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 fraction**
- **Rain**

15 μm
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.

02/21/2021
11am LST
RSP \( N_a \): 679.2 /cc

03/13/2022
11am LST
BCB CCN: 396.2 /cc
Explore LWP-$N_d$ relationship in 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 & $N_d$

Excluding all CAO flights

- LWP, $N_d$ calculated from RSP $\tau$ 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-ν’ 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 $\tau$ 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 $N_a$ $\rightarrow$ more $N_d$ (activation) $\rightarrow$ more LWP”
A cautionary note: $r_e$ uncertainty & LWP-$N_d$ slope

**All 3-year ACB legs (excluding CAO cases)**

- BCT legs CDP-$r_e$, 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?

**Non-CAO**

- RSP-derived
  - MODIS biased high
- MODIS-derived
  - RSP biased high

- CDP in-situ (BCT) $r_e$ vs. LWP
- RSP polarimetric $r_e$ vs. $N_d$
- Column-mean
- Column-median
A cautionary note: $r_e$ uncertainty & LWP-$N_d$ slope
Characterize the role of updraft/turbulence in governing the LWP-$N_d$ relationship; an overlooked confounding of aerosol-cloud interactions in satellite-based approaches?

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.

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?