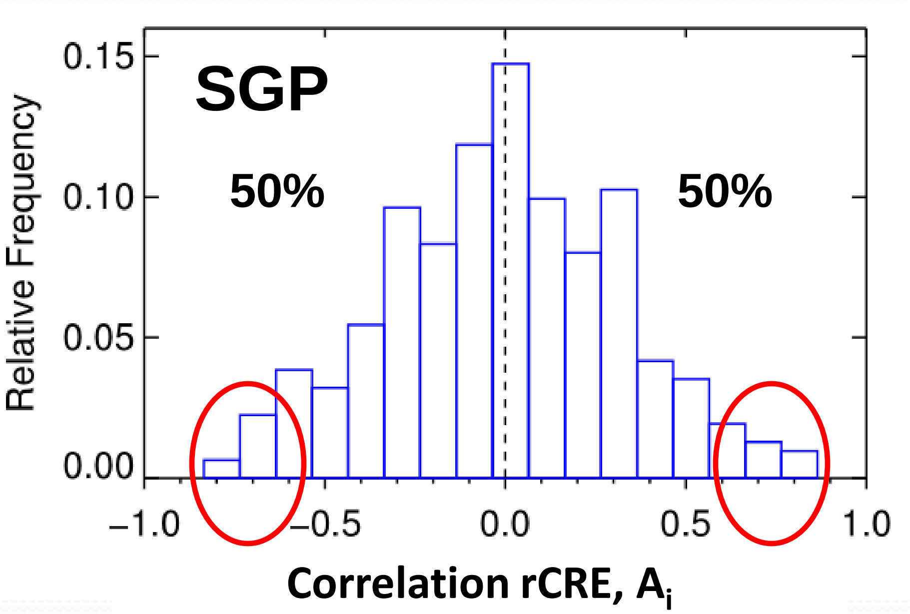

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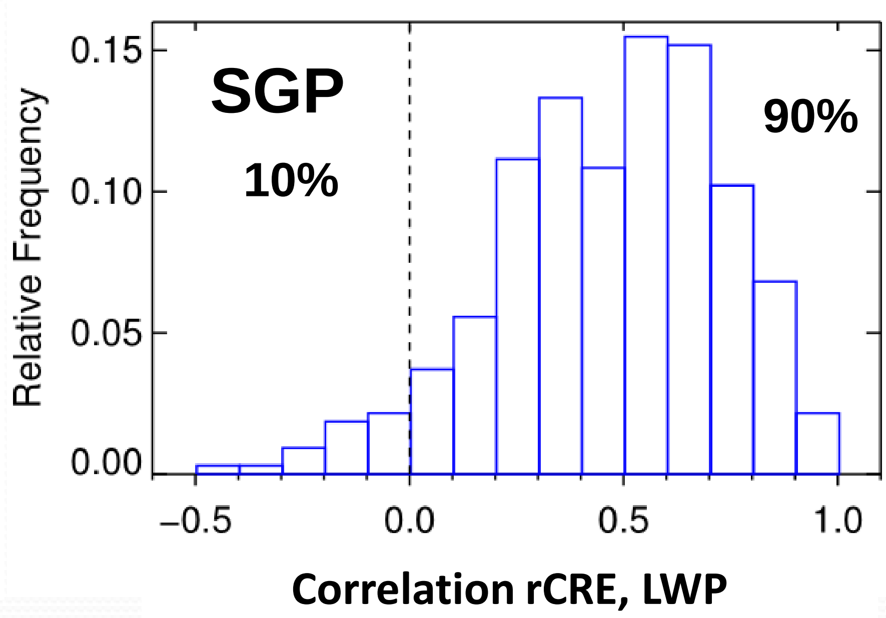

