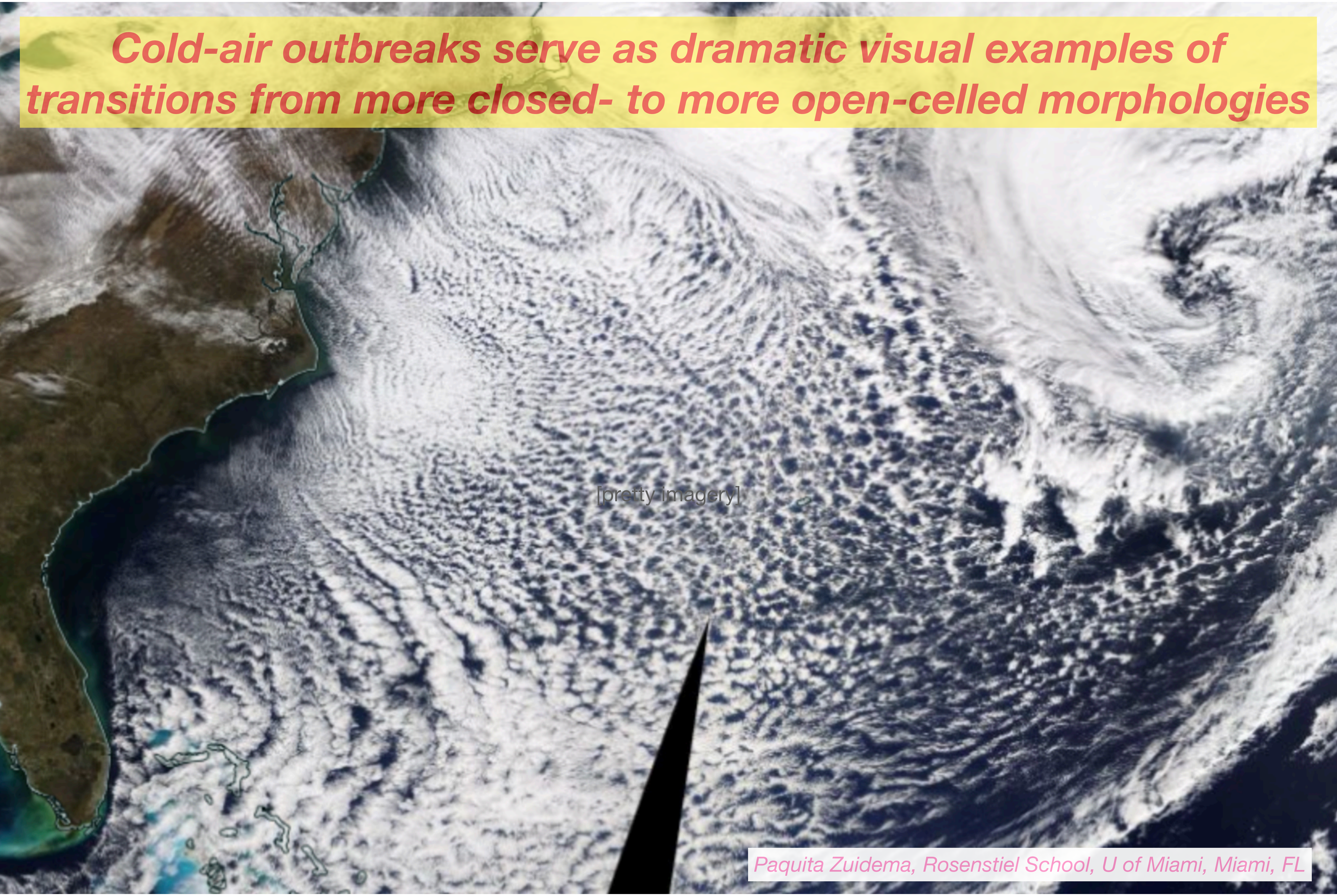
Cold-air outbreaks serve as dramatic visual examples of transitions from more closed- to more open-celled morphologies



Continental air flowing over the Gulf Stream supports strong turbulent fluxes, encouraging cloud break-up through entrainment

Much still unknown about cold-air-outbreak mixed-phase microphysics - and their relevance relative to the strong surface forcing

Off of the wintertime eastern US seaboard:

Wintertime cold-air outbreak clouds are typically mixed-phase,
according to space-based lidar+radar (Field and Heymsfield 2015; Mulmenstadt et al., 2015)

cloud droplet numbers concentrations (N_d) indicate continental aerosol (e.g., Gryspeerdt et al., 2021)

Similar to subtropical stratocumulus:

- high N_d may extend cloud coverage
- high liquid water paths may encourage precipitation, -> N_d depletion

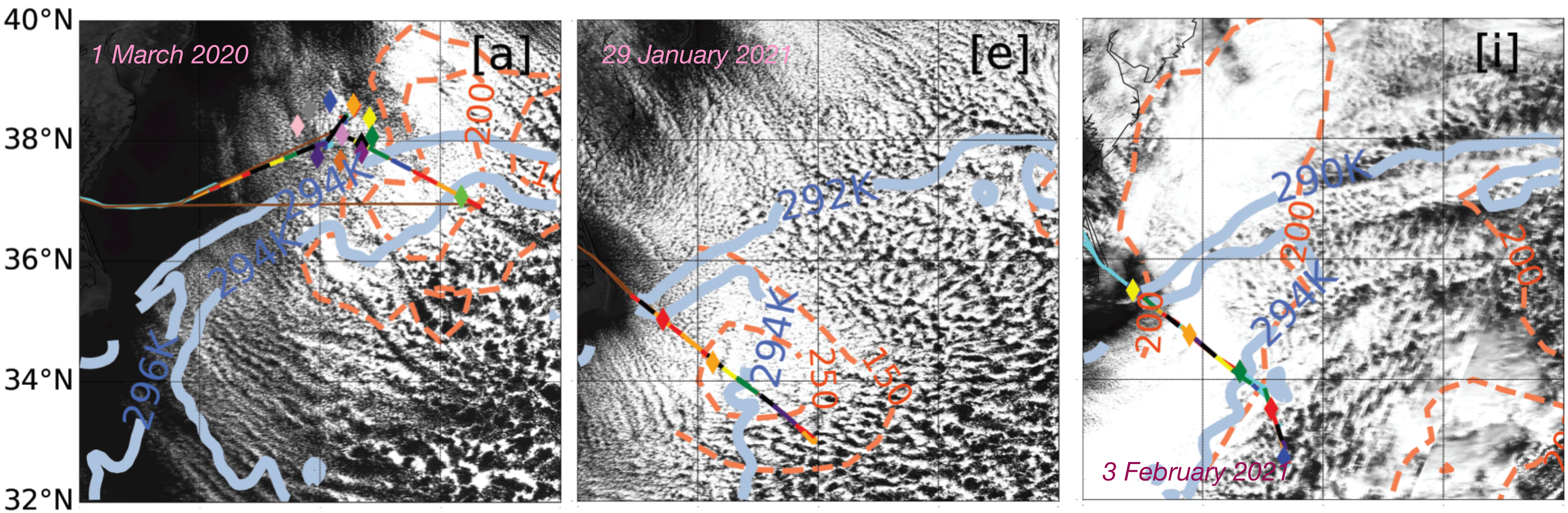
Specific to mixed-phase:

- glaciation hastens cloud transitions (Tornow et al., 2021)
- alters cloud spatial organization (Eirund et al, 2019)

The goal:

- select cold-air-outbreak cases from the ACTIVATE* campaign spanning a range of liquid water paths, cloud droplet number concentrations
- examine the *in-situ* ice microphysics for dependencies

selected 5 cases in which boundary layer flow aligned with flight tracks: a framework



Blue- SST; orange - MODIS LWP

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Aerosol Cloud meTeorology Interactions oVer the western ATlantic Experiment

See also posters by Florian Tornow et al and Michael Brunke et al.

~ coincident upper-flier King Air:
lidar (cloud top height), dropsondes, polarimeter (cloud optical depth+effective radius)

