Ice crystals in Arctic mixed-phase clouds observed by an X-band polarimetric radar

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ARM CLIMATE RESEARCH FACILITY

ASR Atmospheric System Research

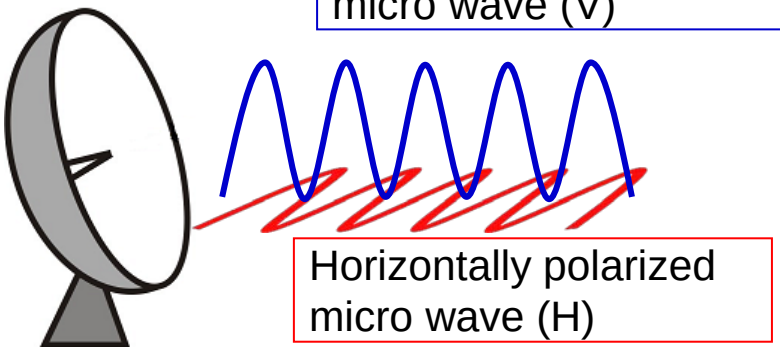
Introduction

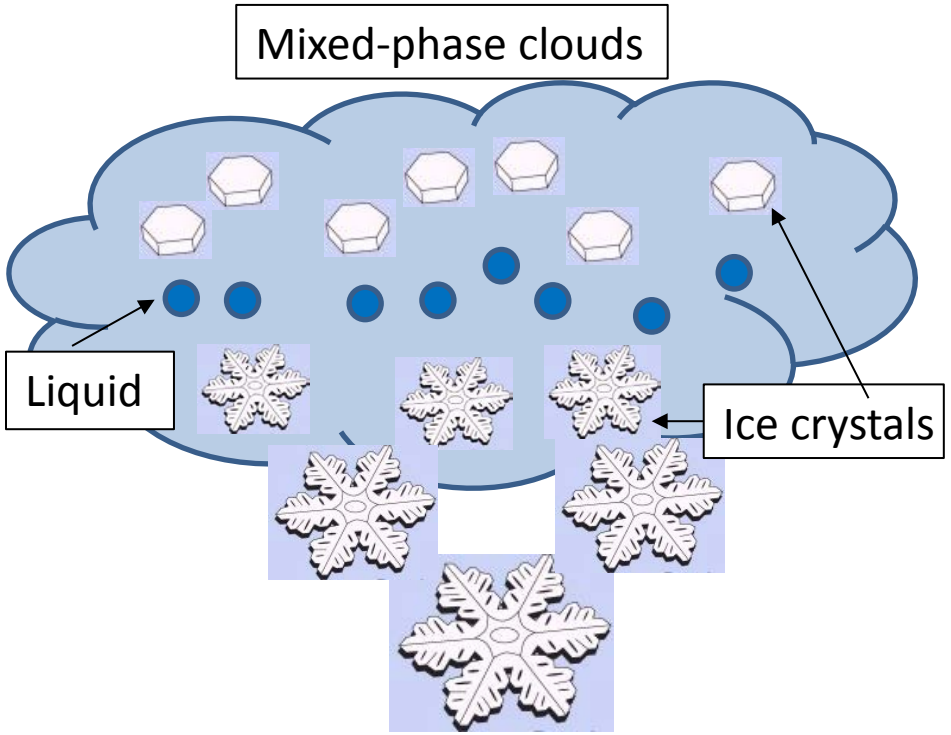
MOTIVATIONS

- **Arctic mixed-phase clouds are frequently present over the North Slope of Alaska and have a strong radiative impact on the surface radiation budget.**
- **Microphysics in these clouds are poorly understood and not handled in current global models.**
- **Polarimetric radar is useful for ice hydrometeor observation**

(Bader et al., 1987; Wolde and Vali, 2001a,b; Hogan et al., 2002)

Reflectivity (Z_H)
Differential reflectivity (Z_{DR})
Correlation coefficient between H and V (ρ_{HV})



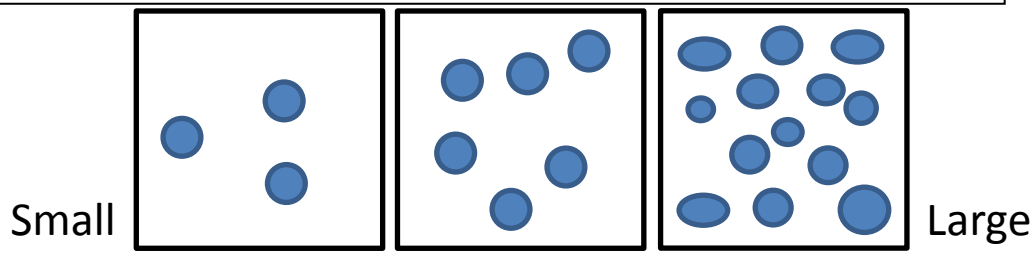


Introduction

Z_H, radar reflectivity, depends on 6th power of particle diameter and number density.

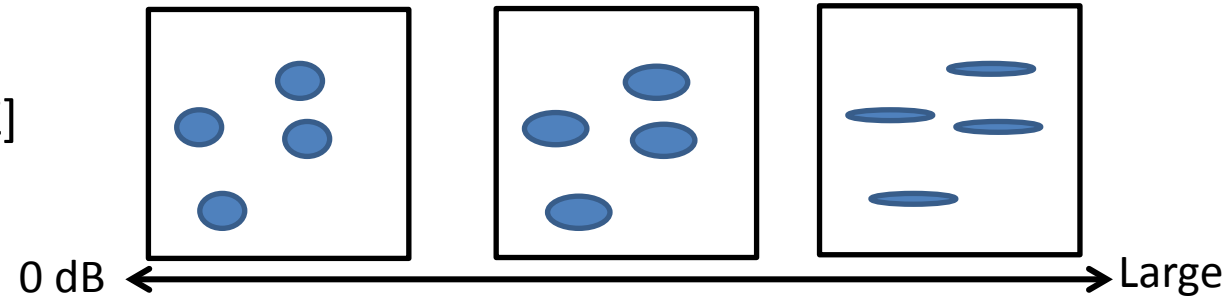
$$Z_H = \int D^6 N(D) dD \quad [\text{mm}^6\ \text{m}^{-3}]$$

$$= 10 \log_{10}(Z_H) \quad [\text{dBZ}]$$

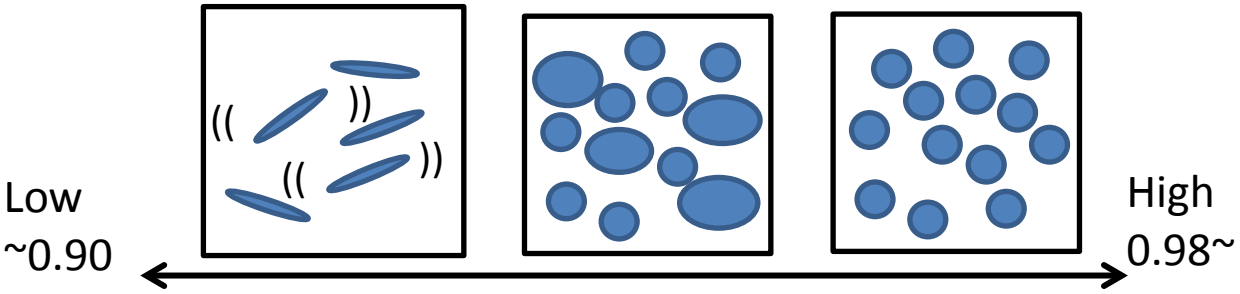


Z_{DR}, differential reflectivity, depends on oblateness of particles.

$$Z_{DR} = 10 \log_{10}\left(\frac{Z_H}{Z_V}\right) \quad [\text{dBZ}]$$



ρ_{HV}, correlation coefficient between H and V signals, represents homogeneities.



Objective: To retrieve vertical profiles of ice crystal habit using X-band polarimetric variables for the Arctic mixed-phase clouds

Observation and data

IOP: May 2013 at Barrow, Alaska

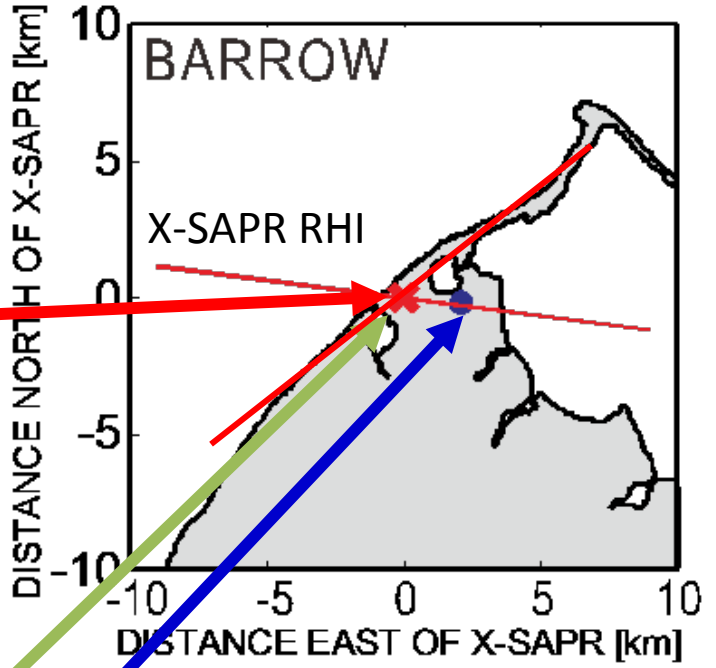
X-band Scanning ARM Precipitation radar (X-SAPR) vertical cross section scan (RHI)

Frequency	9.671 GHz
Beam width	1.0 °
Range gate resolution	75 m
Elevation resolution	~0.25°

Pictures of crystals on the ground

High Spectral Resolution Lidar (HSRL), Microwave Radiometer (MWR)

Sounding (06 and 18 UTC)



Case 1: Shallow, boundary layer precipitating clouds on 2 May

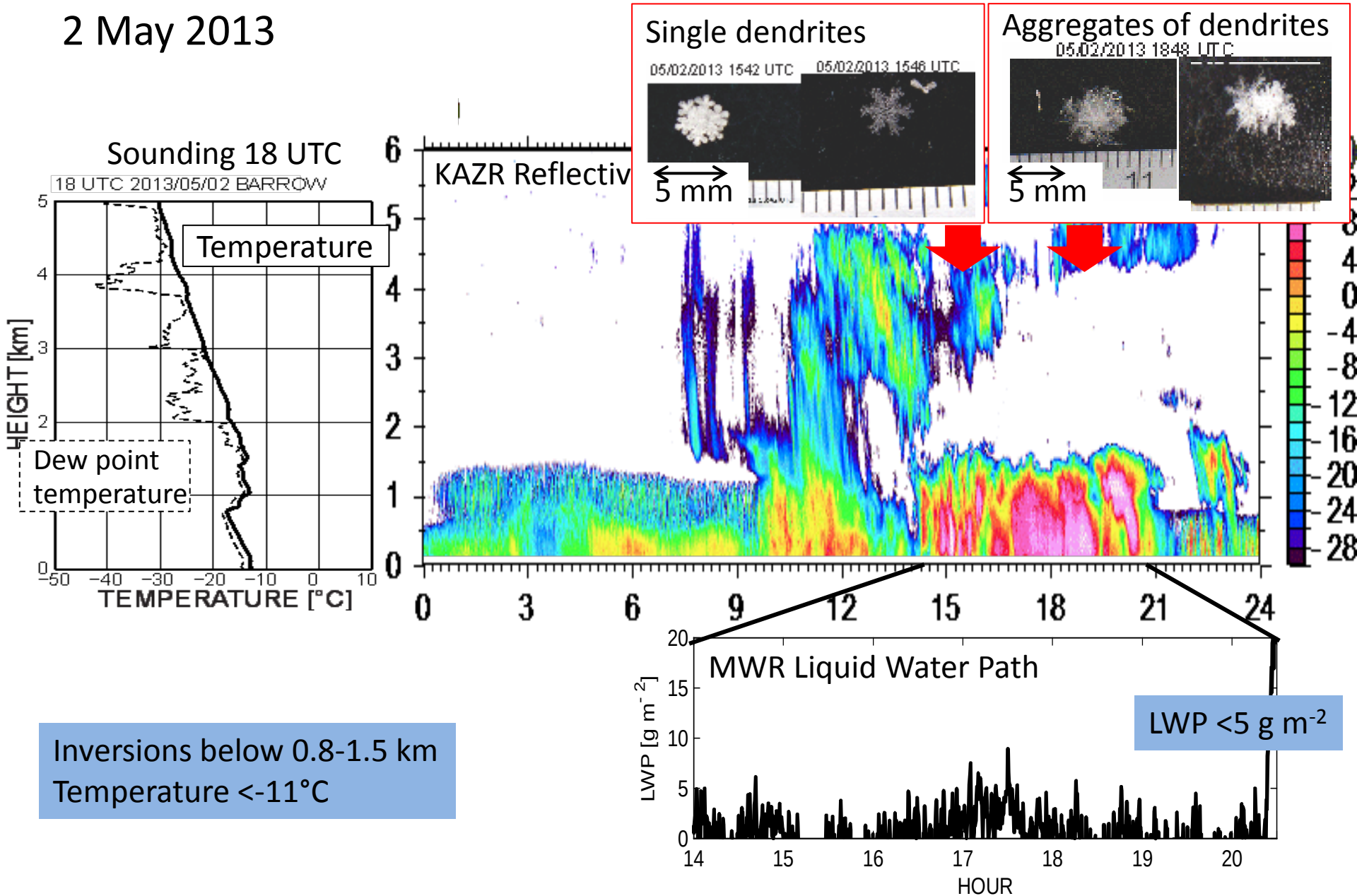
- Single dendrites and aggregates of dendrites on the ground

