PROM Meeting, 25-27 July 2022

Synergy of multi-wavelength radar observations with polarimetry to retrieve ice cloud microphysics

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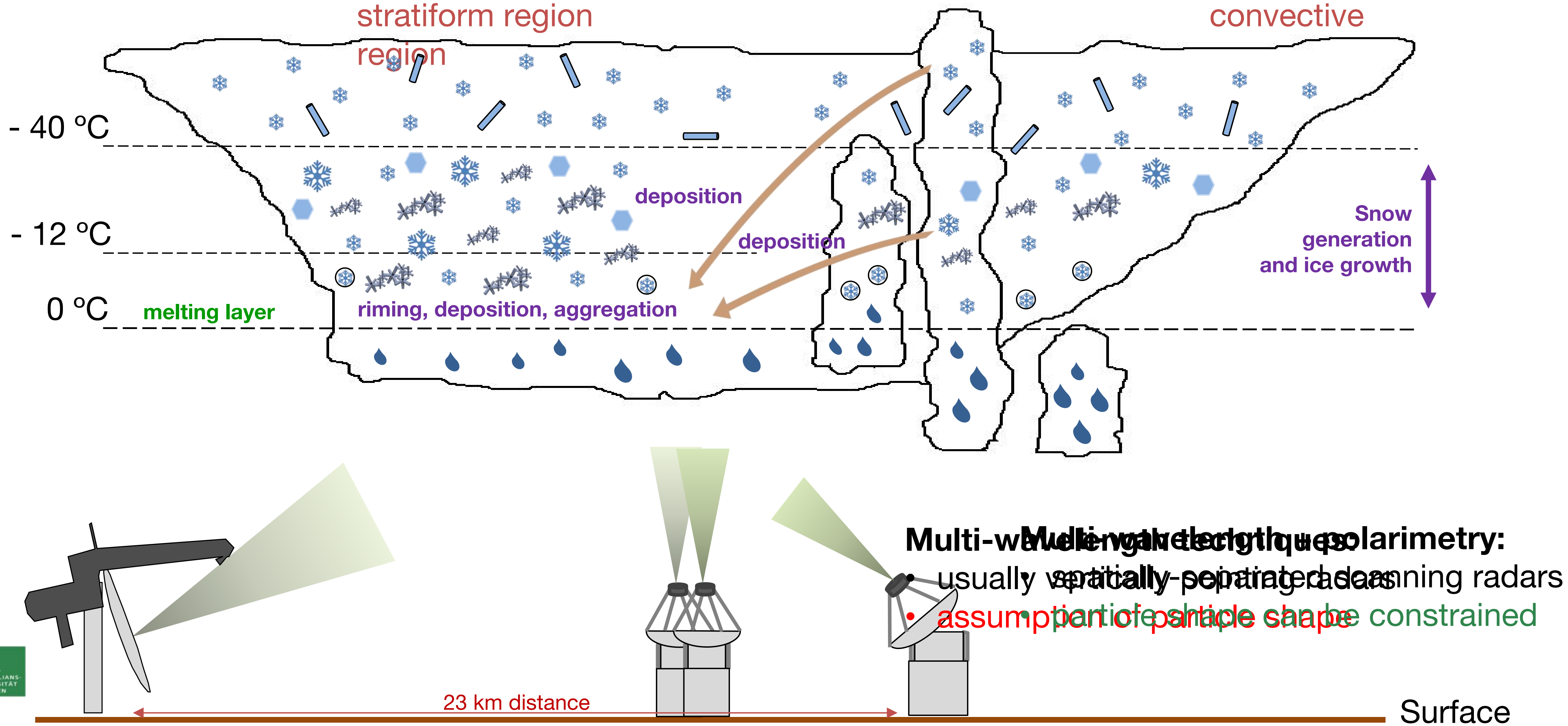
State of the Art
Our new approach

Constrain ice microphysical properties with multi-wavelength radar measurements

Combine multi-wavelength radar measurements with polarimetry

Modified after Houze (1989)



Multi-wavelength techniques:

- vertically-pointing radars
- particle shape can be constrained

Multi-wavelength + polarimetry:

- usually spatially-separated scanning radars
- assumption of particle shape

Research questions of this study

1. Can we **combine two spatially separated radars** to derive information about the size of detected ice hydrometeors?

2. Can we obtain adequate **ice microphysics information using a simple particle model** and different assumptions for 3 degrees of freedom?

