Microphysical evolution in mixed-phase mid-latitude marine cold-air outbreaks

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Now under review for JAS

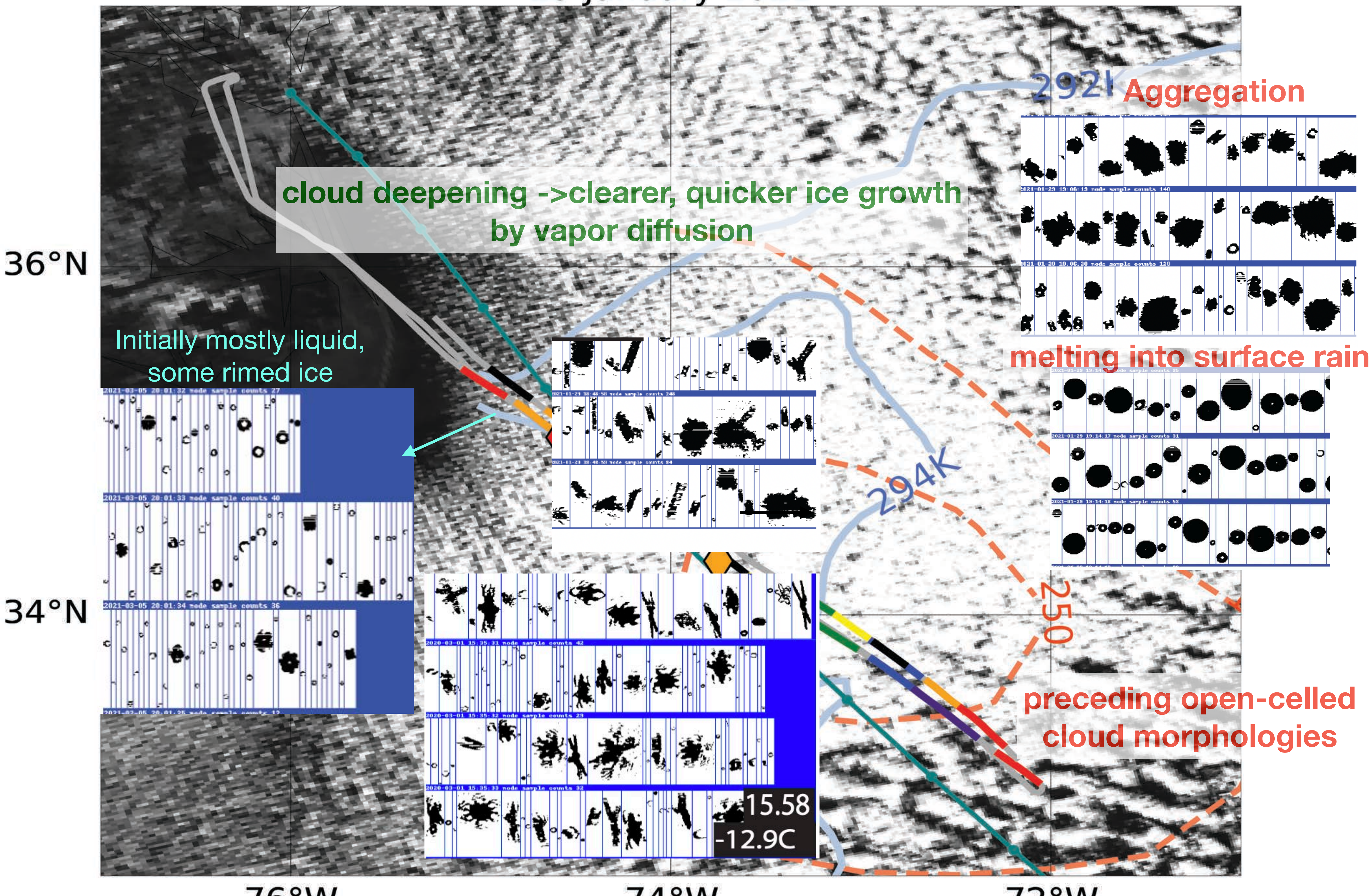
Preprint available at https://eartharxiv.org/repository/view/6196/

Motivated by a desire to understand the importance of cloud phase to changes in cloud morphology for this reason

- and to utilize the unique ACTIVATE measurements on cloud microphysics, vertical structure

date	morning	am dropsondes	afternoon	pm dropsondes
1 March 2020	RF13, both planes	circle of 11	RF14, both planes. no RSP	2 (downwind)
29 January 2021	RF42, King Air (high flying)	2	RF43, Falcon (*in-situ*)	0
3 February 2021	RF44, both planes	5	–	–
5 March 2021	RF49, both planes	5	RF50, both planes	2 (downwind)
8 March 2021	–	–	RF51, both planes	4