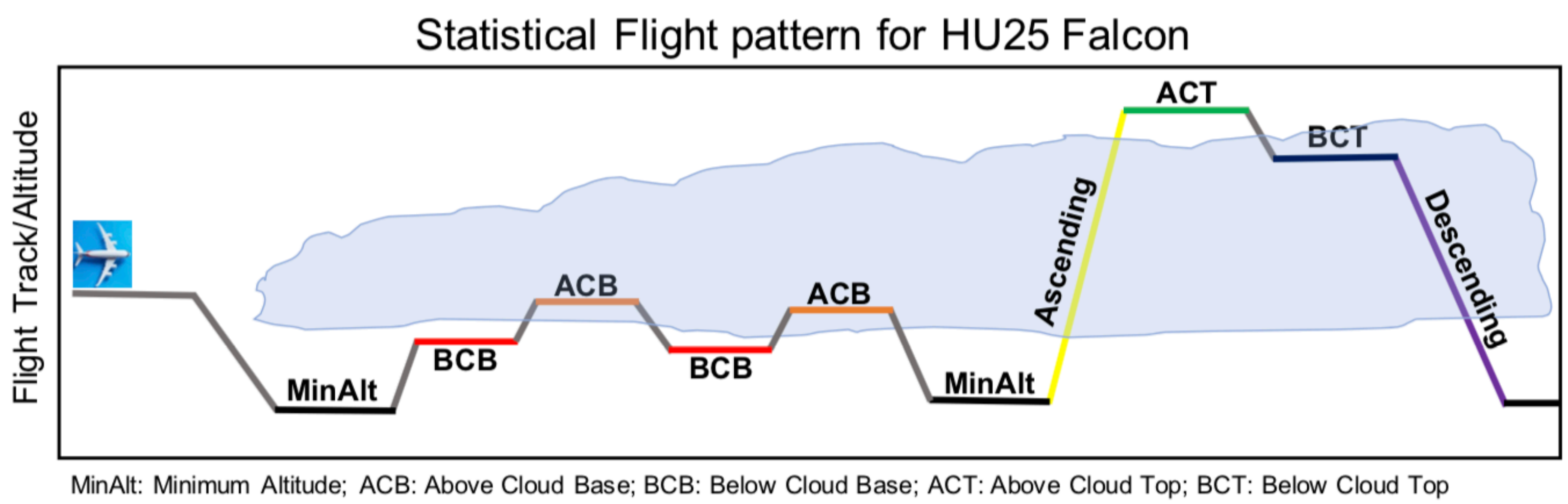


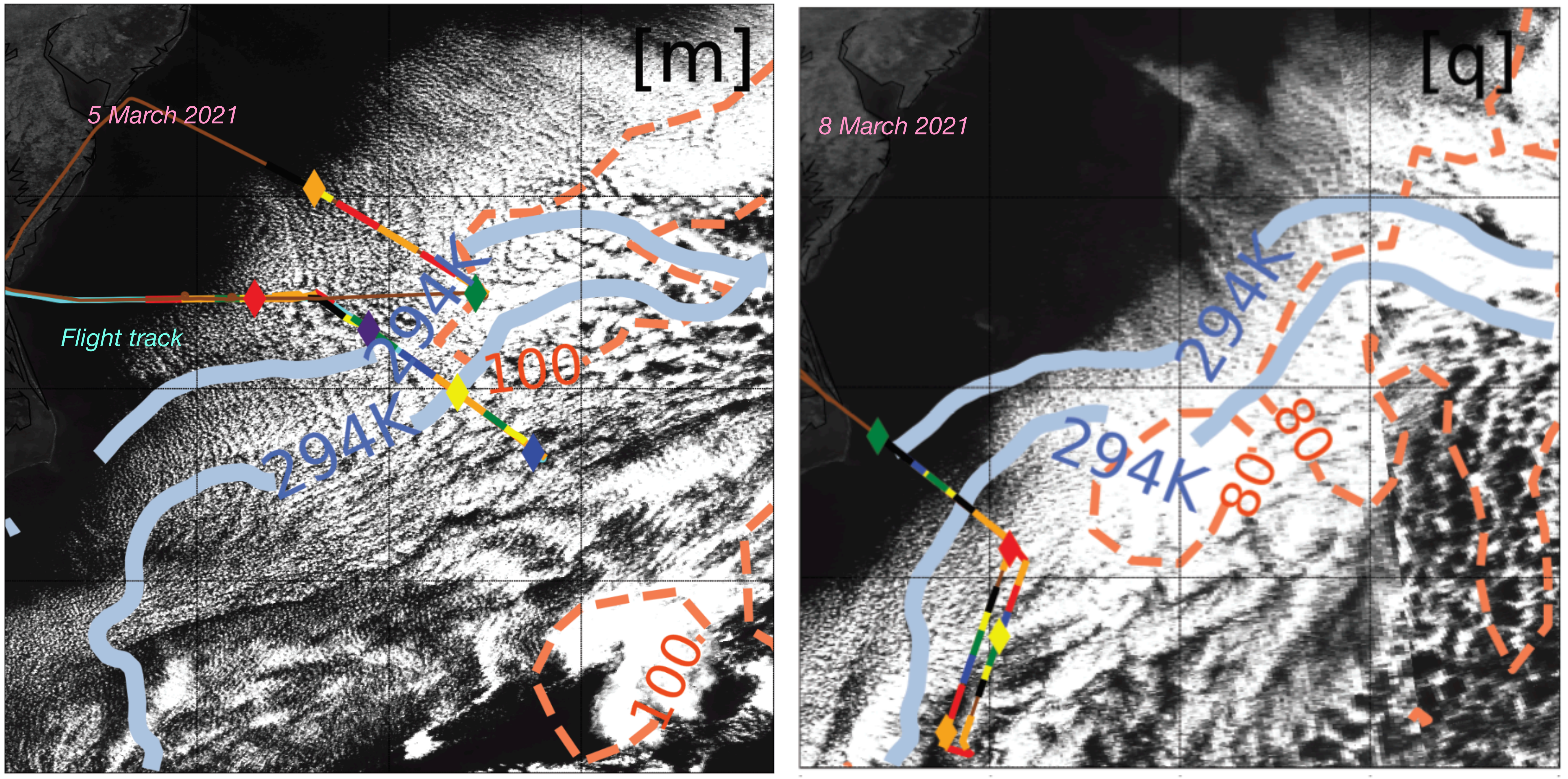
Figure 2. Typical Falcon flight sampling plan, color-coded by the same conventions as in Fig. 1.

Cloud probe (FCDP+2DS) (liquid: 2-20 μm radius, drizzle (20-54 μm radius : rain: 54-732 μm radius), N_d , LWC, rain rate.

Ice shape, IWC (2DS)

Strengths:
- many many flights repeating the same strategy
- good microphysical measurements
- dedicated analysis effort

Caveats: no radar, no ice-nucleating-particle measurements, poor liquid water path information



Blue- SST; orange - MODIS LWP

What we have learned #1:

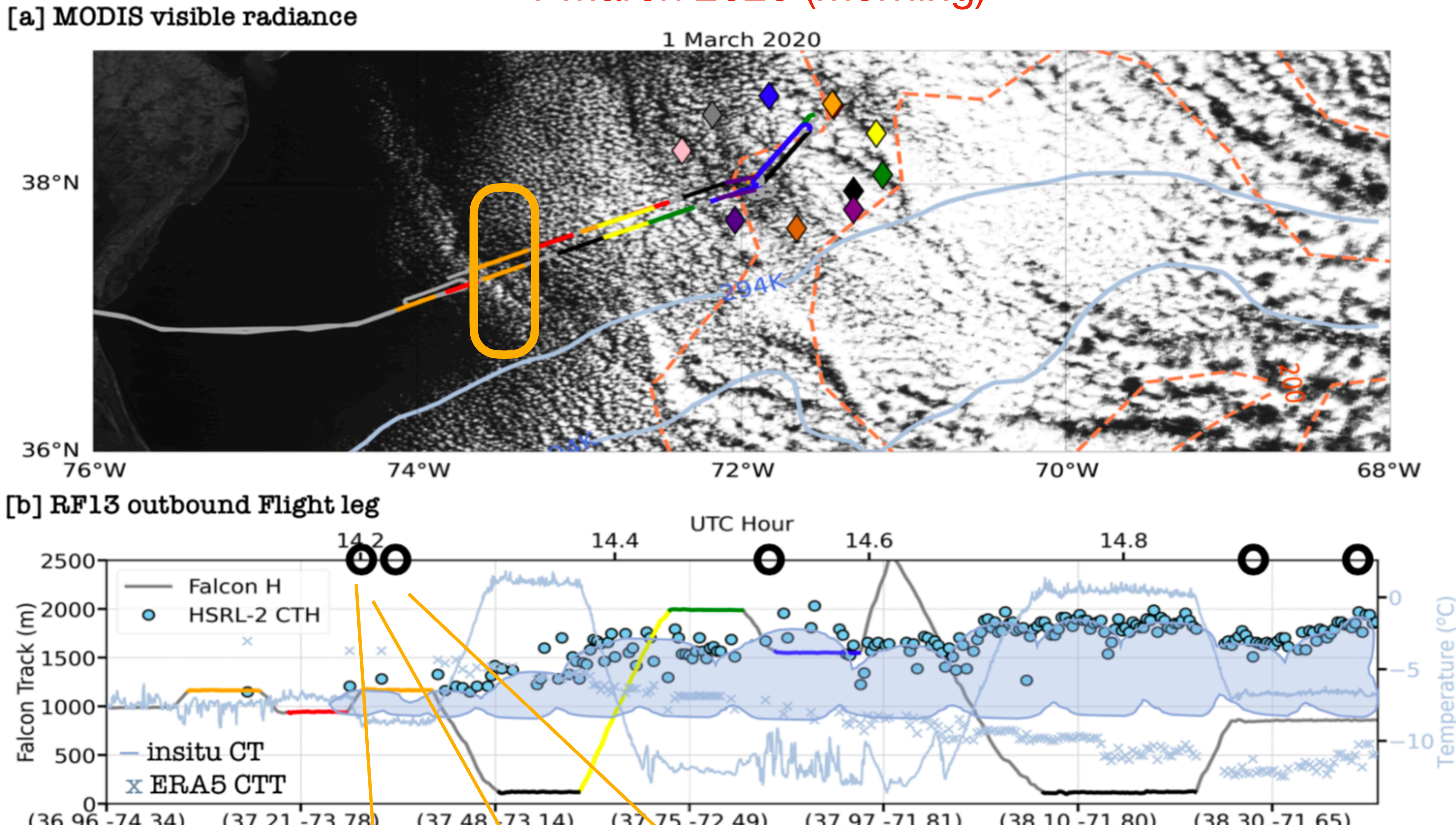
Wintertime cold-air outbreak clouds over the western Atlantic are not ice-deprived

