Synergy between Cloud Radar Polarimetry and Doppler Spectra in Arctic Ice and Mixed-Phase Clouds

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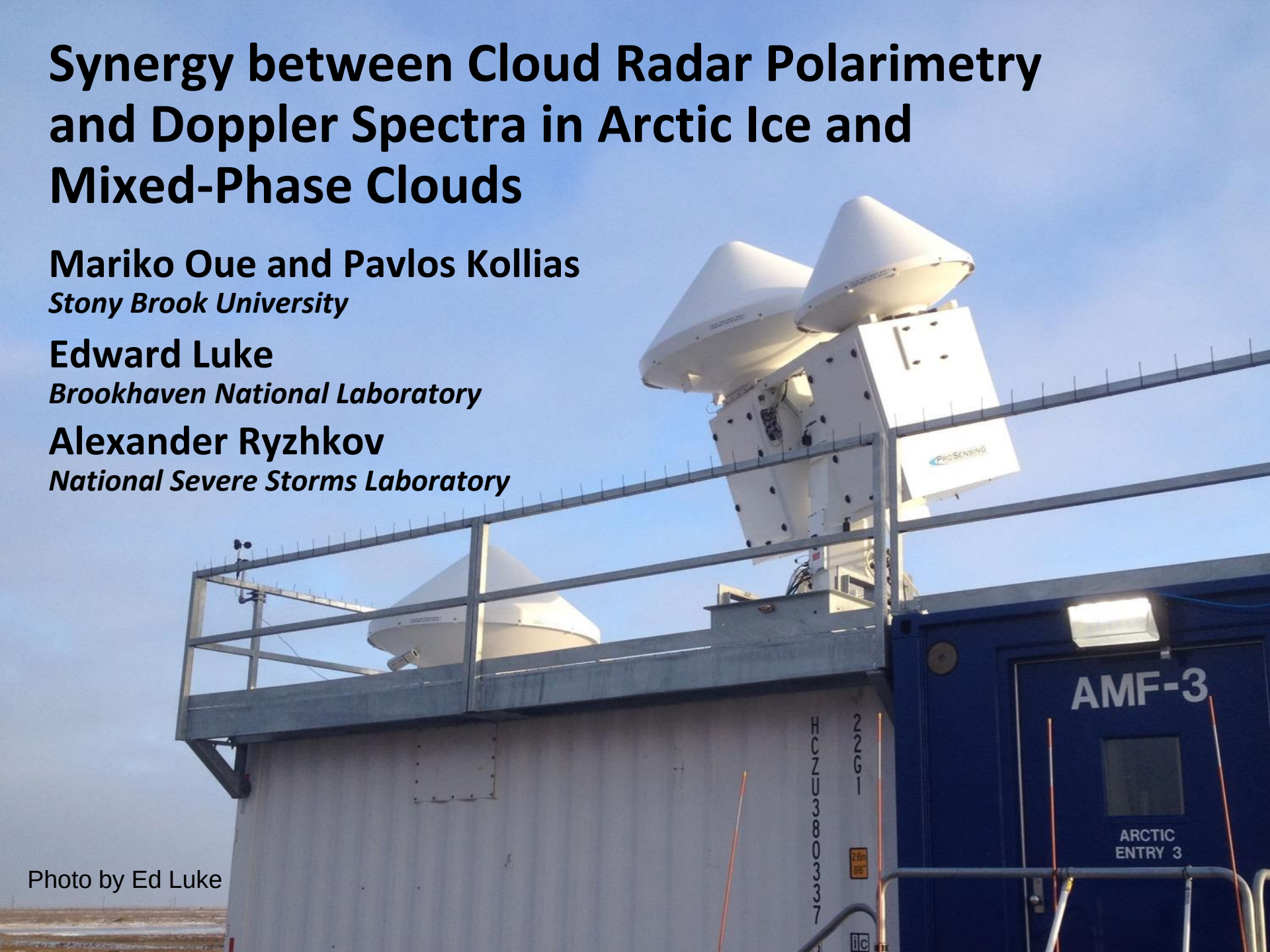


Photo by Ed Luke

Introduction

Motivation

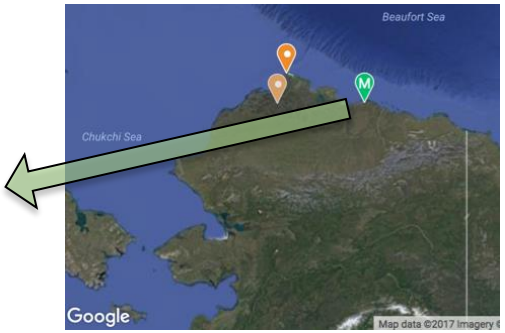
- Ice and mixed-phase clouds produce a variety of ice particle types (via dendritic growth, secondary nucleation, aggregation, riming, etc.).
- Measurements of radar moments (total reflectivity and mean Doppler velocity) are not enough to characterize mixed particles.

