

Background and Motivation for this study, and an Introduction to the Candac Rayleigh-Mie-Raman Lidar (CRL)

Motivation Cloud feedbacks are a large source of uncertainty in estimating Earth's radiative balance budget. This project uses the CRL (CANDAC Rayleigh-Mie-Raman Lidar) at Eureka, Nunavut (80° N, 86° W) to investigate the properties of High Arctic mixed-phase clouds in an attempt to remove some of the uncertainties involved in developing climate models.

Approach The CRL is the only lidar at Eureka capable of discriminating between liquid and ice phases of water in tropospheric clouds. It does so by measuring the polarization of the backscattered laser photons.

Summary A successful 2012 Canadian Arctic ACE Validation Campaign at Eureka, Nunavut (21 Feb - 4 Apr) revealed precipitating and non-precipitating ice clouds, as well as some examples of mixed-phase clouds. Thin (<14 m) liquid layers within thicker icy clouds were observed, and are examined in the context of local meteorological measurements.

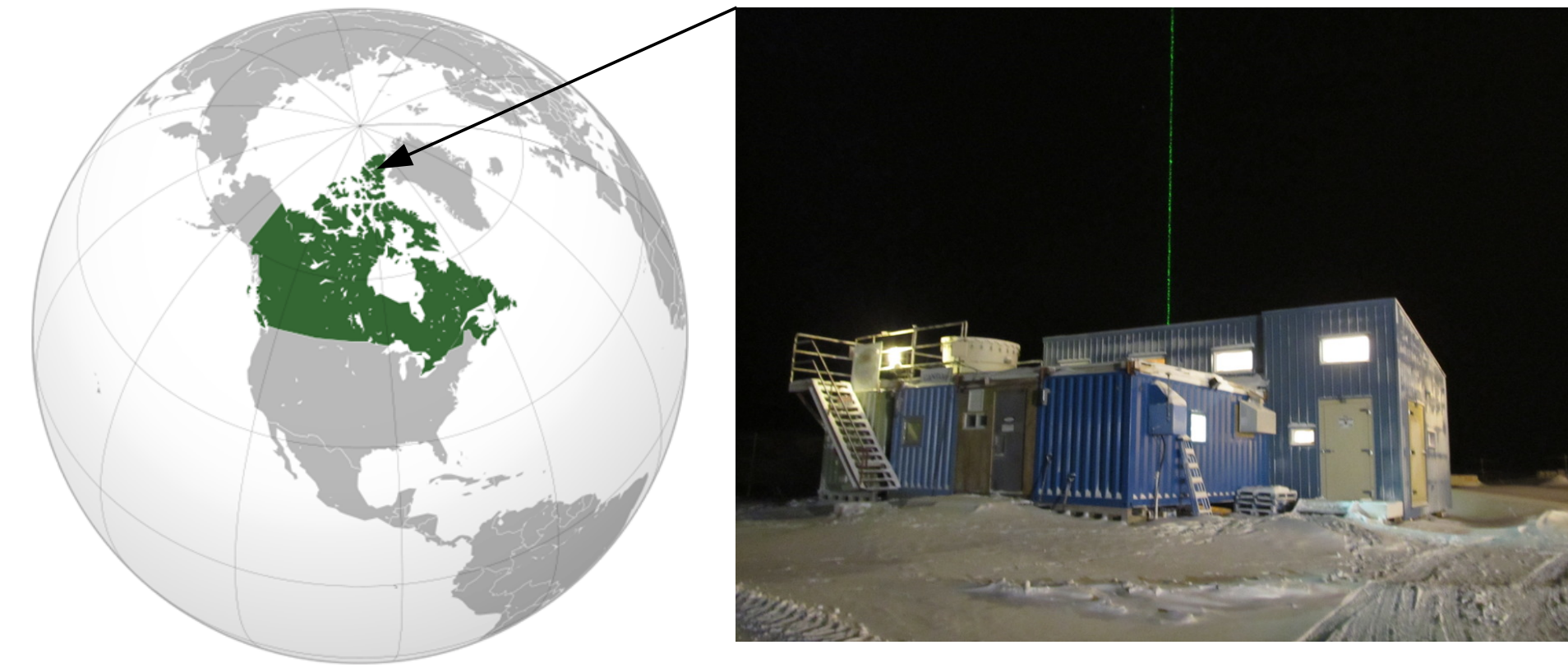


Figure 1, above: CRL at ØPAL (Zero-Altitude PEARL Auxilliary Lab) in Eureka, Nunavut in the Canadian High Arctic (80° N, 86° W). The CRL is at an advantage with its ability to operate both day and night.

