Radar-based ice number concentration retrievals towards studying secondary ice production in mixed-phase clouds

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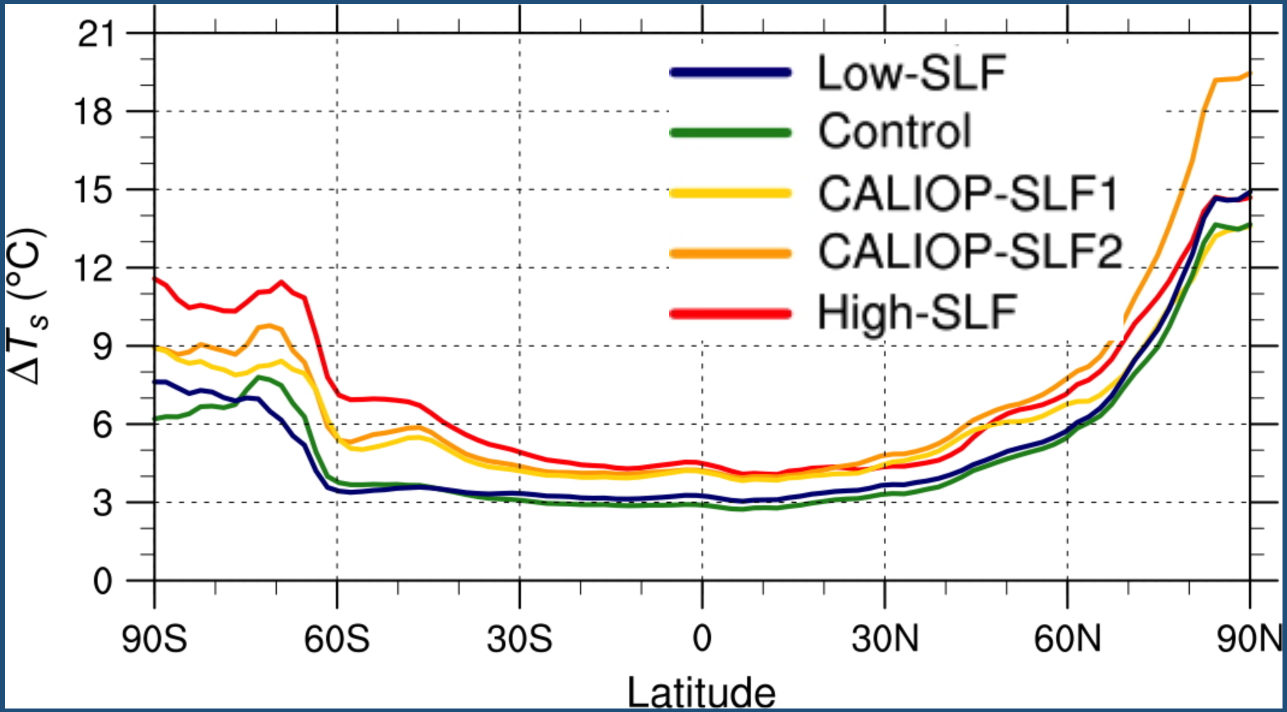
Pristine ice number concentration is often orders of magnitude larger than what is expected

- This phenomenon, known as **secondary ice production**, can rapidly impact cloud evolution
- Its representation remains challenging due to limited observational constraints
- Strong need for long-term, robust observations of pristine ice to better identify these events and their trigger mechanisms

Clouds are particularly sensitive to changes in ice microphysical processes

- Phase partitioning modulates radiative properties, precipitation production, and cloud lifetime
- Phase transitions poorly captured in models - ramifications for climate projection uncertainty



