Consideration of Interactive Influences of Aerosol Size Distribution and Updraft to Reconcile Different Dispersion Effects

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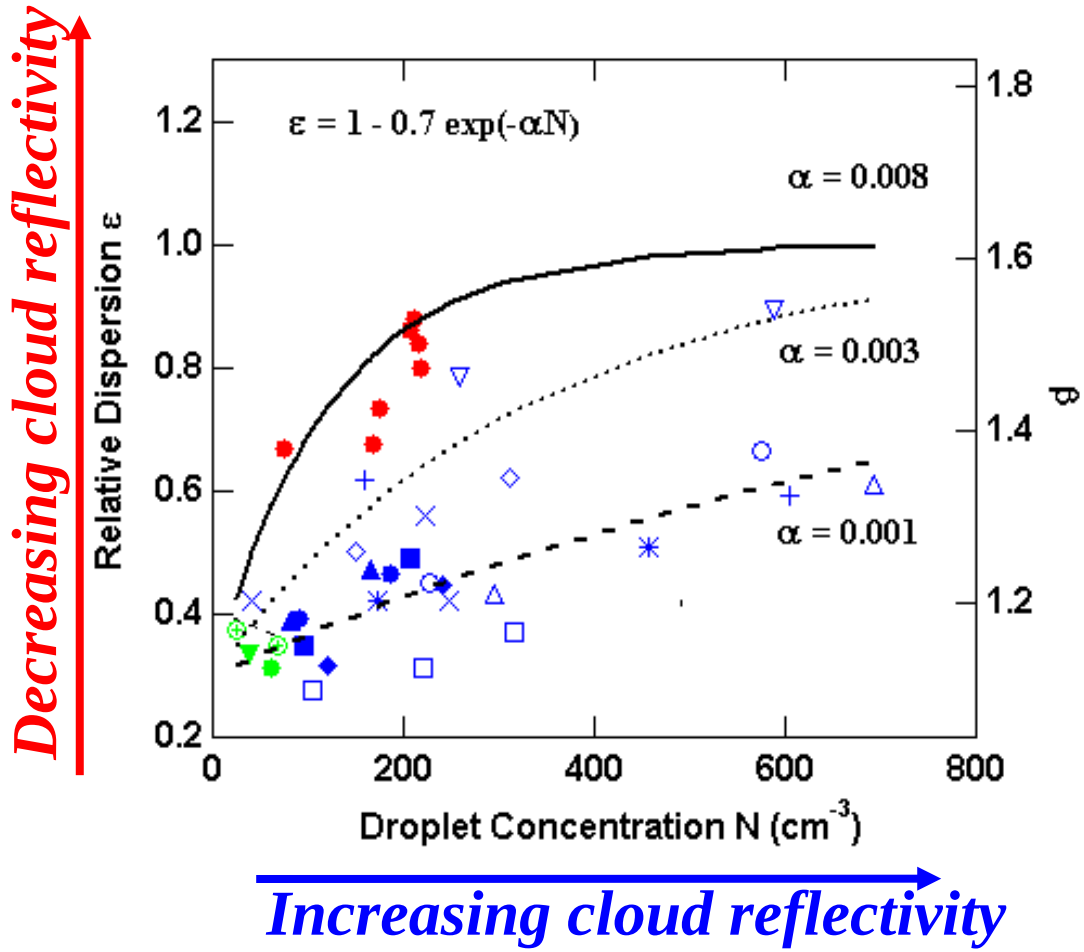
Dispersion Effect

$$r_e = \beta \left(\frac{3}{4\pi\rho_w} \right)^{1/3} \left(\frac{L}{N} \right)^{1/3}$$

$$\beta = \frac{\left(1 + 2\varepsilon^2\right)^{2/3}}{\left(1 + \varepsilon^2\right)^{1/3}}$$

$$\varepsilon = \frac{\sigma}{\bar{r}}$$



Increasing aerosol enhances not just droplet concentrations, but also ε (hence β), increasing effective radius and reducing albedo (Liu & Daum, Nature, 2002; Peng & Lohmann, GRL, 2003, GRL; more similar findings since then ...

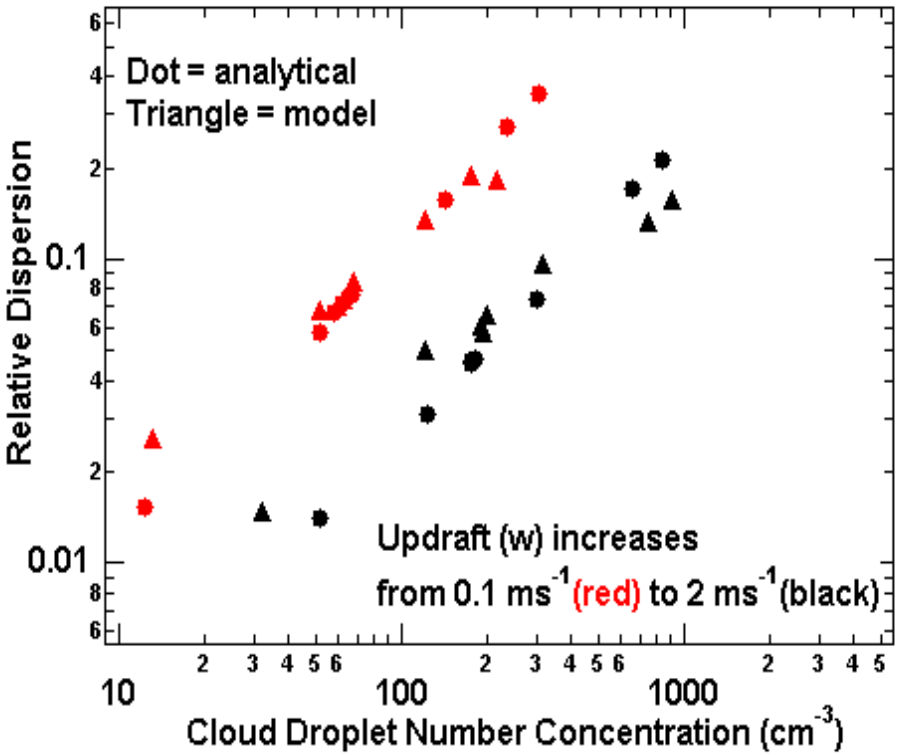
Analytical Formulation

(Liu et al. GRL, 2006)

