Quantifying Aerosol Influences on the Cloud Radiative Effect

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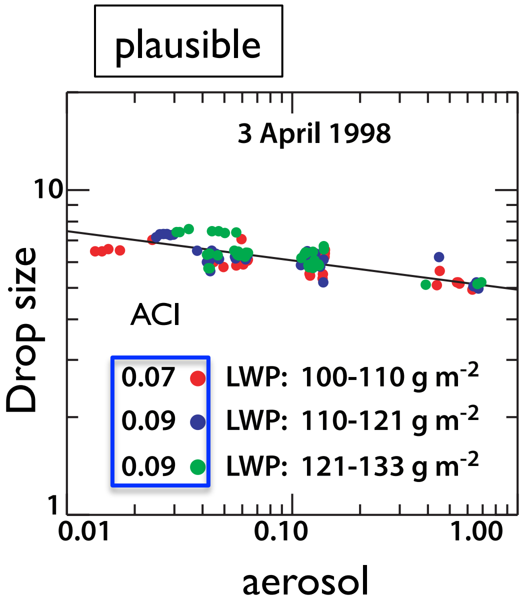
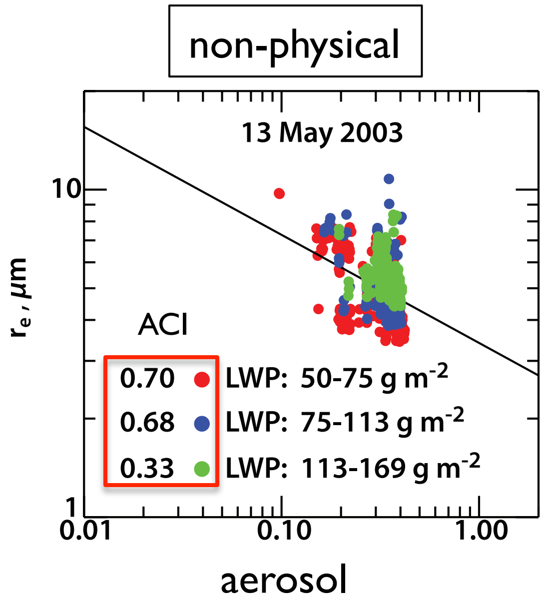
ASR, May 2016

Goal

Observational constraints on the Cloud Radiative Effect (CRE) / Aerosol Indirect Effect (AIE)

Approaches to quantifying Aerosol-Cloud Interactions (ACI)





Quantifying these terms is a challenge

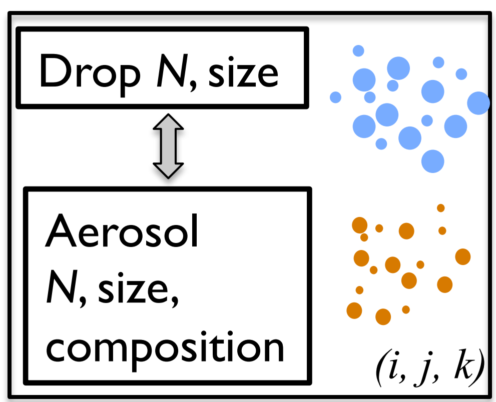
- Measurement errors, scale dependence, etc.

Small differences in ACI magnify to very large differences in CRE

→ *measurements of microphysical ACI metrics do not constrain the CRE!*

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

$$0 < \mathrm{ACI} < 0.33$$

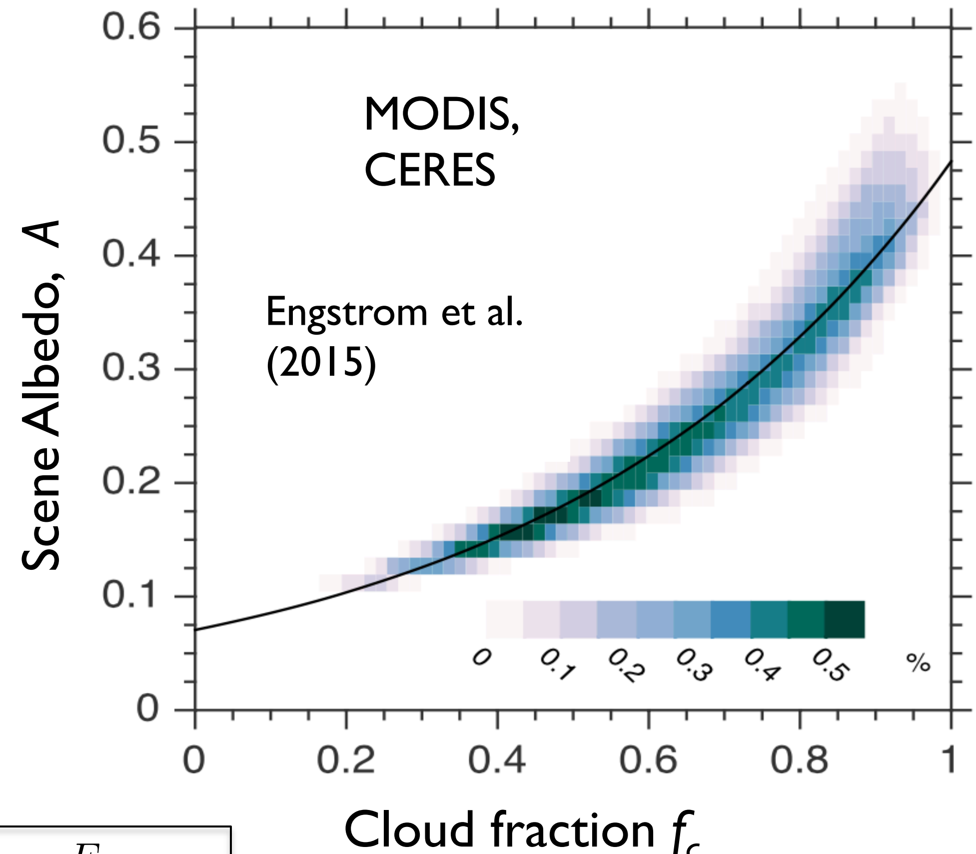


Bottom-up

Approaches to quantifying Aerosol-Cloud Interactions (ACI)

Top-down

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



Cloud field Properties

Cloud fraction, f_c

Liquid water path, L

Optical depth, τ

Cloud albedo, A_c

Cloud depth, H

$A_c = f(L, N)$

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

rCRE= relative cloud radiative effect

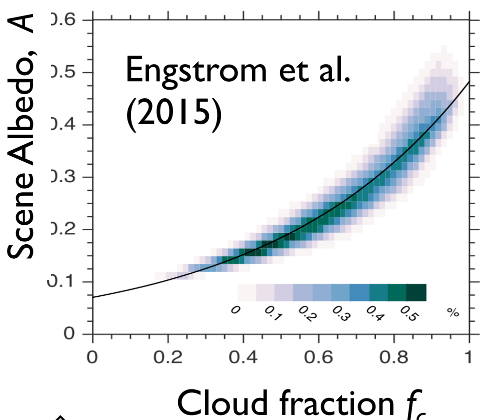
F_{sw} = downwelling shortwave flux

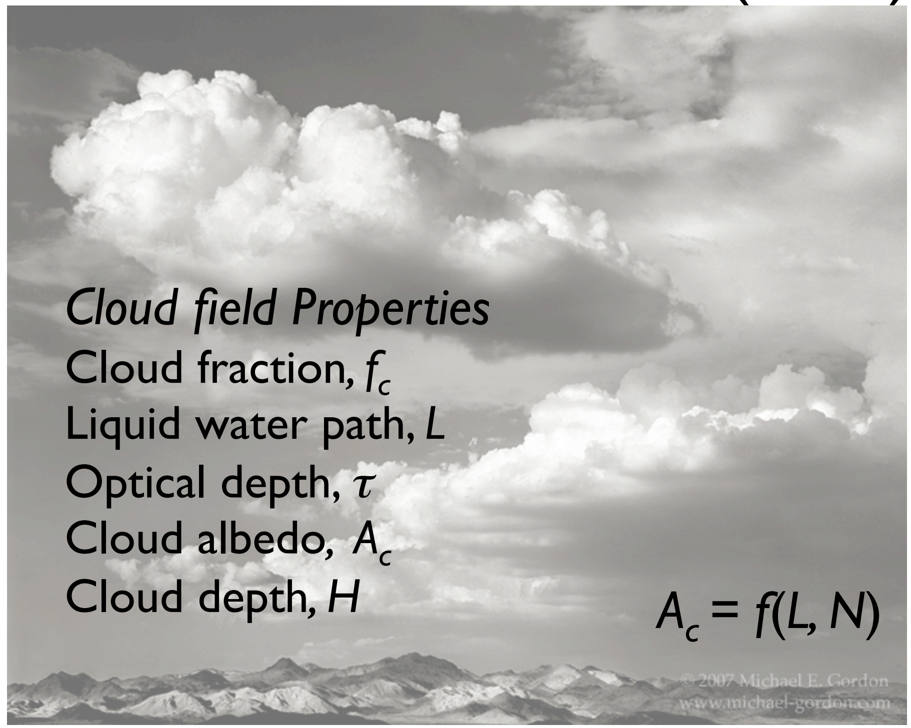
Approaches to quantifying Aerosol-Cloud Interactions (ACI)

Top-down

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

MODIS, CERES





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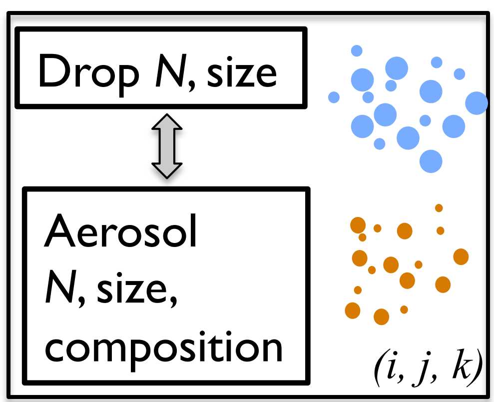


Bottom-up

Approaches to quantifying ACI in cloud systems

Albedo **Emissions**

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

Ghan et al. (PNAS 2016)

$$\frac{dln\tau}{dlnN_d} = \frac{1}{3}\left[1 + 2\frac{dlnL}{dlnN_d} + \frac{dlnk}{dlnN_d} + 3\frac{dlnH}{dlnN_d}\right]$$

Ackerman et al. (2000)

$$\frac{d(lnL)}{d(lnN_d)} =$$

Chen et al. (2014)
Goren and Rosenfeld (2014)

$$\frac{d(lnk)}{d(lnN_d)} =$$

Feingold et al. (1997)
Liu and Daum (2000)

etc..