Result of different phase partitioning

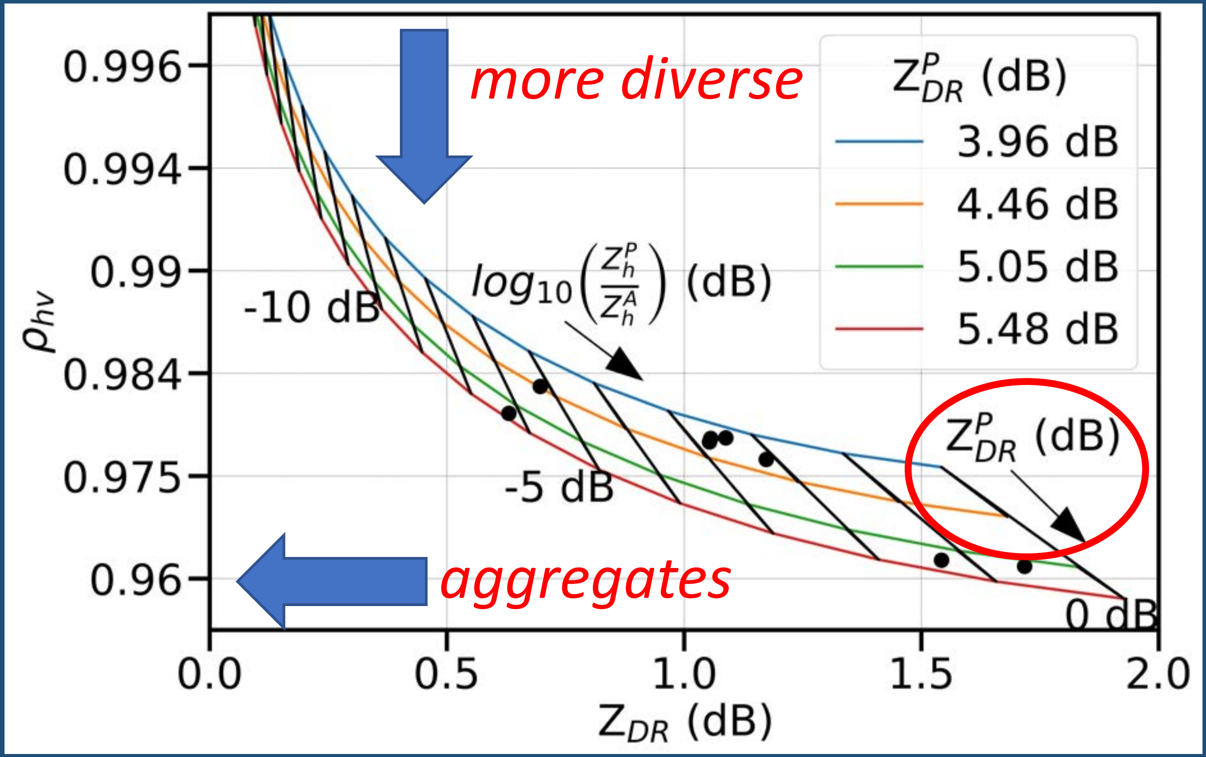
Tan et al. (2018, eBook)

Separating pristine ice from aggregates is a key remote sensing hurdle

4 observables from polarimetric radar:

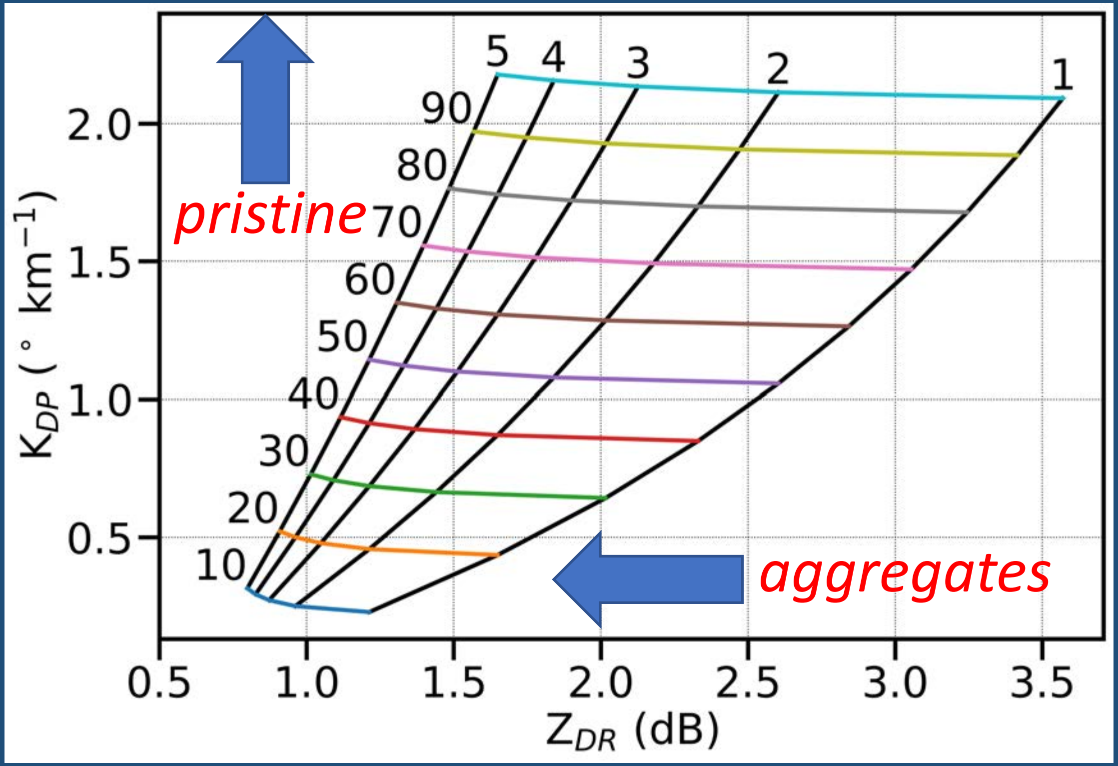
- Reflectivity (Z_H)
- Differential reflectivity (Z_{DR})
- Co-polar correlation coefficient (ρ_{hv})
- Specific differential phase shift (K_{DP})

