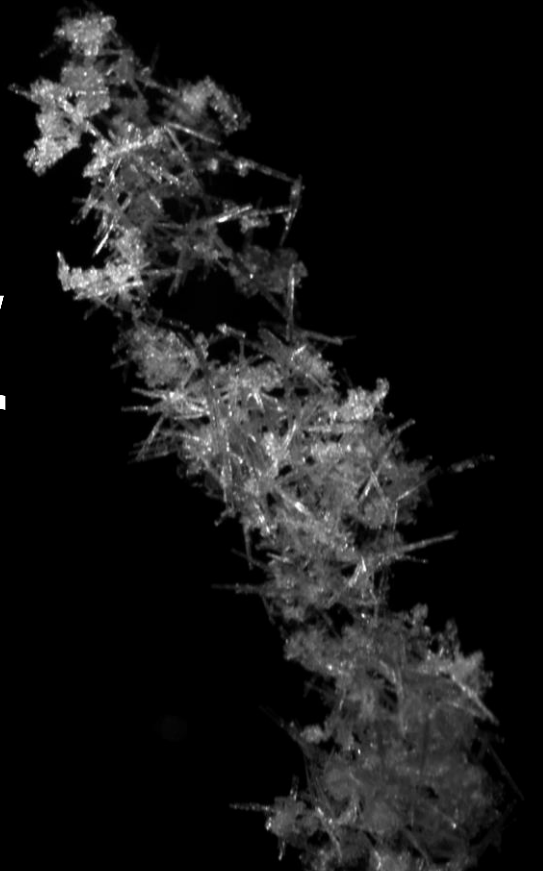
3D characteristics of snow bands and implications for surface snowfall in Northeast Winter Storms



Sandra Yuter & Laura Tomkins

Matthew Miller, Luke Allen, Kevin Burris, Declan Crowe, Jordan Fritz, Logan McLaurin, Toby Peele, the NASA IMPACTS Science Team, & Brian Colle (Stonybrook U.)

18th January 2024

NC STATE UNIVERSITY

Terminology

- Use term “snow” for precipitation-sized ice particle that is large enough to fall in still air
  - Distinct from cloud-sized ice
  - “age of snow” - time since snow particle first attained precipitation-size

- “microphysical pathway” sequence of d(mass)/dt changes a snow particle undergoes as a function of the sequence of environments it falls through along its path through the storm

Big picture takeaways from multi-year winter storm observations

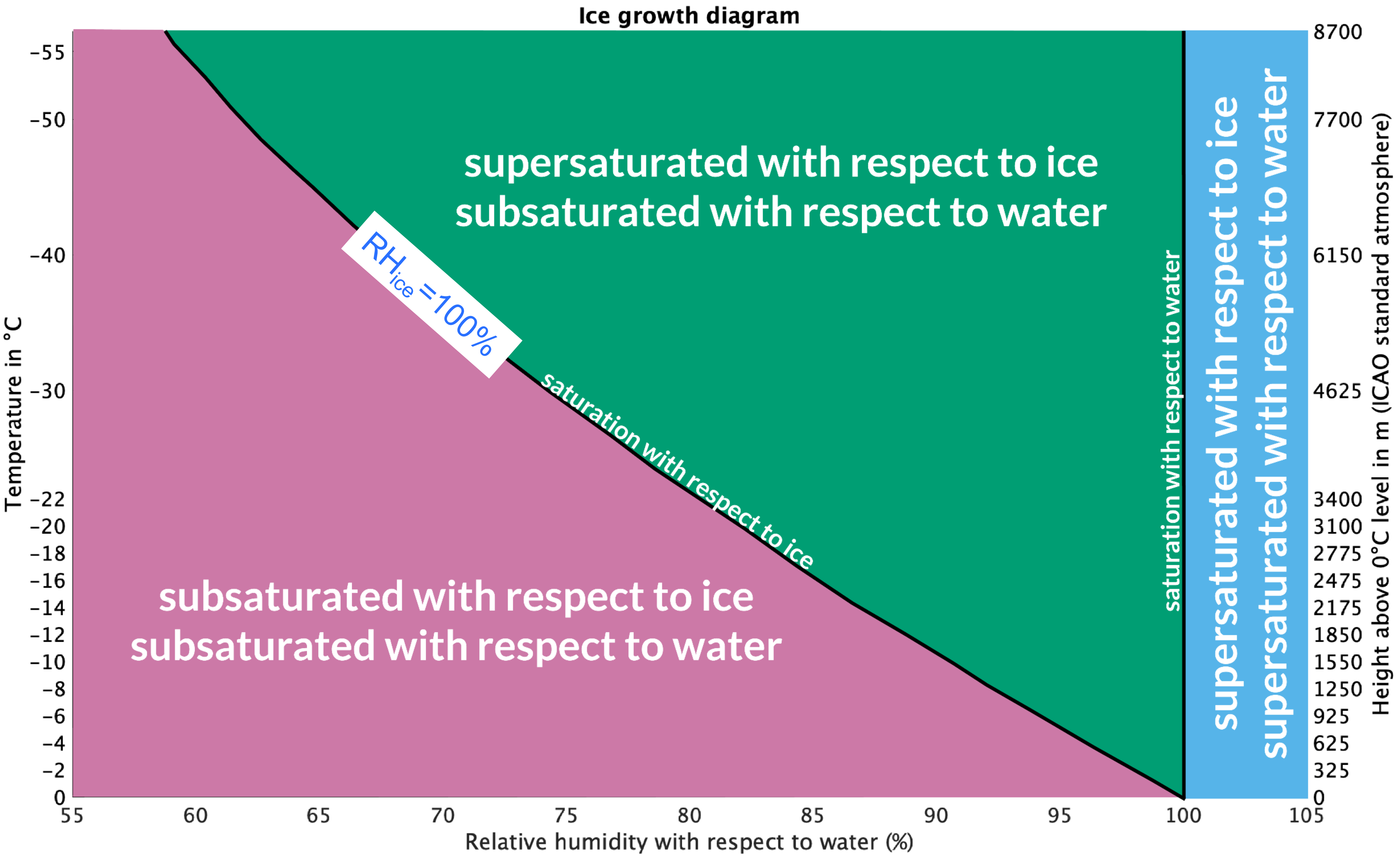
Low correlation between enhanced Z in “snow bands” detected on regional scanning radar and hourly surface snow rates

Usually observe coincident mixtures of snow particle shapes and degrees of riming

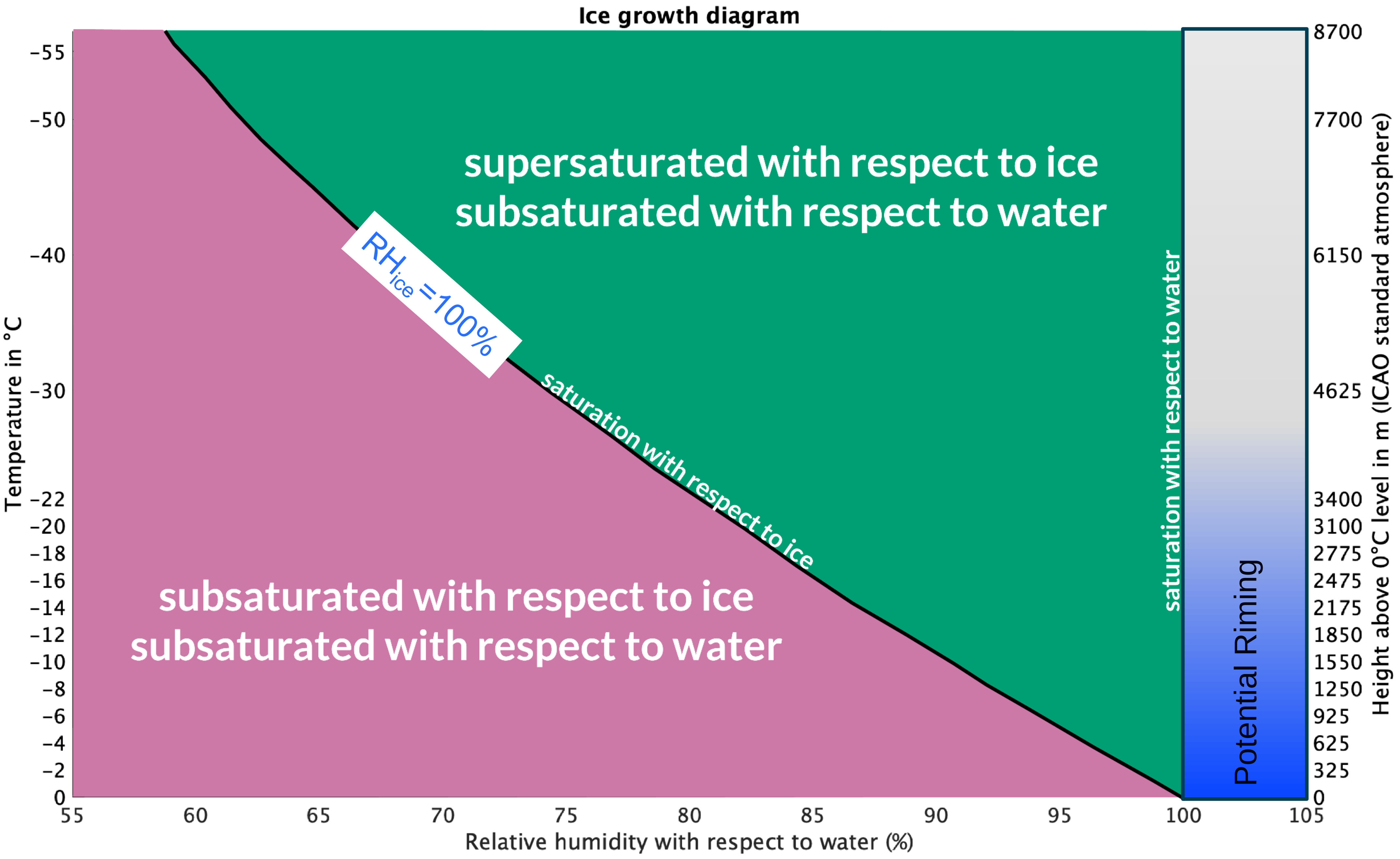
- Mixtures yield varying distributions of shapes, sizes, and densities in the same volume which complicate interpretations and retrievals of snow rate

In the 1-2 hours that it takes a precipitation-sized ice particle to fall from near cloud top to the surface, 3d ice streamers originating in generating cells are tilted and smeared

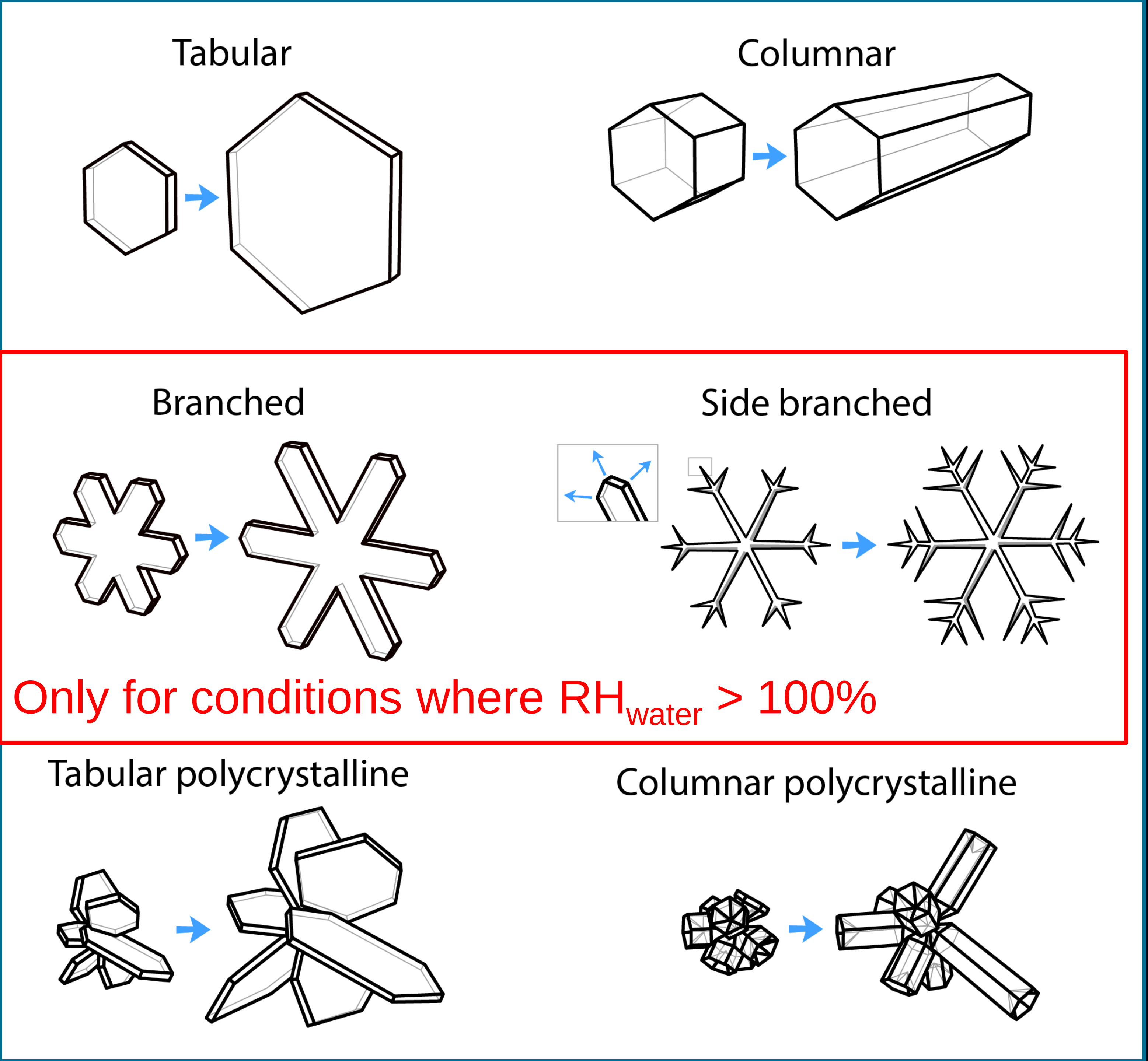
- Lack of vertical column continuity in local enhancements in radar Z



Hueholt et al. (2022)



Hueholt et al. (2022)



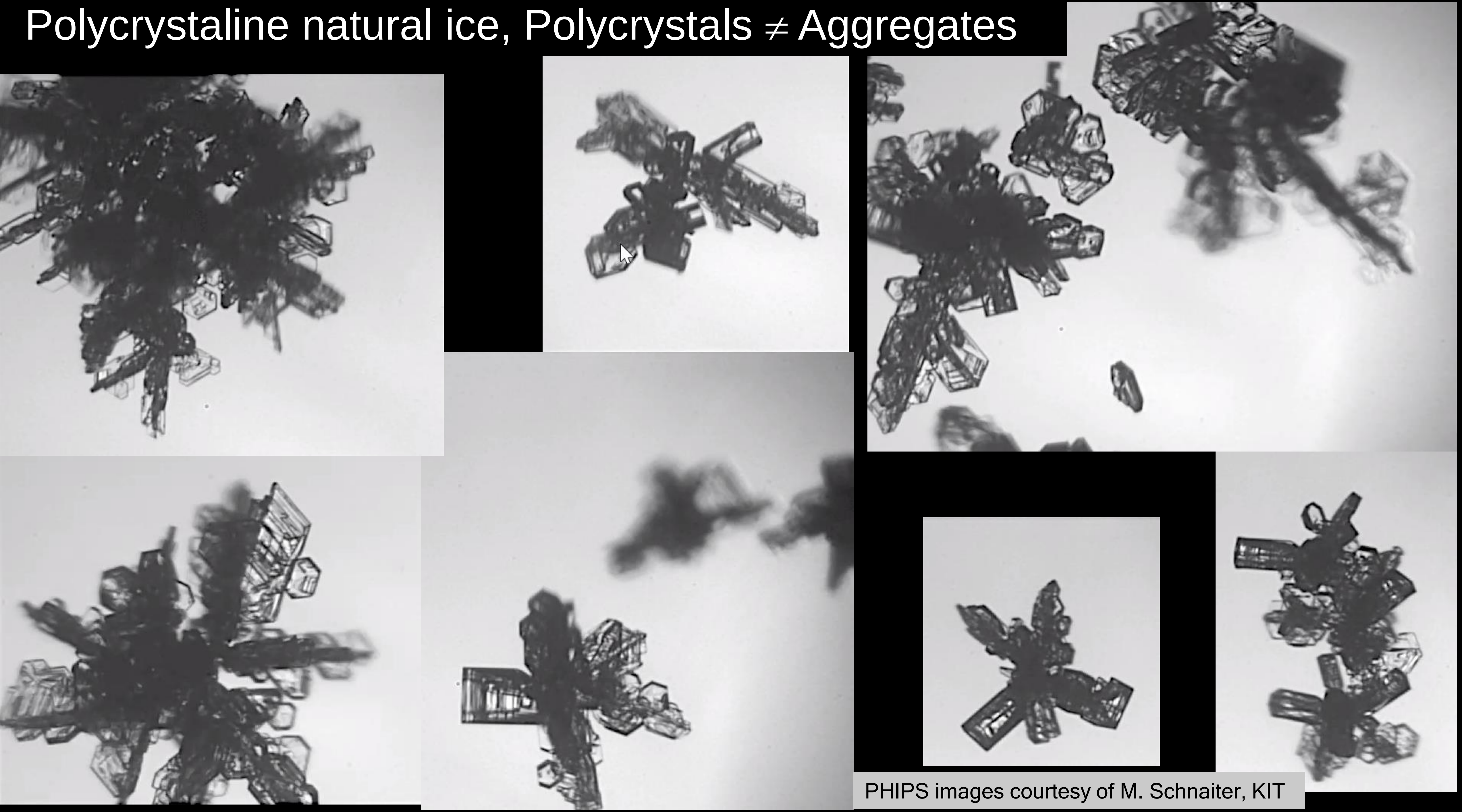
Ice growth forms

Ice growth form depends on air temperature **and** vapor content of air.

As particles fall and temperature and vapor content of environmental air changes, growth type can change.