Objective

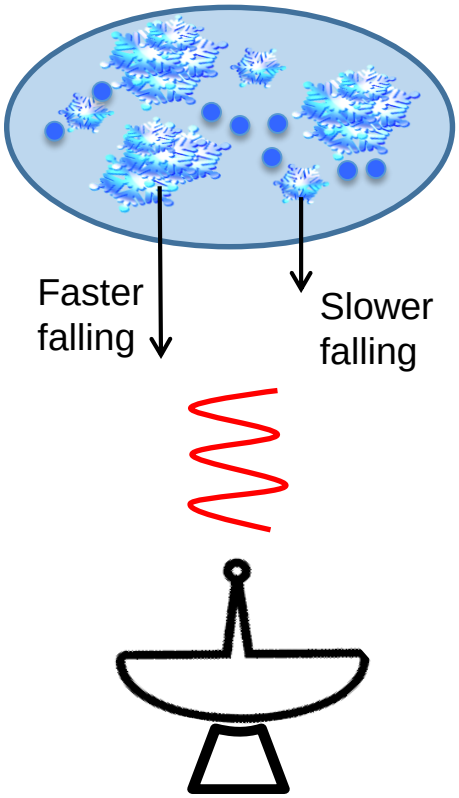
- Ice particle properties (fall speed, shape, and fraction) mixed in the same volume are revealed using radar Doppler spectra and polarimetric measurements.

