Exploring emergent properties of complex aerosol-cloud-meteorology interactions over the WN Atlantic during ACTIVATE

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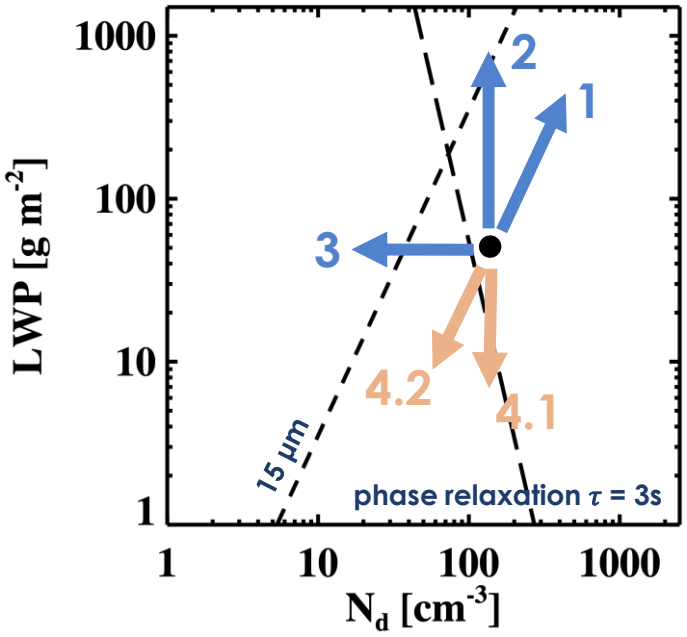
Emergent properties of warm cloud system

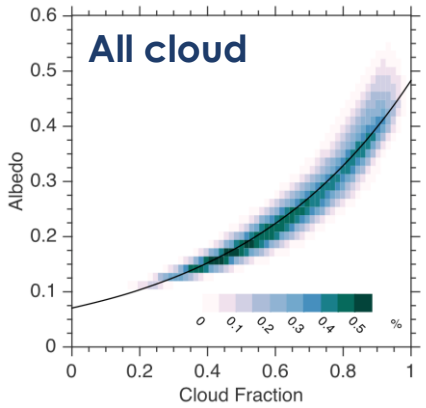
LWP-N_d



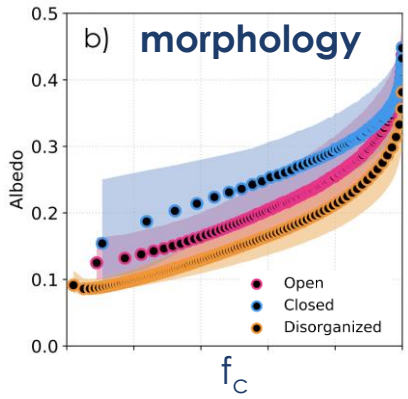
1. Droplet activation
2. Condensational growth
3. Collision-coalescence
4. Entrainment
   1) homogeneous
   2) inhomogeneous