Case 2: Deep, warm frontal precipitating clouds on 6 May

- Rimed dendrites and irregular crystals on the ground

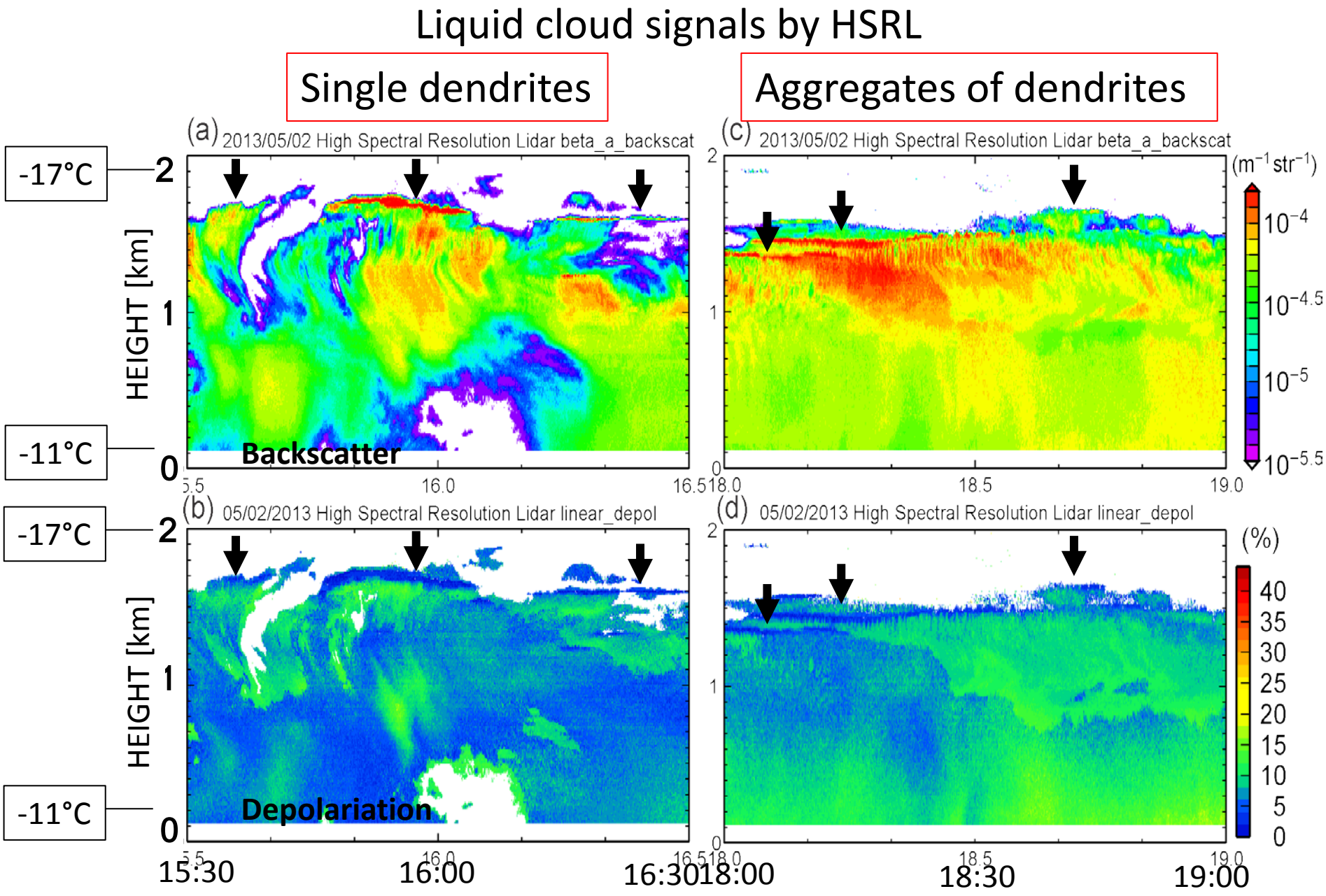
Case 1: Shallow boundary layer clouds

2 May 2013



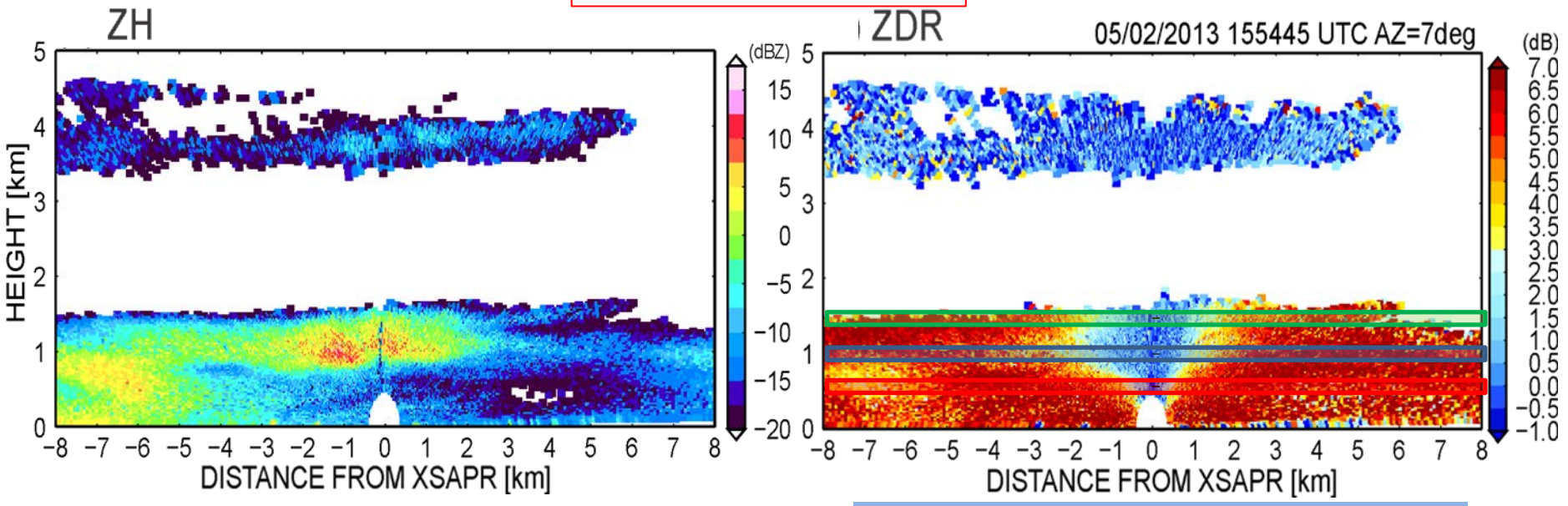
Inversions below 0.8-1.5 km
Temperature <-11°C

Case 1: Shallow boundary layer clouds



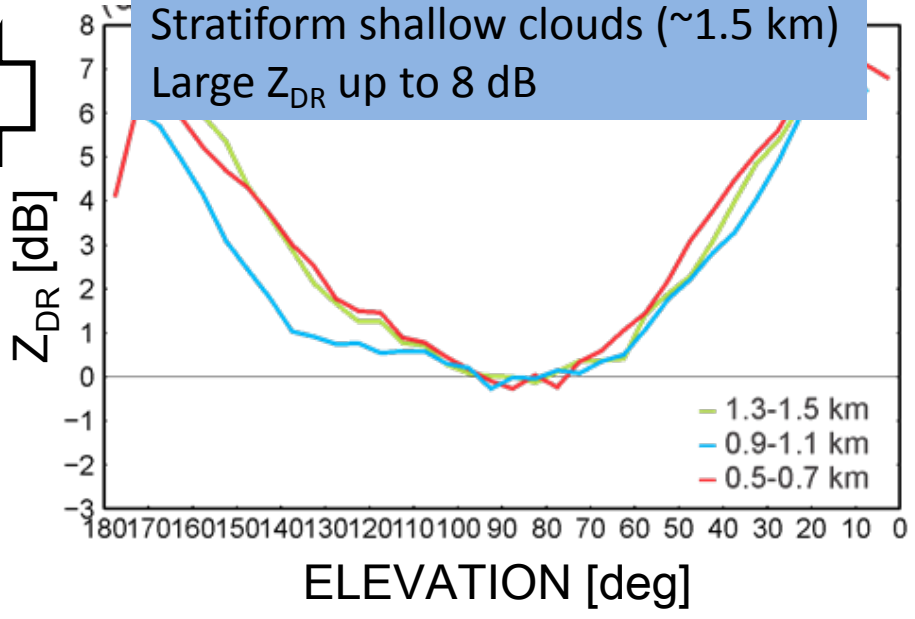
Case 1: Shallow boundary layer clouds

Single dendrites



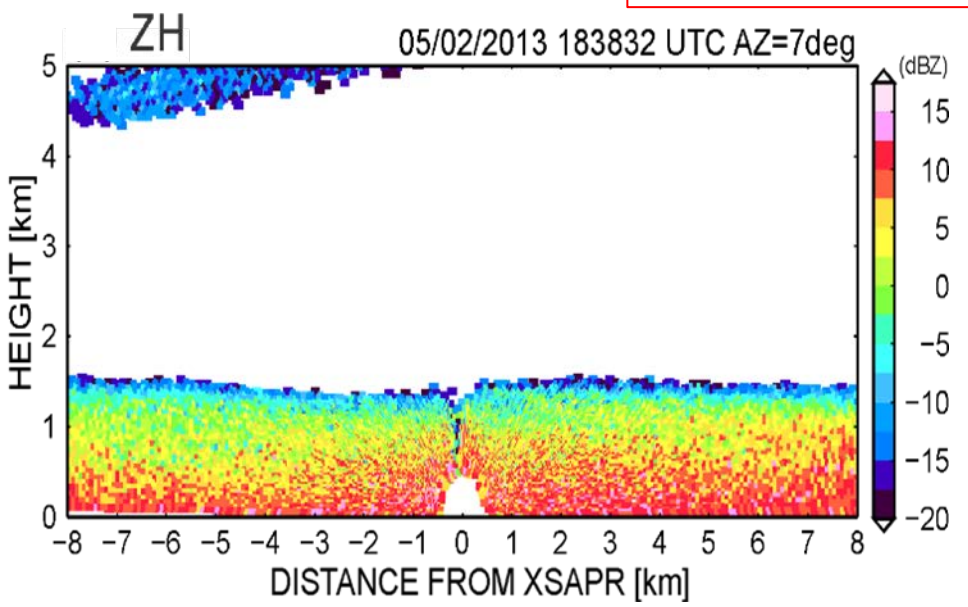
Large dendrites forming in mixed-phase clouds were falling down.