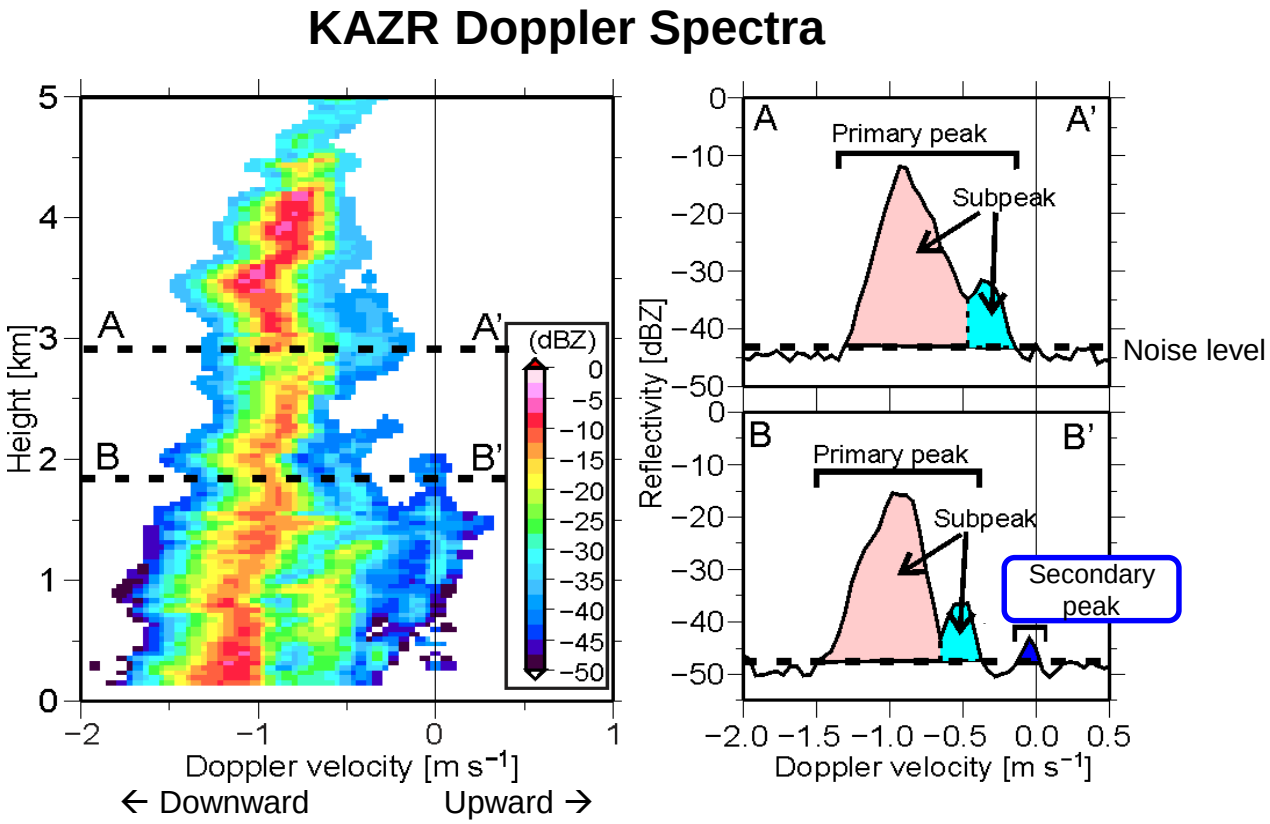
ARM Mobile Facility at Oliktok

- Ka-band Zenith Pointing Radar (KAZR)
- Ka/W-band polarimetric Scanning Cloud Radar (Ka/W-SACR2)
- Microwave Radiometer (MWR)
- Multi-Angle Snow Camera (MASC)
- Ceilometer



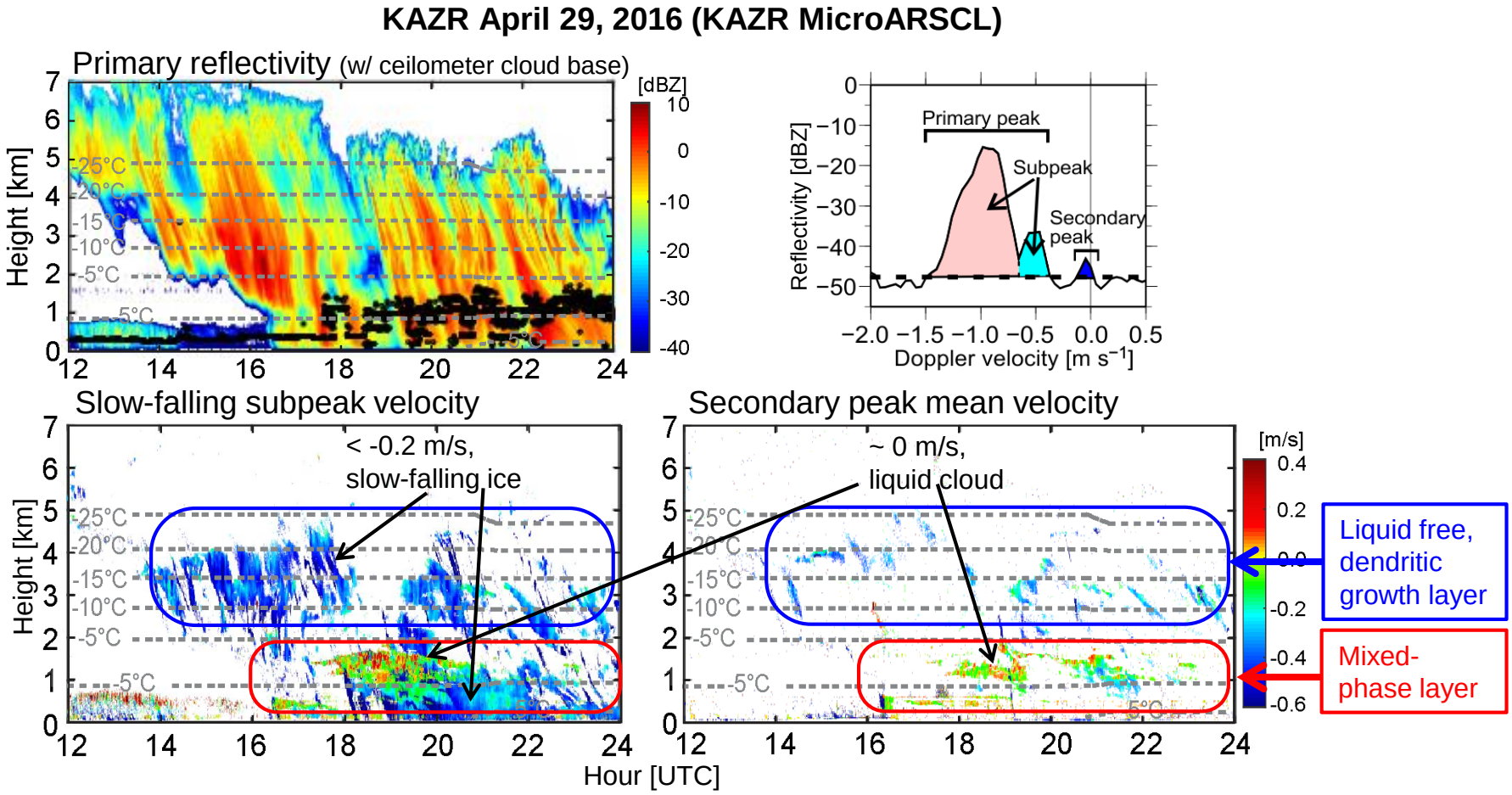
Decomposition of Multimodal Doppler Spectra