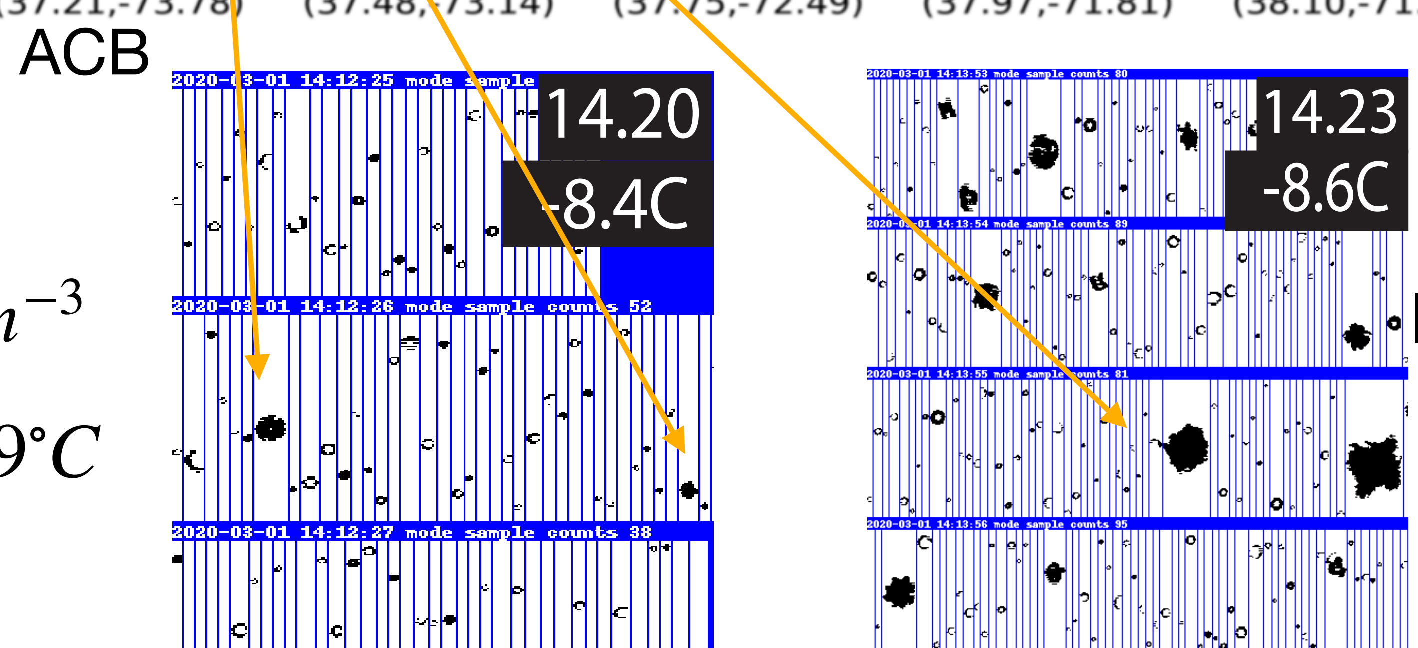
4 out of the 5 cases already contained ice as soon as clouds developed

This despite cloud top temperatures > -10C, and small dropsizes

Original premise that clouds start all-liquid then transition to mixed-phase thrown out the window

1 March 2020 (morning)





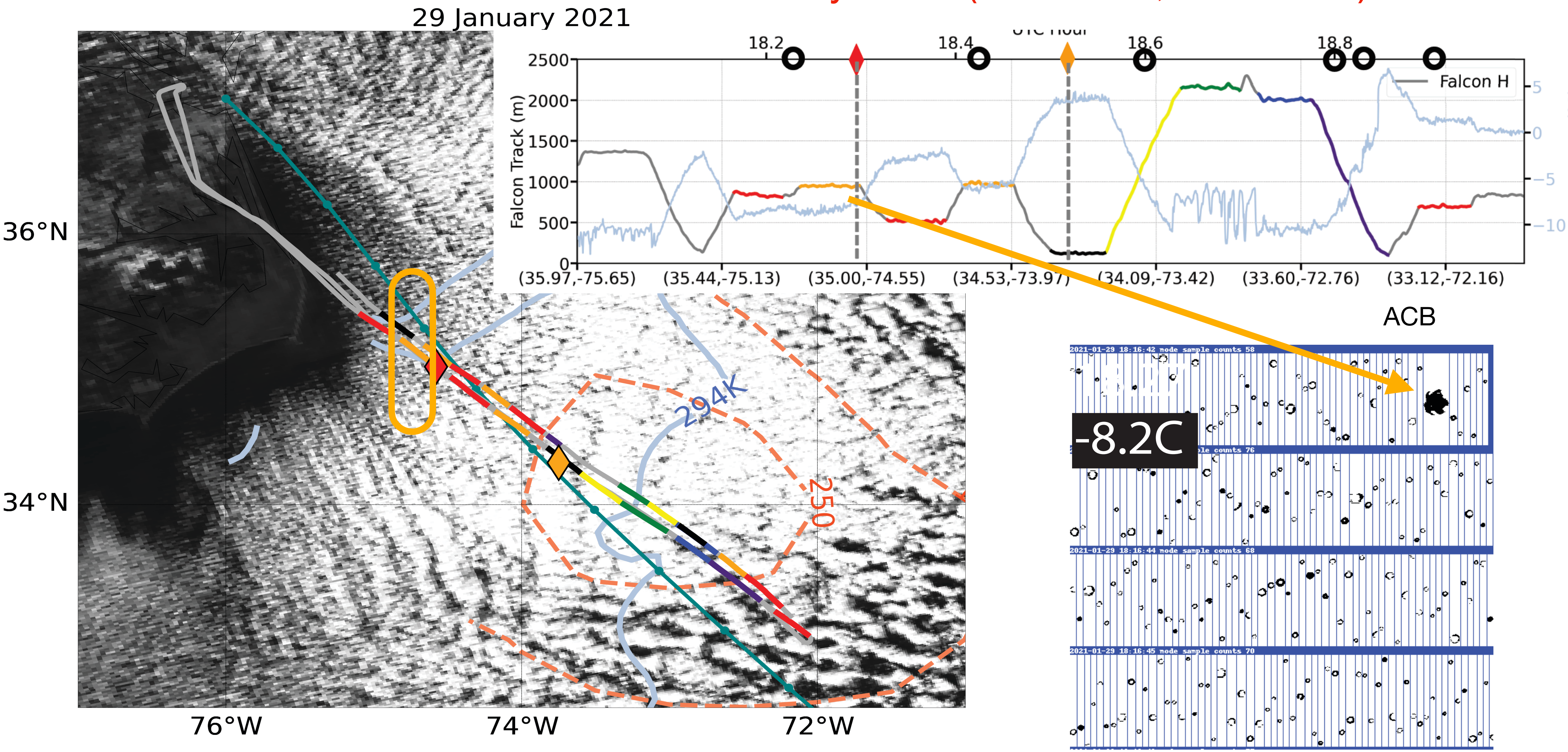
$$\overline{N_d} = 501 cm^{-3}$$

$$T = -8, -9°C$$

Rimed ice

In-situ radius~ 5 micron

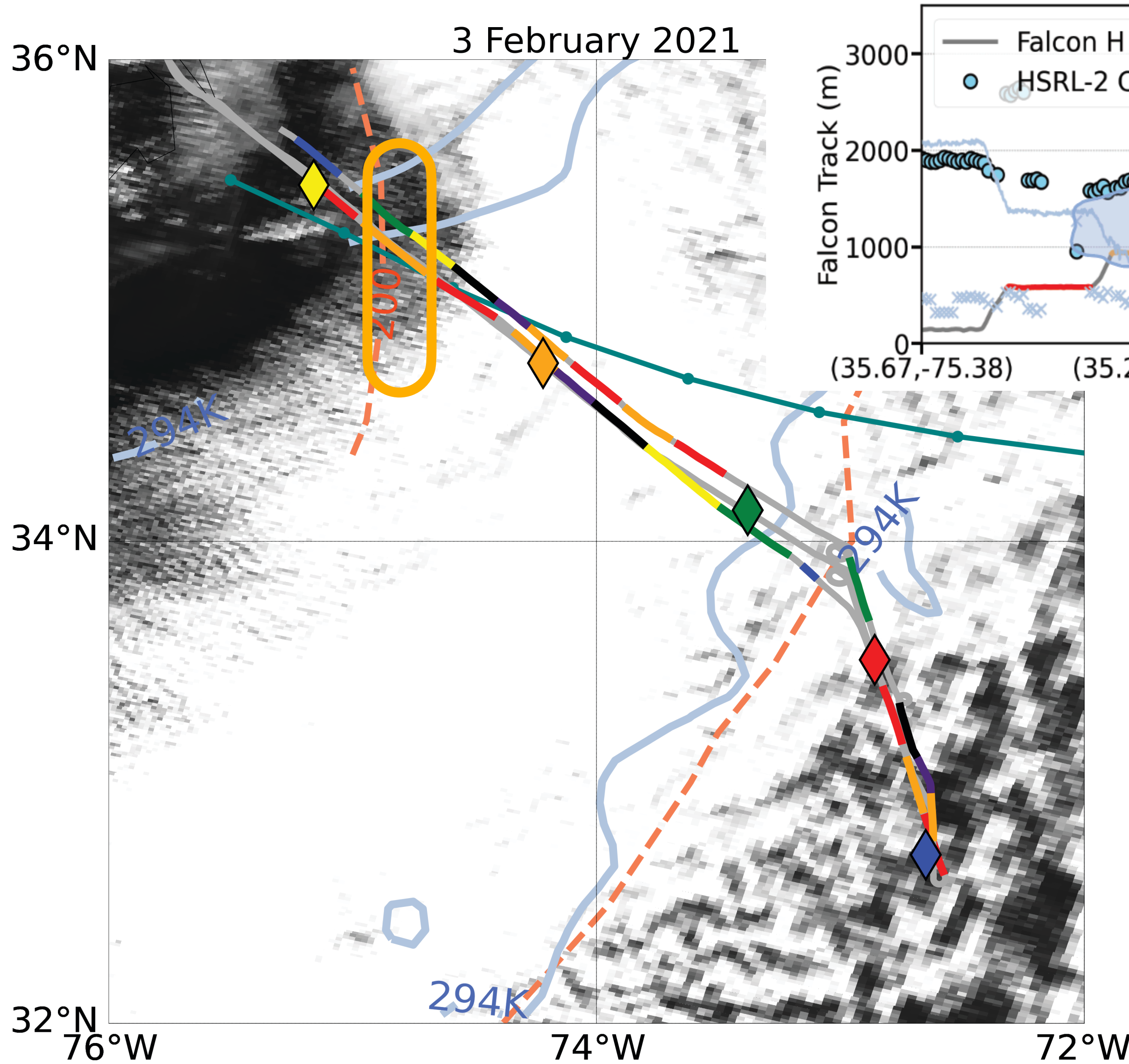
29 January 2021 (afternoon, outbound)