Caution!!
Uncertainties compound

Demonstration of Difference Between Approaches

Example from LES

Two sets of simulations (~100 each)

differing only in co-variability of initial meteorology and aerosol conditions:

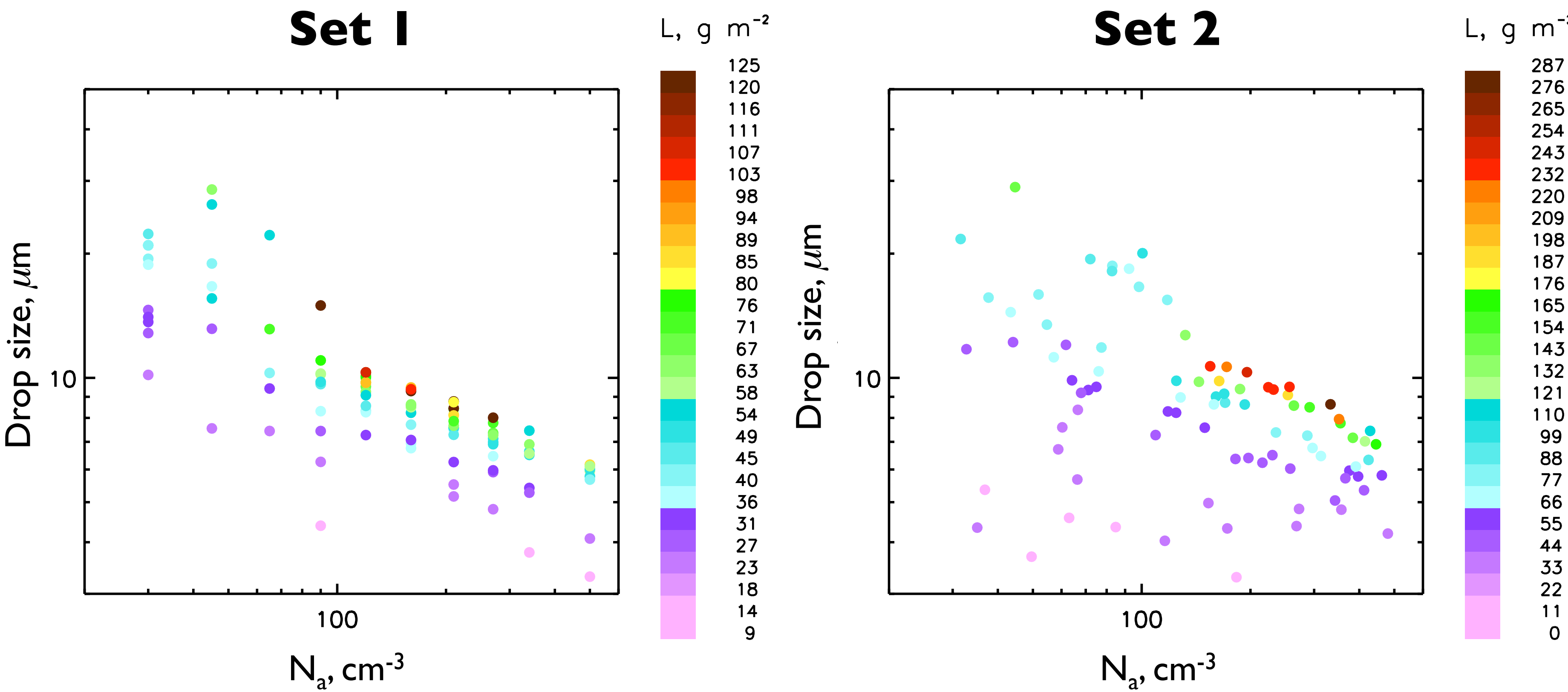
Set 1: regular grid spacings in 6-D parameter space; many runs vary N for fixed met conditions

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

Neither is realistic but differences will be illuminating

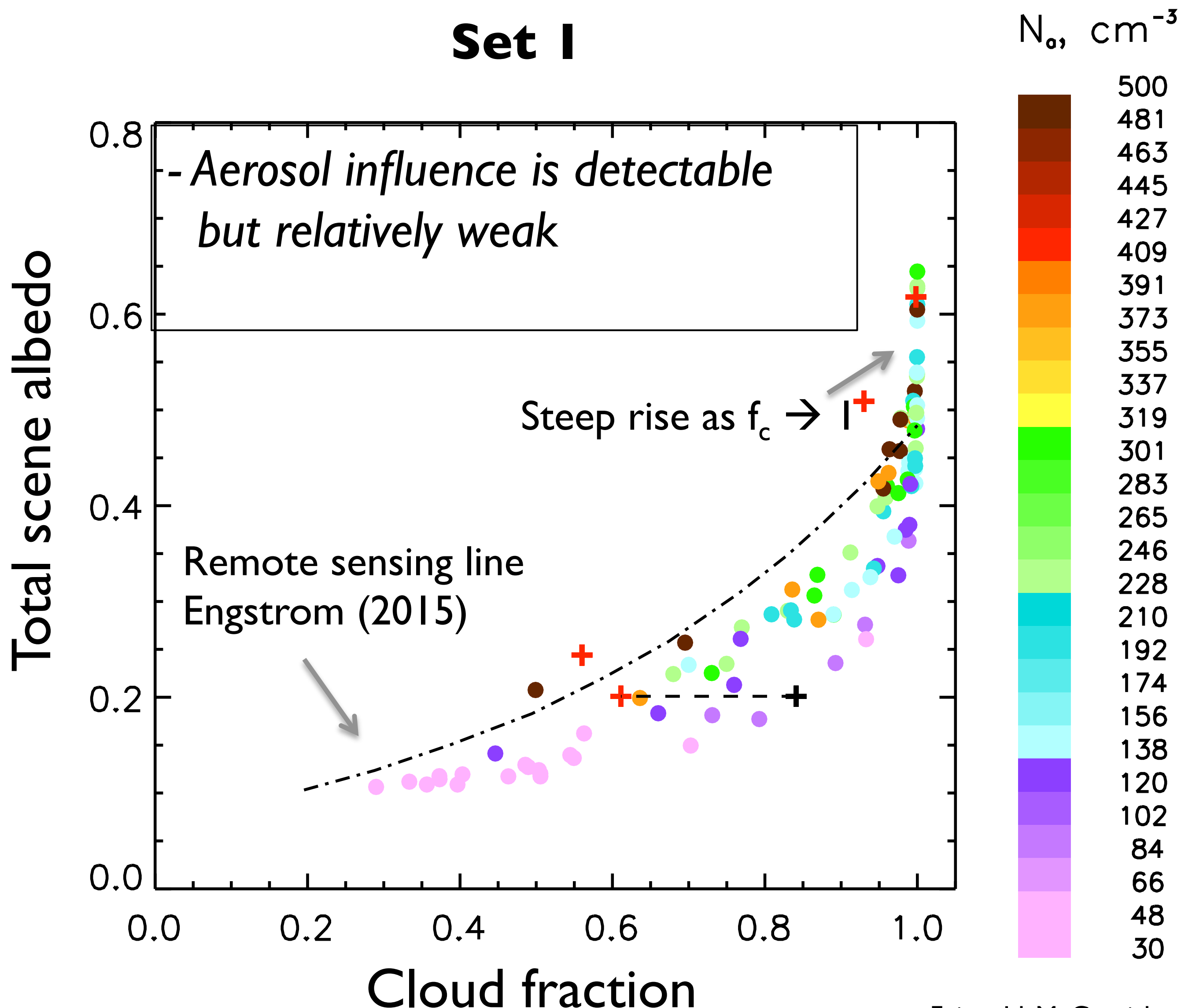
Microphysical Response (bottom-up)

Both Sets show expected reduction in r_e with increasing N_a



Albedo-f_c Response (top-down)