$$N_{CCN} = CS^{K};$$

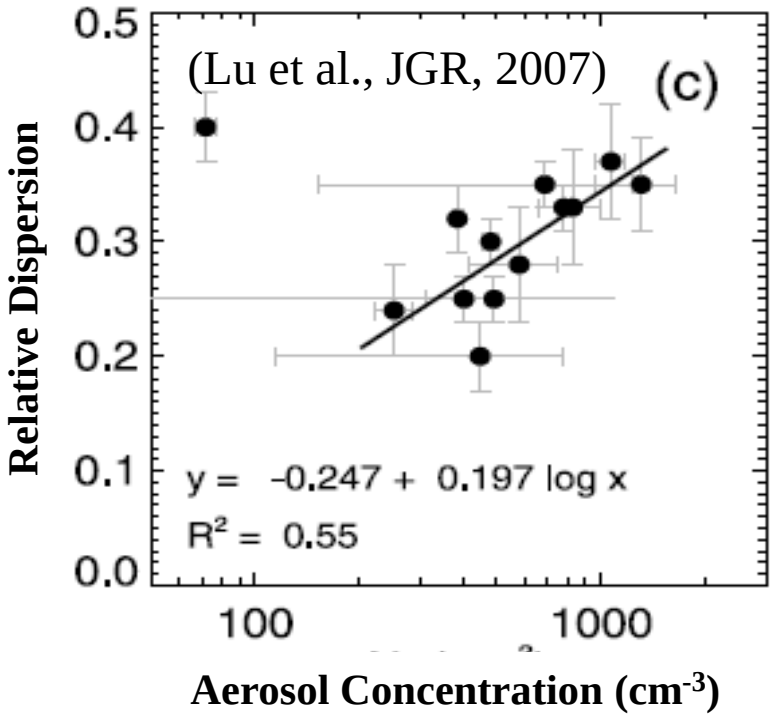
$$N \propto w^{3K/(2(k+2))} C^{2/(K+2)};$$

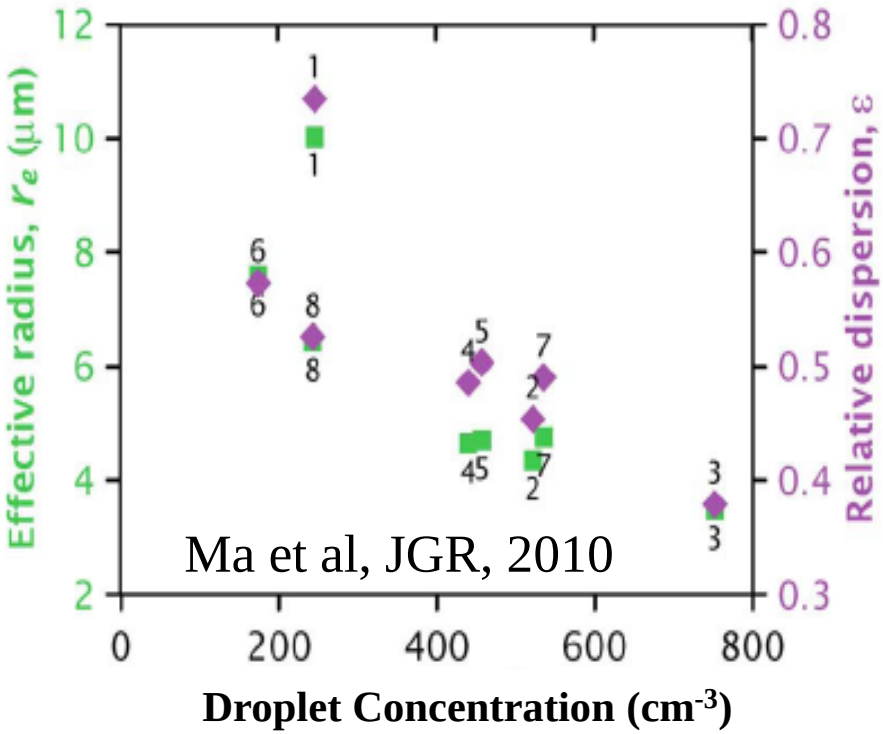
$$\varepsilon \propto w^{(K-1)/(K+2)} C^{2/(K+2)}$$



I thought then, "incorrectly", that the problem of dispersion effect was basically solved, and some studies reporting negative ε-N correlation were either about dynamical effect or for drizzling clouds … However, lately I realize that this view was too simplistic and we.need new understanding.

Contrasting Results from Subsequent Studies





Warming dispersion effect
(Chen et al, ACP, 2012;
Pandithurai et al, JGR, 2012)

Cooling Dispersion Effect
(Martins et al, ERL, 2009;
Hudson et al, JGR, 2012)

These observational results suggest that dispersion effect can either mitigate or enhance the cooling from the number effect.

Why ?

