A Synthesis of Polarimetric and Dual-Frequency Radar Observations of Winter Storms for Estimating Ice Water Content

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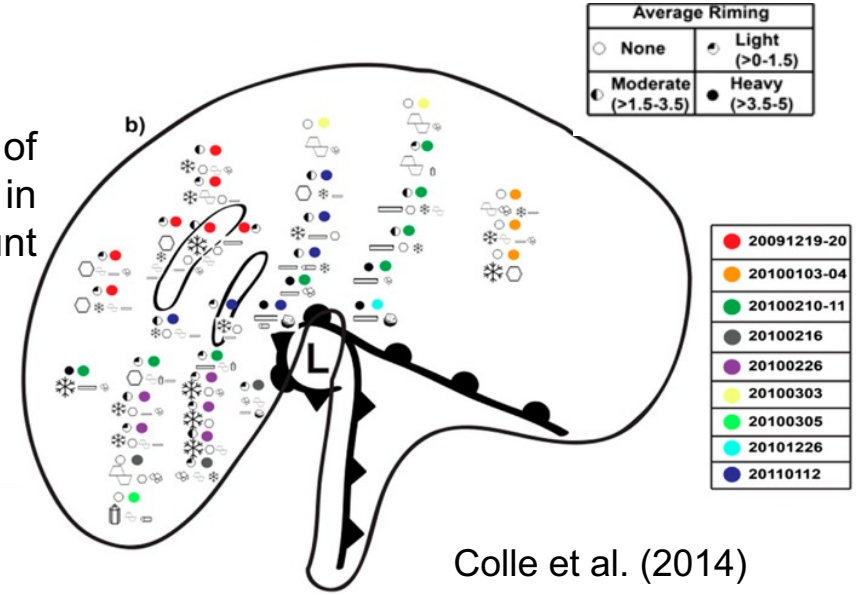
Motivation

- A variety of ice particles with different degrees of riming/aggregation and their distribution in snowstorms cause large uncertainty of snow amount estimates.



Colle et al. (2014)

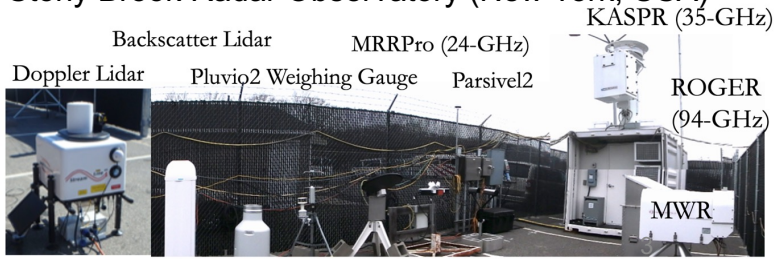
Motivation

- A variety of ice particles with different degrees of riming/aggregation and their distribution in snowstorms cause large uncertainty of snow amount estimates.
- Recently the radar network has been complemented by high spatiotemporal, high-sensitivity millimeter-wavelength (cloud) radars.
- They can provide additional constraints to improve the snow retrievals.
- However, establishing robust equations for the snow amount estimates is very challenging, because of non-Rayleigh scattering at millimeter wavelengths in addition to complexity of snow particle shapes and variety of rime degrees.

Jülich ObservatorY for Cloud Evolution (Germany)

Löhnert et al. (2015)

Stony Brook Radar Observatory (New York, USA)



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Objectives

- Propose a simple technique to estimate IWC from the Ka-band polarimetric radar measurements
  - Adapt the previously-established IWC retrievals for S-band radar measurements
  - Use a synergy of the dual-wavelength radar measurements and polarimetric observations.
  - No scattering calculation is needed.
- Evaluate the IWC estimates from the Ka-band radar measurements for snowstorms observed along U.S. Northeast Coast between 2017 and 2021.

Stony Brook Millimeter-Wavelength Cloud Radar Observatory

SBRO has been supported by NSF as CIF.

