Towards Constraining the Aerosol-Cloud Radiative Effect

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Key Questions:

- Can top-down approaches to quantifying aerosol-cloud radiative effect be used in concurrence with bottom-up ACI metrics to constrain aerosol-cloud radiative forcing?
- How does the relative Cloud Radiative Effect-Albedo-Cloud fraction (rCRE-*A*-f_c) relationship vary under different meteorological conditions and aerosol concentrations?
- What controls the rCRE-*A*-f_c relationship?
- Do rCRE-*A*-f_c relationships vary as a function of resolution or scale?

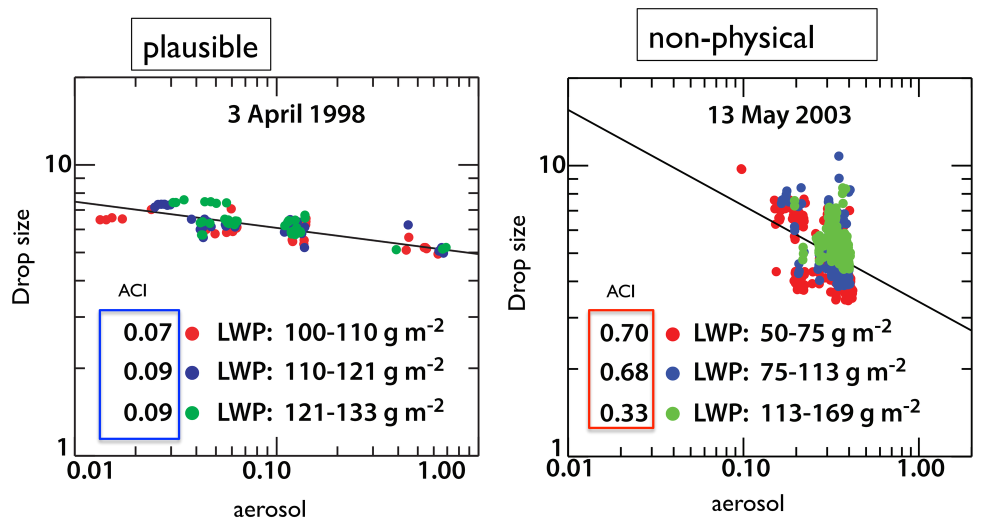
Key Results:

- rCRE-*A*-f_c relationships are remarkably robust;
- Co-variability of meteorology and aerosol influences detectability of aerosol effects on cloud and shape of A, f_c relationship!
- Strong case for routine LES accompanying routine observations (LASSO) for understanding interconnected aerosol and meteorological processes and their influence on rCRE.

1. Approaches to quantifying ACI in cloud systems

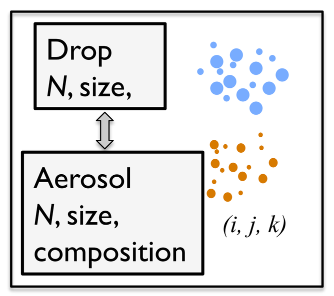
The Bottom-up Approach:

Quantify cloud microphysical responses to aerosol perturbations



$$ACI = -\left.\frac{\partial r_e}{\partial N_a}\right|_L$$

$$0 < ACI < 0.33$$



Albedo — Emissions

$$\Delta R = R\frac{\Delta\ln R}{\Delta\ln\tau}\frac{\Delta\ln\tau}{\Delta\ln N_d}\frac{\Delta\ln N_d}{\Delta\ln CCN}\frac{\Delta\ln CCN}{\Delta\ln E}\Delta\ln E$$

Ghan et al. (PNAS 2016)

$$\frac{d\ln\tau}{d\ln N_d} = \frac{1}{3}\left[1 + 2\frac{d\ln L}{d\ln N_d} + \frac{d\ln k}{d\ln N_d} + 3\frac{d\ln H}{d\ln N_d}\right]$$

$$\frac{d(\ln L)}{d(\ln N_d)} =$$

$$\frac{d(\ln k)}{d(\ln N_d)} =$$

etc..