Revisit of Liu2006 Formulation

Liu2006 formulation:

$N_{CCN} = CS^K$;

$N_C \propto w^{3K/(2(k+2))} C^{2/(K+2)}$;

$\varepsilon_C \propto w^{(K-1)/(K+2)} C^{2/(K+2)}$

Implicit assumption: constant C and K

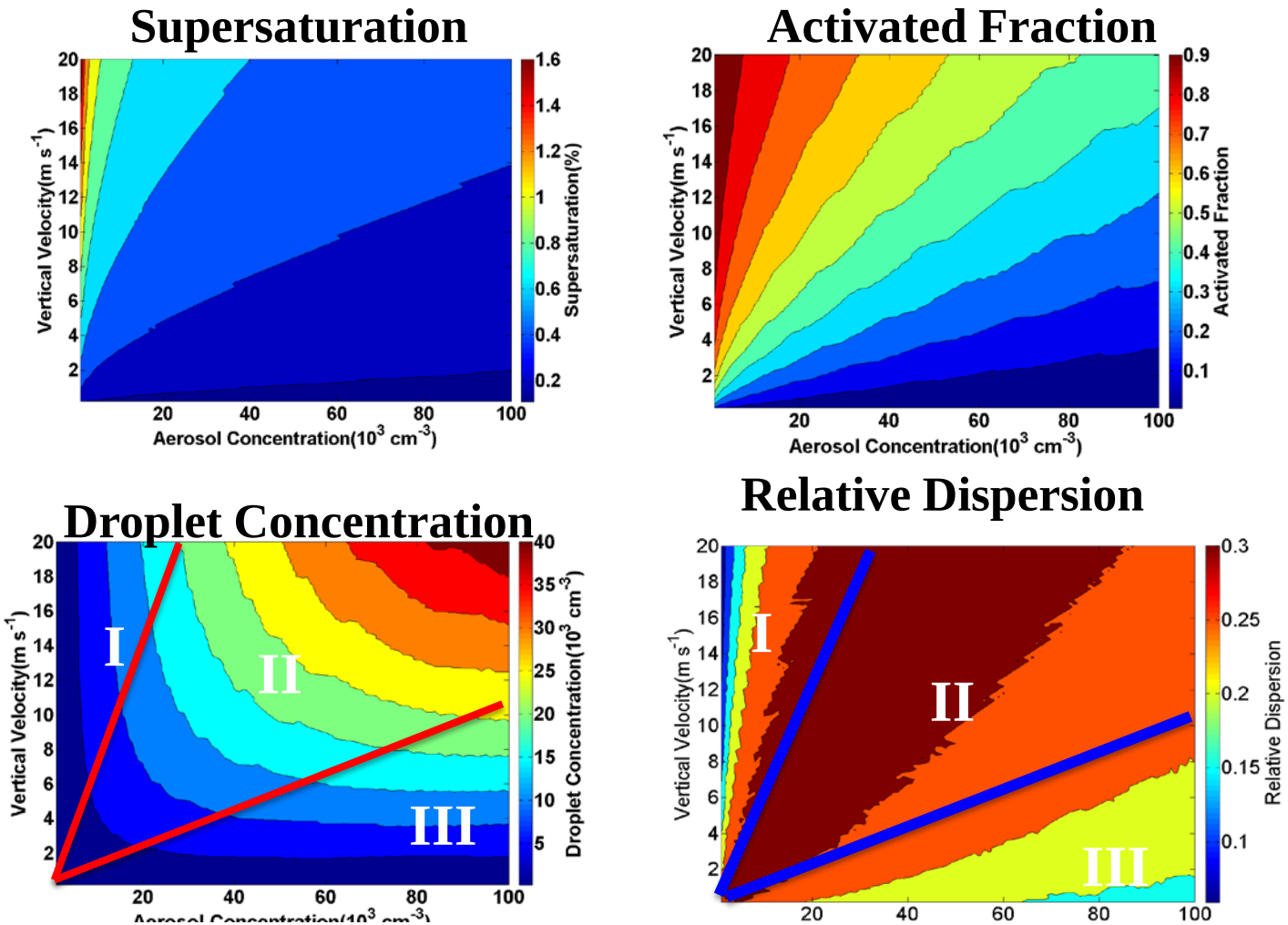
- C and K should depend on cloud supersaturation S and thus w and pre-cloud aerosol properties, leading to the new formulation whereby C and K are both functions of w and aerosol properties, instead constants!

- The dependence of C and K on w and aerosol properties may lead to the complex dispersion effects, pending on the combination of w and aerosols >> parcel model investigation confirms this next, with κ-Kohler activation and aerosol spectrum:

$$n(r) = \frac{N}{\sqrt{2\pi} r \ln \sigma_g} \exp[-\frac{(\ln r - \ln r_g)^2}{2 \ln^2 \sigma_g}]$$

Regime Classification of 1st AIE

(Reutter et al. ACP, 2009)