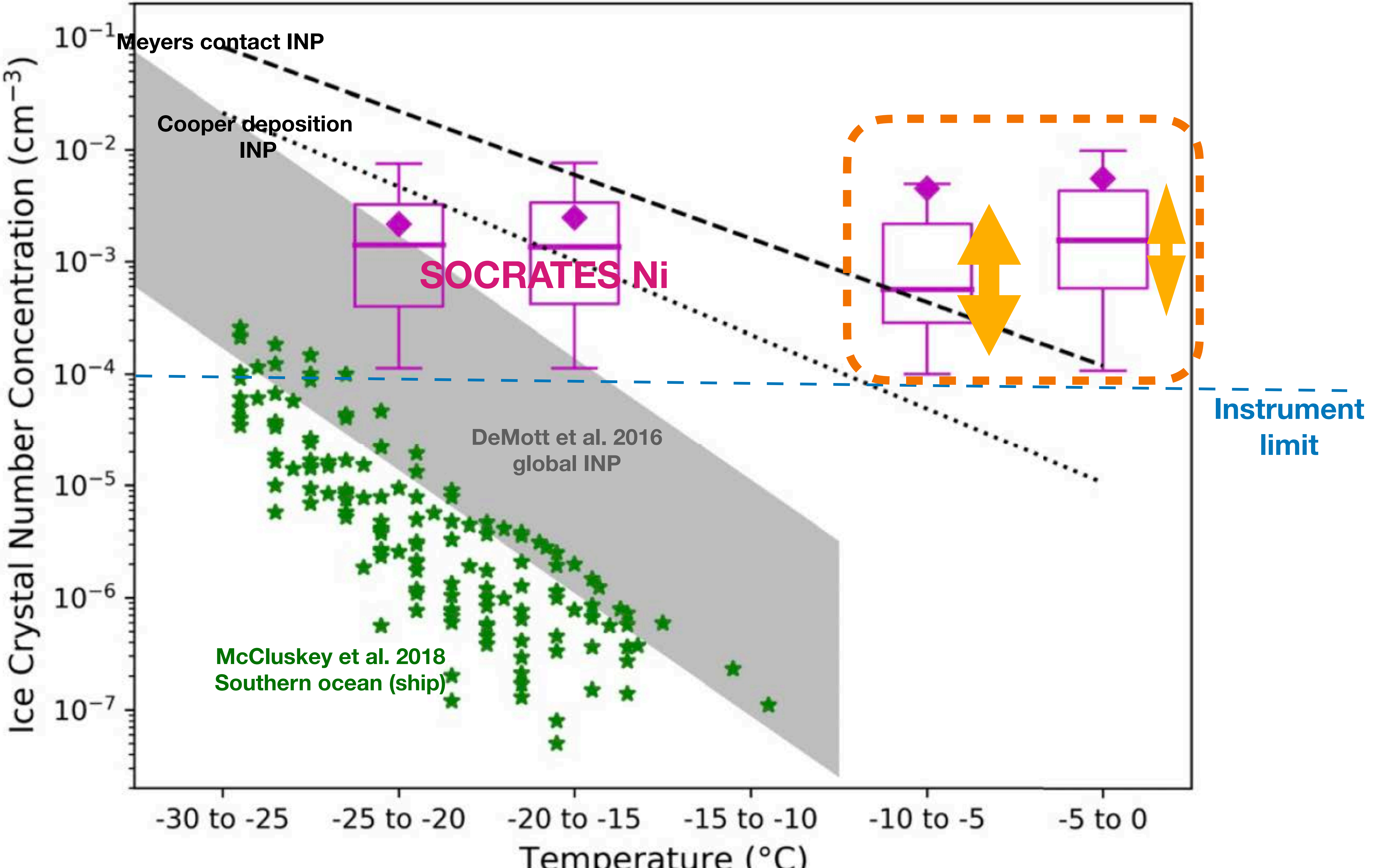
29 January 2021



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

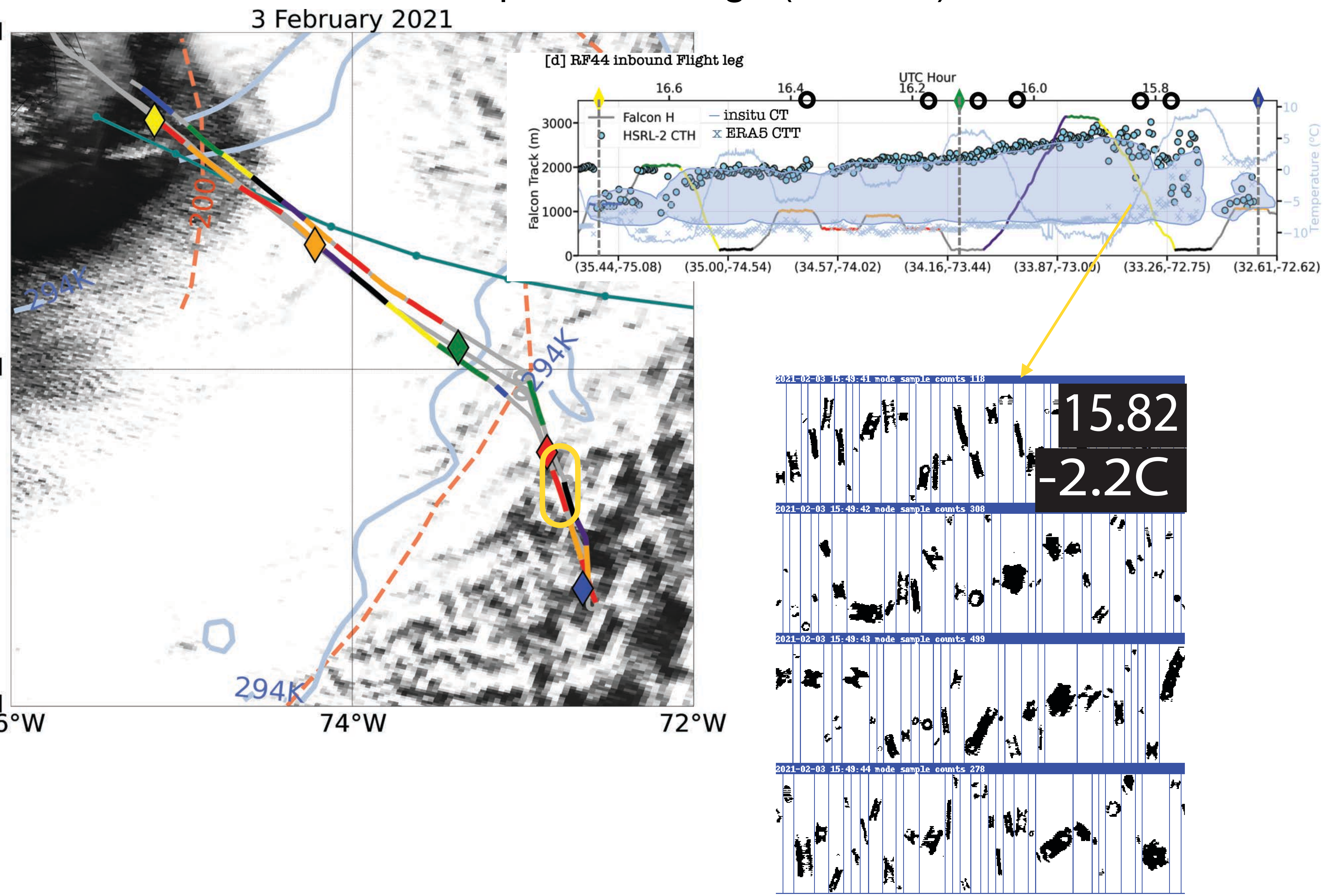
ACTIVATE ice crystal number concentrations indicate secondary ice production, on par with southern ocean values

Could those secondary ice production processes be identified?