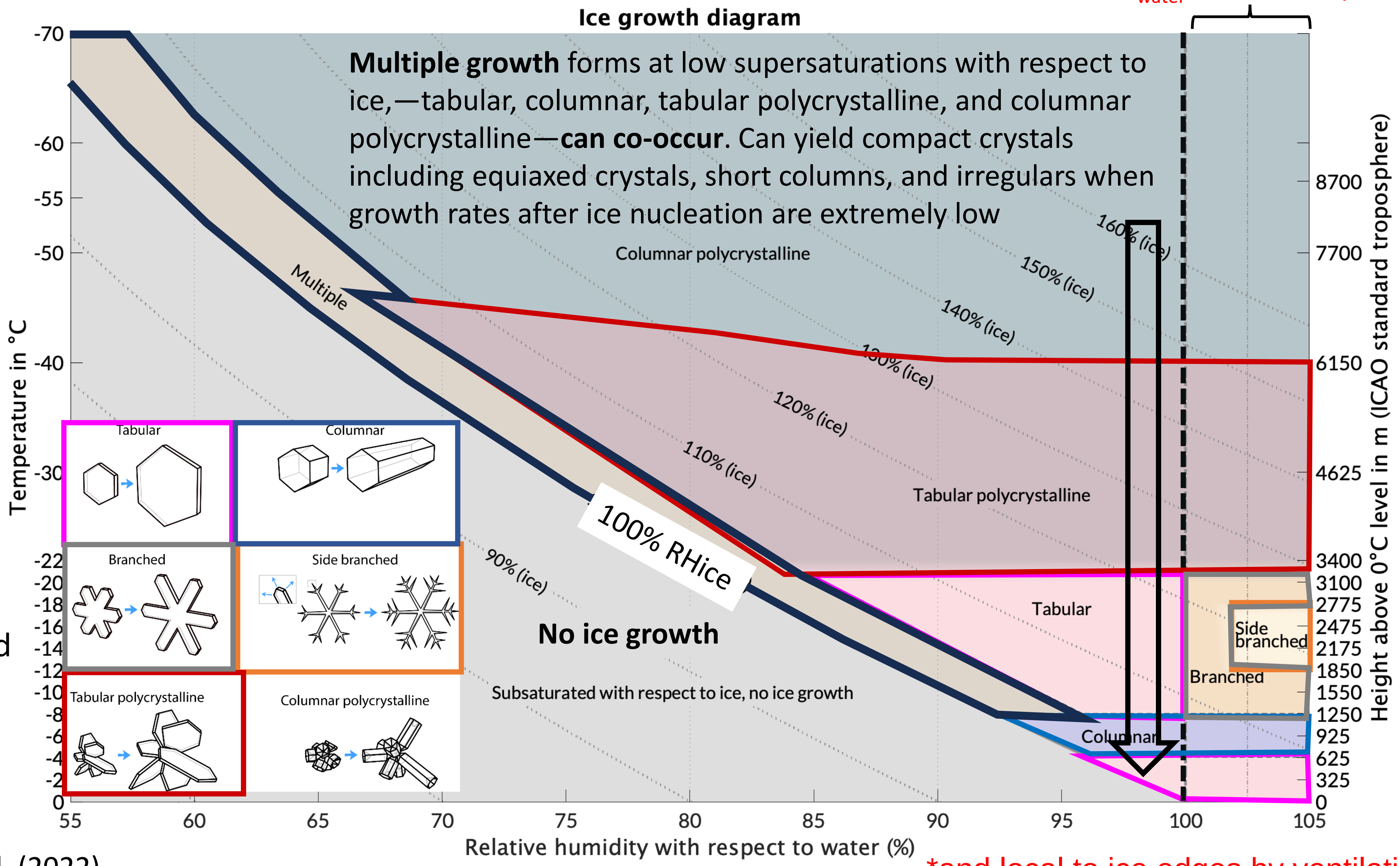
Hueholt et al. (2022, BAMS)

Polycrystaline natural ice, Polycrystals ≠ Aggregates



PHIPS images courtesy of M. Schnaiter, KIT

Ambient RH_{water} > 100% in updrafts*

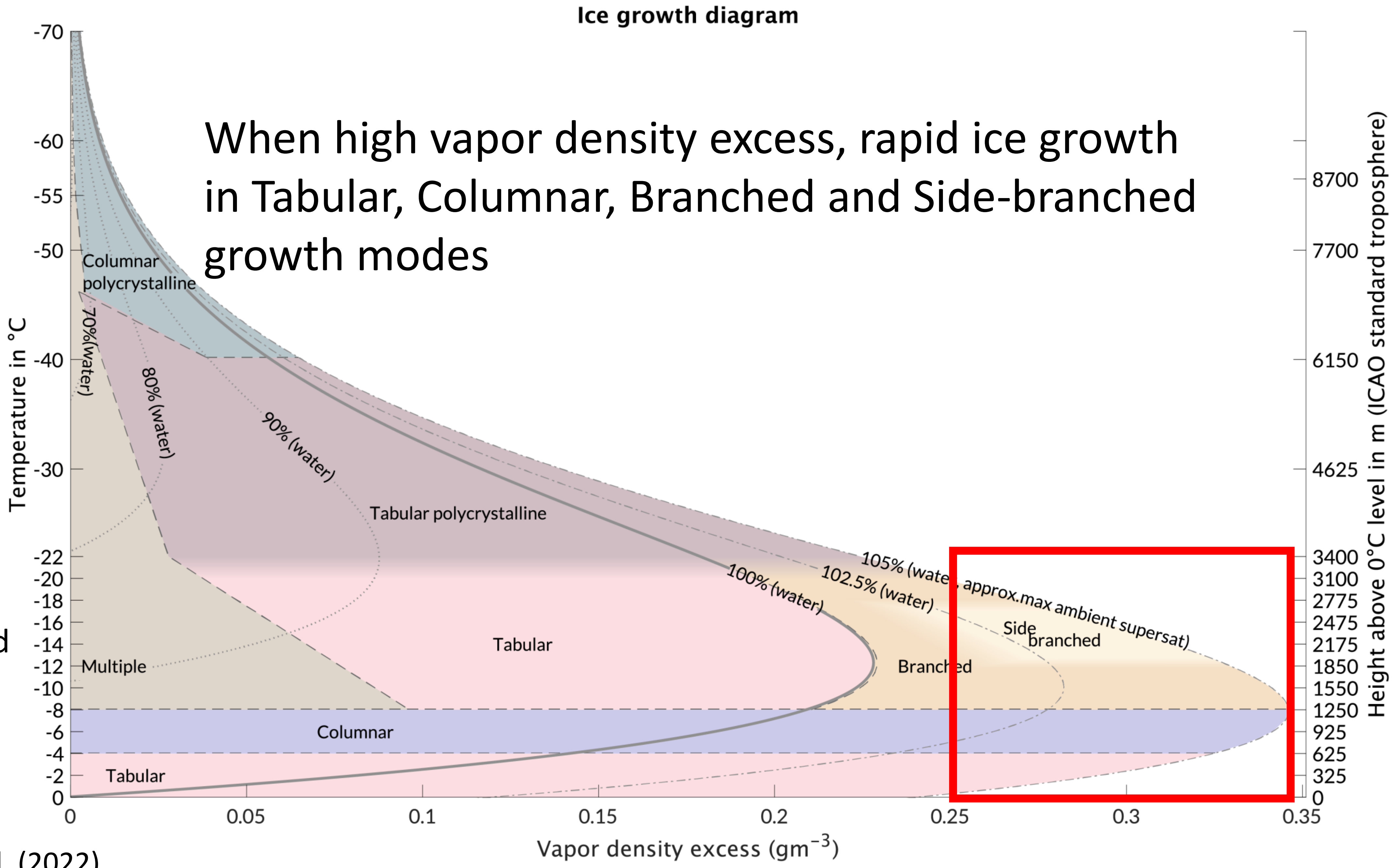


Revisualized diagram based on established science

Hueholt et al. (2022)

*and local to ice edges by ventilation

When high vapor density excess, rapid ice growth in Tabular, Columnar, Branched and Side-branched growth modes

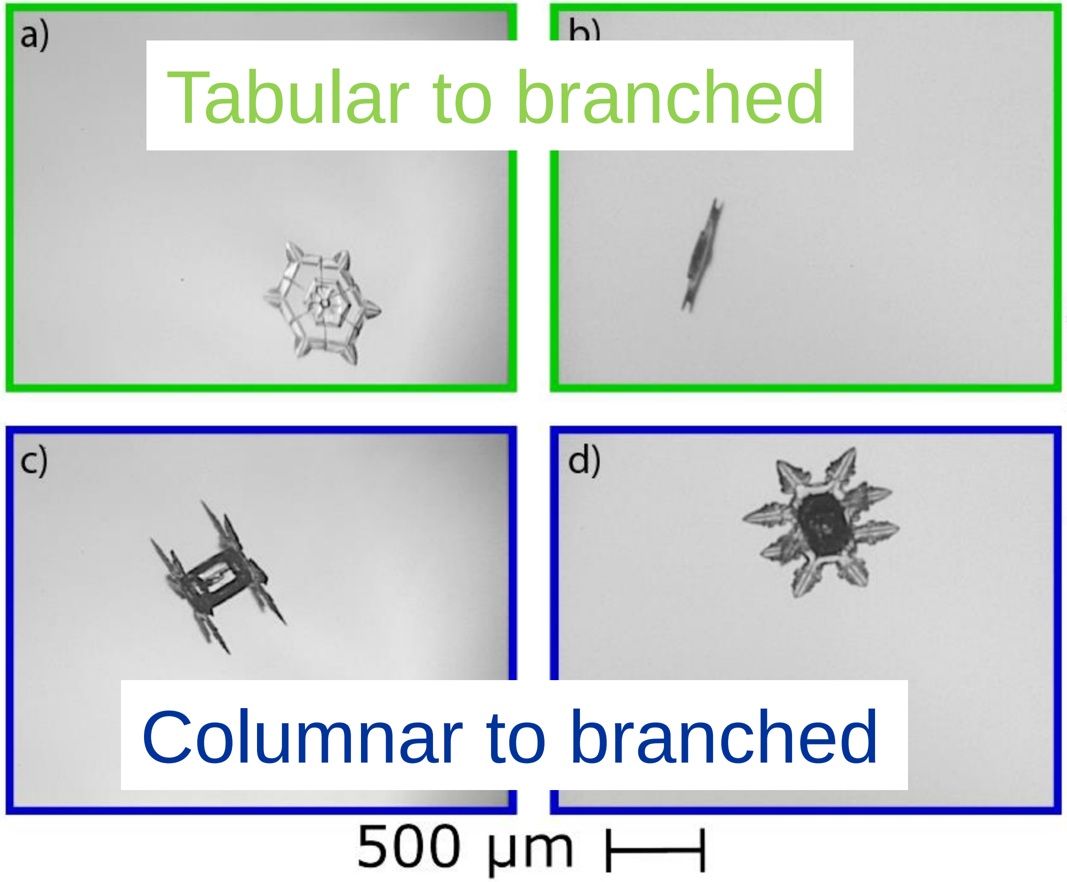


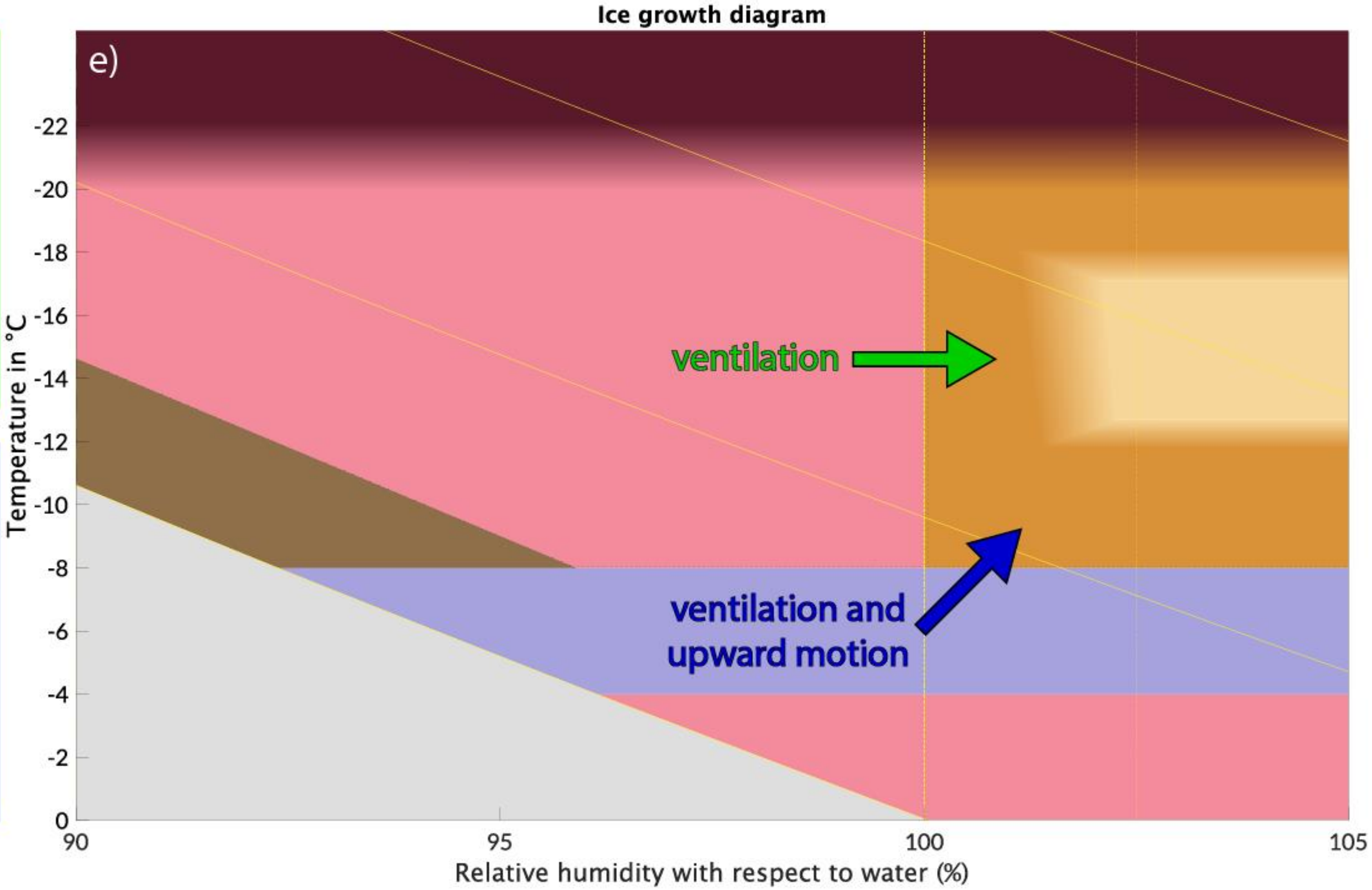
Revisualized diagram based on established science

Hueholt et al. (2022)

Often get sequences of ice growth in different environments

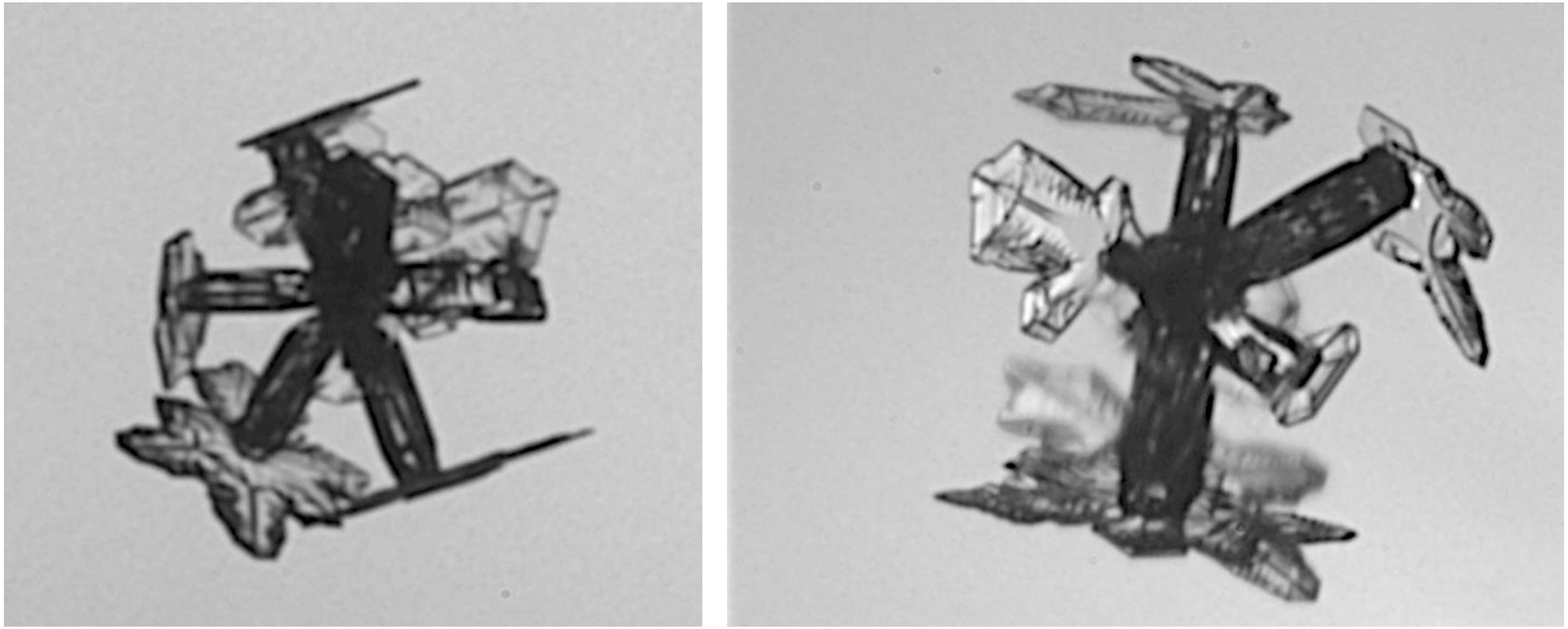
Same color outlines two views of the same particle





Hueholt et al. (2022)