This project is part of the larger CANDAC (Canadian Network for the Detection of Atmospheric Change) project at PEARL (Polar Environment Atmospheric Research Laboratory).

CRL Transmitter: Co-aligned 532 nm green and 355 nm UV lasers. Only the green is used for depolarization.

CRL Receiver: 1-m Dall-Kirkham telescope, polychromator (eight detection channels with photomultiplier tubes (PMTs) & Licel combined analogue/photon-counting electronics.

Operations: The CRL may be remotely operated from anywhere with internet access. The measurements presented here involved coordination between a remote observer and an on-site operator.

Depolarization Theory and Methods

Mie Theory Spherical (liquid) and non-spherical (solid) cloud particles scatter polarized laser light differently.

A spherical droplet induces no change in polarization. All light returns polarized "parallel" with respect to the laser. $\delta \approx 0\%$ sphere (liquid)

A non-spherical ice particle depolarizes the laser light somewhat. Some photons return "parallel" and some "perpendicular". $\delta > 30\%$ non-sphere (ice)

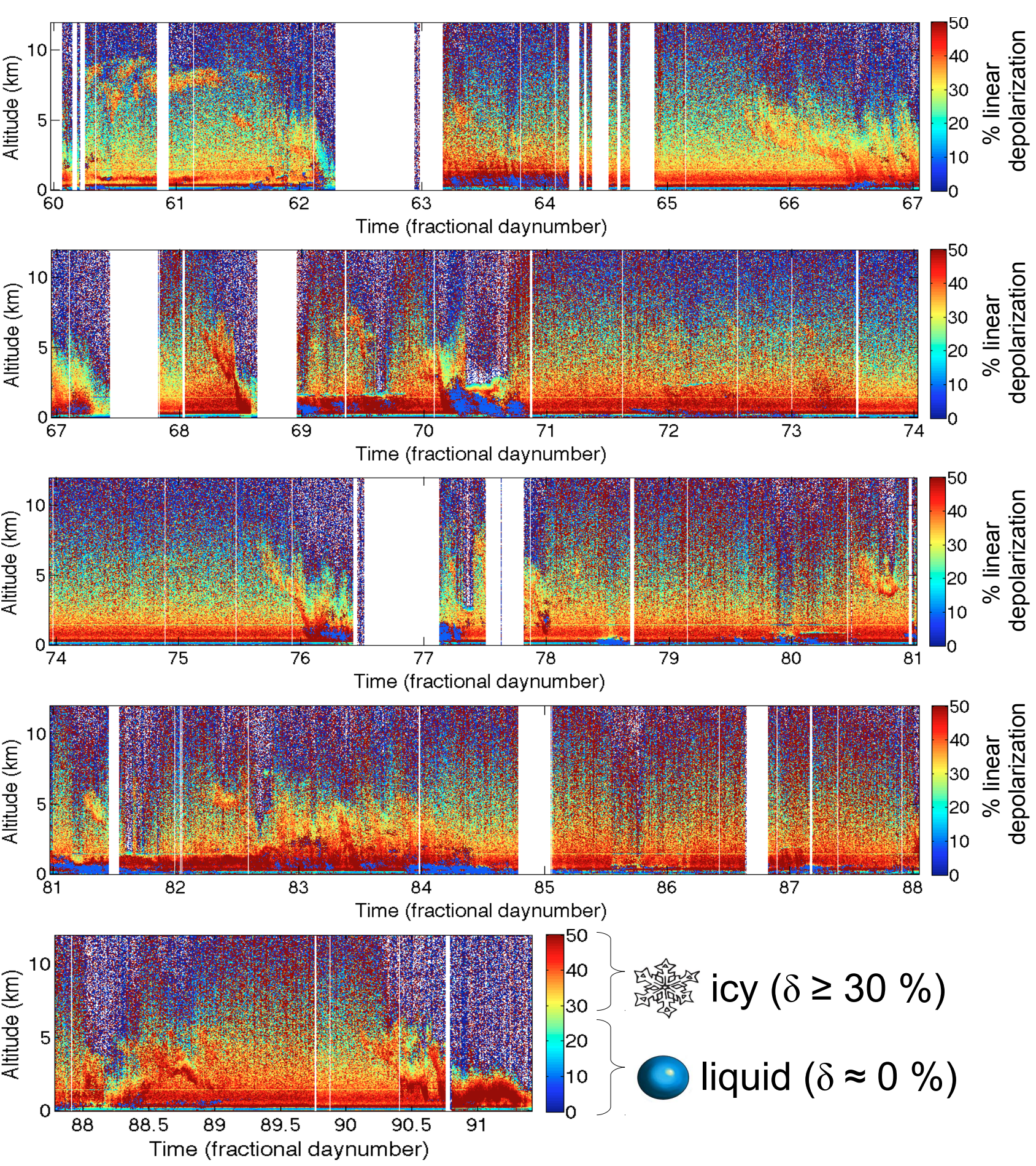
Calculating δ , the depolarization ratio $\delta = \left(\frac{n_{total}}{n_{||}} \right) (C) - 1$

