Ice number concentration retrievals from scanning cloud radar measurements for studying secondary ice production

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Motivation

- Secondary ice production plays an important role in precipitation production, anvil dynamics, and cloud radiative forcing
- Yet, representing secondary ice production processes remains challenging, due to limited observational constraints from laboratory and field experiments
- There is a strong need for long-term, advanced, robust observations of pristine ice, in order to better identify secondary ice production and its trigger mechanisms

Key Scattering Properties of Ice

- The AMF Biogenic Aerosols–Effects on Clouds and Climate (BAECC) campaign at Hyytiälä, Finland provides a wide range of polarimetric radar data, allowing us to retrieve pristine ice number concentration (**N_{ice}**) and to monitor its evolution
- **Key radar observables:** radar reflectivity (**Z_H**), differential reflectivity (**Z_{DR}**), specific differential phase (**K_{DP}**), and copolar correlation coefficient (**ρ_{hv}**)
- **Key retrieval principle**: Higher **N_{ice}** embedded in aggregates shows signals of high non-sphericity in **Z_{DR}**; high diversity in **ρ_{hv}** (see **Fig. 1**); and high **K_{DP}**. All information is combined through our Ensemble Cloud Retrieval (ENCORE) method, providing retrieved number concentration and size of pristine ice, and uncertainty.

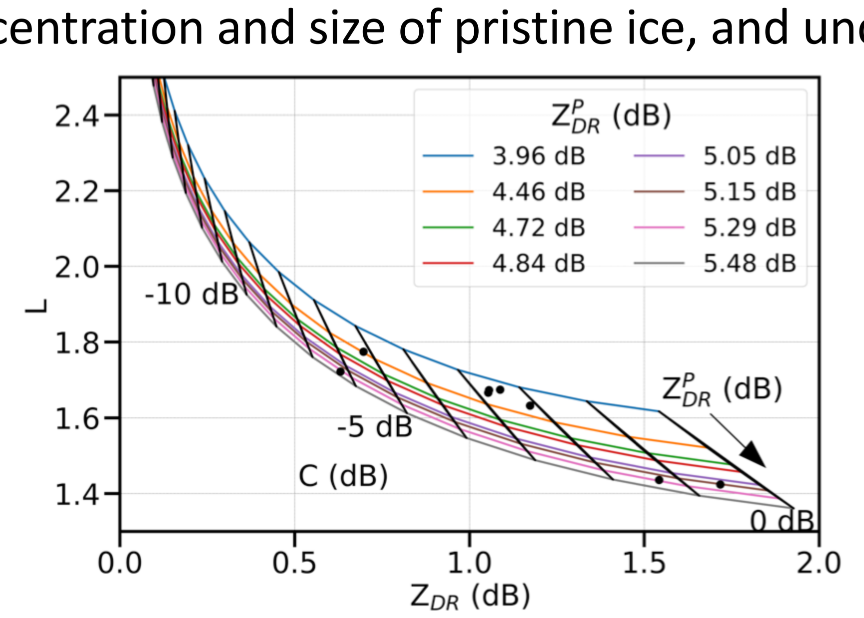


Fig. 1.: Relationship between Z_{DR} (*indicating particle non-sphericity*) and L (function of ρ_{hv}, *indicating diversity of particles in scattering volume*) for a range of Z^P_{DR} (*Z_{DR} of pristine ice*) and C (*log-ratio of pristine/aggregate contributions to horizontal backscattered power*), using monodisperse columns at side incidence. Black points are examples of observations from the BAECC campaign in 2014.

Case Study

- An example of along-wind scans from the ARM X-band cloud radar at ~12 UTC, on 18 August 2014 during the BAECC campaign
- This case in **Fig. 2** represents overcast clouds, with a melting layer at 2 km and stratiform precipitation of 5–10 mm hr^{-1} at surface