Sequential growth as particle falls to surface can yield complex 3D particles

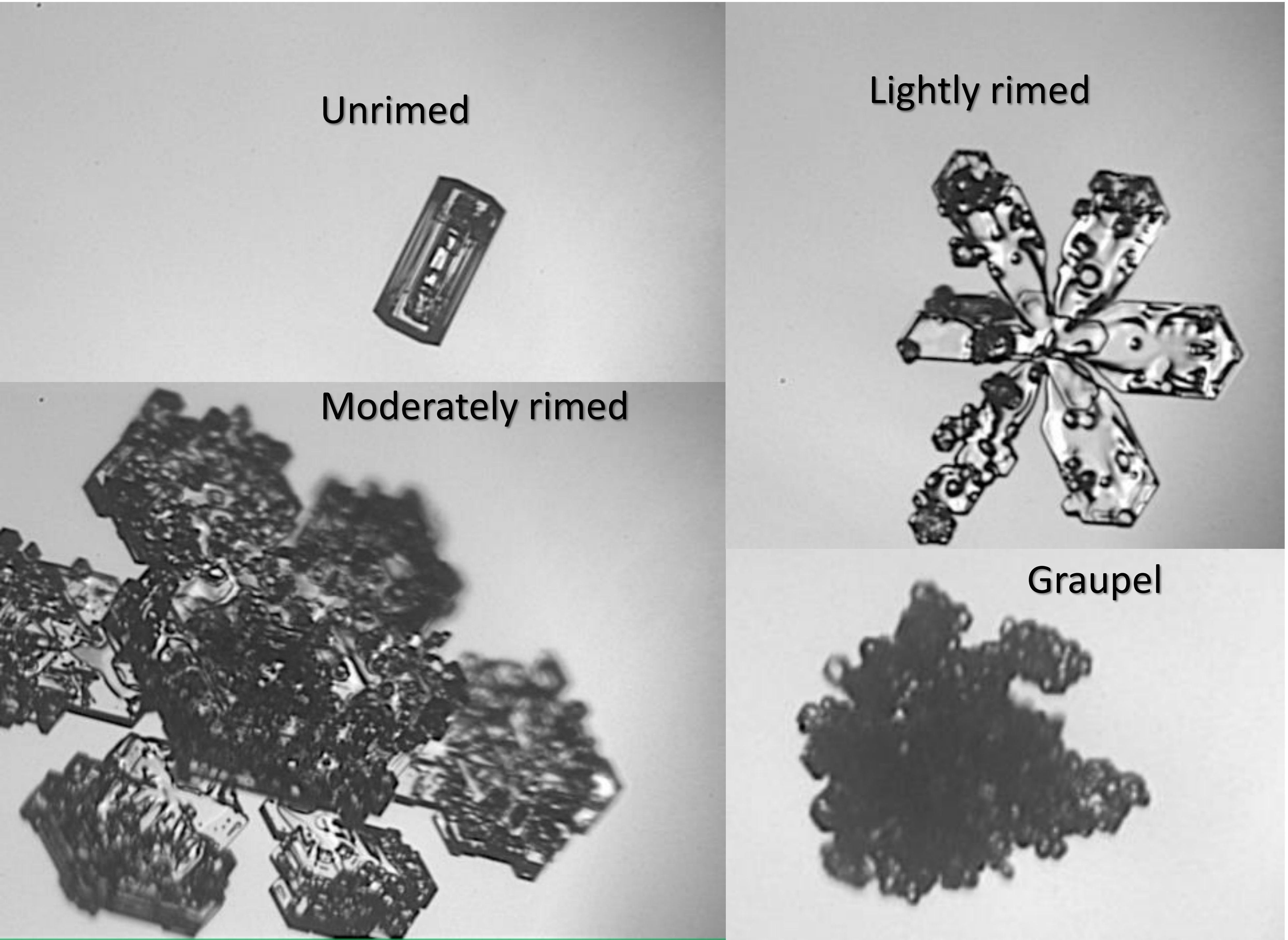


NASA IMPACTS PHIPS images,

2 views of the same particle

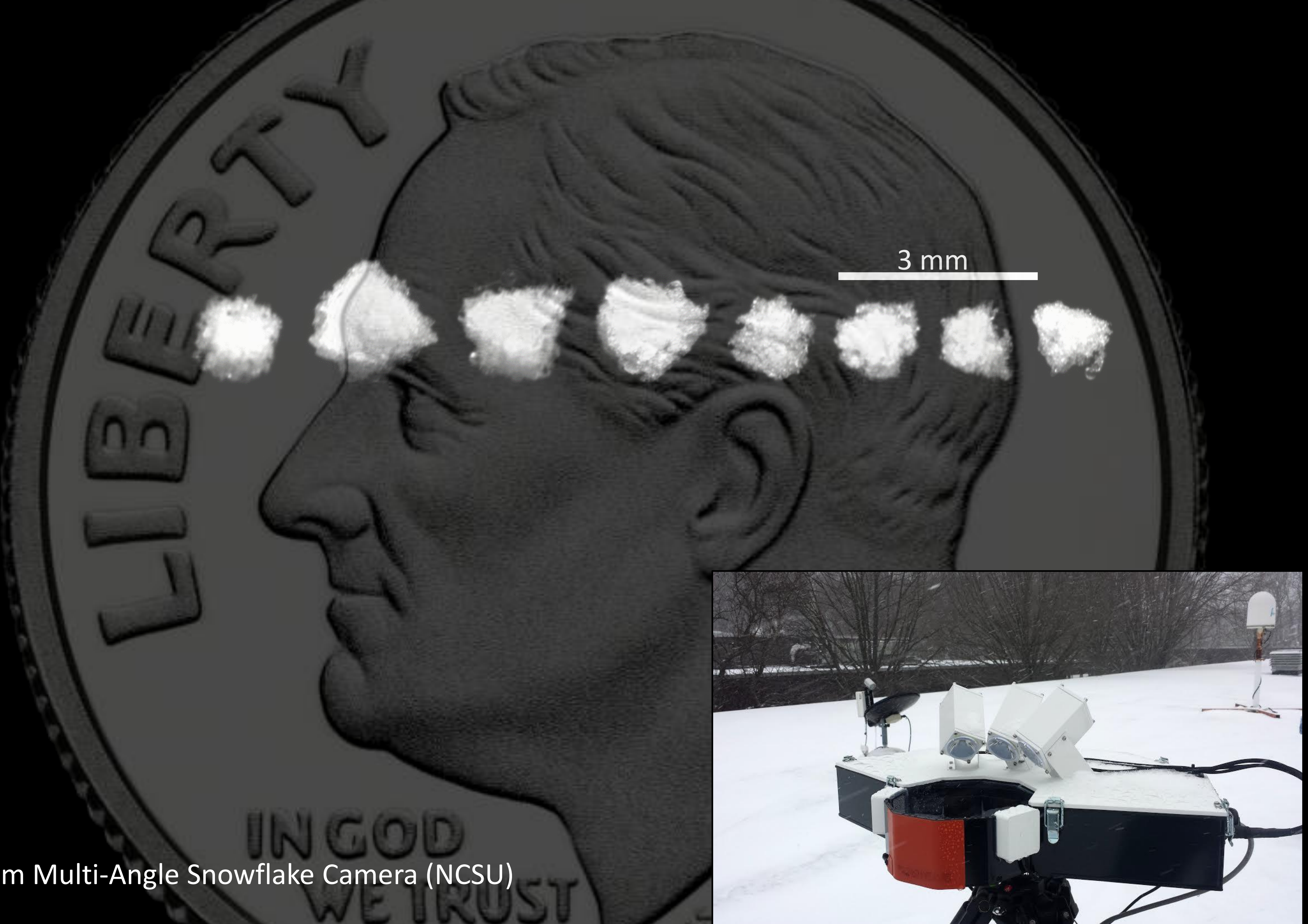
initial columnar polycrystalline growth followed by tabular growth then branched growth

Different degrees of riming

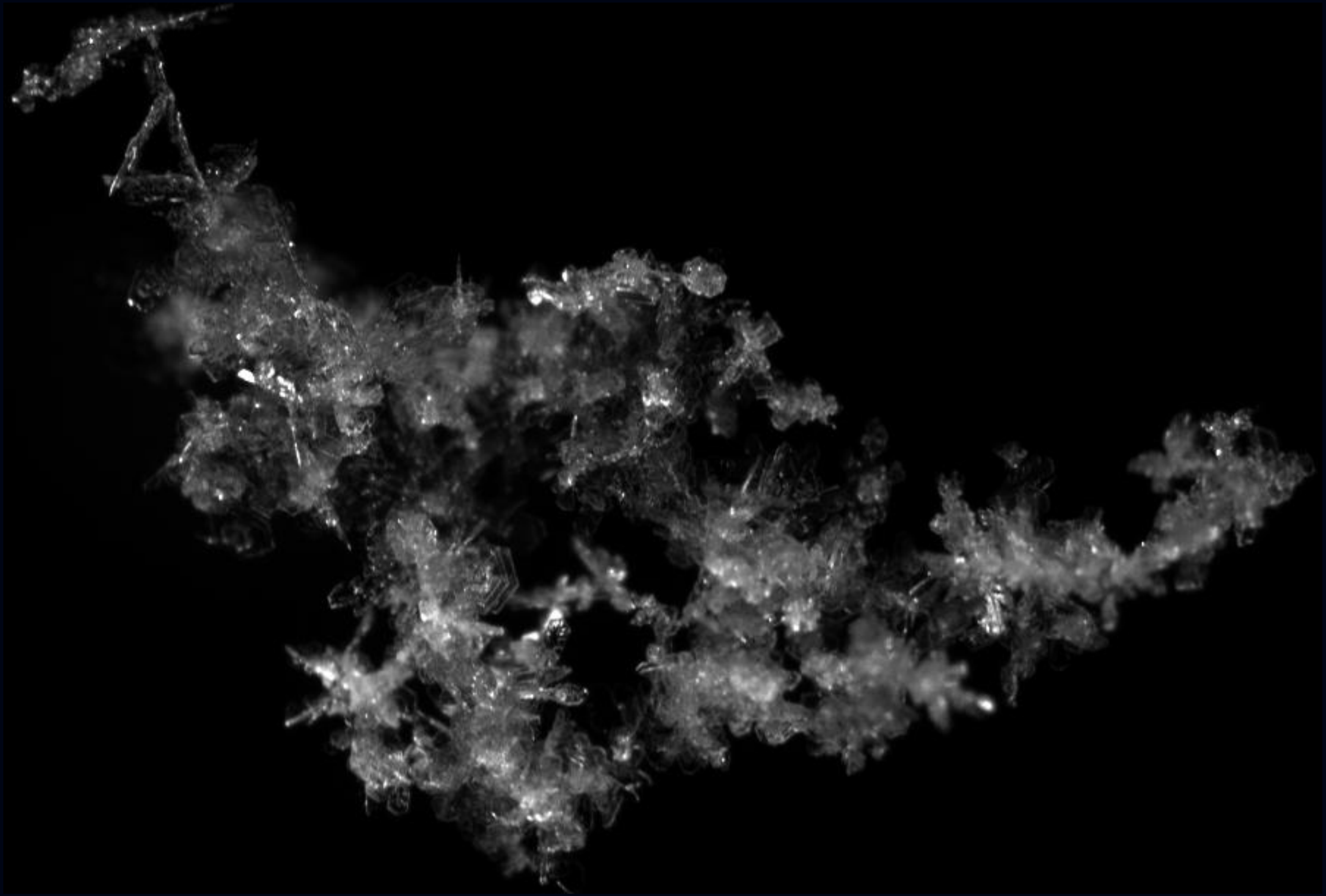


NASA IMPACTS field project
PHIPS data (Schnaiter)

Graupel



Surface Observations from Multi-Angle Snowflake Camera (NCSU)

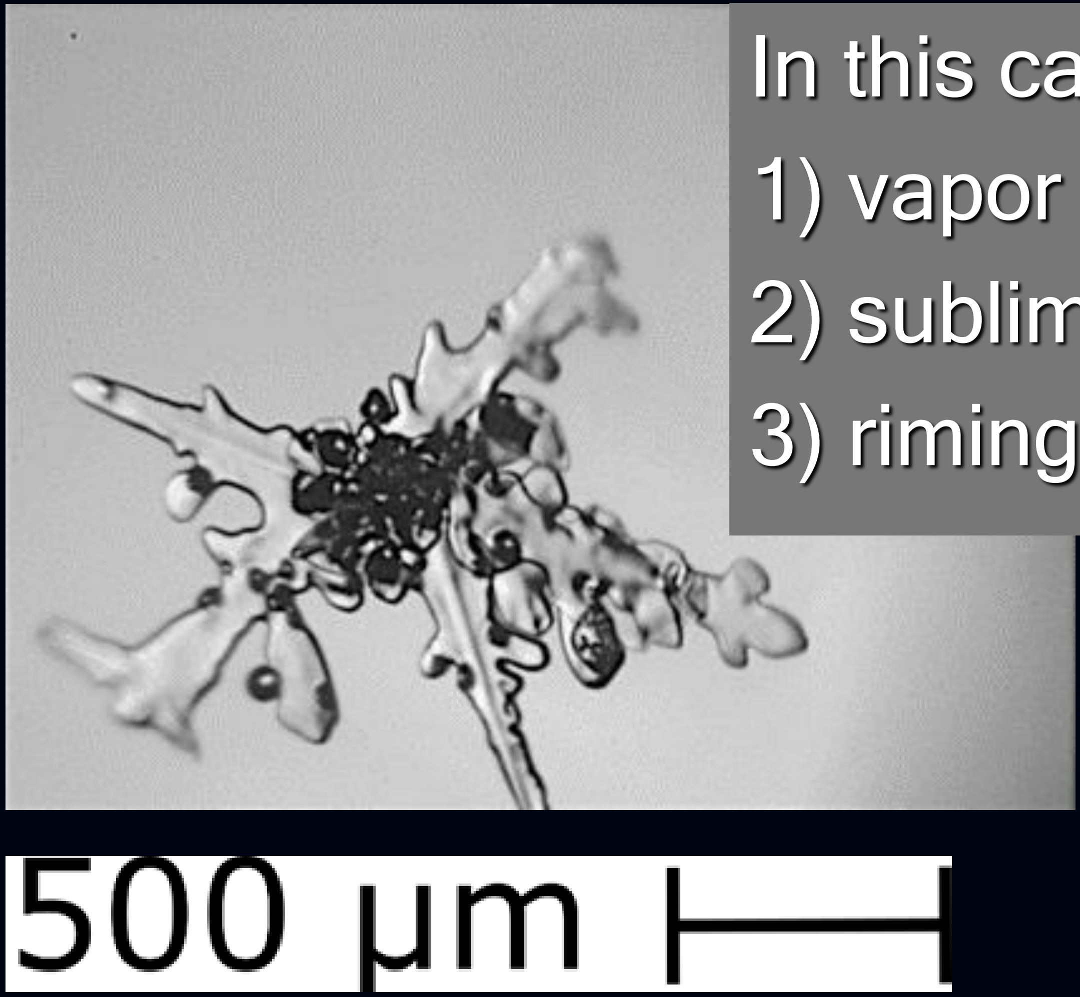


Aggregation- collection of ice particles > 0.2 mm diameter, yields jumbles of multiple individual ice particles called aggregates)

Often includes ice particles with different shapes

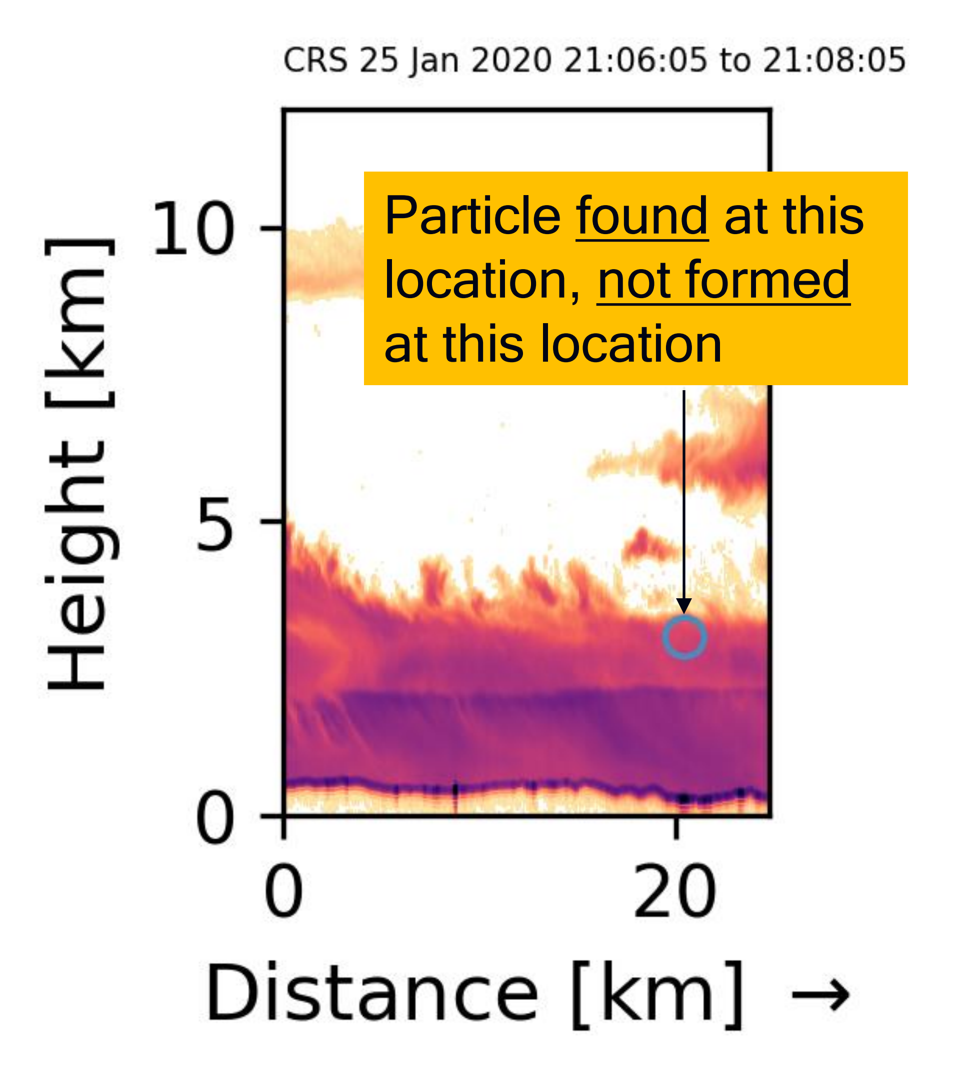
2015 01 24 07 42 00, max diameter 17.8 mm, fall speed 1.33 m/s

Time-integrated state of individual snow particles
--everything that happened to particle prior to observation



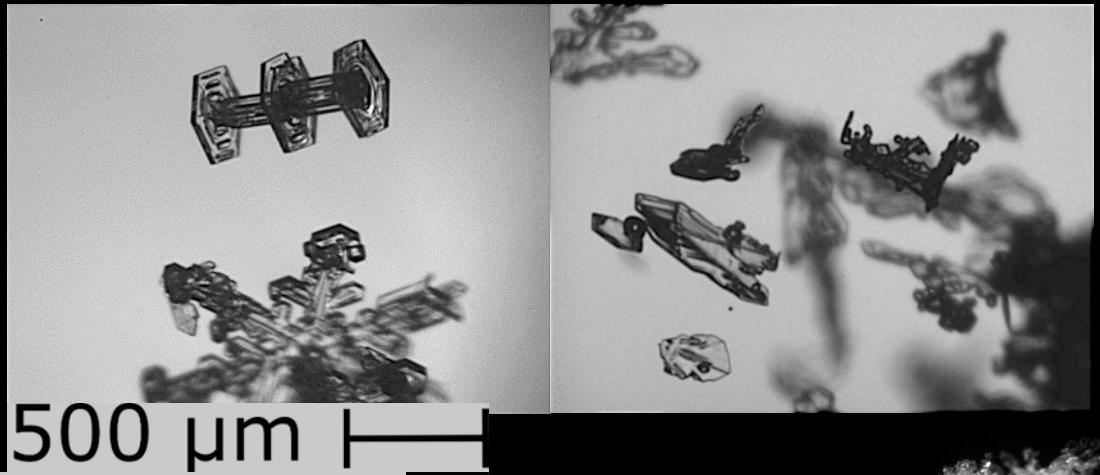
In this case,

1) vapor deposition
2) sublimation
3) riming

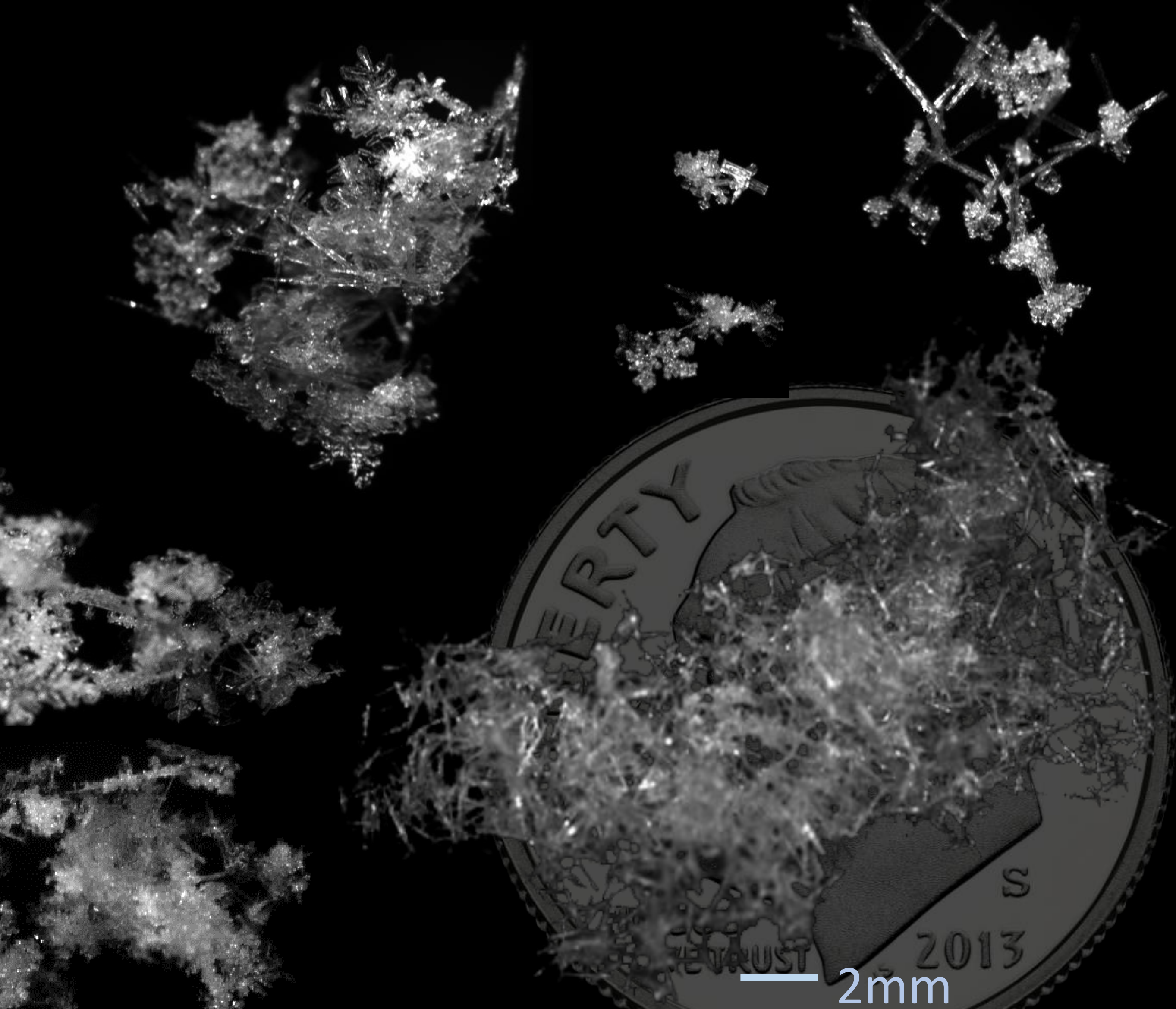


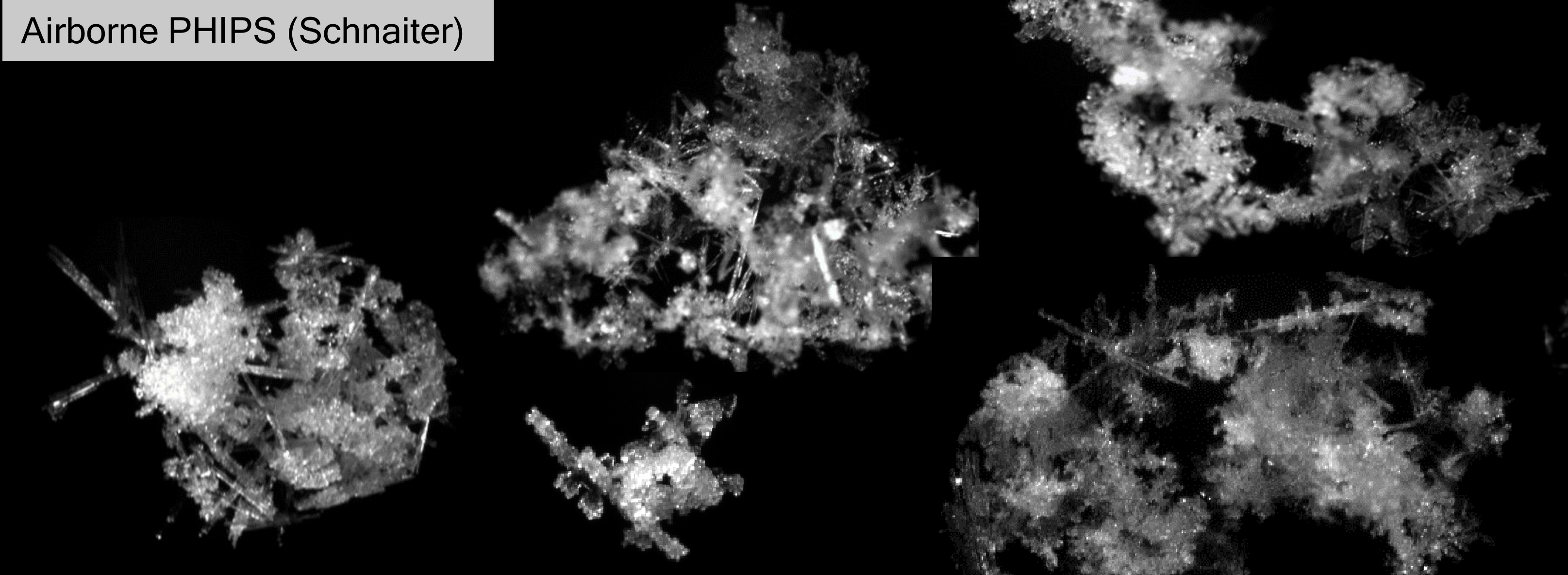
NASA IMPACTS field program PHIPS particle image (Schnaiter) and ER-2 Cloud Radar (McLinden, Li)