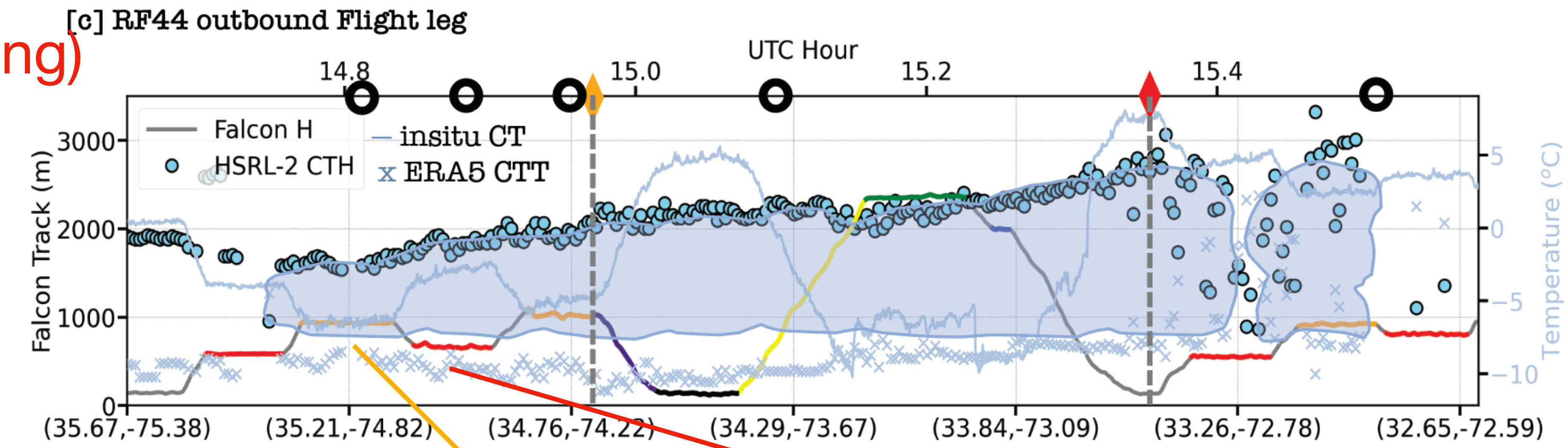


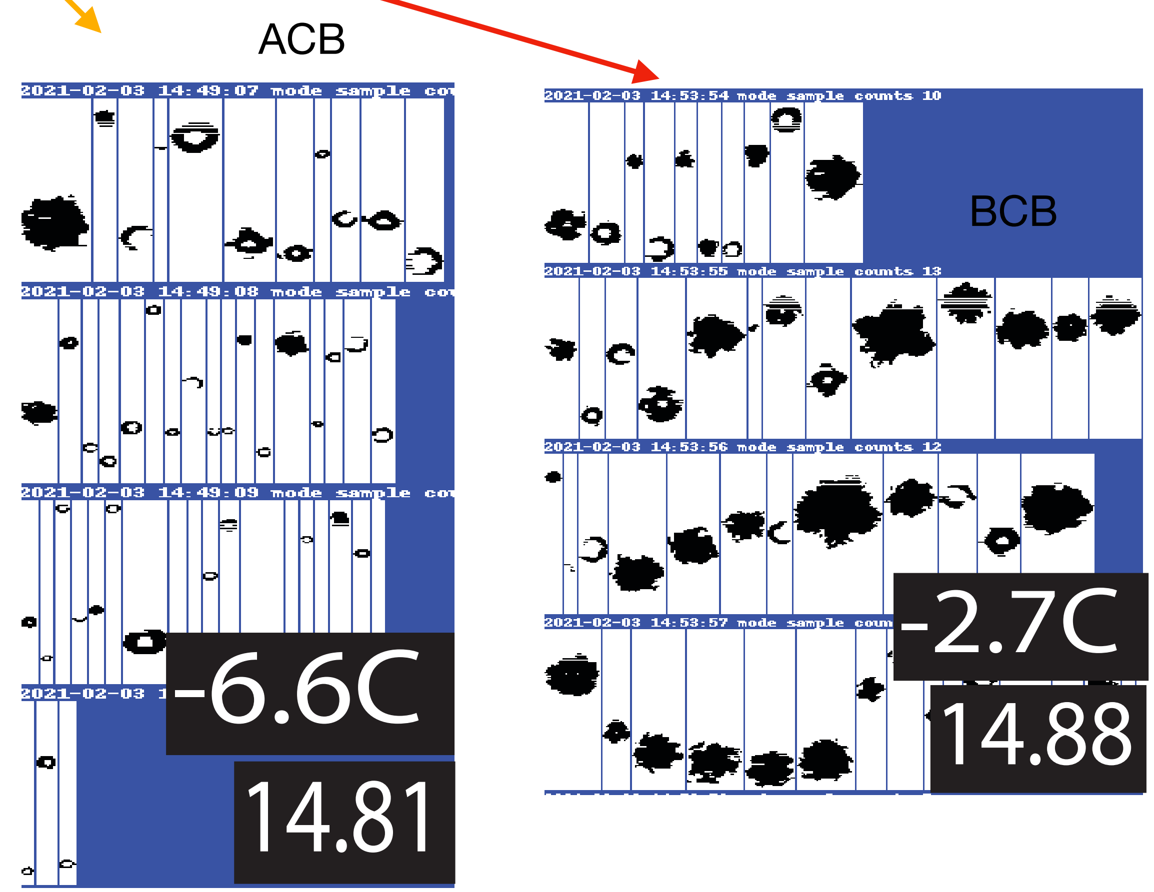
$\overline{N_d} = \ 160 cm^{-3}$ $\qquad T_{ct} \sim -10^{\circ}C$

