

Explore Relationships between Vertical Velocity, Entrainment, Mixing, and Microphysics

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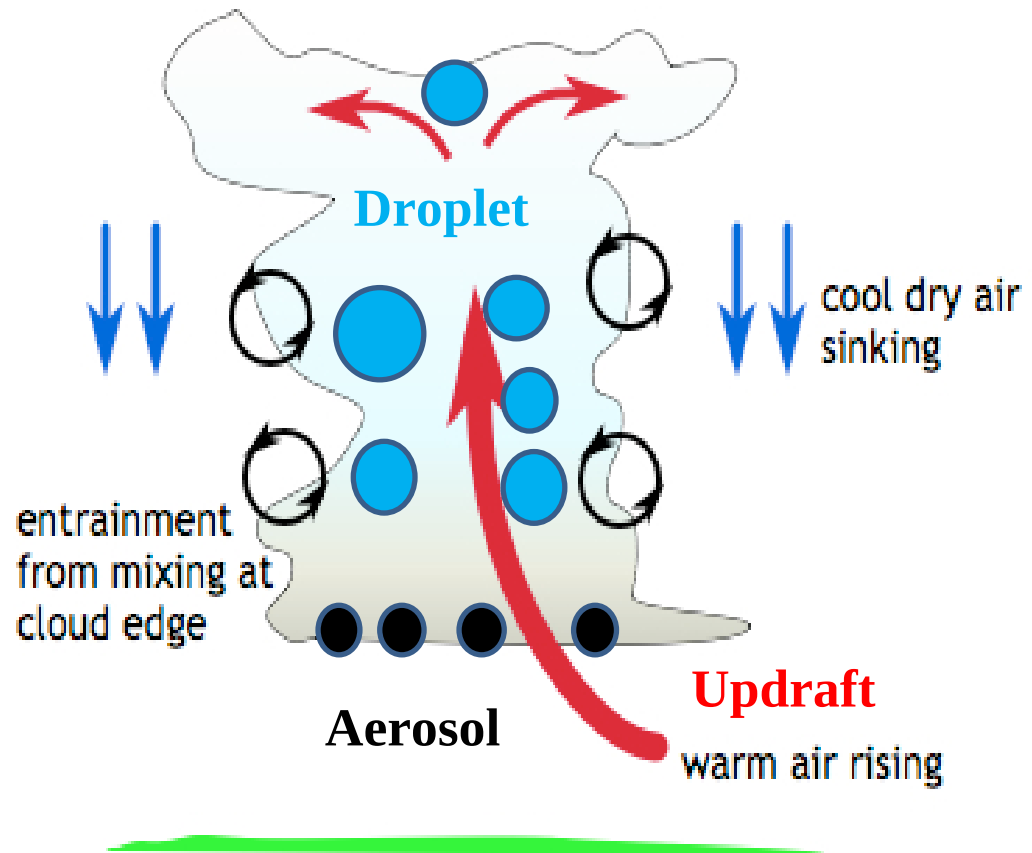
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Cloud as a Multi-Physics System

Factors to address today:

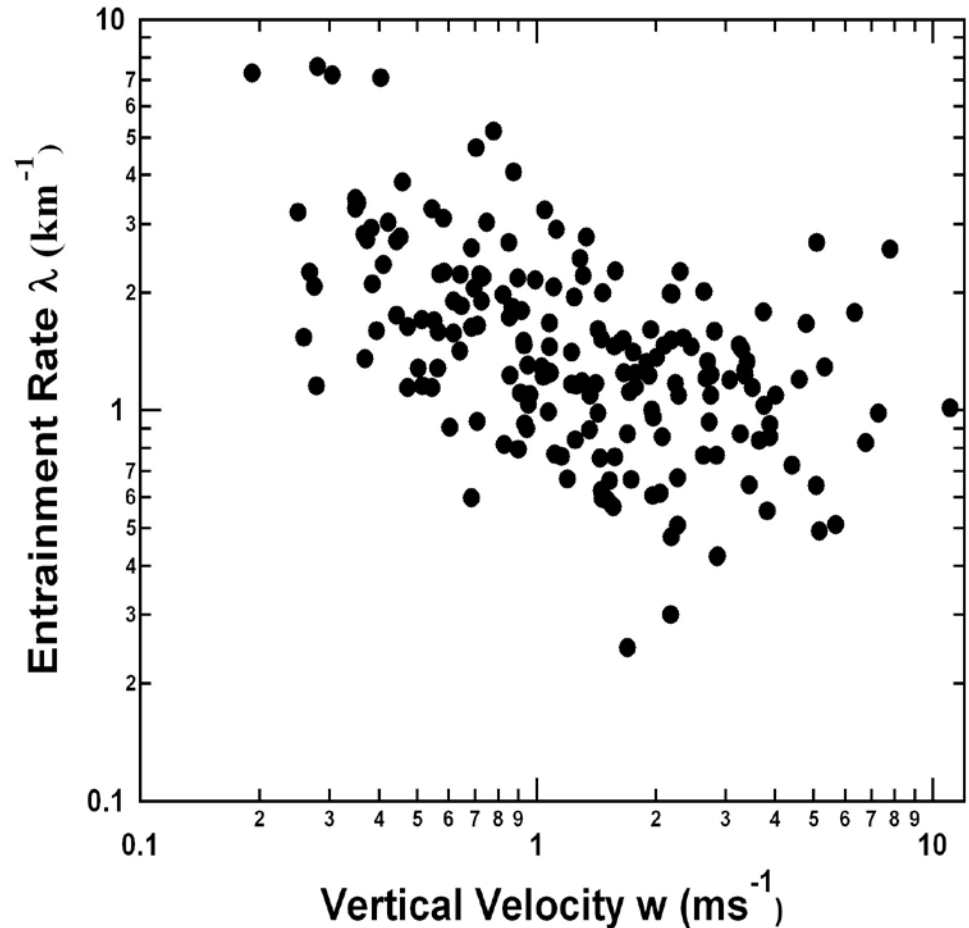
- Vertical velocity
- Entrainment
- Turbulent mixing
- Microphysics



Understanding and representing such an open system hold great promise to improve parameterizations of convection and aerosol-cloud interactions and reduce uncertainties in climate sensitivity and aerosol indirect effects.

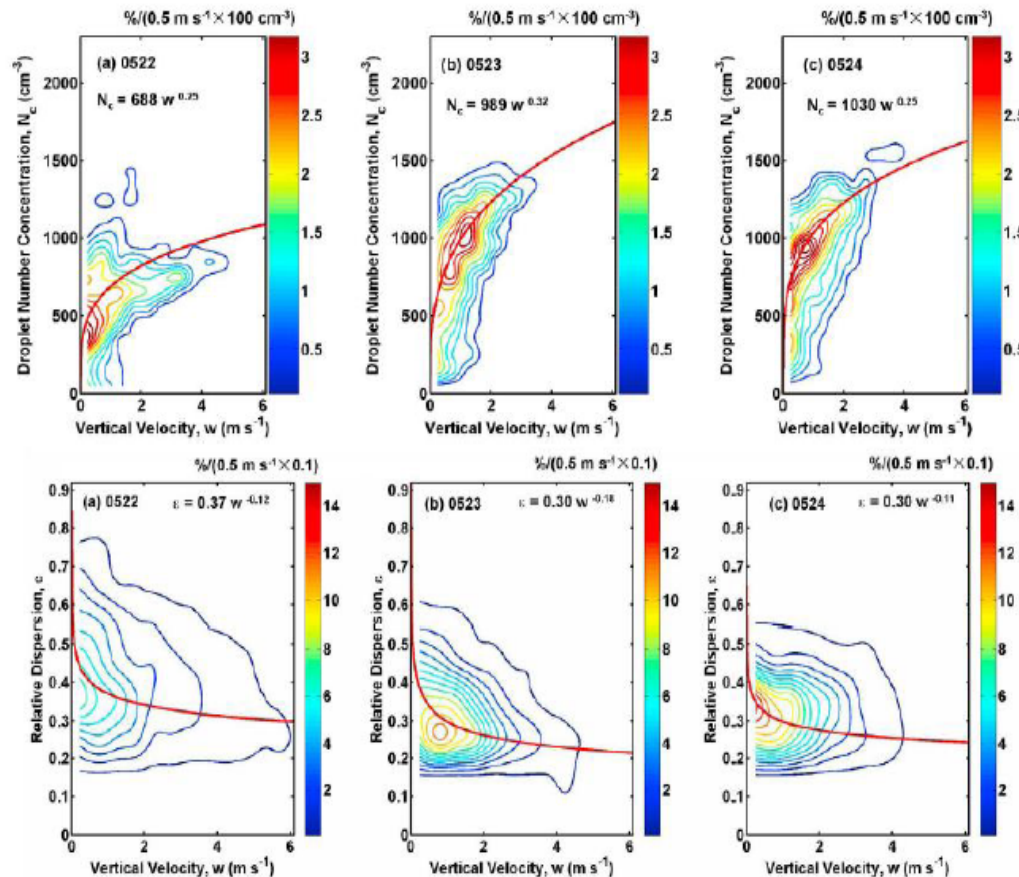
Relationship between Vertical Velocity and Entrainment Rate