The number of photons backscattered in all polarization states (n_{total}), is measured in one PMT and compared to the number of photons, $n_{||}$, which return polarized parallel to the laser (second PMT with a polarizer). C is a calibration constant. Some ice crystal shapes (at warmer temperatures) can have low δ , so there is a range of cutoff values reported in the literature. Here, we use 30%.

Depolarization Data Coverage for the March 2012 campaign

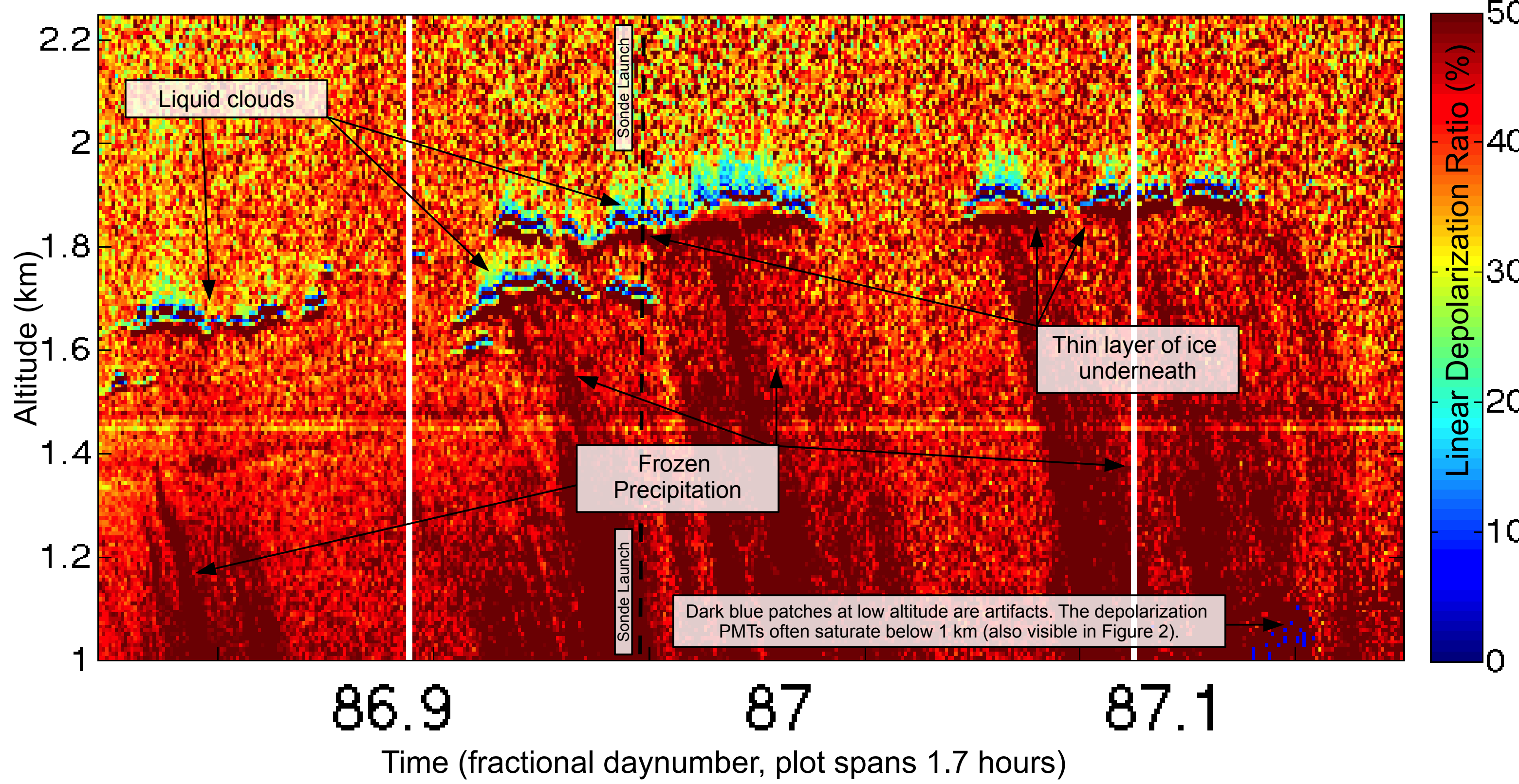


Figure 2, below: Linear depolarization ratio measurements were made 24h/day during March of the 2012 ACE Validation campaign at Eureka, Nunavut. Gaps due to calibration runs and bad weather are shown in white.



Example #1 Liquid clouds precipitating frozen particles

Figure 3, below Linear depolarization ratio measurements on 26 - 27 March 2012 show frozen precipitation falling from clouds with an upper liquid (light blue) and lower solid (icy, dark red) layer.