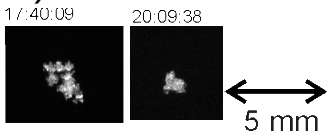


- Fast-falling subpeak DV << 0 m/s : Large ice particles
- Slow-falling subpeak DV < 0 m/s : Small ice particles
- Secondary peak DV =~0 m/s : Supercooled liquid

Multimodal Doppler Spectra Reveal Ice Processes

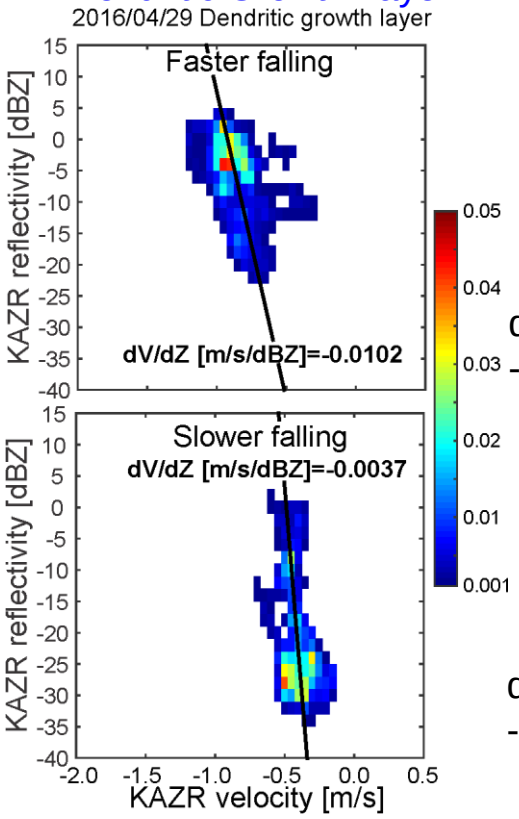


- Dendritic growth layer (~ -15°C): Slower falling particles were suggested as precipitating ice particles.
- Mixed-phase layer (~ -6°C): Slower falling peaks included both precipitating ice and liquid cloud droplet signals. Secondary ice nucleation was expected (e.g., Hallett-Mossop process).
- Rimed, compact aggregates were observed at the ground.