Albedo-f_c

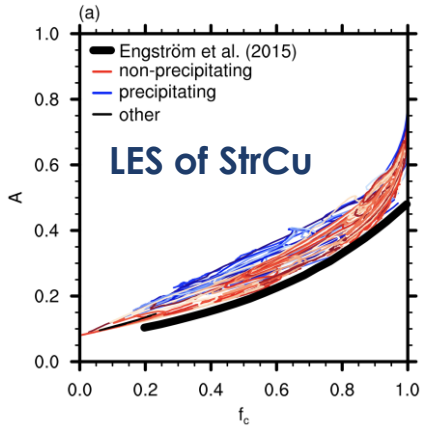
Engstrom et al. 2015



McCoy et al. 2023

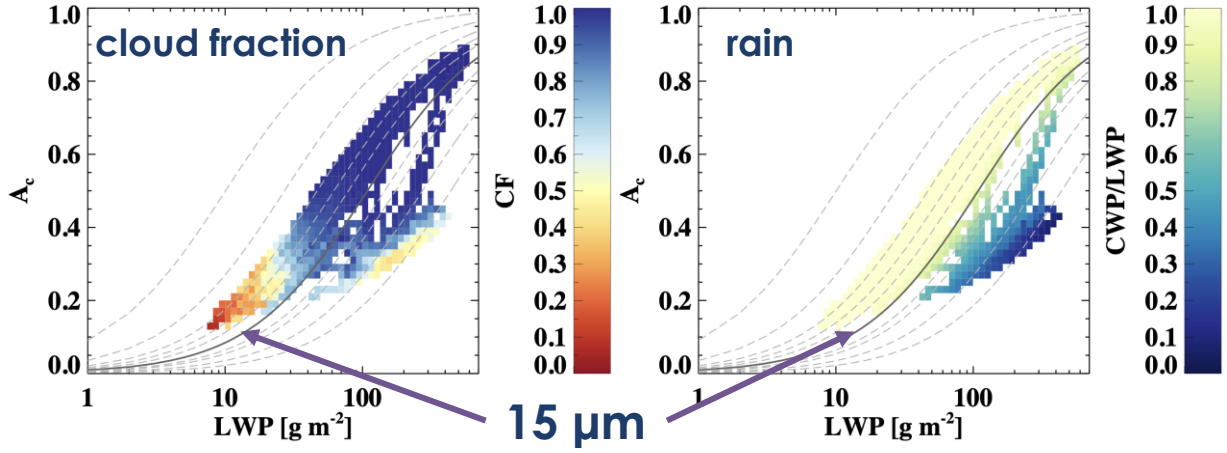


Hoffmann et al. 2023



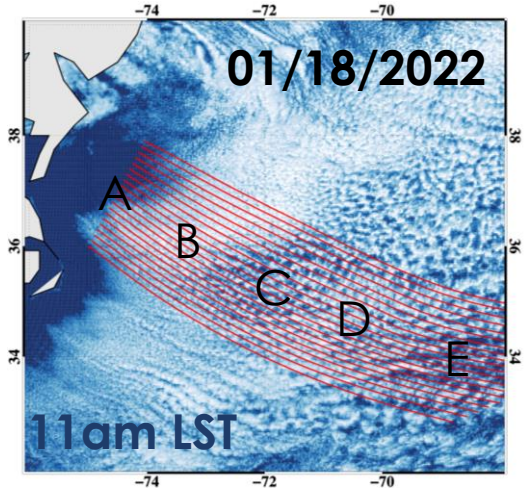
Albedo$_{cld}$-LWP

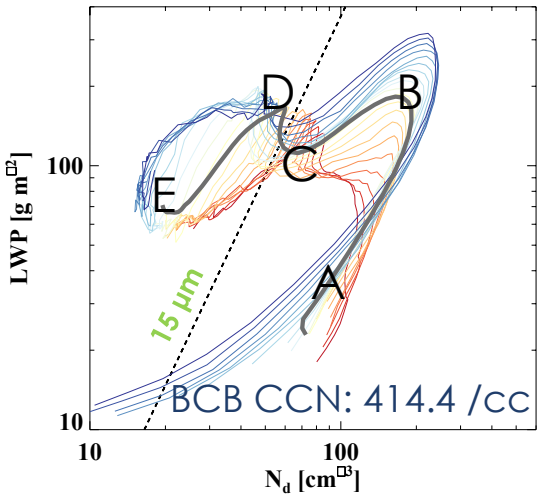
data: LES ensemble of StrCu

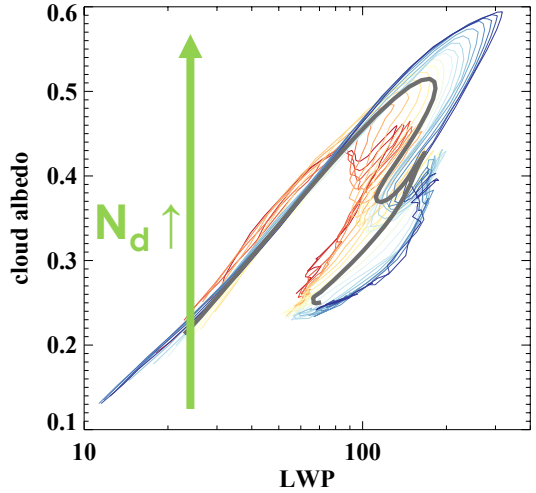


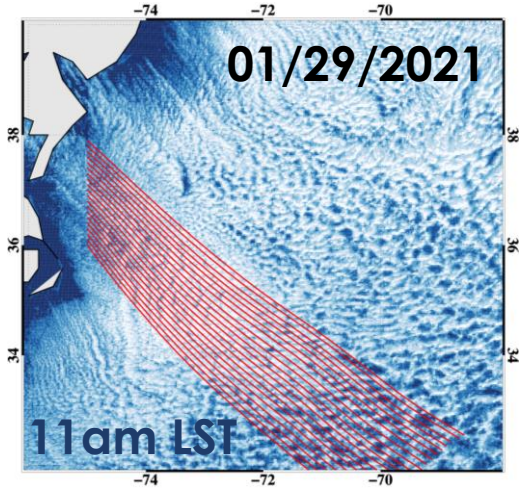
Cloud street evolution during Cold-Air-Outbreaks