- RACORO cumuli
- Aircraft measurement
- Method for estimating entrainment rate (Lu et al., GRL, 2012)
- Positive correlation



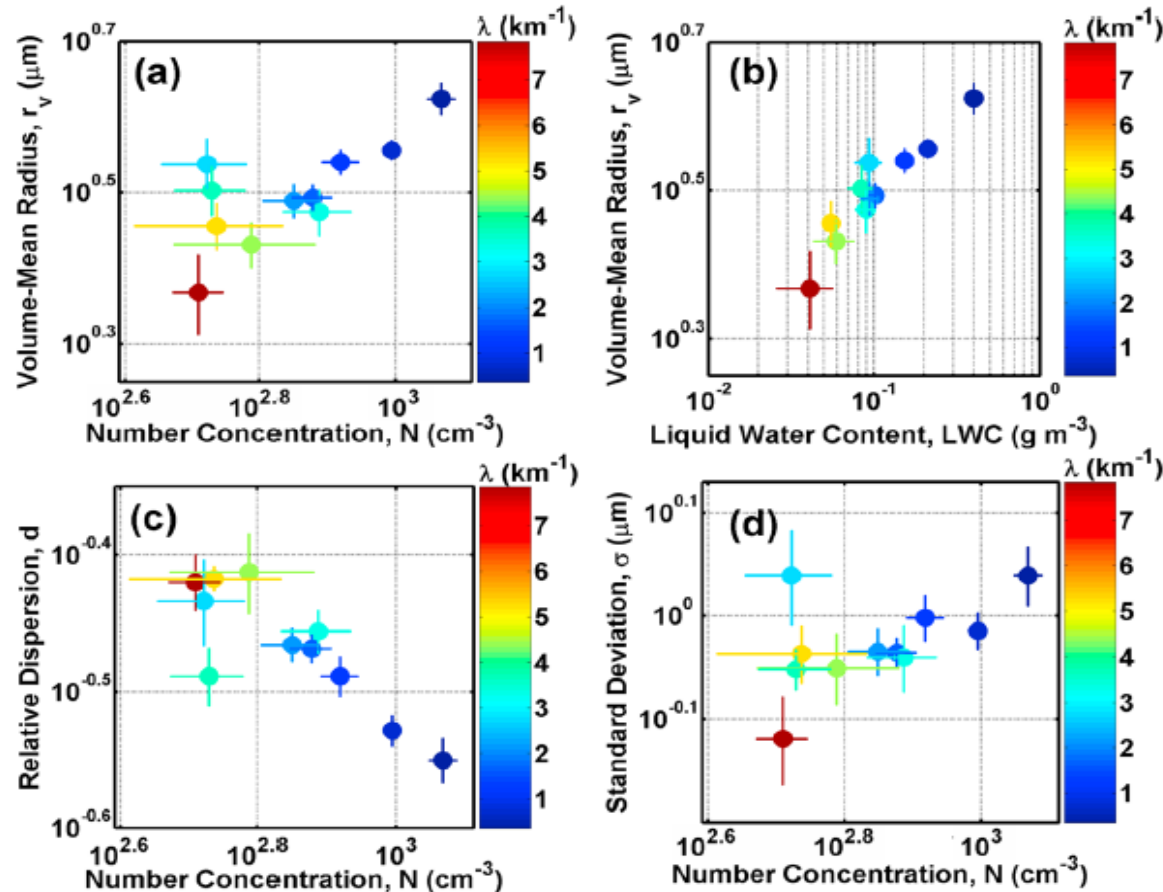
The positive correlation provides observational evidence for on-going efforts at improving parameterization of convection and entrainment rate.