Habit Dependency of Fall Velocity

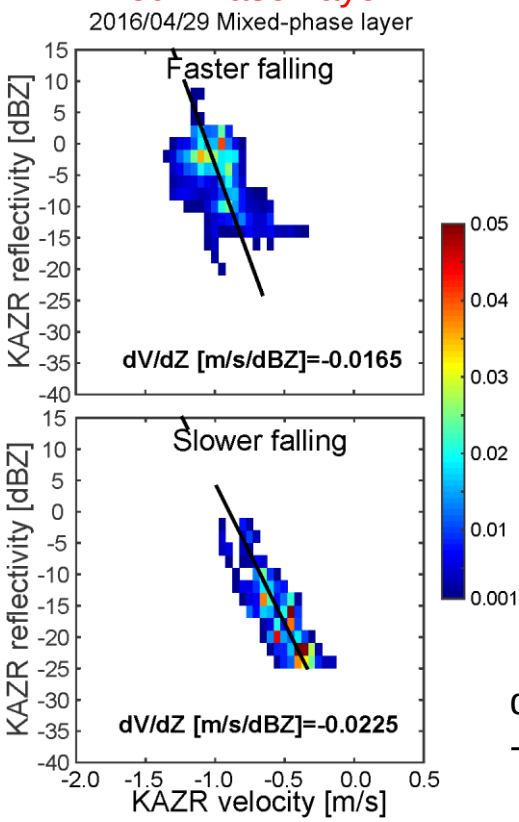
Dendritic Growth Layer



dV/dZ = -0.010 m/s/dBZ

dV/dZ = -0.004 m/s/dBZ

Mixed-Phase Layer



dV/dZ = -0.017 m/s/dBZ

dV/dZ = -0.023 m/s/dBZ

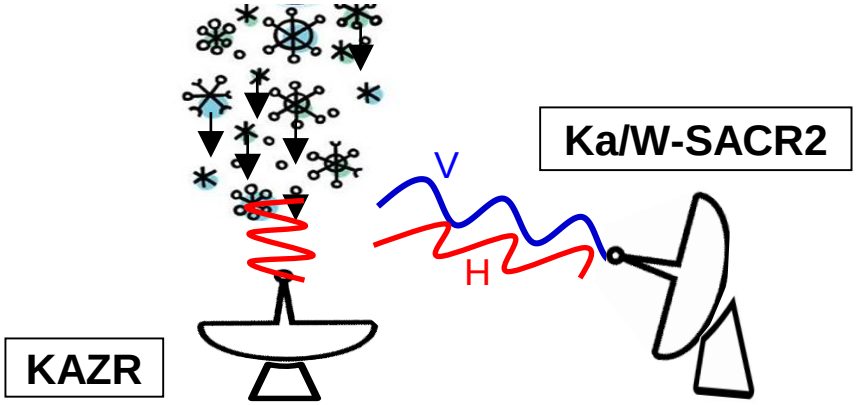
❑ Dendritic growth layer

- Ice fall speeds slowly increased with reflectivity (<0.01 m/s/dB).
- Low density, aggregates and/or depositional growth processes.
- The lowest gradient suggests that more depositional growth process dominated.

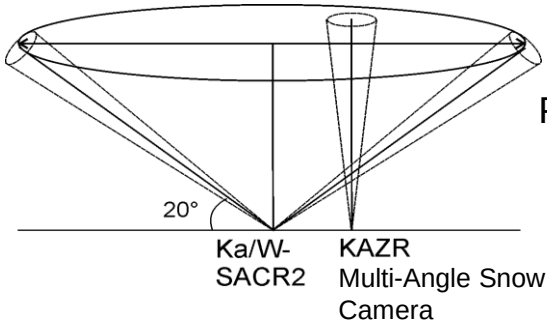
❑ Mixed-phase layer

- Ice fall speeds quickly increased with reflectivity (~-0.02 m/s/dB).
- Riming process, producing compact, fast-falling particles.

Synergy between Doppler Spectra and Polarimetry

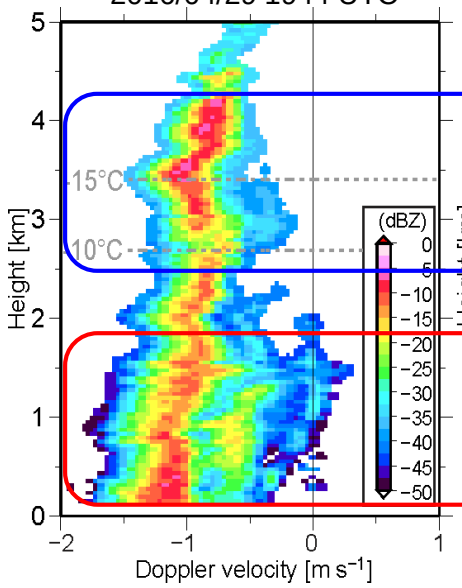


Quasi Vertical Profiles (QVP, *Ryzhkov et al. 2016*)

