A long-term study of aerosol-cloud interactions at a mid-latitude and a tropical continental site

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Aerosol-cloud interactions

\[ \tau_c = c(T, p) N_d^3 LWP^{5/6} \]

(Twomey, 1974)
But...
Motivation

Changes in Cloud Microphysics  

Cloud Albedo Change

Goal

Clarify how aerosol and meteorological properties impact the cloud radiative forcing, using ground-based observations.
Previous approaches

Microphysical responses

\[ \alpha = - \frac{\partial \ln n_r}{\partial \ln A_i}\bigg|_{LWP} \]

\[ 0 < ACI < 0.33 \]

CCN

McComiskey et al., 2009

ACI (\(\alpha\)):
Proposed approach

Radiation responses

Cloud Radiative Forcing

Aerosol

LWP

Cloud fraction
Methodology

- Coincident ground-based measurements of clouds, aerosol and meteorological properties from ARM deployments were used.
- Ice crystals and precipitation were avoided by selecting only low non-drizzling clouds.
- The measurements were taken at 1-minute resolution.
# Measurements and retrievals

<table>
<thead>
<tr>
<th>Measurement / Retrieval</th>
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<tr>
<td>Column Maximum Reflectivity ( Z_{\text{max}} )</td>
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<td>Cloud base height ( h_{\text{CB}} )</td>
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<td>Cloud top height ( h_{\text{CT}} )</td>
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<td>Doppler vertical velocity at ( h_{\text{CB}} ) ( w )</td>
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<td>Liquid water path ( \text{LWP} )</td>
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<td>Relative cloud radiative forcing ( \text{rCRF} )</td>
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<td>Cloud optical depth ( \tau_c )</td>
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<td>Cloud fraction ( f_c )</td>
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<td>Cloud albedo ( A_c )</td>
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<td>Scattering at 550 nm ( \sigma_{550\text{nm}} )</td>
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<td>Ångström exponent ( \AA )</td>
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<td>Lifting condensation level ( \text{LCL} )</td>
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<td>Lower tropospheric stability ( \text{LTS} )</td>
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Properties analyzed

**RELATIVE CLOUD RADIATIVE EFFECT**

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

Non-dimensional measure for the surface cloud radiative effect.

**PROXY FOR TURBULENCE**

\[ \frac{w'}{2} = [w - w_0]^2 \]

\( w_0 \) is the mean vertical velocity at the cloud base within 1 hour from each measurement.

**AEROSOL INDEX**

\[ A_i = \sigma_{550nm\text{Å}} \]

Proxy for CCN.

**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. \( \theta_j \) is the potential temperature at level \( j \).
How do different properties influence the rCRE?

Southern Great Plains (SGP)

rCRE x LWP

At Fixed LWP:
Weak trends with $A_i$ in both directions.

2 cloud regimes:
- Low $f_c$; High $w'^2$
- High $f_c$; Low $w'^2$

$\rho_{fc,Di} = 0.72$

$\rho_{fc,LTS} = 0.55$
Aerosol x LWP signals on rCRE

\[ \rho_{rCRE,Ai} \]

**SGP**
- 50% frequency
- 50% frequency

**MAO**
- 10% frequency
- 90% frequency

\[ \rho_{rCRE,LWP} \]
Case study 1: $\rho_{r\text{CRE}, \text{Ai}}$ Positive

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

After about 16h UTC:

$A_i$ ; LWP

More coupling in the afternoon.
Case study 1: $\rho_{rCRE,Ai}$ Positive

Jan-09-2006

**EFFECTIVE RADIUS**

$$r_e = 1.5 \frac{LWP}{\tau_c}$$

**ACI ($\alpha$):**

$$\alpha = - \frac{\partial \ln r_e}{\partial \ln A_i} \bigg|_{LWP}$$

- $\alpha$ positive, as expected.
- Large variance for $\alpha$. 

$\rho_{rCRE,Ai} +; \rho_{LWP,Ai} +$
Case study 2: $\rho_{rCRE, Ai}$ Negative

After about 14h UTC:

$A_i \uparrow$; LWP $\downarrow$

More coupling in the afternoon.

Strong positive correlation between rCRE, $\tau_c$ and LWP.
Case study 2: $\rho_{\text{CRE,}A_i}$ Negative

**Apr-26-2006**

- Top left: $R = -0.65$
- Top right: $R = 0.64$
- Bottom left: $R = -0.44$

**EFFECTIVE RADIUS**

- $r_e = 1.5 \frac{LWP}{\tau_c}$

**ACI ($\alpha$):**

$$\alpha = - \frac{\partial \ln r_e}{\partial \ln A_i} \bigg|_{LWP}$$

- $\alpha$ negative, contrary to expectation.
Usually, if the aerosol index and LWP are correlated positively (negatively), the correlation between rCRF and aerosol index is positive (negative).
Summary

1) The influence of aerosol on cloud radiative forcing 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 like rCRE, LWP, fc, Cloud albedo.
Thank you!

Obrigada!