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



Feingold, McComiskey, Yamaguchi et al., 2016 PNAS

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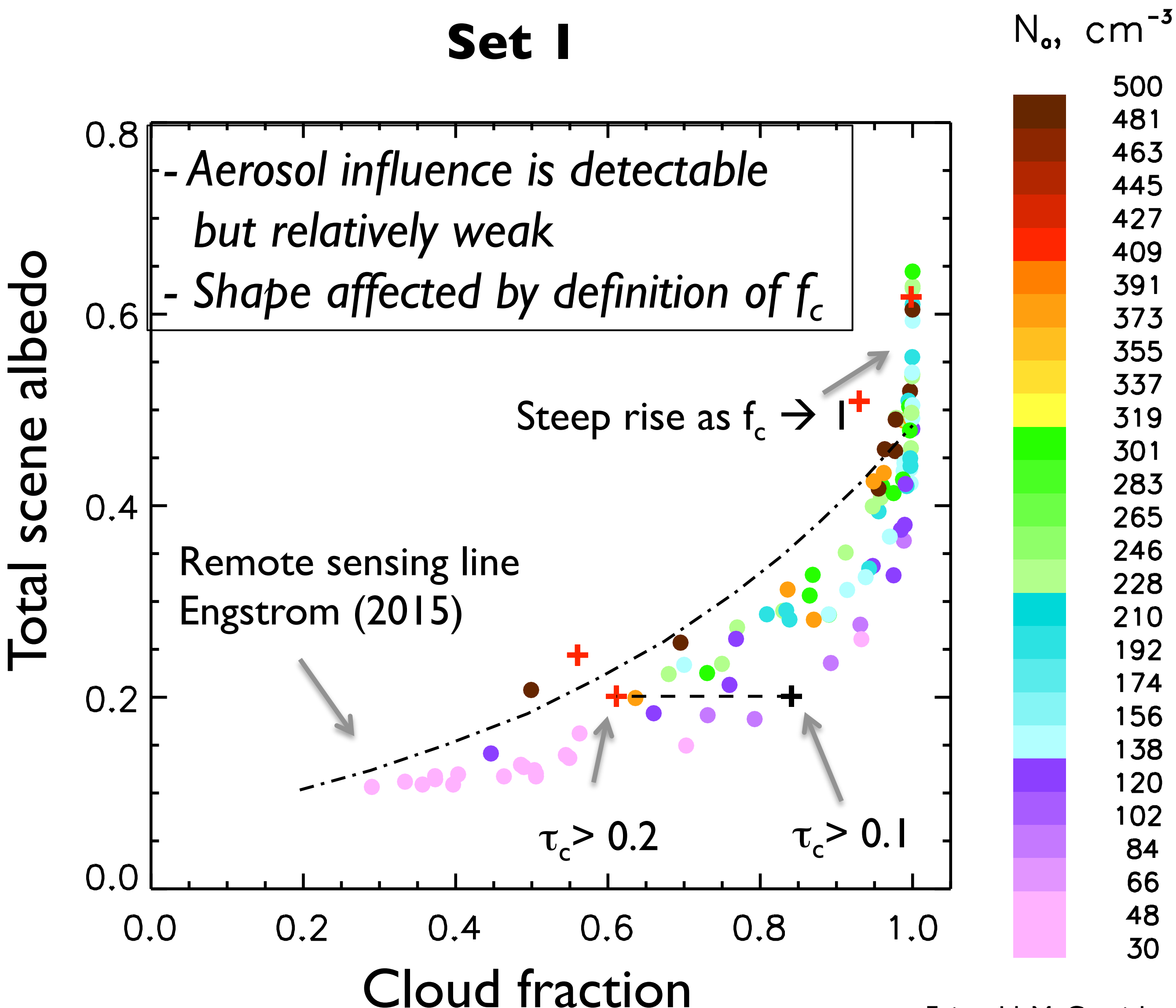

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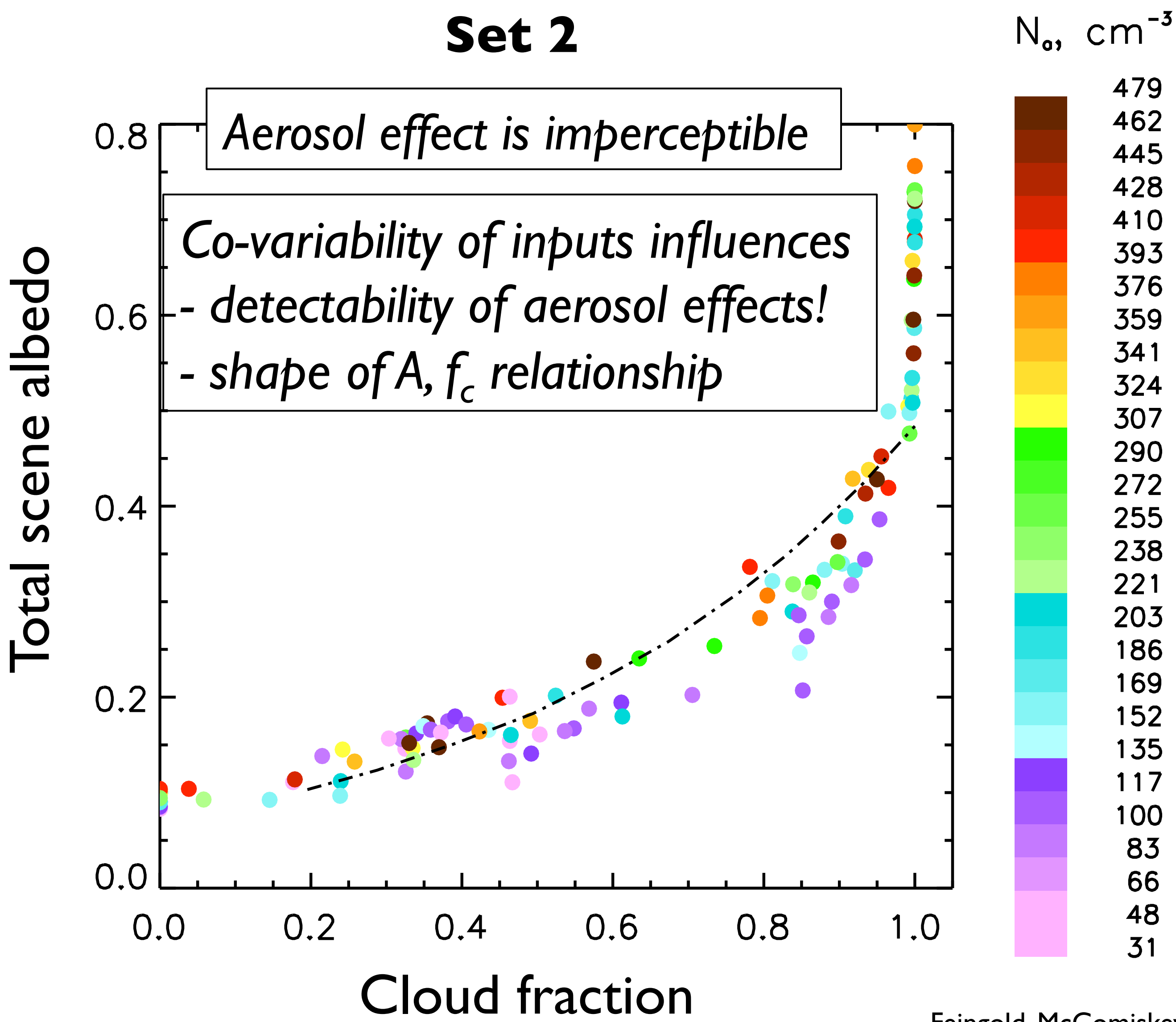
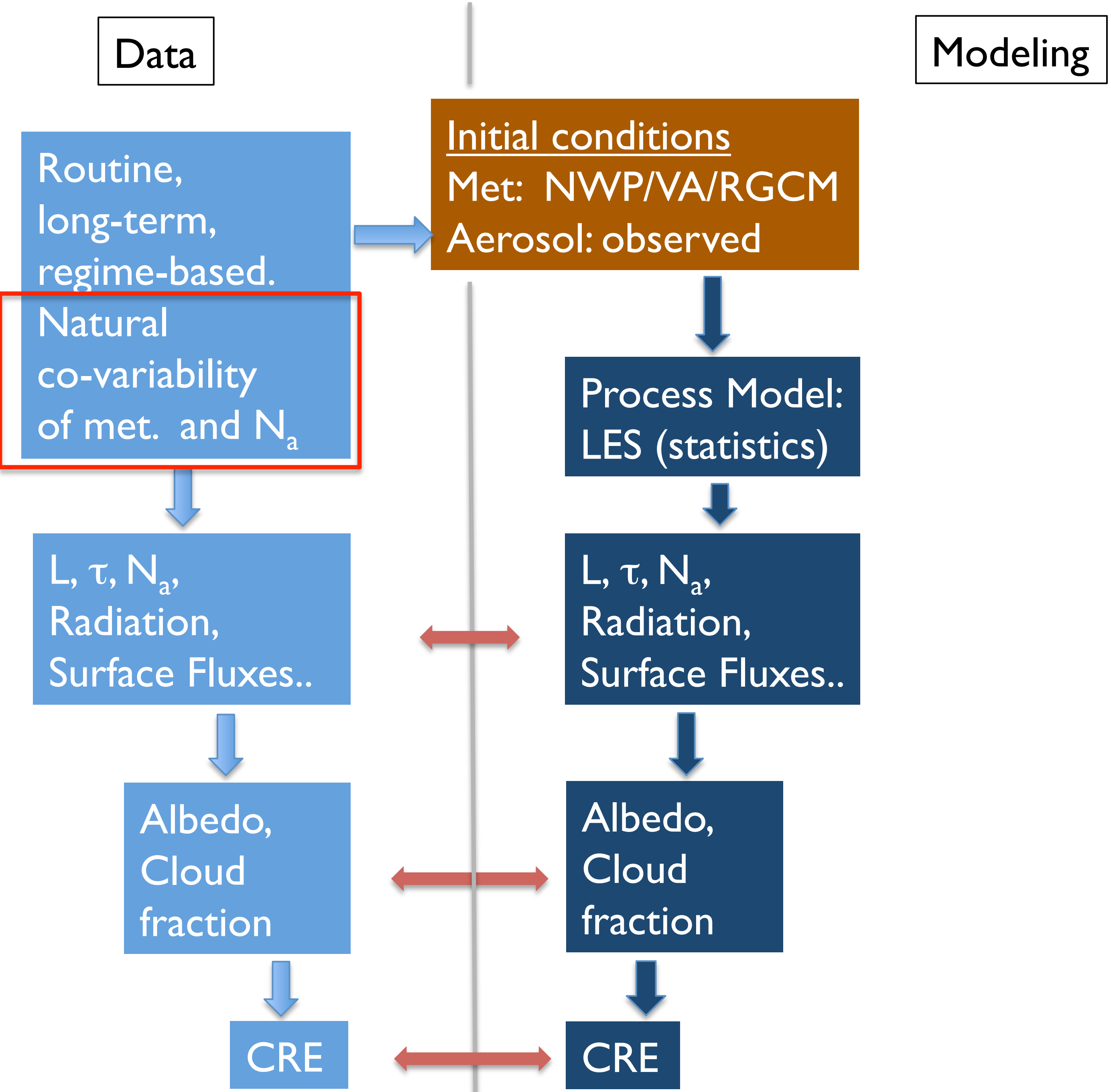
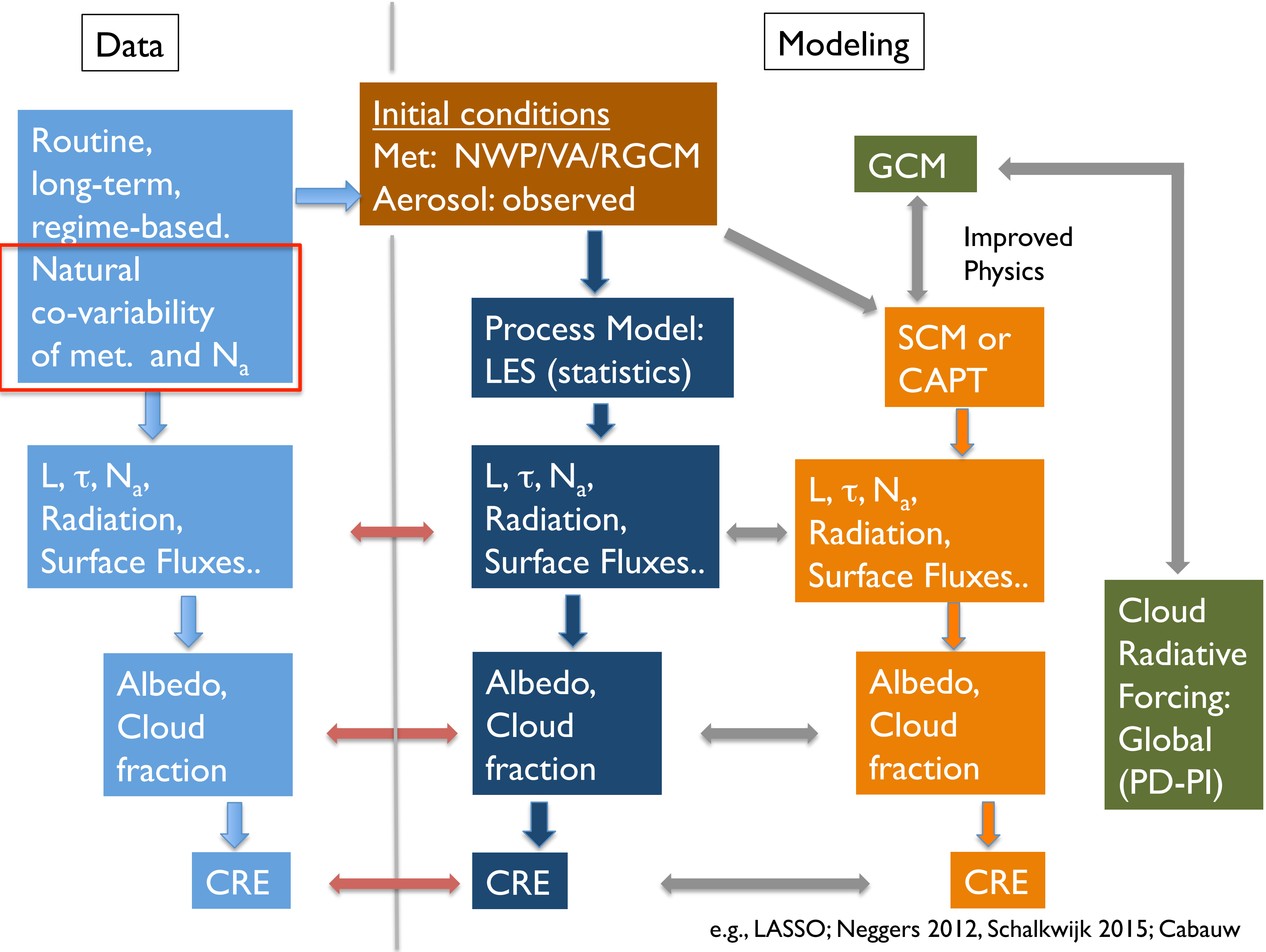