Ka band Scanning Polarimetric Radar

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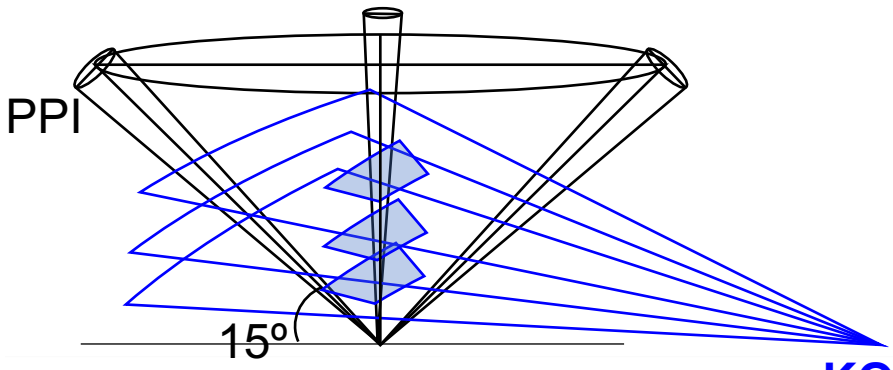
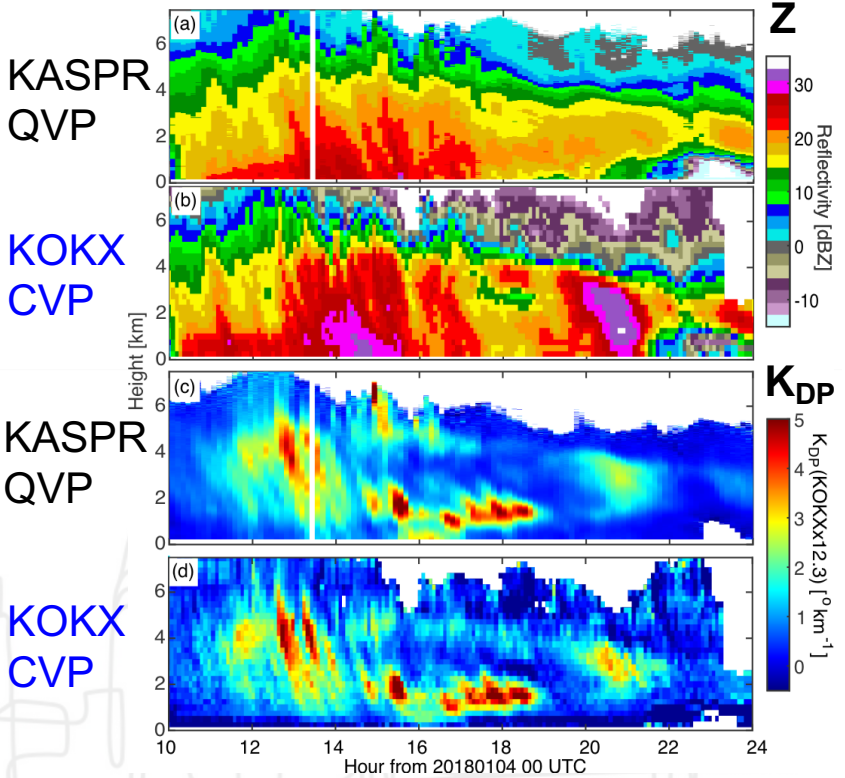
Synergy Between KASPR (Ka) and KOKX (S)



KASPR
Quasi vertical profile (QVP)
Vertical pointing (VPT)

Parsivel
Pluvio

KOKX
Columnar quasi vertical profile (CVP)



