Using airborne measurements to evaluate forecasts of freezing drizzle aloft: results from the WINTRE-MIX field campaign

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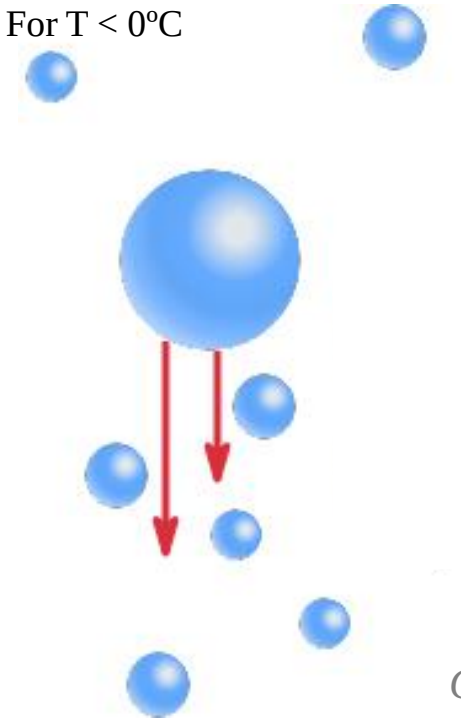
PRECIPITATION PROCESSES OF SLD

- Supercooled large droplets (SLD) are water droplets that are in a liquid state below 0ºC that have a diameter greater than 100 μm
- Significant icing hazard as SLD accretes on aircraft
- Intricate precipitation processes pose a challenge to numerical weather prediction (NWP) when predicting SLD *(Jensen et al. 2023)*

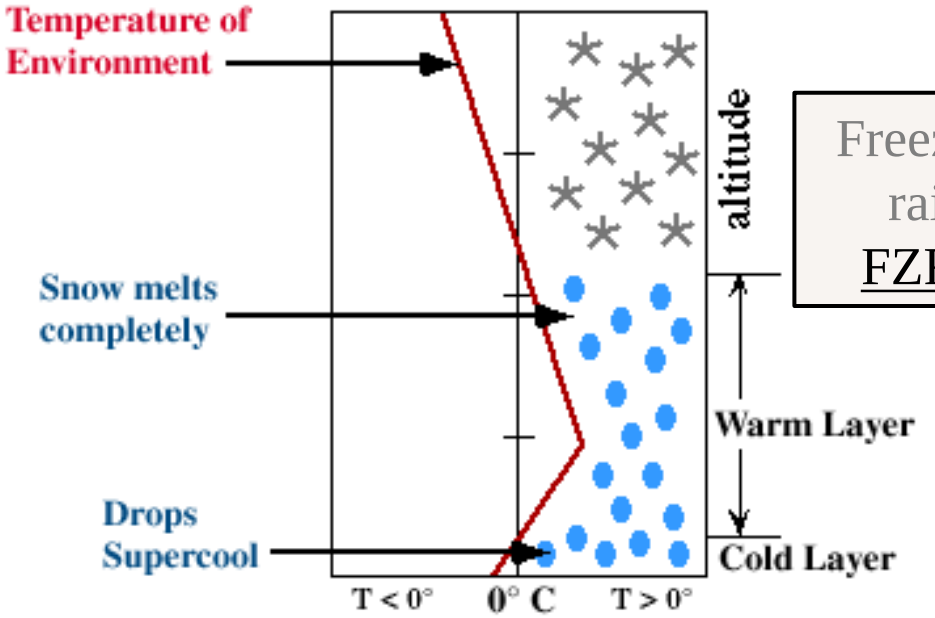
Collision Coalescence

Freezing drizzle **FZDZ**



CMMAP

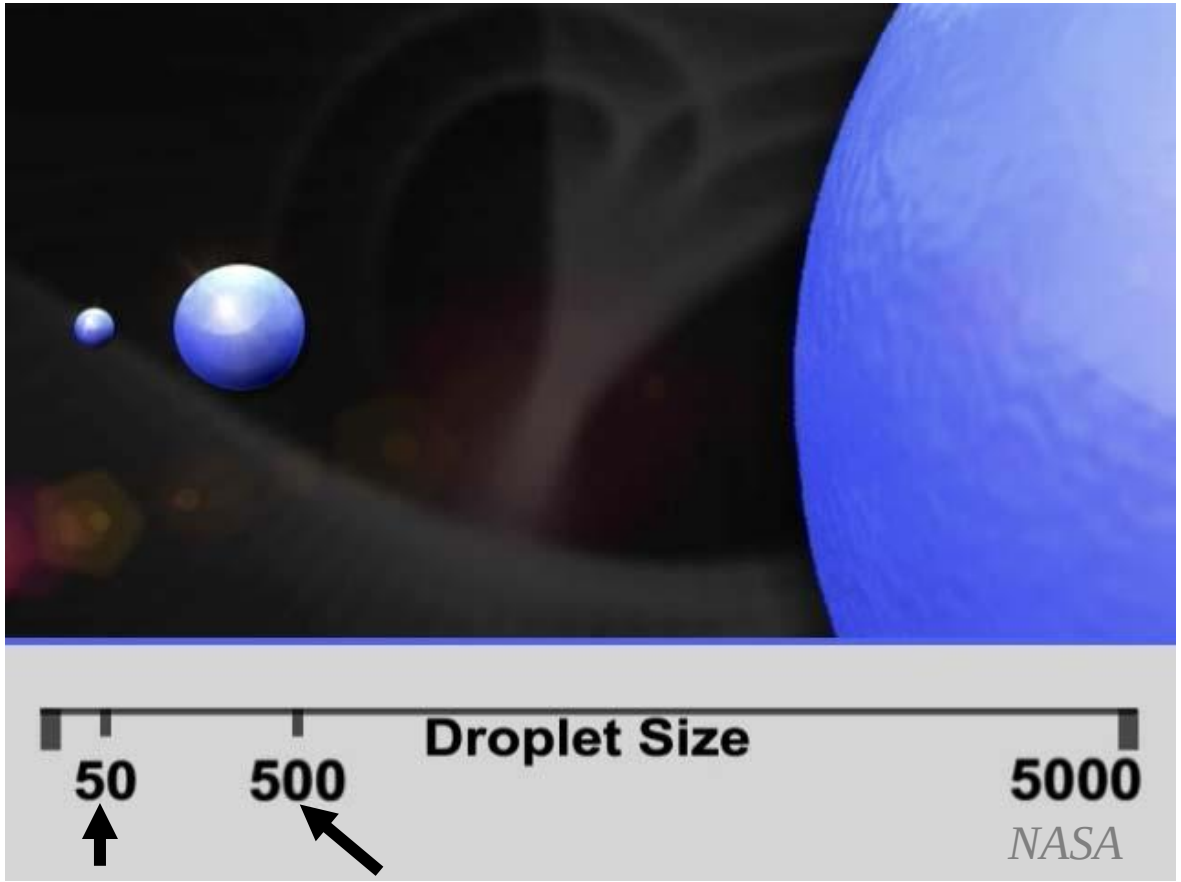
Ice Melting Process



Freezing rain FZRA

University of Arizona

ICING FORECAST CHALLENGES



- Microphysical properties remain a challenge for NWP as liquid water content (LWC) and drop size distribution (DSD) fail to be modeled correctly *(Thompson et al. 2008, Thompson et al. 2017, Bernstein et al. 2019, Tessendorf et al. 2021)*
- Aviation forecasts use high-resolution operational models given their use of multiple hydrometeor, mixed-phased microphysics *(Benjamin et al. 2016)*

Code of Federal Regulations Title 14 Chapter 1 Part 25
Small Drop → Appendix C
Large Drop → Appendix O