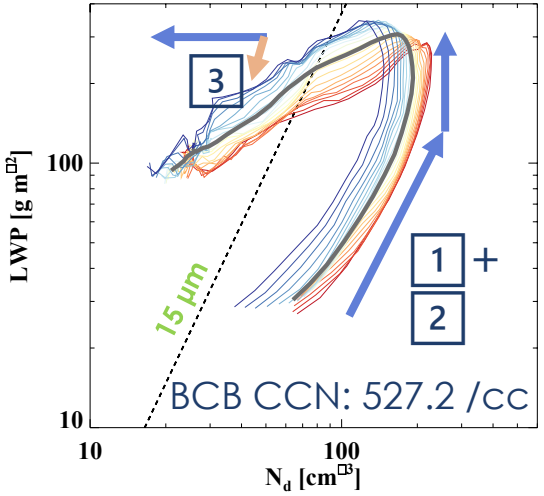
Precip-driven breakup

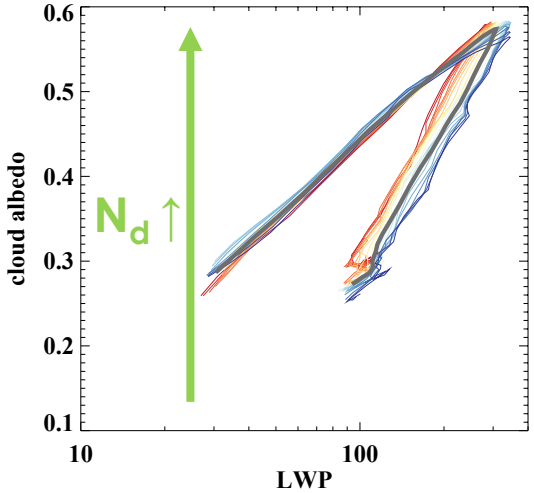












2-D "trajectories" inferring cloud street evolutions

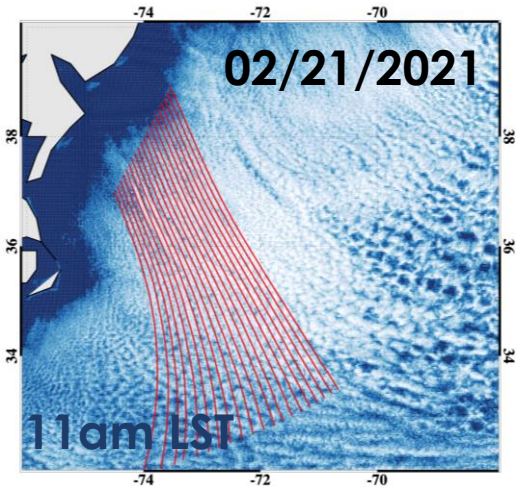
- ERA5 1000hPa winds
- GOES16 LWP, N_d, A_c

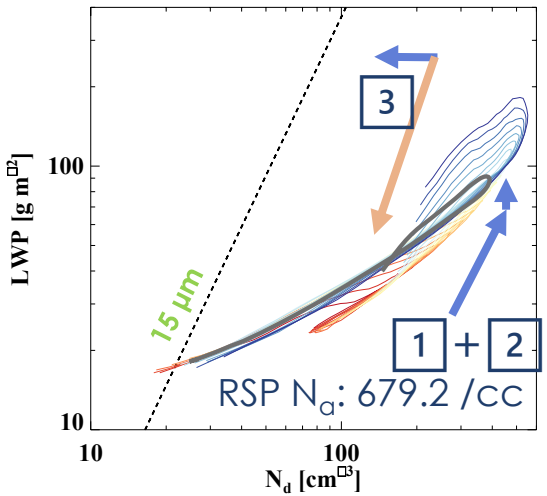
Precip-driven breakup

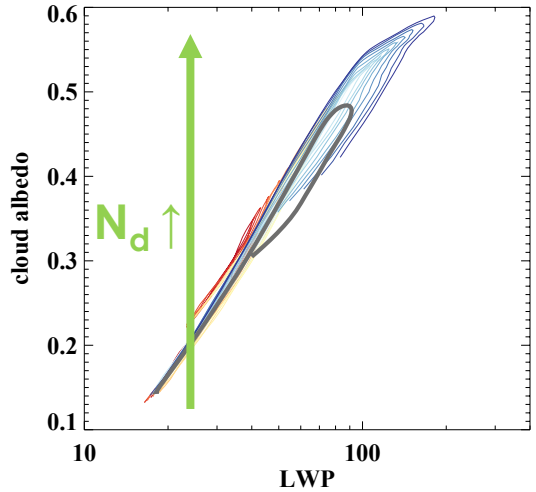
1) drop activation
2) condensational growth
3) collision-coalescence dominates, while entrainment reduce LWP
- fewer and bigger drops, leading to lower cloud albedo.

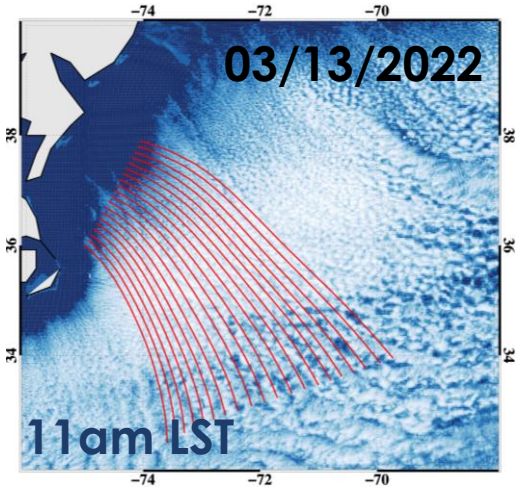
Cloud street evolution during Cold-Air-Outbreaks