Scattering models - 3 pristine ice habits and 5 aggregate types (Lu et al. 2015)



Similar to Keat and Westbrook (2017, JGR)

K_{DP} dominated by pristine ice, revealing their sizes and abundance even in the presence of aggregates



Similar to Schrom and Kumjian (2015, JAMC)

- Use an iterative ensemble method to provide <u># concentration and size</u> for both pristine/aggregates
- Radar data corrected for attenuation and systematic bias/noise, smoothing applied (Chandrasekar group)

ENCORE-ICE uses the iterative Ensemble Kalman Filter to find the best estimate of the state vector

$$\boldsymbol{x}_{i+1} = \boldsymbol{x}_i + \mathbf{K}\big(\boldsymbol{y} - h(\boldsymbol{x}_i)\big) - (1 - \mathbf{KH})(\boldsymbol{x}_i - \boldsymbol{x}_b)$$

updated state

current state

obs.

forward model and its linearization

background state

Kalman Gain

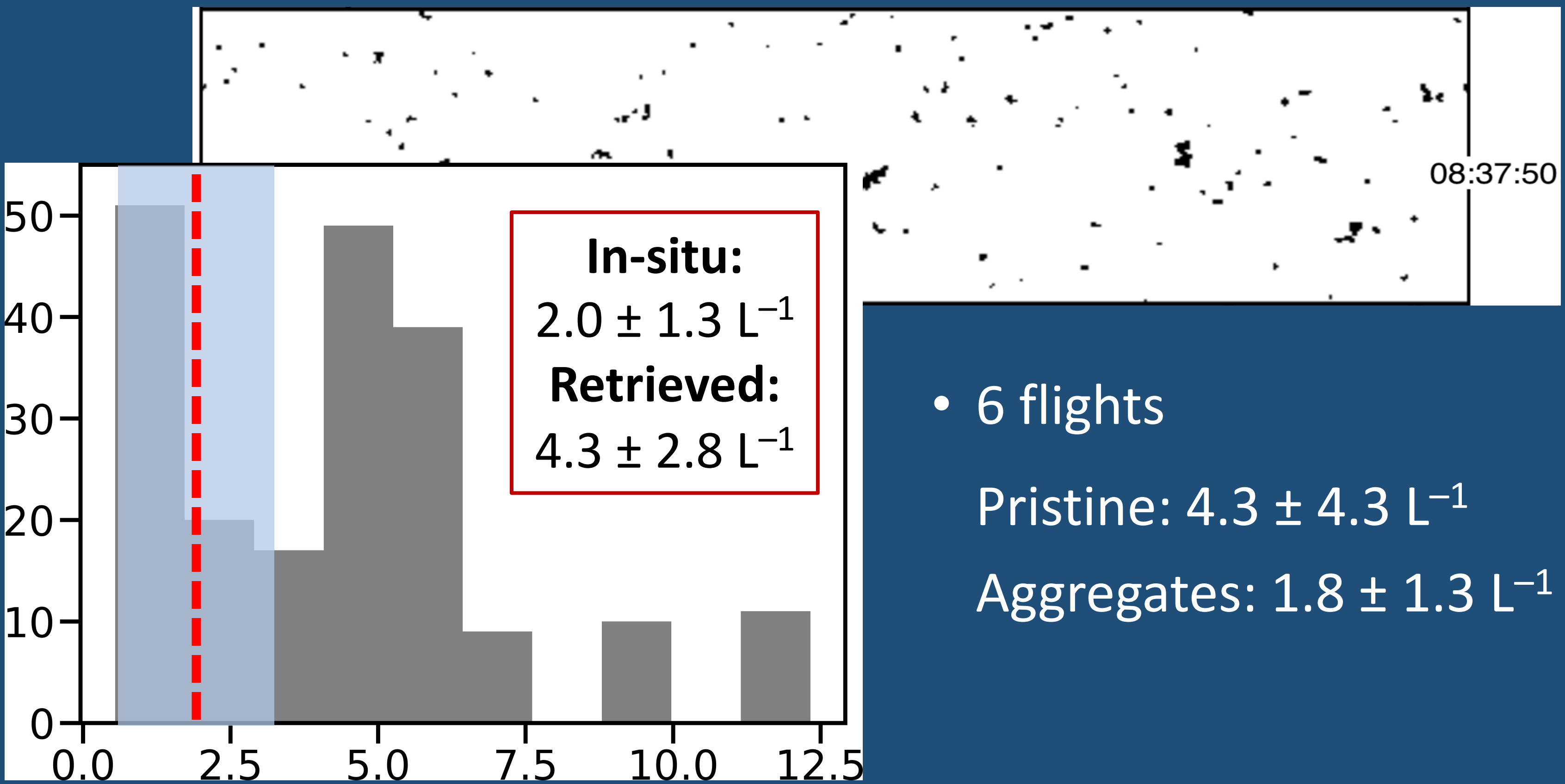
controls how much weight is placed on the observations, compared to the current state