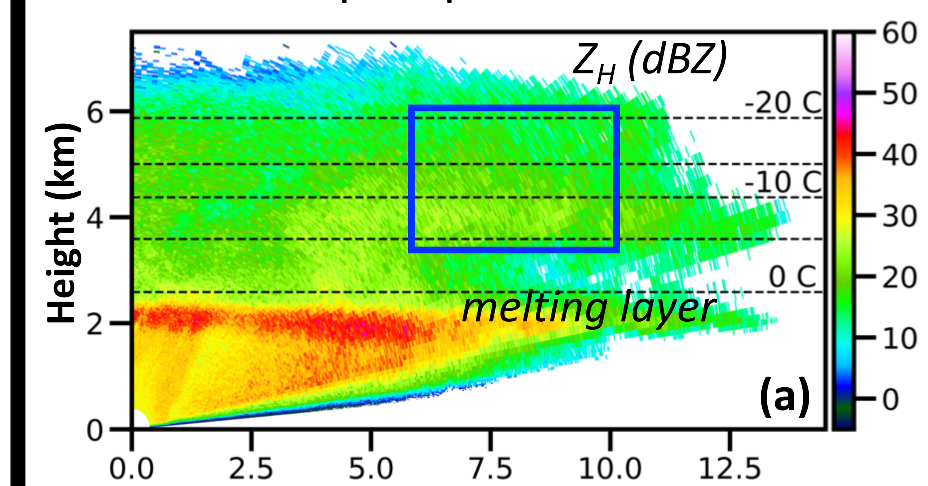
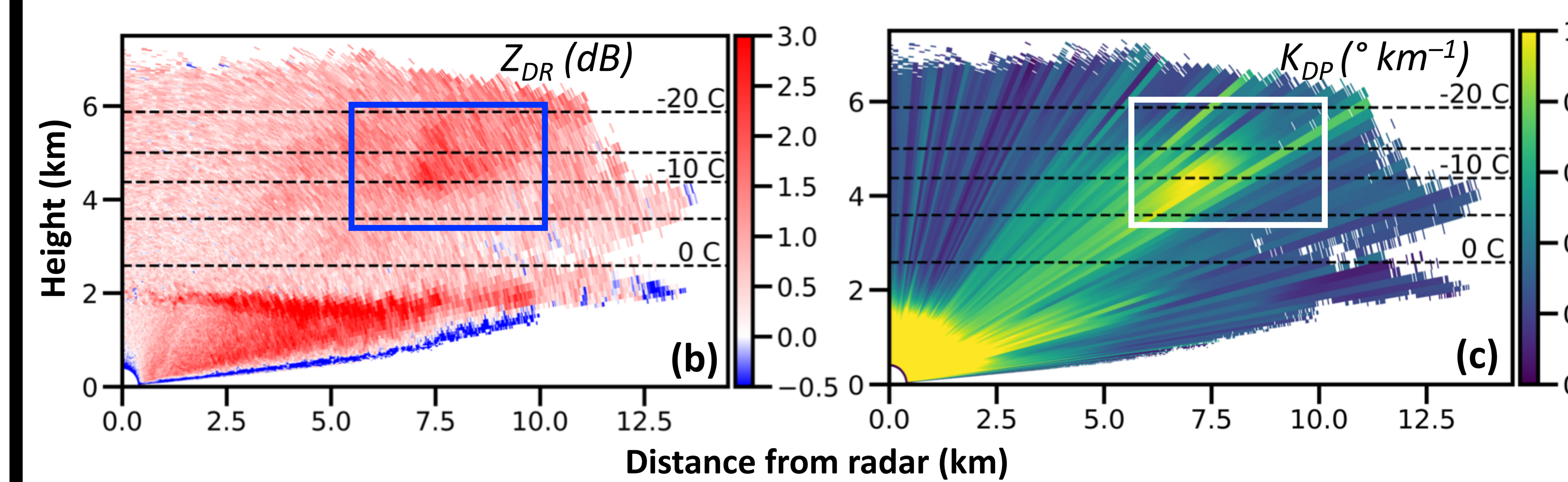


Fig. 2. Polarimetric observables (a) Z_H (b) Z_{DR} and (c) K_{DP} from XSACR on 8/18/2014, duration: 12:04:33 UTC – 12:04:55 UTC. Temperature contours are co-plotted from 0 to –20°C with an interval of 5°C. Retrieval region is denoted by colored rectangle.