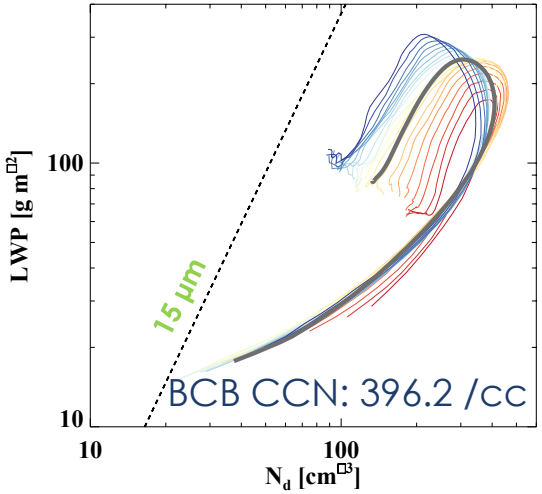
Entrainment-driven breakup

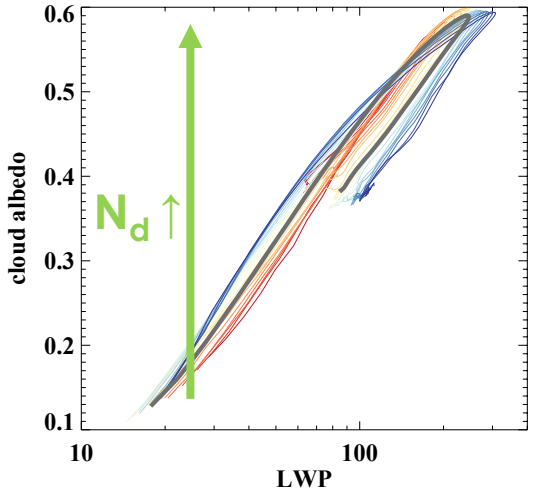












2-D "trajectories" inferring cloud street evolutions

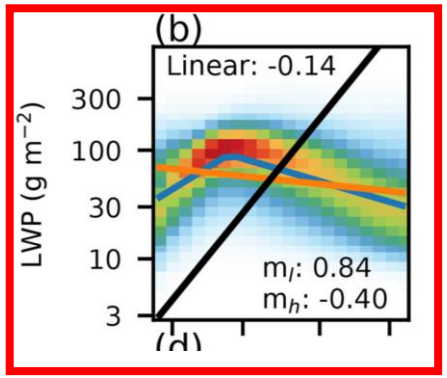
- ERA5 1000hPa winds
- GOES16 LWP, N_d, A_c

Entrainment-driven breakup

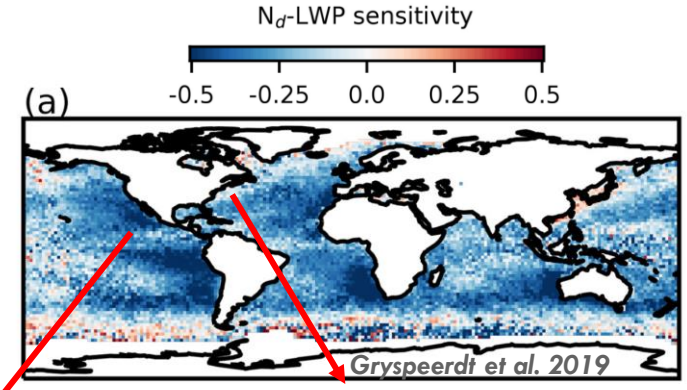
1) drop activation with abundant aerosol
2) Minimal condensational growth
3) Entrainment dominates, while collision-coalescence increase r_e
- breakup phase maintains similar albedo.

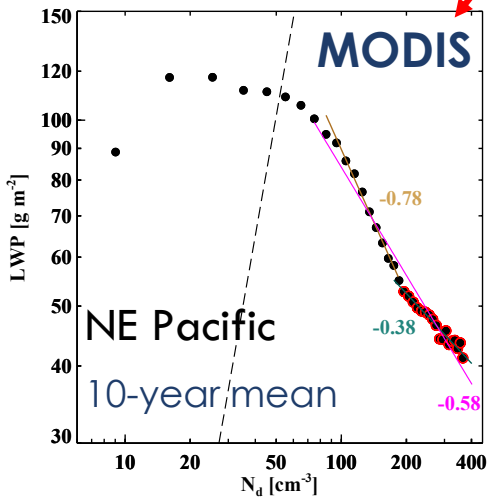
Explore LWP-N_d relationship in ACTIVATE region

global LWP-N_d relationship 'inverted-V'