Time-integrated state of set of particles that end up in the same volume--Snow particles that initially formed separately often get mixed together



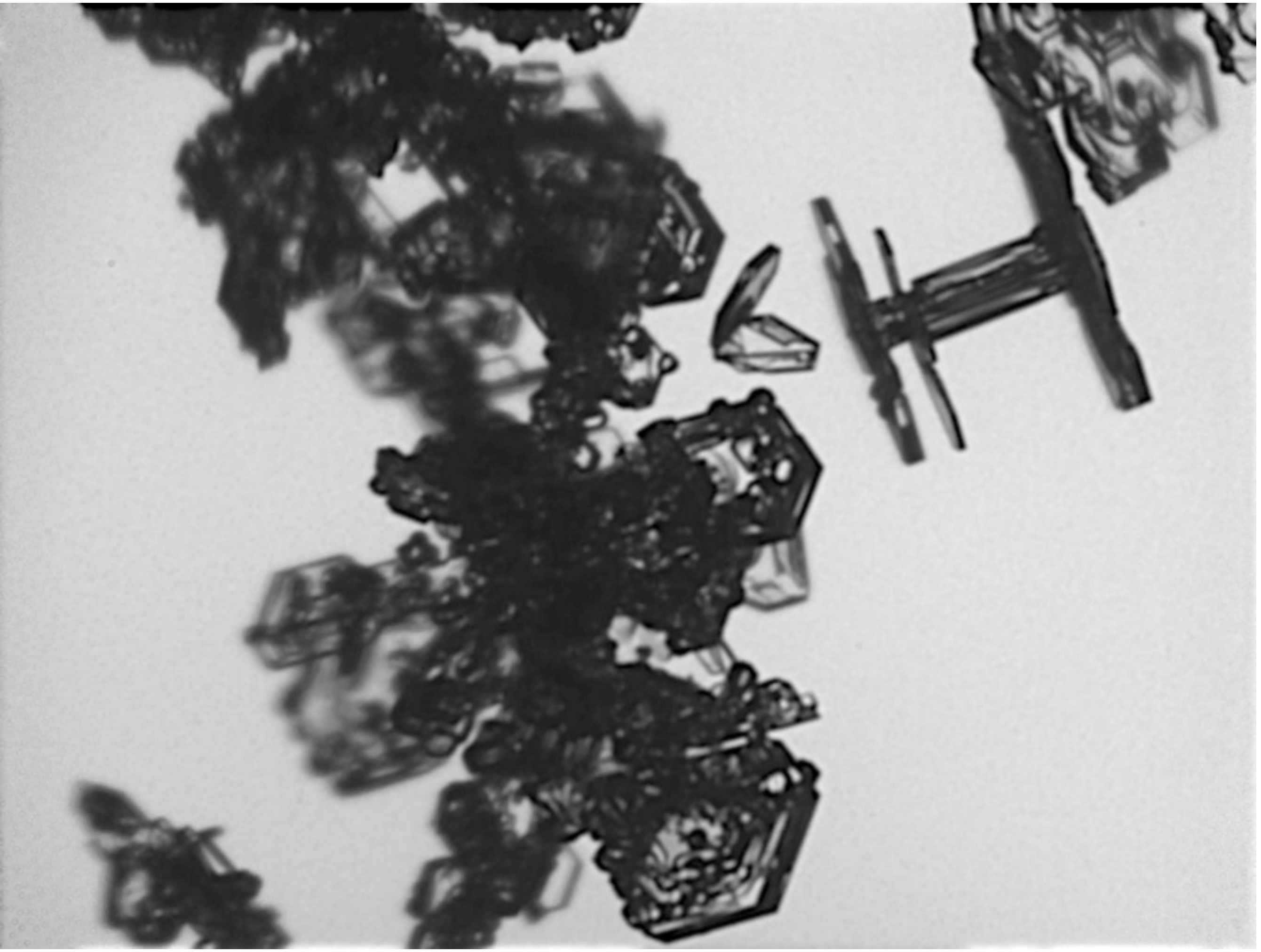
Airborne PHIPS (Schnaiter)





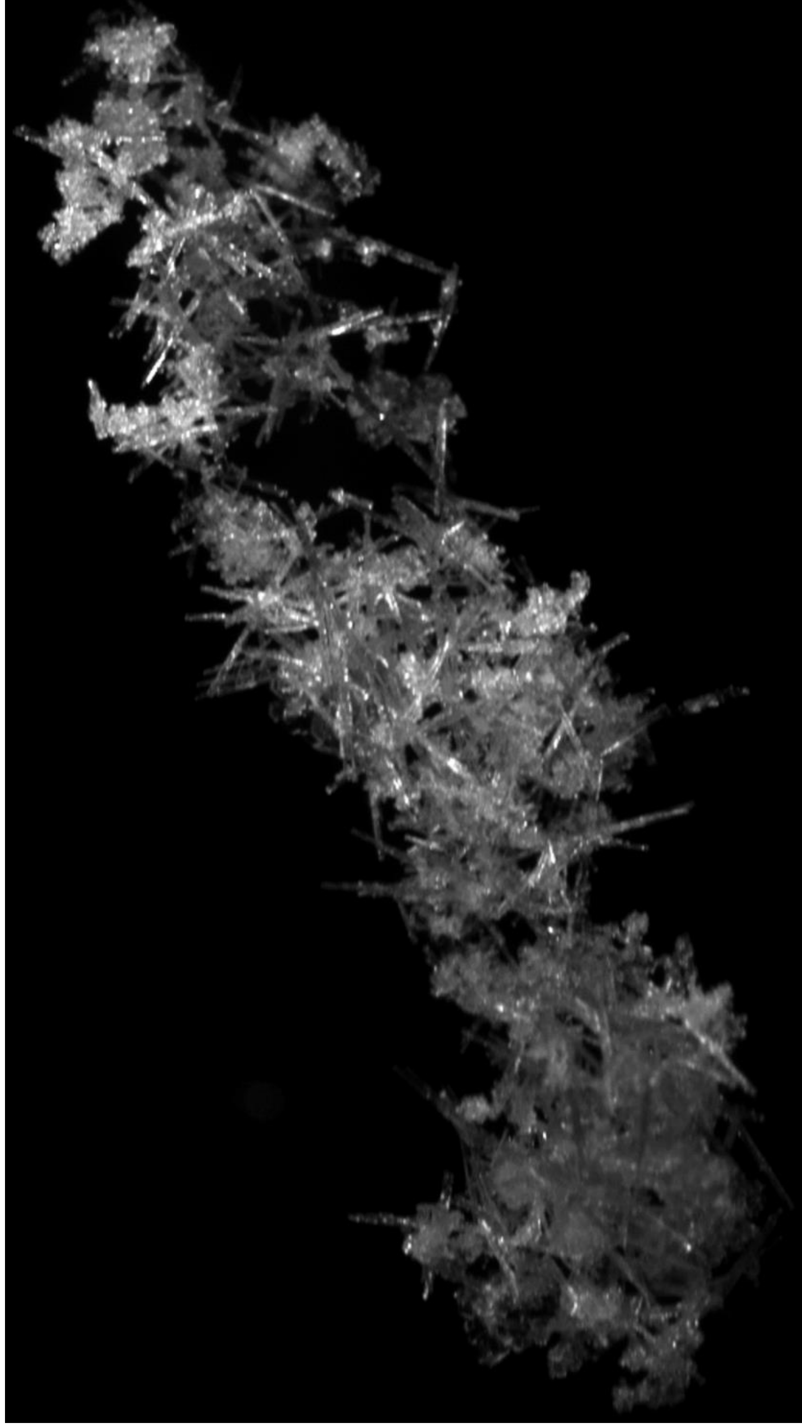
Surface Observations from Multi-Angle Snowflake Camera (NCSU)

Particles with different shapes and degrees of riming often co-occur in the same volume



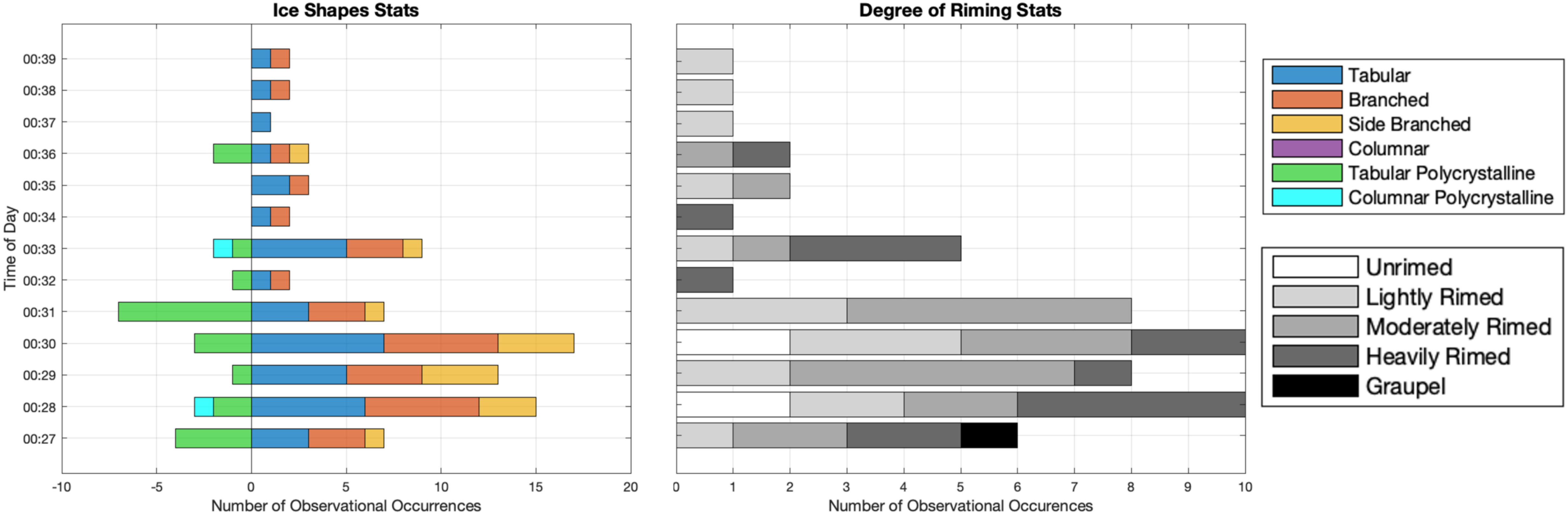
Airborne PHIPS (Schnaiter)

Surface snowflake camera (NCSU)



Mixtures of shapes and degree of riming based on airborne PHIPS ice particle images, minute by minute

P-3 Leg 2: 2/26/20 00:27 – 00:39

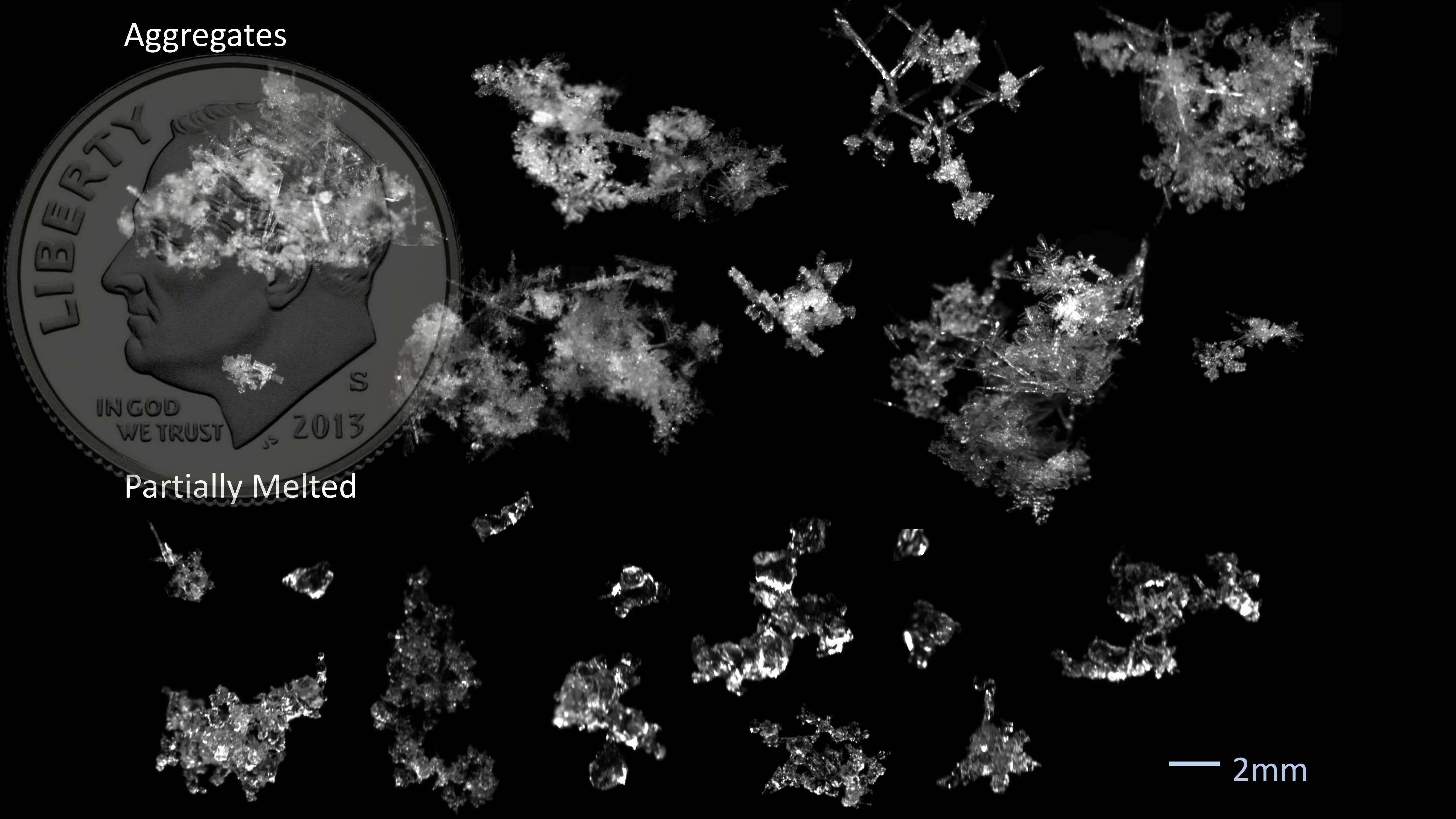


Near cloud-top flight leg sample for NASA P-3 closely coordinated with NASA ER-2

Processes that change reflectivity (Z)

In snow, changes in Z do not necessarily mean changes in mass per unit volume

Process	Change to IWC/LWC	Change to radar reflectivity
Riming	**Increase**	**Increase**
Vapor Deposition	**Increase**	**Increase**
Collision-Coalescence	**Increase**	**Increase**
Condensation	**Increase**	**Increase**
Aggregation	*No change*	**Increase**
Melting	*No change*	**Increase**
Evaporation	**Decrease**	**Decrease**
Sublimation	**Decrease**	**Decrease**
Freezing	*No change*	**Decrease**
Fragmentation	*No change*	**Decrease**
Raindrop Breakup	*No change*	**Decrease**


Aggregates
LIBERTY
IN GOD WE TRUST
S
2013
Partially Melted
2mm

Mapping from volumetric water content to radar reflectivity has much larger uncertainty in snow compared to rain

	Rain	Snow
Density of individual particles	Constant	*Varies* with degree of riming and aggregation
Mass to shape relationship of individual particles	Well defined	*Varies* depending on microphysical pathway
Mass per unit volume to equivalent backscatter (shape, size, number)	Well defined if can assume exponential-like particle size distributions	*Varies* with different mixtures of snow with different shapes, riming, and aggregation properties