can be directly calculated

Method allows for full uncertainty estimation

Evaluations against in-situ cloud measurements

- Using data from the UK PICASSO campaign (Parameterizing ice clouds using airborne observations and triple-frequency Doppler radar data)



- 6 flights

  Pristine: $4.3 \pm 4.3\ L^{-1}$

  Aggregates: $1.8 \pm 1.3\ L^{-1}$

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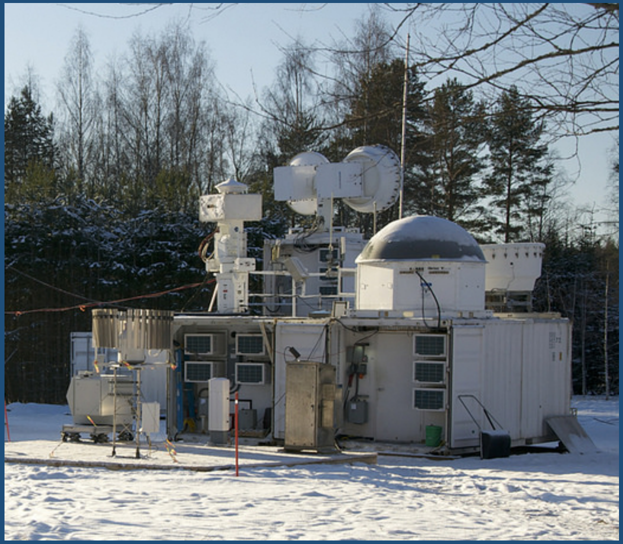
ARM Mobile Facility deployment in Finland

- Biogenic Aerosols – Effects on Clouds and Climate (BAECC) in 2014
- Particularly interested in along-wind scans from X-band radar to follow microphysical processes in a Lagrangian sense
- Comprehensive aerosol measurements to compute primary ice # concentration from Demott et al. (2010)



Petäjä et al. (2016, BAMS)

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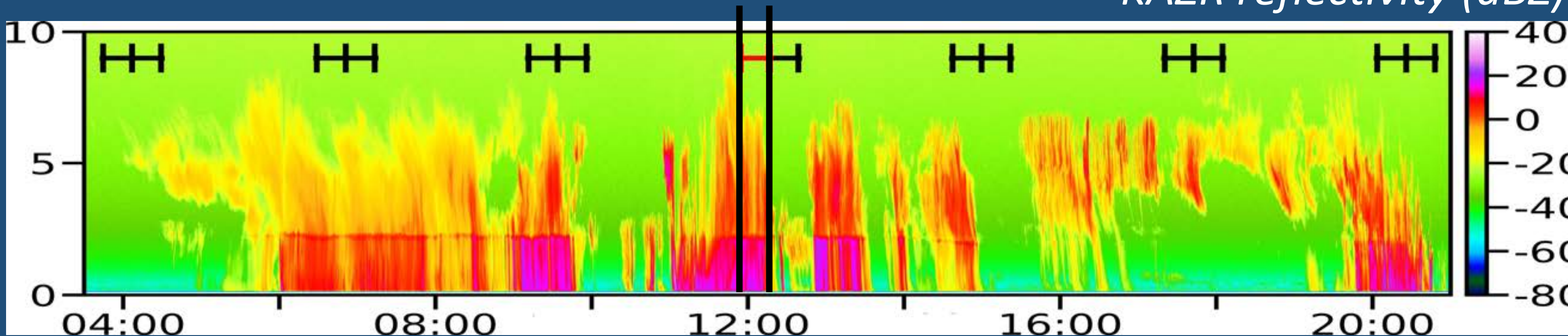
A stratiform cloud case on 18–19 August 2014

KAZR reflectivity (dBZ)