At the first in-situ sampling, rimed ice is already present

3 February 2021 (morning)



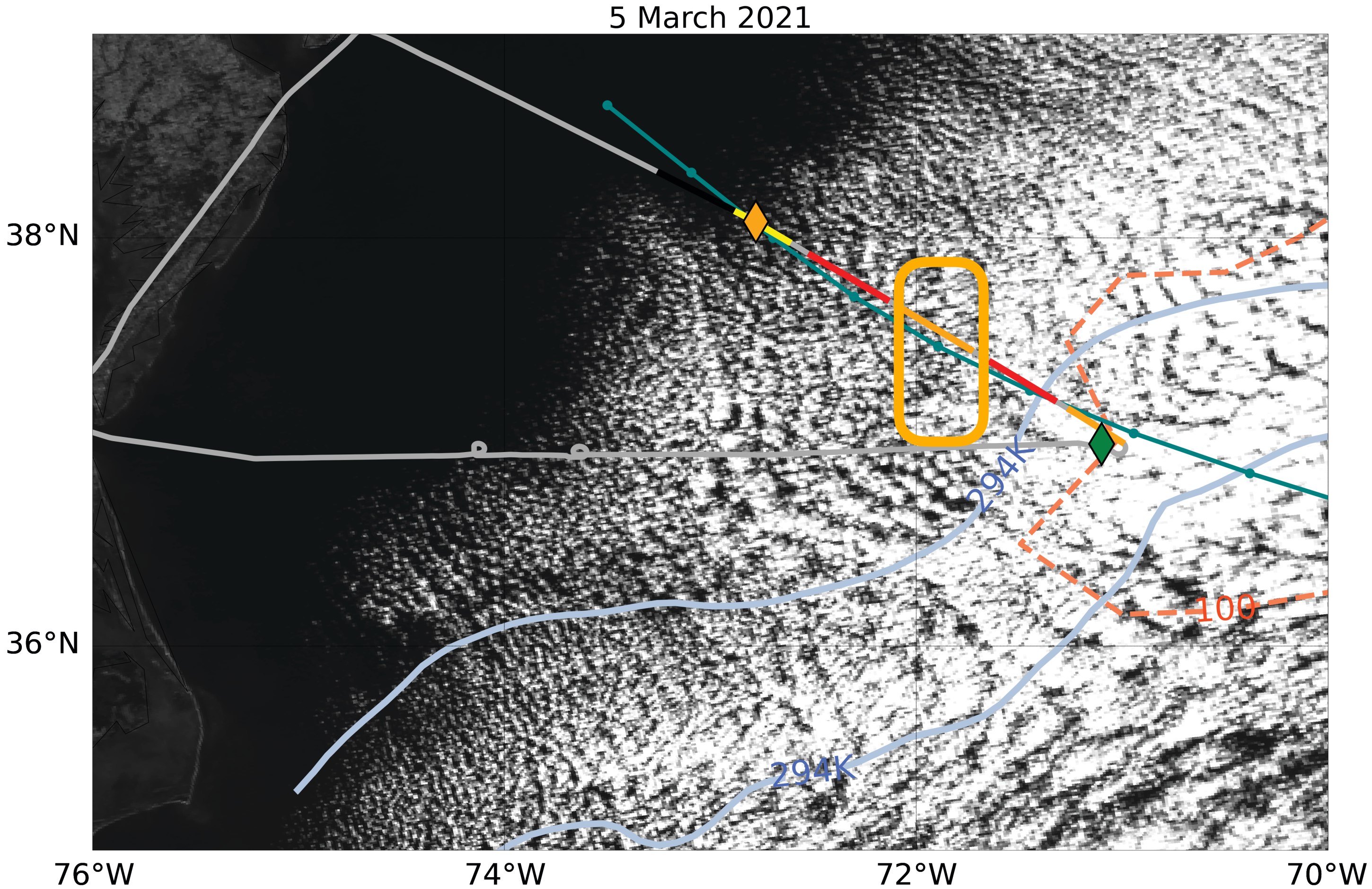


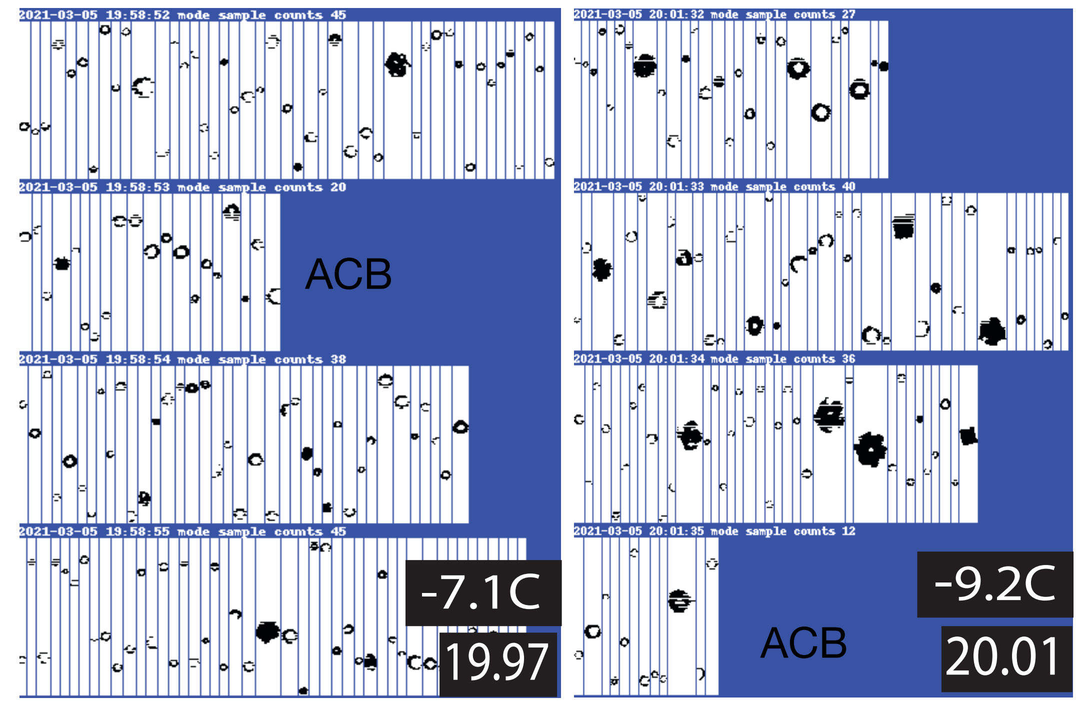


$\overline{N_d} = 200cm^{-3}$ $T_{ct} \sim -8°C$

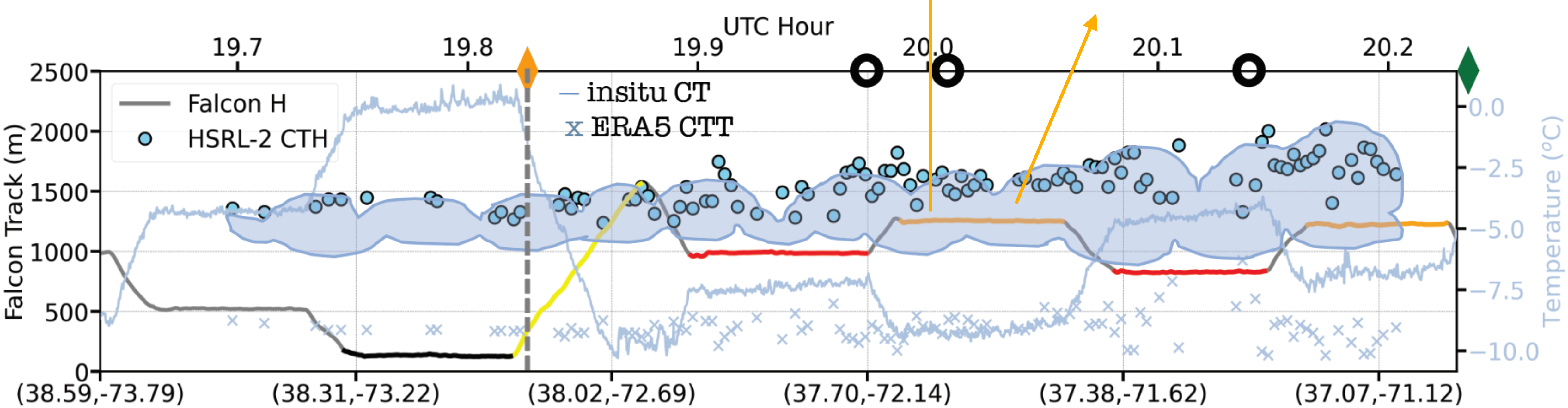
Ice detected on very first pass through thin cloud; cloud quickly deepened to LWP of 200 g m^{-2}