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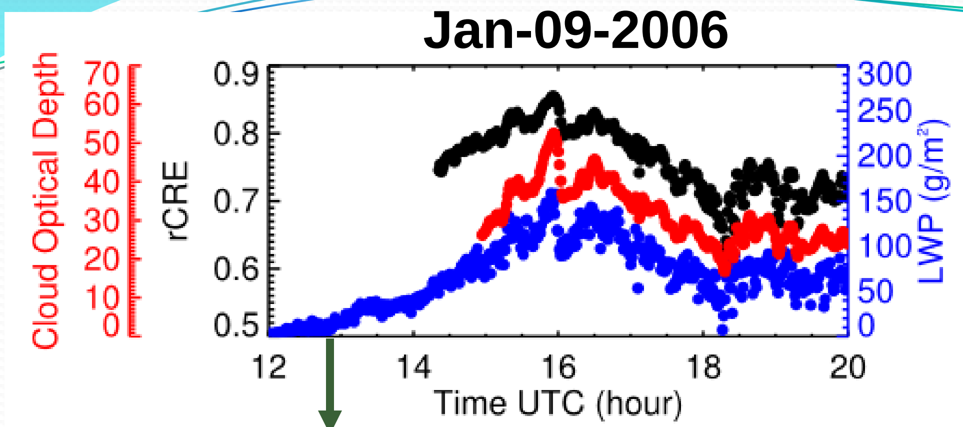
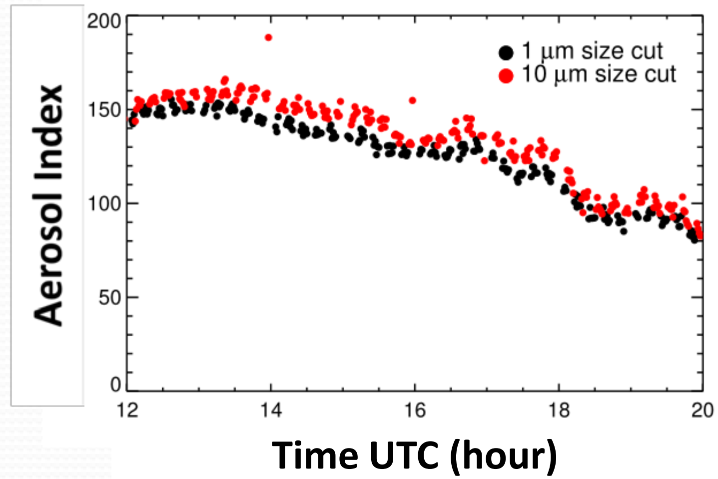
Case study 1: Positive correlation, $\rho_{rCRE,Ai} = 0.75$



Strong positive correlation between rCRE, τ_c and LWP.



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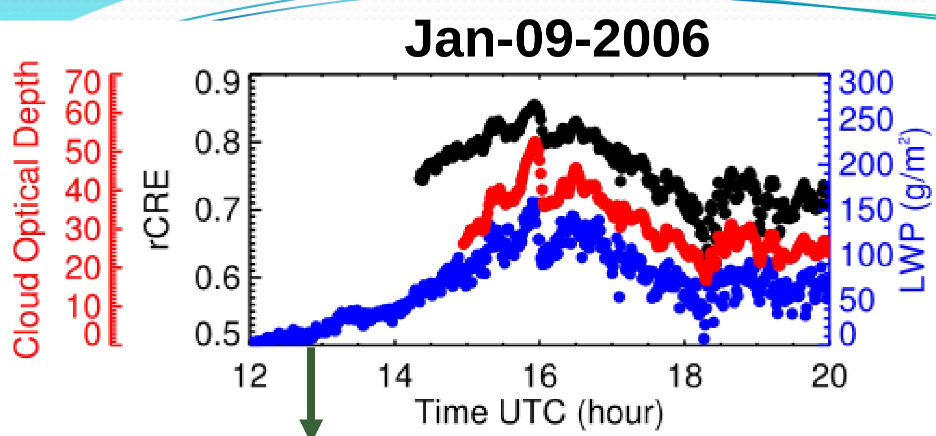

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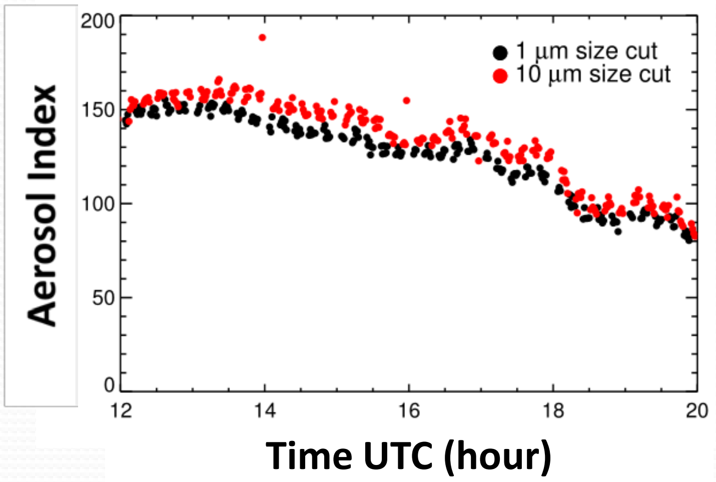