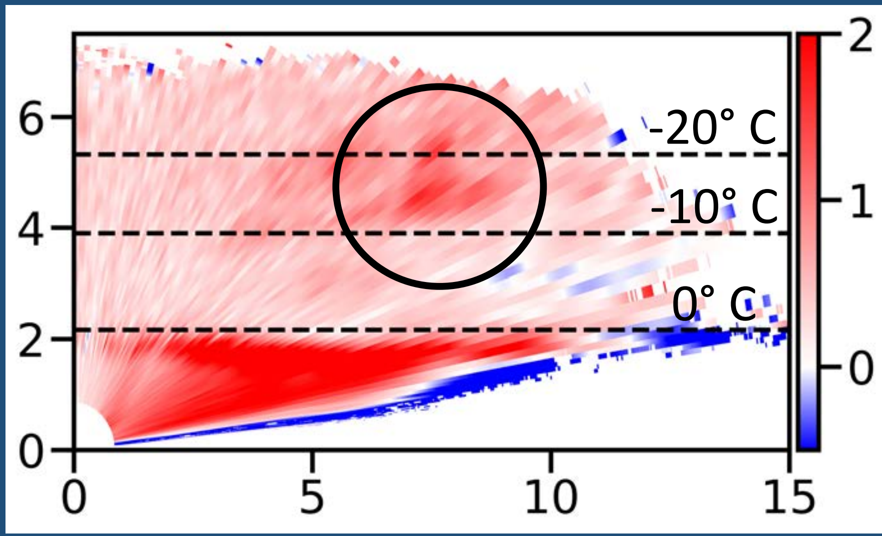
Height (km)

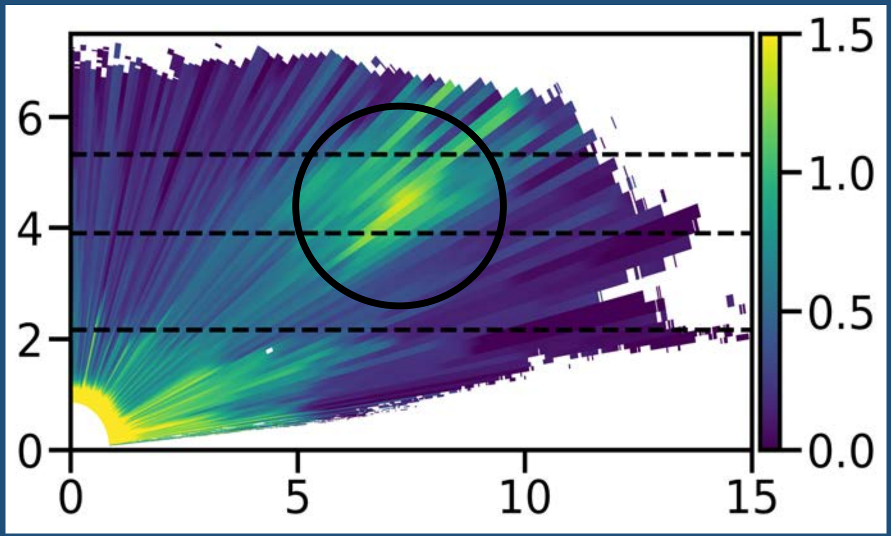


Z_{DR} (dB)

K_{DP} (° km^{-1})

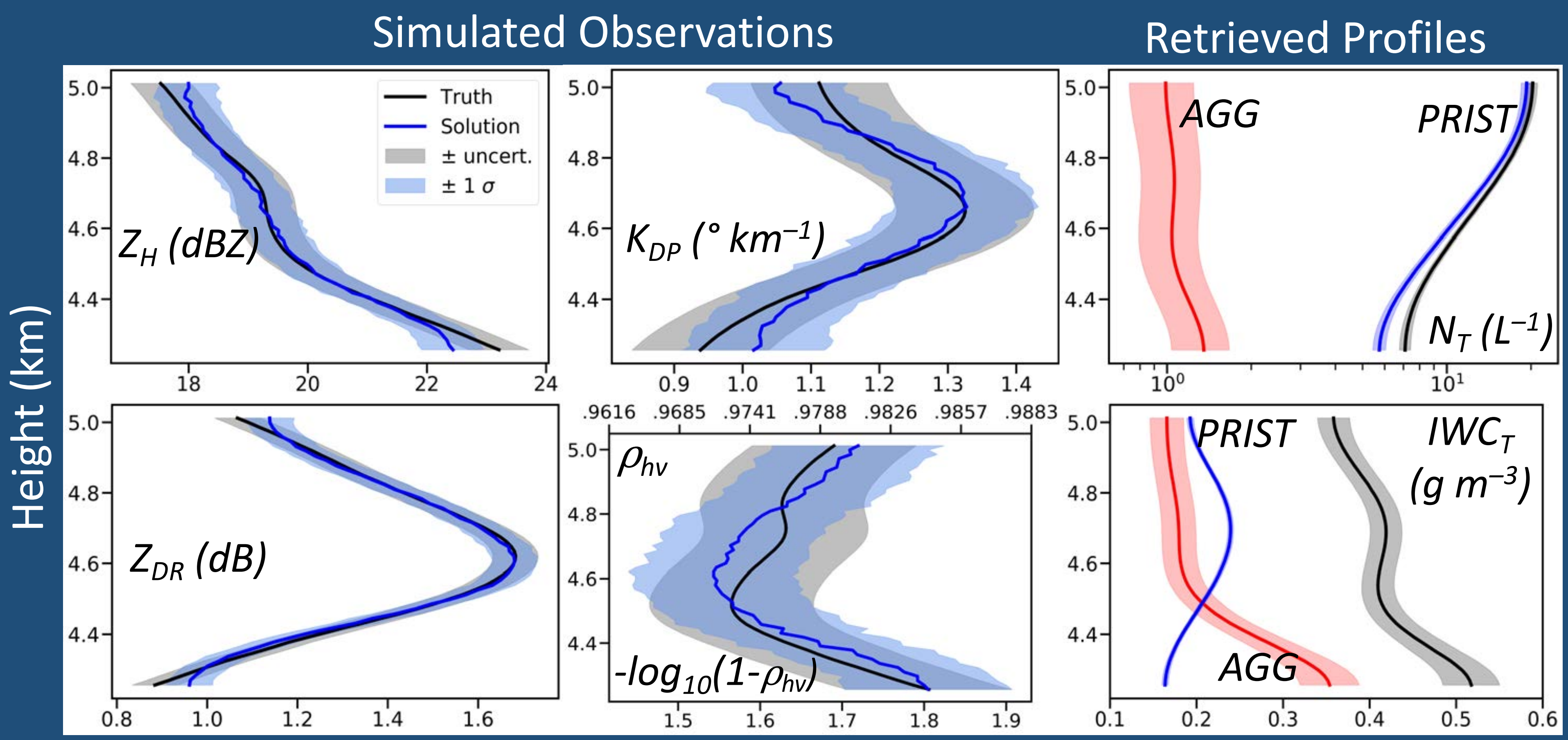
Height (km)