5 March 2021 (afternoon)



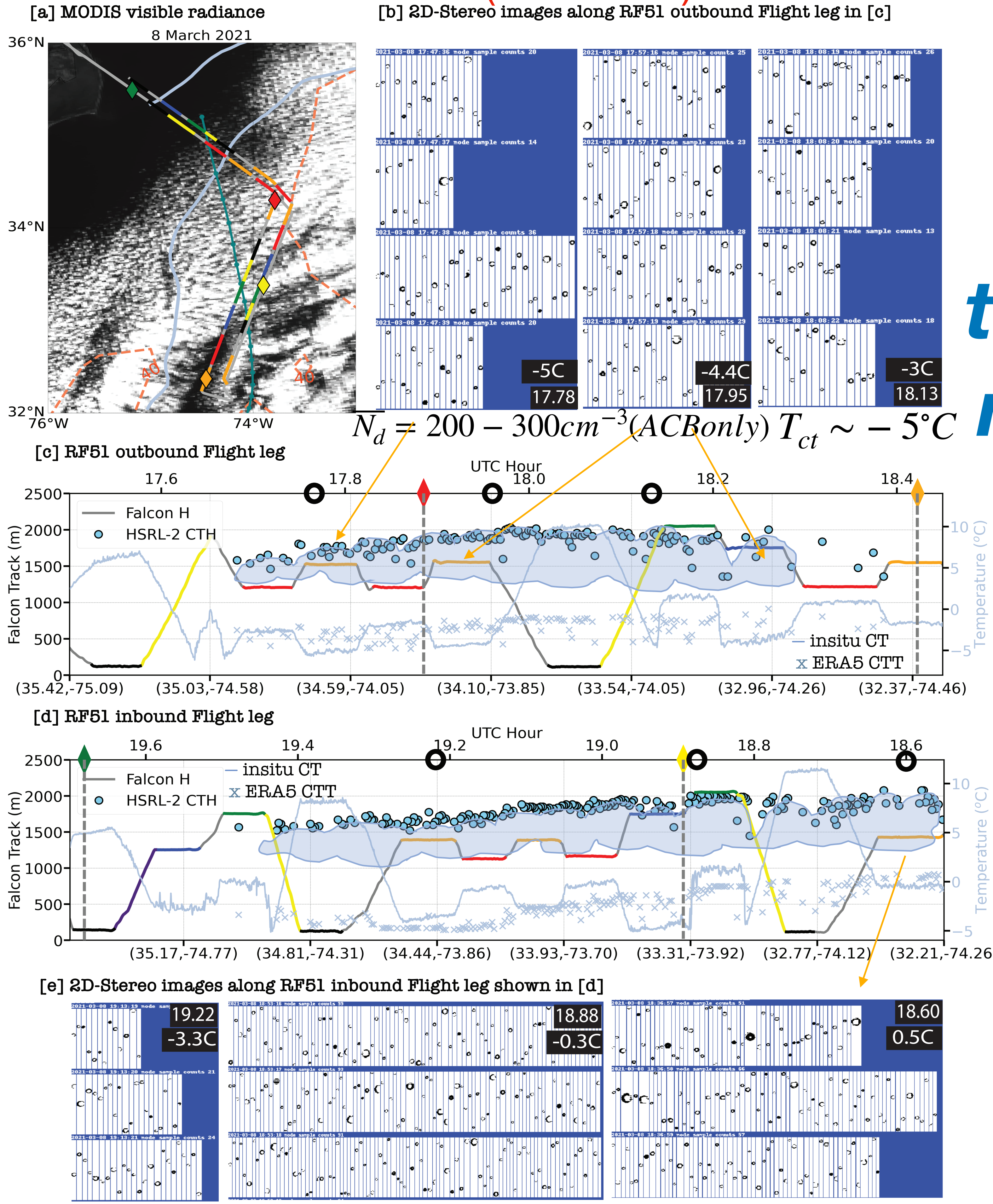


$$\overline{N_d} = 250cm^{-3} \quad T_{ct} \sim -10^{\circ}C$$



Ice detected on first ACB pass through thinnish cloud

8 March 2021 (afternoon)



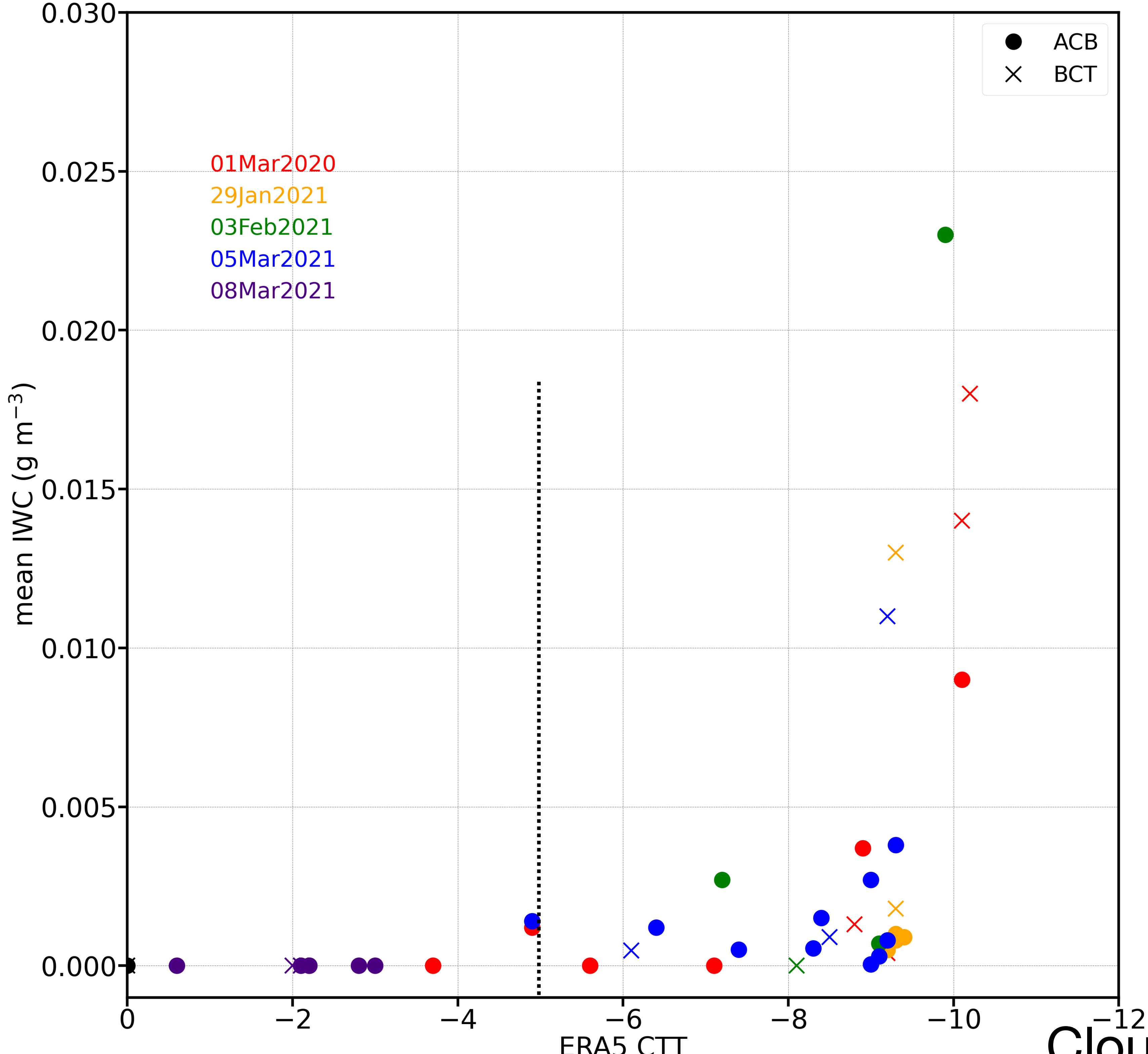
$N_d = 200 - 300 cm^{-3} (ACB only)\ T_{ct} \sim -5°C$

the one flight with no evidence of ice

(still has a nice morphological transition into largish cloud rolls)

Conditionally-sampled leg-mean IWC (IWC>0 only) shows ice production starting at T_{ct} of -5C

IWC



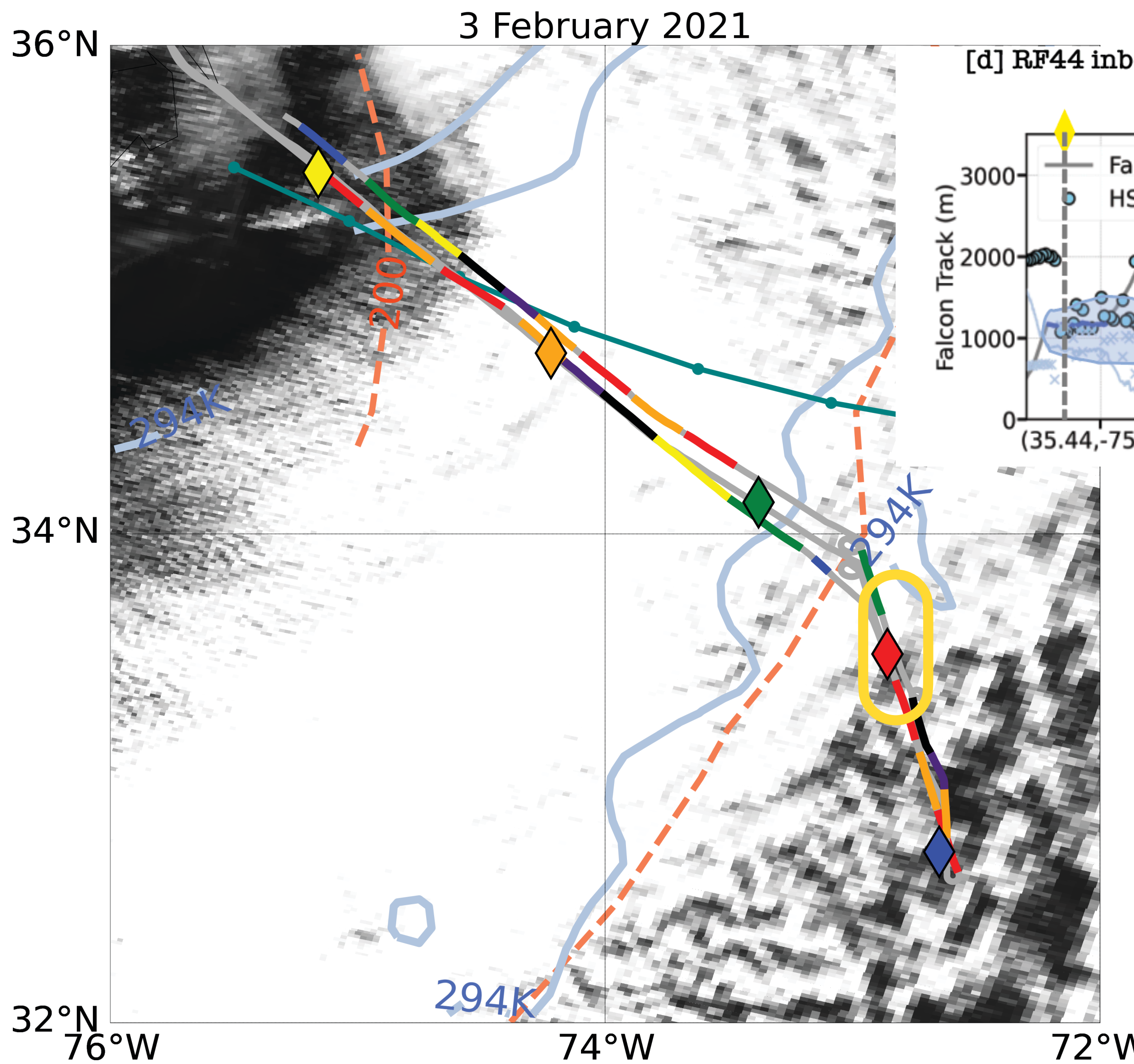
Cloud top temp.

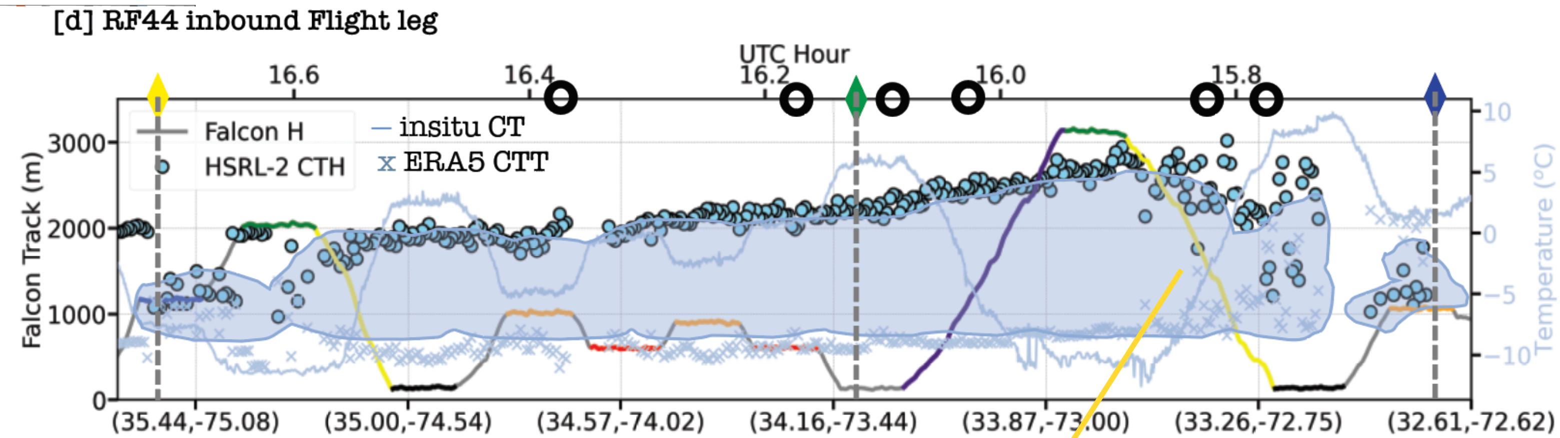
What we have learned #2:

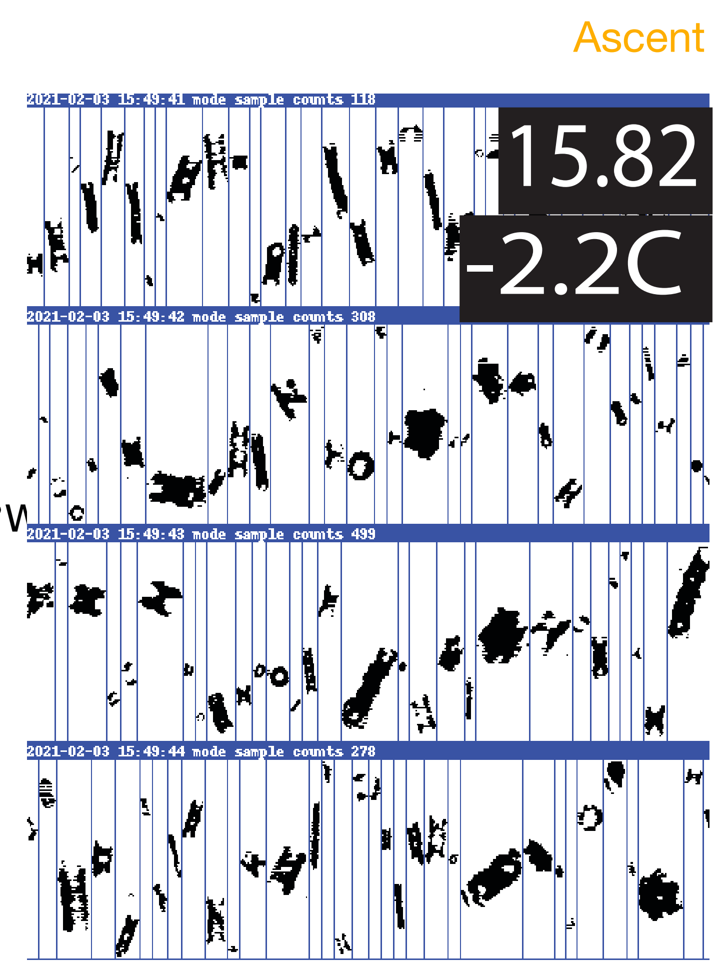
Ice habit either dominated by vapor diffusional growth (2 flights) or riming (2 flights)