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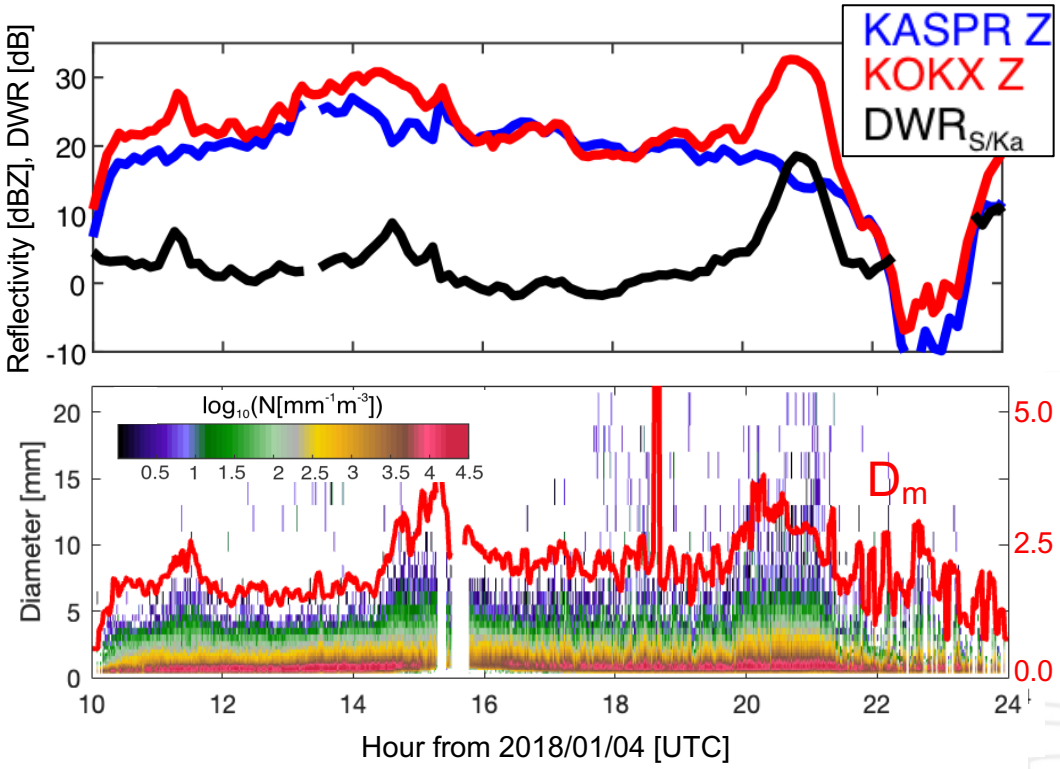
Synthesis of S and Ka: DWR



- Large DWR is consistent with large D_m.
- DWR from non-collocated radars can be used to roughly estimate Rayleigh proxy for Z(Ka) and D_m.

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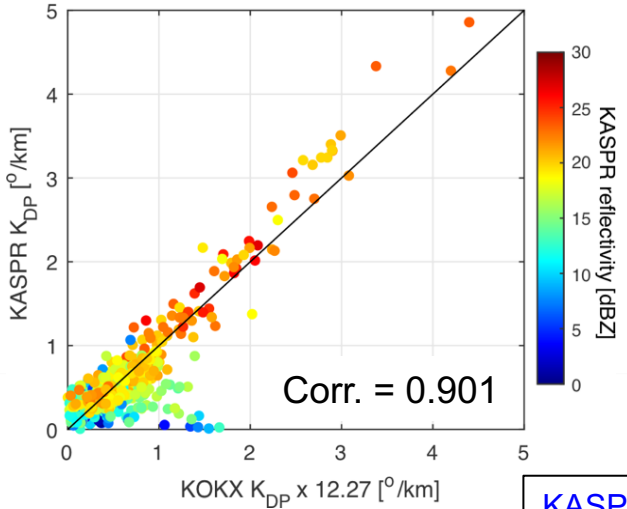
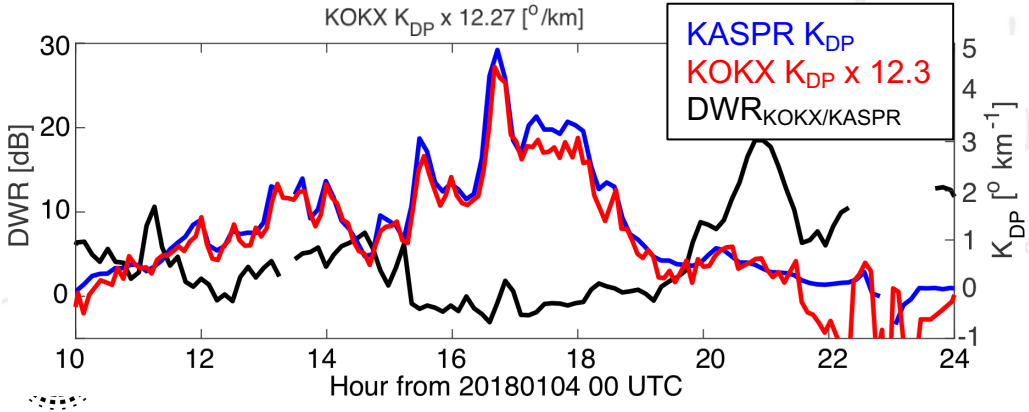
Synthesis of S and Ka: K_{DP}





- Consistent and well scaled by the radar wavelength.
- KASPR K_{DP} can work in the retrievals with Rayleigh assumption.
- Larger K_{DP} values are collocated with small (near-zero) DWR, because K_{DP} is more sensitive to the number concentration of particles, while DWR is sensitive to larger particles.