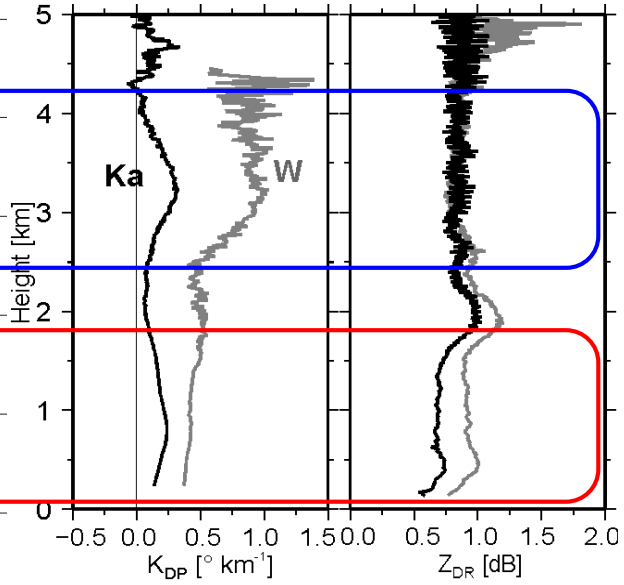


PPI scan

Doppler spectra



QVP



K_{DP} is proportional to IWC and sensitive to aspect ratio, while Z_{DR} is sensitive to aspect ratio of larger particles.

- ❑ Dendritic Growth Layer
  - K_{DP} increased while Z_{DR} was low.
  - Different shapes contributed to K_{DP} and Z_{DR}.
- ❑ Mixed-Phase Layer
  - Both Z_{DR} and K_{DP} values were low.

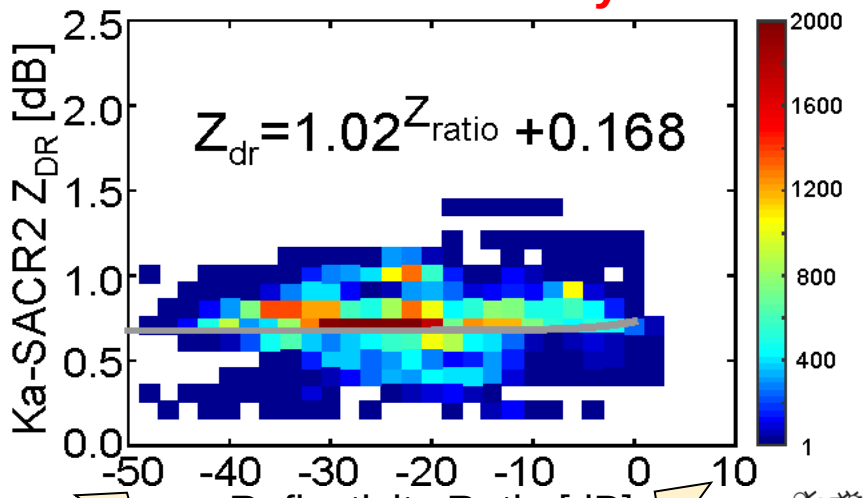
How much did slower-falling particles contribute to reflectivity and Z_{DR}?

Intrinsic Z_{DR} from Fast- and Slow-Falling Particles

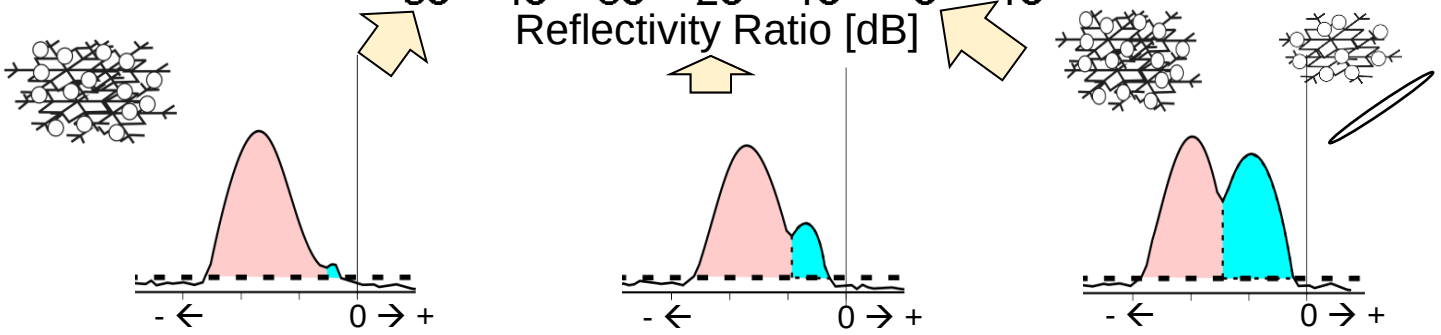
Reflectivity ratio (Z_{ratio}) = Slower-falling subpeak reflectivity (Z_H^{Slow}) / Faster-falling subpeak reflectivity (Z_H^{Fast})