100 m scale aircraft observations from SNOWIE (Idaho) project

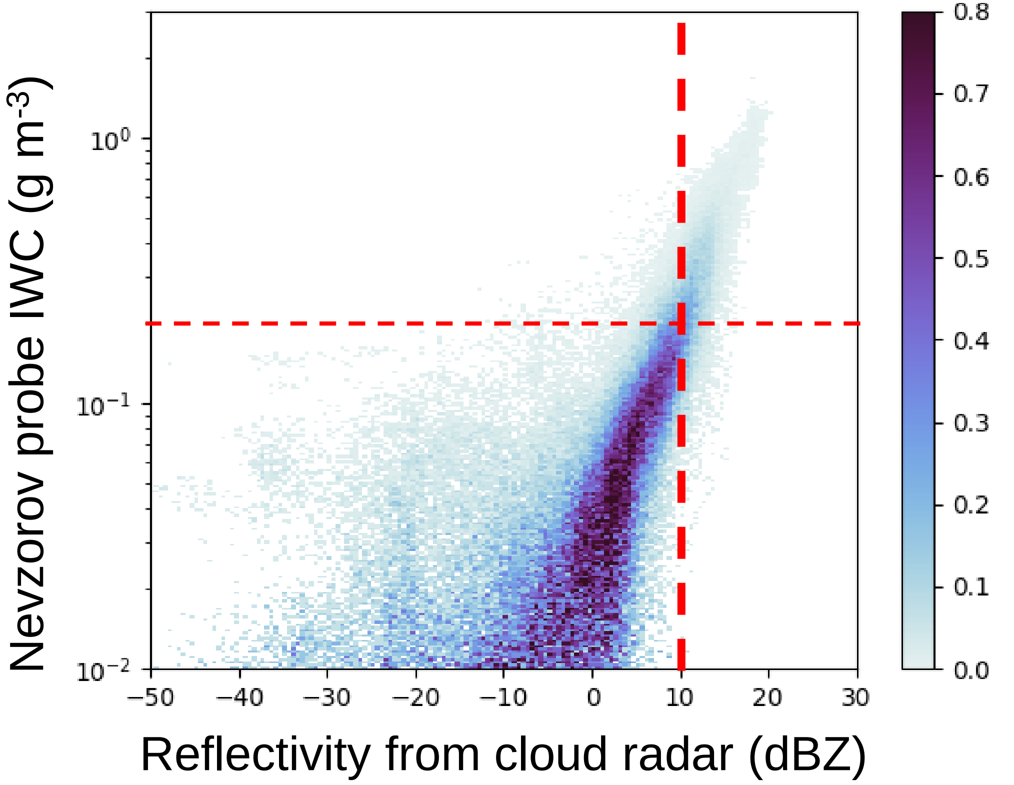
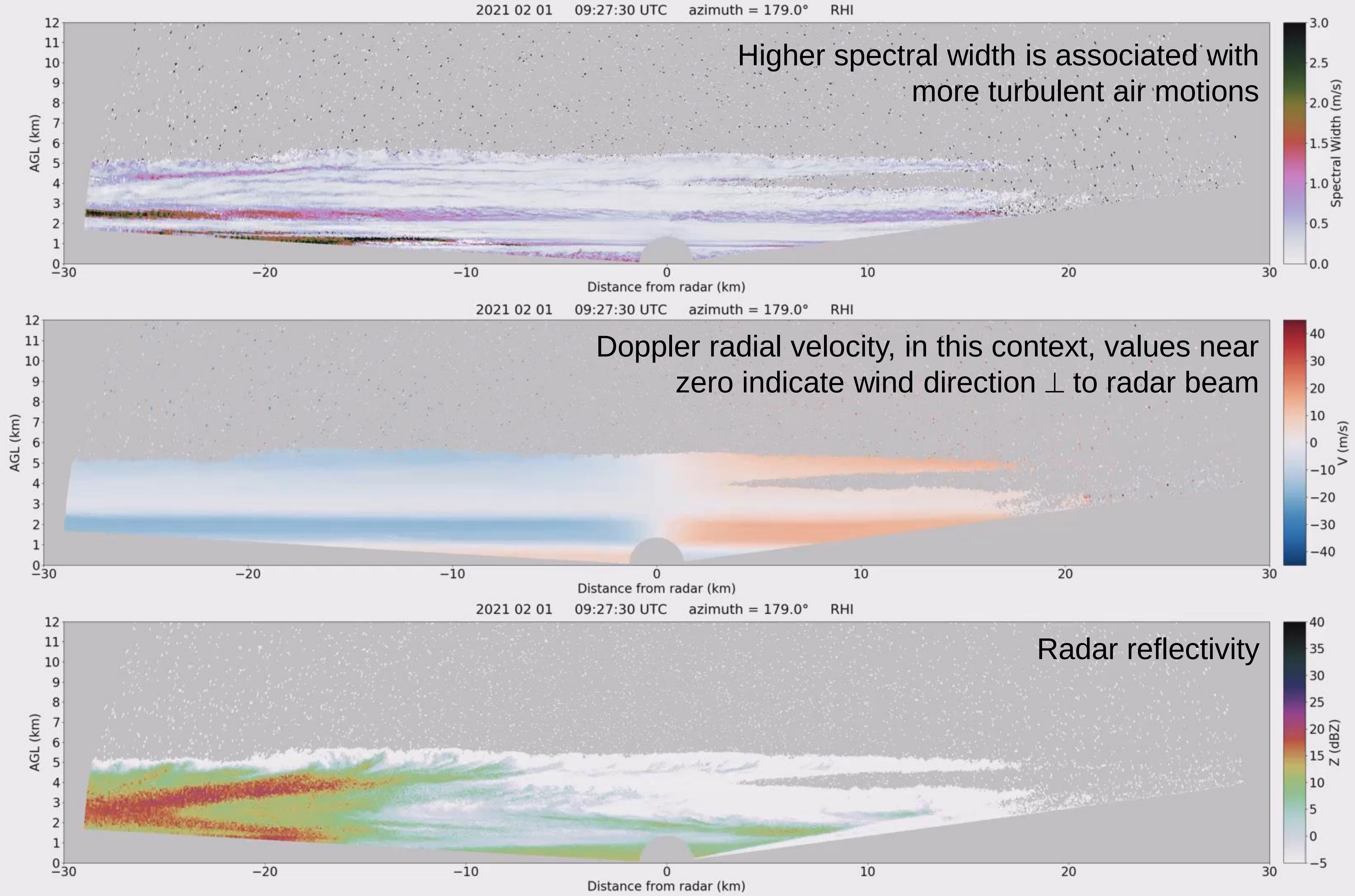


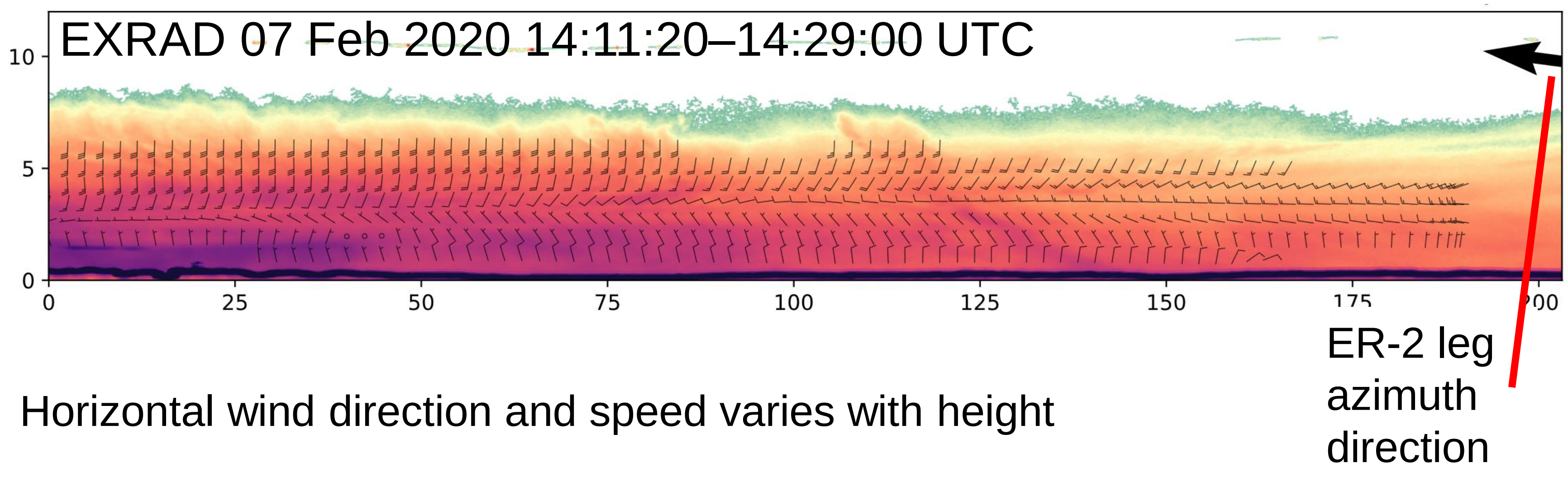
Figure adapted from Zaremba et al. (2023, JAMC)



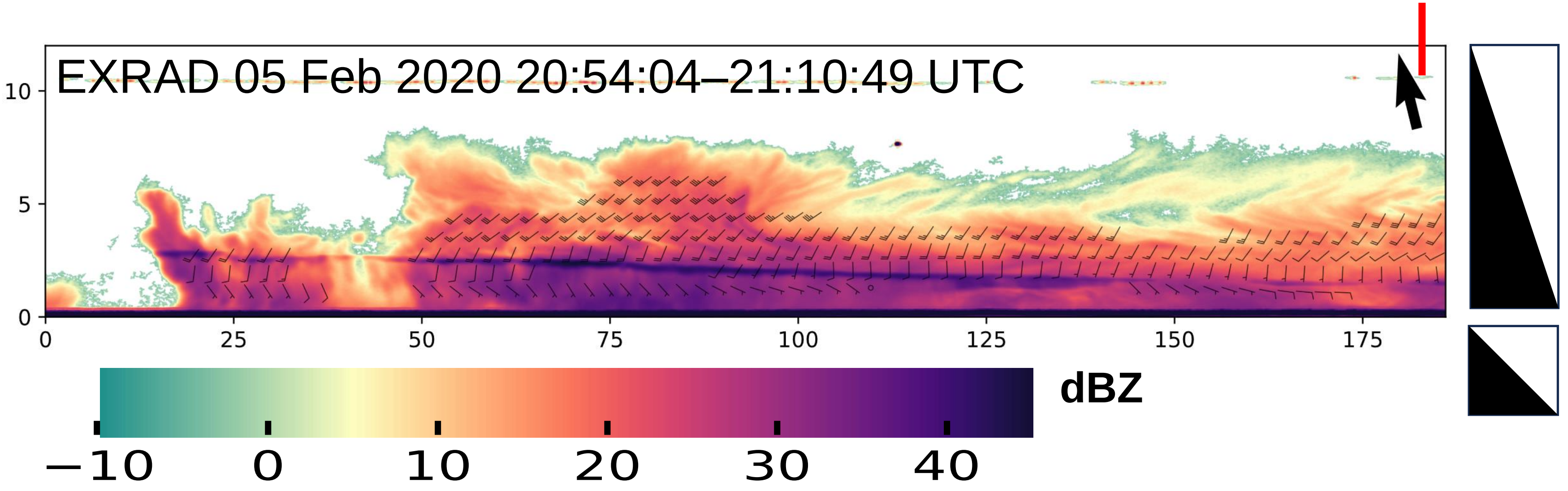
Stonybrook University KASPR radar RHI sequence from 1 Feb 2021 (1:1 aspect ratio)

KASPR data courtesy of Mariko Oue and Pavlos Kollias

Snow falls slowly ~1± 0.5 m/s, takes ~67 min to fall 4 km



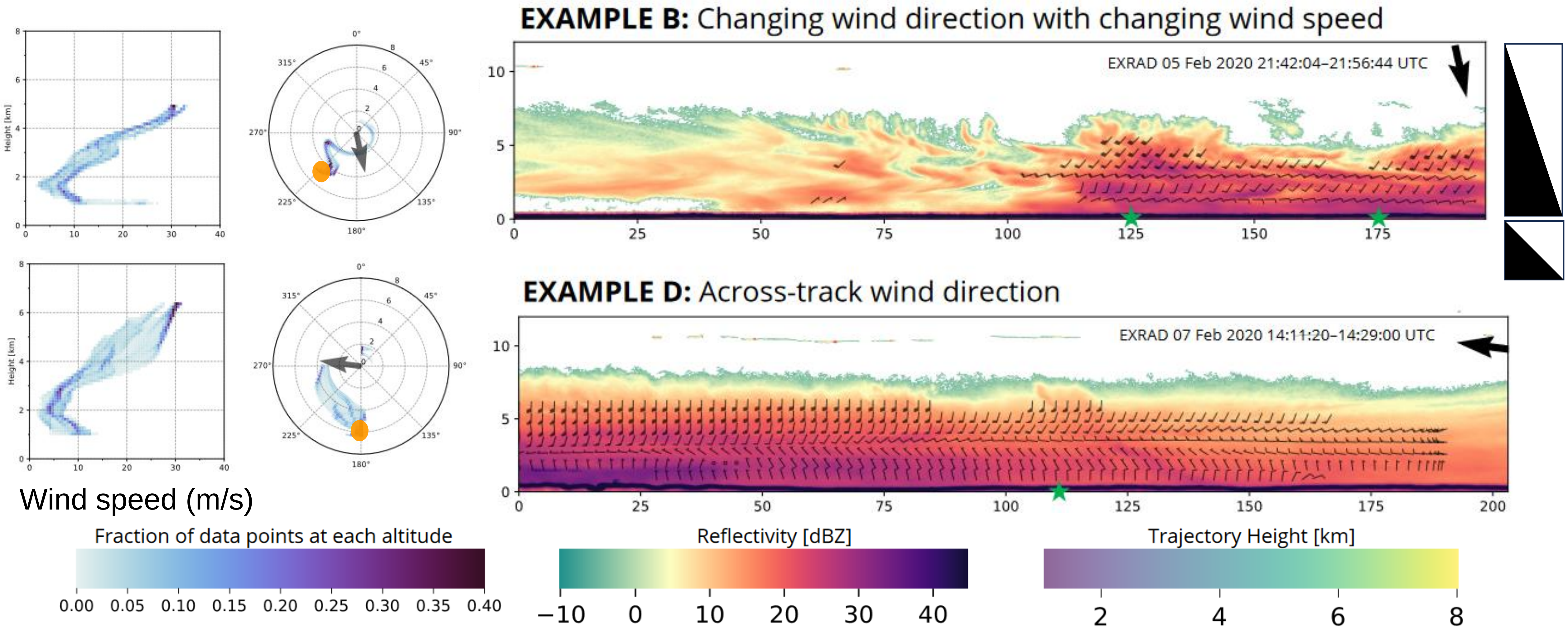
Horizontal wind direction and speed varies with height



Layers with snow have fair amount of time for integrated properties to accumulate

NASA ER-2 X-band radar (McLinden, Li) with VAD winds overlaid (Helms)

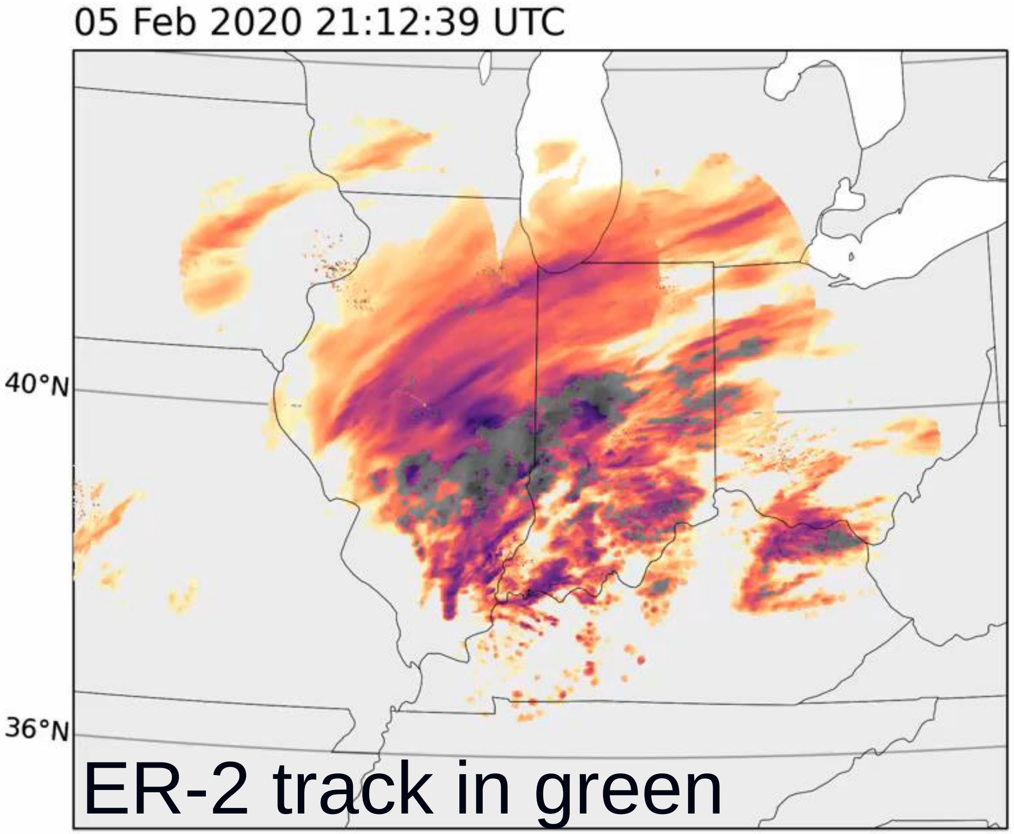
Commonly see wind speed and direction changes with height which can advect ice particles > 50 km in horizontal from origin generating cell



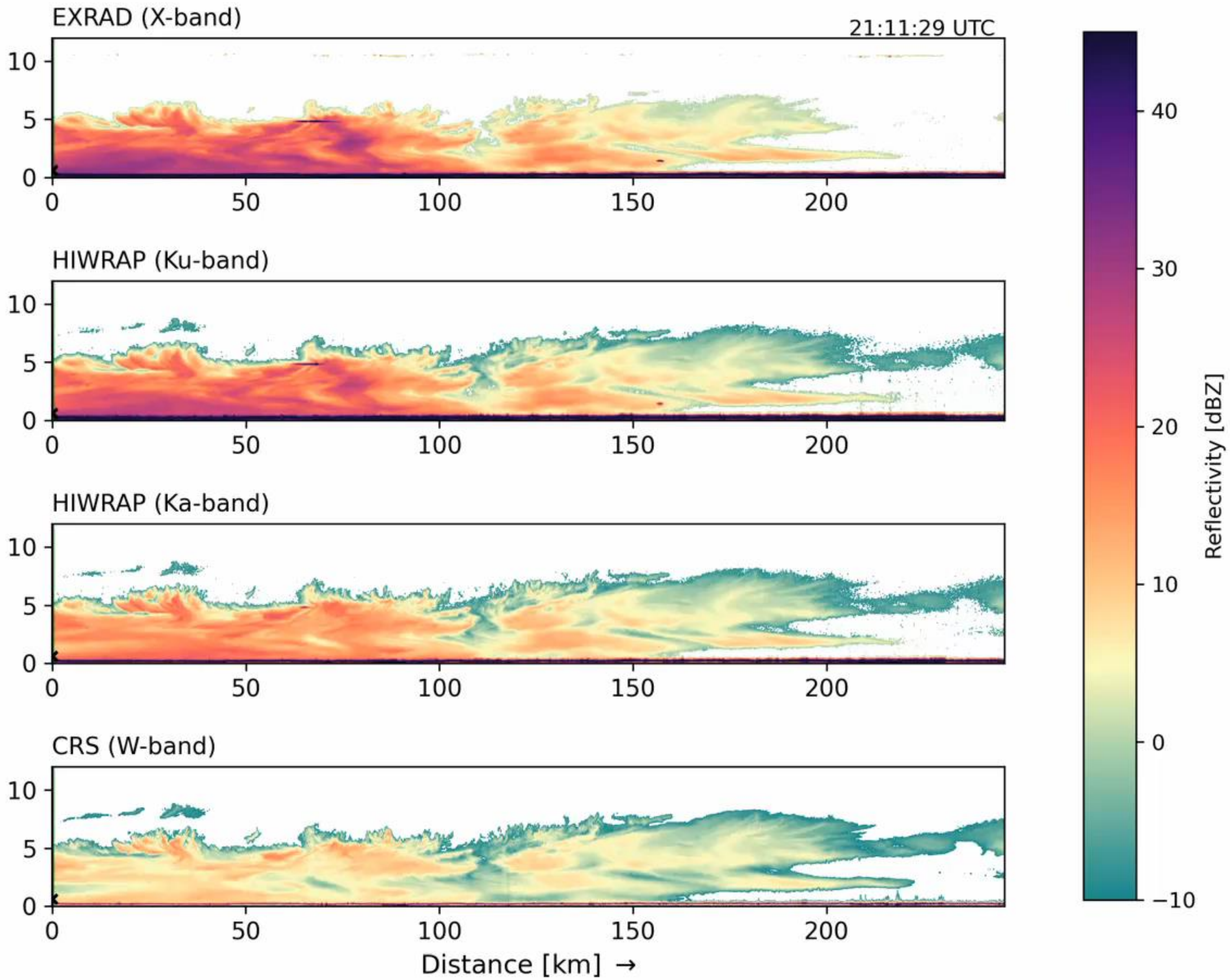
Flight track azimuth direction

NASA ER-2 X-band radar (McLinden, Li) with VAD winds overlaid (Helms)