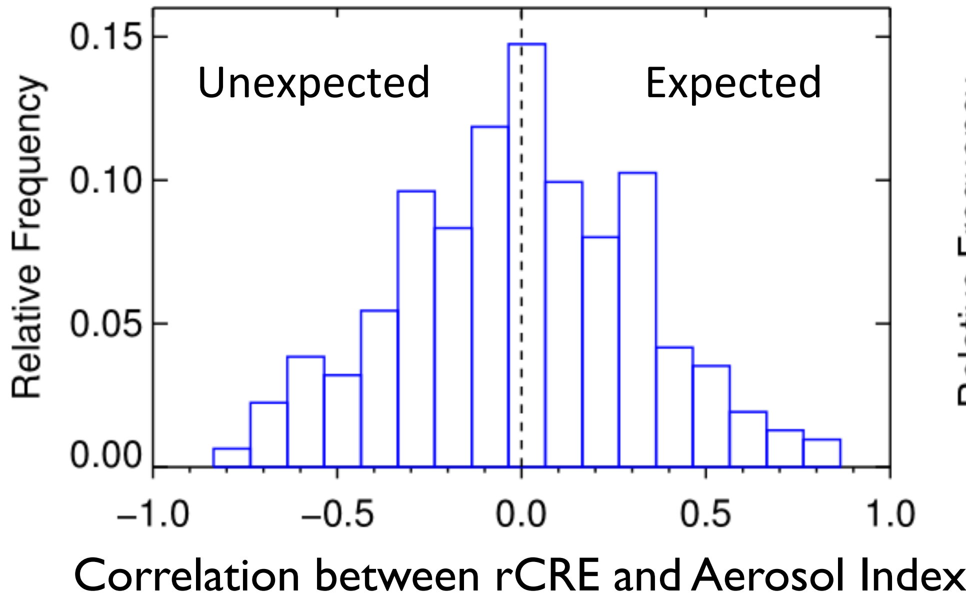
Feingold, McComiskey, Yamaguchi et al., 2016 PNAS

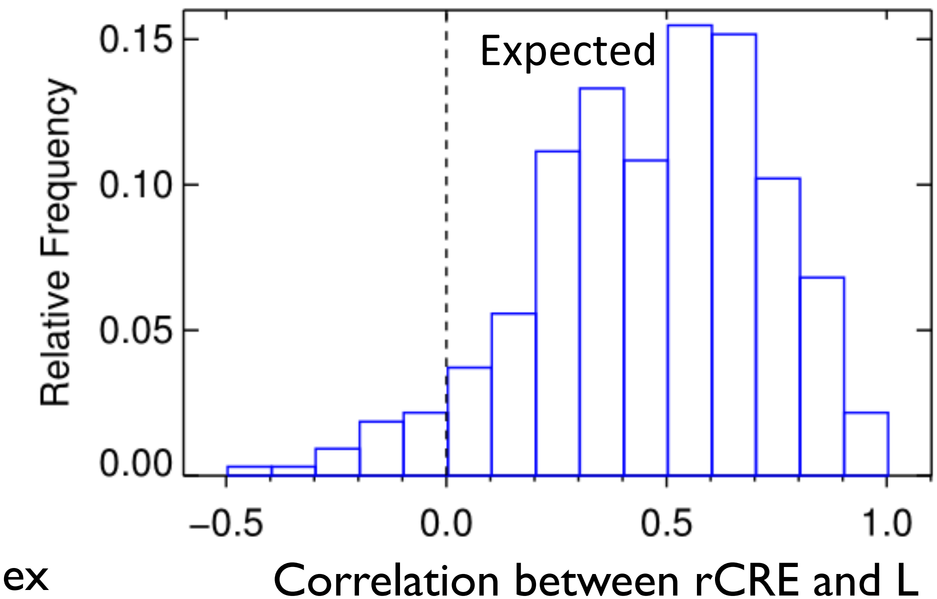


e.g., LASSO; Neggers 2012, Schalkwijk 2015; Cabauw


Data
Modeling
Routine, long-term, regime-based.
Natural co-variability of met. and N_a
Initial conditions
Met: NWP/VA/RGCM
Aerosol: observed
GCM
Improved Physics
Process Model: LES (statistics)
SCM or CAPT
L, τ, N_a, Radiation, Surface Fluxes..
L, τ, N_a, Radiation, Surface Fluxes..
L, τ, N_a, Radiation, Surface Fluxes..
Albedo, Cloud fraction
Albedo, Cloud fraction
Albedo, Cloud fraction
Cloud Radiative Forcing: Global (PD-PI)
CRE
CRE
CRE
e.g., LASSO; Neggers 2012, Schalkwijk 2015; Cabauw