APPROACH

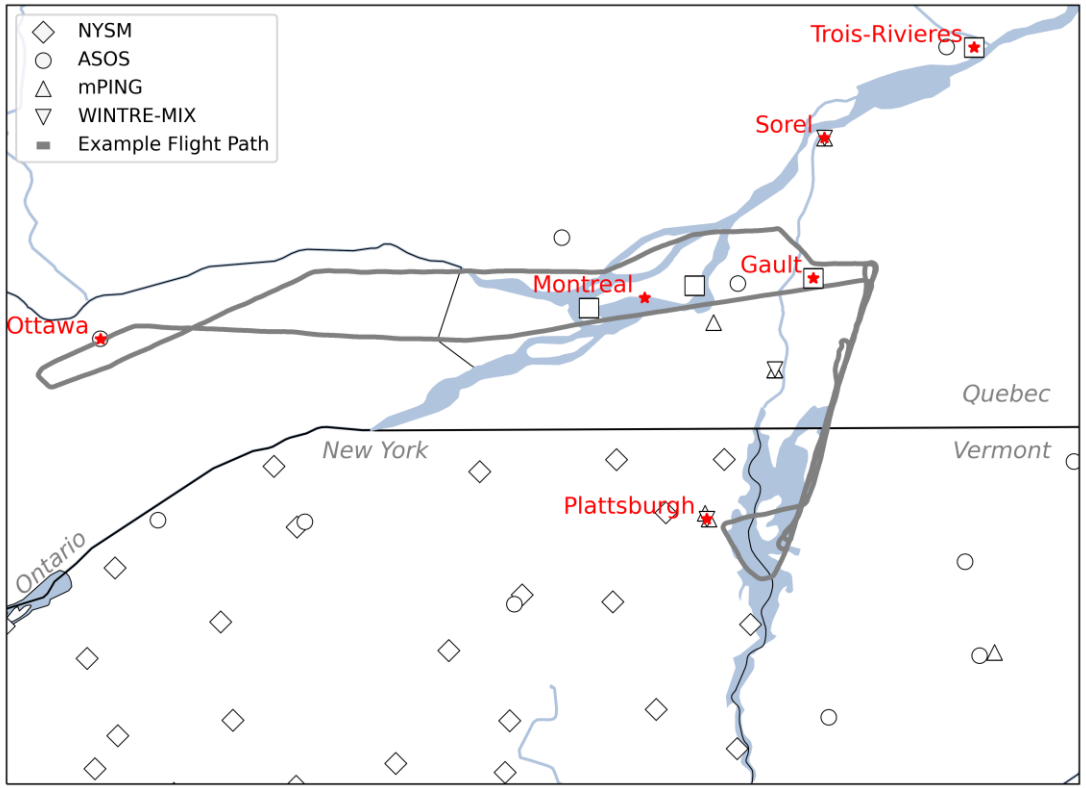
Evaluate the capability of operational high-resolution model (HRRR) to accurately predict FZDZ aloft

Understand sources of biases in model forecasts of FZDZ aloft

Perform WRF simulation to match HRRR configuration

Conduct additional sensitivity experiment to mitigate biases

WINTRE-MIX OVERVIEW



- The Winter Precipitation Type Research Multi-scale Experiment (WINTRE-MIX) conducted 11 intensive observing periods (IOPs) in winter 2022 *(Minder et al. 2023)*
- Aimed to improve observations and forecasts of mixed precipitation in complex terrain

WINTRE-MIX OVERVIEW

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- Leg0 of the first flight of IOP9 will be focus of this analysis due to …
  - Widespread FZDZ observations in abnormally cold cloud top temperatures < -15ºC
  - Significant evidence of SLD by in-situ measurements on aircraft

METHODS – *OBSERVATIONS*

	Instrument	Variable Measured
Micro-physical	Cloud Droplet Probe (CDP)	LWC, Number concentration
Micro-physical	2D-Stereo Probe (2DS)	Number concentration, Size distribution
Micro-physical	High Volume Precipitation Spectrometer (HVPS)	Number concentration
Micro-physical	Nevzorov Hot-wire Probe	LWC, TWC
Aircraft State	Rosemount Total Air Temperature Probe	Temperature
Aircraft State	Rosemont Icing Detector	Icing detector magnetostrictive oscillator (MSO) frequency
Radar	NRC W-band Airborne Radar (NAW)	W-band radar reflectivity

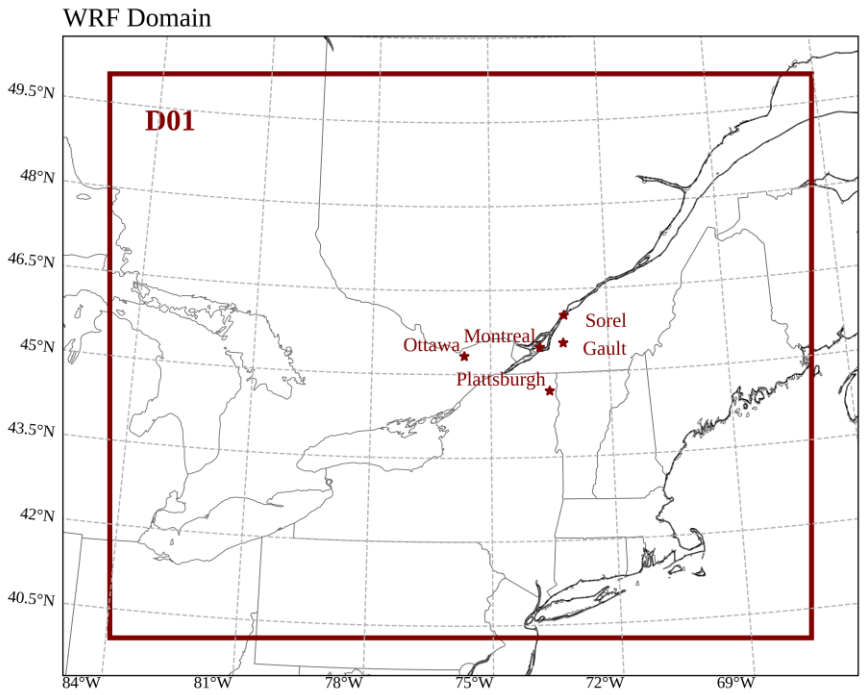
- Used instrumentation on board NRC Convair-580 aircraft
- Developed "Roundness Algorithm" to classify roundness of particles for confirmation of pure liquid conditions
  - Input data provided by Dr. Jeff French and Eden Koval

METHODS – *NUMERICAL WEATHER PREDICTION*

- **Operational model (*HRRR*)** and WRF simulations are initialized at 1200 UTC 7 March 2022
- 1600 UTC – 2000 UTC were examined [FH04 – FH08]

Control experiment (*CTRL*)

- WRF simulations forced using RAP data
- HRRR-like configuration
  - 3-km resolution
  - Thompson Aerosol-Aware Microphysics Scheme *(Thompson and Eidhammer, 2014)*
  - Aerosols sourced from climatology
- CR-SIM post-processing used to simulate cloud radar reflectivity *(Oue et al. 2020)*