Illustration of vertical structures associated with horizontal Z features



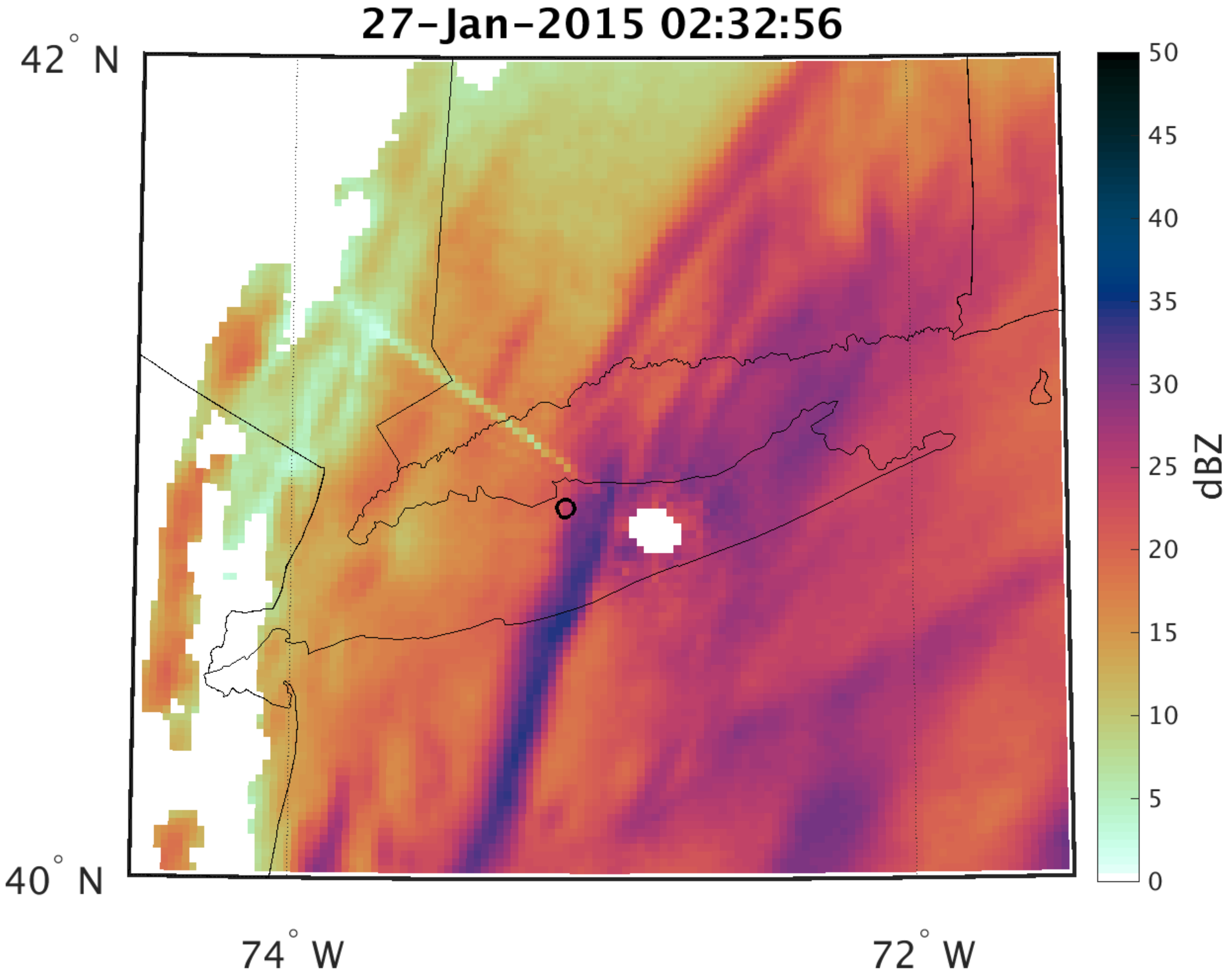
NEXRAD regional map with low RHO_{HV} values (melting regions) in gray scale



x indicates altitude of NEXRAD data used in map based on lowest elevation angle, when radars overlap uses max Z

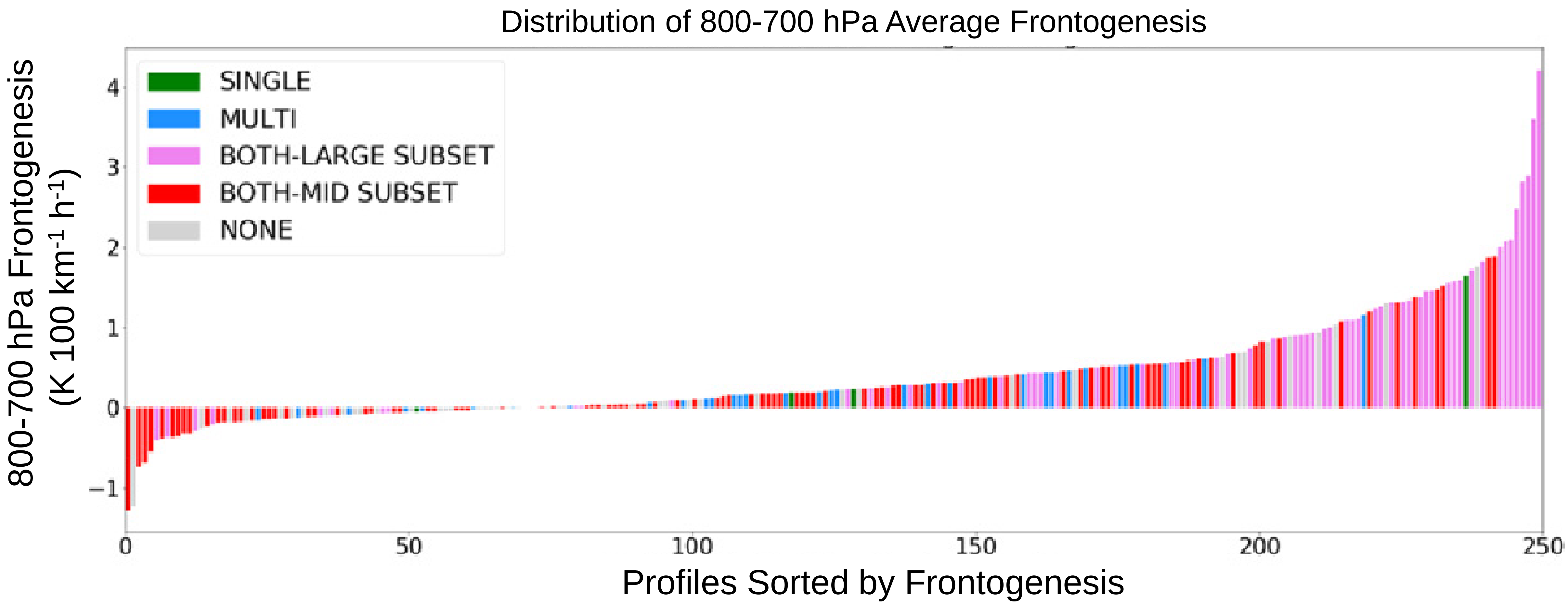
NASA ER-2 radar (McLinden, Li)

Winter storm mesoscale bands in radar reflectivity



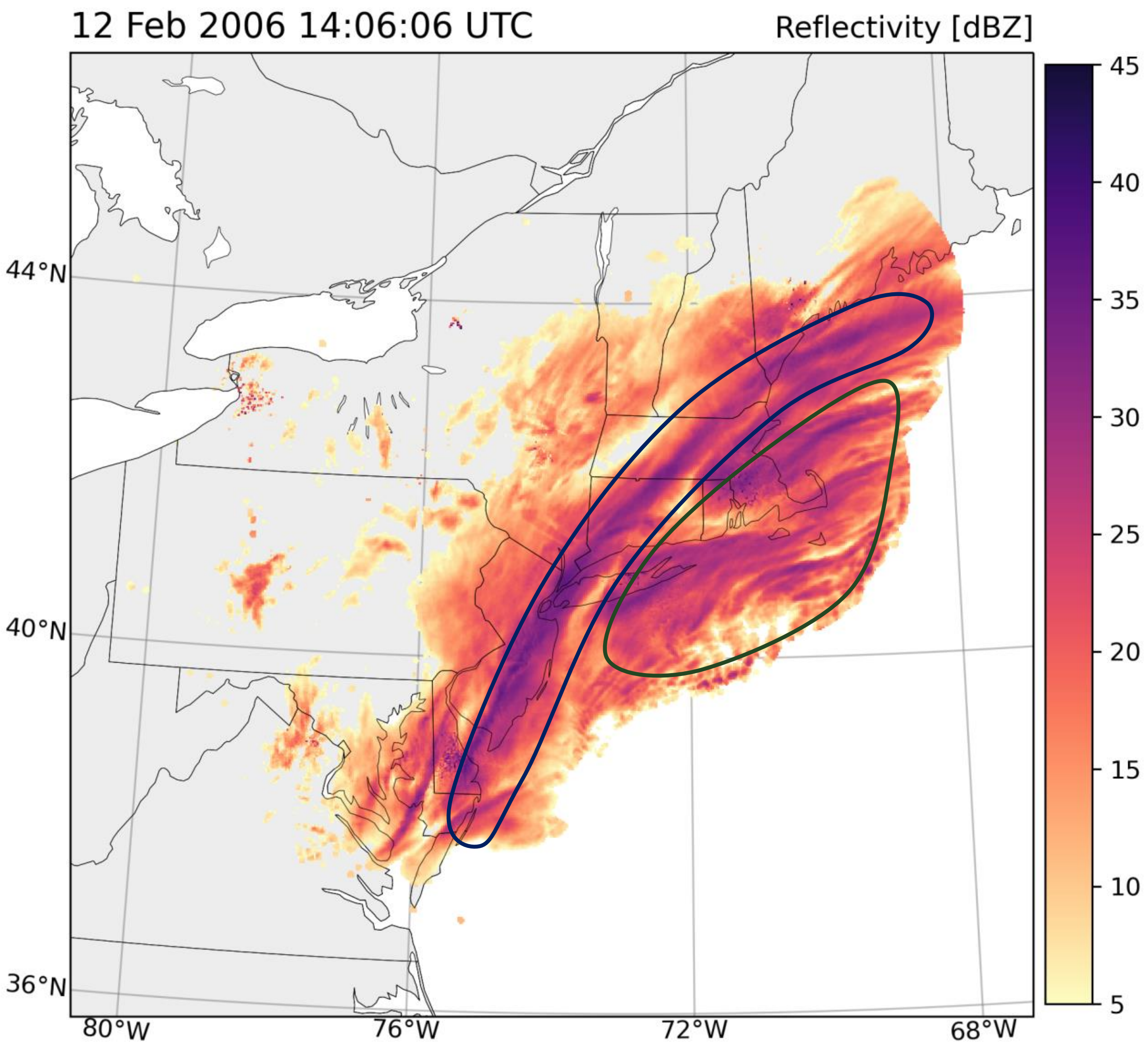
- **Unlike warm season convective lines**
- Some (esp. longer bands) are associated with strong frontogenesis
- Appear as transient features in a fluid rather than static entities moving with the mean flow
- Better defined as local enhancements to dBZ field than as a fixed dBZ threshold

Ganetis et al (2018) analysis of data from 108 cool season storms (1996-2016). Strong frontogenesis increases the likelihood of a single band forming, but these long bands as well as shorter multibands also frequently occur in environments of weak frontogenesis to frontolysis



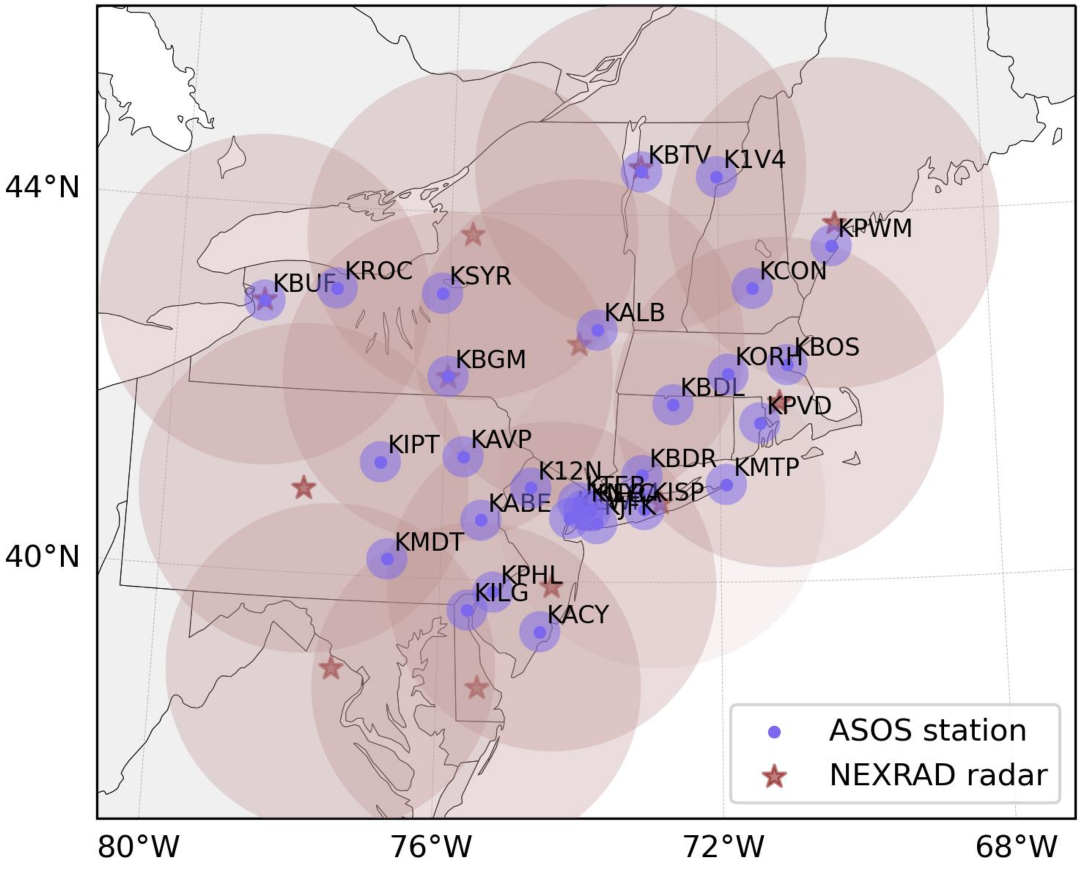
Ganetis et al. (2018)

Snow bands and surface snow rates



To what degree do locally- enhanced reflectivity banded features have an impact on surface snow fall rates?

Data: Hourly ASOS surface station data (2012-2023)

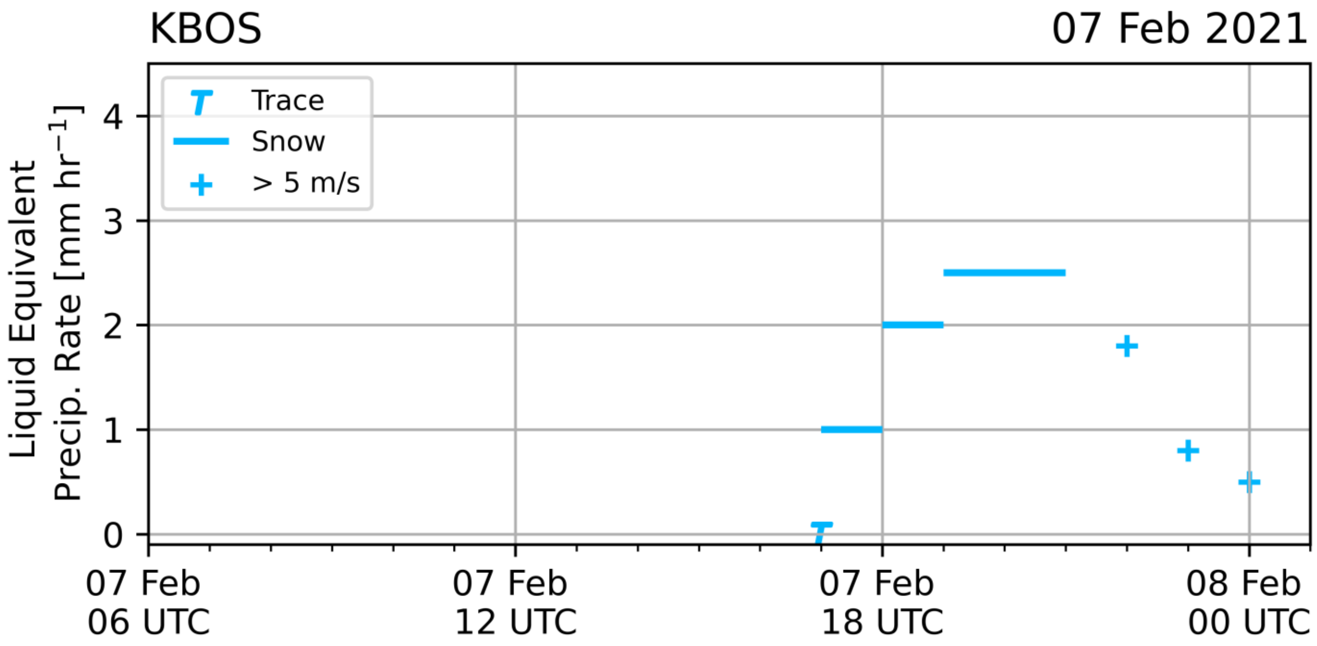


***ASOS stations* with 25 km radius range**

NEXRAD stations with 200 km range ring

1 sample = 1 hour at 1 ASOS station

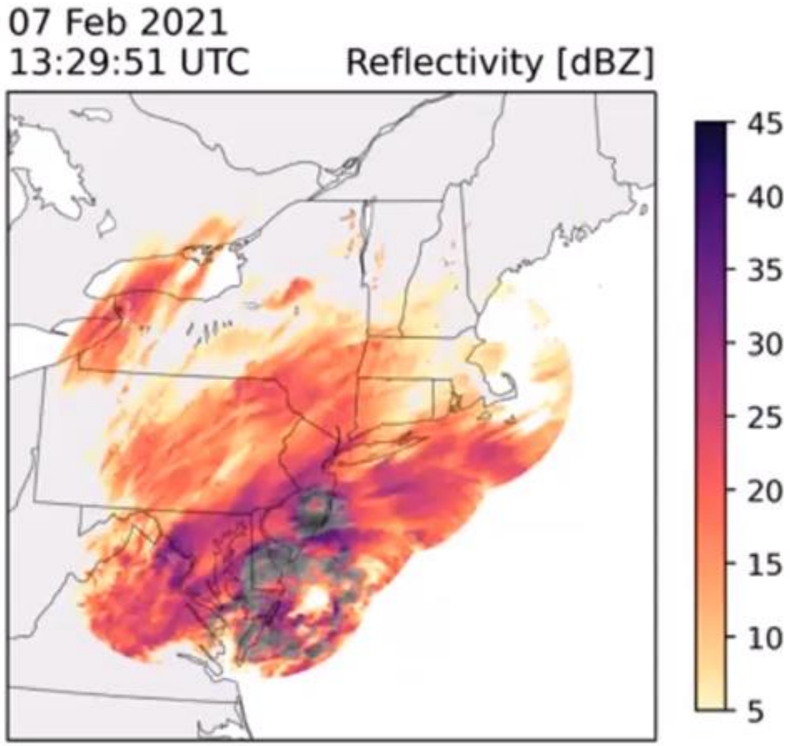
17,486 total samples over 29 stations and 264 storm days



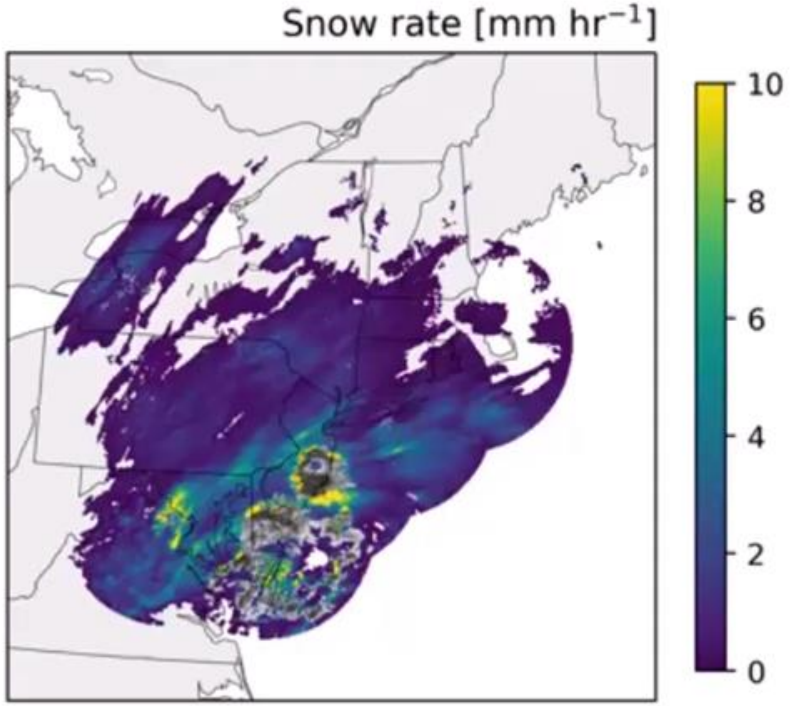
Criteria:

- Must have reported snow for at least 4 hours
- Only using snow observations with wind speed < 5 m s^{-1} *(removes ~40% of observations)*
- Only using stations with AWPAG weighing gauges with wind shields for best LWE measurements of frozen precipitation