Observations: 14 years of warm clouds at SGP Continental US





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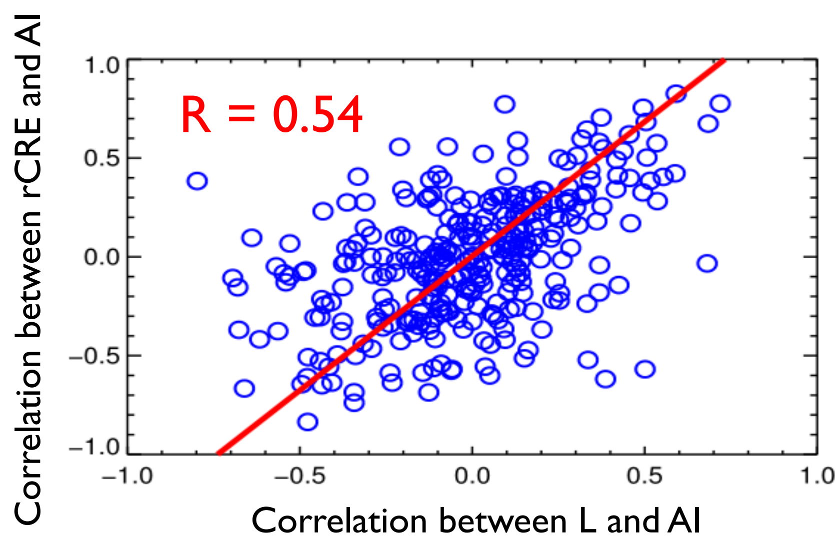
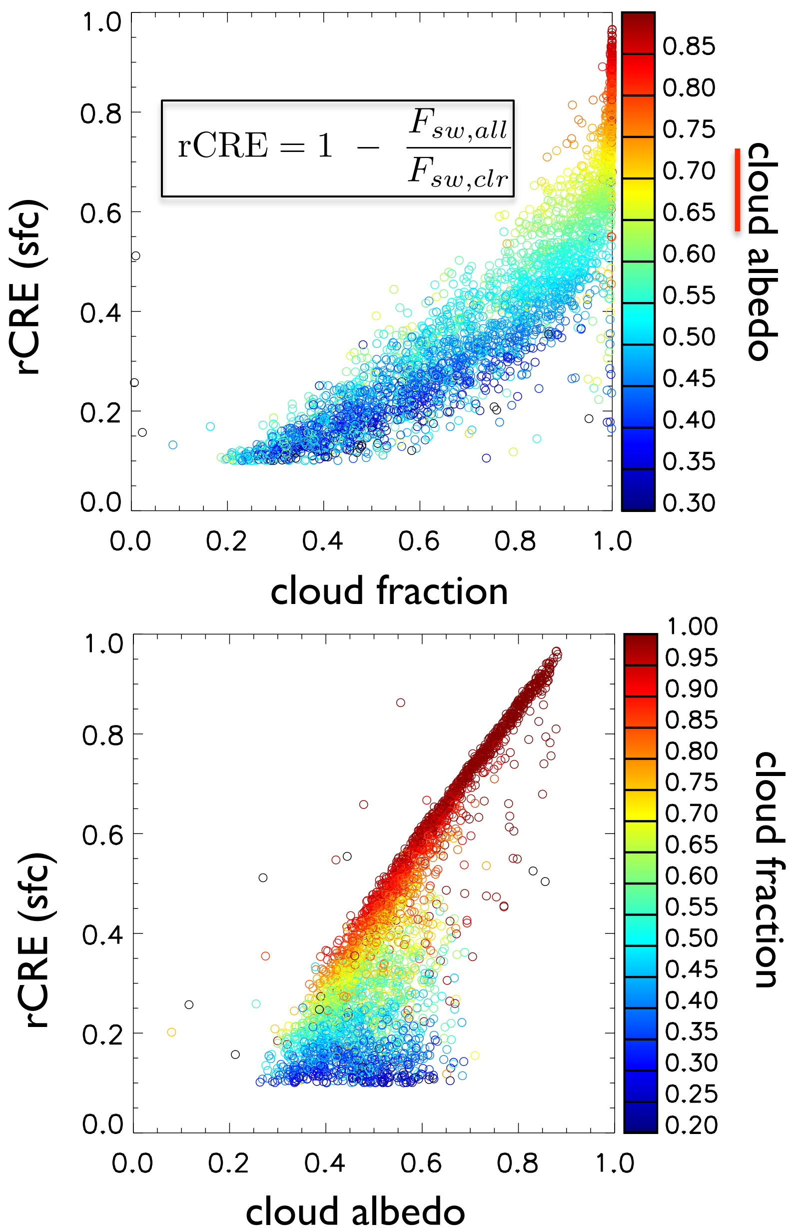


Sena et al., 2016

Observations: 12 years of warm clouds at SGP Continental US (McComiskey and Long, to be submitted)



Feingold et al., 2016

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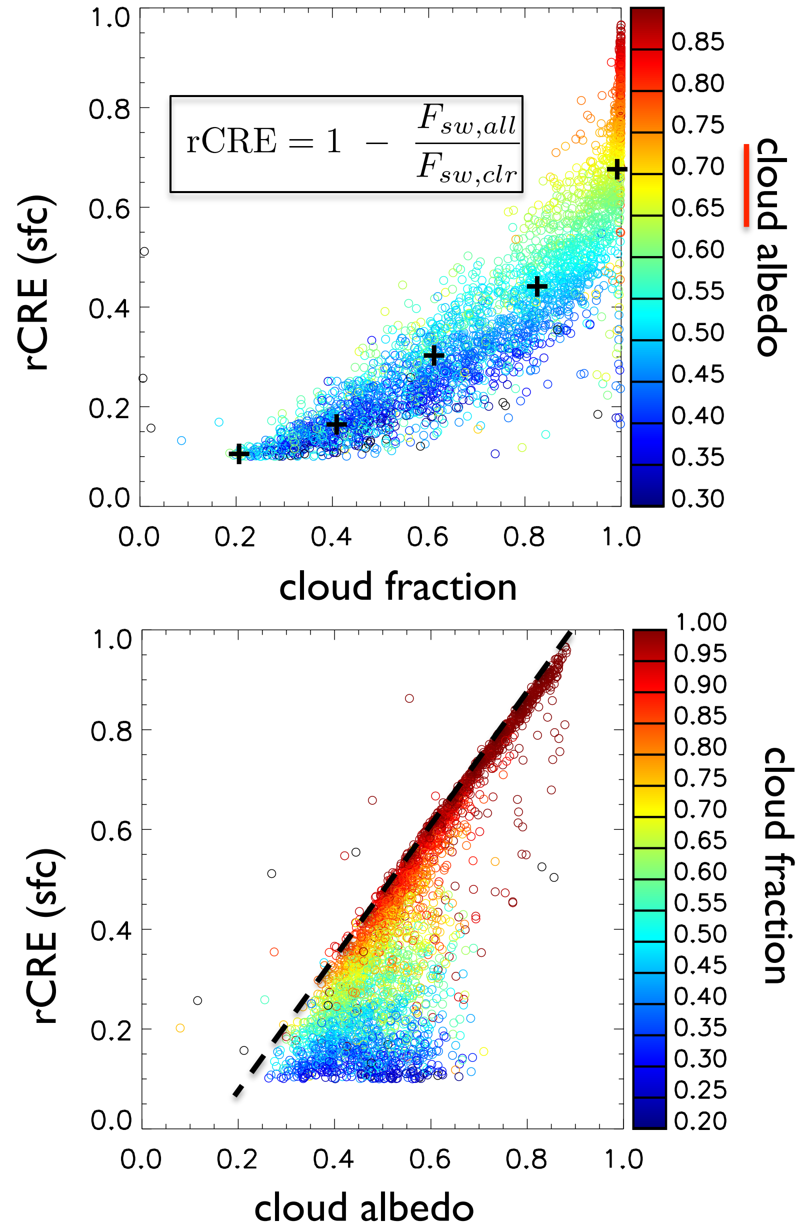
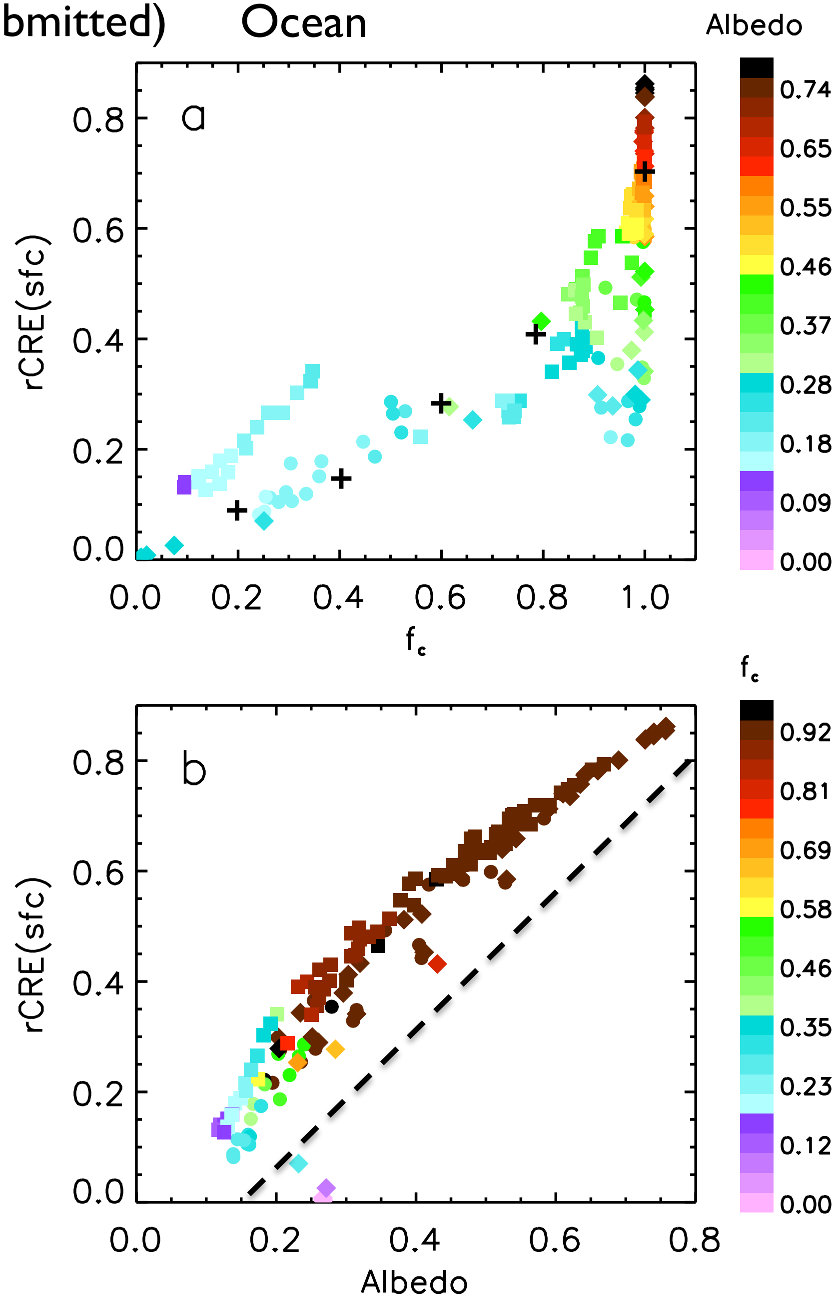