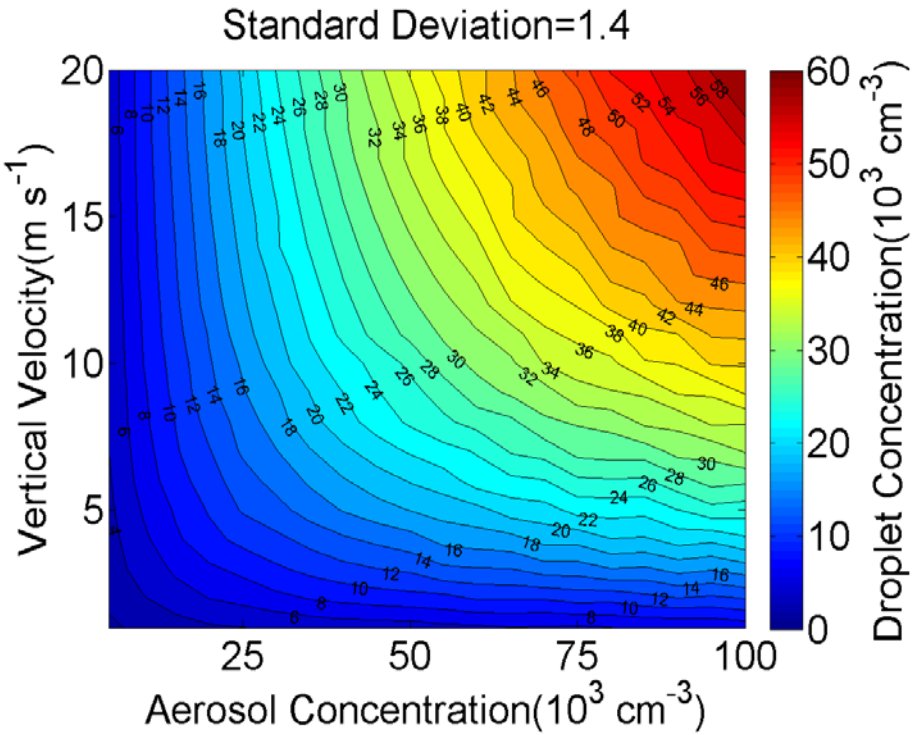


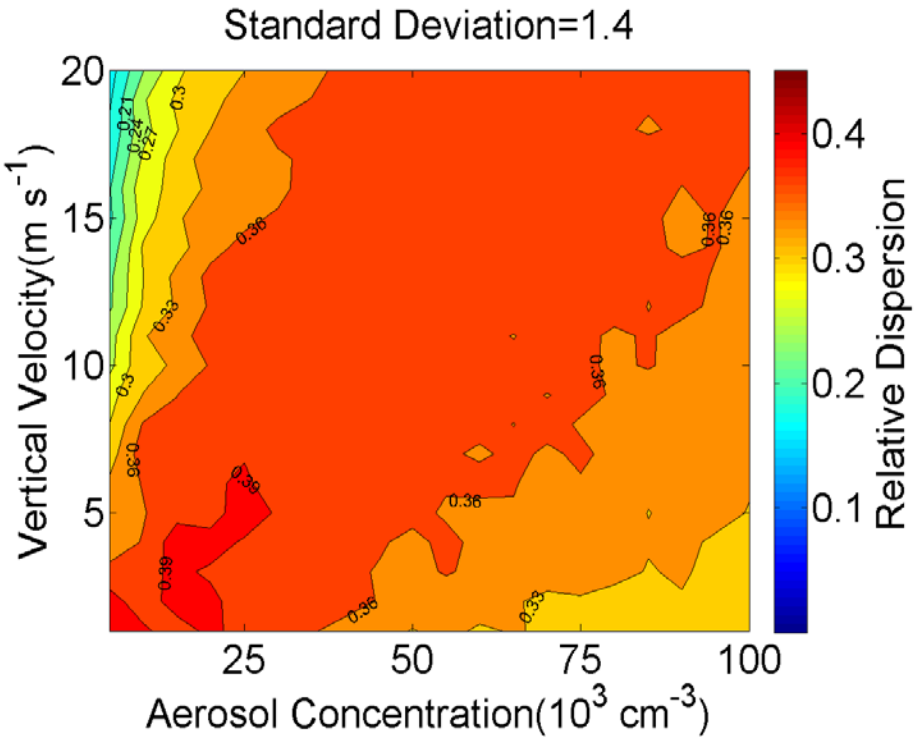
As droplet concentration, dependence of relative dispersion on updraft and aerosol concentration can be classified into aerosol-limited (I), transitional (II) and updraft-limited regimes, in which opposite dispersion effects may occur!

Effect of Aerosol Spectral Shape

$$n(r) = \frac{N}{\sqrt{2\pi} r \ln \sigma_g} \exp[-\frac{(\ln r - \ln r_g)^2}{2 \ln^2 \sigma_g}]$$