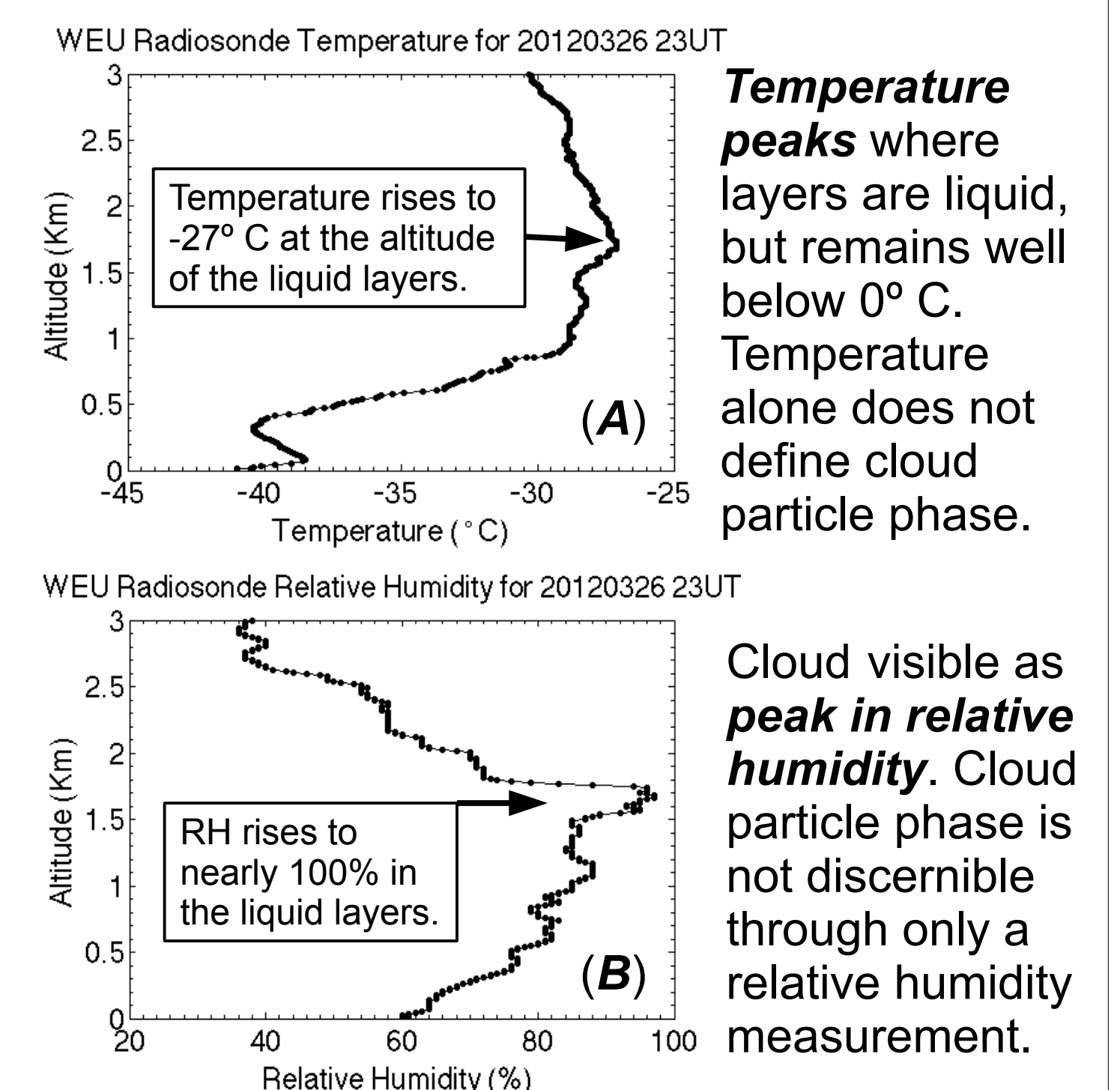


Such clouds are common. Many examples of Ice-precipitating liquid clouds observed in Eureka in March 2012. Of 31 measurement days in March, 13 days displayed at least one such cloud.

Usual altitudes: Almost always at or around 2 km altitude, with a few examples observed as high as 4 km. Separate, thicker ice clouds are often seen several km above these thin liquid layers.

Vertical extent: These liquid clouds are always narrow in vertical extent, never exceeding 100 m thickness.

Figure 4, below Radiosonde temperature (A) and relative humidity (B) corresponding to Fig 6.



Temperature peaks where layers are liquid, but remains well below 0° C. Temperature alone does not define cloud particle phase.

Cloud visible as peak in relative humidity. Cloud particle phase is not discernible through only a relative humidity measurement.

Take-home point Neither temperature nor relative humidity can alone discern cloud particle phase. The depolarization capability of the CRL is important for identifying cloud types at the microphysical level. Ice-precipitating liquid clouds were common in March 2012 at Eureka, with many examples being observed.

Example #2 Thin liquid layers within a thick ice cloud

Figure 5, below Radiosonde temperature plot corresponding to Figure 6. Despite temperatures below 0° C, liquid layers persist within the cloud.