LES/CRM Modeling

Ocean



Feingold et al., 2016

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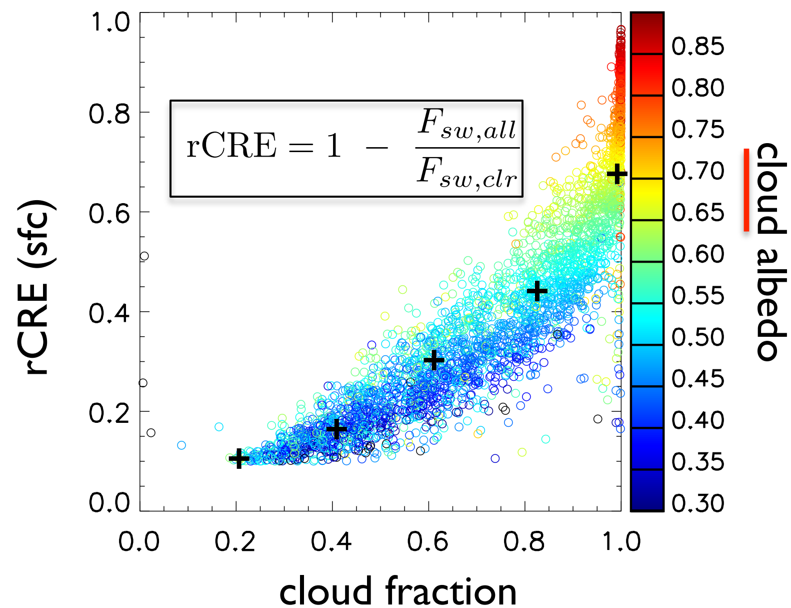
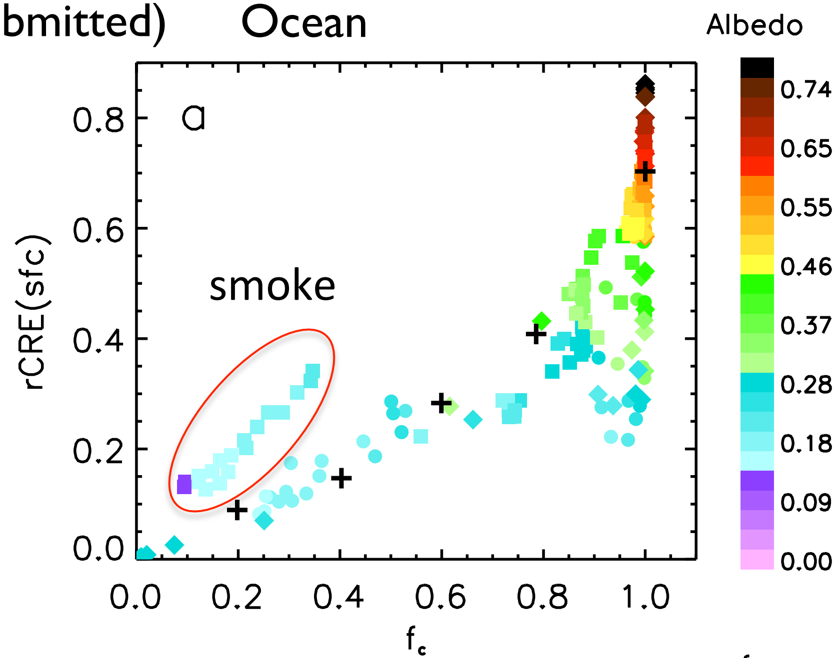
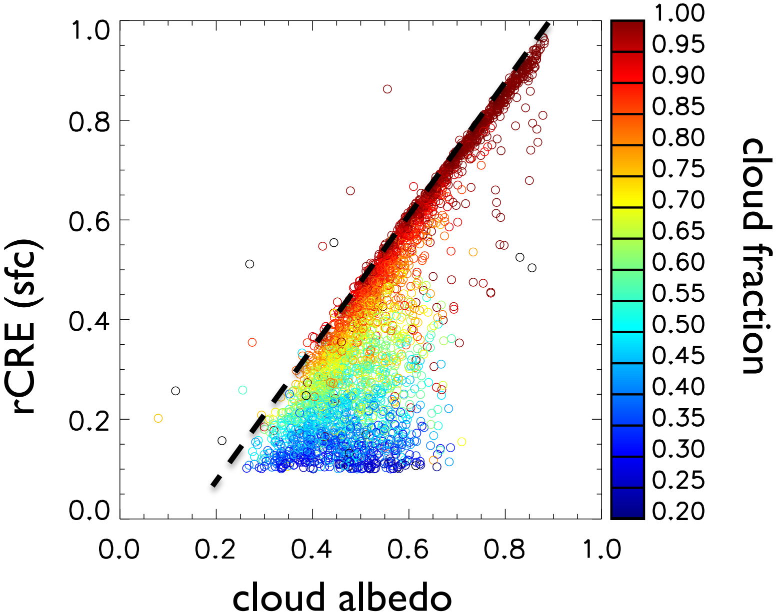
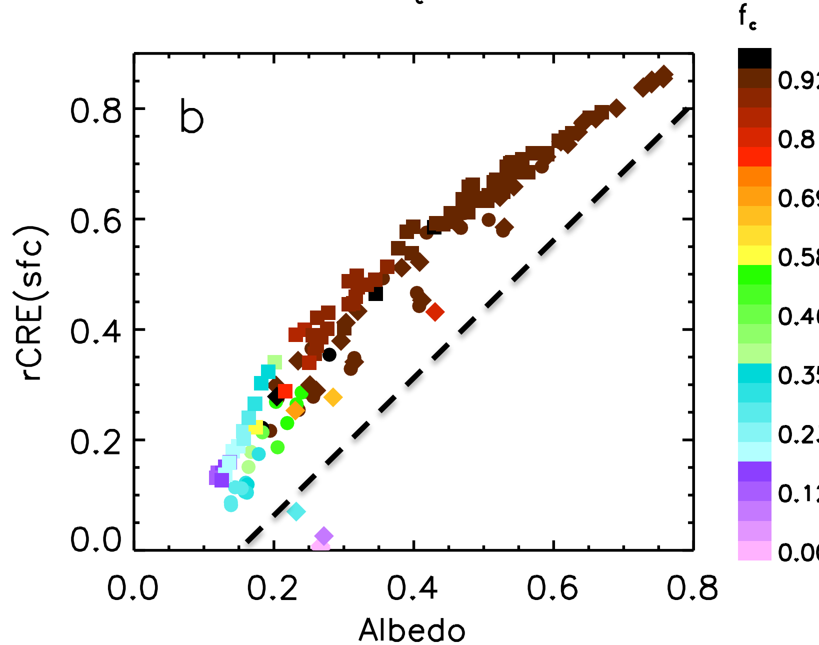








Feingold et al., 2016

Constraining dL/dN

Can S_o or S_{pop} be used to constrain d*L*/dN

Large Eddy Simulation (Stratocumulus)