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Adaptation of IWC(N_t,Z) and IWC(K_{DP},Z)

For S band

$$IWC(N_t, Z) = f(\mu) N_t^{0.5} Z^{0.5}$$

$$IWC(K_{DP}, Z) = 0.0709 {f_{rim}}^{-0.94} (K_{DP}\lambda)^{0.66} Z^{0.28}$$

Number concentration [m^{-3}]

$$N_t = 1.18 \frac{Z}{D_m^4}$$

Mean volume diameter [mm]

$$D_m = 0.67 \left(\frac{Z}{K_{DP}\lambda}\right)^{1/3}$$

PSD shape parameter μ

f_{rim} = 1/(1-Rime mass fraction)

(Bukovcic et al. 2018; Huang et al. 2021; Ryzhkov and Zrnic 2019)

$$DWR_{S/Ka} = {D_m}^{1.73}\ [dB]$$

(Matrosov, 2022)

For Ka band

$$IWC(N_t, Z) = f(\mu) N_t^{0.5} (10^{0.1(dBZ + {D_m}^{1.73})})^{0.5}$$

$$IWC(K_{DP}, Z) = 0.293 {f_{rim}}^{-0.94} {K_{DP}}^{0.66} (10^{0.1(dBZ + {D_m}^{1.73})})^{0.28}$$

$$N_t(DWR) = 1.18 \frac{10^{0.1\,(dBZ + {D_m}^{1.73})}}{\left[\frac{\sqrt[1.72]{\frac{{D_m}^{1.73}}{0.86}}}{1.09}\right]^4}$$

$$D_m = 0.67 \left(\frac{10^{0.1\,(dBZ + {D_m}^{1.73})}}{K_{DP}\lambda}\right)^{1/3}$$

Applicable to any mm-wavelength with DWR-D_m

Work with single radar measurements

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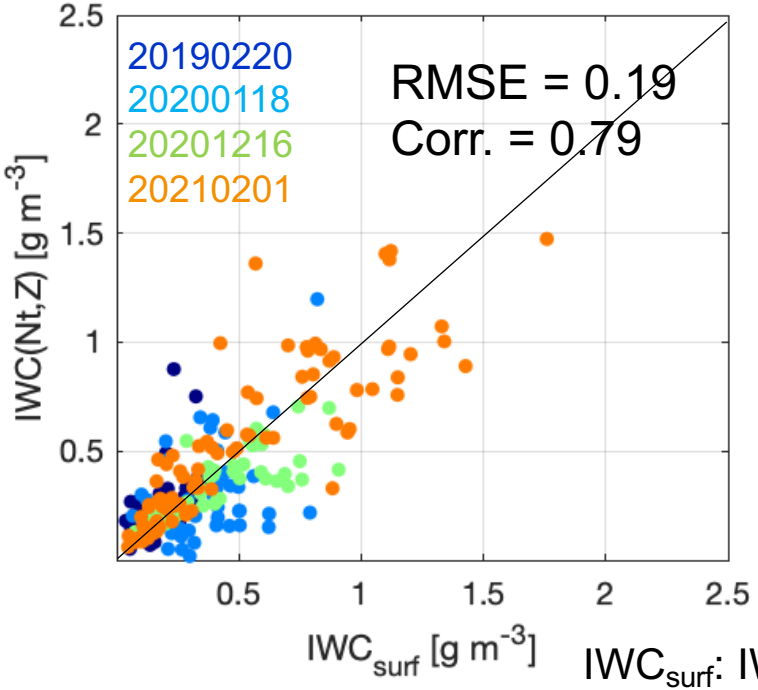
Results: IWC(N_t,Z)

$$IWC(N_t, Z) = f(\mu) N_t^{0.5} (10^{0.1(dBZ + {D_m}^{1.73})})^{0.5}$$



- μ is optimized for each case using the surface IWC.