Caution!! Uncertainties compound

Quantifying these terms is a challenge

- Measurement errors, scale dependence, etc.
- *Experience shows that ACI metrics do not constrain the aerosol-cloud radiative effect*

The Top-down Approach:

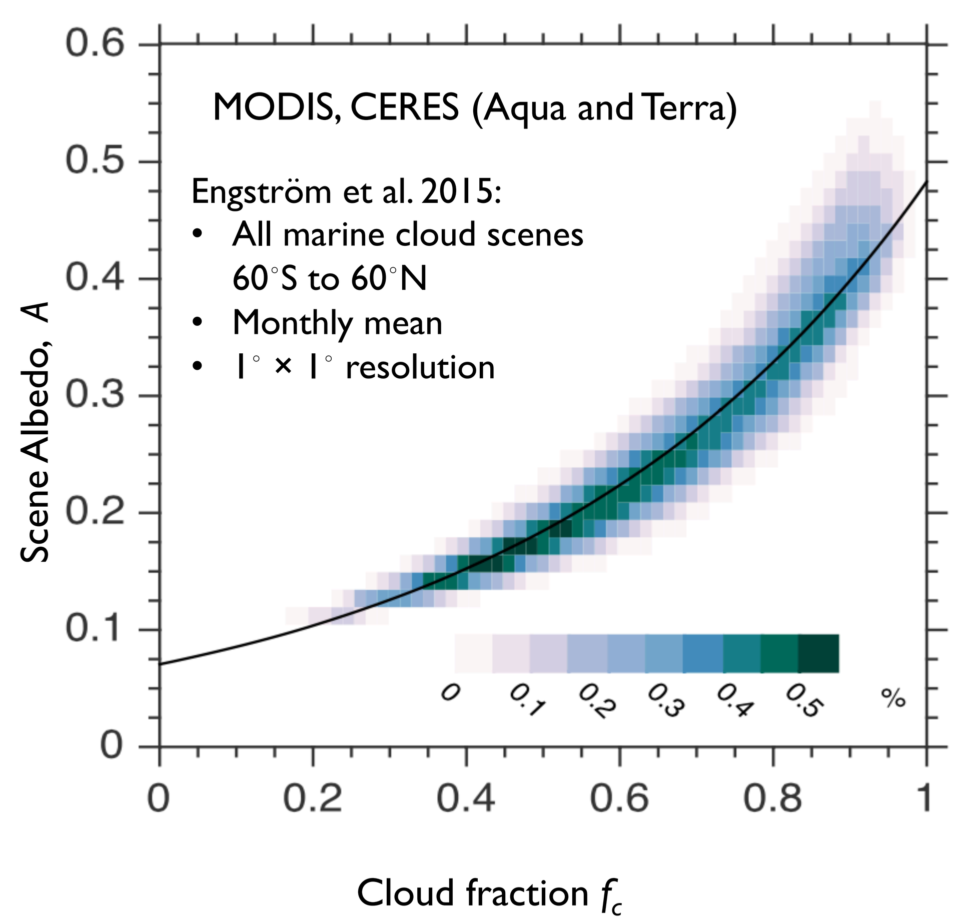
Quantify Radiative and cloud macroscale properties

$$A = A_c f_c + A_s(1 - f_c)$$

Cloud field Properties:
Cloud fraction, f_c
Liquid water path, *L*
Optical depth, τ
Cloud albedo, A_c
Cloud depth, *H*
Relative cloud radiative forcing, rCRE