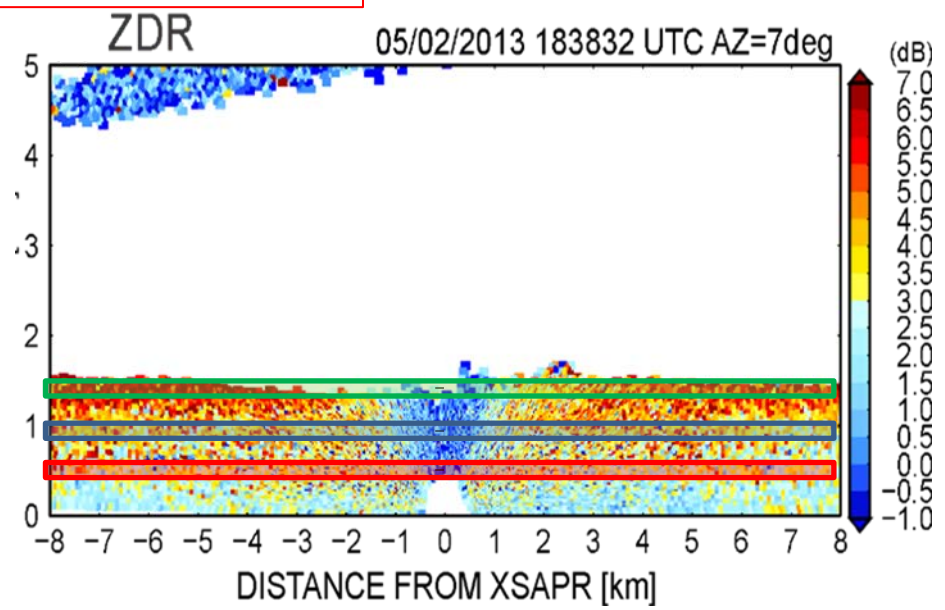
Stratiform shallow clouds (~1.5 km)
Large Z_{DR} up to 8 dB

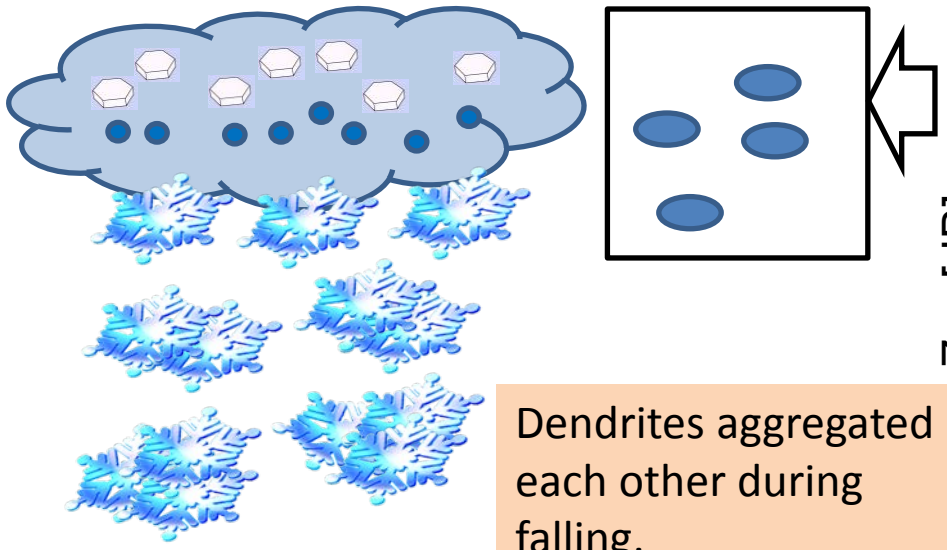


Case 1: Shallow boundary layer clouds

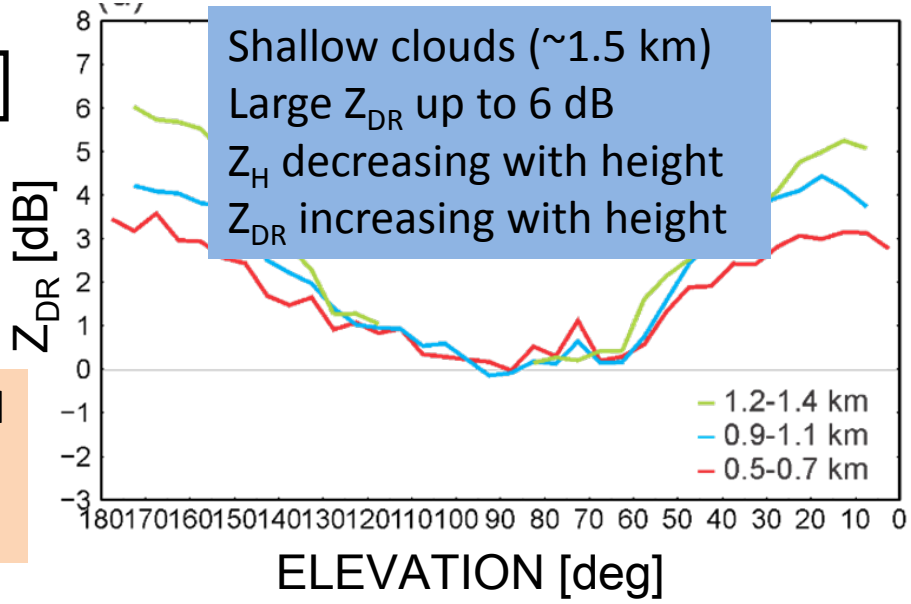
Aggregates of dendrite



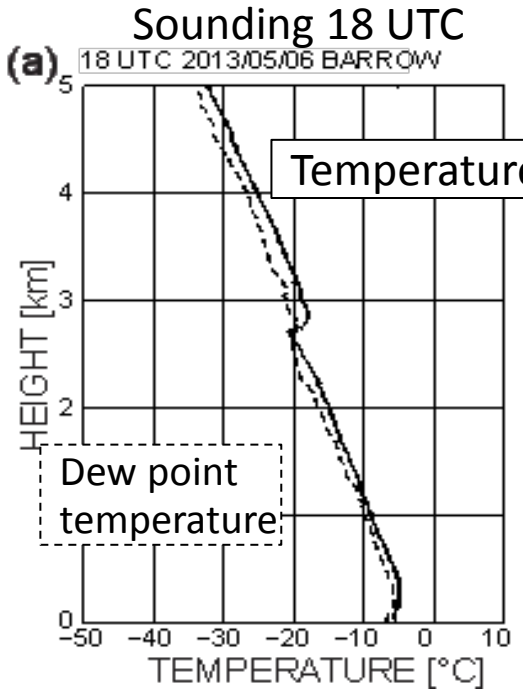


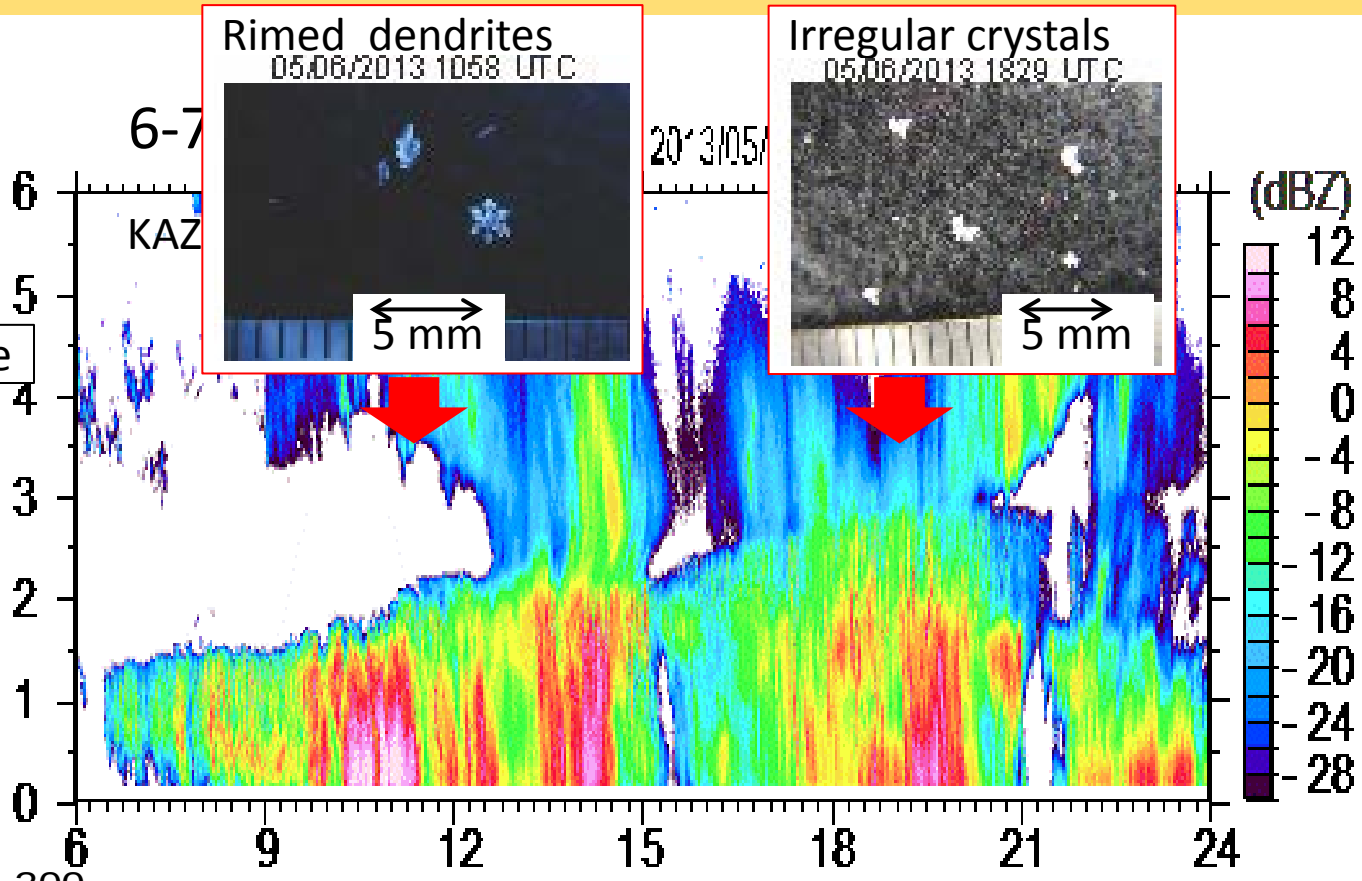


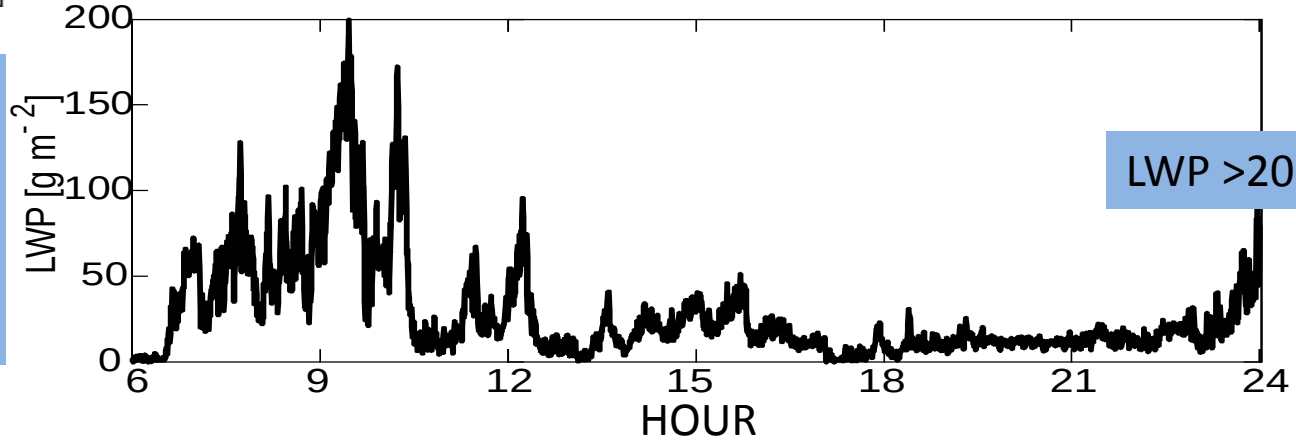
Dendrites aggregated each other during falling.