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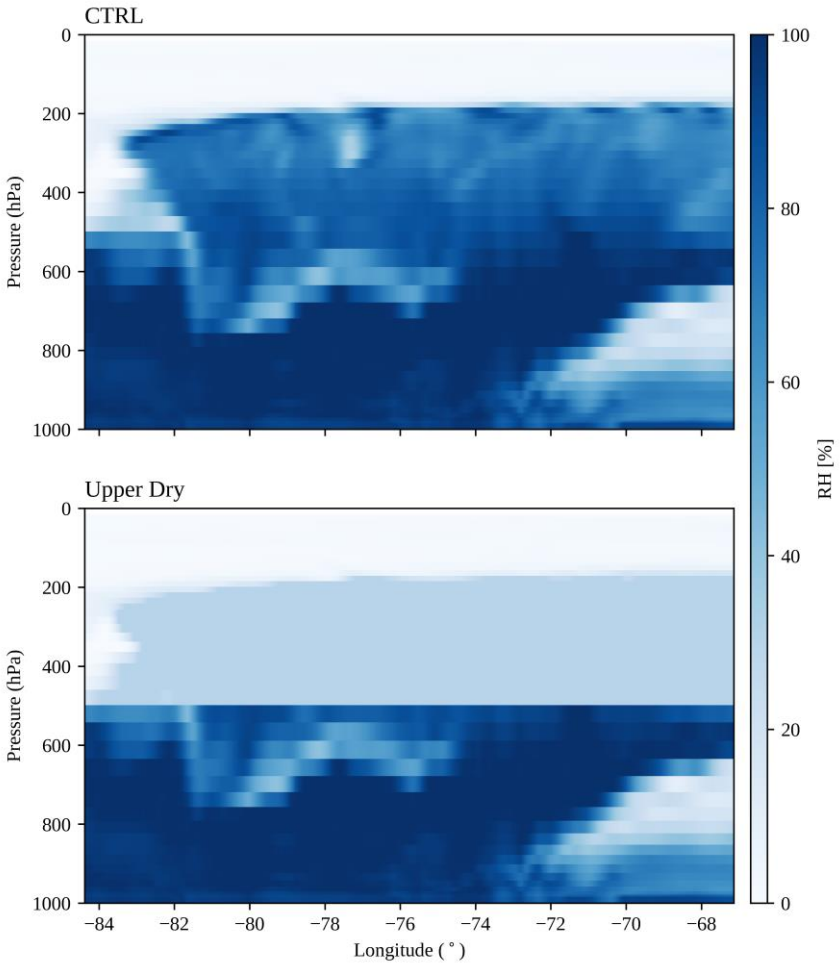
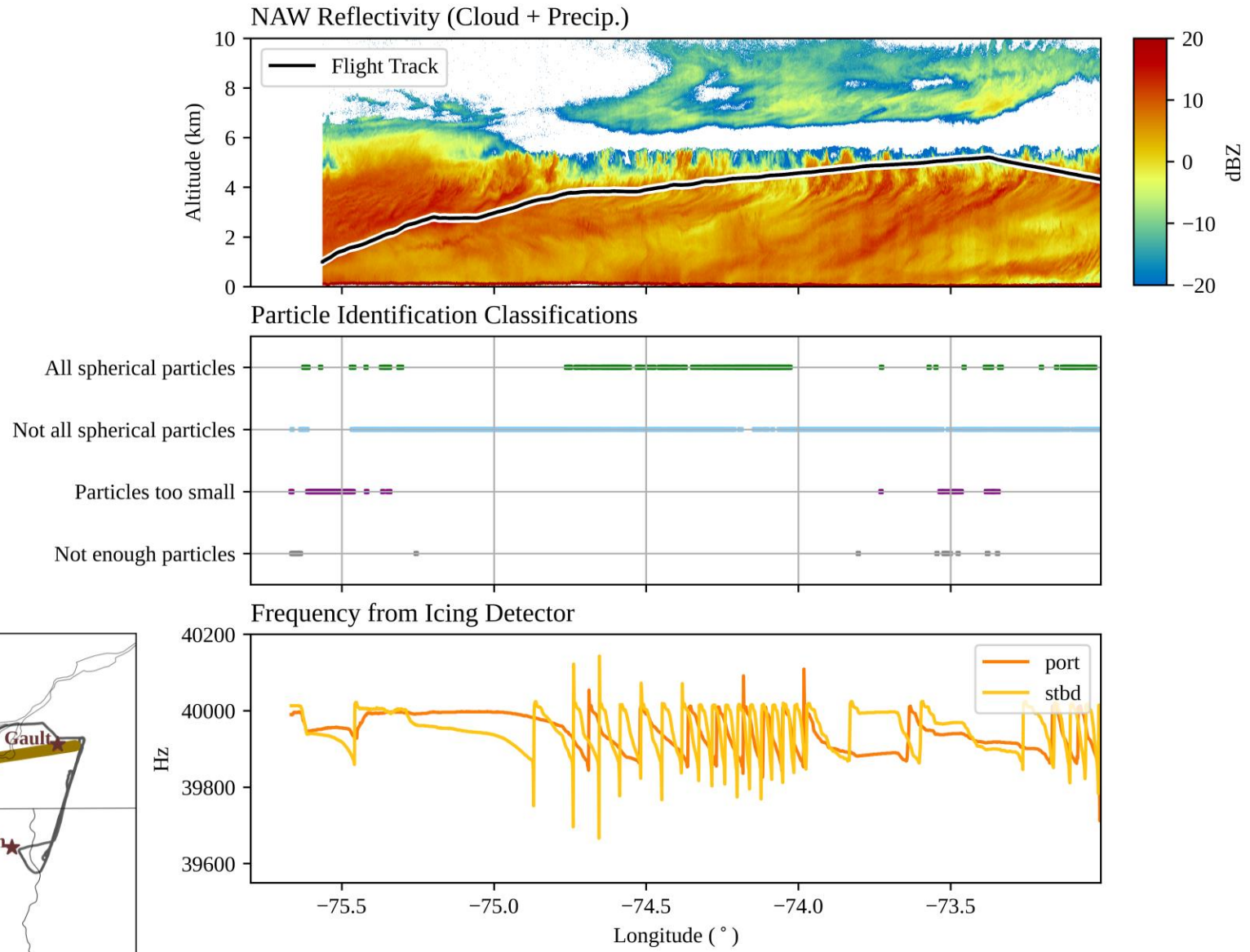
Sensitivity experiment (*UpperDry*)

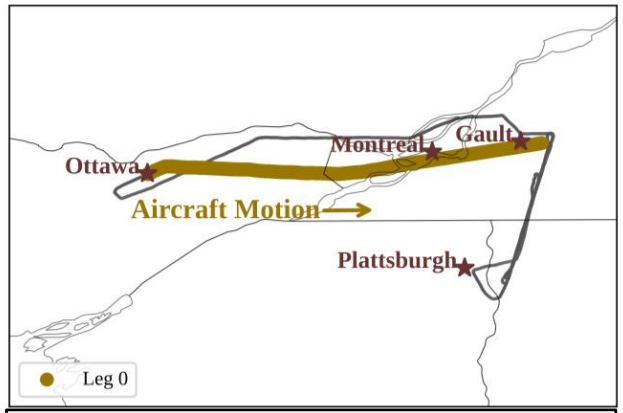
- Same HRRR-like configuration as CTRL
- Decreasing RH above approximately 5 km to less than or equal to 30% in the WRF initial conditions



OBSERVATIONS (OBS.)