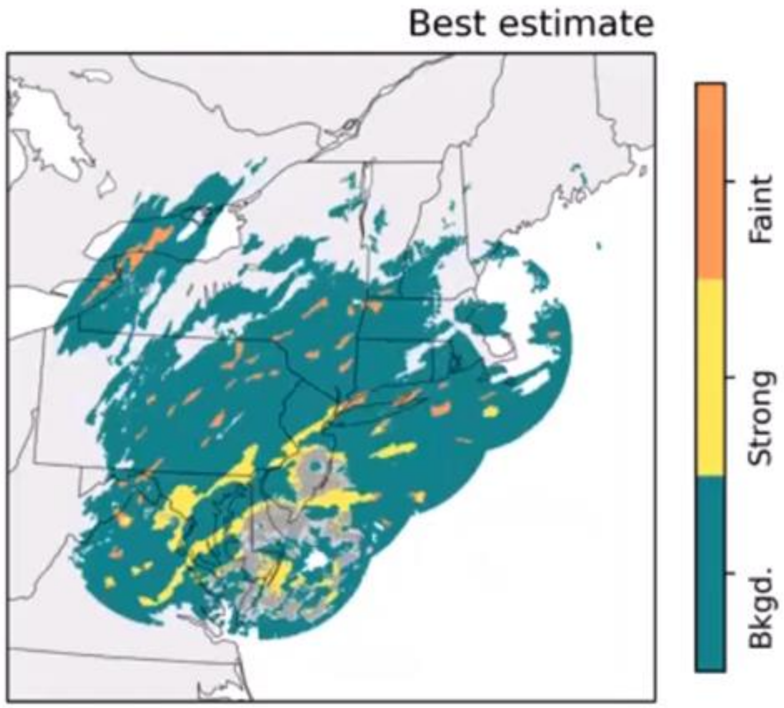
Data: NEXRAD regional radar maps



Radar Reflectivity [dBZ]
melting and mixed precip regions removed from analysis *Tomkins et al. (2022)*



Snow Rate [mm hr^{-1}]
Rescaled Z to better represent snow field using following equation:
$Z_e = 57.3\ S^{1.67}$
Rasmussen et al. (2003)



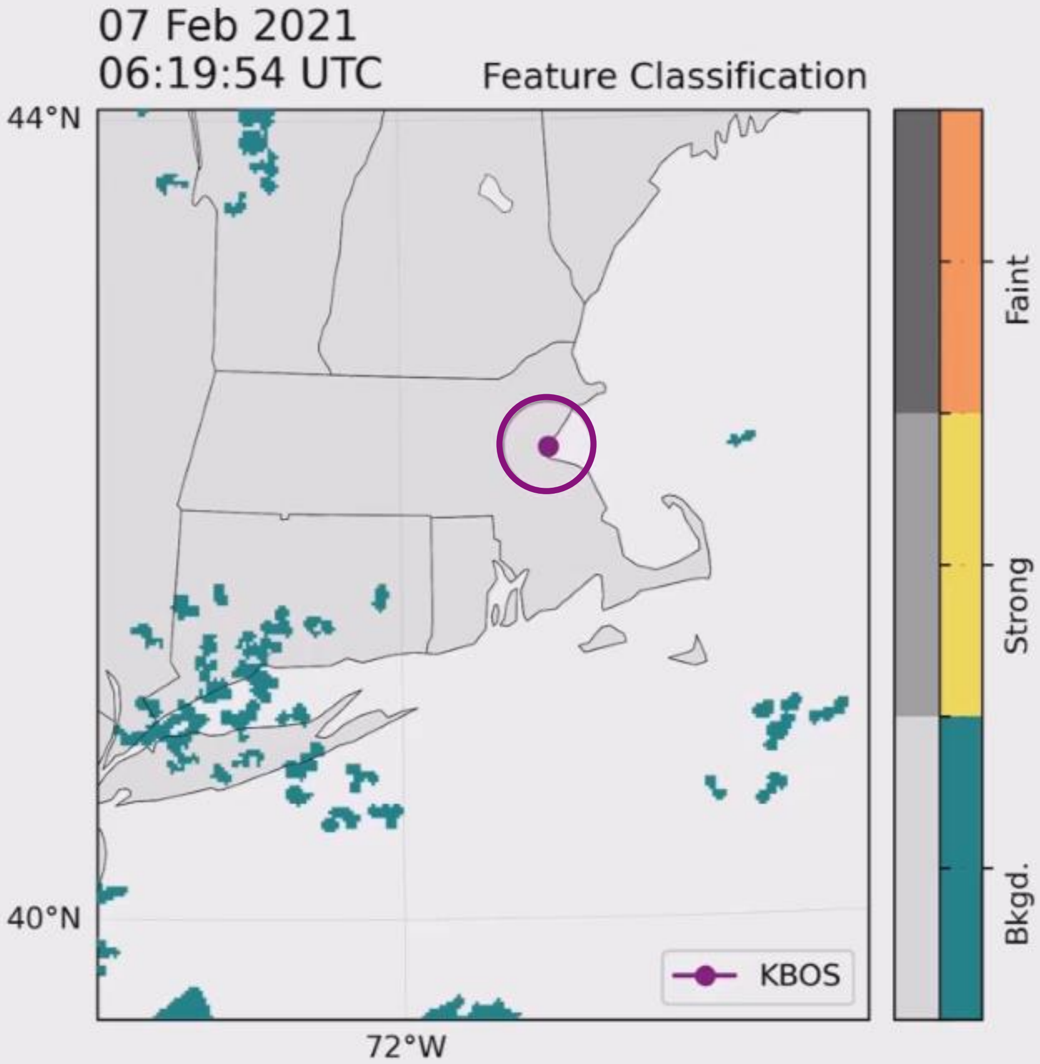
Objective Feature Detection for snow bands
Tomkins et al. (2023)

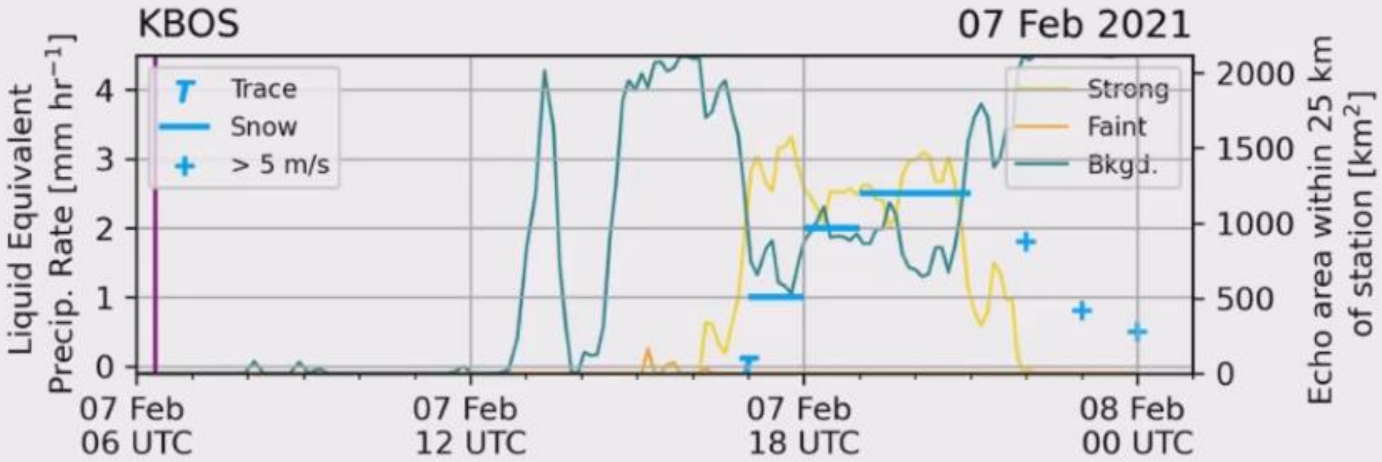
Faint: not very distinct features
Strong: very distinct features
Background: echo surrounding objects

netCDF files for all regional composites between 1996-2023 available on Dryad (open-source data repository) soon

- 1996-2012 *(pre dual-pol)* DOI: **10.5061/dryad.zcrjdfnk6**
- 2012-2023 *(post dual-pol)* DOI: **10.5061/dryad.rbnzs7hj9**

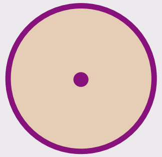
Methods: Combining ASOS hourly surface station data and feature detection regional radar maps



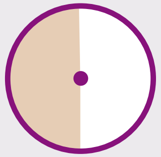


Area * Time fraction

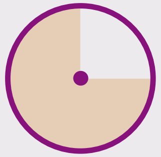
Fraction of 0.5 could be obtained many ways, including:



100% coverage of 25 km radius circle for **30 minutes**

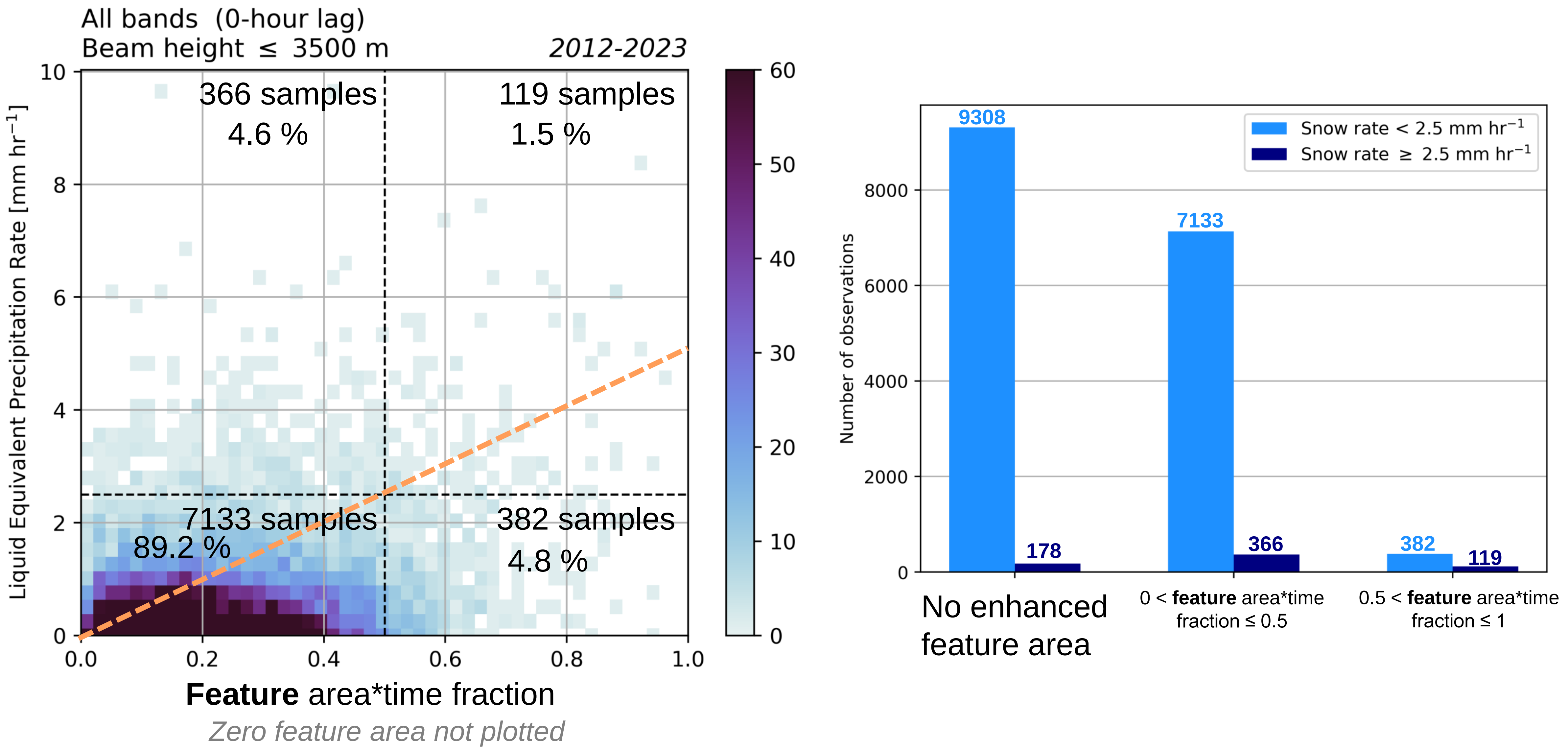


50% coverage of 25 km radius circle for **1 hour**



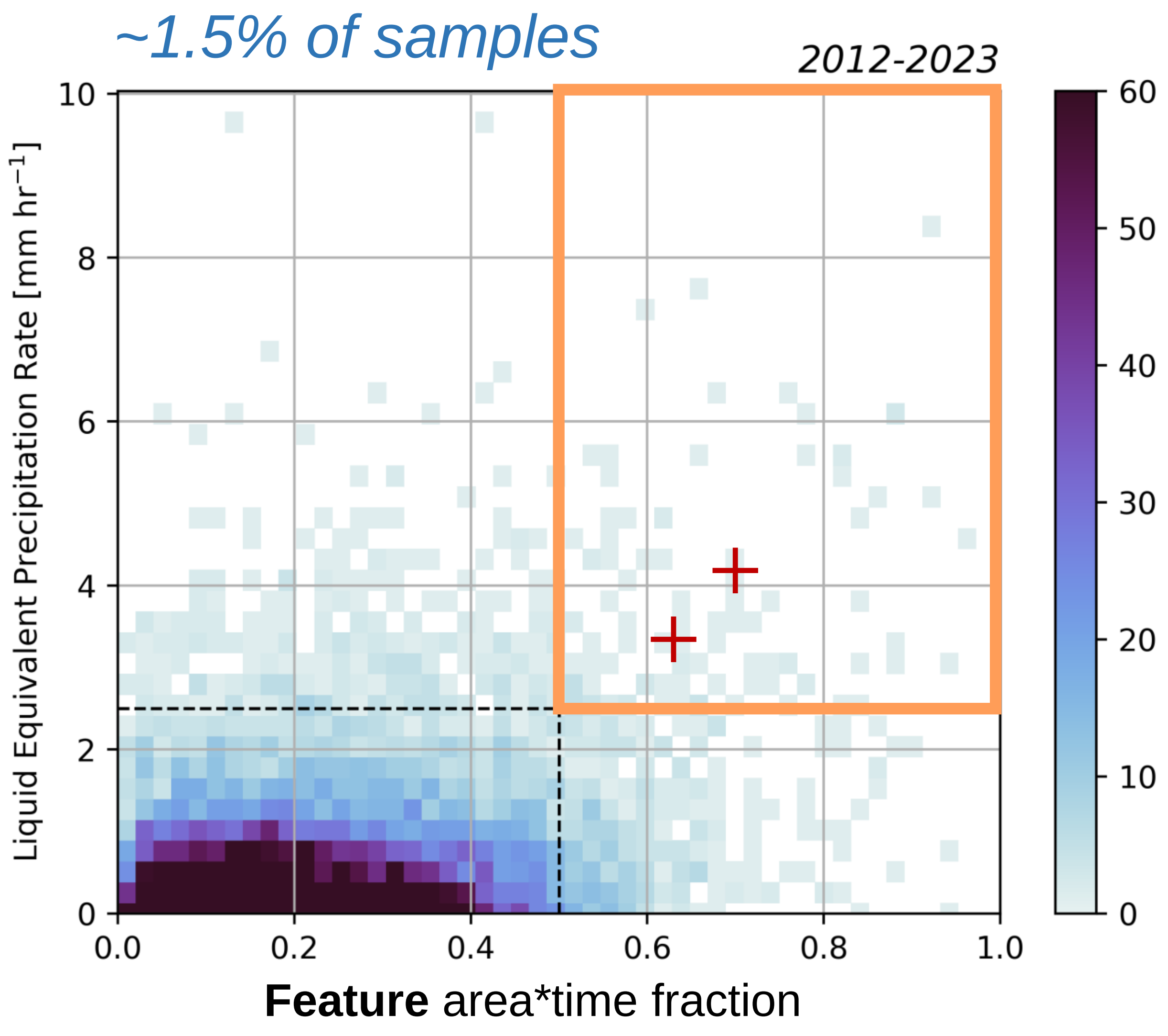
75% coverage of 25 km radius circle for **40 minutes**

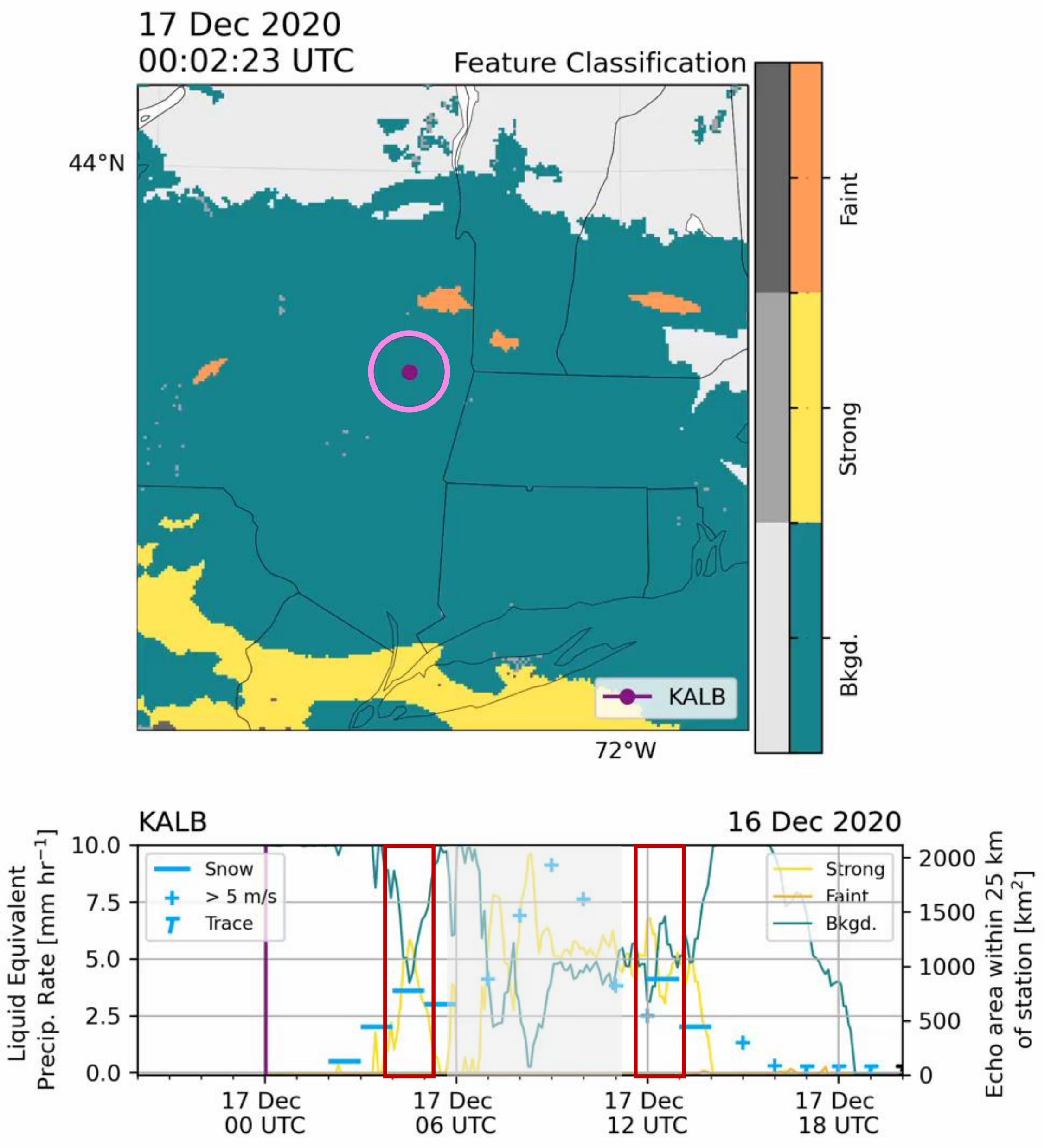
Most of the time, locally enhanced reflectivity is associated with low snow rates.