Case 2: Deep frontal clouds







Surface temperature of -5 °C
Inversion at 2.8 km
Liquid water path > 20 g m^{-2}

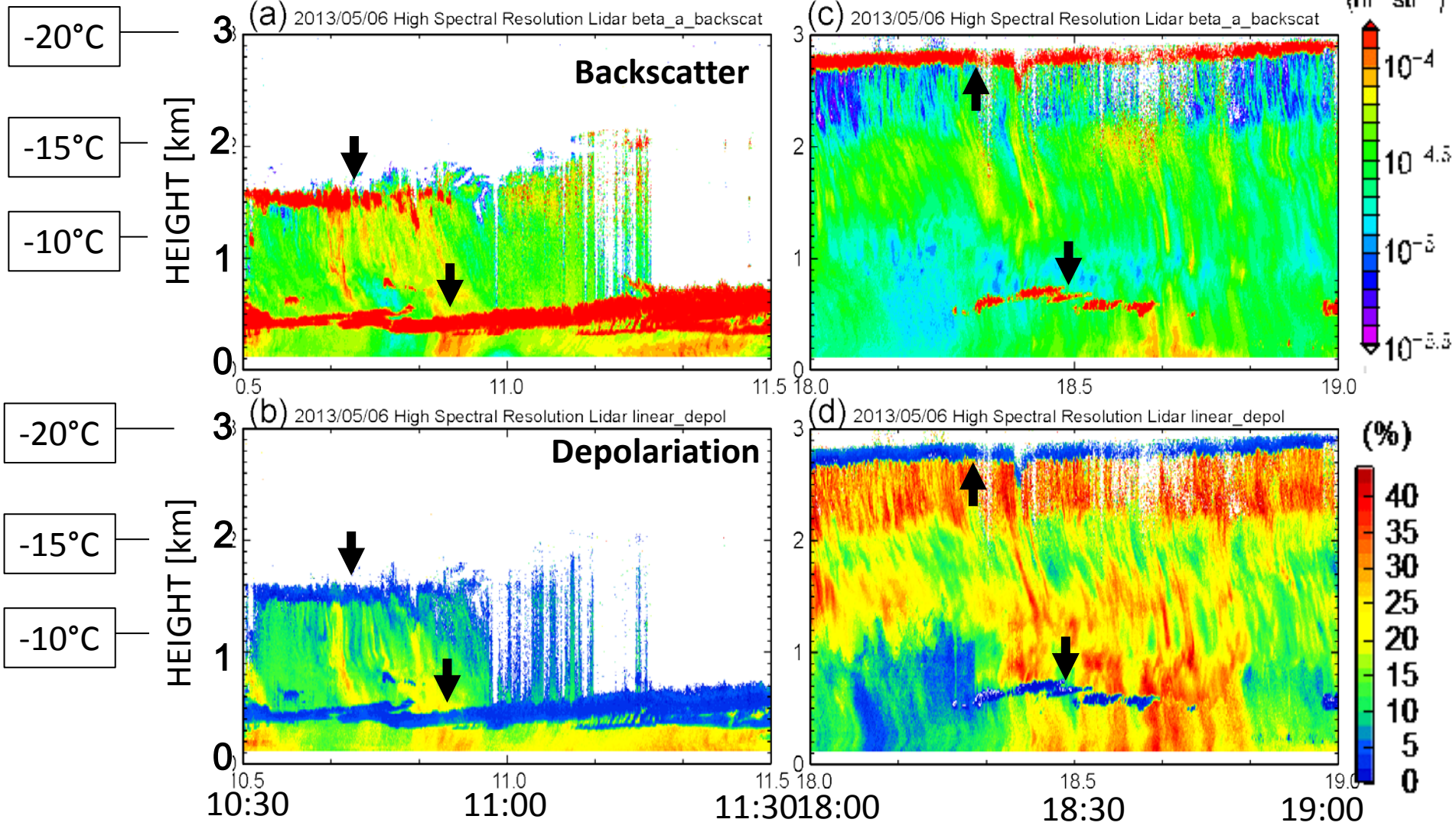
LWP >20 g m^{-2}

Case 2: Deep frontal clouds

Liquid cloud signals by HSRL

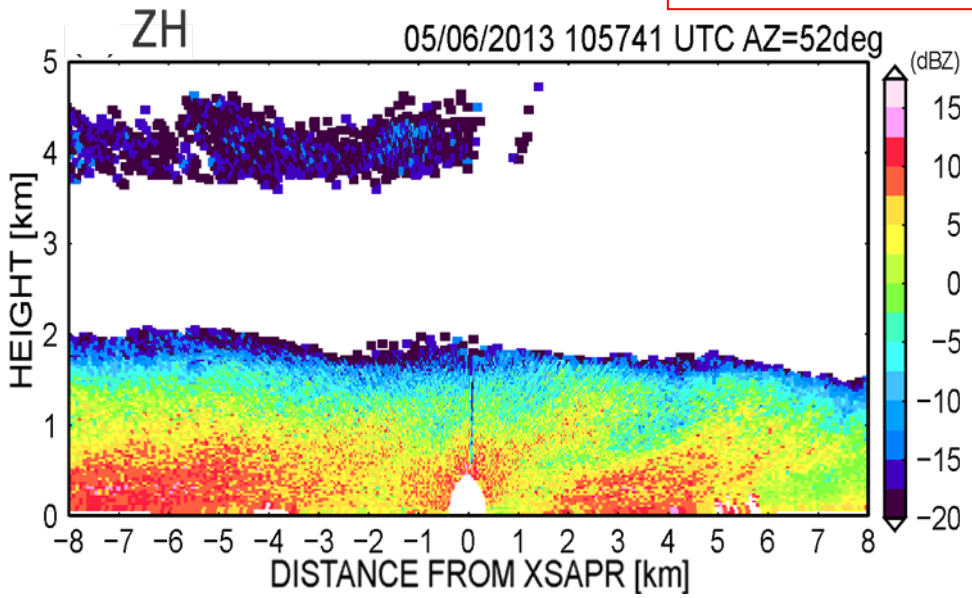
Rimed dendrites

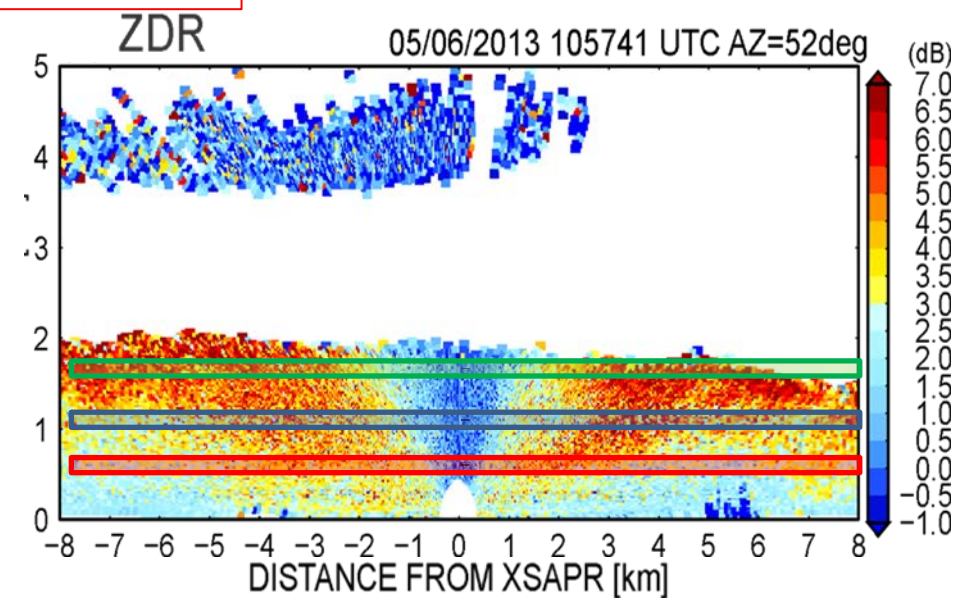
Irregular crystals

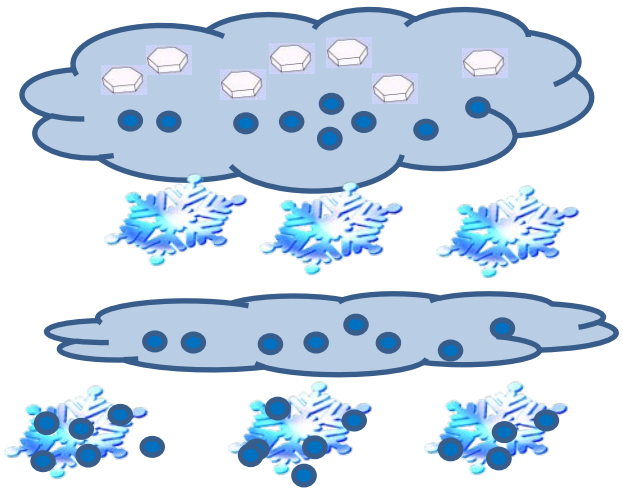


Case 2: Deep frontal clouds

Rimed dendrites

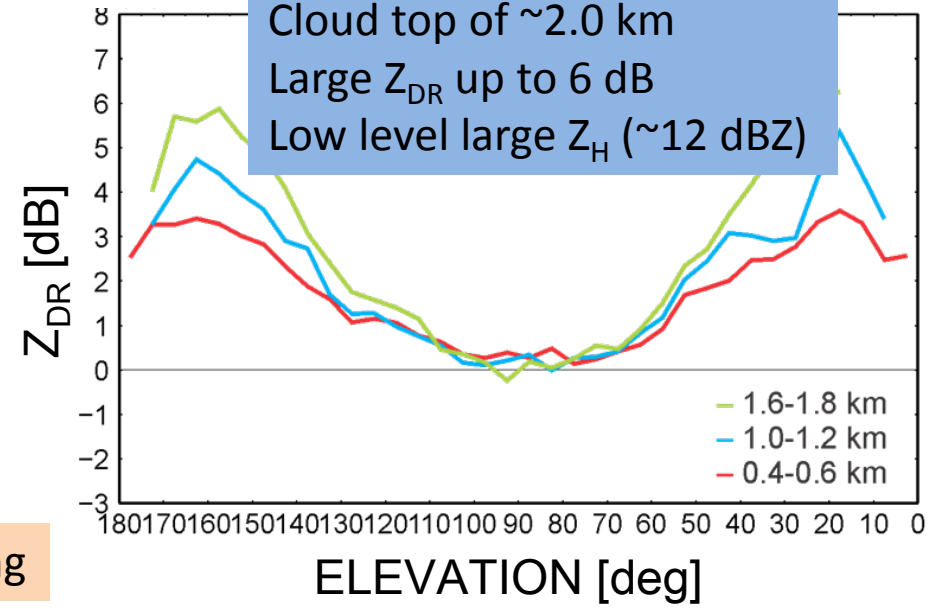






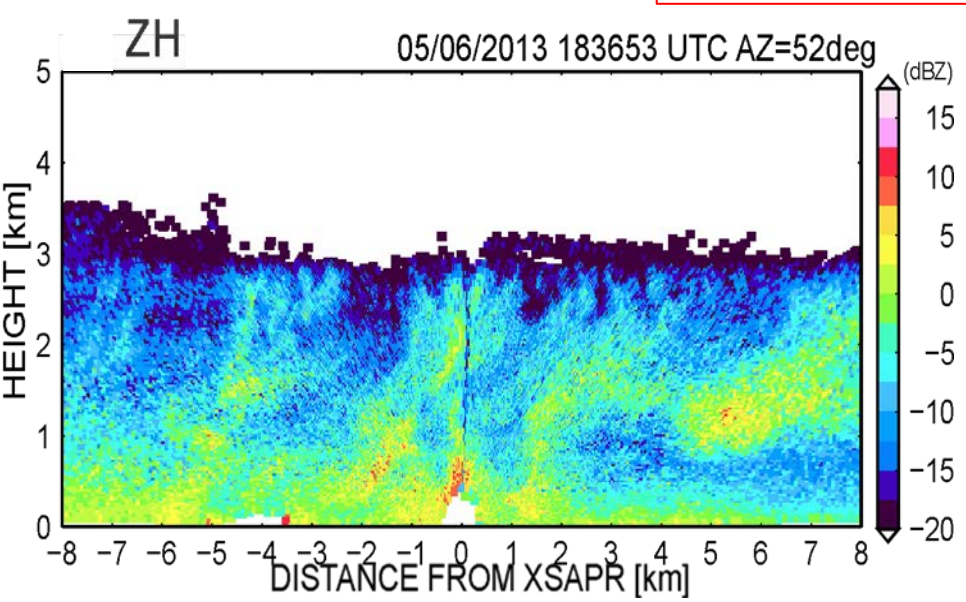
Growth of dendrites in basal plane by riming