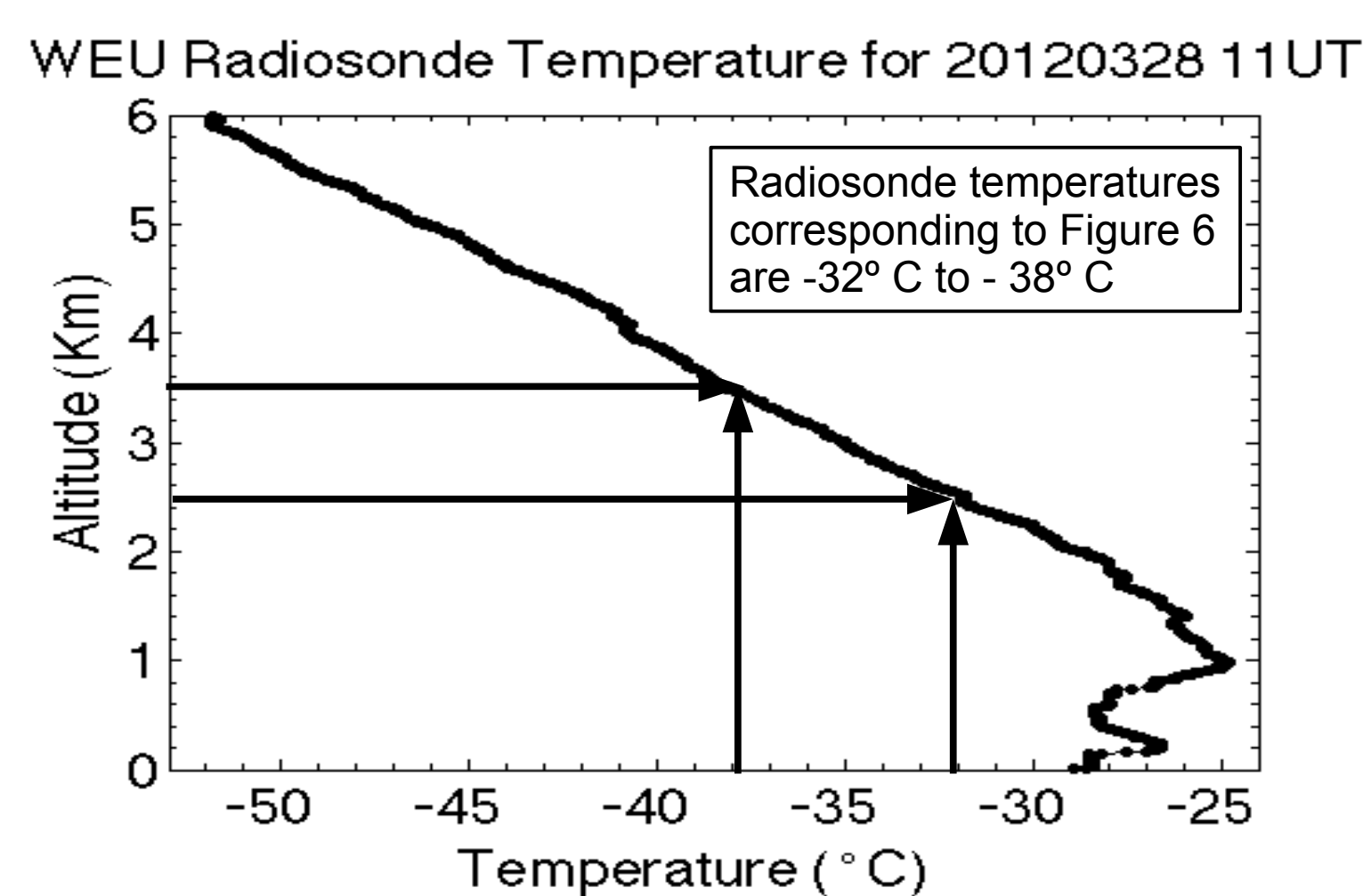


Figure 7, below Context plot for Figure 6, showing the icy cloud which hosts the liquid layers.