3. How do the **microphysical assumptions affect the retrieval** of ice microphysics?
Which one is the most substantial? What do we gain by adding polarimetry?

RQ1: Combination of two spatially separated radars

Photo by Martin Hagen

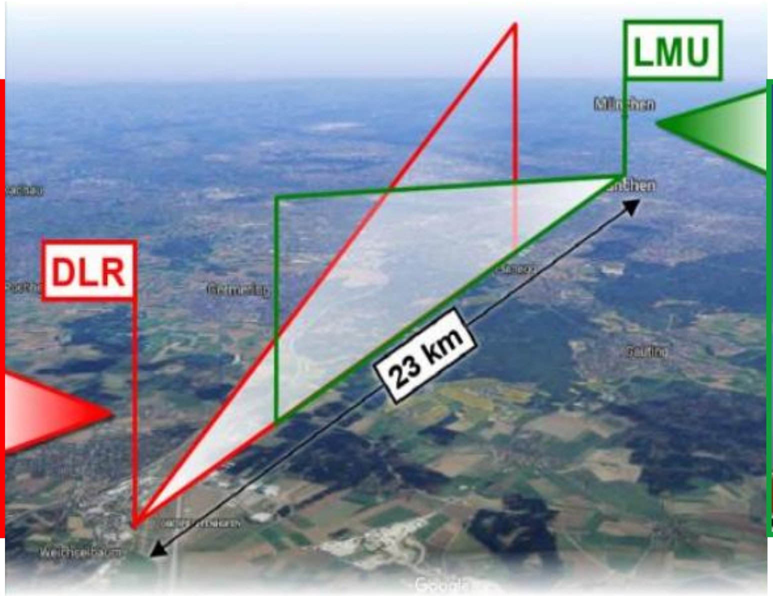


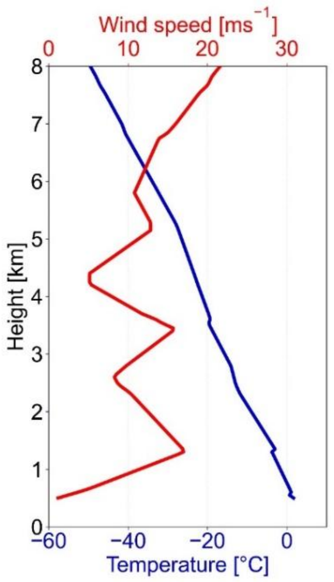
Photo by Florian Ewald

Photo by Bernhard Mayer

- ✓ Synergy of POLDIRAD (DLR, Oberpfaffenhofen) and MIRA-35 (LMU, Munich).
- ✓ Stratiform precipitation in the cross-section area was monitored.
- ✓ Snowfall events from winter 2019 were investigated using ZDR + DWR measurements.