Retrieval Statistics

- For the region indicated in Fig. 2, **Fig. 3** and **Fig. 4** show that for pristine ice the retrieved number concentration is (3.8 ± 2.5) L^{-1} and ice water content (IWC) of (0.08 ± 0.07) g m^{-3}, based on spatial resolution of ~25 m.
- For aggregates, the retrieved number concentration is (3.9 ± 11.5) L^{-1} and IWC is (0.38 ± 0.21) g m^{-3}.
- The mean relative contribution of pristine ice to the radar signal is about 15%

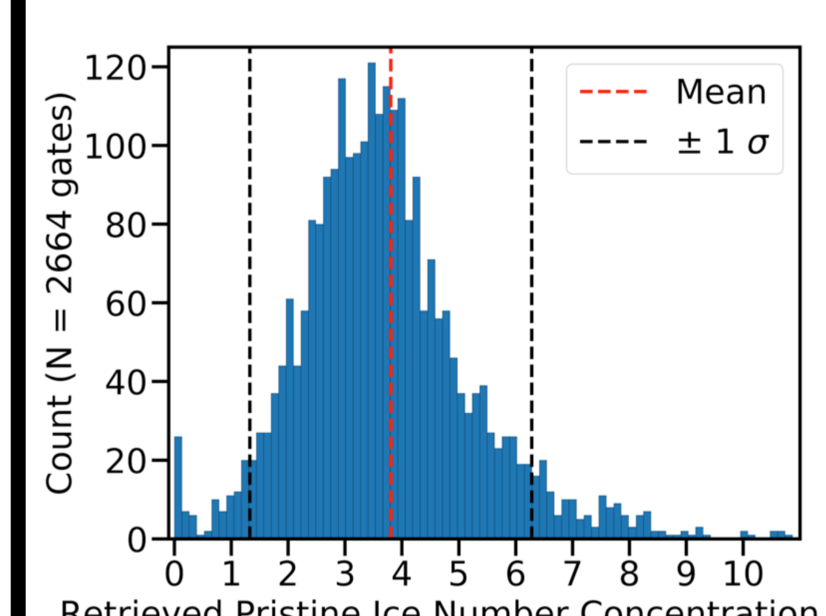


Fig. 3. Distribution of retrieved pristine ice number concentration from the region defined by the colored rectangle in Fig. 2.

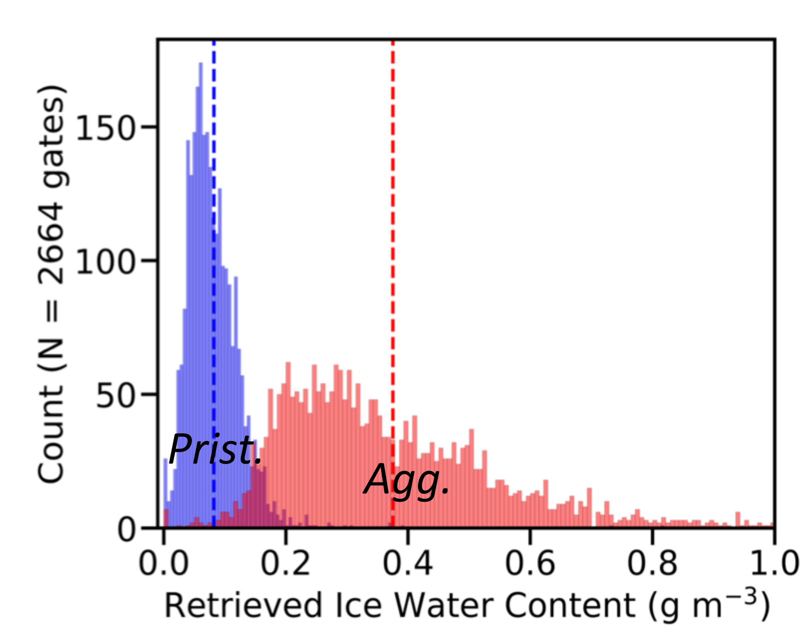


Fig. 4. Distribution of retrieved ice water content from the region defined by the colored rectangle in Fig. 2.

Key Takeaways

- Using polarimetric radar measurements from the AMF deployment in Finland, we demonstrate that it is possible to separate signals between aggregates and pristine ice, and to retrieve their number concentrations
- In the temperature zone of ≅ –10°C, our retrieved pristine ice number concentration is at least one order of magnitude larger than the estimated primary ice number concentration, indicating the potential occurrence of secondary ice production

Did Secondary Ice Production Occur?