Mixed-Phase Layer

Z_{DR}^{Fast} ~ 0.7 dB



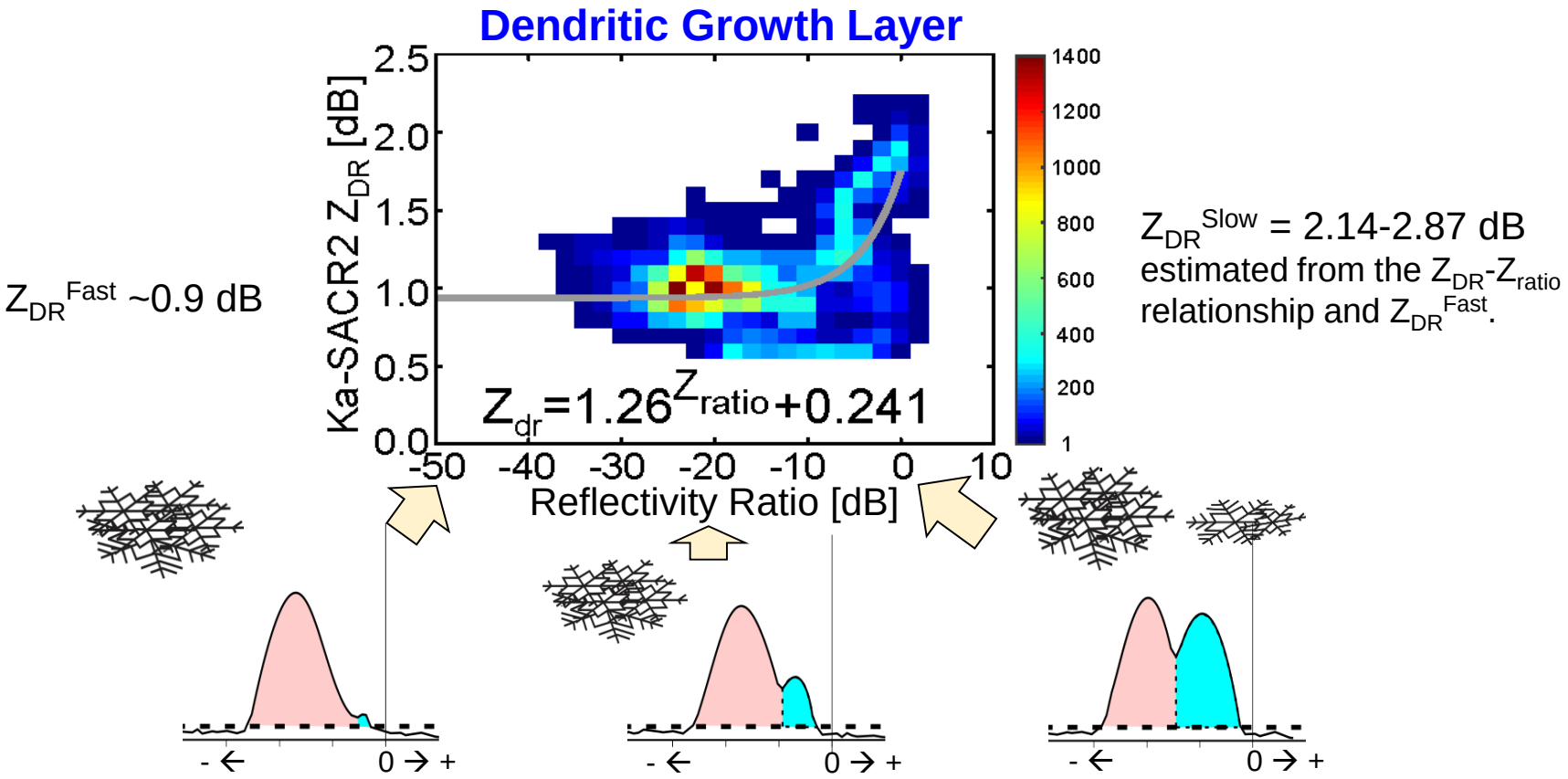
Z_{DR}^{Slow} ~ 0.7 dB



- Observed Z_{DR} is constant regardless the reflectivity ratio.
- Z_{DR}^{Fast} and Z_{DR}^{Slow} can be ~ 0.7 dB (quasi-isotropic particles, needles).