$$rCRE = 1 - \frac{F_{sw,all}}{F_{sw,clr}}$$

F_{sw} = downwelling shortwave flux



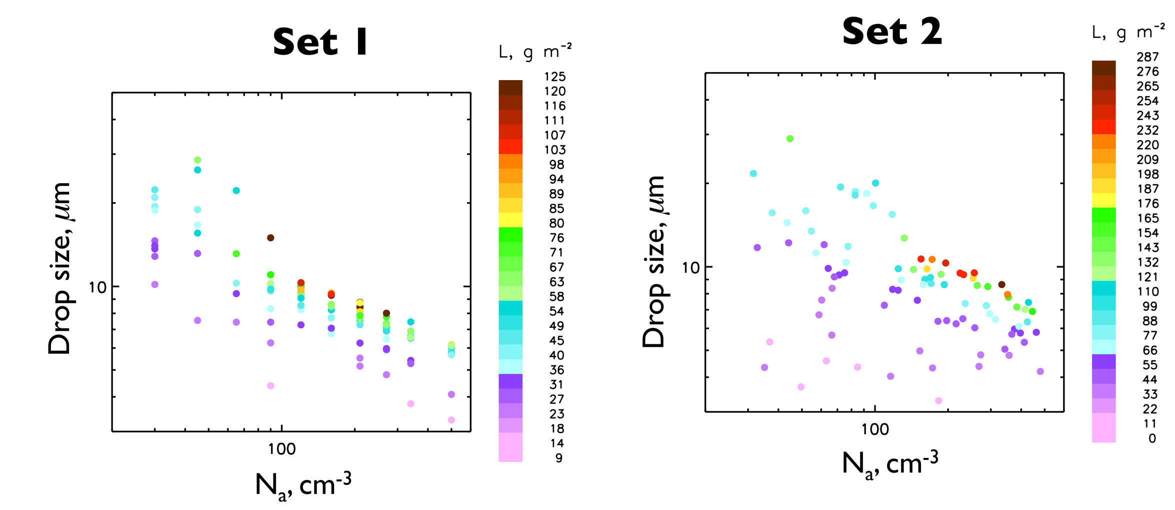
2. The importance of co-variability between meteorology and aerosol

Example from LES: Two sets of simulations (~100) *differing only in co-variability of initial meteorology and aerosol conditions*

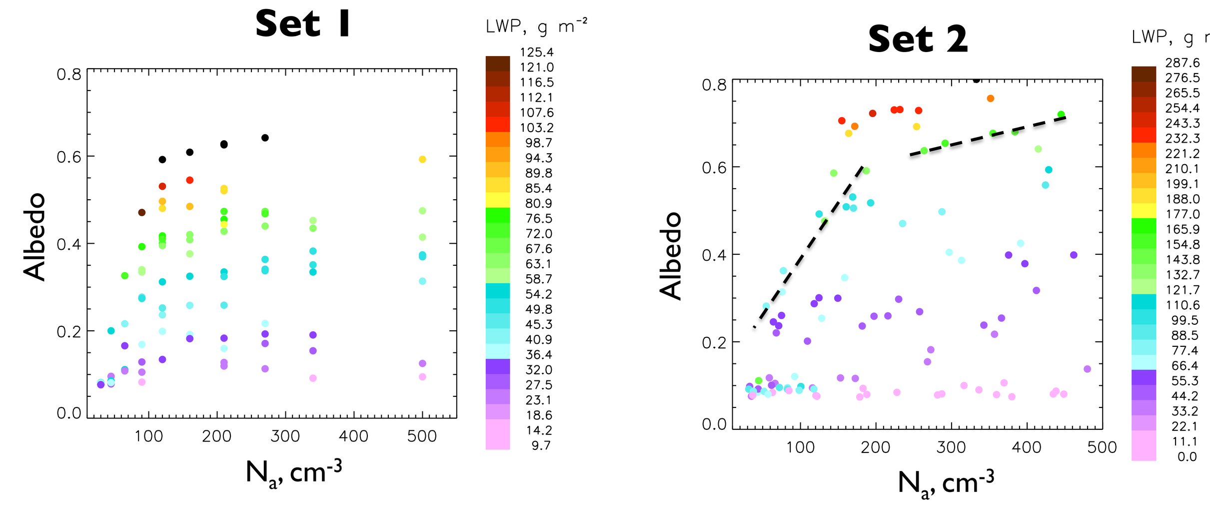
Set 1: regular grid spacings in 6-D parameter space; many runs vary N for fixed met conditions

Set 2: Latin Hypercube Sampling of 6-D parameter space; maximizes minimum distance between parameters for optimal coverage