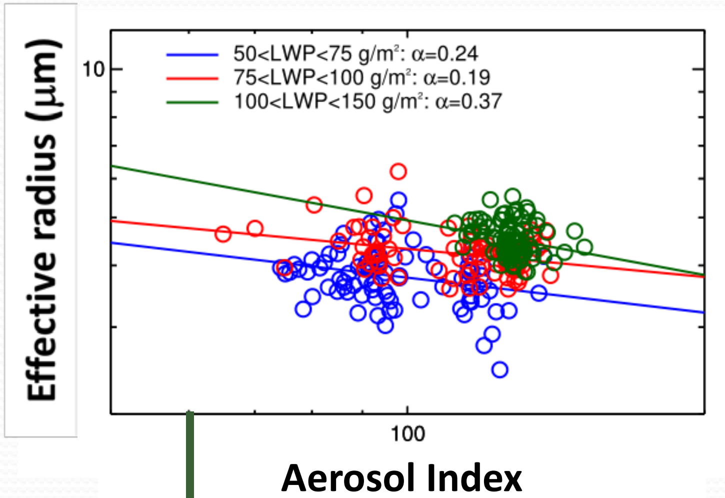

- Negative slopes, as expected.
- Large variance for slopes.

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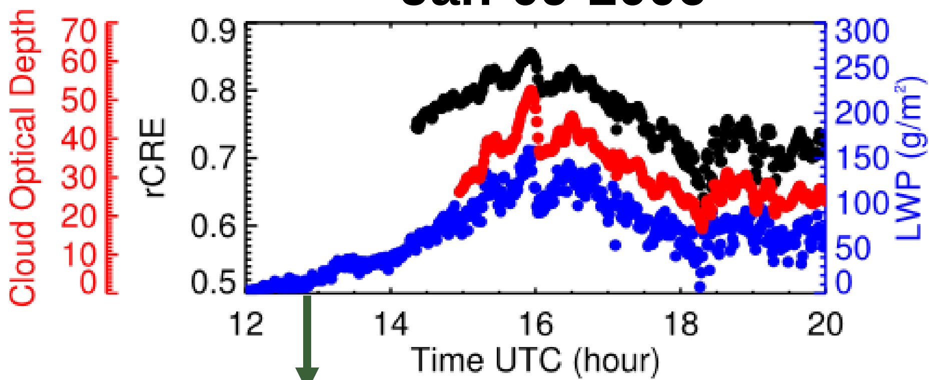
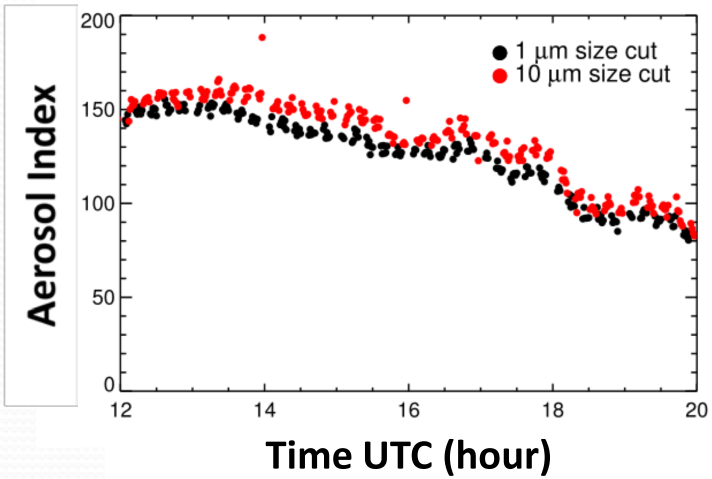
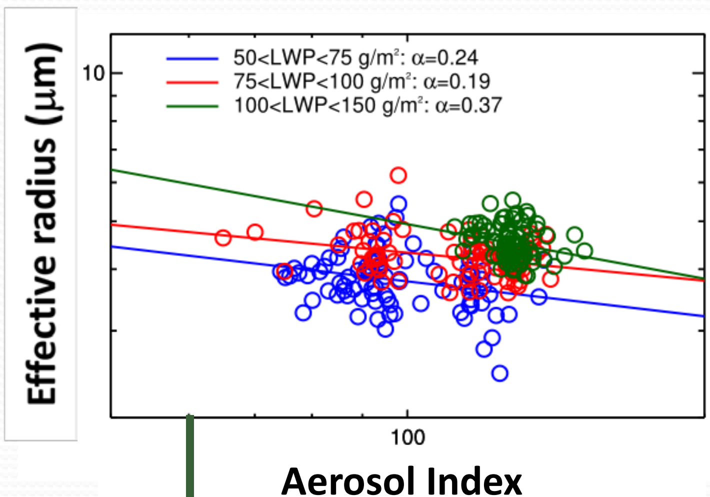
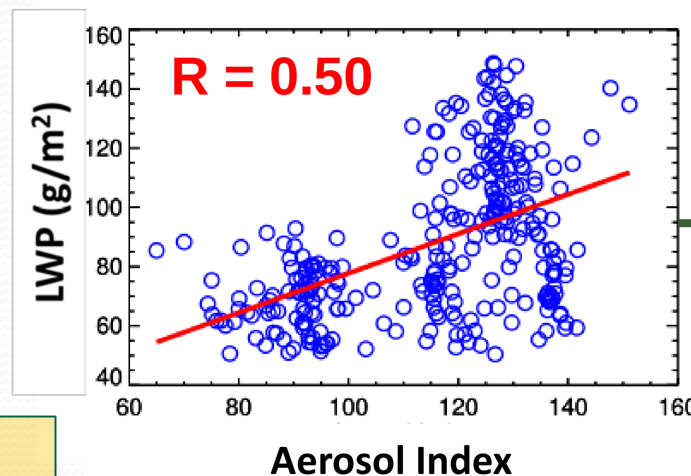