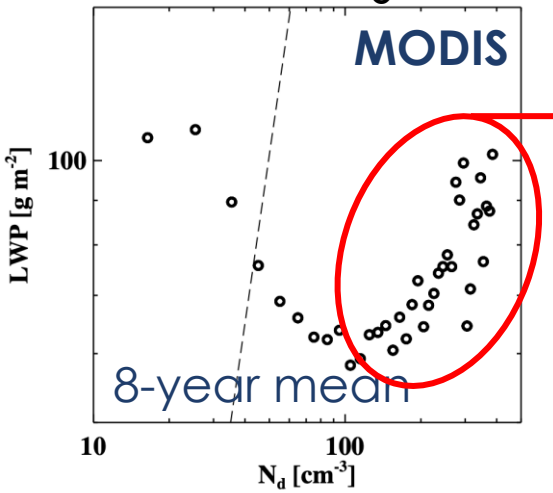


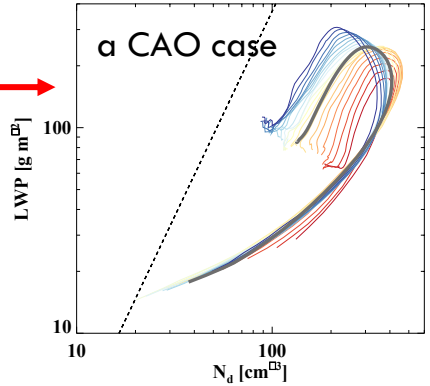
MODIS





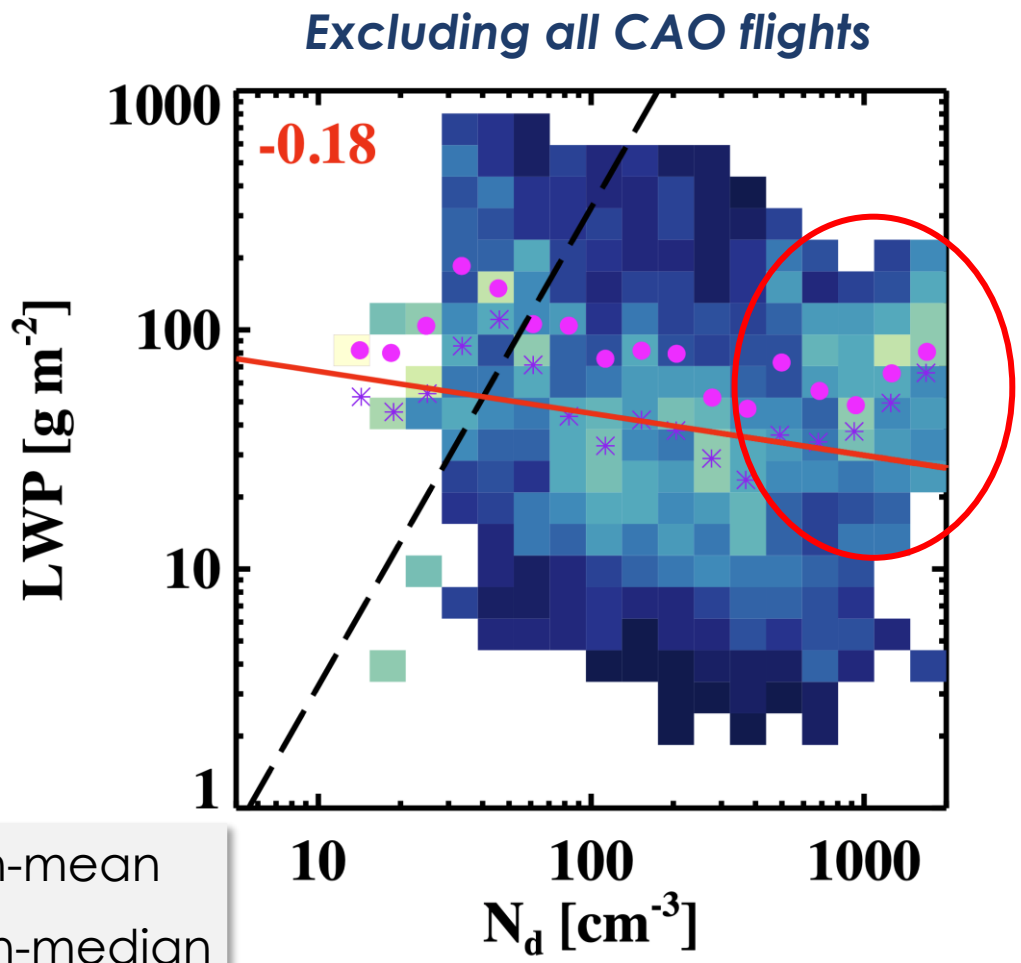
ACTIVATE region





- Why ACTIVATE region show 'v-shape'?
  - Is this due to all the CAO cases?
  - Other confounding factors?
- Can we really use LWP-N_d relationship globally to infer aerosol-cloud interactions for ***all*** low clouds **???**