σg: 1.4—2.2μm



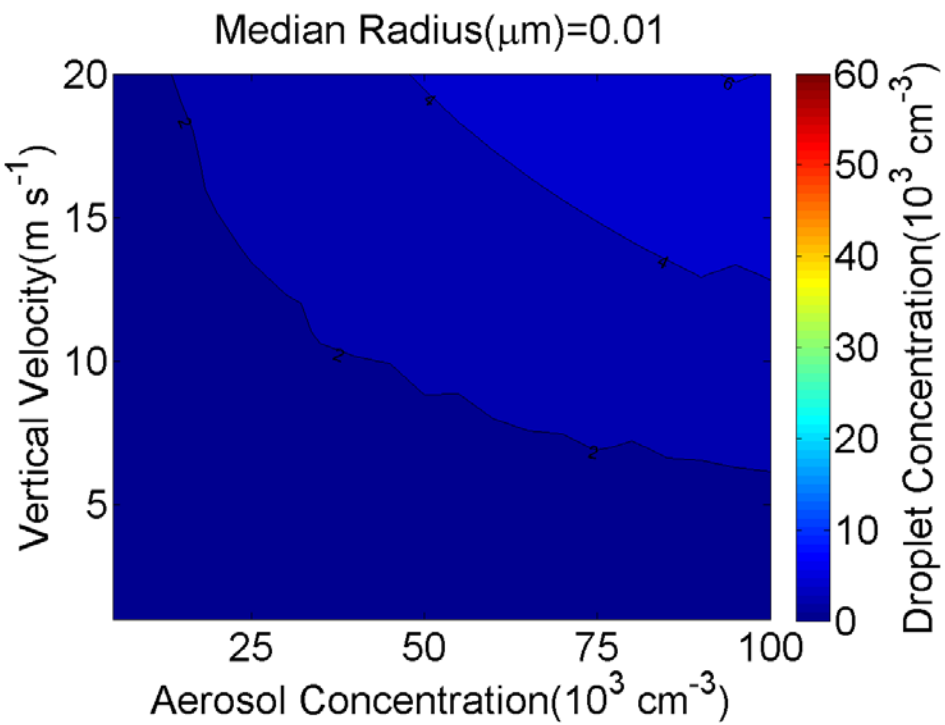


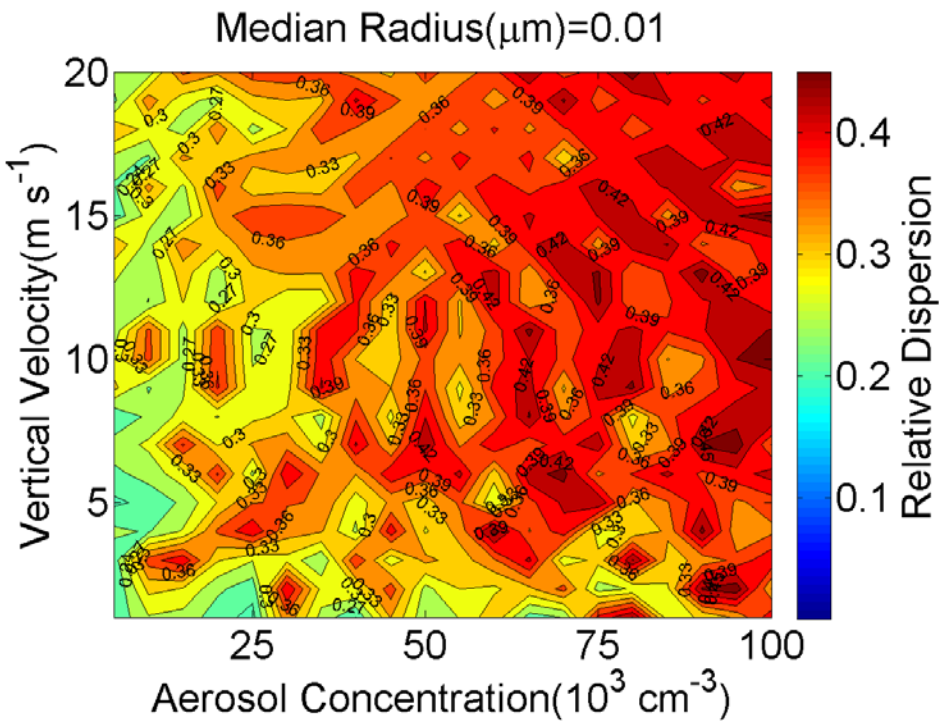
The regime classification based on relative dispersion is more sensitive to the effect of aerosol spectral shape.

Effect of Aerosol Median Radius

$$n(r) = \frac{N}{\sqrt{2\pi} r \ln \sigma_g} \exp[-\frac{(\ln r - \ln r_g)^2}{2 \ln^2 \sigma_g}]$$