Relationship between Vertical Velocity and Microphysics



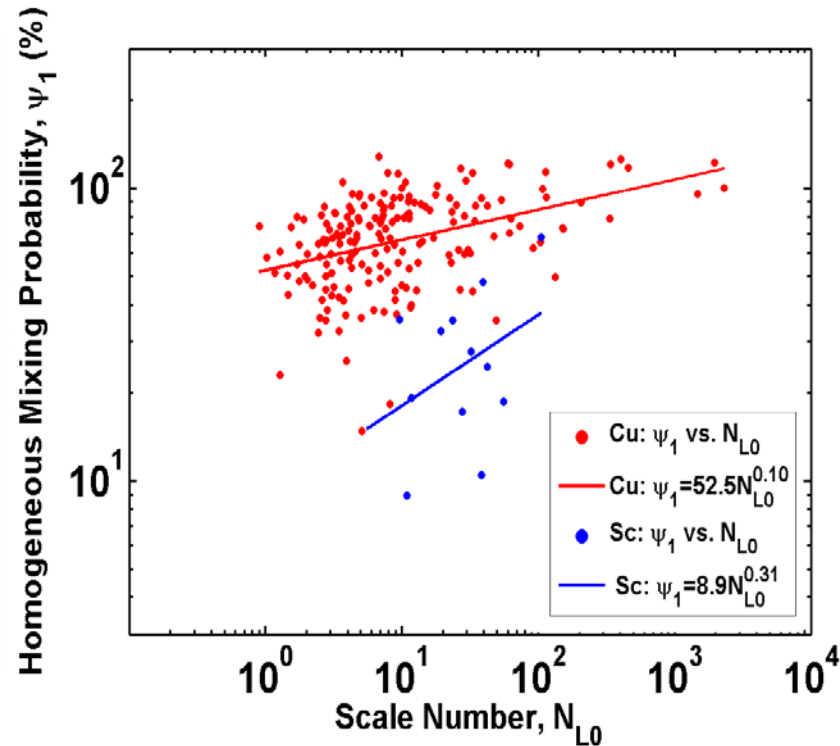
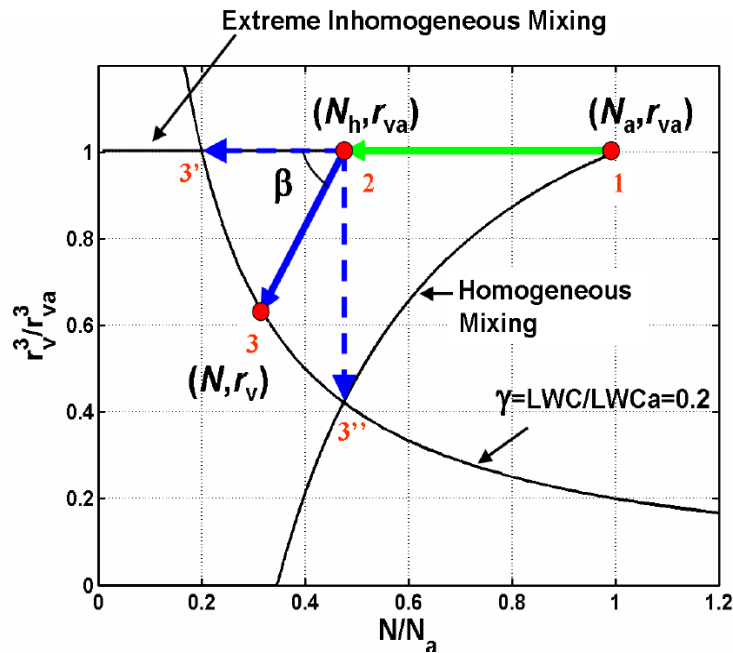
An increase in updraft leads to an increase droplet concentration but a decrease of relative dispersion, consistent with theoretical prediction of Liu et al. (GRL, 2006) (Lu et al., GRL, 2013a).