20190220	-0.7
20200118	-0.9
20201216	-0.9
20210201	-0.7

- Better estimates than IWC(K_{DP},Z)

IWC_{surf}: IWC estimated from Parsivel and Pluvio

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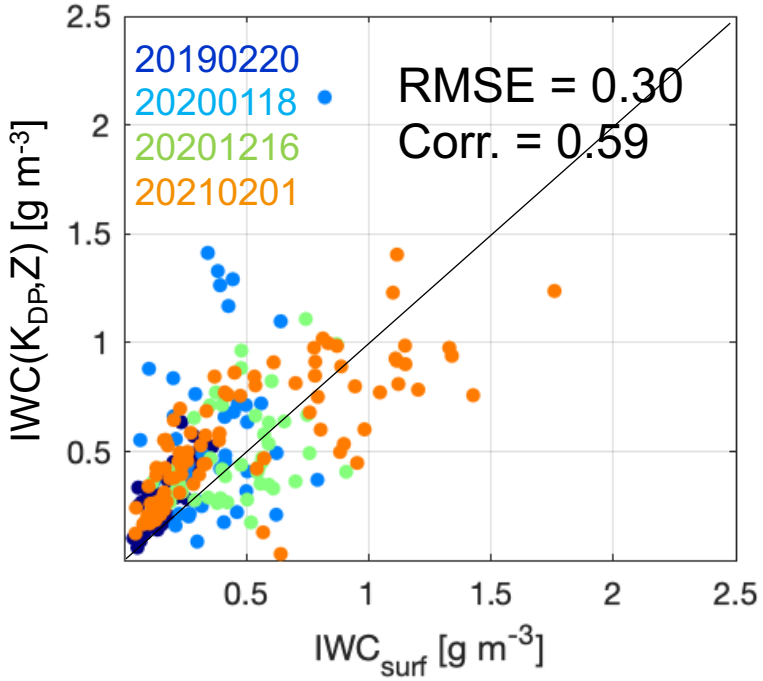
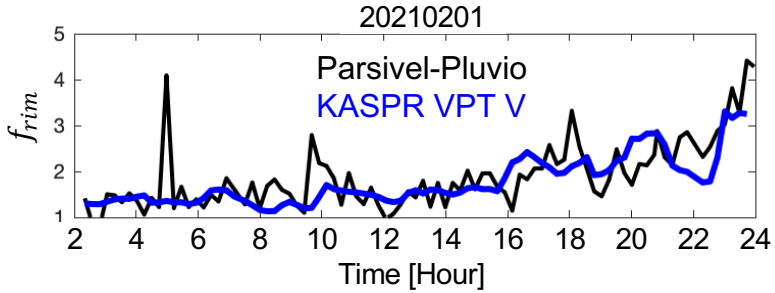
Results: IWC(K_{DP},Z)

$$IWC(K_{DP},Z) = 0.293 f_{rim}{}^{-0.94} K_{DP}{}^{0.66} (10^{0.1(dBZ+D_m{}^{1.73})})^{0.28}$$



- f_{rim} is estimated from VPT Doppler velocity measurements (Kneifel and Moisseev 2020).



- Estimating f_{rim} is challenging, but Doppler velocity from VPT is useful.

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Summary and Discussions

- IWC(N_t,Z) and IWC(K_{DP},Z) relations for Ka-band radar is proposed without complex scattering calculations.
  - The S-band K_{DP} scaled by the radar wavelength shows a good agreement with the Ka-band. The Ka-band K_{DP} can work with a Rayleigh assumption.
  - The bulk $DWR_{S/Ka}$ from CVP/QVP is well correlated with D_m, even though their radar beams do not match.
  - The DWR-D_m relationship is used. This allows for single mm-wavelength radar retrievals using D_m(K_{DP},Z). Use of larger $DWR_{S/Ka}$ (>10 dB) can further improve.
  - Optimization of μ is a key for better IWC(N_t,Z) estimate. Negative μ values are plausible for the cases.
  - f_{rim} estimate for IWC(K_{DP},Z) is challenging, but Ka-band VPT measurements can help. DWR-V measurements will help for further improvement.

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