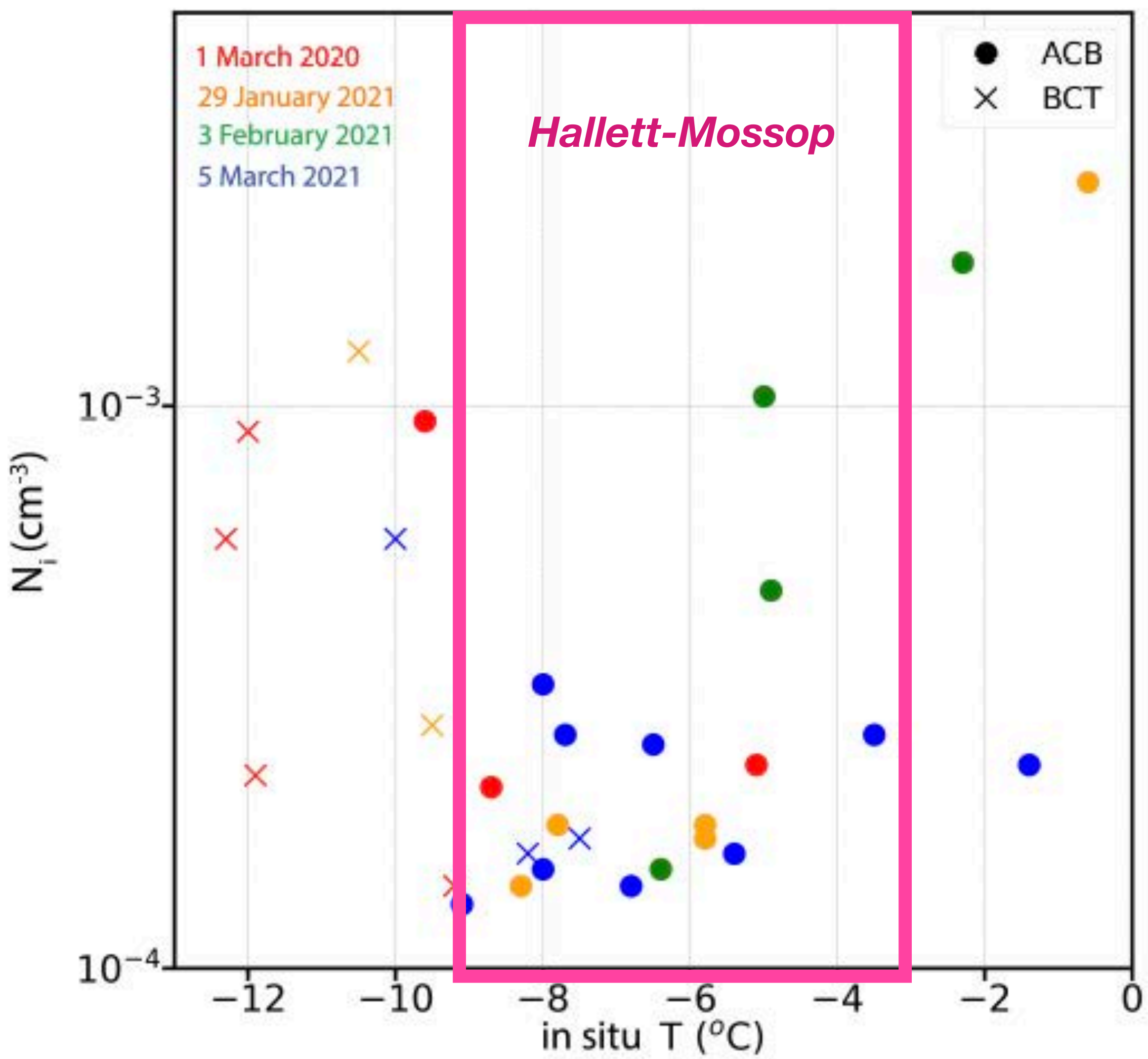


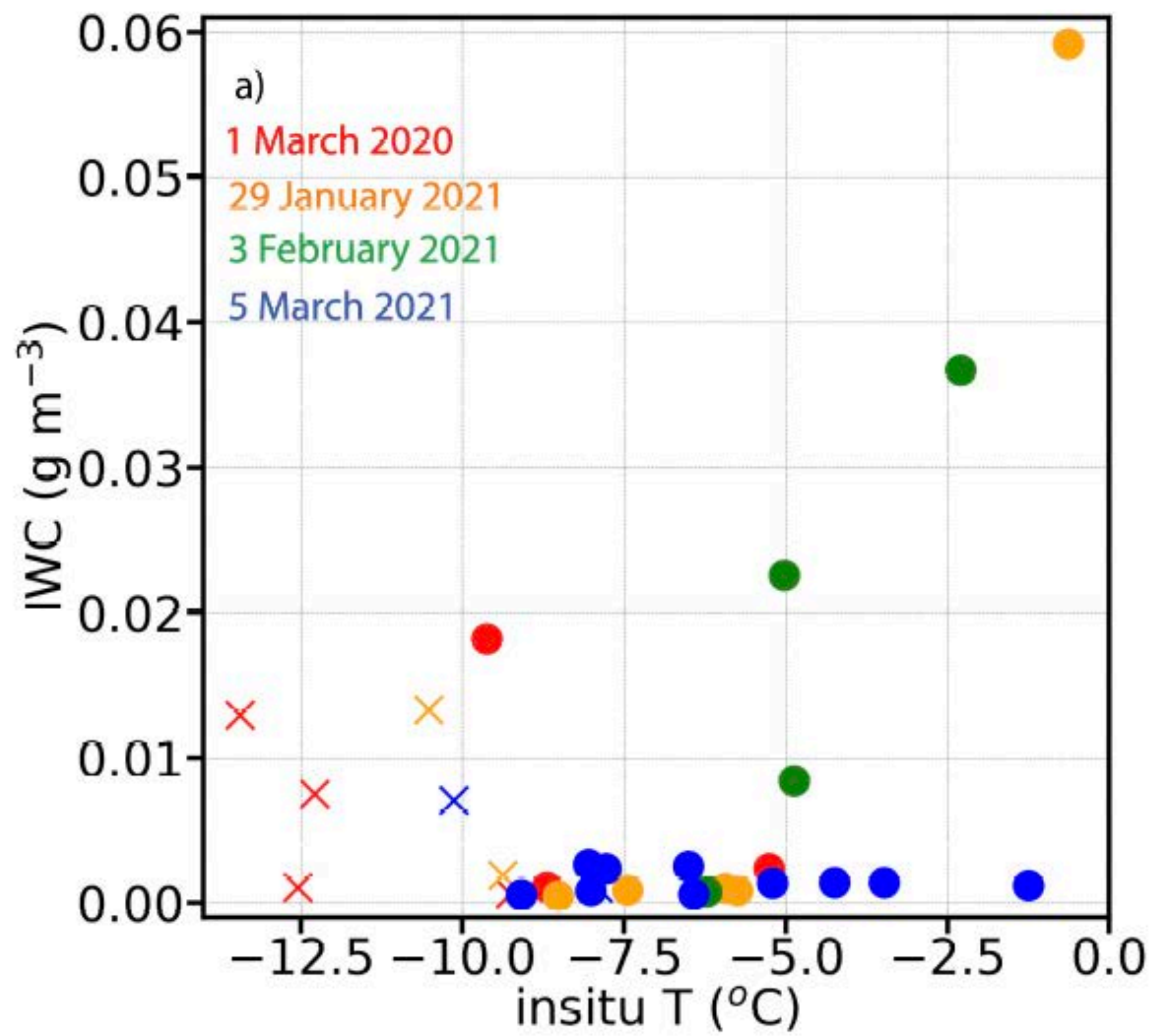
Atlas et al., 2022, AGU Advances

Some rime-splintering into columns occurring in the ‘Hallett-Mossop’ temperature range (-3 - -8C)