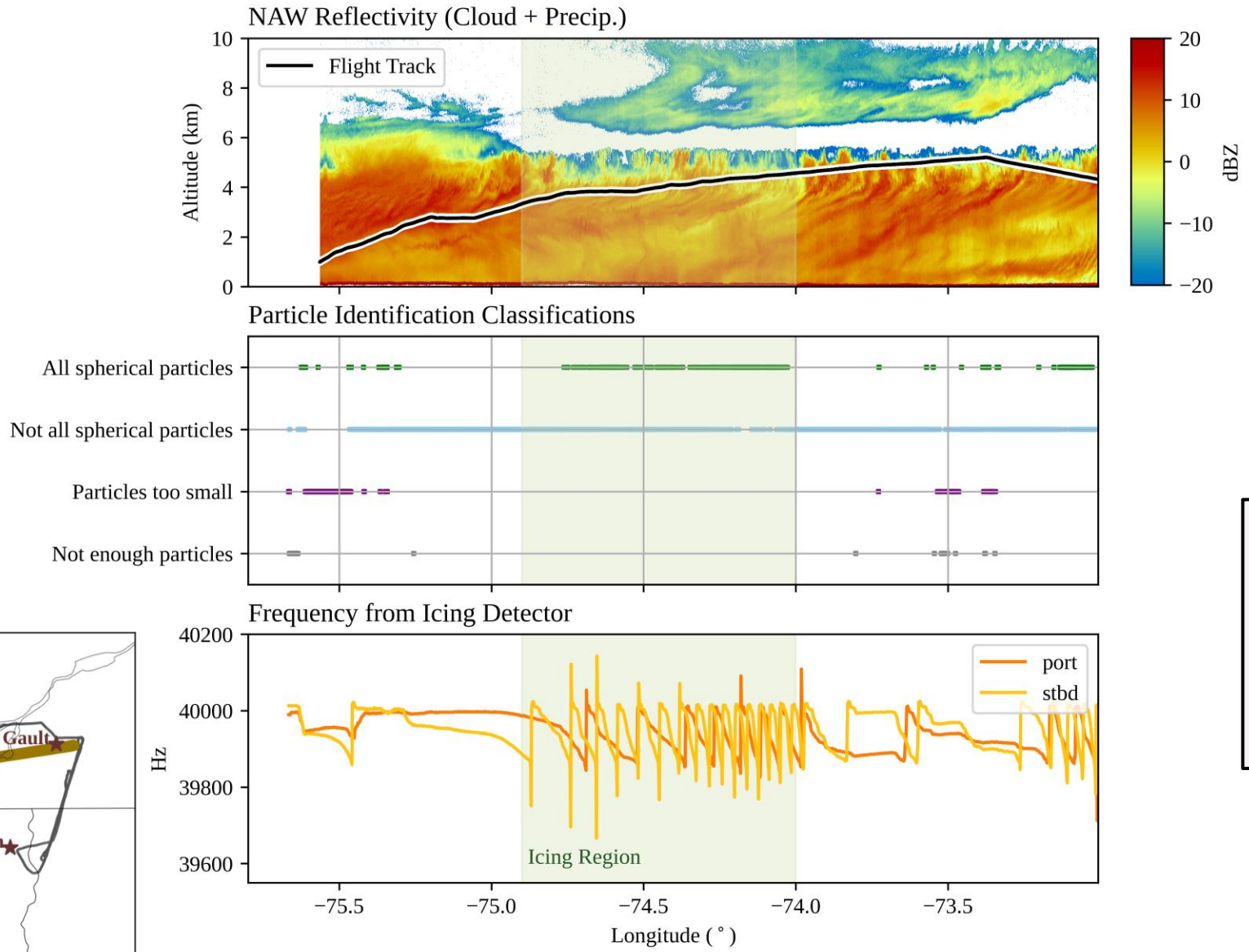


Two-layer cloud and precipitation structure



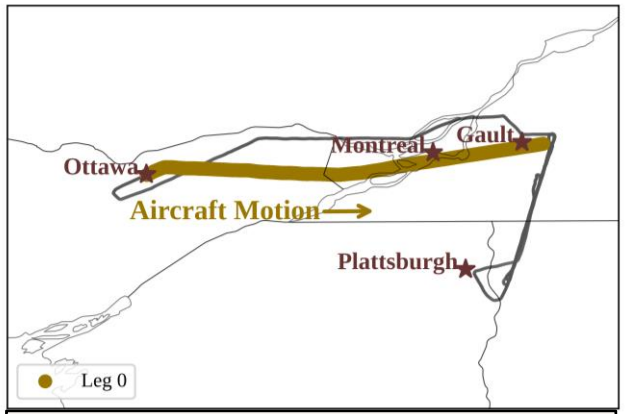
Leg0: 1611 UTC - 1641 UTC

OBSERVATIONS (OBS.)



Two-layer cloud and precipitation structure

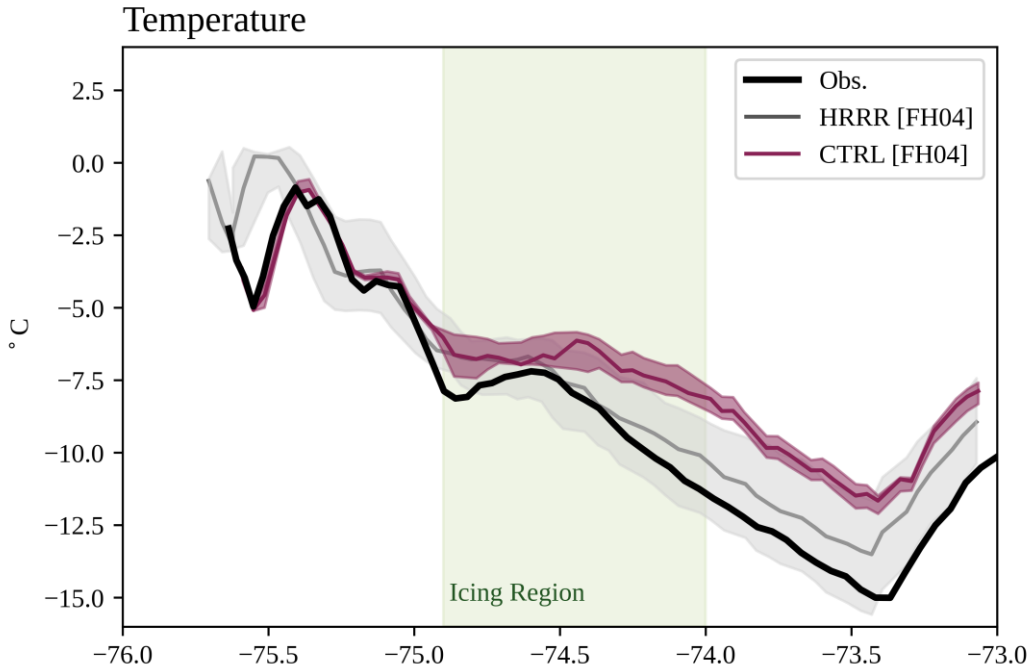
Icing conditions observed between -74.9 ºW and -74.0 ºW

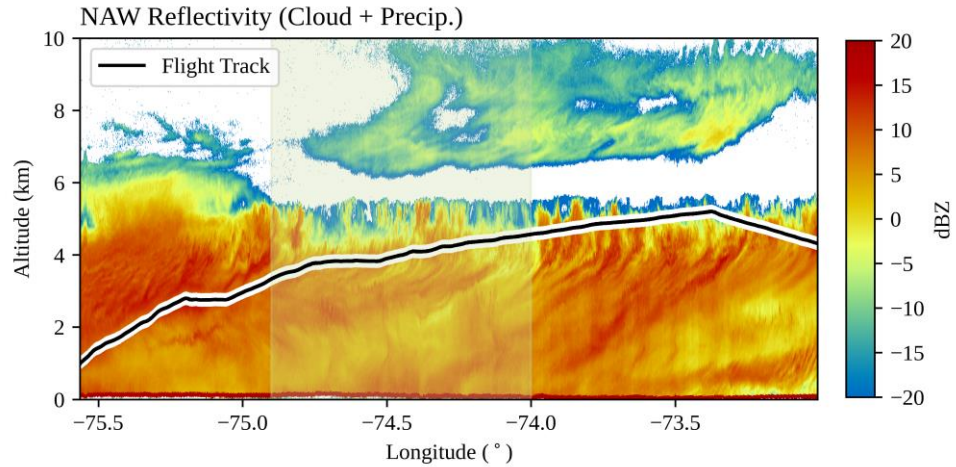


Leg0: 1611 UTC - 1641 UTC

OBS. & MODEL COMPARISON – TEMPERATURE

Model analysis include a 9 km x 9 km horizontal buffer (shading)