\

vapor diffusional growth produces higher IWCs

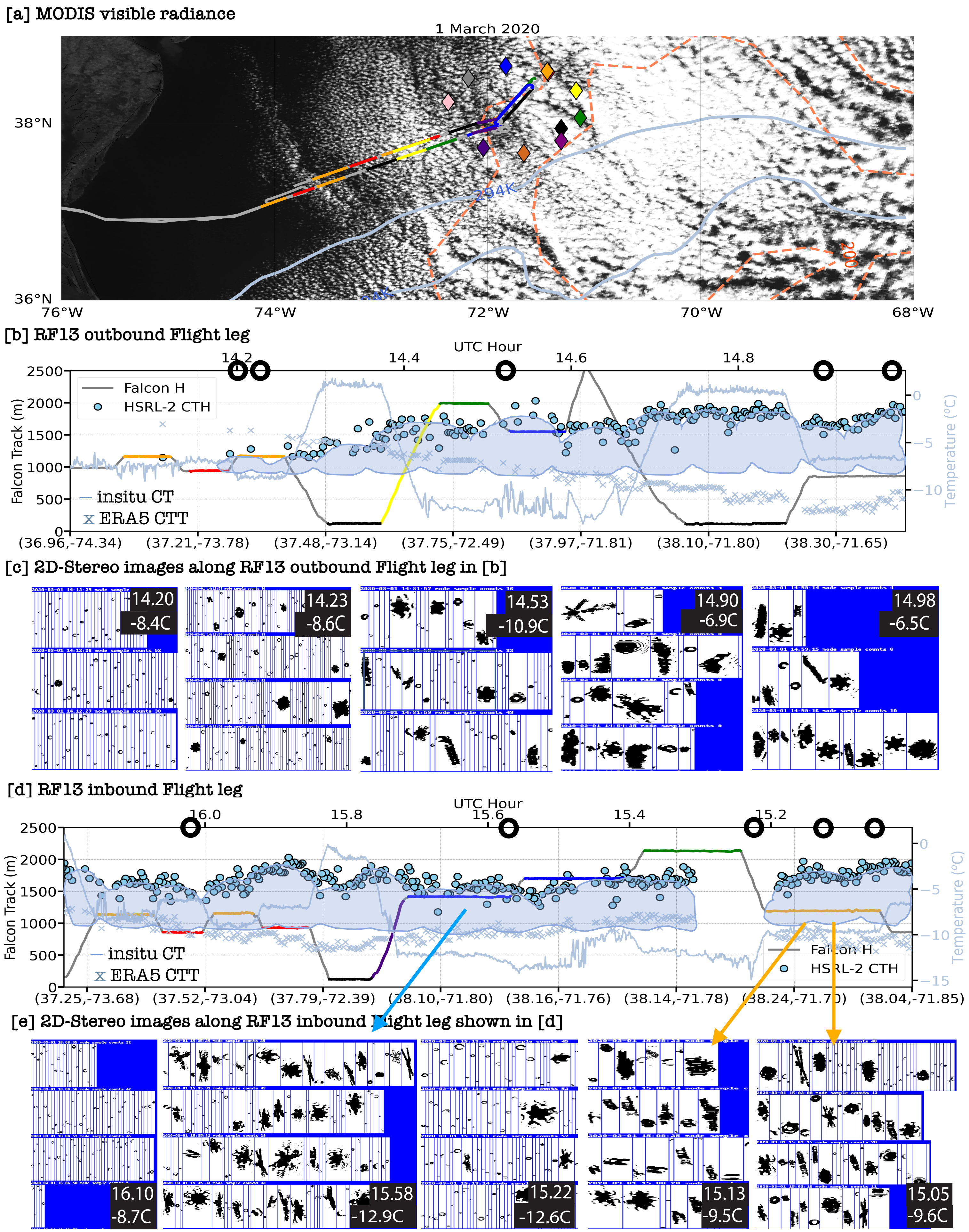






Temperature range correct for growth into columns

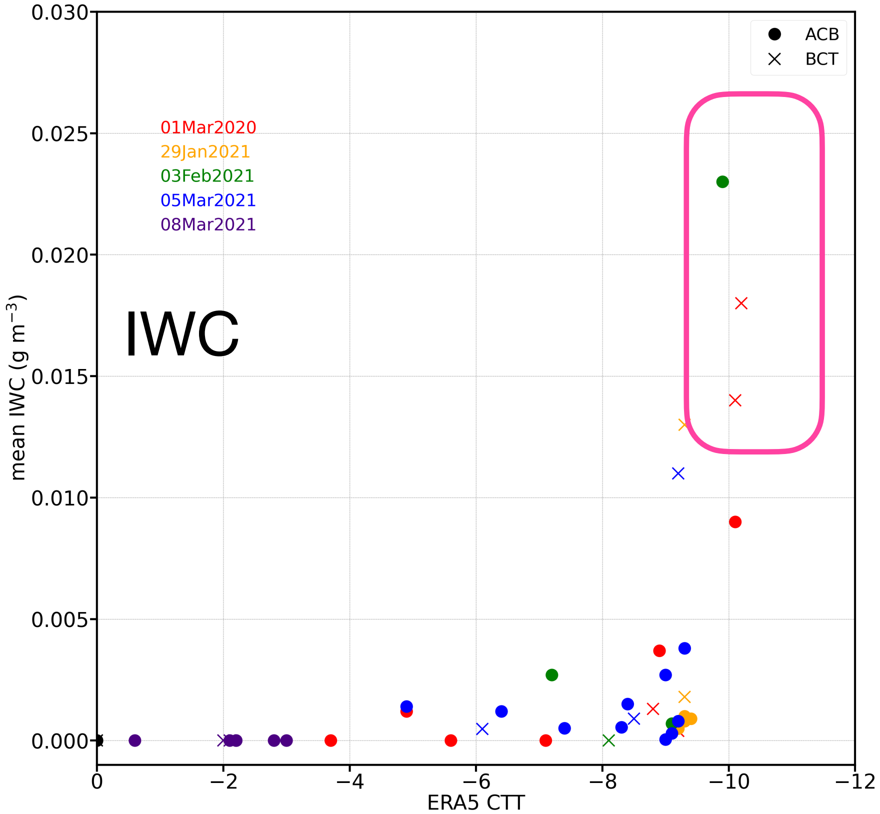
3 February 2021 (morning)



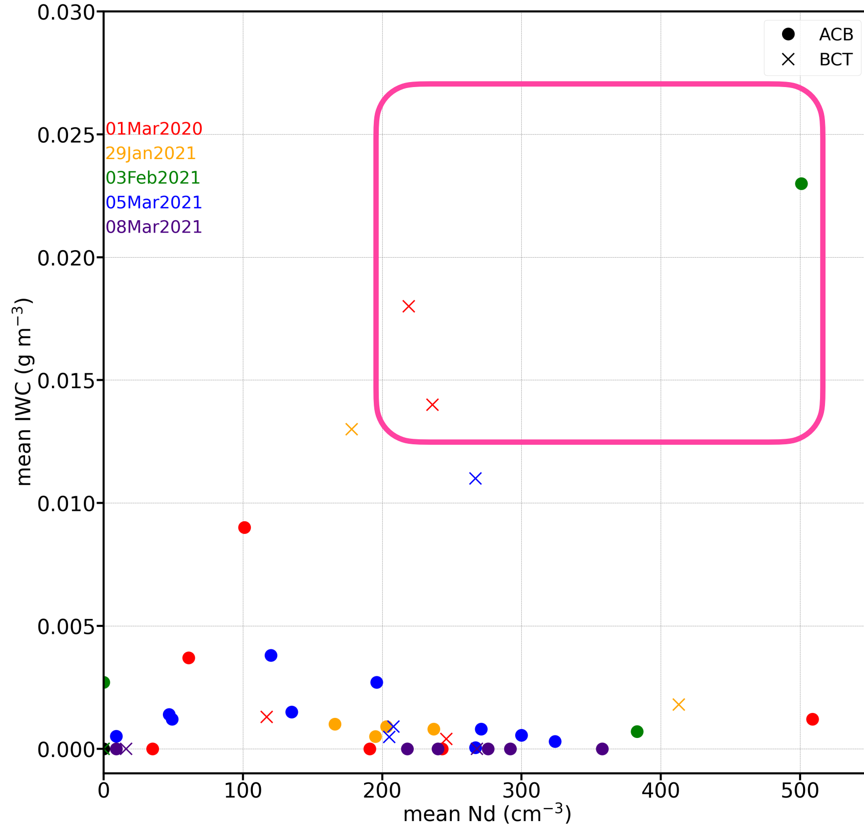
...and snowflakes in the most ice-super-saturated temperature range approaching -15C