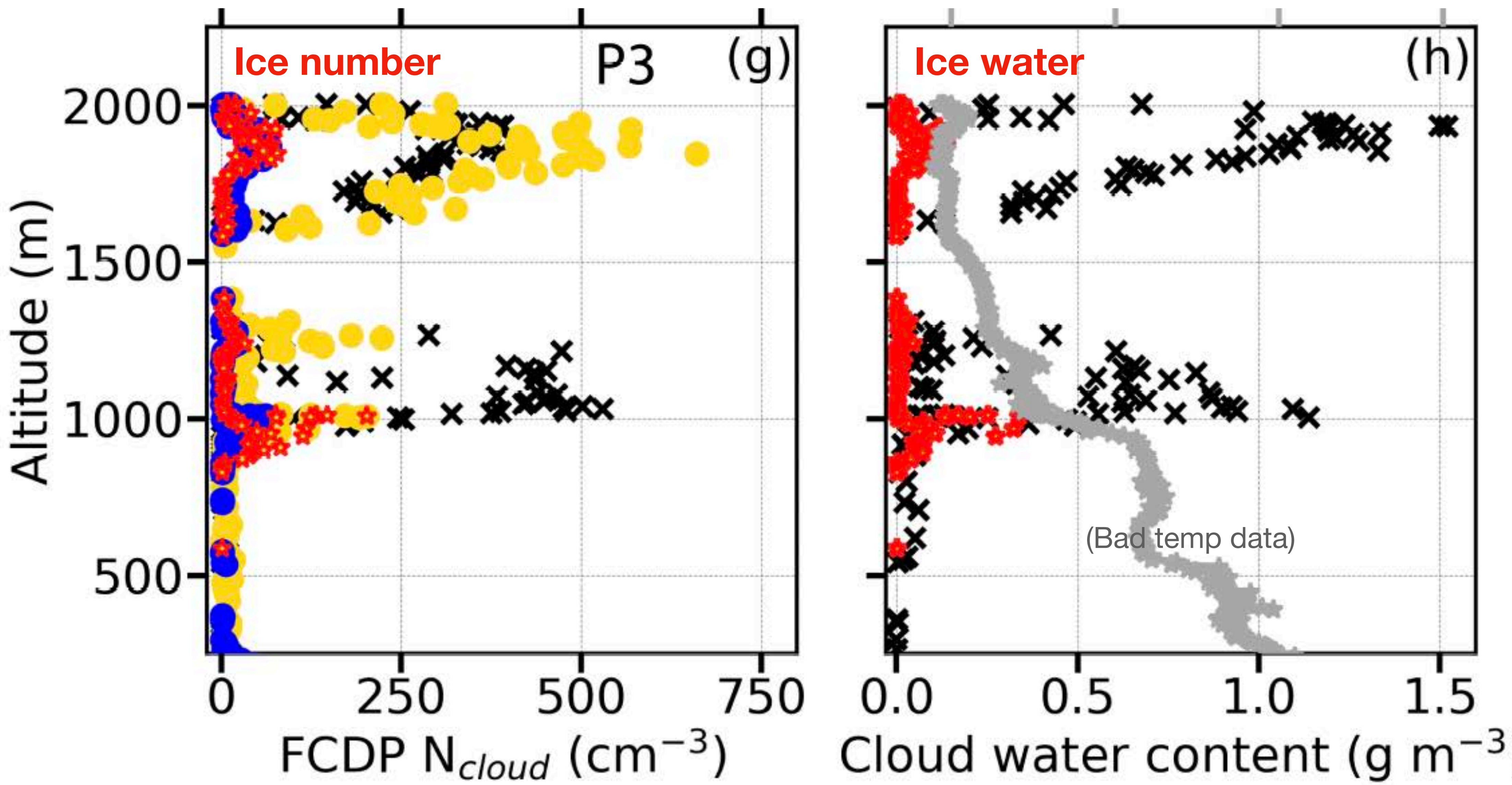


While secondary ice is being produced between -3 and -8C (the Hallett-Mossop rime-splintering mechanism), additional ice is also produced at colder temperatures near cloud top, and warmer temperatures near cloud base





Profiles consistently showed two preferred regions for ice production: near cloud top, and by cloud base

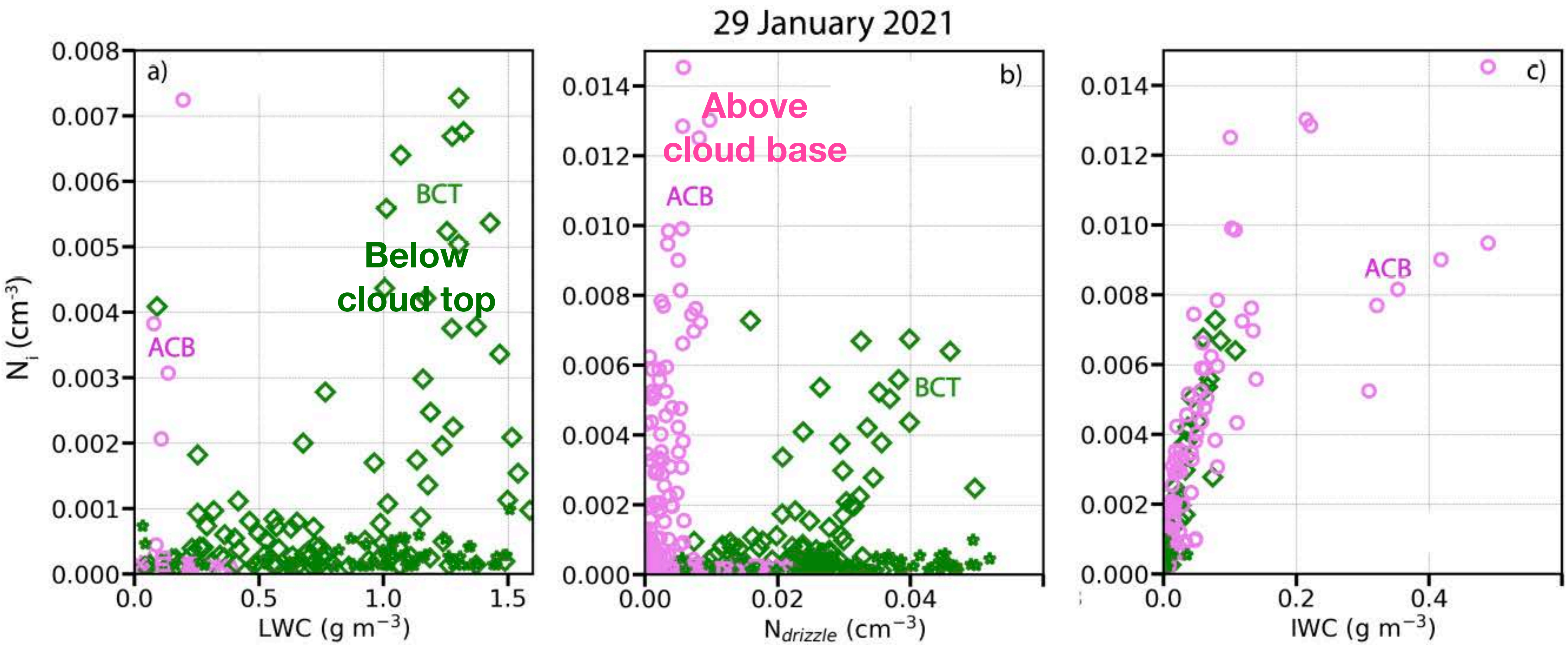


@ cloud top, Ni correlate well with liquid water content, large drops, IWC

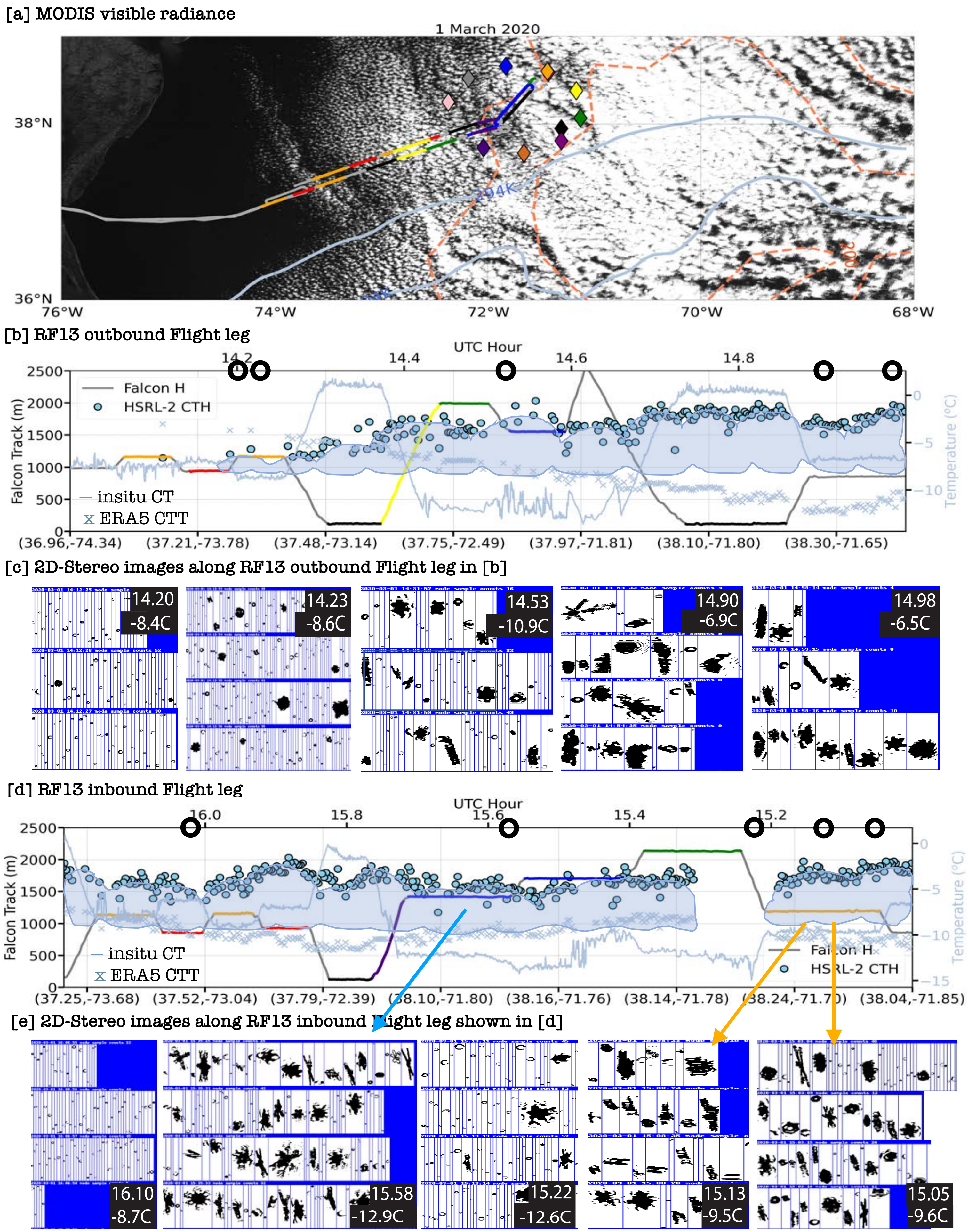
temperatures encourage dendritic growth, **collisions encourage ice-ice, ice-graupel breakup**