Example:

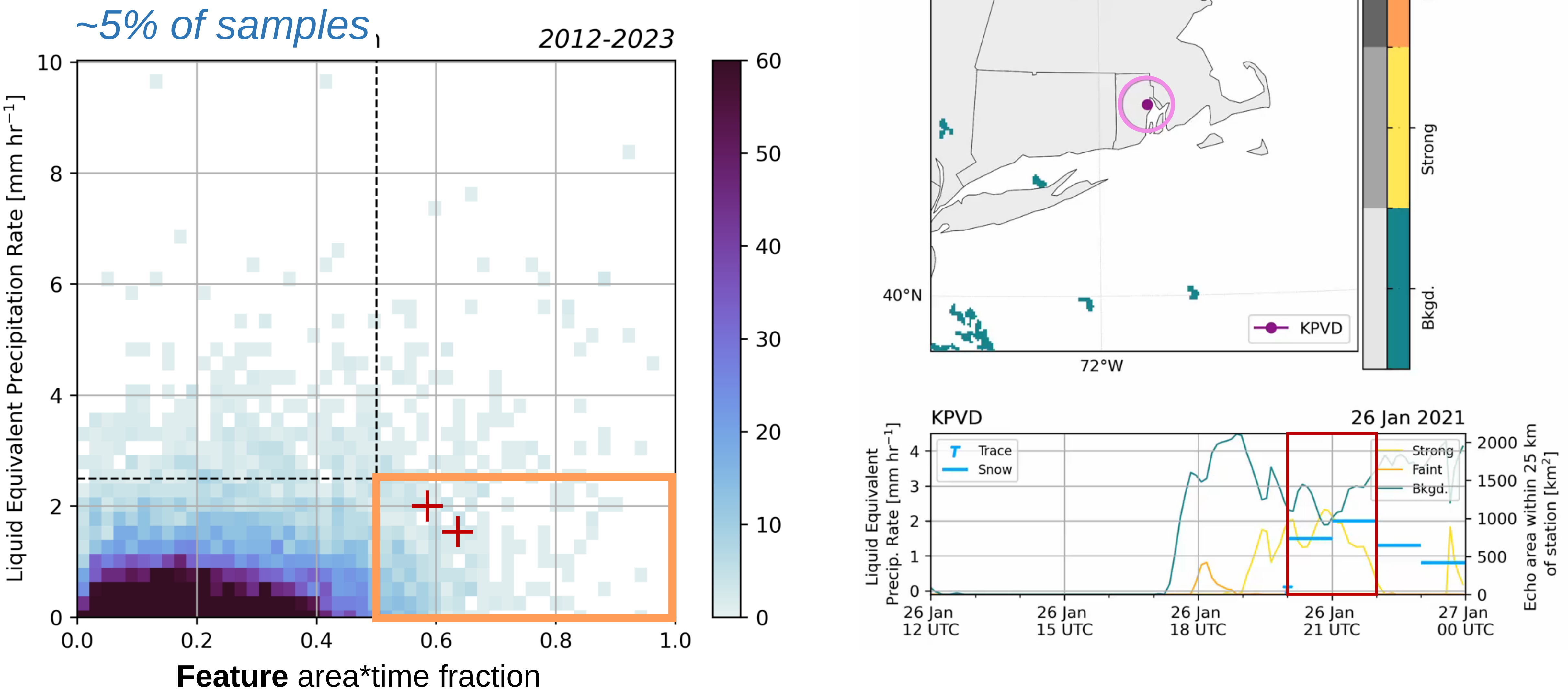
High feature area, heavy snowfall





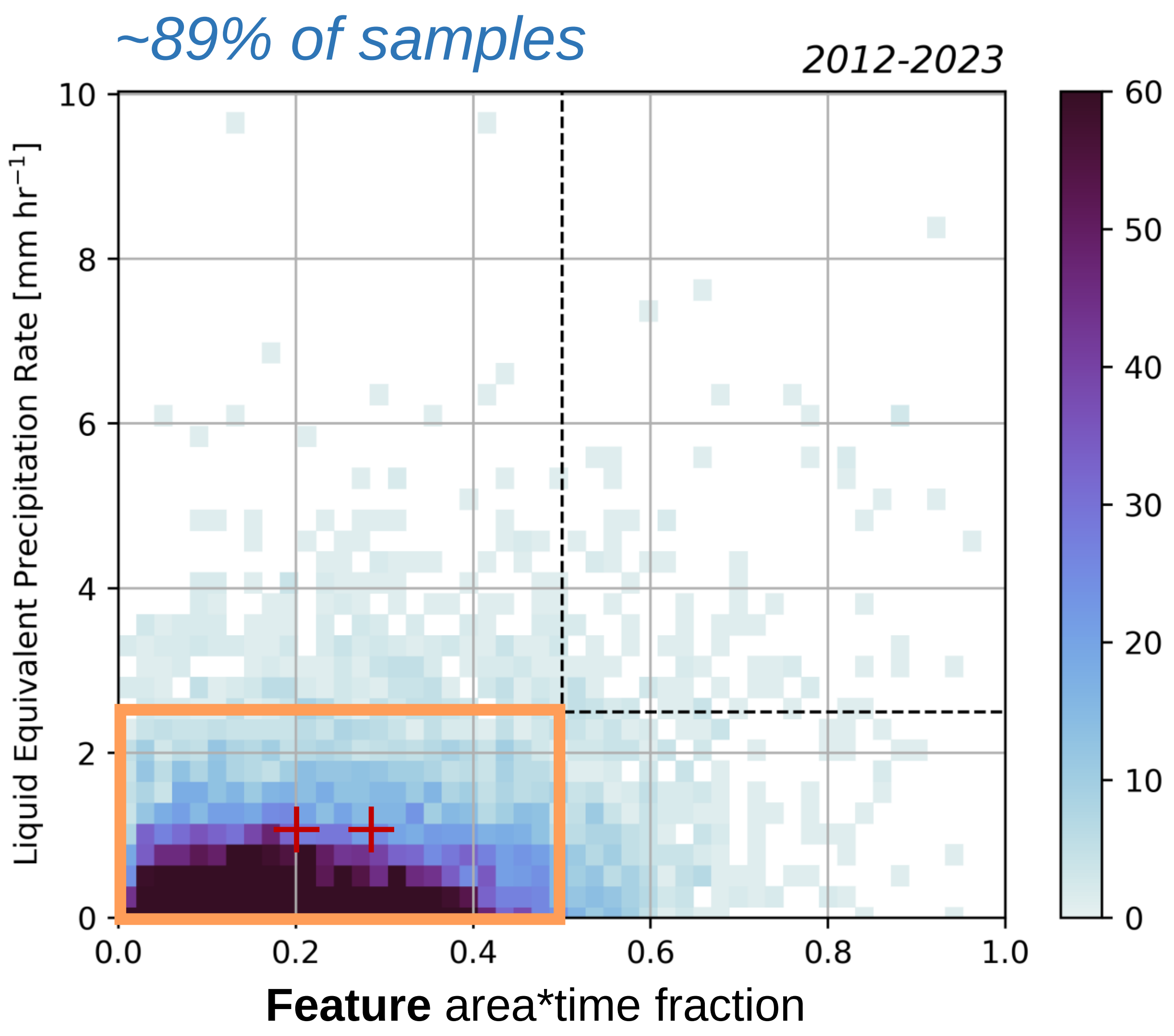
Example:

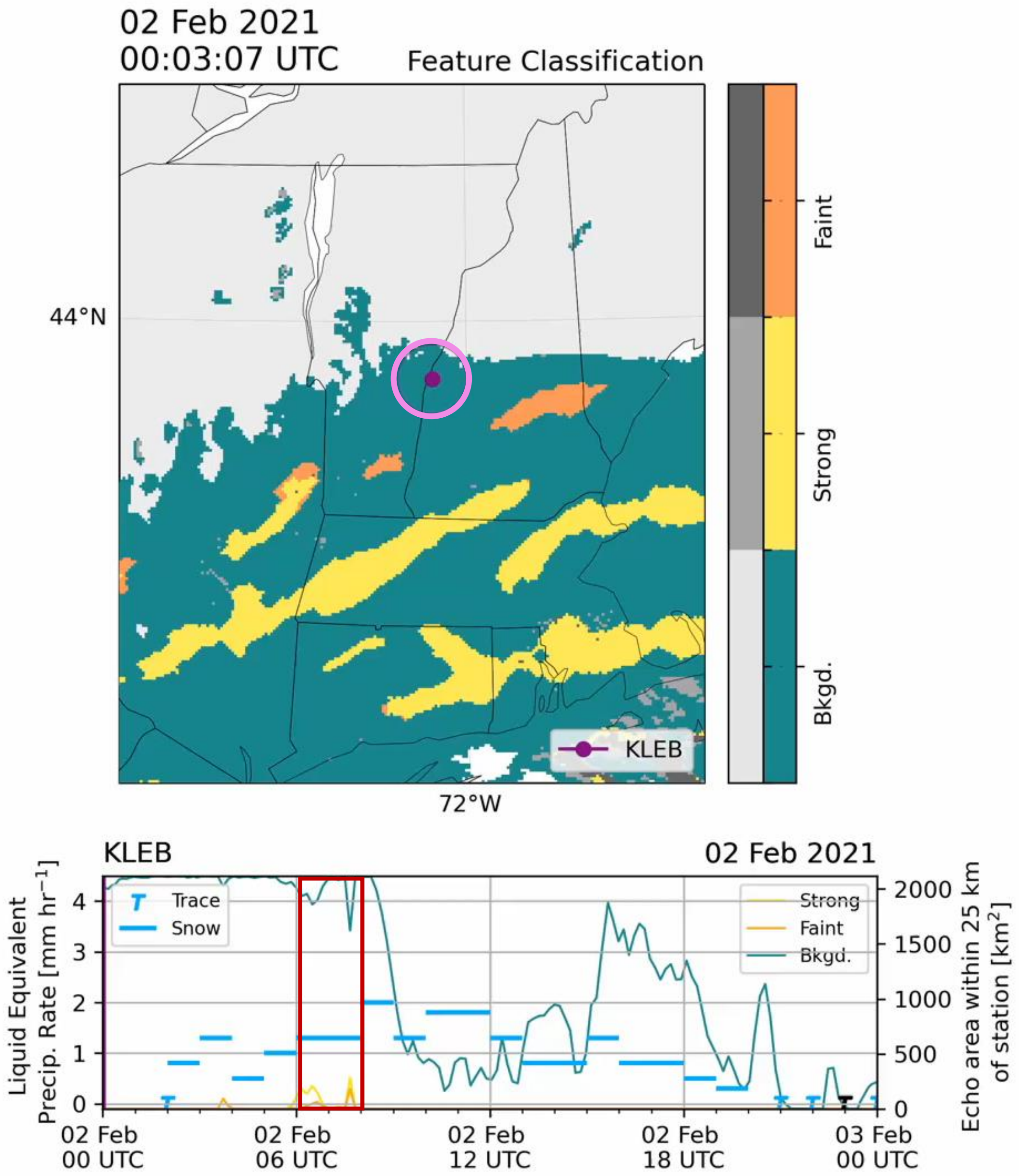
High feature area, low/moderate snowfall



Example:

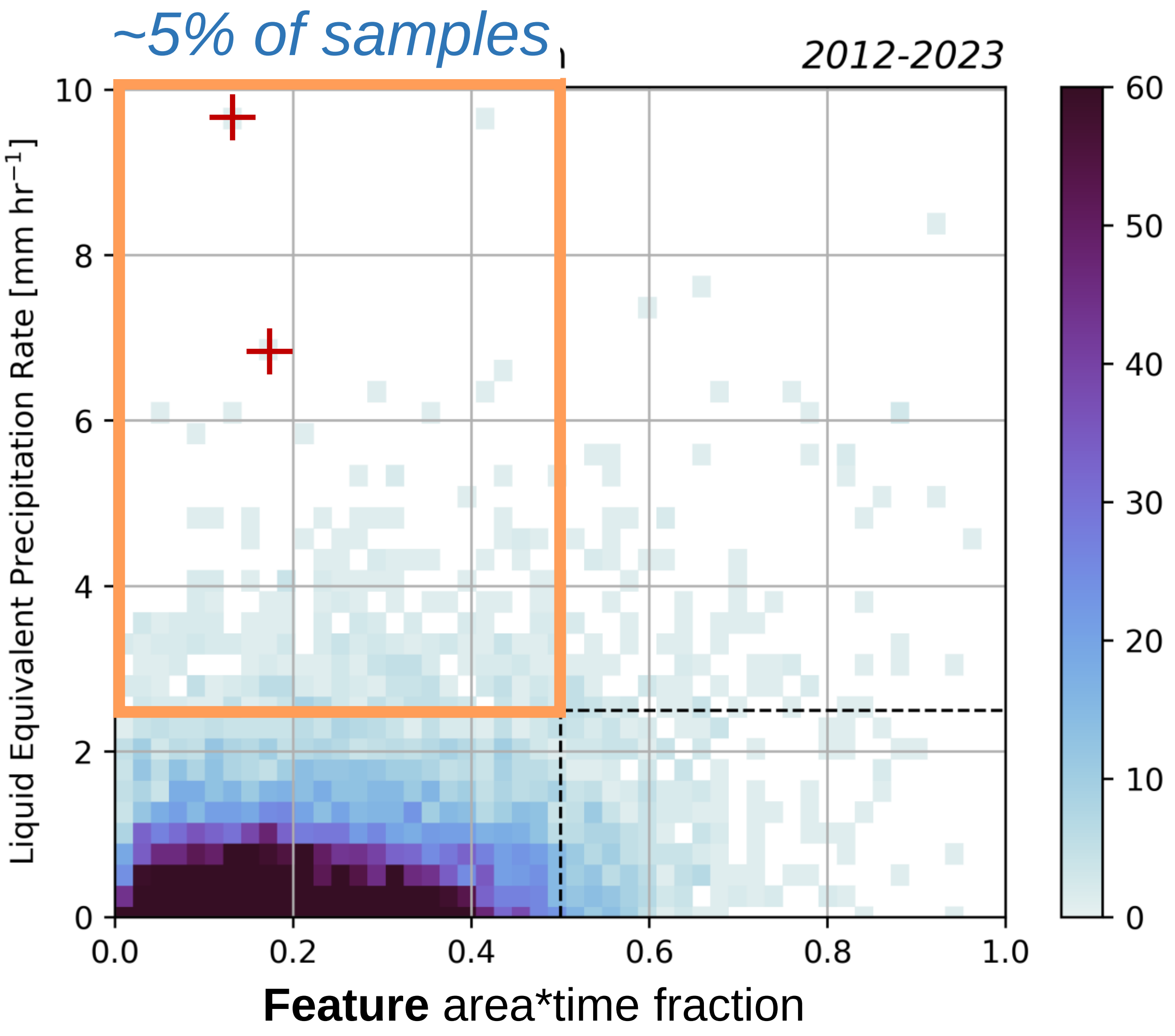
Low feature area, low/moderate snowfall

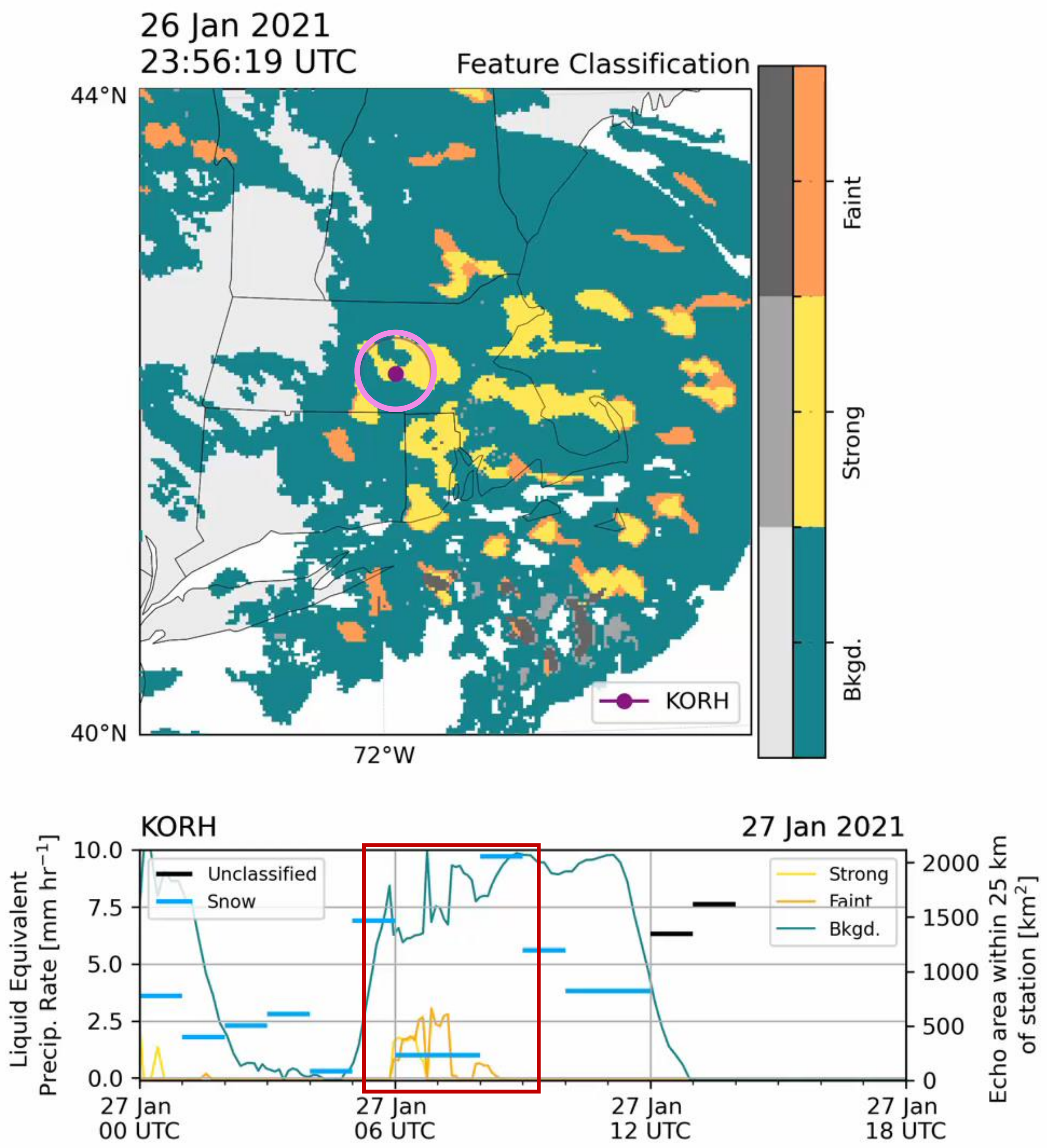




Example:

Low feature area, High snowfall





Big picture takeaways from multi-year winter storm observations

Low correlation between enhanced Z in “snow bands” detected on regional scanning radar and hourly surface snow rates

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- Mixtures yield varying distributions of shapes, sizes, and densities in the same volume which complicate interpretations and retrievals of snow rate

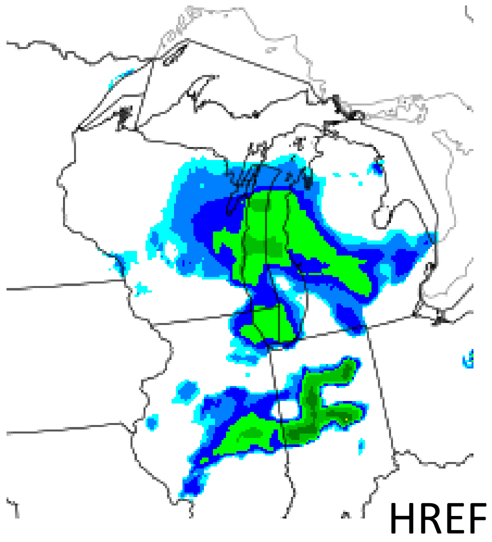
In the 1-2 hours that it takes a precipitation-sized ice particle to fall from near cloud top to the surface, 3d ice streamers originating in generating cells are tilted and smeared

- Lack of vertical column continuity in local enhancements in radar Z

Further Thoughts

- In regions without distinct upward forcing (e.g. strong frontogenesis, orographic lifting), refrain from labeling as “snow bands” most *observed* mesoscale linear features of higher reflectivity in winter storms

- Beware of conflating *forecast model* predictions of locally enhanced snowfall based on ice water contents that are converted to radar reflectivity *for display* using simple Z-S relations (where there is a 1:1 between increasing snow rate and increasing Z) with *observed* radar reflectivities



- Suggest better bet for evaluating model predictions of snowfall are hourly surface snowfall liquid equivalent measurements (in non-blizzard conditions) rather than retrievals from observed radar data