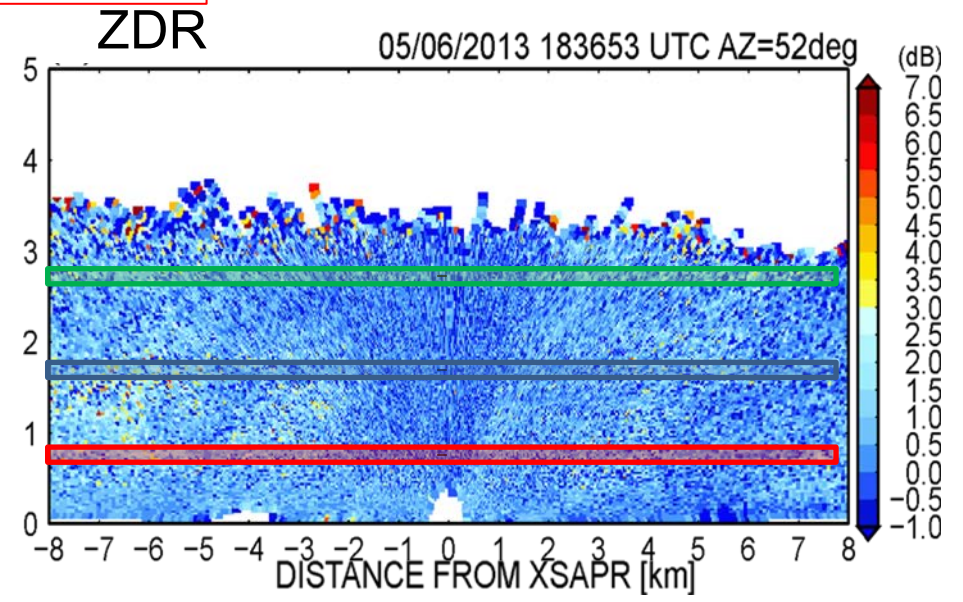
Cloud top of ~2.0 km
Large Z_{DR} up to 6 dB
Low level large Z_H (~12 dBZ)

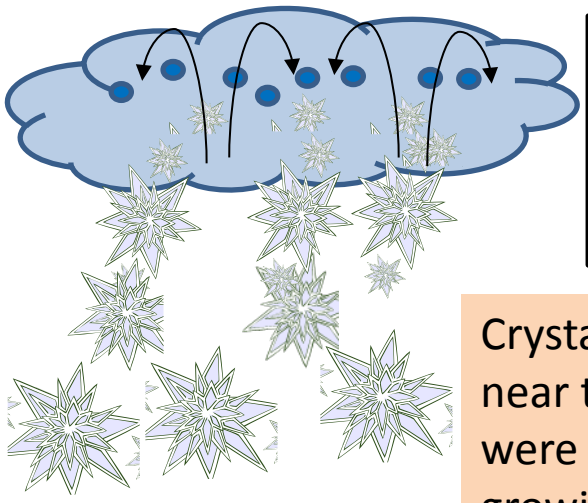


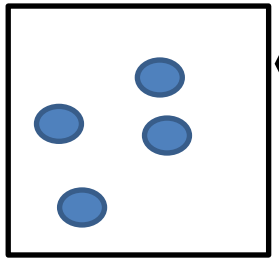
Case 2: Deep frontal clouds

Irregular crystals



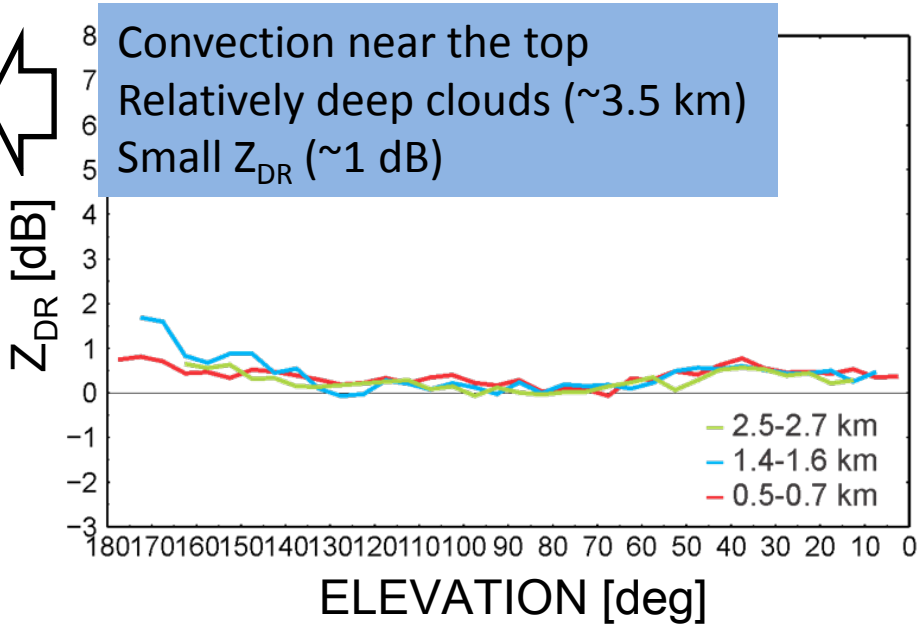






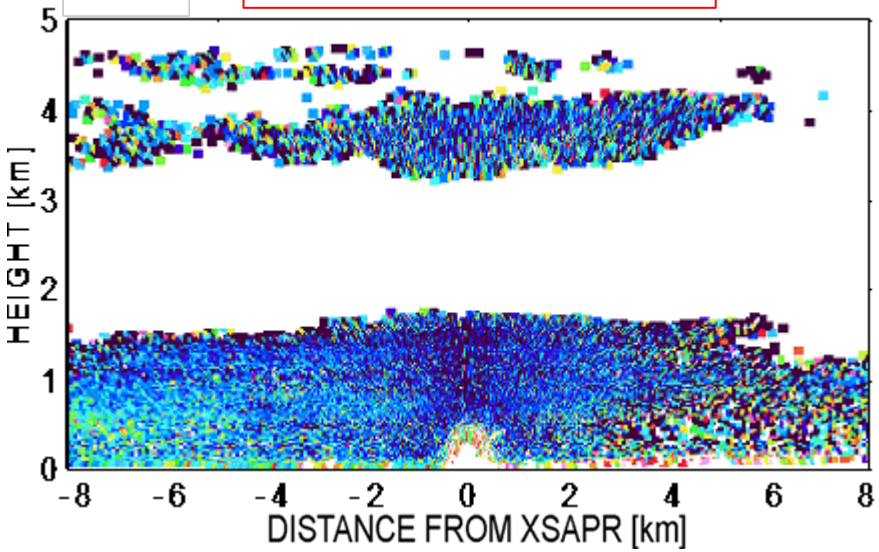
Crystals forming near the cloud top were isotropically growing to irregular crystals.

Convection near the top
Relatively deep clouds (~3.5 km)
Small Z_{DR} (~1 dB)