Bottom-up Approach



As expected, higher N → smaller drops at constant L

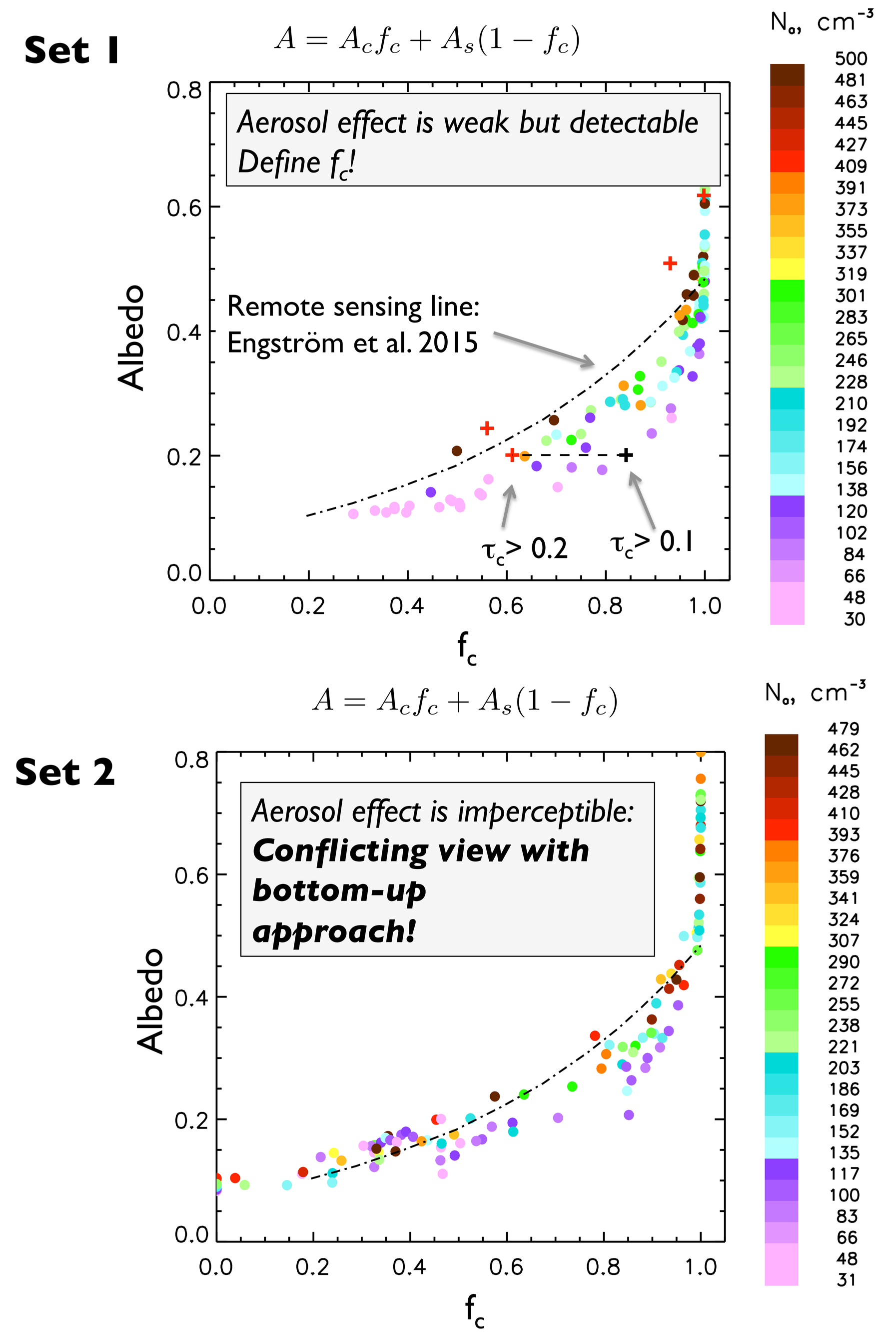


Both sets show the expected Albedo Susceptibility response
Higher susceptibility at smaller N