Strong positive correlation between rCRE, τ_c and LWP.

After ~16h UTC: A_i ; LWP

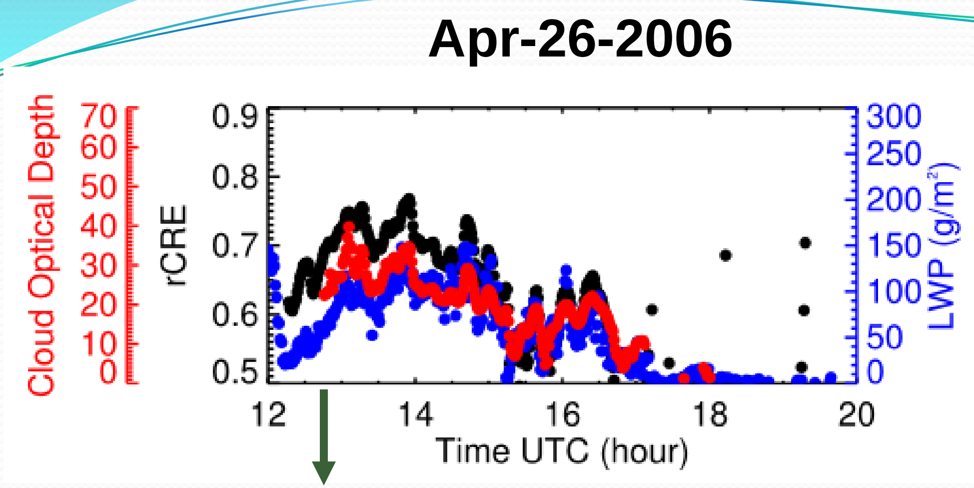


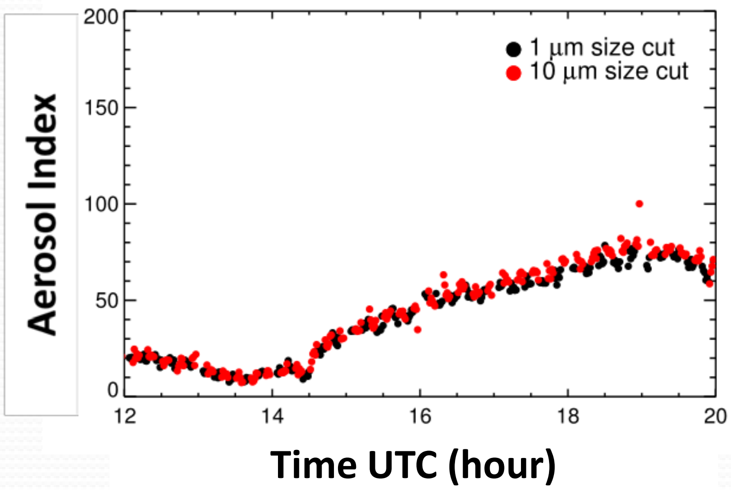


$\rho_{rCRE,Ai}$ +
$\rho_{LWP,Ai}$ +

- Negative slopes, as expected.
- Large variance for slopes.