non-CAO low-clouds, RSP LWP & N_d



● column-mean

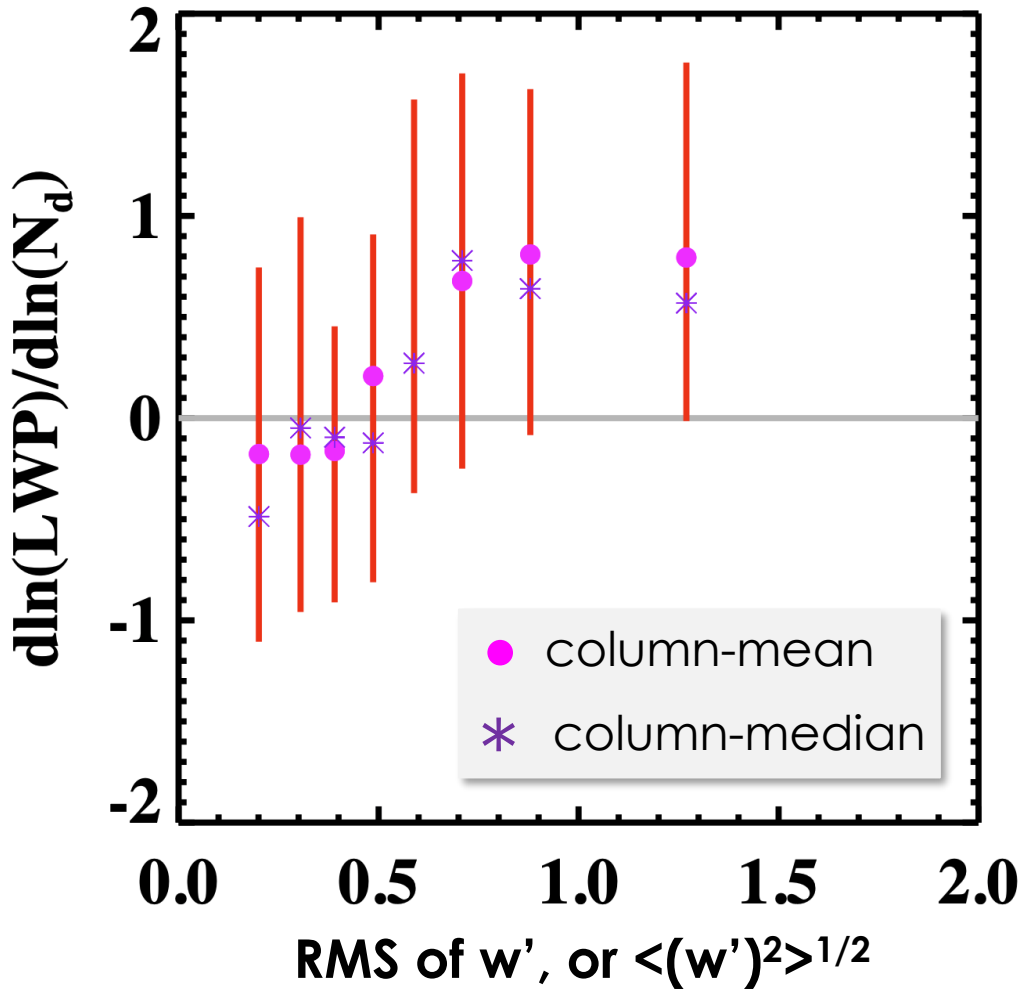
∗ column-median

All 3-year BCB legs (excluding CAO cases)

- LWP, N_d calculated from RSP τ and r_e (polarimetric) using adiabatic model
- RSP and BCB leg collocation: 15km and 30min

- Overall a '–ve' LWP-N_d slope (-0.18)
- 'inverted-v' shape evident
- **But, a '+ve' slope at high N_d still exists.**

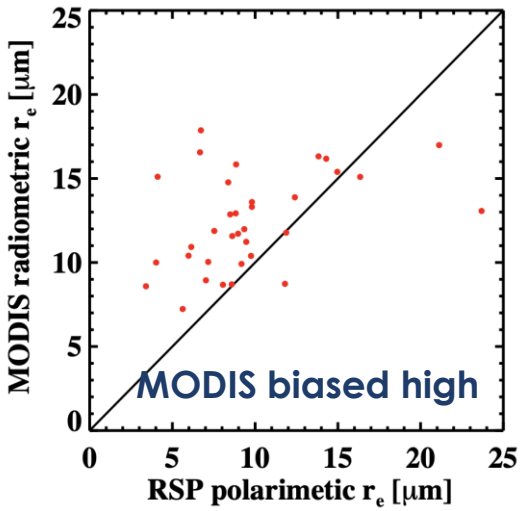
The role of updraft speed (BCB turbulence)

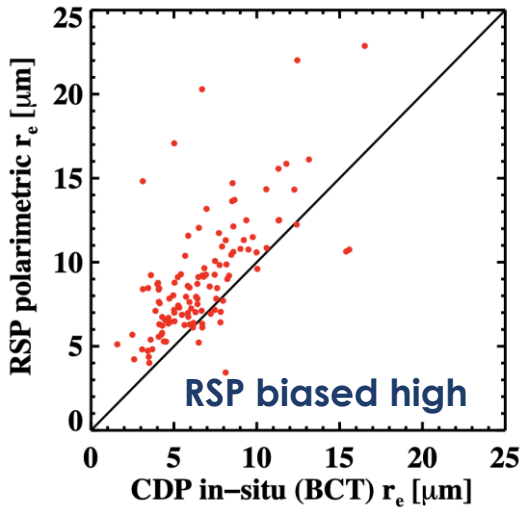


All 3-year BCB legs (excluding CAO cases)