rg: 0.01—0.12μm

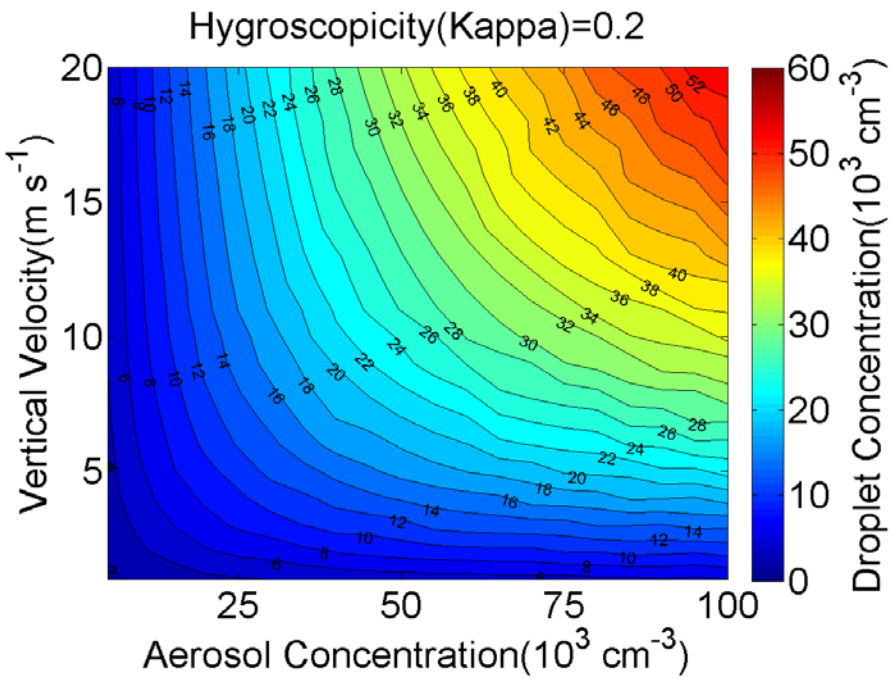


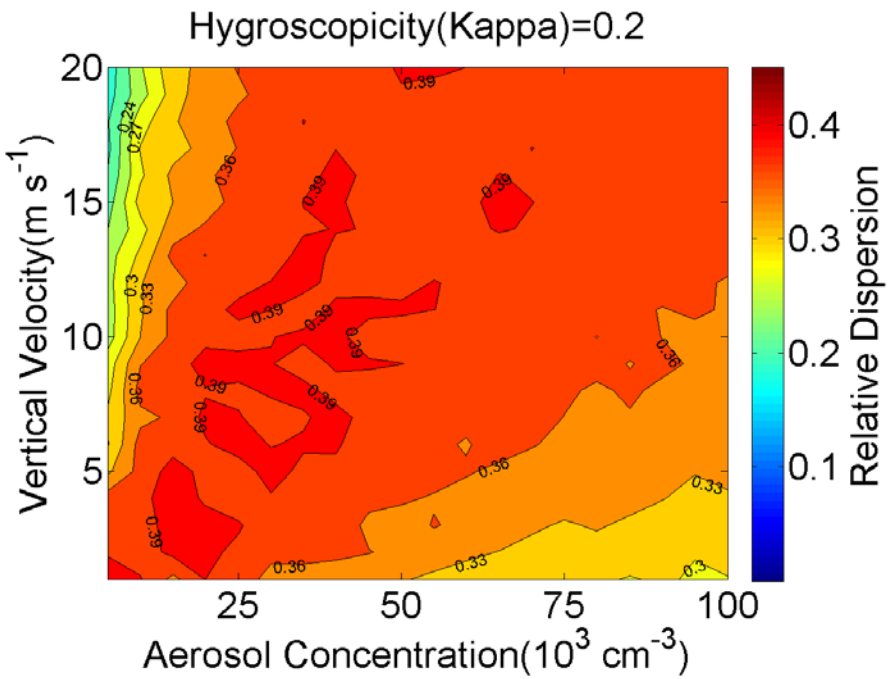


The regime classification based on relative dispersion is more sensitive to the size effect.

Hygroscopicity effect

K: 0.2—1.2





The regime classification based on relative dispersion is more sensitive to the hygroscopicity effect

Take-Home Messages

- **Dispersion effect can be warming or cooling, pending on relative impacts of w and aerosol concentration or regime (updraft-limited regime, aerosol-limited regime, and transitional regime).**

- **We need better understanding of regime classification:**

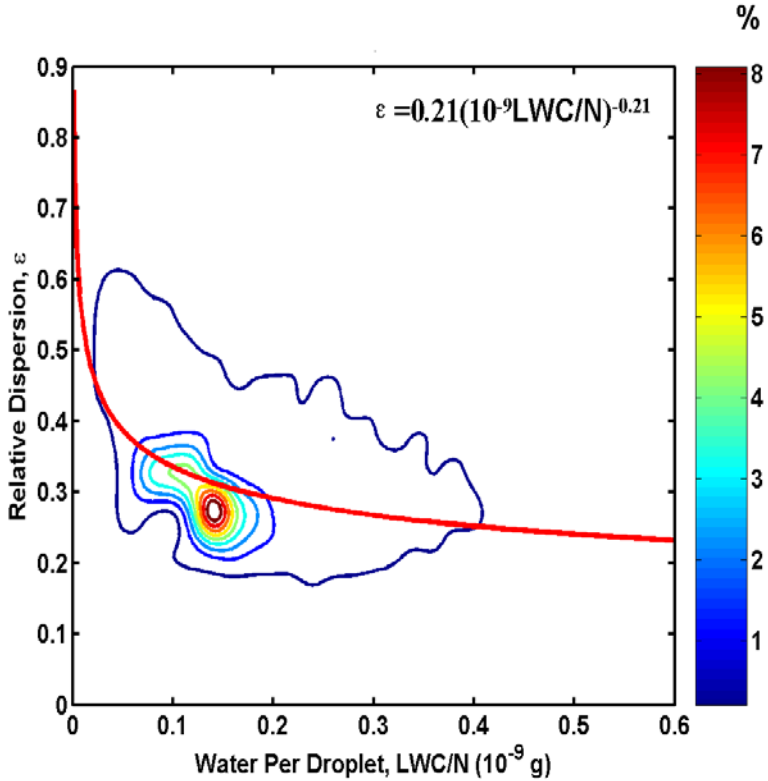
-- Consideration of aerosol properties of secondary importance, e.g., mean radius, standard deviation, chemical composition.

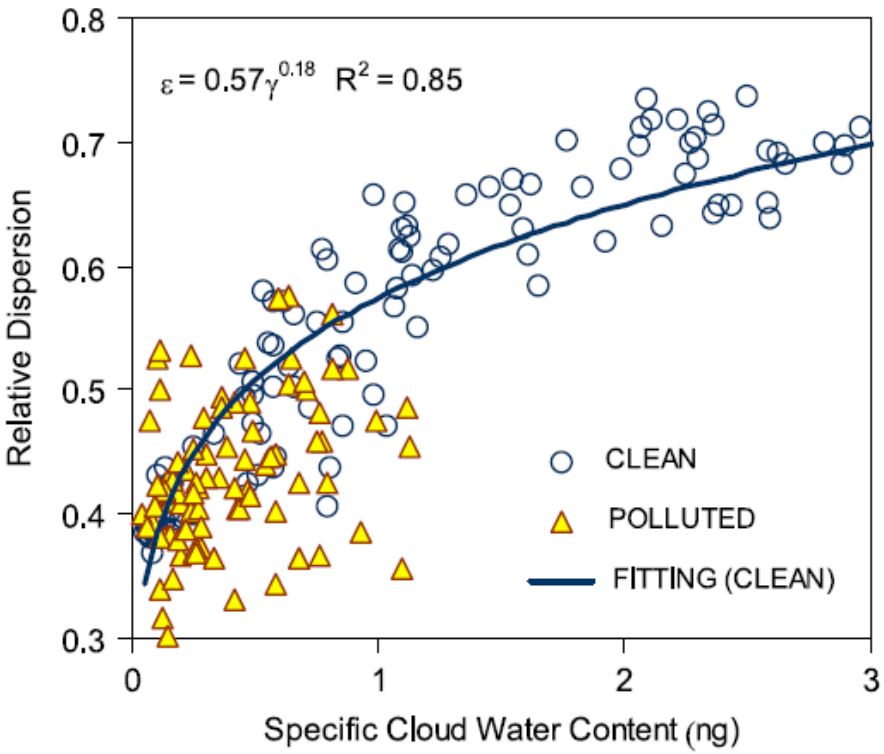
-- Which regimes do ambient clouds belong to?