Case study 2: Negative correlation, $\rho_{rCRE,Ai}$ = -0.65

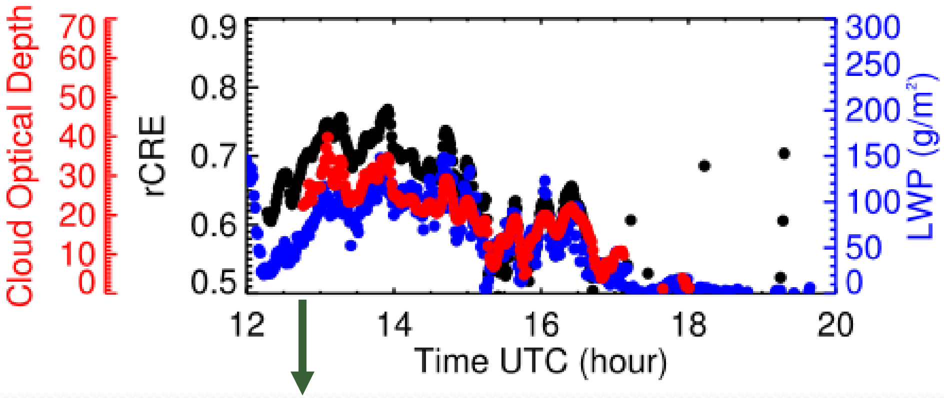


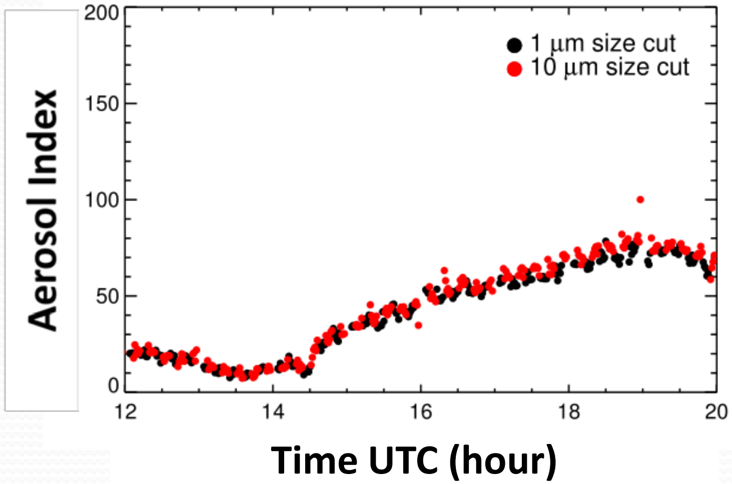


Strong positive correlation between rCRE, τ_c and LWP.