Relationship between Entrainment and Microphysics



An increase in entrainment rate corresponds to decreases in LWC, droplet concentration, droplet size and standard deviation, but an increase in relative dispersion (Lu et al., GRL, 2013b).

Effect of Different Mixing Mechanisms



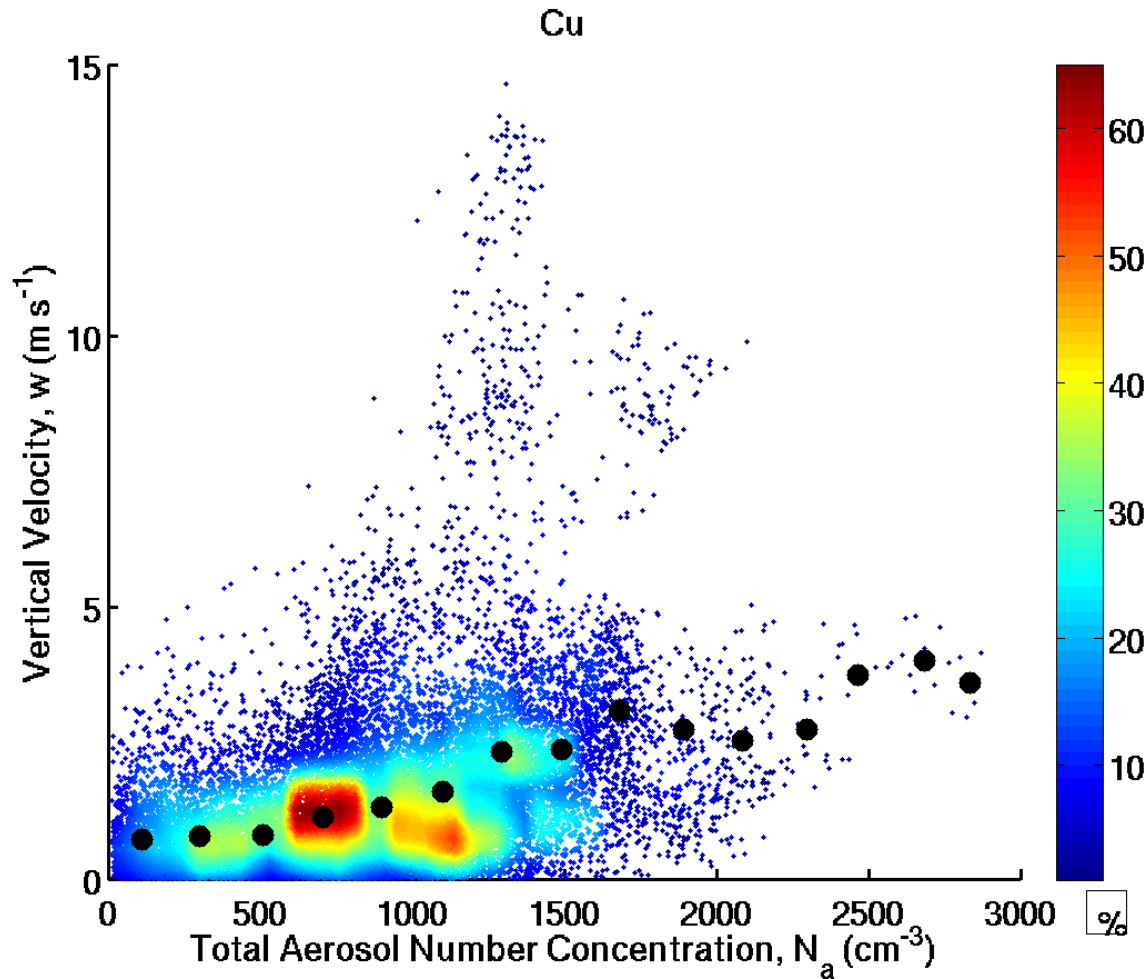
Turbulent mixing processes in clouds often falls between the two extreme mechanisms; turbulent mixing in RACORO cumuli tend to be more homogeneous than stratiform clouds (Lu et al., JGR, 2013).