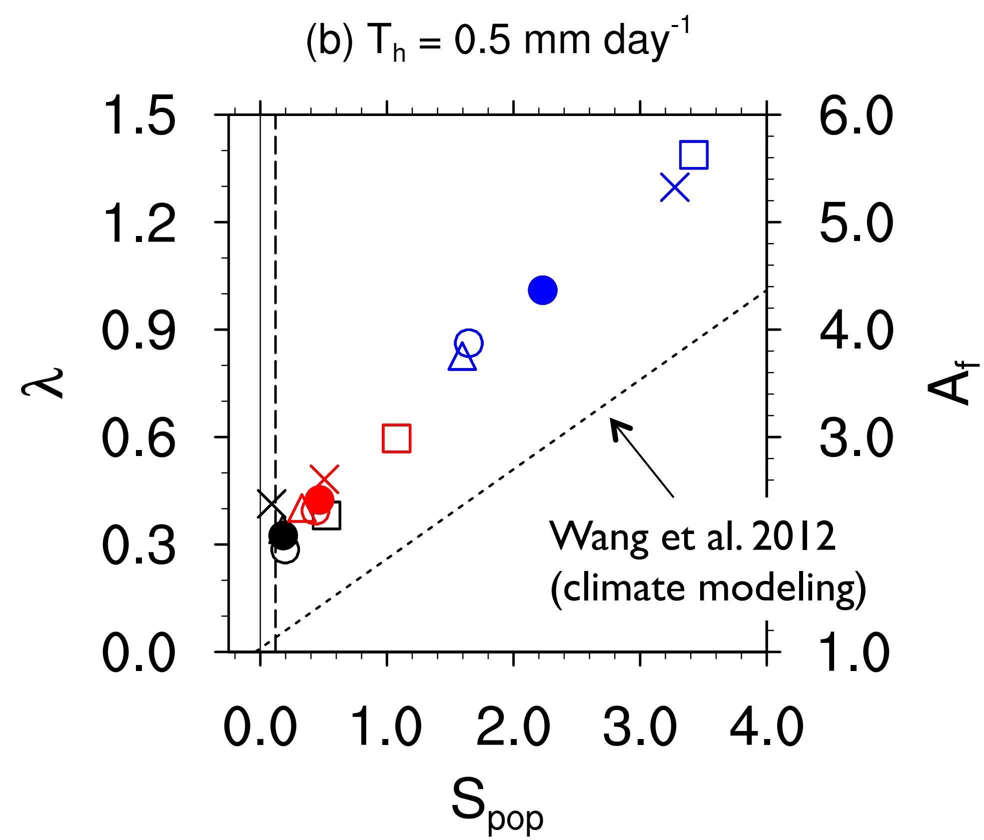
λ is positive; albedo is enhanced

Quantitative differences from GCM

Dependence on R threshold
(not shown)

$$\lambda = \frac{dlnL}{dlnN}$$

A_f = Albedo enhancement factor due to λ
(enhancement over Twomey albedo effect)

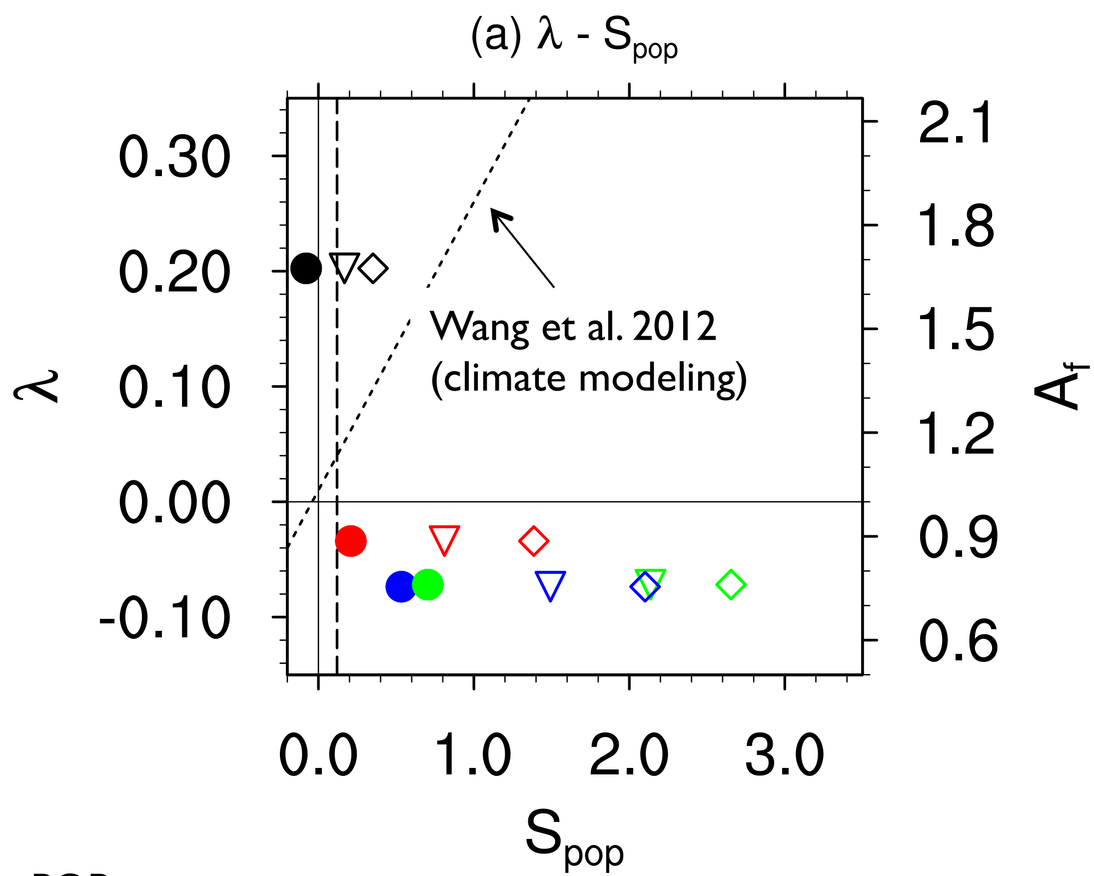


Lebo and Feingold ACP 2014

Constraining dL/dN

Large Eddy Simulation (Cumulus)

λ becomes <u>negative</u> for large enough aerosol perturbations



Symbol types represent different R thresholds for POP

Lebo and Feingold ACP 2014

Summary

Observational constraints on Cloud Radiative Effect (CRE)

- Top-down vs. bottom-up approach
  - More focus on macroscale parameters tightly linked to radiation (CRE, A, f_c, L)
- Link CRE, A, f_c plots to:
  - microphysics, cloud field properties, scale, place
  - co-variability in controlling parameters

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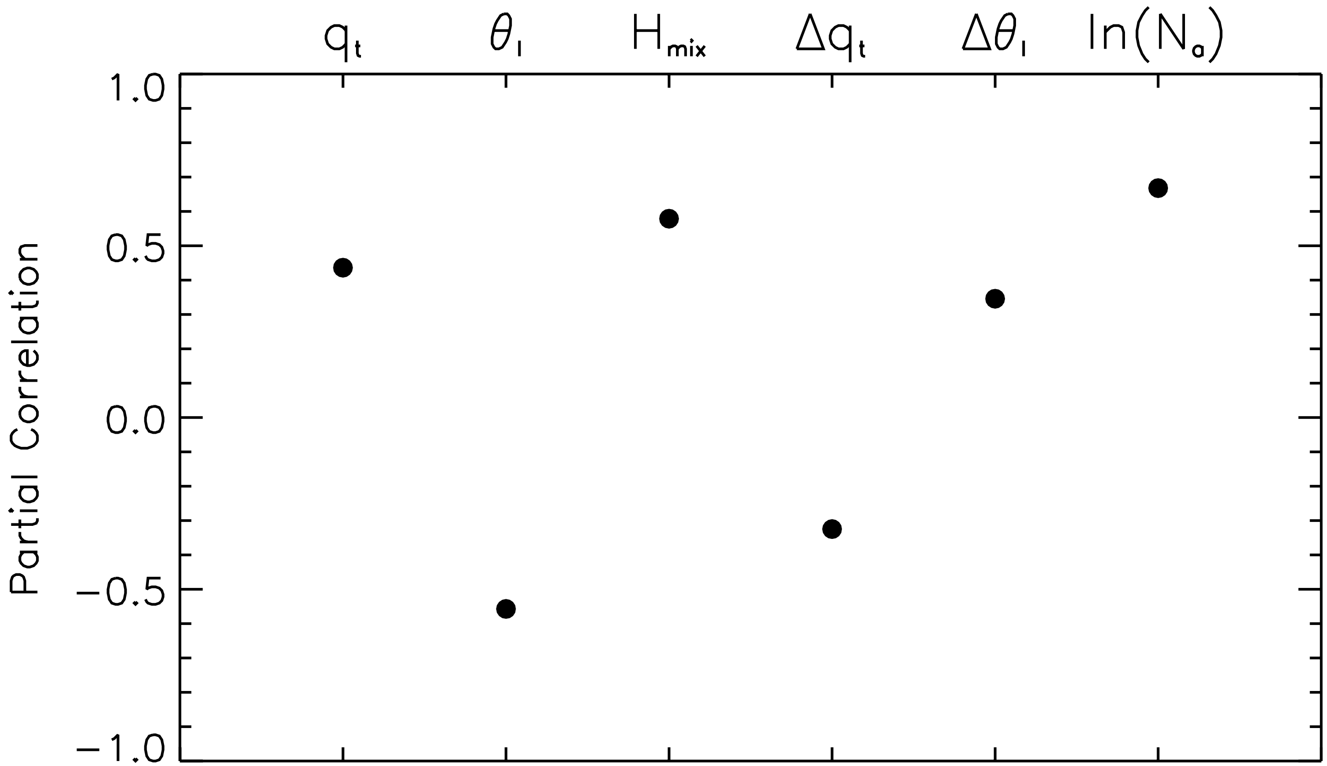
  - co-variability in controlling parameters