Case study 2: Negative correlation, $\rho_{rCRE,Ai} = -0.65$

Apr-26-2006





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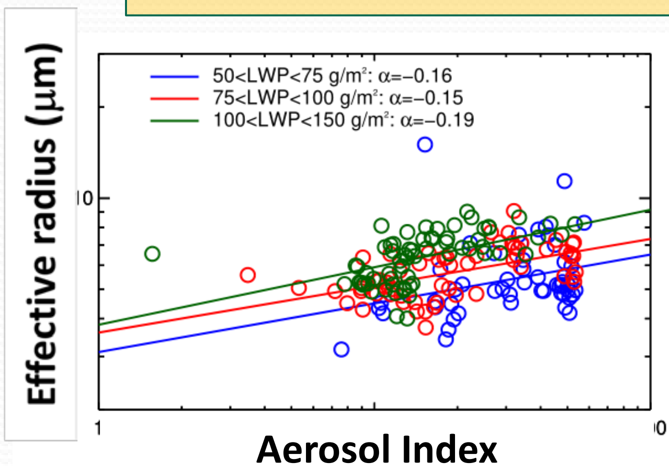
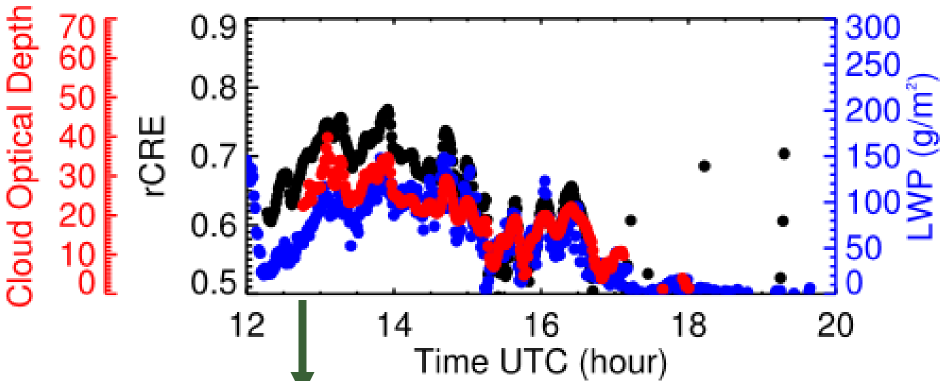
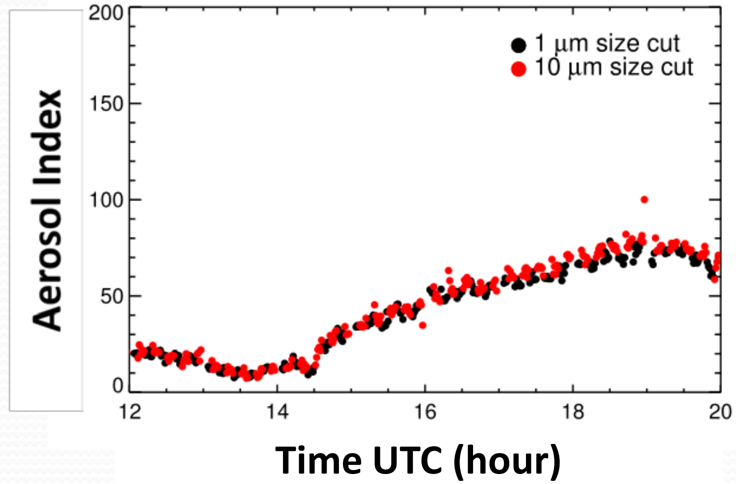


Positive slopes, contrary to expectation.

Case study 2: Negative correlation, $\rho_{rCRE,Ai}$ = -0.65

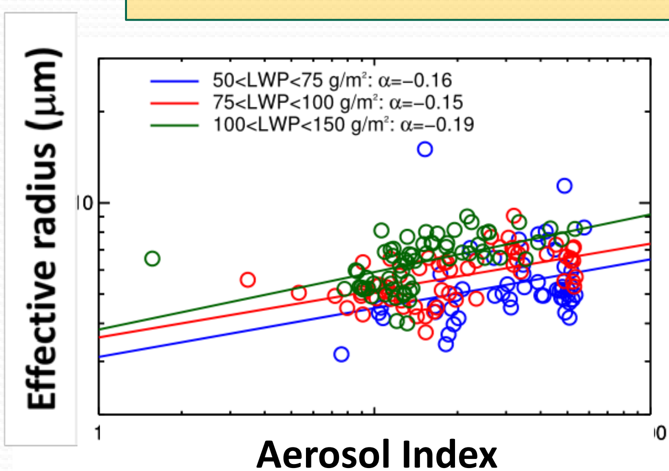
Apr-26-2006

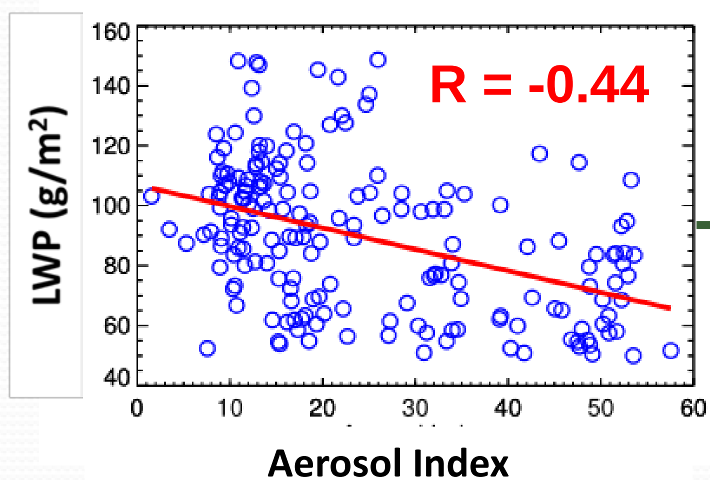




Strong positive correlation between rCRE, τ_c and LWP.