@cloud base, Ni correlates best with IWC. quali-liquid layer on ice surface can encourage

intense aggregation*, easing ice particle breakup



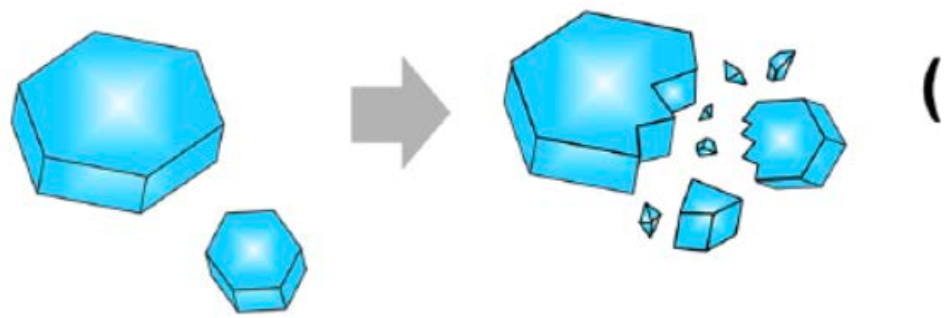
*Fabry & Zawadowski, 1995; intense aggregation often observed near 0C in convective clouds



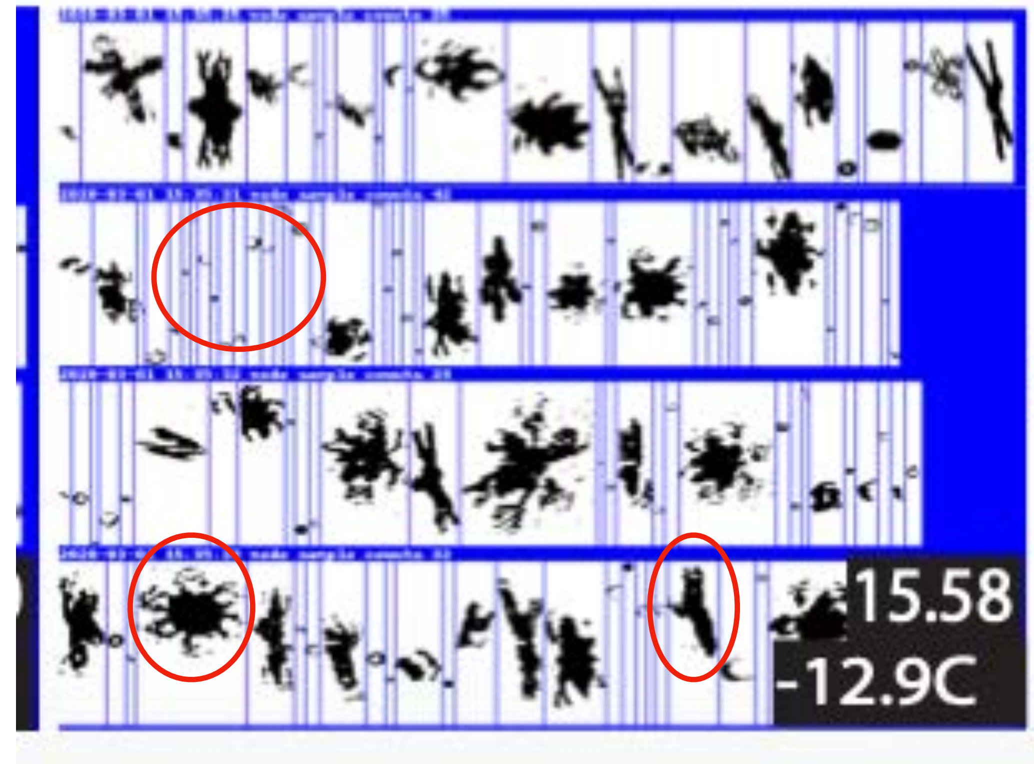
snowflakes are more likely near cloud top, where temperatures can approach -15C

What could be happening at cloud top

Fragmentation during ice-ice collision

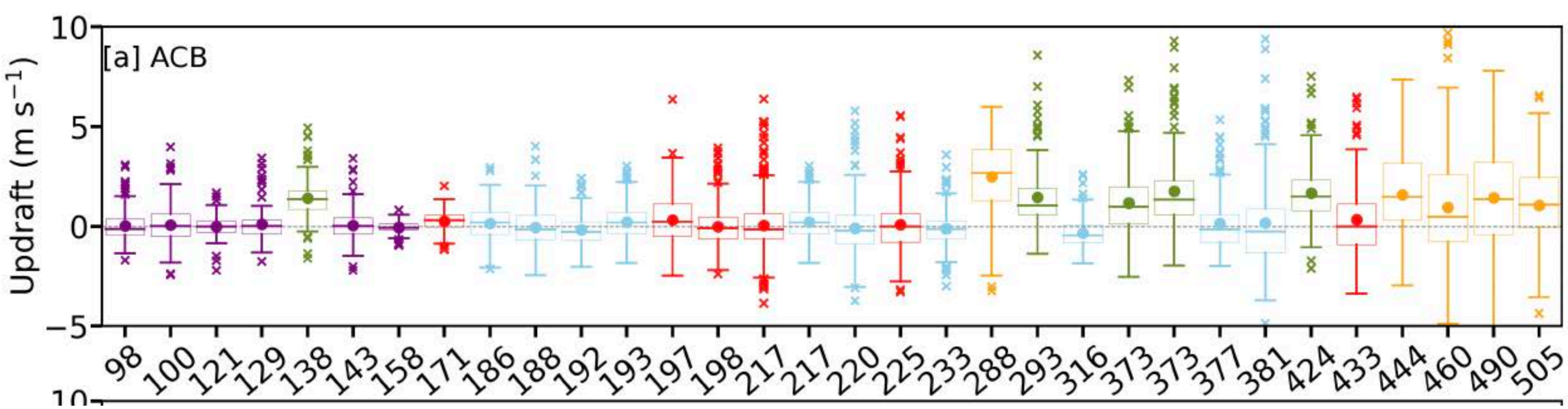


+Rime-induced splintering



At cloud base: ice aggregation often observed near 0C level in convective clouds, Attributed to enhancement via a liquid layer on an ice surface increasing 'stickiness'

Fabry, F., and I. Zawadzki, 1995: Long-termradar observations of the melting layer of precipitation and their interpretation. J. Atmos. Sci., 52, 838–851.