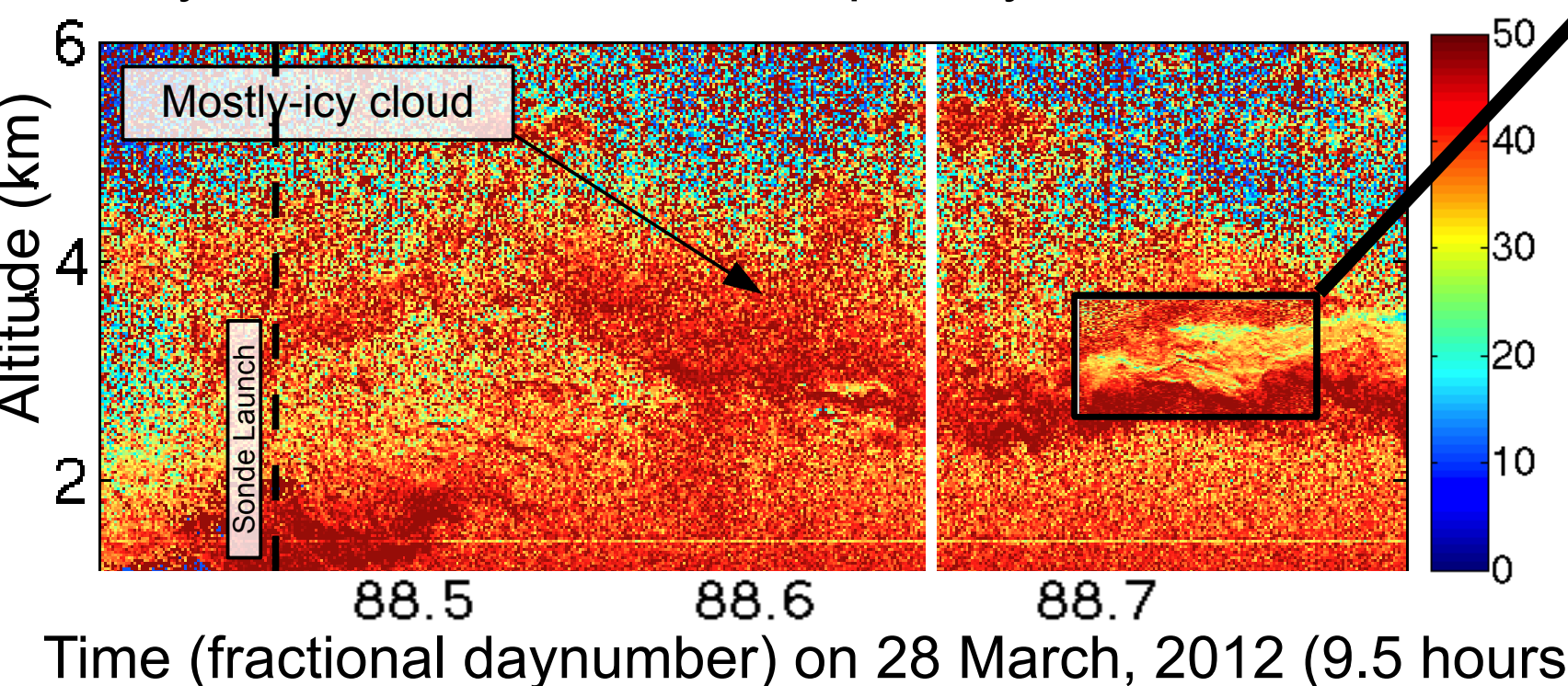