= flights with evident vapor diffusional growth

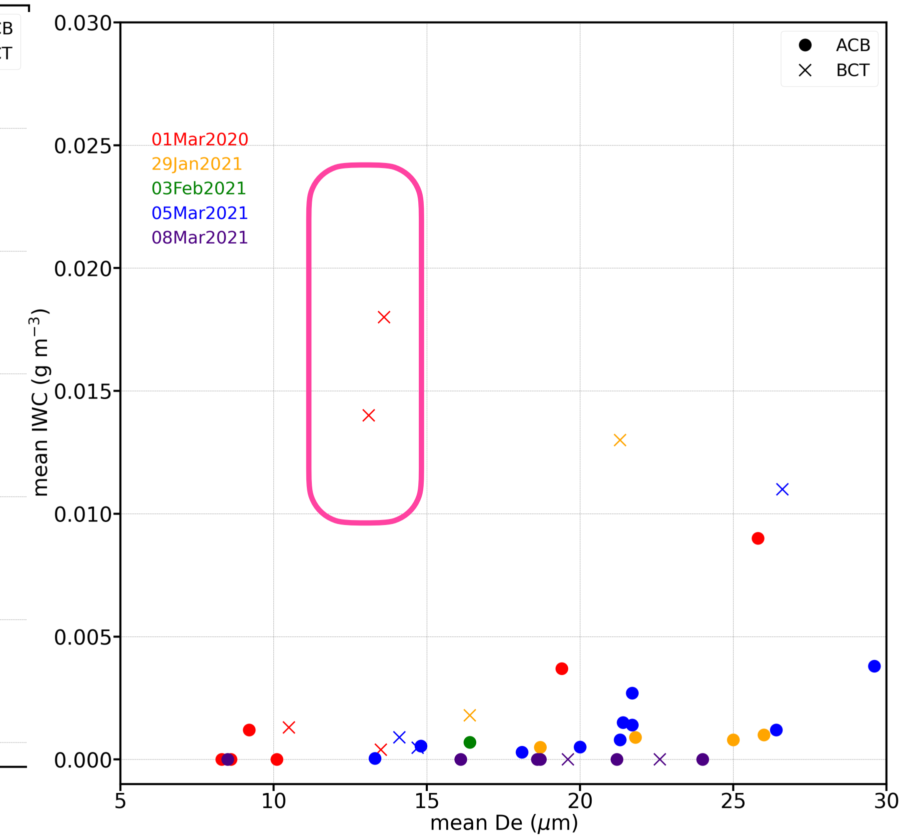
Ice water contents are higher when vapor diffusional growth dominates



Cloud top temp



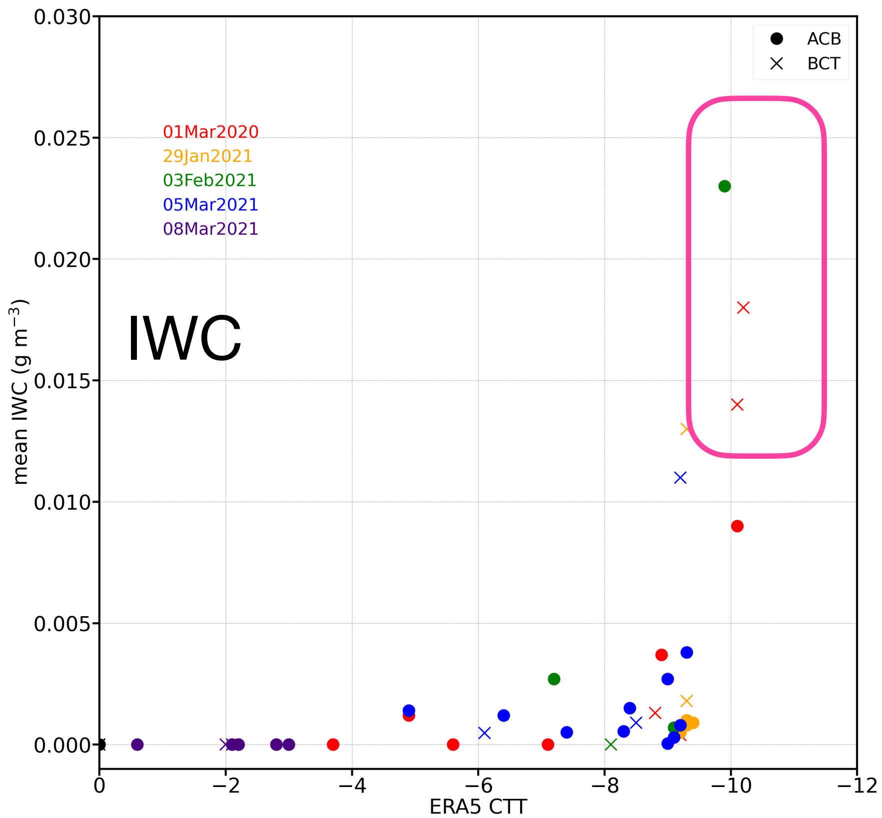
N_d



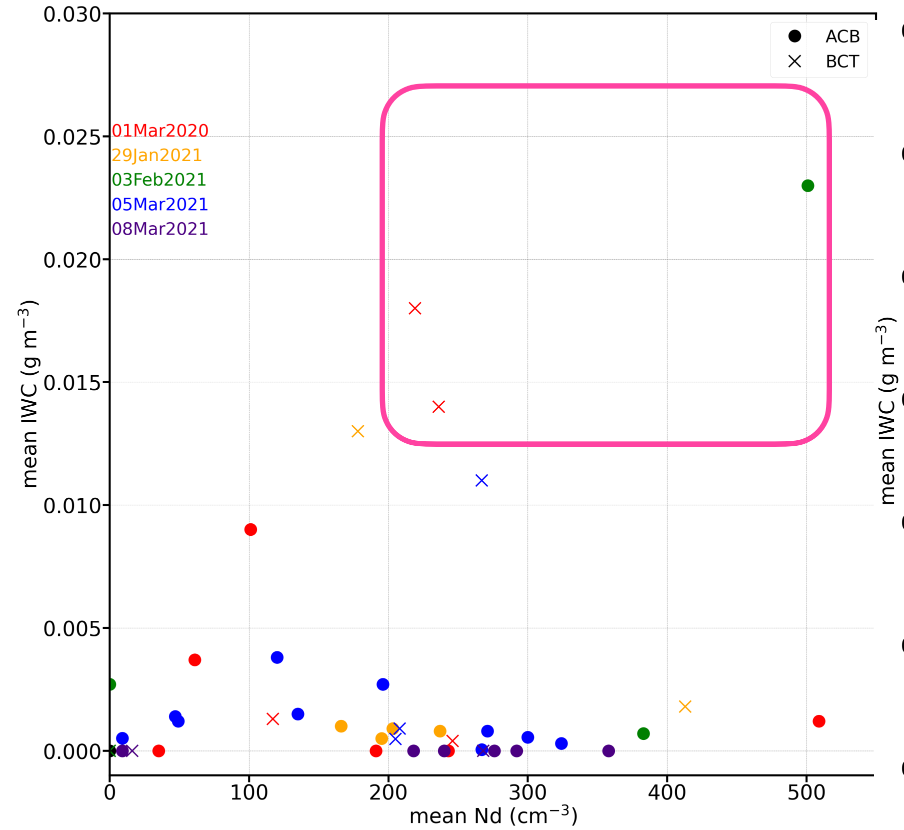
D_{eff}

= flights with evident vapor diffusional growth

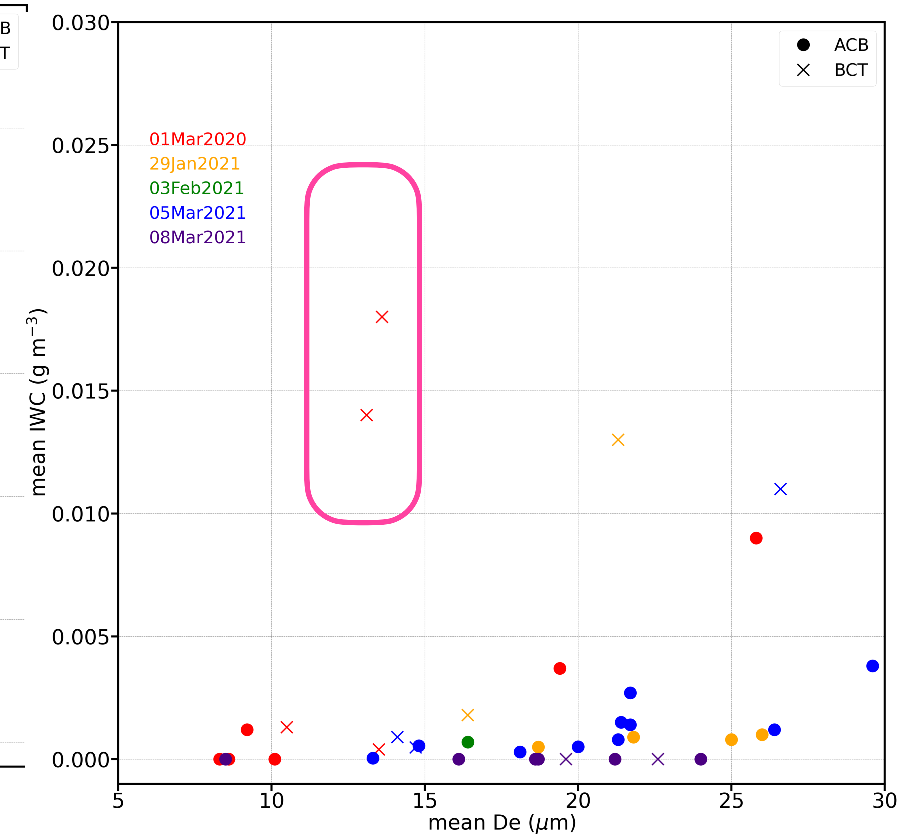
Ice water contents are higher when vapor diffusional growth dominates



Cloud top temp



N_d



D_{eff}

Anecdotal observations:

Transitions, cloud morphology shows little correspondence to ice habit or IWC

Remotely-sensed LWPs (RSP, MODIS) are too high (not shown) compared to profile values, surface rainfall rates not super-high

The cloud deepening can be pronounced (e.g. Naud et al 2020)

Could mesoscale circulations be playing a stronger role in the transitions than the microphysics?

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