Cloud top temperature < -15ºC

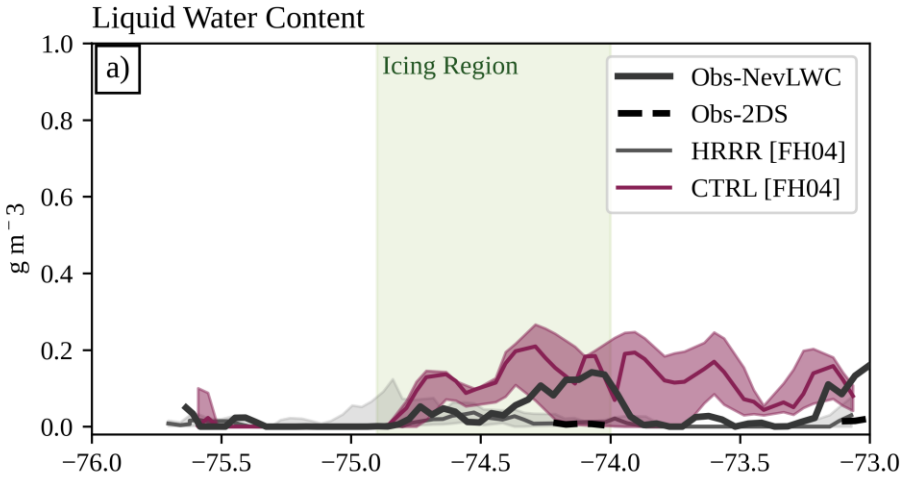
HRRR captures temperature well

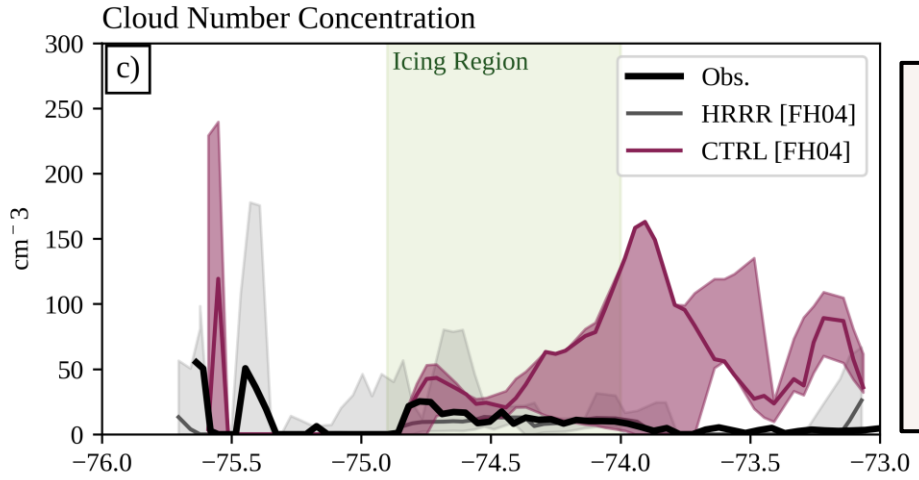
CTRL shows warm bias following aircraft's initial ascent

OBS. & MODEL COMPARISON – MICROPHYSICS

HRRR underpredicts

CTRL overpredicts except at observed maximum

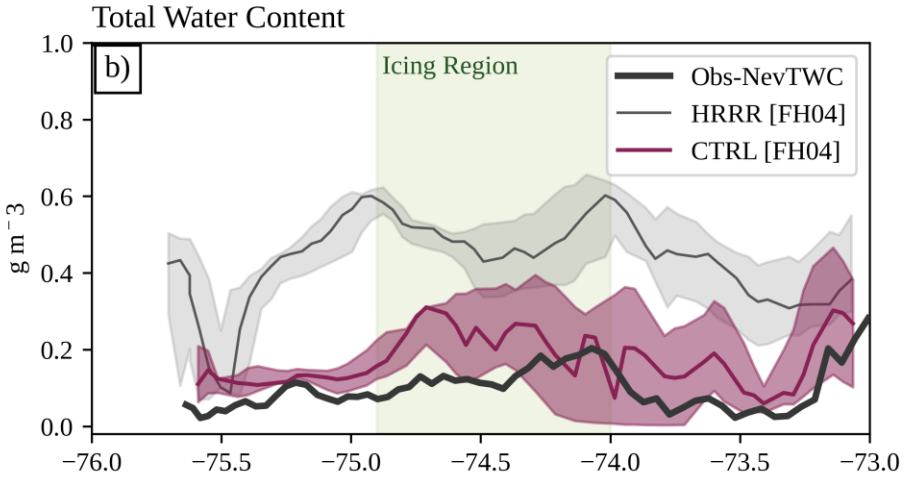


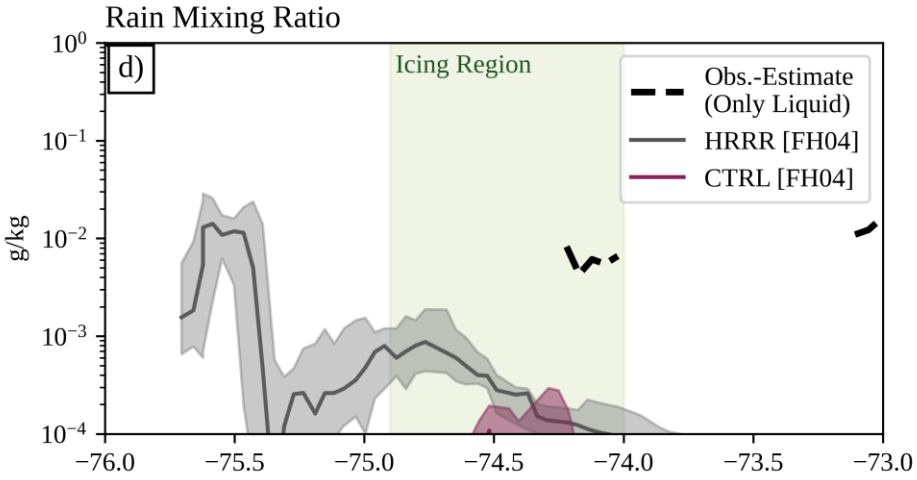


Low cloud number concentrations, encourages collision coalescence

HRRR overpredicts* frozen hydrometeors

CTRL overpredicts* frozen hydrometeors except at observed maximum



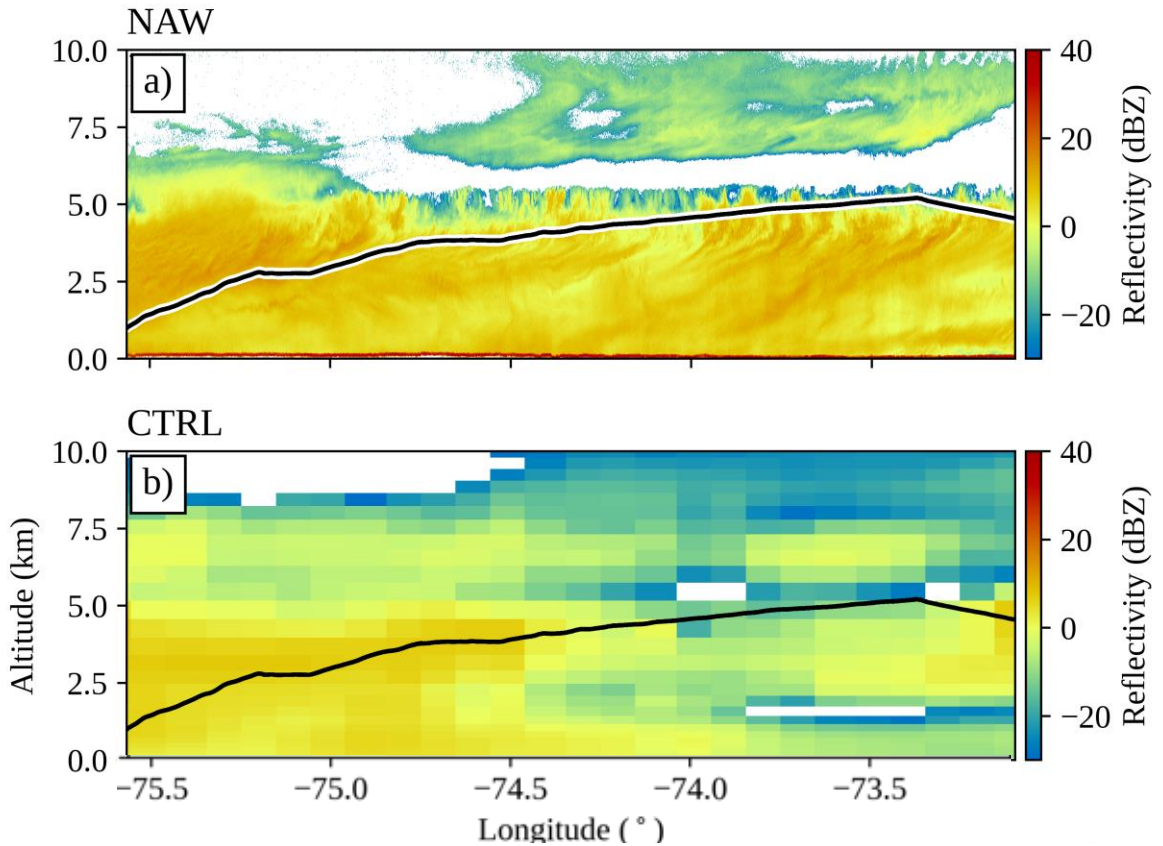


Models produce **rain mixing ratios orders of magnitude smaller than Obs.**

Longitude (°)