Buoyancy fluxes

Strong observed updrafts would support this mechanism

Expectation is that ice depletes cloud

(Super-cooled liquid)

Water vapor gravitates towards the ice particles
they grow & fall out

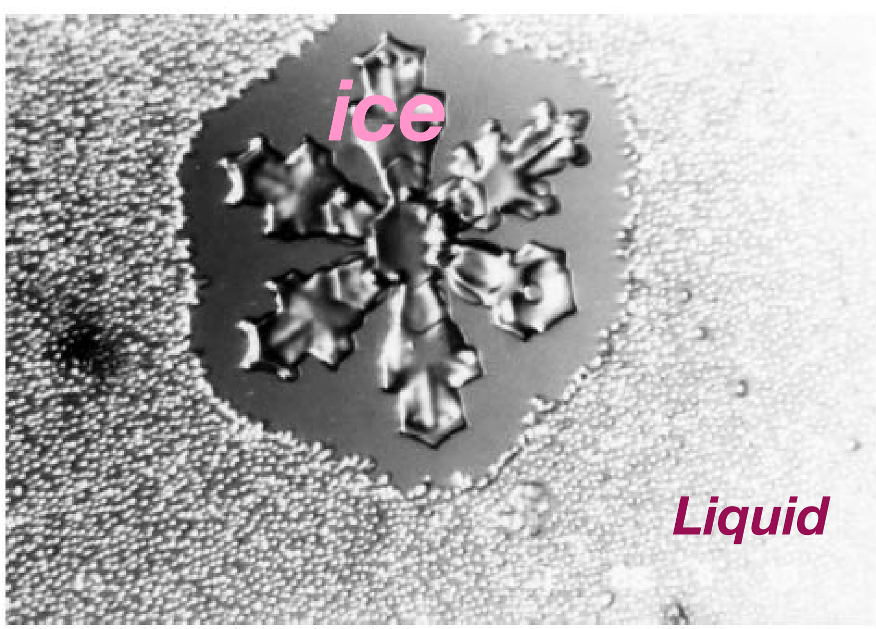
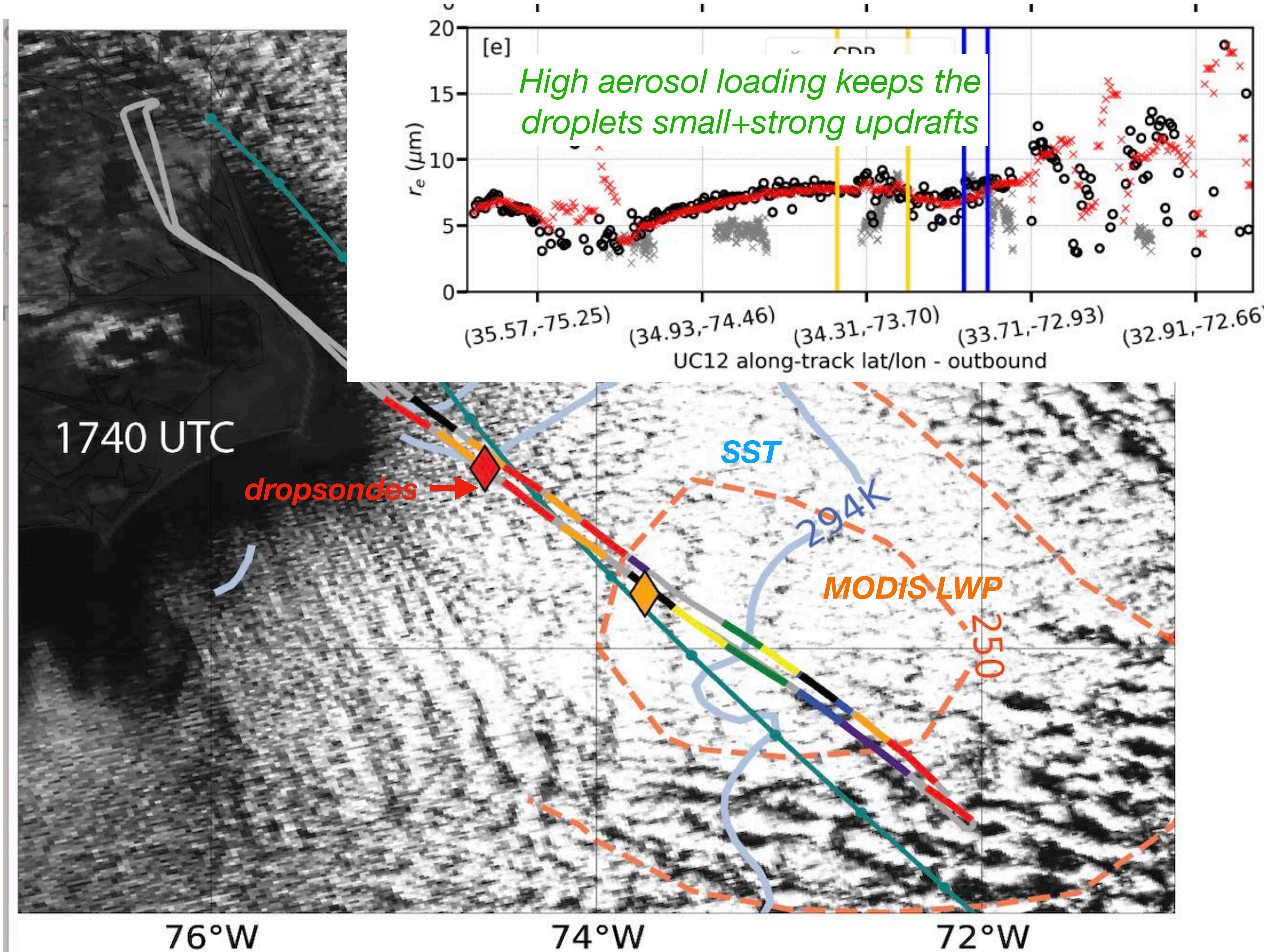


Fig. 6.36 Laboratory demonstration of the growth of an ice crystal at the expense of surrounding supercooled water