Take-Home Messages

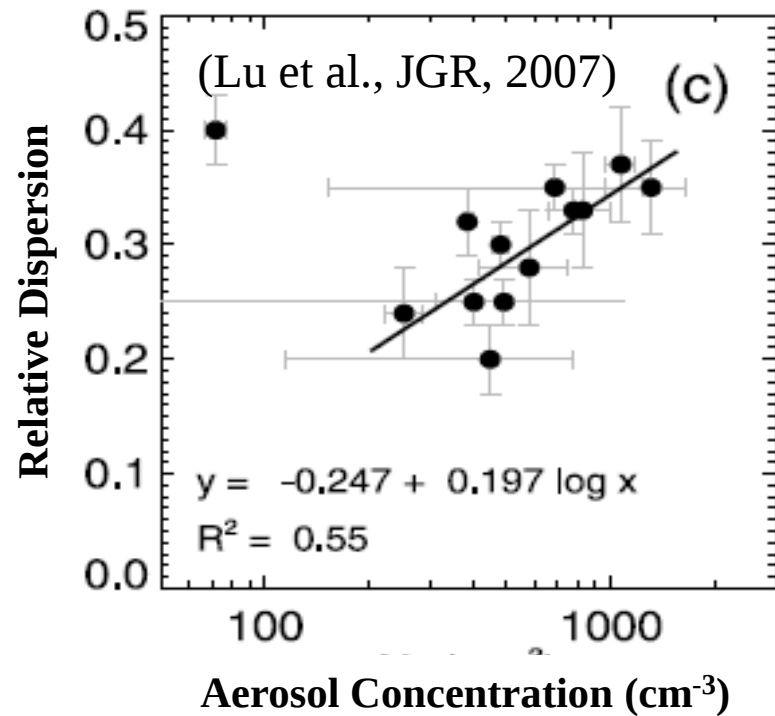
- **There are clear relationships between vertical velocity, entrainment rate, turbulent mixing mechanisms, aerosols and cloud microphysics.**
- **Disentangling these relationships is key to improving parameterizations of convection and aerosol-cloud interactions, and thus reducing uncertainty in climate sensitivity and aerosol indirect effects.**
- **Just scratch the surface; remote sensing techniques for measuring entrainment rate and mixing mechanisms; modeling studies needed.**