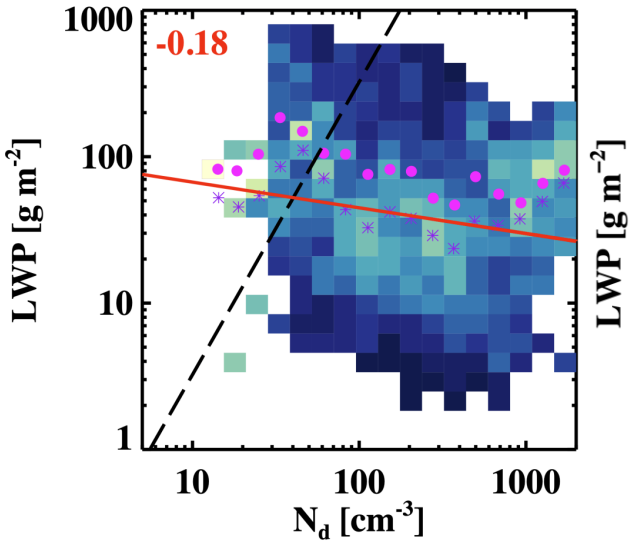
- LWP, N_d calculated from RSP τ and r_e (polarimetric) using adiabatic model
- RSP and BCB leg collocation: 15km and 30min
- $\langle(w')^2\rangle^{1/2}$ as a measure of sub-cloud turbulence
- '+ve' LWP-N_d slope explained by sub-cloud dynamics
- High-turbulence condition consistent with "more N_a → more N_d (activation) → more LWP"

A cautionary note: r_e uncertainty & LWP-N_d slope

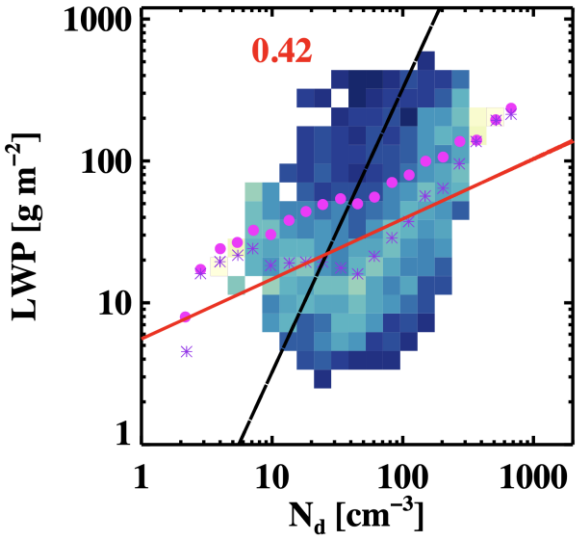




Non-CAO
RSP-derived



Non-CAO
MODIS-derived



● column-mean
∗ column-median

All 3-year ACB legs (excluding CAO cases)

- BCT legs CDP-re, collocated with RSP polarimetric r_e and MODIS bi-spectral (2.5° and 1hr).
- Markedly different LWP-N_d slope between the 2 methods.
- ***Perhaps the slope has nothing to do with physics, purely from retrieval errors?***

A cautionary note: r_e uncertainty & LWP-N_d slope

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Article

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Aerosol effects on clouds are concealed by natural cloud heterogeneity and satellite retrieval errors

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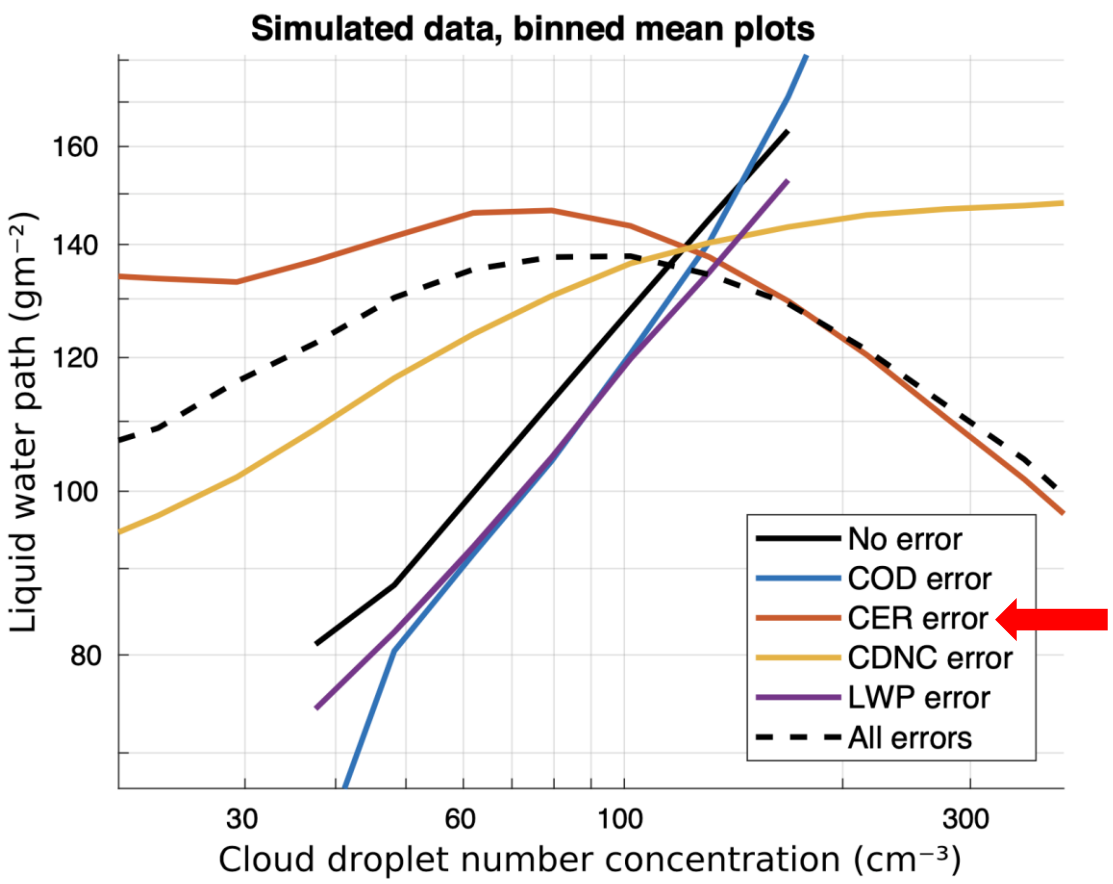
Adiabatic Assumption

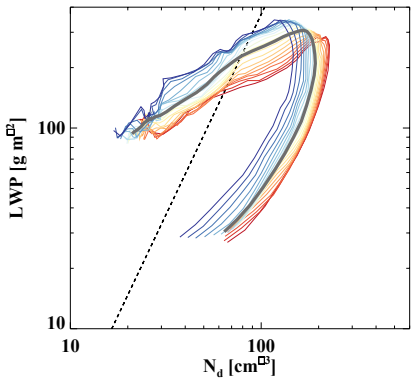
$$N_d = K\tau^{1/2} r_e^{-5/2}$$

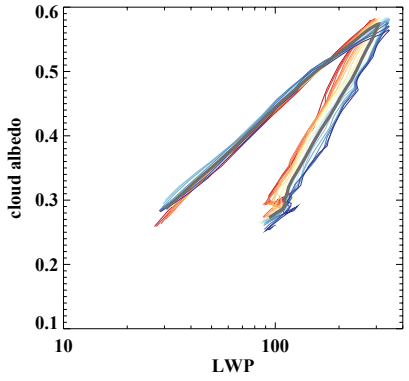
$$L_p = \frac{5}{9}\rho_w \tau r_e$$



Summary

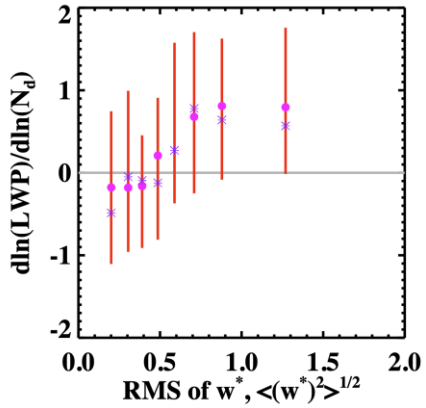
Questions? Suggestions? Comments?

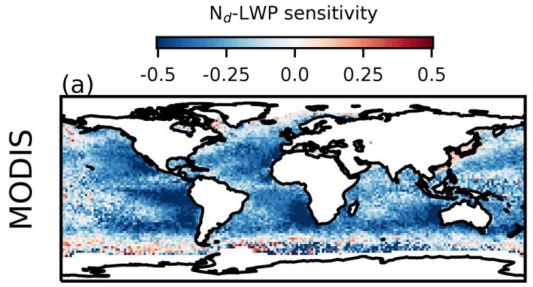


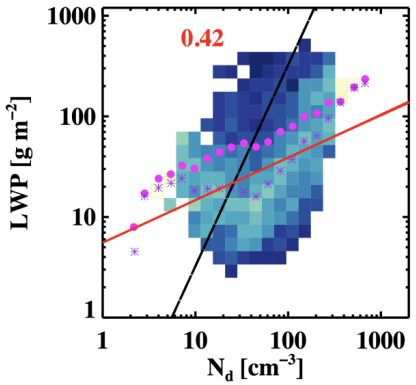


- CAO-evolution characterization in GV spaces – a framework to integrate process/large-scale modeling and in-situ/satellite observations (seeking collaborations).
- **Next step: understand aerosol & large-scale environmental control on precip- vs entrainment- driven breakup.**

- Characterize the role of updraft/turbulence in governing the LWP-N_d relationship; an overlooked confounding of aerosol-cloud interactions in satellite-based approaches?







- Can we really use satellite observed LWP-N_d slope to infer ACI for ***all*** low clouds (especially disorganized, broken clouds)?
- **How much of the slope is due to r_e uncertainties in retrievals?**

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CIRES