Feingold, McComiskey, Yamaguchi et al. PNAS, 2016

$$S_a = \frac{\partial A}{\partial N_d} = \frac{A(1-A)}{3N_d}$$

Top-Down Approach

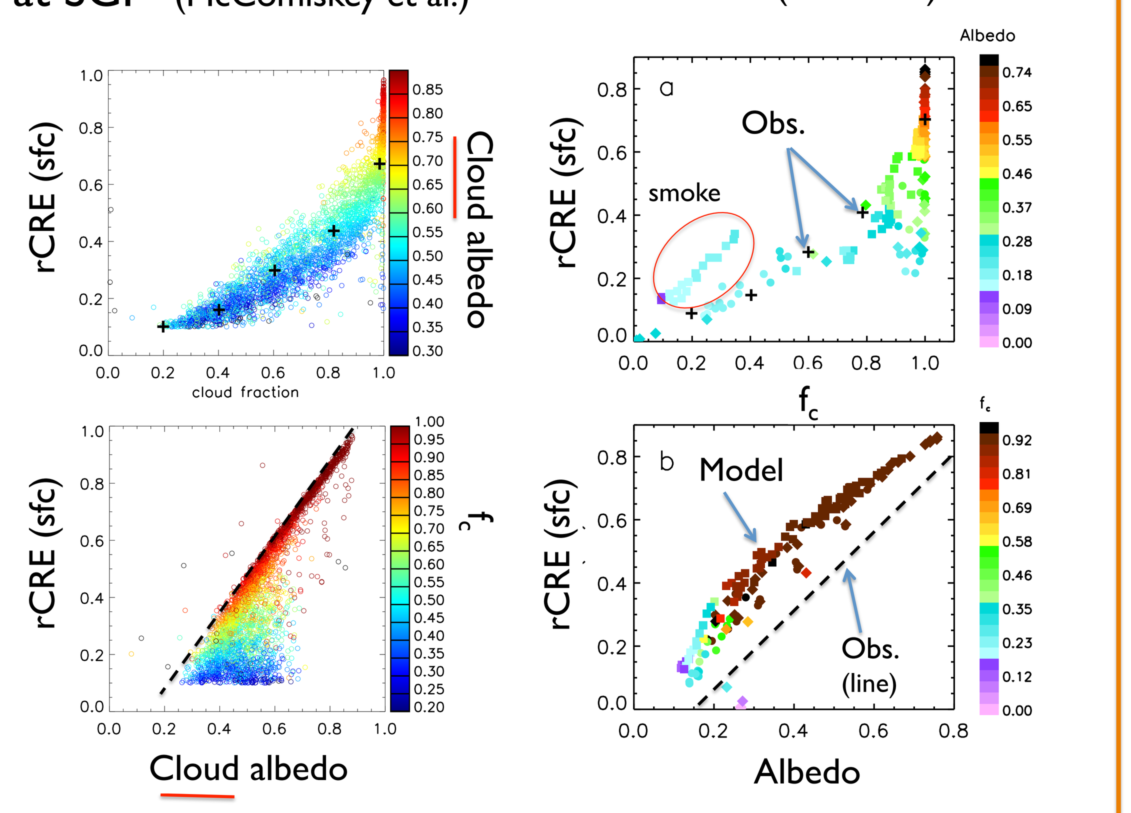


- *Co-variability of inputs influences detectability of aerosol effects; Strong Case for Routine LES accompanying Routine Observations (LASSO)*
- *Understand what controls shape of rCRE-A-f_c relationship!*
- *Carefully define f_c!*

Top-Down Approach: Observations (SGP) vs. Modeling (Ocean)

Observations:
14 years of warm clouds at SGP (McComiskey et al.)