These clouds last a while despite copious ice, however

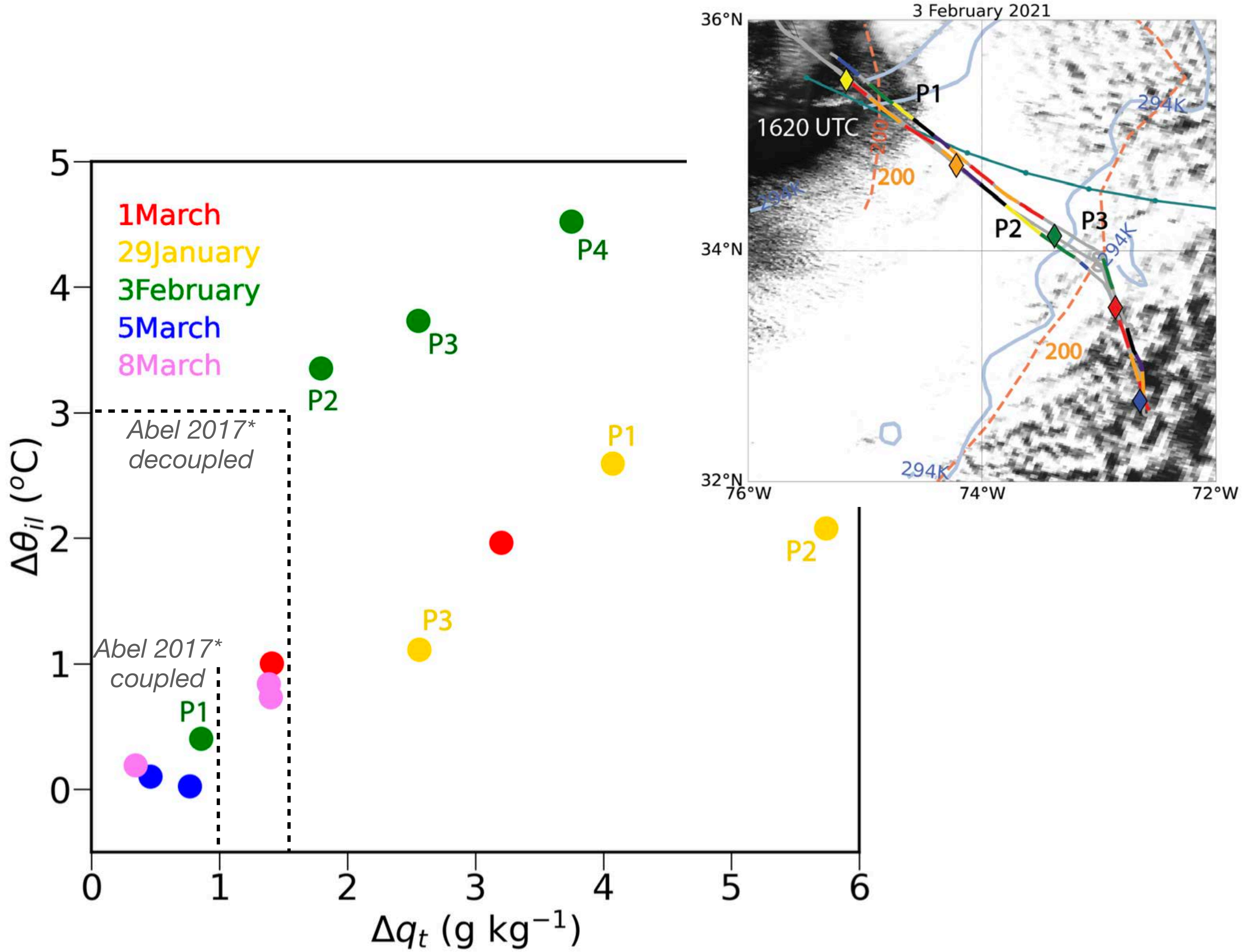


overcast cloud fields persist despite decoupled boundary layers

$$\theta_{il} \sim \theta - \frac{L_v}{c_p} q_l$$

$$\Delta\theta_l = \theta_{l,25\%top} - \theta$$

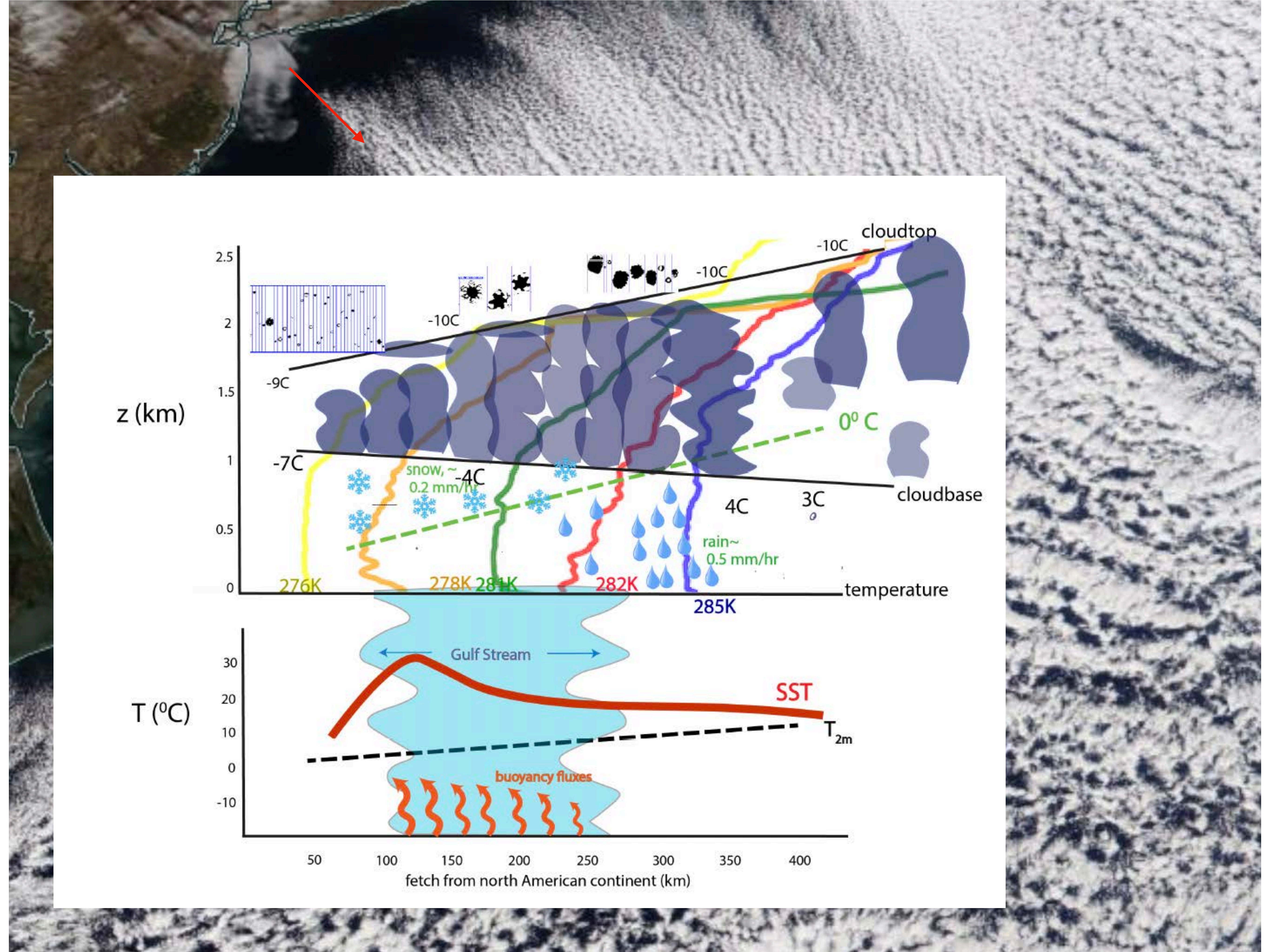
Jones et al., 2011,ACP



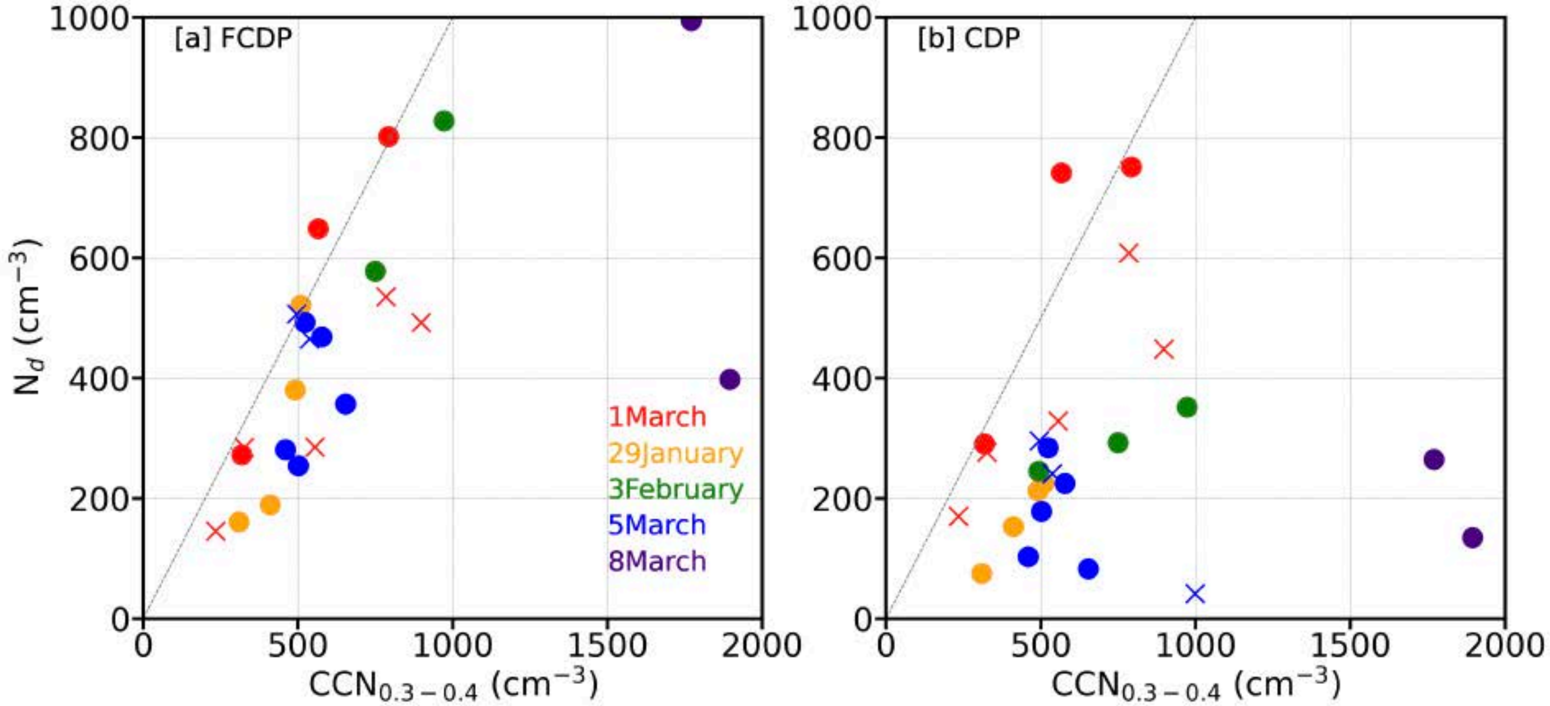
$$q_{total} = q_v + q_l + q_i$$

$$\Delta q_t = q_{t,25\%top} - q_{t,25\%,bottom}$$

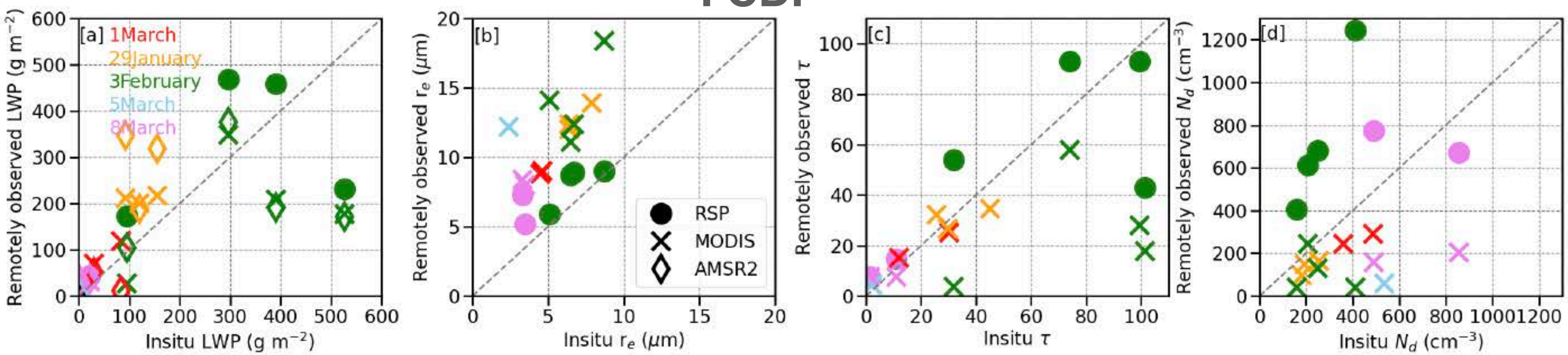
*Abel et al. 2017: The role of precipitation in controlling the transition from stratocumulus to cumulus clouds in a northern-hemisphere cold-air outbreak


cloudtop
-10C
-10C
-10C
-9C
-7C
-4C
snow, ~
0.2 mm/hr
0⁰ C
4C
3C
cloudbase
rain~
0.5 mm/hr
276K
278K
281K
282K
285K
temperature
z (km)
2.5
2