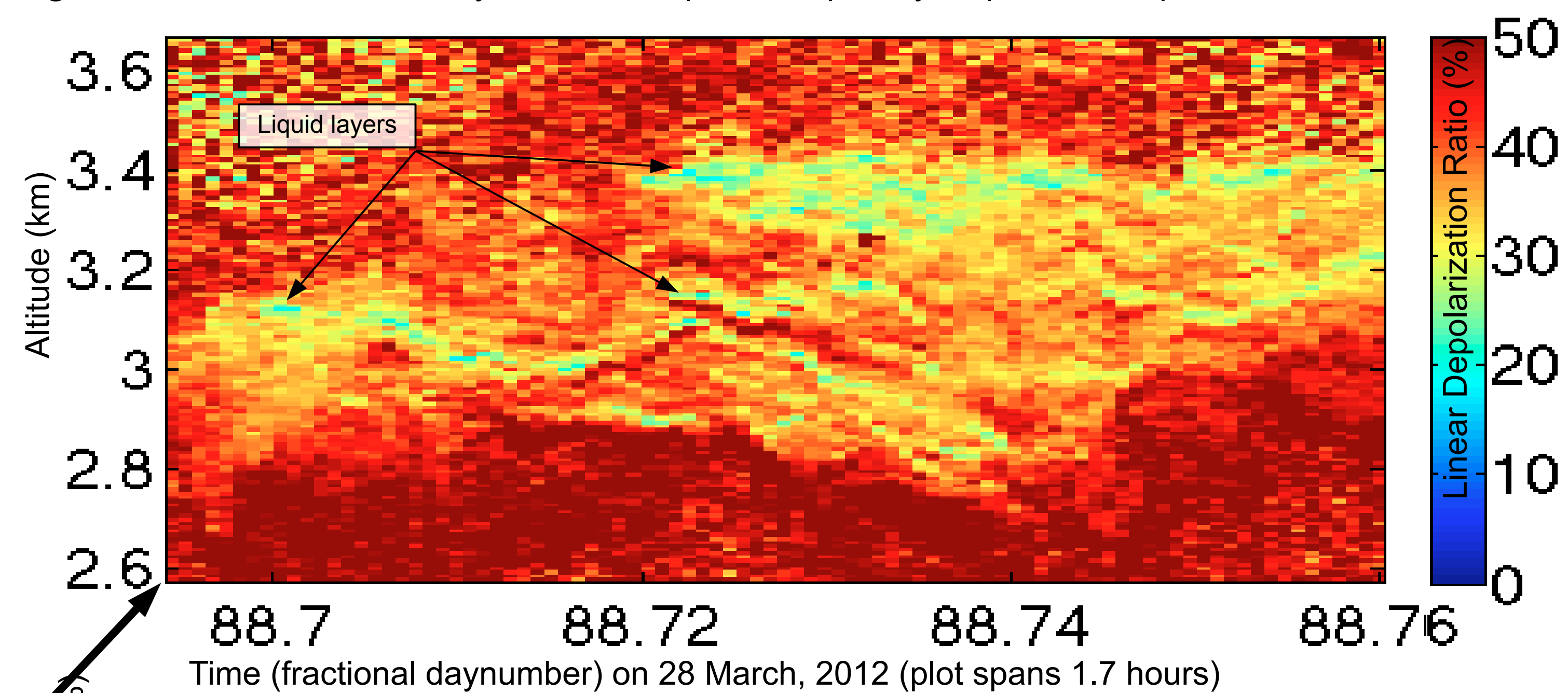