After ~14h UTC: A_i ; LWP





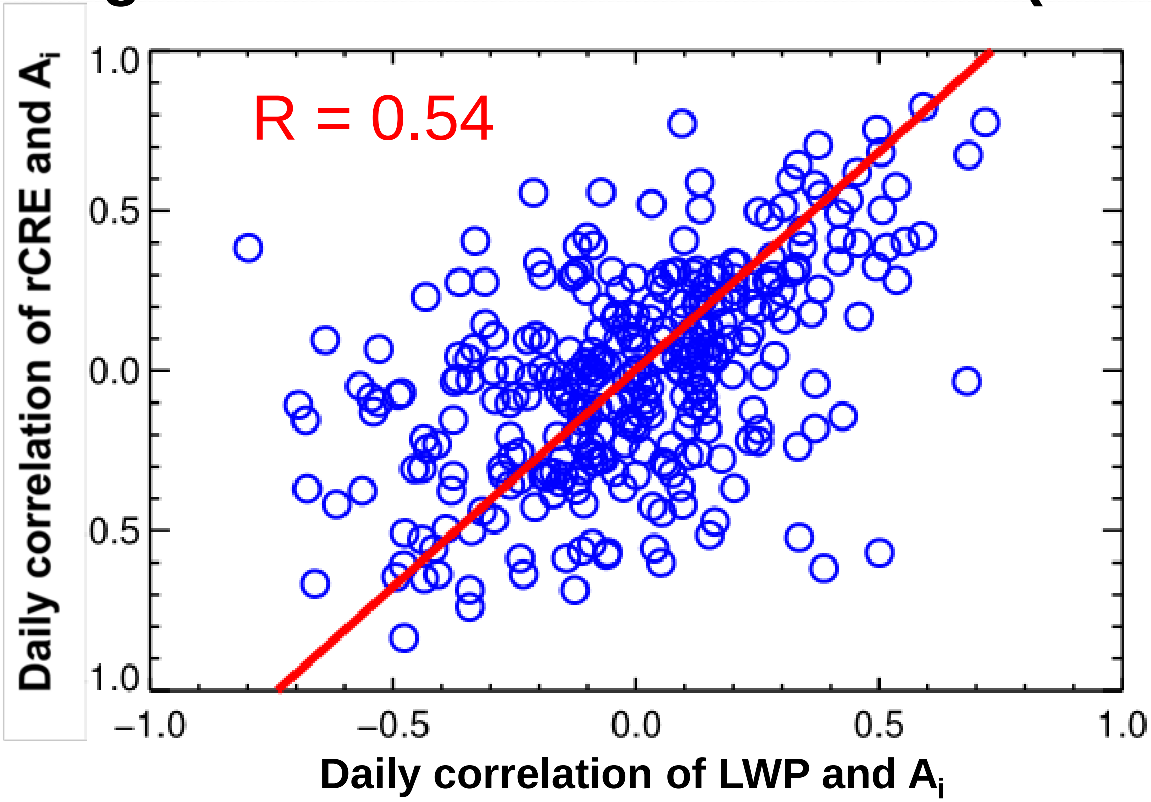
$\rho_{rCRE,Ai}$ -

$\rho_{LWP,Ai}$ -

Positive slopes, contrary to expectation.

Correlation between correlations

Are we actually seeing the LWP signal instead of the aerosol signal in Cloud Radiative Effect (rCRE)?



N = 323 days

Usually, if the aerosol index and LWP are positively correlated, the correlation between rCRE and aerosol index is positive (and vice-versa).

Summary

1) For SGP, the influence of aerosol on cloud RF is weak; macroscopic cloud properties and dynamics play a much larger role in cloud RF compared to microphysical effects.

2) Microphysical metrics to estimate aerosol-cloud interaction are very uncertain.

3) We propose looking at aerosol indirect effects using higher-order properties that more significantly affect RF.

4) We are using the same approach to study sites under different cloud regimes (Amazônia).

Reference:

Sena, E. T., McComiskey, A., and Feingold, G.: A long-term study of aerosol–cloud interactions and their radiative effect at a mid latitude continental site using ground-based measurements, Atmos. Chem. Phys. Discuss., 2016.