1.5
1
0.5
0
Gulf Stream
SST
T2m
buoyancy fluxes
T (⁰C)
30
20
10
0
-10
50
100
150
200
250
300
350
400
fetch from north American continent (km)

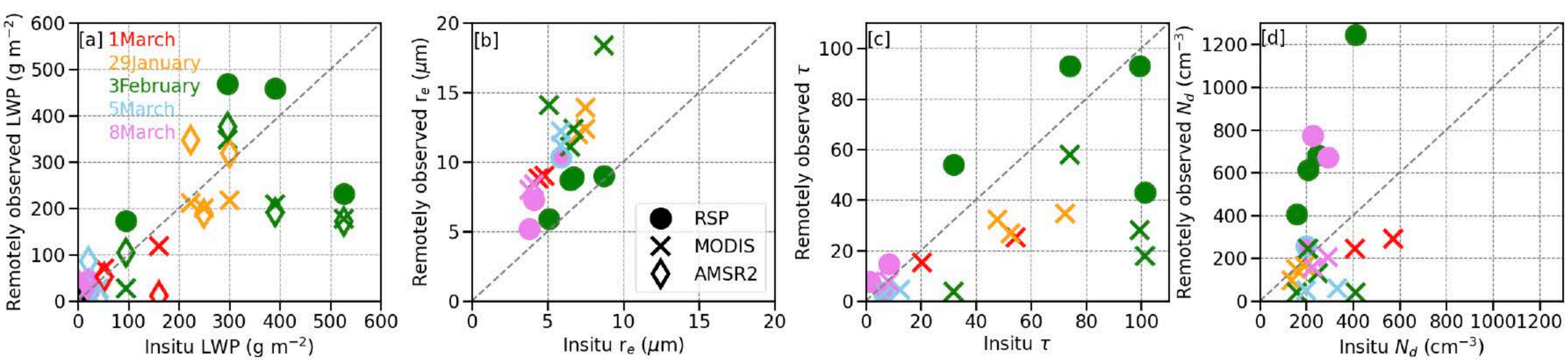
Extra


[a] FCDP
[b] CDP
N_d (cm^{-3})
CCN$_{0.3-0.4}$ (cm^{-3})
1March
29January
3February
5March
8March

FCDP


[a]
[b]
[c]
[d]
1March
29January
3February
5March
8March
RSP
MODIS
AMSR2
Remotely observed LWP (g m^{-2})
Insitu LWP (g m^{-2})
Remotely observed r$_e$ (μm)
Insitu r$_e$ (μm)
Remotely observed τ
Insitu τ
Remotely observed N_d (cm^{-3})
Insitu N_d (cm^{-3})

CDP


[a]
[b]
[c]
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Insitu LWP (g m^{-2})
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Insitu r$_e$ (μm)
Remotely observed τ
Insitu τ
Remotely observed N_d (cm^{-3})
Insitu N_d (cm^{-3})