Figure 6, below Within thick icy clouds, multiple thin liquid layers persist for upwards of an hour at a time.



Deep reds and yellows show an ice cloud more than 2 km in vertical extent, spanning at least 5 hours.

Light blue around 3 km are liquid layers (often paired with dark red ice layers directly underneath) within the otherwise icy cloud.

Dark blue areas below 1 km are artifacts which occur when one or the other detection channels becomes saturated with a count rate that is too high.

Take-home point The high time resolution of the CRL measurements is of importance for identifying these cloud types as their morphology is variable on timescales of several minutes. The high vertical resolution exposes several examples in March with layers < 14 m in vertical extent.

Opportunities for Comparisons

With many co-located instruments at Eureka, there is the potential to expand this study to examine:

- 1. How typical was spring 2012?** Compare liquid layer frequency with previous years' CRL data, and High-Spectral Resolution Lidar data pre-2010 for context. Continue CRL depolarization measurements during the 2013 ACE Validation Campaign (Polar Sunrise 2013).
- 2. Fine-scale cloud structure.** Compare with water vapour and Millimetre Cloud Radar measurements, and Extended-range Atmospheric Emitted Radiance Interferometer measurements of cloud-bottom temperature.
- 3. What conditions allow the thin liquid layers to form?** Comparisons with radiosonde T and RH measurements, Environment Canada Precipitation Suite, Windprofiler Radar. Comparisons with satellite-borne instruments having overpasses of the high Arctic, in particular the ACE experiment on SCISAT-1.

In all cases, we will have to examine any low values of depolarization ratio in conjunction with temperature data to discern between supercooled water and specific ice crystal shapes which can exhibit the similar values of δ .

