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

Elisa Sena¹, Allison McComiskey², Graham Feingold²

(elisats@if.usp.br)

¹ University of São Paulo
² NOAA-ESRL

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Aerosol-cloud interactions

- Aerosol conc., $N_a$
- Cloud Condensation Nuclei conc., CCN
- Drop conc., $N_d$
- Cloud optical depth, $\tau_c$
- Cloud albedo, $A_c$
- Drop effective radius, $r_e$

All else equal (Liquid water path, LWP)

Less reflective clouds (few large drops)

More reflective clouds (many small drops)
Aerosol, macroscopic cloud properties and dynamics are interconnected

LWP Adjustments

Changes in Cloud Microphysics

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**

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

Non-dimensional measure for the surface cloud radiative effect.

**AEROSOL INDEX**

\[ A_i = \sigma_{550\text{nm}\AA} \]

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**

\[ LTS = \theta_{700\text{hPa}} - \theta_{\text{surface}} \]

Related to the strength of the capping inversion. \( \theta \) is the potential temperature.
Previous approaches vs. New approach

Microphysical responses vs. SW Radiative responses

Unperturbed Cloud (constant LWP)

\[ ACI = -\frac{\partial \ln r_e}{\partial \ln A_i} \bigg|_{LWP} \]

McComiskey et al., 2009

\[ ACI_r = 0.11, 0.10, 0.14 \]

Cloud Radiative Effect (rCRE)

Liquid water path (g/m²)
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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2 cloud regimes:
- Low $f_c$; High $w'^2$
- High $f_c$; Low $w'^2$
Aerosol vs. LWP signals on rCRE

Distributions of daily correlations

ρ_{rCRE,A_i}  

SGP  

50%  

Mean: 0.00 ± 0.02

Correlation rCRE, A_i

ρ_{rCRE,LWP}  

SGP  

10%  

90%  

Mean: 0.46 ± 0.02

Correlation rCRE, LWP

At least 25 observations per day. N = 323 days
Aerosol vs. LWP signals on rCRE

Distributions of daily correlations

$\rho_{rCRE,Ai}$

- SGP
  - 50%
  - 50%

$\rho_{rCRE,LWP}$

- SGP
  - 10%
  - 90%

Mean: $0.00 \pm 0.02$

Mean: $0.46 \pm 0.02$

At least 25 observations per day. N = 323 days
Case study 1: Positive correlation, $\rho_{\text{rCRE, Ai}} = 0.75$

Strong positive correlation between rCRE, $\tau_c$ and LWP.
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- Negative slopes, as expected.
- Large variance for slopes.
Case study 1: Positive correlation, $\rho_{rCRE,Ai} = 0.75$

Strong positive correlation between $rCRE$, $\tau_c$ and LWP.

After ~16h UTC: $A_i$; LWP

- Negative slopes, as expected.
- Large variance for slopes.
Case study 2: Negative correlation, $\rho_{rCRE, Ai} = -0.65$

Strong positive correlation between rCRE, $\tau_c$ and LWP.

Apr-26-2006

Aerosol Index

Time UTC (hour)
Case study 2: Negative correlation, \( \rho_{rCRE,Ai} = -0.65 \)

Strong positive correlation between \( rCRE, \tau_c \) and LWP.

Positive slopes, contrary to expectation.
Case study 2: Negative correlation, $\rho_{r\text{CRE},Ai} = -0.65$

Strong positive correlation between $r\text{CRE}$, $\tau_c$ and LWP.

After ~14h UTC: $A_i \uparrow$; LWP $\downarrow$

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)?

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

R = 0.54

N = 323 days
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: