1. Examine the winter cold-air outbreak data from the point of view of generalizing their attributes & extending to satellite, reanalysis datasets. Focusing on 5 cases we believe are encompass the phase space in $N_d$, LWP, $T_{ct}$

2. This includes assessing remotely-sensed cloud properties ($N_d$, LWP, $T_{ct}$)

3. Examine cloud microphysics as a function of ASTER-derived cloud spatial scales
What we did

• Selected 5 cold-air-outbreak cases spanning a representative range of environmental/aerosol conditions
  flight-maxima LWPs: 80-250 g m⁻² (MODIS)
  cloud top temperatures flight-minima: -5 to -15 °C
  *in-situ* flight-maxima N_d *: 500-1540 cm⁻³

=> examine the *in-situ* ice microphysics for dependencies

*a framework*

*continental aerosol outflow; Painemal et al 2021 JGR; Tornow et al 2021 GRL.

*in-situ* near-cloud-top effective radii only reach 9 micron at best.
5 March 2021  
8 March 2021

Flight track

Blue- SST; orange - MODIS LWP
What we have learned #1:

Wintertime cold-air outbreak clouds over the western Atlantic are not ice-deprived

4 out of the 5 cases already contained ice as soon as clouds developed

This despite cloud top temperatures > -15C, and small dropsizes

Original premise that clouds start all-liquid then transition to mixed-phase thrown out the window
8 March 2021 (afternoon)

-the one flight with no evidence of ice-

\[ \overline{N_d} = 1000 - 1100 cm^{-3} \]

\[ T_{ct} \sim -5^\circ C \]

RSP LWPs \(<~ 80 \text{ g m}^{-2} \)

Surface wind speeds low (~8 m/s)

No near-surface rain

(cloud clearing most likely through cloud top entrainment)
ACTIVATE ice crystal number concentrations indicate secondary ice production, on par with southern ocean values.
Ice water contents are higher when vapor diffusional growth dominates, particularly dendritic growth.

Ice production starts at CTT of ~ -5°C

[Graph showing data points with labels for 1March, 29January, 3February, and 5March.]
Ice water contents are higher for deeper clouds (colder tops), producing more liquid rain (if present) rates are also higher for higher LWPs.
Initially mostly liquid, some rimed ice

Cloud depth becomes the primary control on this evolution
High $N_d$ almost a given (extending the closed cells)

Cloud deepening $\rightarrow$ clearer, quicker ice growth by vapor diffusion

Aggregation

preceding open-celled cloud morphologies

melting into surface rain

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Because the MODIS LWPs can reach up to 800 g m\(^{-2}\) we are also investigating the profiles to put MODIS on a better footing.

**Figure 11.** *In situ* February 3, 2021 morning RF44 descent at 33.91°N, 73.07°W profiles. Same conventions as in Fig. 5. FCDP failed in the upper cloud layer. CDP \(N_d\) not yet corrected.
The 5-case CAO analysis is fairly mature.

Plan is to extend the profile analysis to all the wintertime ACTIVATE cases as a remote sensing assessment.

Shares some goals with the ASTER assessment
(For which we hope to say something about remotely-sensed microphysics as a function of cloud macrophysics)
Three ASTER* under flights with broken, low clouds & minimum upper-level cloud

* Advanced Spaceborne Thermal Emission and Reflection Radiometer
• 15-m spatial resolution cloud mask over a 60 km swath, based on 3 visible nadir bands (0.52- 0.86)+ 11micron (90m resolution)

• No ASTER microphysical retrievals

• RSP derives cloud optical depth ($\tau$), effective radius ($r_e$) using a polarized cloud bow retrieval @ 0.863 micron

  - $N_d, LWP$ derived using $N_d = 1.4067 \times 10^{-6} [cm^{-1/2}] \frac{\tau^{1/2}}{r_e^{5/2}}$ and $LWP = \rho_w \frac{5}{9} r_e \tau$

  (Painemal and Zuidema, 2011), ‘confident cloudy’ MODIS cloud mask

• in-situ $N_d$ from FCDP (1.5-50 micron) and CDP
March 29, 2021, 15:37-15:50 UTC

~50 km span

Not a perfect colocation but: -

data a homogeneous aerosol &

cloud environment:

- $N_{aerosol} (>100 \text{ nm})$ of

  200-250 cm$^{-3}$

- $H_{ct}$ of 1.2-1.4 km, $T_{ct} > -10 \degree C$

- Little (no?) rain

=> statistical relationships okay

Includes in-situ corrected time offset; 5 minutes diff from ASTER,
2km offset between the two planes
Based on 5 10-km domains

Optical depth less for smaller clouds (expected)

Effective radius doesn't vary much with cloud size

In-situ Nd somewhat invariant with cloud size (unexpected)

LWP less for smaller clouds (expected)

FCDP&RSP equivalence may be fortuitous (we need to check)

True for both in-situ and remote sensors.
In-situ probes show Nd, re are [slightly] positively correlated, suggesting growing inner cloud cores & dissipating edges [but still need to put that on firmer ground]

While remote retrievals suffer at the edges, RSP extends to smaller cloud sizes/higher Nd

Good correspondence between RSP, FCDP Ignores 300m of vertical Displacement
can UC-12 camera imagery be used to extend to more scenes (10 m spatial resolution, ~15 km swath)?

Unclear, might at the least need to identify some useful cases