-- Analytical formulation of regime classification

Wait, Even More Interesting Stuff

Contrasting Examples



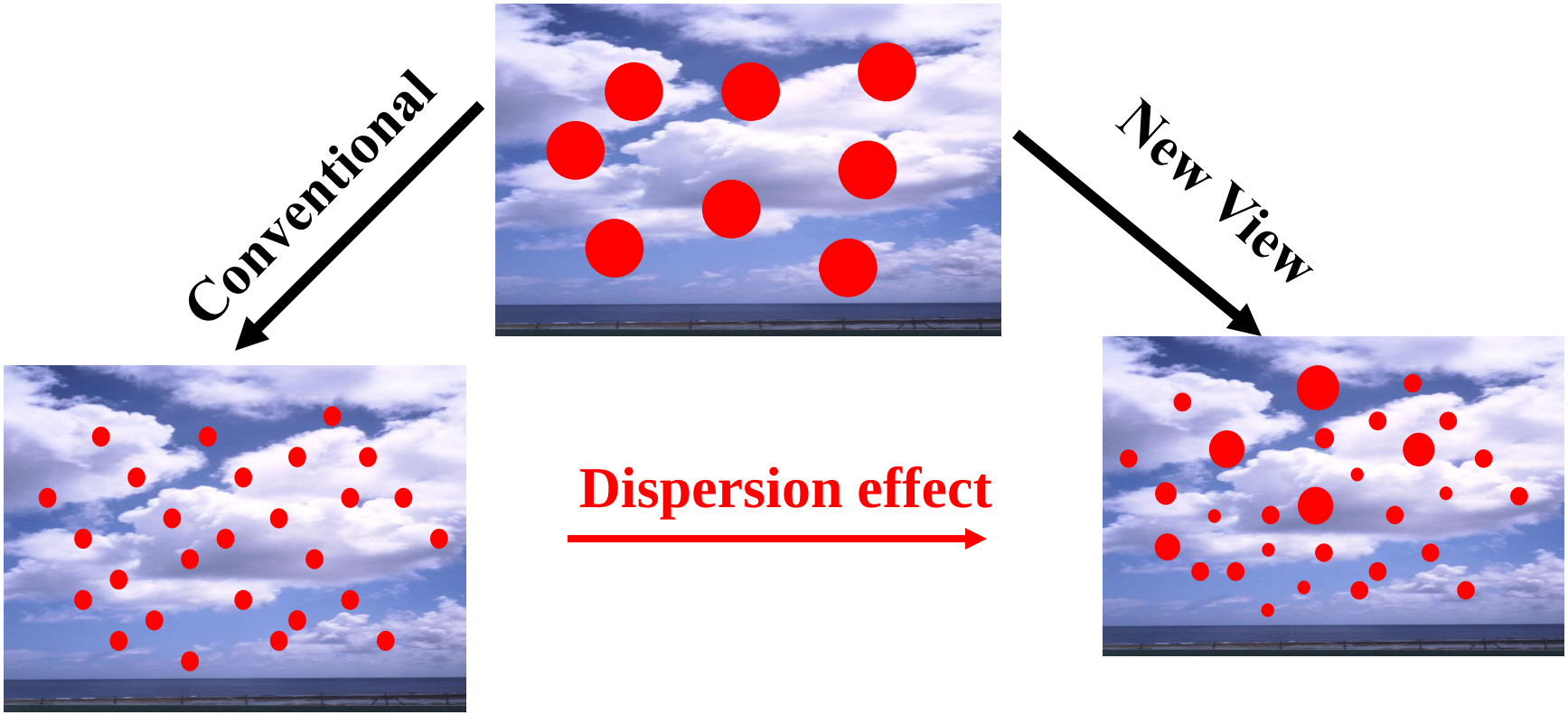


New results from non-precipitating cumuli at the ARM SGP site collected during the 6 month RACORO campaign.

Figure 6. Relative dispersion as a function of the specific cloud water content, calculated from FSSP measurements. Each point represents a cloud average during the dry season under CLEAN and POLLUTED conditions in the Amazonian region.

Droplet dispersion effect can either diminish or enhance the cooling of number effect; there is much more to be learned!