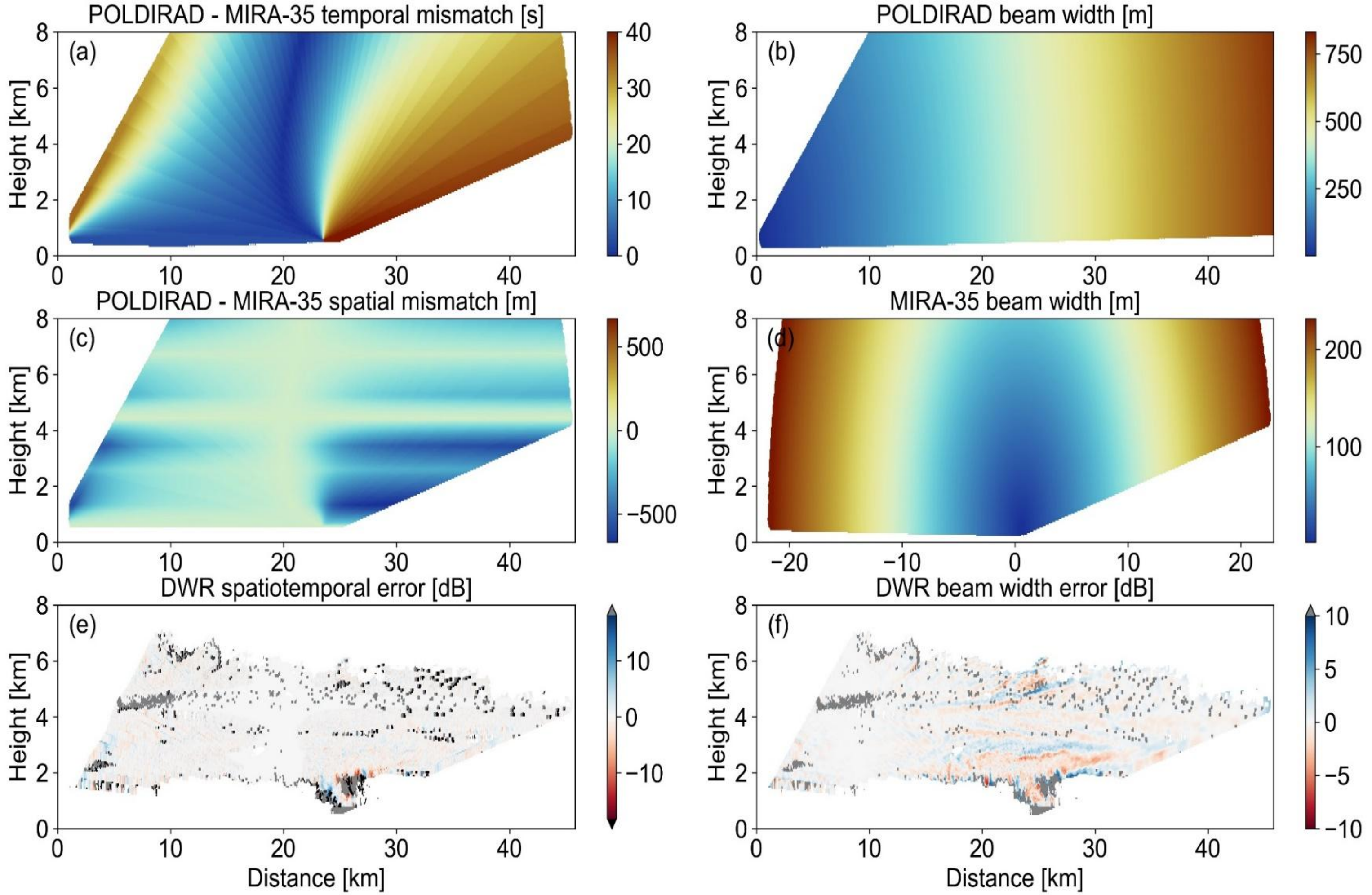
**Investigation of the initiation of convection and the evolution of precipitation using simulations and polarimetric radar observations at C- and Ka-band*

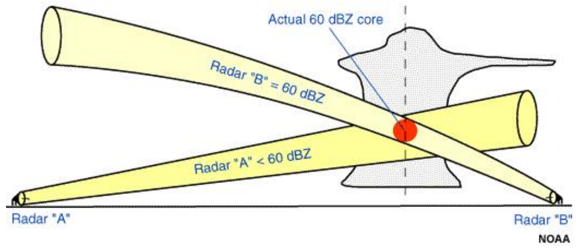
RQ1: Combination of two spatially separated radars – Considered aspects/errors



spatiotemporal difference

beam width difference





Stratiform, snowfall cases

Large features captured by both radar beams.

Negligible hydrometeors attenuation even in Ka-band cloud radar.

gaseous attenuation

(ITU + ECMWF ERA5)

ice mask

other error sources

Azimuthal and absolute radiometric calibration, systematic and random biases

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Tetoni et al. (2022), AMT

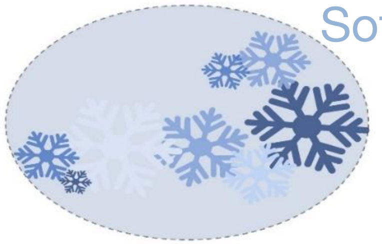
RQ2: Developing an ice microphysics retrieval

Scattering simulation assumptions

Ice scattering simulations structured in look-up tables helped in ice microphysics retrievals. For the simulations we assumed:

- Soft spheroid density: mass-size relationship
- Soft spheroid shape: varying the **aspect ratio**
- Oblates or horizontally aligned prolates 
- PSD: Exponential particle size distribution with varying **median size** and **ice water content**

  Typical for snow (e.g., Matrosov and Heymsfield, 2017).