HRRR and CTRL demonstrate a similar microphysical bias with the **under production of rain** and **overproduction of frozen hydrometeors**

OBS. & MODEL COMPARISON – CLOUD RADAR REFLECTIVITY



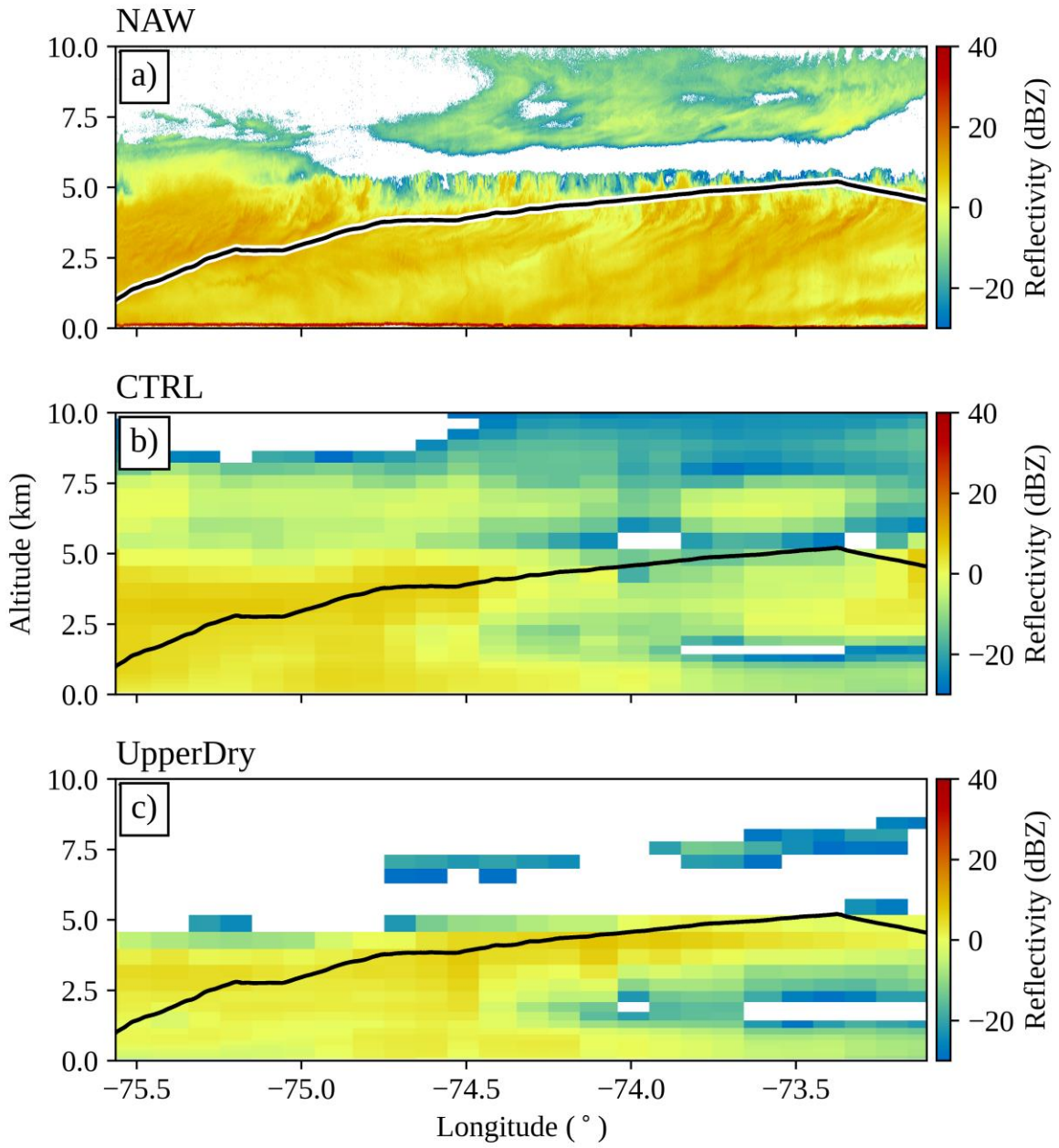
Two-layer cloud and precipitation structure

Continuous reflectivity

↓

Are particles aloft seeding cloud below?

OBS. & MODEL COMPARISON – CLOUD RADAR REFLECTIVITY



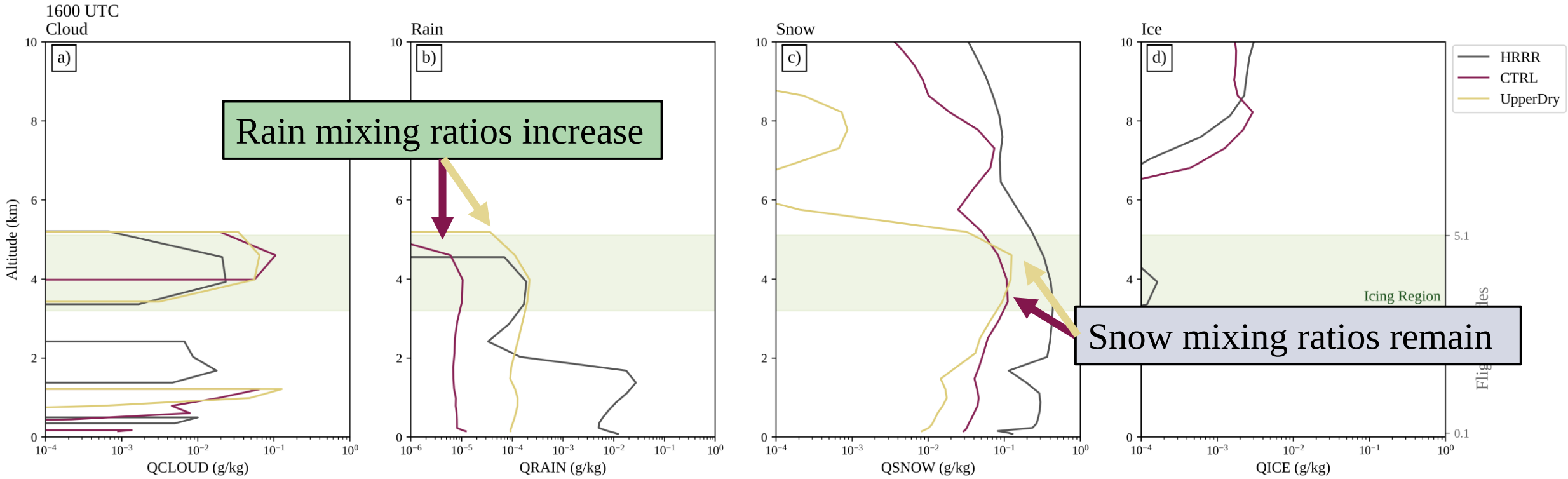
Two-layer cloud and precipitation structure

Continuous reflectivity

Are particles aloft seeding cloud below?