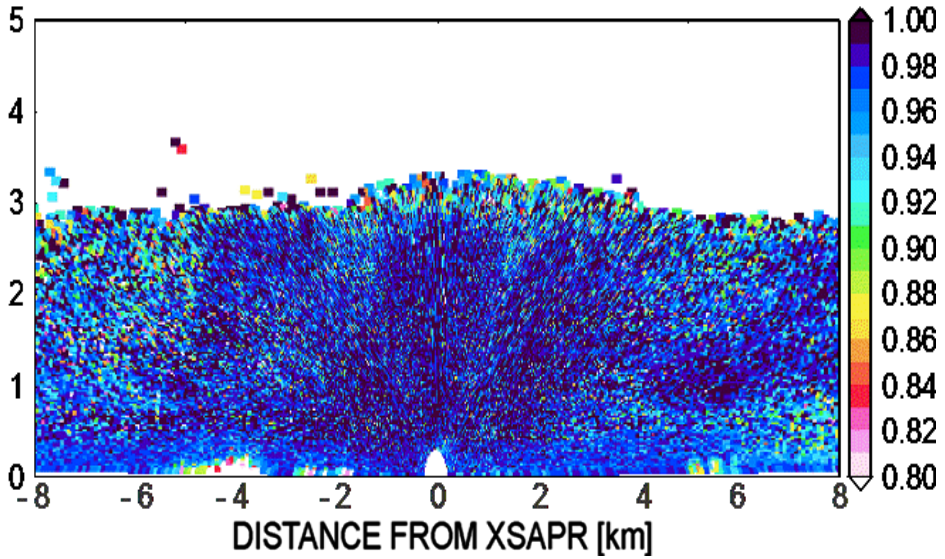


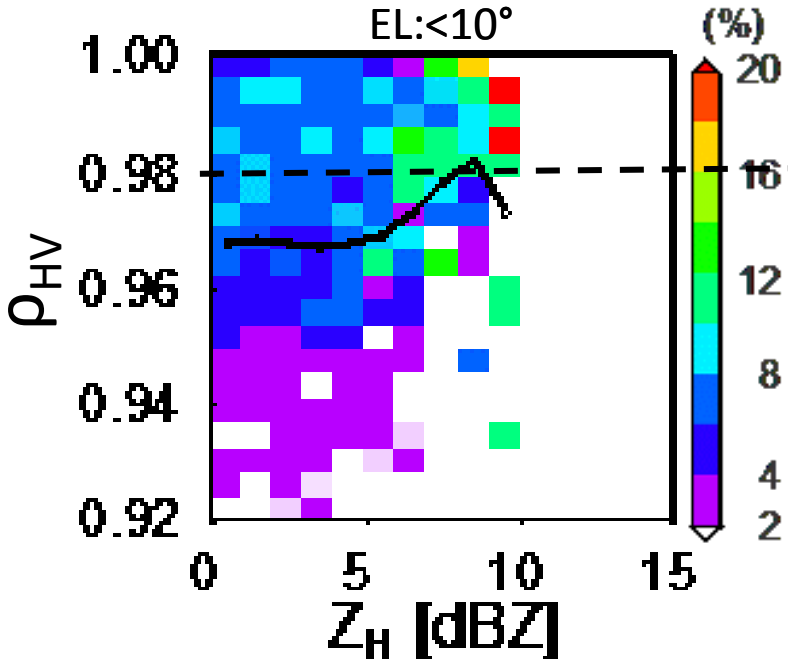
Correlation coefficient, ρ_{HV}

Single dendrites

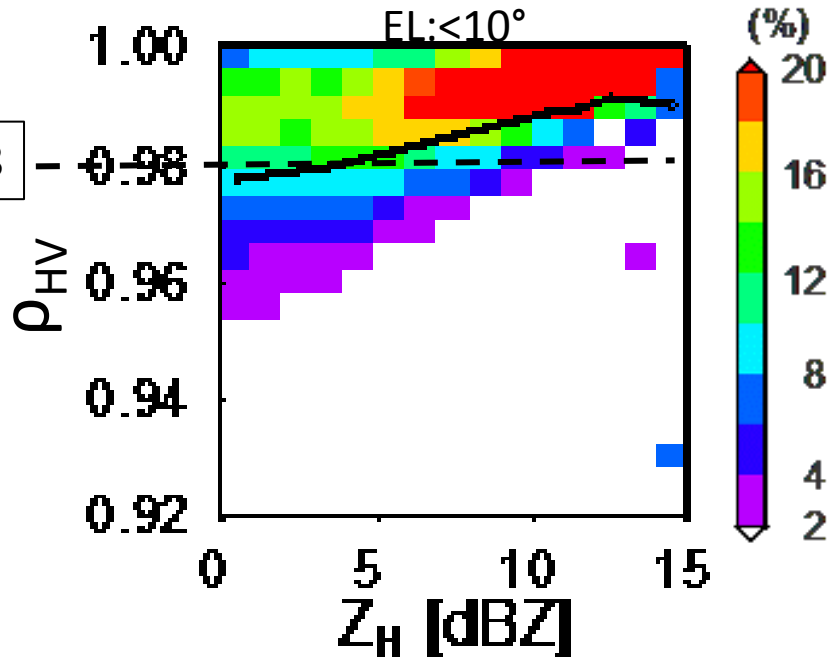


Irregular crystals



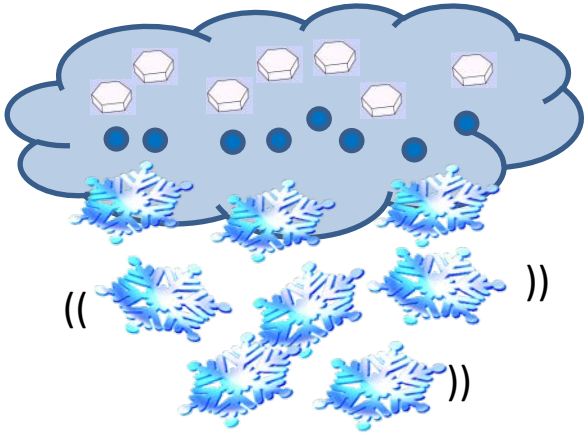


0.98

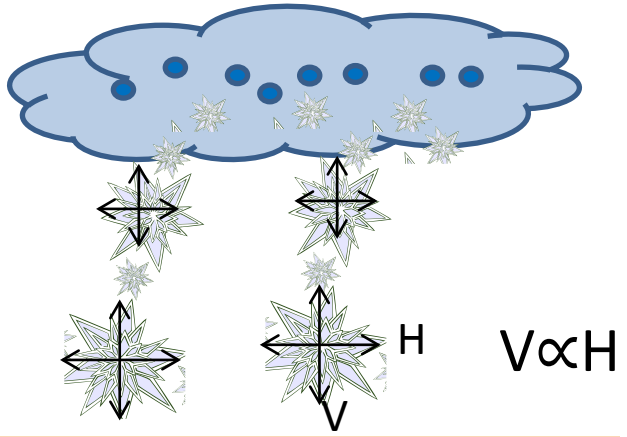


Correlation coefficient, ρ_{HV}

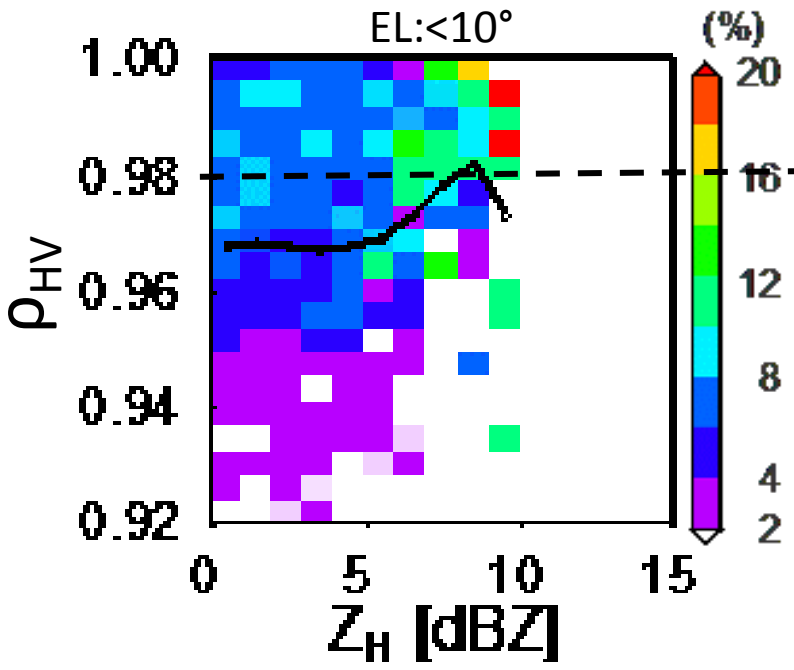
Single dendrites



Irregular crystals

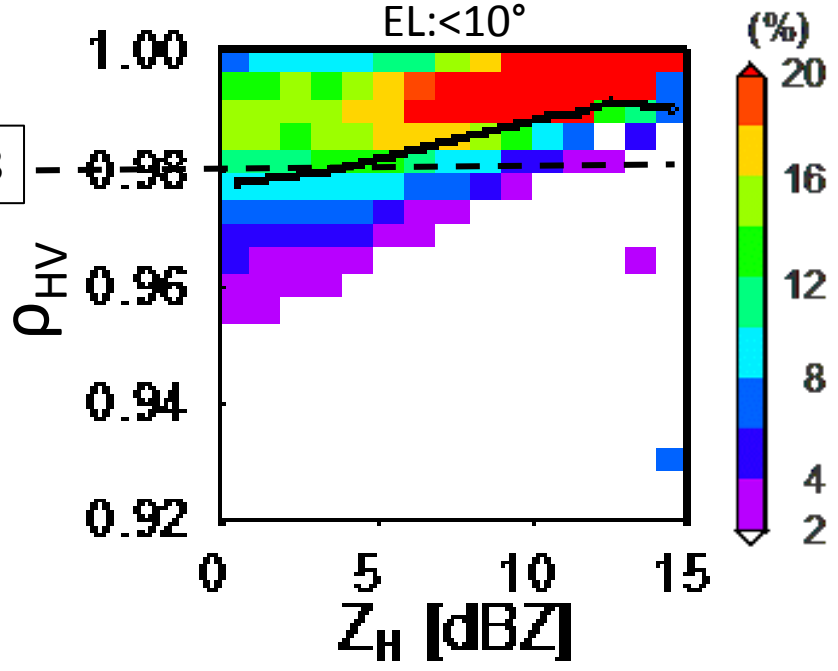


Swinging or tumbling of large dendrites



0.98

Isotropically-growth crystals

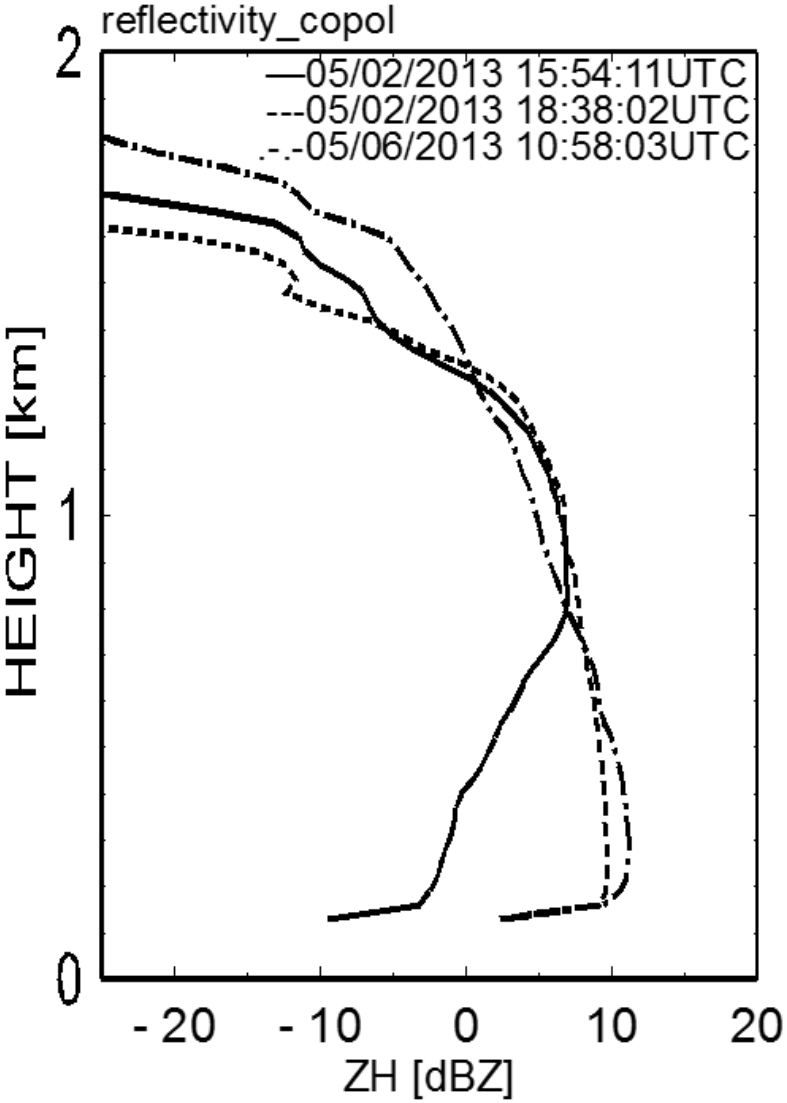


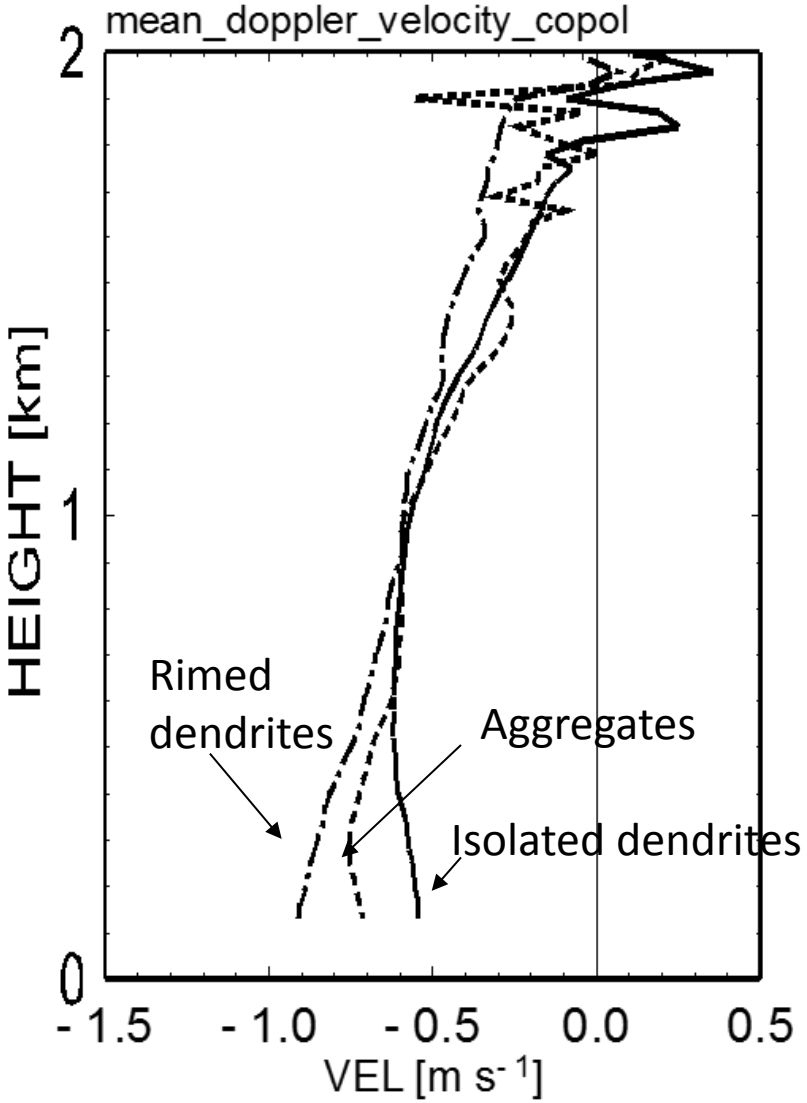
Summary

Ice crystal habits in Arctic mixed-phase clouds were observed by X-band polarimetric radar.

- Shallow boundary layer precipitating clouds:
  - Single dendrites form near the cloud top and grew in the shallow boundary layer. These dendrites tumbled with falling through the air.
  - Dendrites formed near the cloud top aggregated with falling.
- Deep warm frontal clouds:
  - Dendrites forming near the cloud top were rimed with falling through multiple liquid layers.
  - Irregular crystals formed near the echo top with temperature of ~-20°C and grew isotropically.