Distance from radar (km)

ENCORE-ICE exhibits skill in matching polarimetric observations



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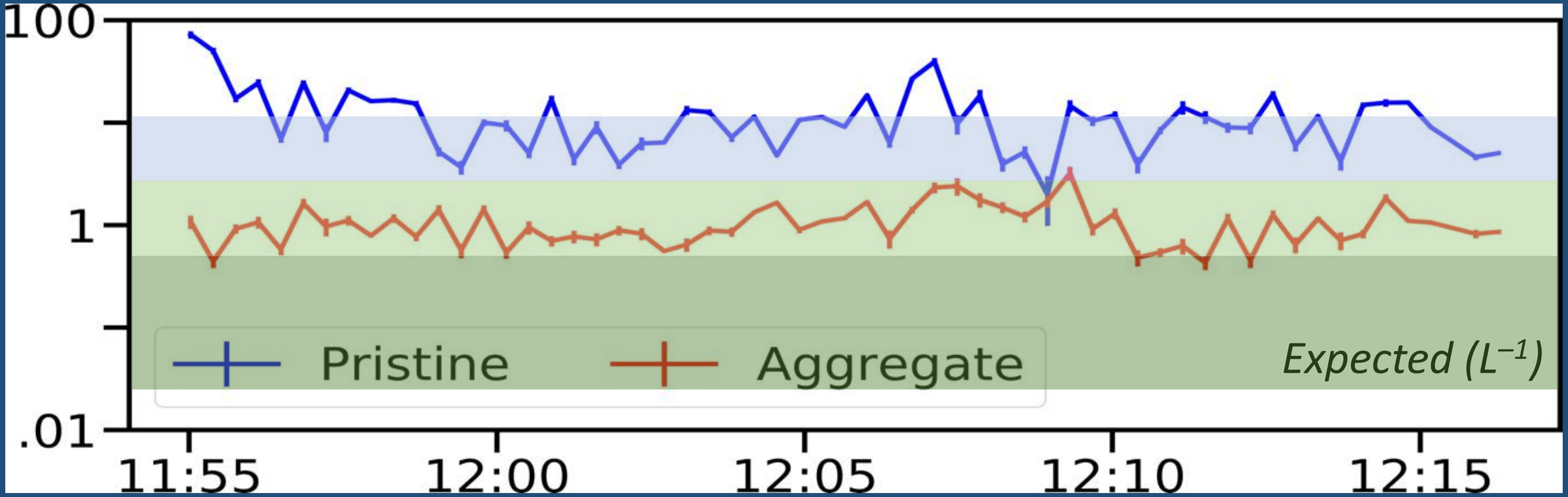
Time evolution of ice number concentration

Ice Number Concentration (L^{-1}) in a zone between –5 and –20°C



This scan period:

Pristine: 12.7 ± 1.1 L^{-1}

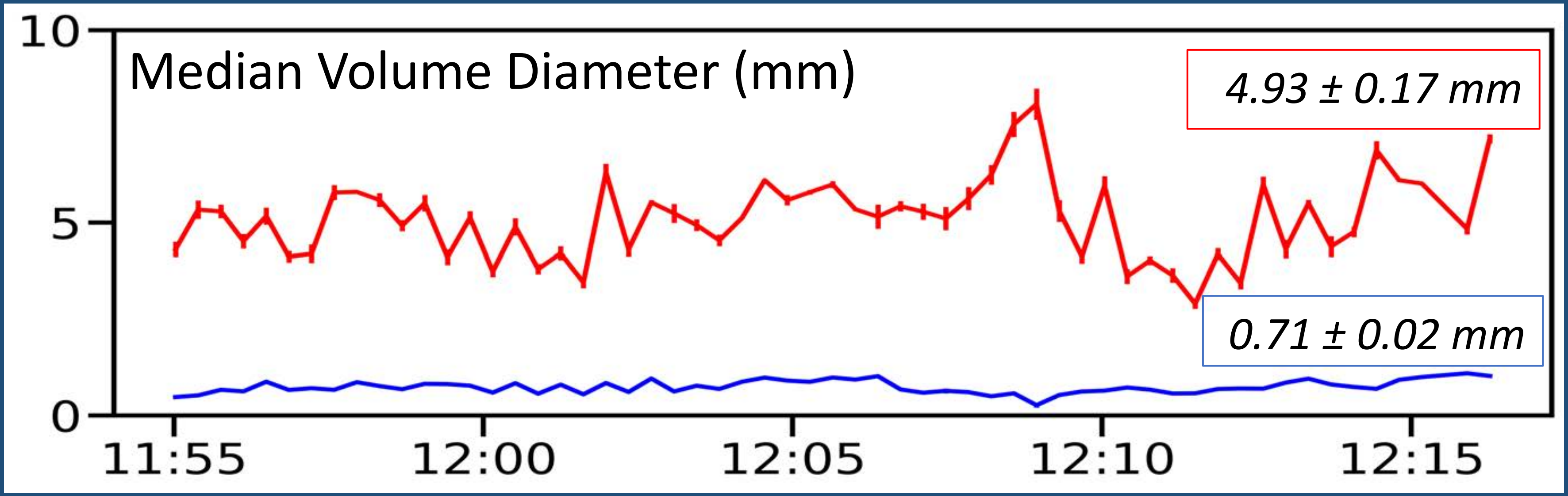
Aggregate: 1.0 ± 0.1 L^{-1}

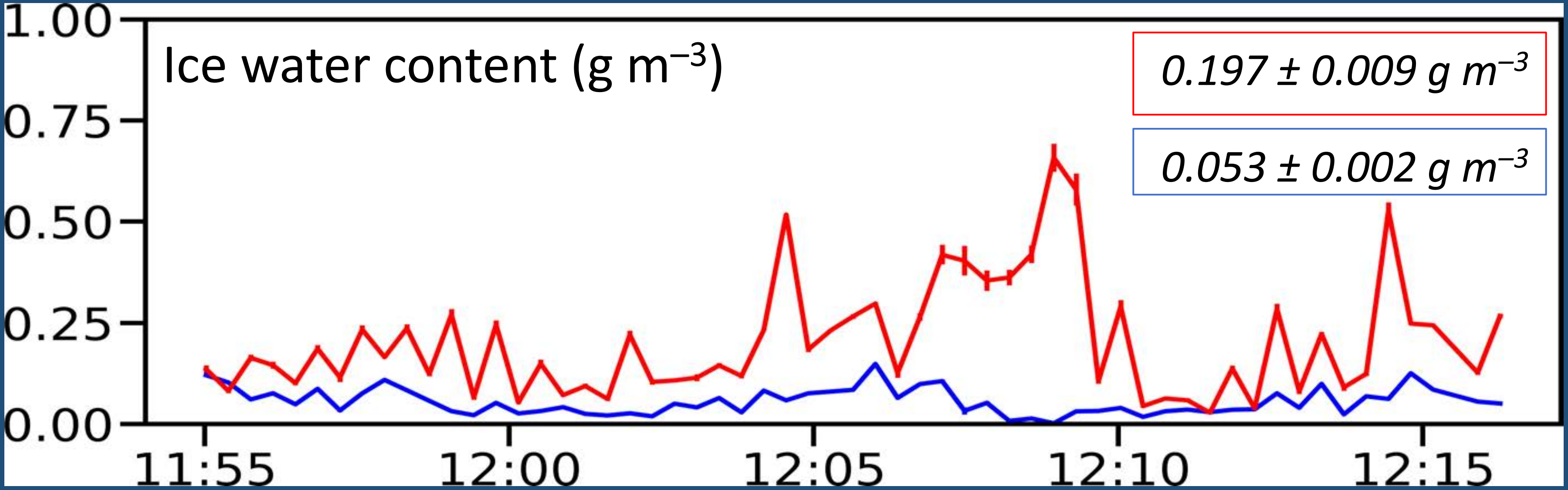
PICASSO

Pristine: 4.3 ± 4.3 L^{-1}

Aggregate: 1.8 ± 1.3 L^{-1}

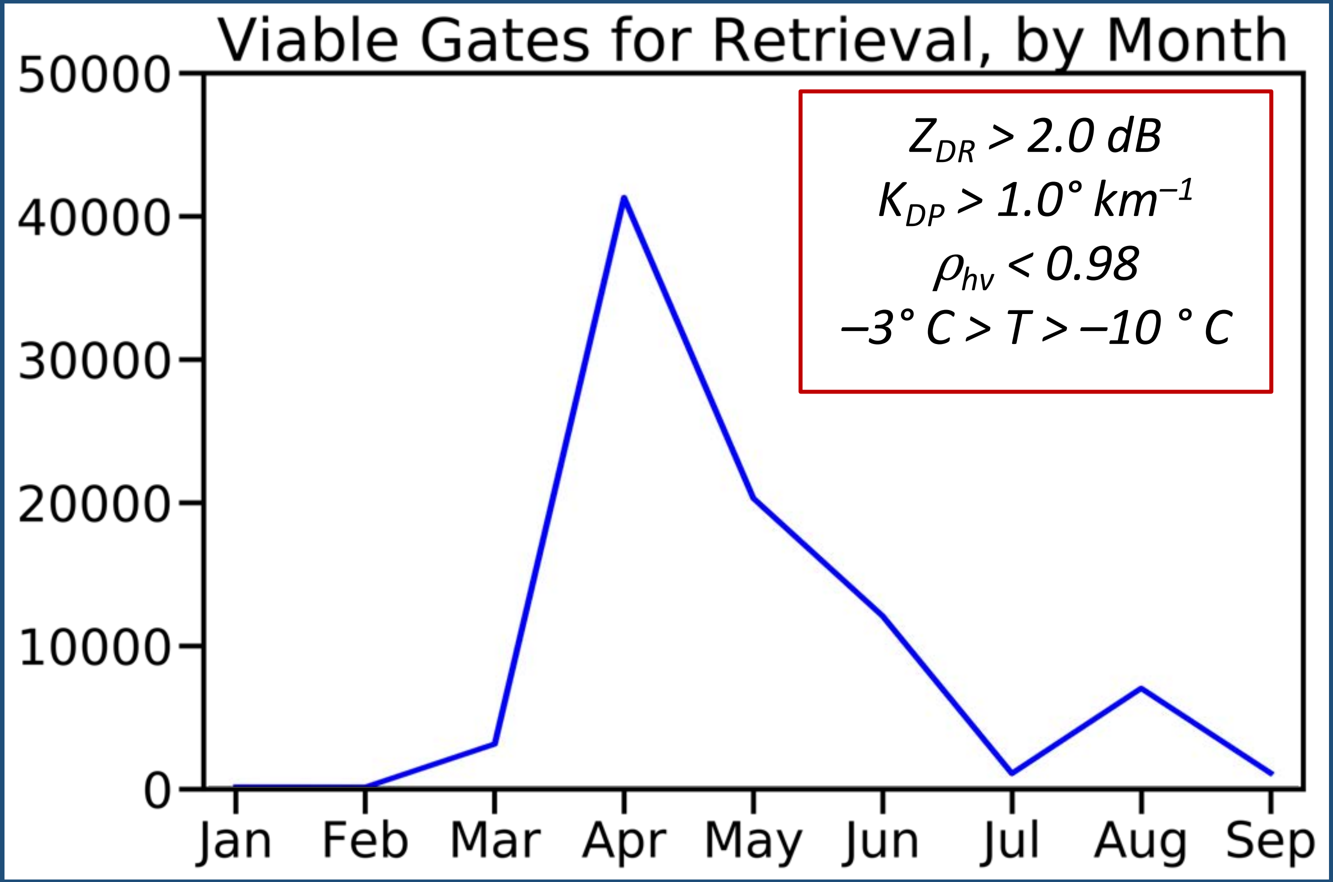
Pristine/aggregate microphysical properties





Towards robust characterization of secondary ice production events

Gate Count



Rich amount of data with strong polarimetric signal in favorable temperature regimes

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Summary

- We retrieve pristine ice and aggregate number concentrations simultaneously using polarimetric scanning cloud radar data, showing good agreement with in-situ data
- In the temperature region that secondary ice production likely occurs (e.g., about –8 to –10°C), the retrieved pristine ice number concentration is about an order of magnitude larger than primary ice number concentration
- While the enhancement in ice number is not as large as expected, some multiplication processes may be present and warrant further analysis

Literature

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