Co-variability between aerosol and meteorology affects detectability of ACI

- Embrace the co-variability!
- Routine process modeling and observations will capture this co-variability (LASSO; Cabauw, SGP, HDCP2)

Cumulative Multivariate Correlation: Set 1

$$\text{Albedo}=f(q_t,\ \theta_l,\ H_{mix},\ \Delta q_t,\ \Delta\theta_l,\ \ln(N_a))$$

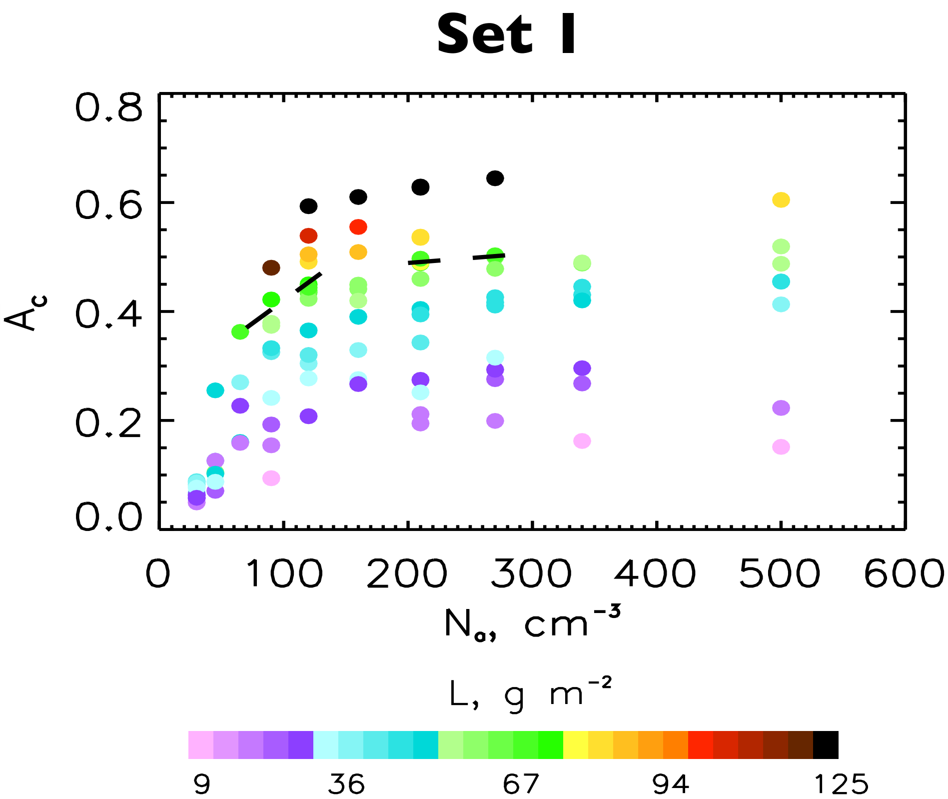


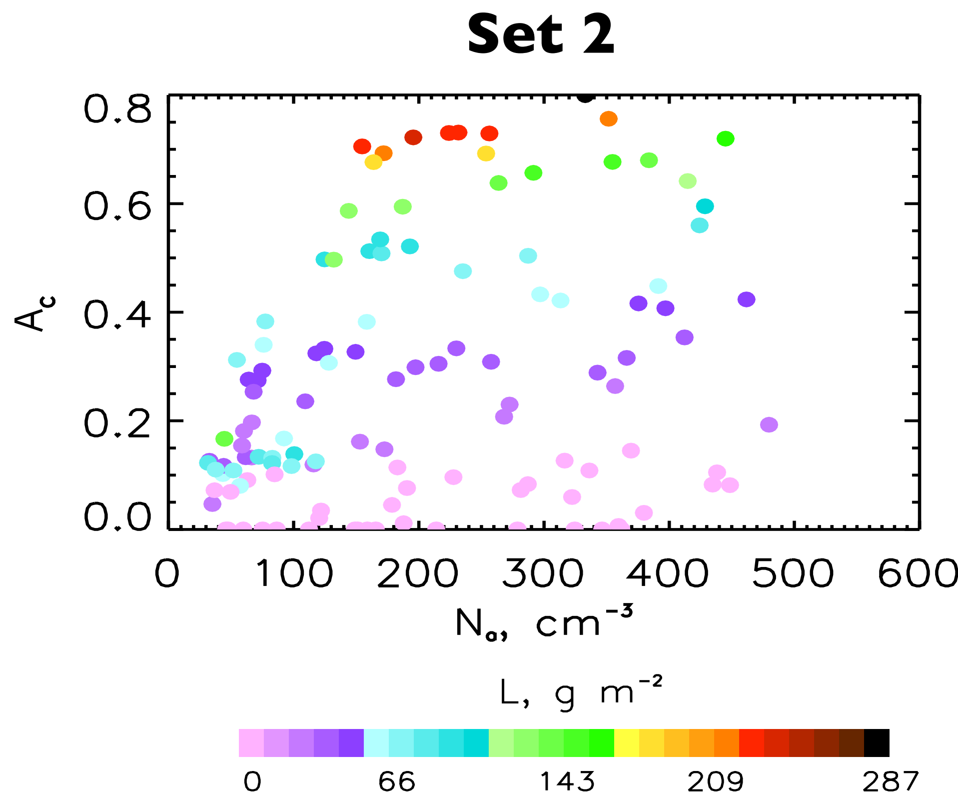
All variables contribute to the Albedo

Albedo Susceptibility

$$S_a = \left.\frac{\partial A_c}{\partial N_d}\right|_L = \frac{A_c(1 - A_c)}{3N_d}$$

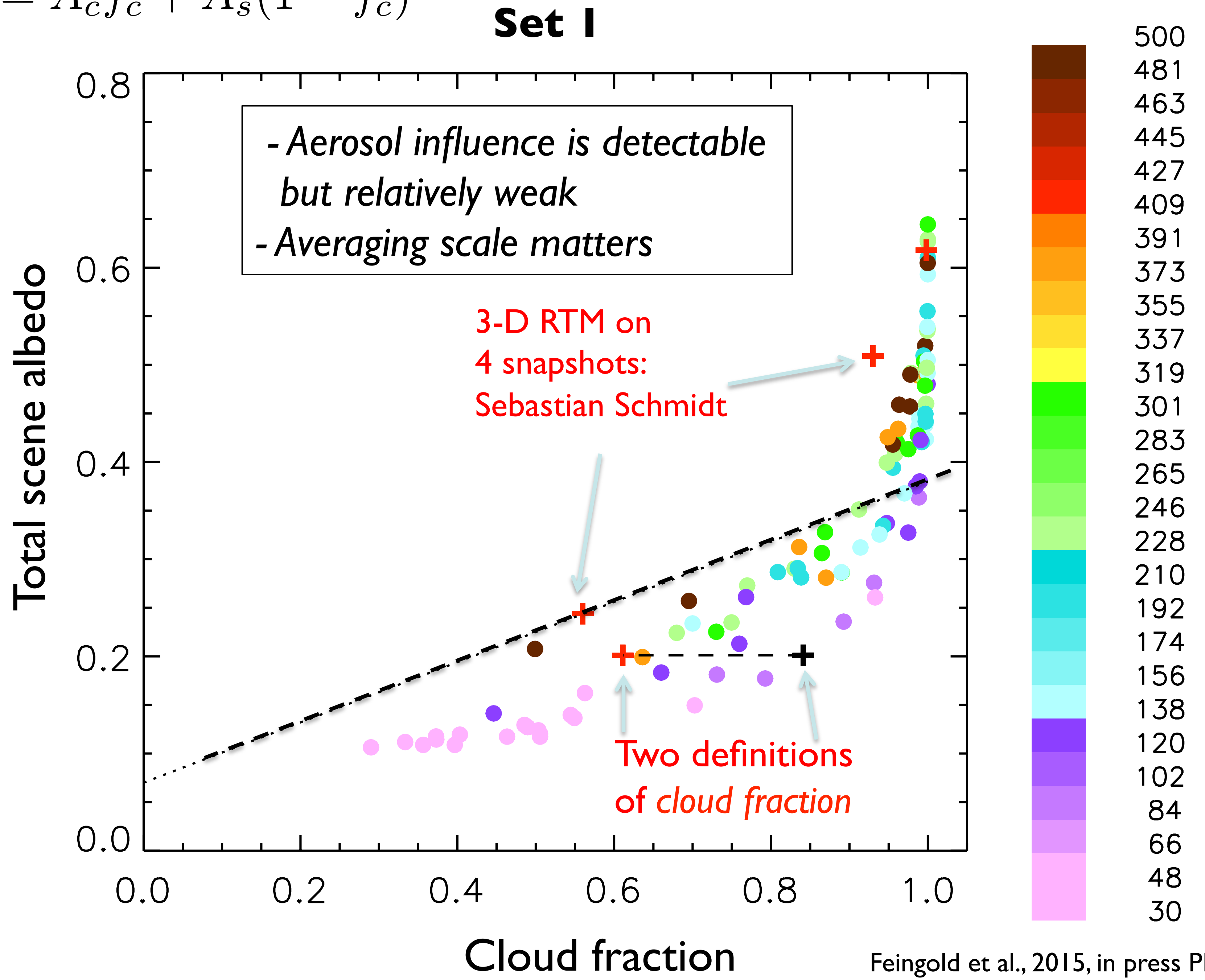
Both Sets show expected steeper slopes at small N and $A_c \sim 0.5$





A_c calculated based on plane parallel assumptions

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



Feingold et al., 2015, in press PNAS