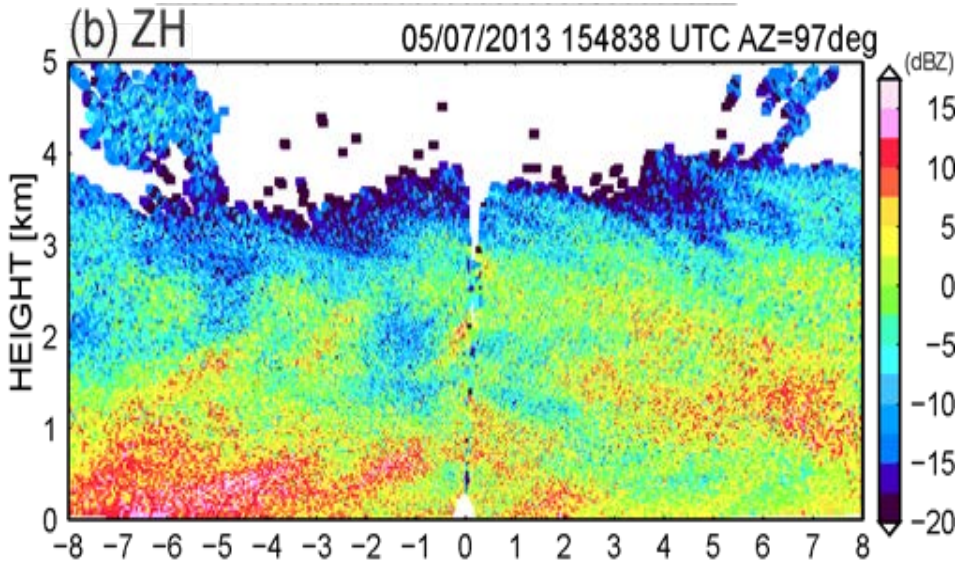
KAZR MOMENTS 10-MIN AVERAGE

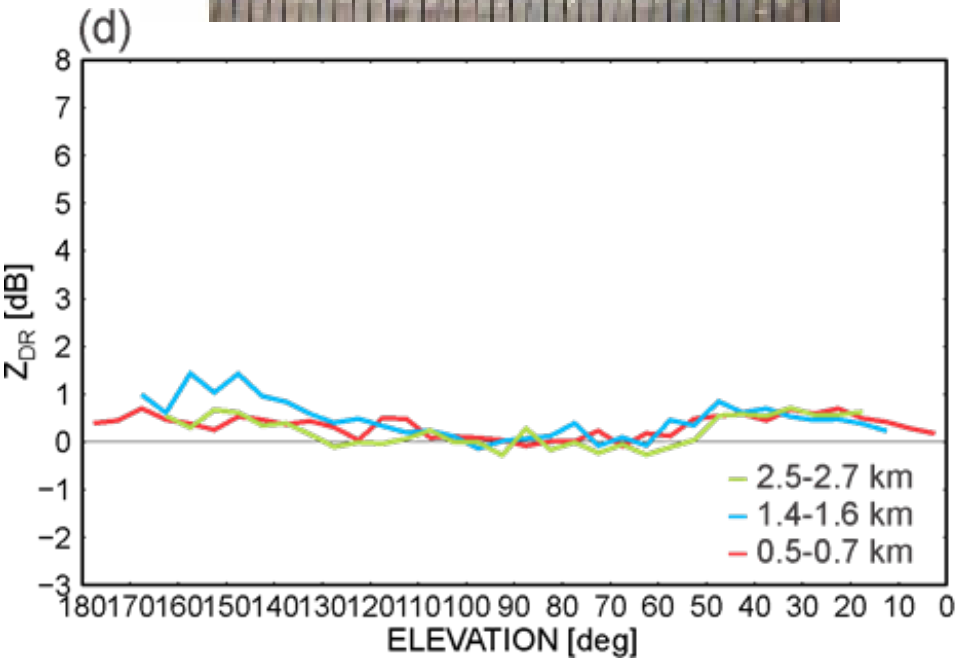


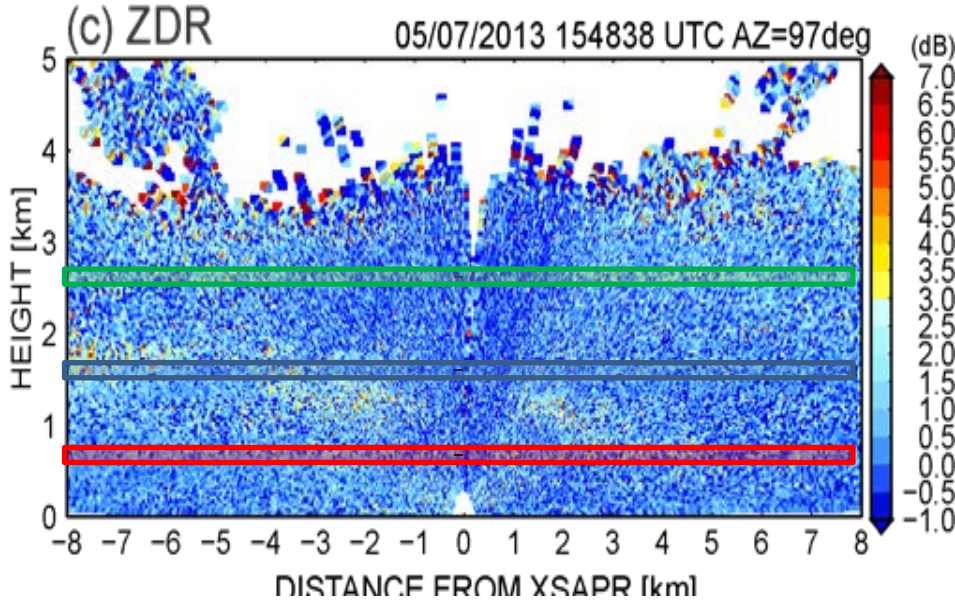


Case 2: Deep frontal clouds

Mixture of habits







5. Discussions: Reasonability of measured Z_{DR} values

Z_h v.s. Z_{DR} diagrams from Scattering calculation

Dendrites with D~4mm

Columns

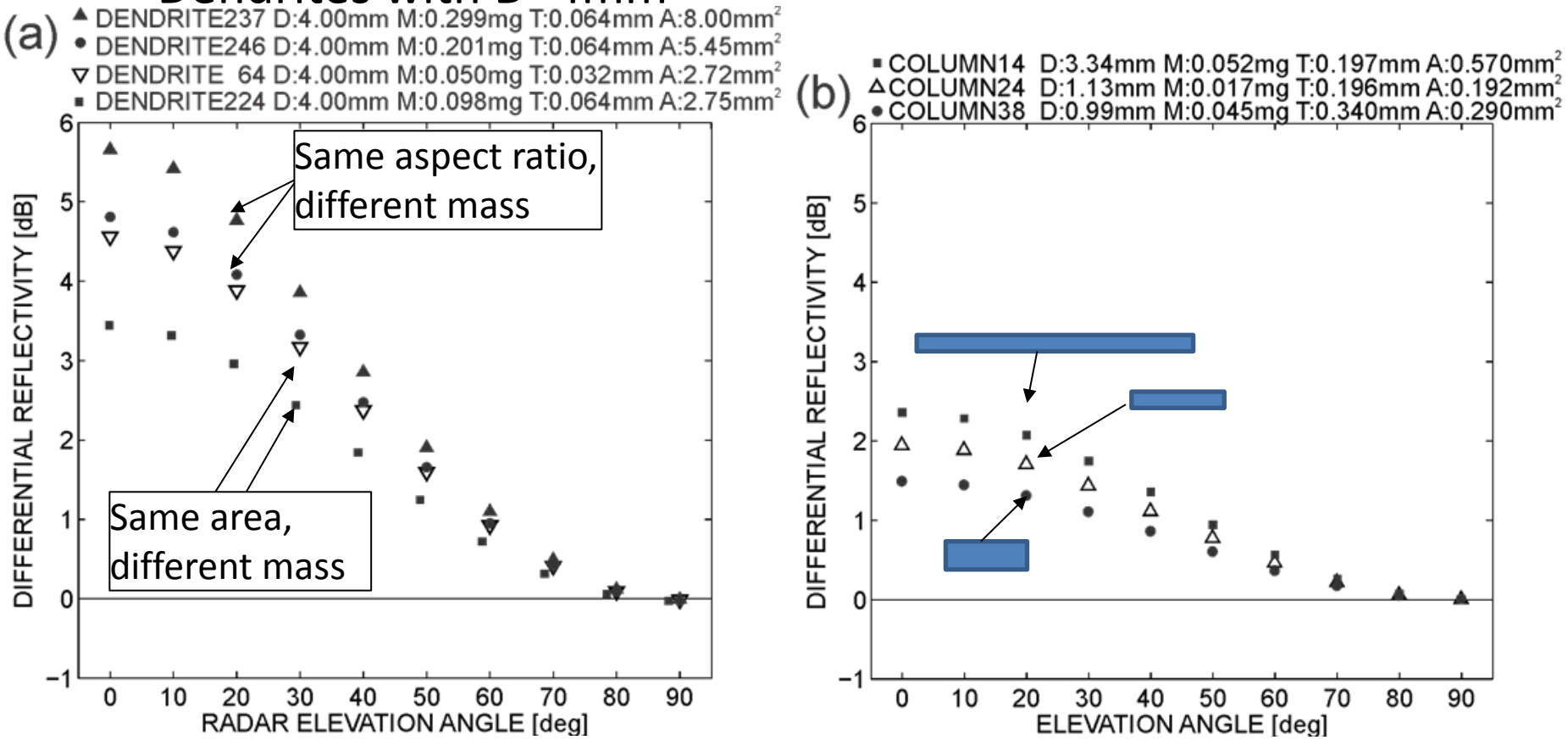
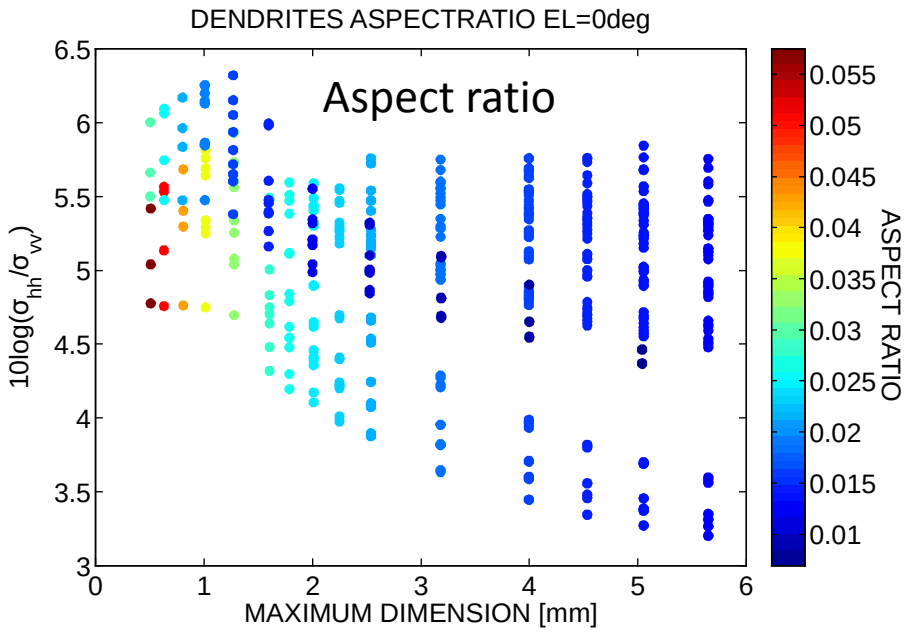
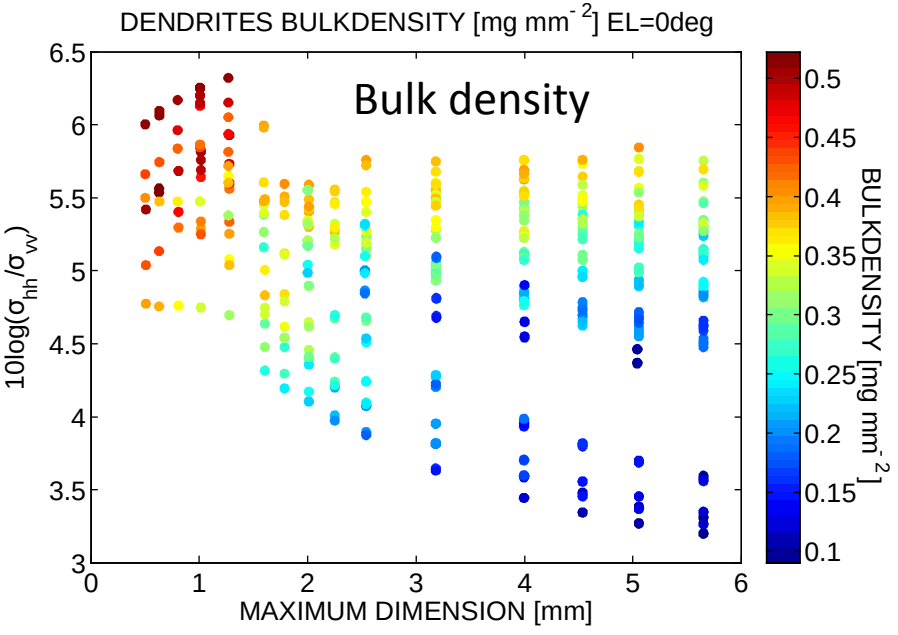
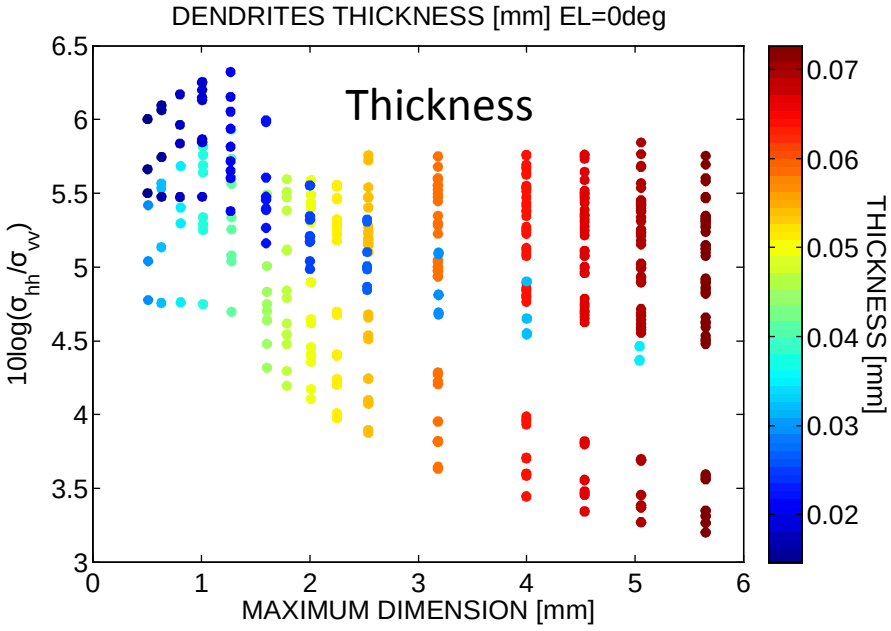
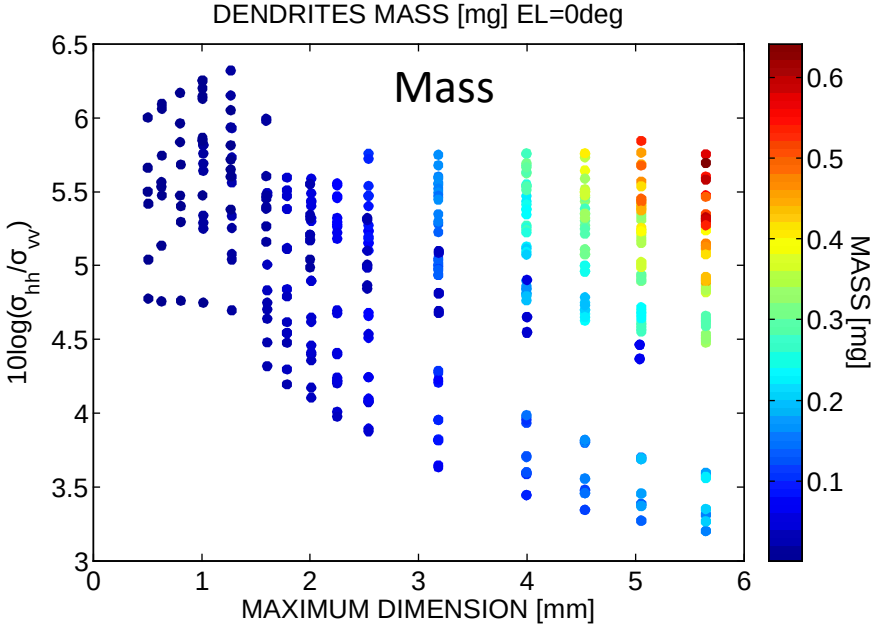