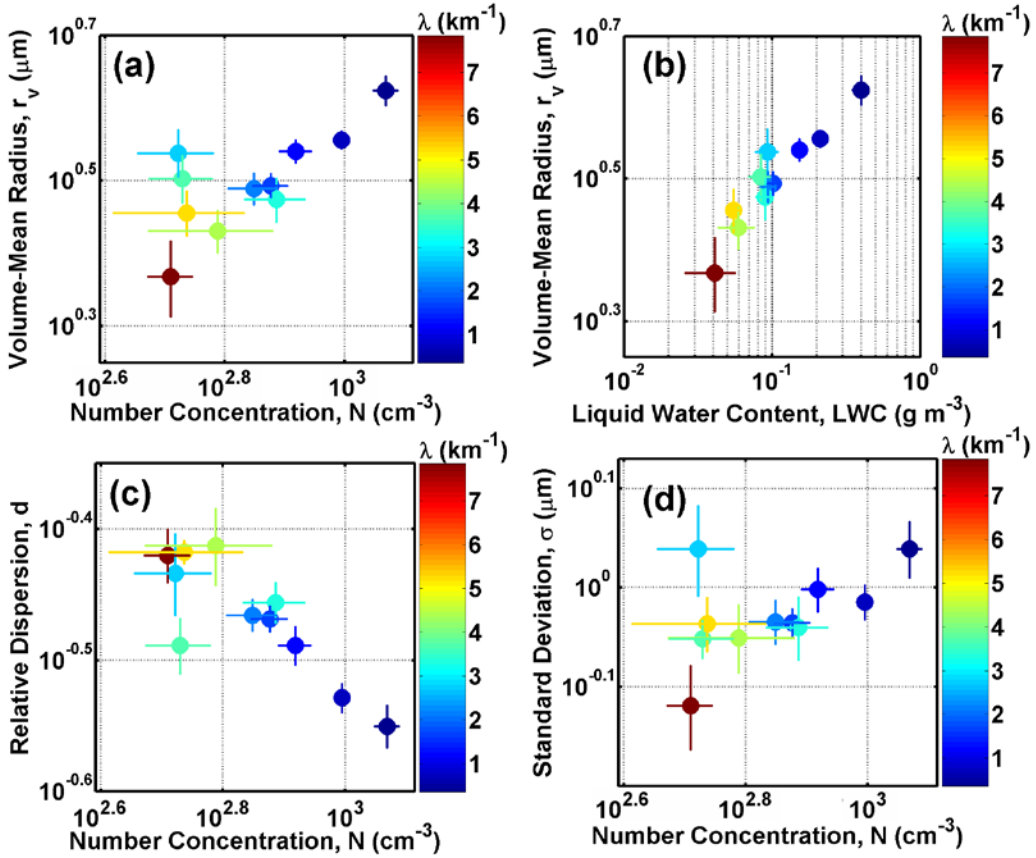
New View on Indirect Aerosol Effects

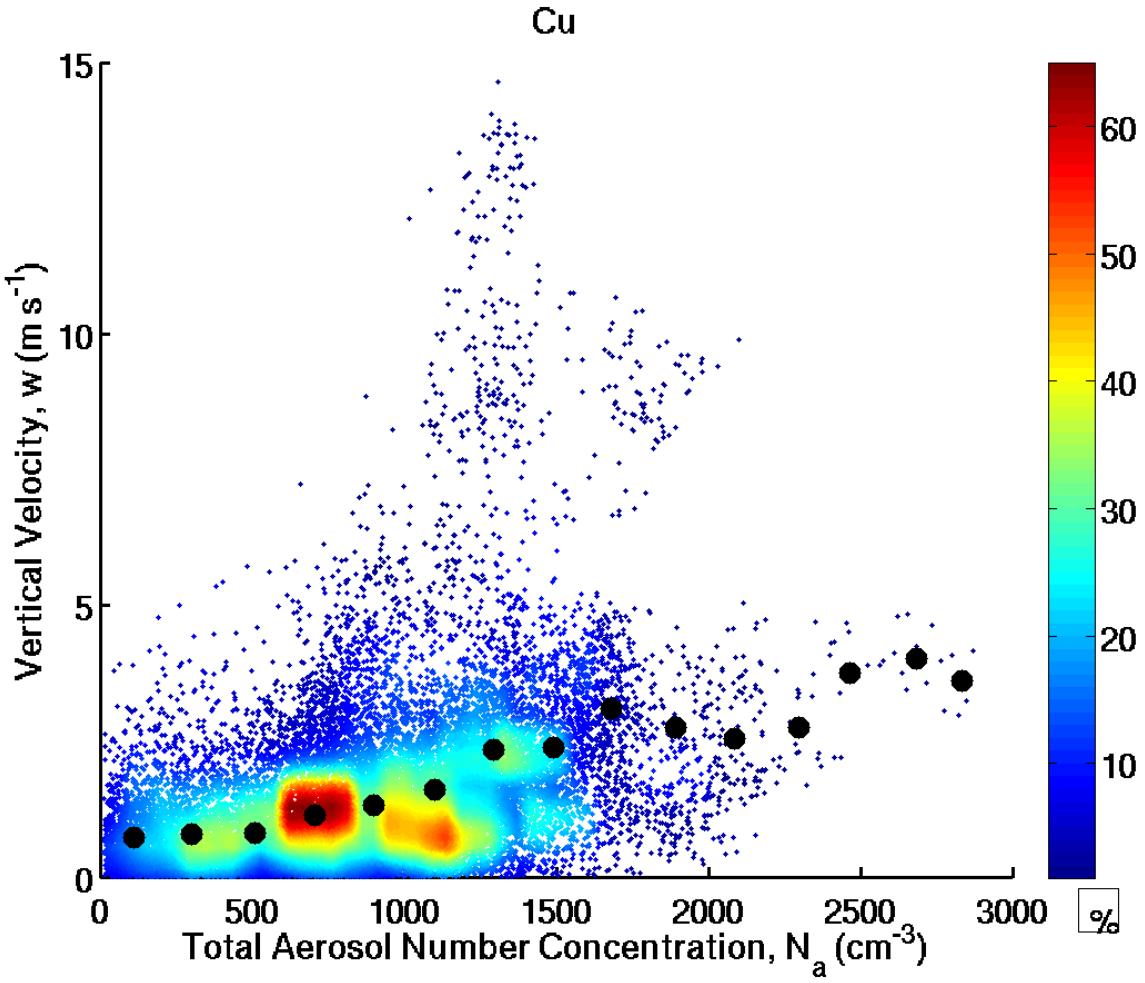


New View:

Indirect Effect = Number Effect + Dispersion Effect

Separation of Dynamical Effects from Aerosol Effect: Entrainment



Dependence of microphysical relationships on entrainment rate (λ) as observed from 186 RACORO cumuli (Lu et al, GRL, 2013)

Indirect Aerosol Effect Via Dynamics?