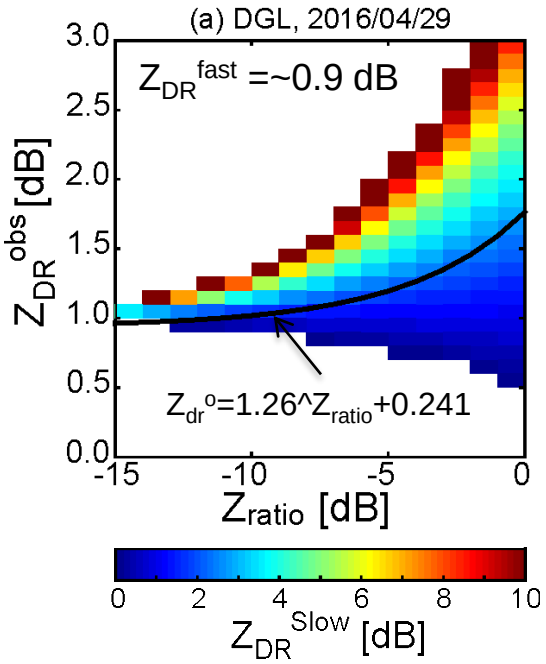
Intrinsic Z_{DR} from Fast- and Slow-Falling Particles

Reflectivity ratio (Z_{ratio}) = Slower-falling subpeak reflectivity (Z_H^{Slow}) / Faster-falling subpeak reflectivity (Z_H^{Fast})



- Observed Z_{DR} increases when contribution of slow-falling particle reflectivity increases.
- Slower-falling particles had lower aspect ratio (e.g., dendrites, light aggregation).
- Z_{DR}^{Fast} ~0.9 dB (quasi-isotropic aggregates).
- Z_{DR}^{Slow} ~ 2.14-2.87 dB (light aggregation of dendrites).

Estimation of Z_{DR}^{slow} in Dendritic Growth Layer



Assuming that a volume was composed of two types of ice particles (faster-falling and slower-falling particles),

$$Z_{dr}{}^{obs} = \frac{Z_h{}^{Fast} + Z_h{}^{Slow}}{Z_v{}^{Fast} + Z_v{}^{Slow}}$$

where $Z_{ratio} = \frac{Z_h{}^{Slow}}{Z_h{}^{Fast}}$, $Z_{dr}{}^{Fast} = \frac{Z_h{}^{Fast}}{Z_v{}^{Fast}}$

Z_{DR} from slower-falling particles (Z_{DR}^{slow}) can be estimated as:

$$Z_{dr}{}^{Slow} = \frac{Z_{dr}{}^{obs} Z_{dr}{}^{Fast} Z_{ratio}}{Z_{dr}{}^{Fast}(1 + Z_{ratio}) - Z_{dr}{}^{obs}}$$

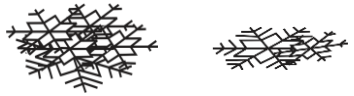
Applying Z_{DR}^{fast} =~0.9 dB and Z_{dr}^{o}=1.26^Z_{ratio}+0.241,

Z_{DR}^{Slow} = 2.14 – 2.87 dB

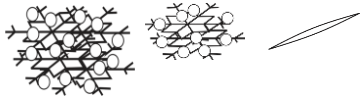
Summary

Combination of radar Doppler spectra and polarimetric radar QVP quantitatively improves the identification of ice particles and their characteristics (shape and fall speed) in mixed ice particle regions.

- ❑ Dendritic growth layer
  - Produced high K_{DP} and relatively low Z_{DR}.
  - Showed small increase of fall velocity with reflectivity (< 0.01 m/s/dB).
  - ➢ Suggests that larger, low-density quasi-isotropic aggregates (Z_{DR} < 1 dB) coexisted with smaller highly oblate aggregates (Z_{DR} > 2 dB) of dendrites.



- ❑ Mixed-phase layer
  - Produced low K_{DP} (K_{DP} < 0.3 °/km) and low Z_{DR} (Z_{DR} < 1 dB) .
  - Showed fast increase of fall velocity with reflectivity (~0.02 m/s/dB).
  - ➢ Suggests that high-density, compact particles produced by riming dominated (Z_{DR} < 1 dB). Secondary ice nucleation likely occurred.



References

Oue, M. P. Kollias, A. Ryzhkov, and E. P. Luke (2017), Synergy between cloud radar polarimetry and Doppler spectral analysis in ice and mixed-phase clouds. Submitted to J. Geophys. Res.

Applied Radar Science Group Website: http://radarscience.weebly.com/