Lower layer feature remains

MODEL COMPARISON – AVG. VERTICAL PROFILES



- The removal of seeding mechanisms aloft increases rain mixing ratios but does not stop partial glaciation of the lower-level cloud
- Partial glaciation bias points to existence of additional microphysical errors within models
  - Subsequent sensitivity experiments will include modification of aerosols and ice initiation

SUMMARY

- WINTRE-MIX observations revealed **aircraft encountered hazardous icing conditions** (LWC_{max} = 0.157 g m^{-3}) aloft **in abnormally cold cloud top temperatures** (T < -15ºC)
- Operational model (HRRR) & HRRR-like simulations (CTRL) reveal similar bias of the **underproduction of SLD and overproduction of snow**
- Removing the upper-level cloud to inhibit seeding led to an increase in rain mixing ratios but **did not prevent partial glaciation of the lower-level cloud**
- **Simulations in progress** to further isolate sources of bias in simulated SLD formation

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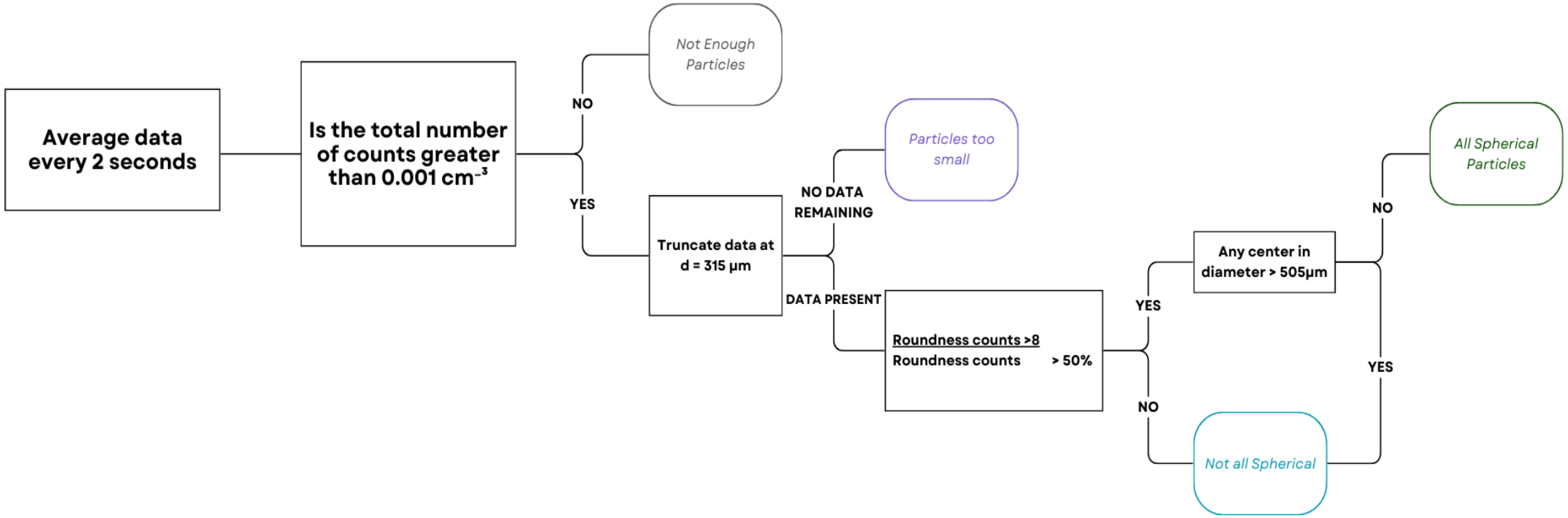
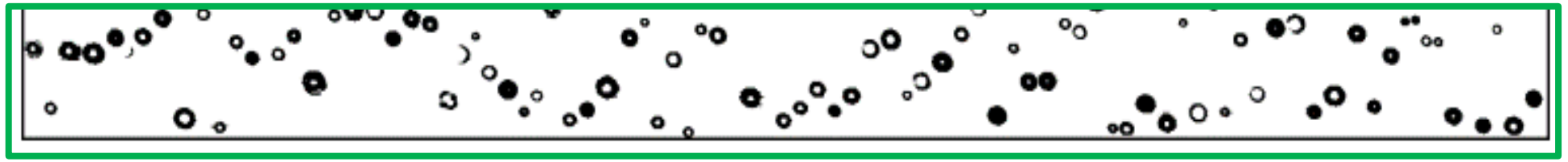
SUPPLEMENTAL SLIDES