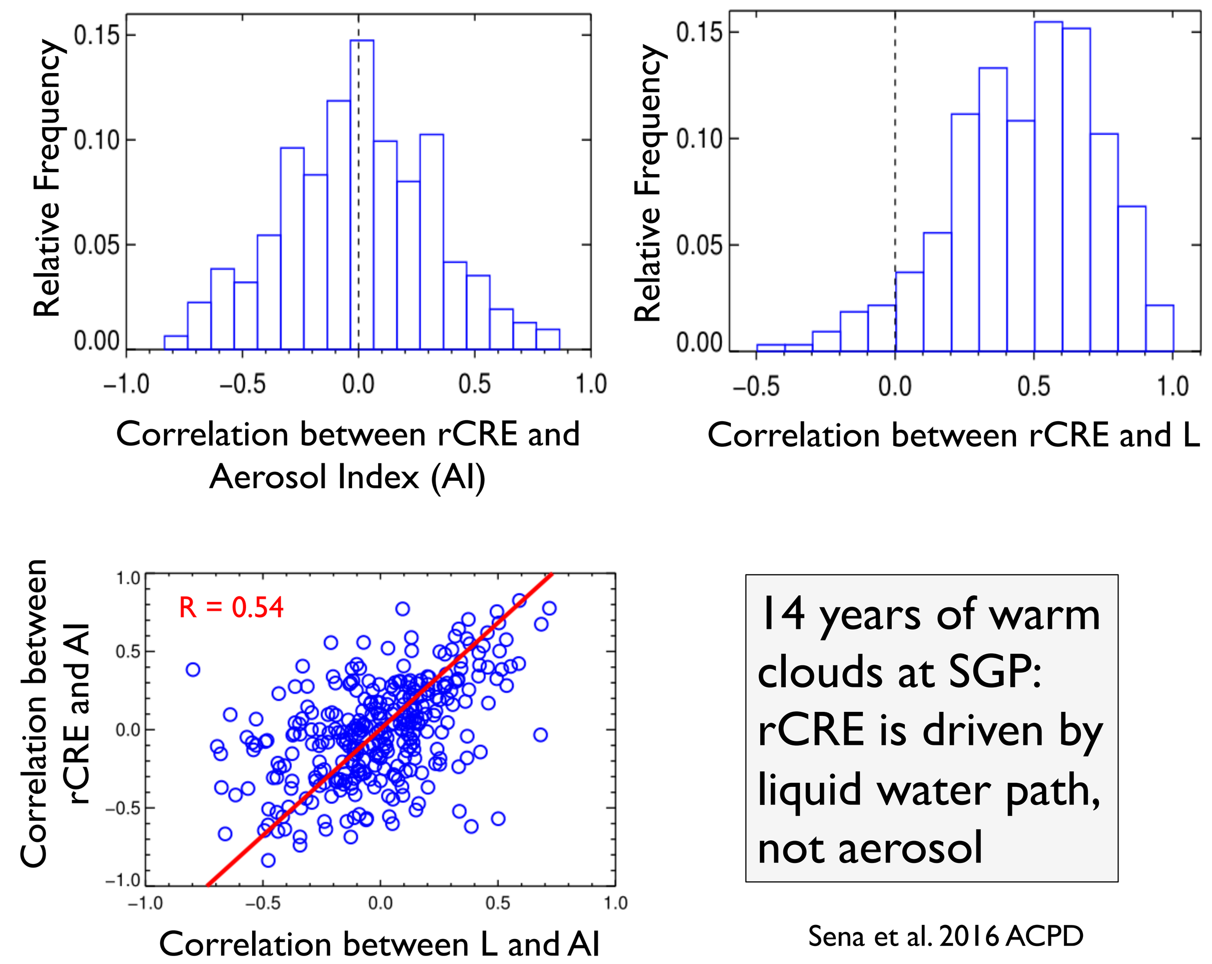
LES/CRM Modeling
Ocean: SCu (closed→ open)
SCu→ Cu (+ smoke)



$$rCRE = 1 - \frac{F_{sw,all}}{F_{sw,clr}}$$

Feingold, McComiskey, Yamaguchi et al. PNAS, 2016

Top-Down Approach: Observations at SGP



14 years of warm clouds at SGP: rCRE is driven by liquid water path, not aerosol

Sena et al. 2016 ACPD