Backup Slides

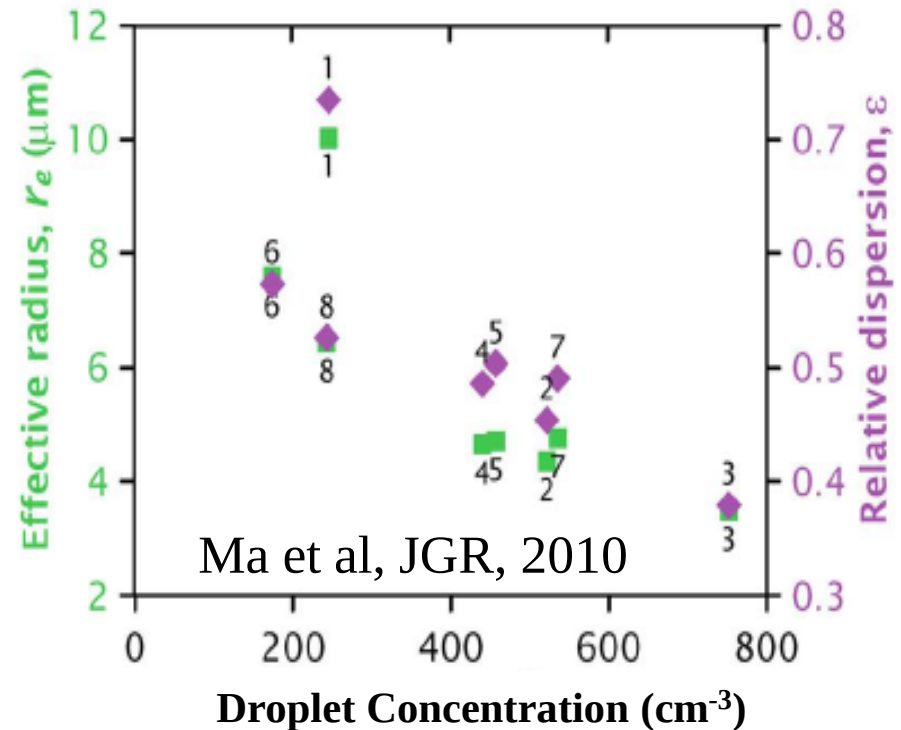
Another Dimension: Aerosol and Updraft Association



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.

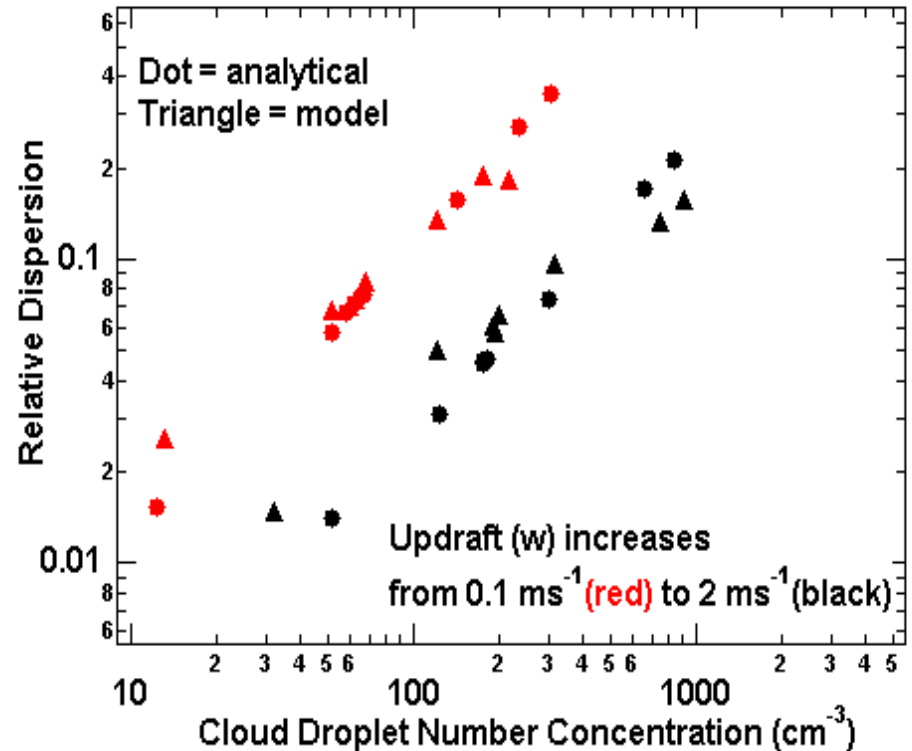
Analytical Formulation

(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.