Particle Identification Algorithm



EXAMPLE CLASSIFICATIONS FROM ALGORITHM

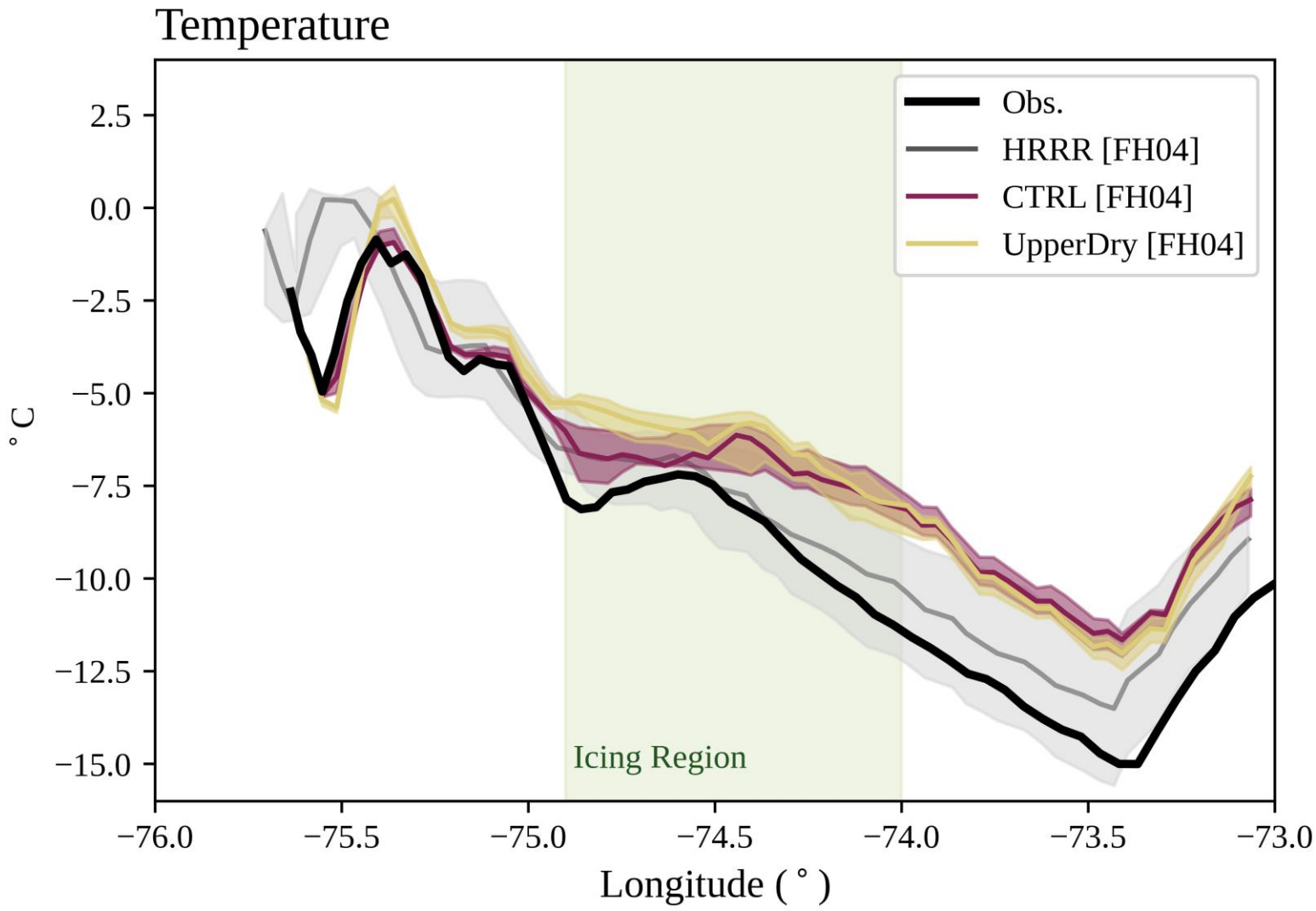
All Spherical Particles



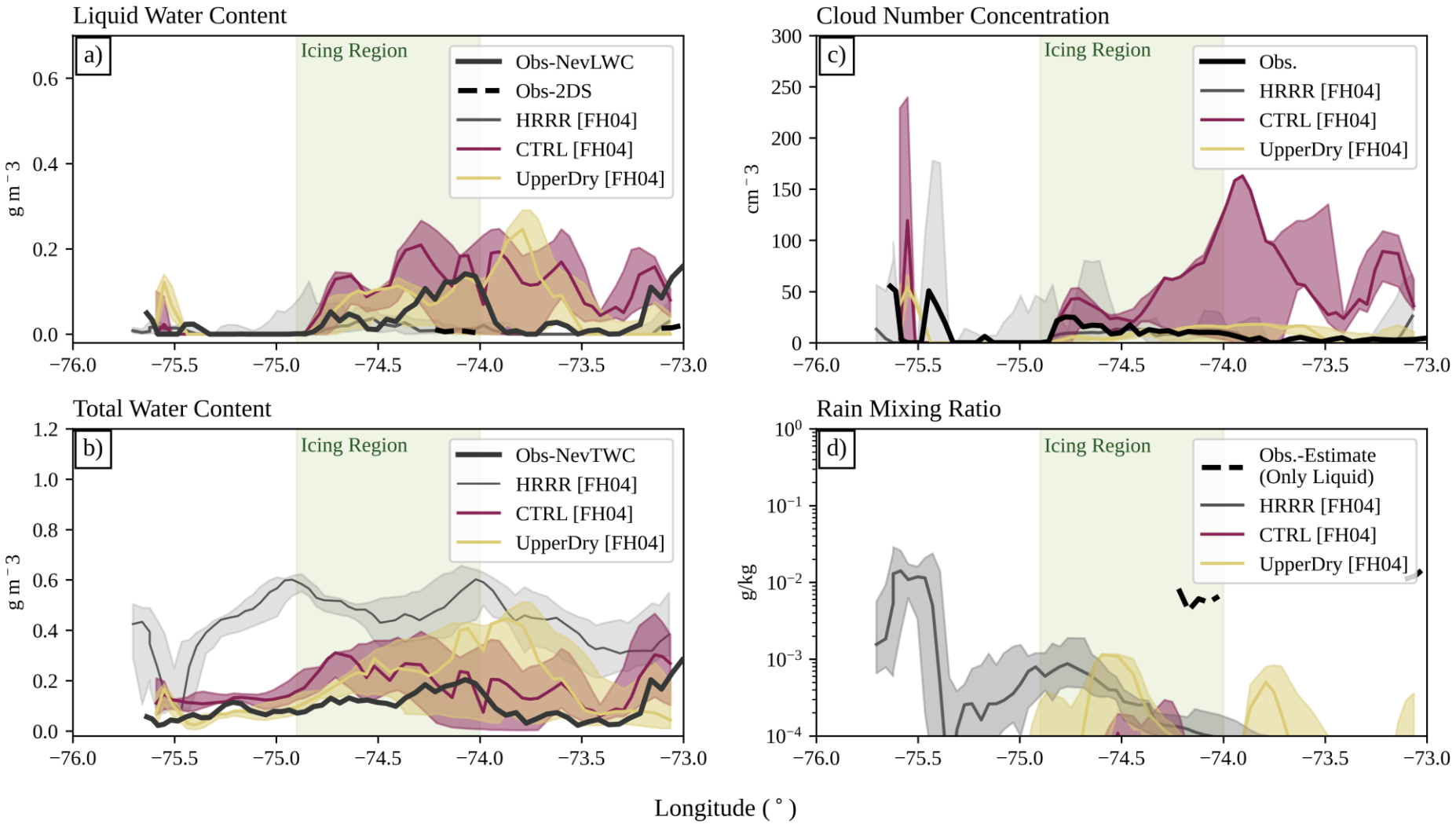
Not All Spherical Particles

Particles too small

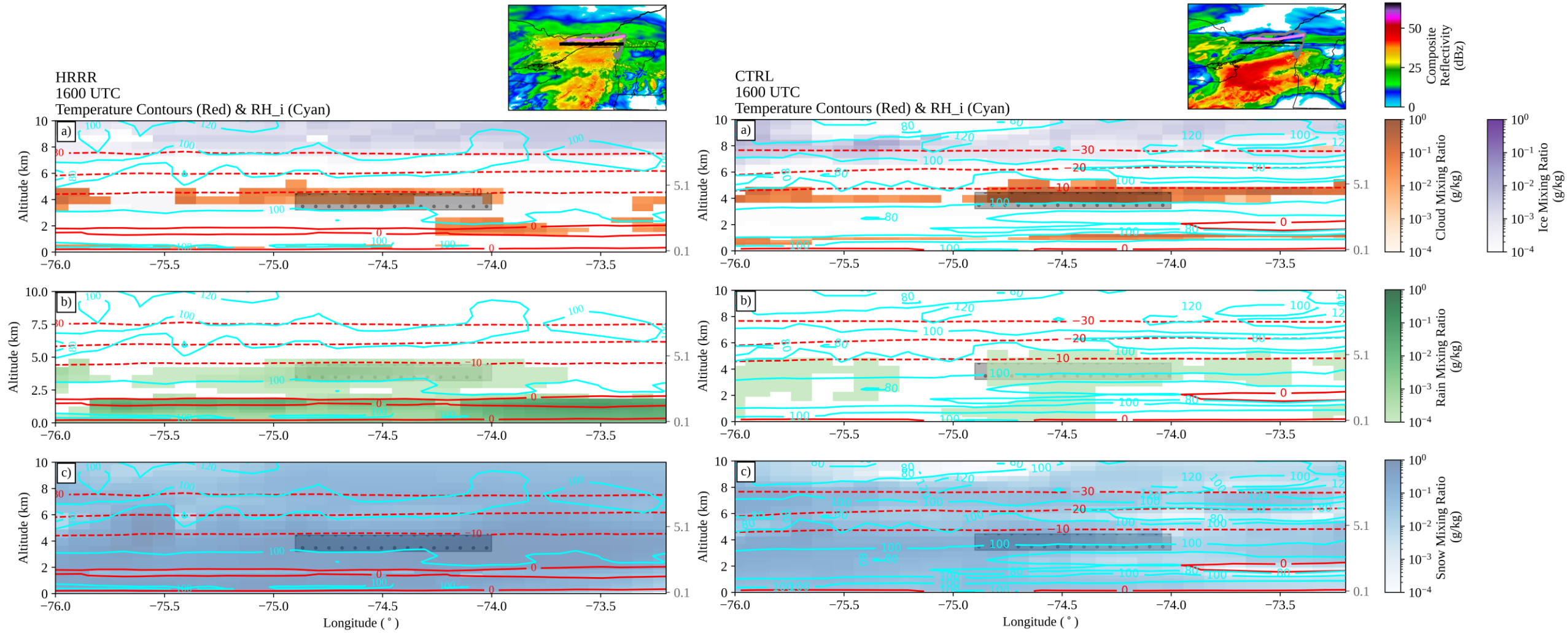
OBS. & MODEL COMPARISON – TEMPERATURE



OBS. & MODEL COMPARISON – MICROPHYSICS



MODEL COMPARISON – MIXING RATIO CATEGORIES



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