- We compare our retrieved pristine ice number concentration to estimated number concentration of primary ice
- Primary ice number concentration is estimated using various parameterizations: e.g. Demott et al. (2010), Cooper (1986) and Fletcher (1962), using sonde temperature profiles and surface-based aerosol size distribution measurements
- At layers with temperature ranging between –8 and –10°C, **Fig. 5** shows that the retrieved ice number concentration can be larger than primary ice by at least one order of magnitude.

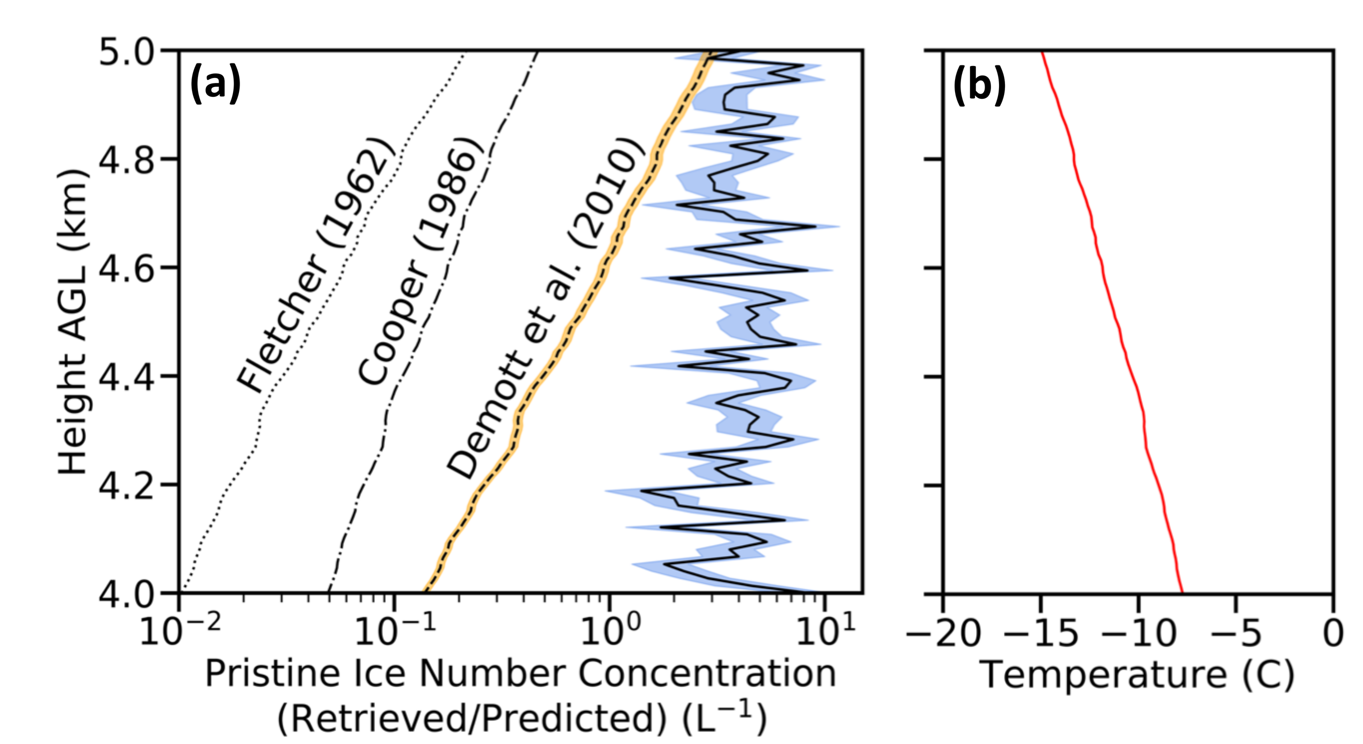


Fig. 5. (a) Retrieved pristine ice number concentration (solid black line, ± 1 σ shading) and (b) atmospheric temperature as a function of height above the radar along the ray of maximum K_{DP} in the region specified in Fig. 2. The corresponding number concentrations of primary ice nuclei are also co-plotted, using parameterizations from Fletcher (1962), Cooper (1986), and Demott et al. (2010). The shading in the line from Demott et al. (2010) depicts ice nuclei estimates using different aerosol concentrations prior to, and after, precipitation occurred.