Fig. 12


DENDRITES ASPECTRATIO EL=0deg
Aspect ratio
10log(σhh/σvv)
MAXIMUM DIMENSION [mm]
ASPECT RATIO
0.055
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01


DENDRITES BULKDENSITY [mg mm-2] EL=0deg
Bulk density
10log(σhh/σvv)
MAXIMUM DIMENSION [mm]
BULKDENSITY [mg mm-2]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1


DENDRITES THICKNESS [mm] EL=0deg
Thickness
10log(σhh/σvv)
MAXIMUM DIMENSION [mm]
THICKNESS [mm]
0.07
0.06
0.05
0.04
0.03
0.02

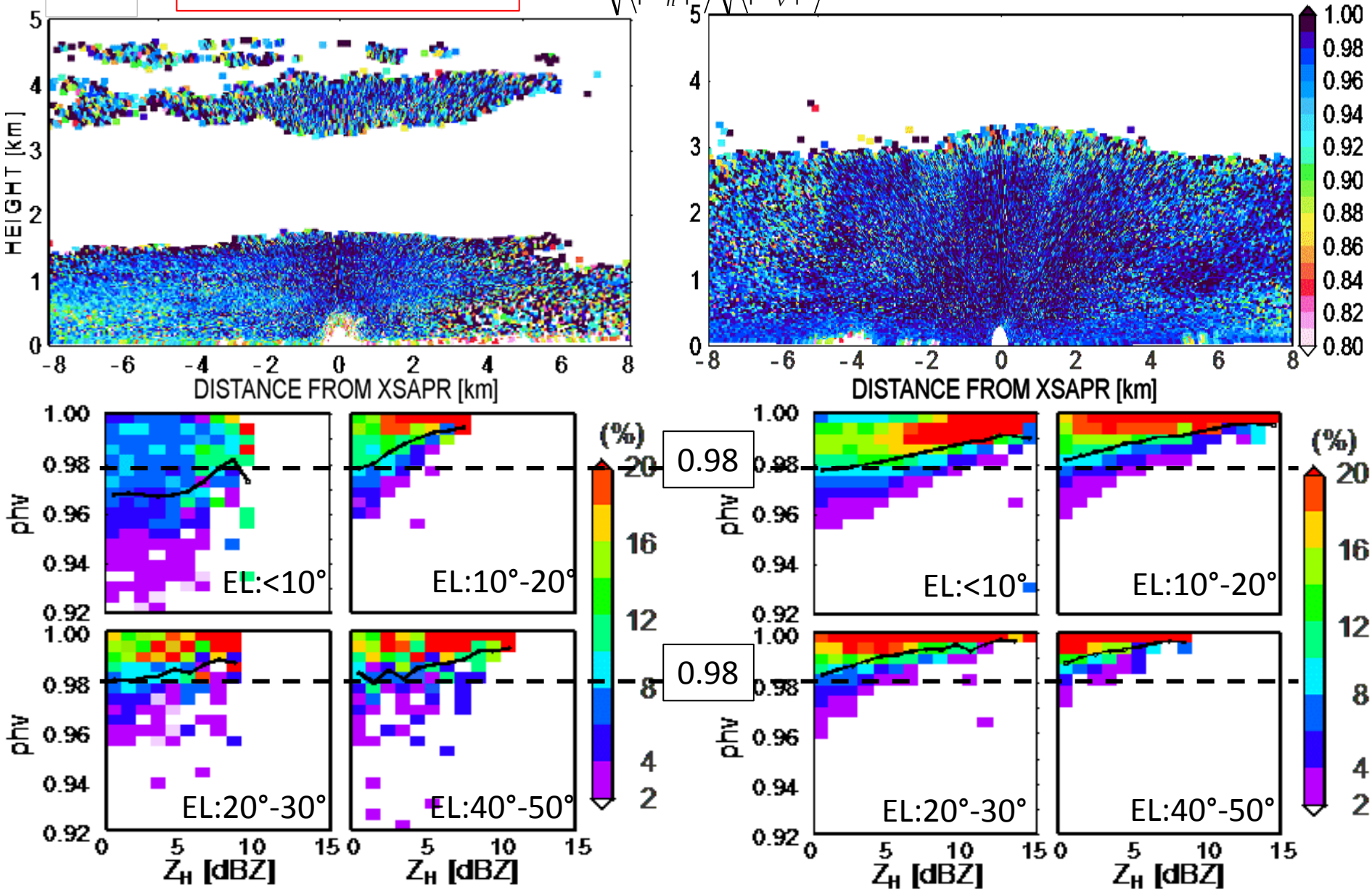

DENDRITES MASS [mg] EL=0deg
Mass
10log(σhh/σvv)
MAXIMUM DIMENSION [mm]
MASS [mg]
0.6
0.5
0.4
0.3
0.2
0.1

Correlation coefficient, ρhv

$$\rho_{hv} = \frac{\left|\left\langle S_v S_h^* \right\rangle\right|}{\sqrt{\left\langle |S_h|^2 \right\rangle}\sqrt{\left\langle |S_v|^2 \right\rangle}}$$

Single dendrites

Irregular crystals

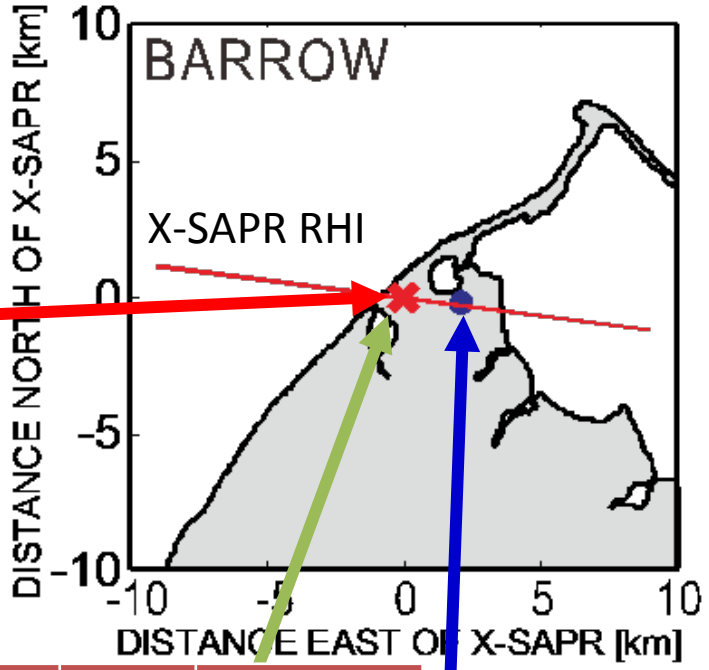


Observation

IOP: May 2013 at Barrow, Alaska

X-band Scanning ARM Precipitation radar (X-SAPR)

Frequency	9.671 GHz
Beam width	1.0 °
Altitude of antenna above sea level	32 m
Radar coverage in radius	40 km



	Pulse repetition frequency	Pulse width	Range spacing	Number of integration pulses	Scan rate	Synoptic condition
1554 UTC, 2 May	1950 Hz	0.50 μs	75 m	256	2° s^{-1}	
1838 UTC, 2 May	1950 Hz	0.50 μs	75 m	162	6° s^{-1}	
1057 UTC, 6 May	1950 Hz	0.50 μs	75 m	256	2° s^{-1}	
1837 UTC, 6 May	1950 Hz	0.50 μs	75 m	256	2° s^{-1}	

Picture of crystals on the ground

Sounding (06 and 18 UTC)

High Spectral Resolution Lidar (HSRL), Microwave Radiometer (MWR)