Soft spheroid model

PyTMatrix

Leinonen (2014)

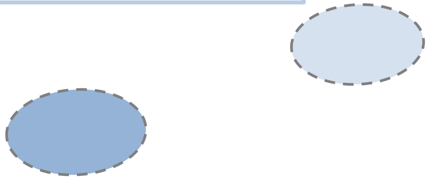
Brown and Francis (1995)

$$m(D_{max}) = 480 D_{max}^3, \quad D_{max} < 6.6 \times 10^{-5}\ \mathrm{m}$$

$$m(D_{max}) = 0.0121 D_{max}^{1.9}, \quad D_{max} \geq 6.6 \times 10^{-5}\ \mathrm{m}$$

Yang et al. (2000)

$$m(D_{max}) = \frac{\pi \rho_w D_{eq}^3}{6} = \frac{\pi \rho_w}{6} {e^{\sum_{n=0}^{4} b_n (\ln(D_{max}))^n}}^3$$



Simulations of
Z_e, ZDR and DWR

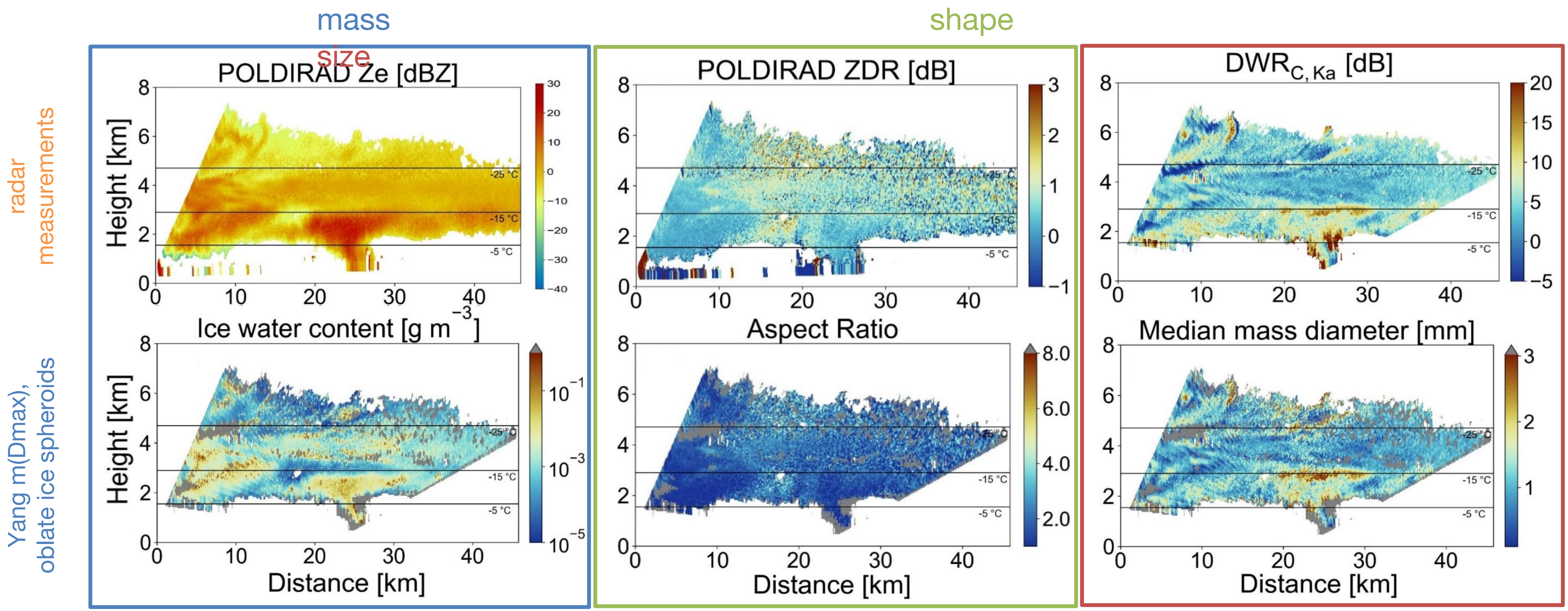
Compared to measured
Z_e, ZDR and DWR

→ IWC, AR, D_m

color code: shape size mass

RQ2: Ice microphysics retrieval results

Case study from 30th January 2019 at 10:08 UTC



Tetoni et al. (2022), AMT

RQ2: Ice microphysics retrieval error

Averaged profiles of D_m and IWC for oblate ice particles

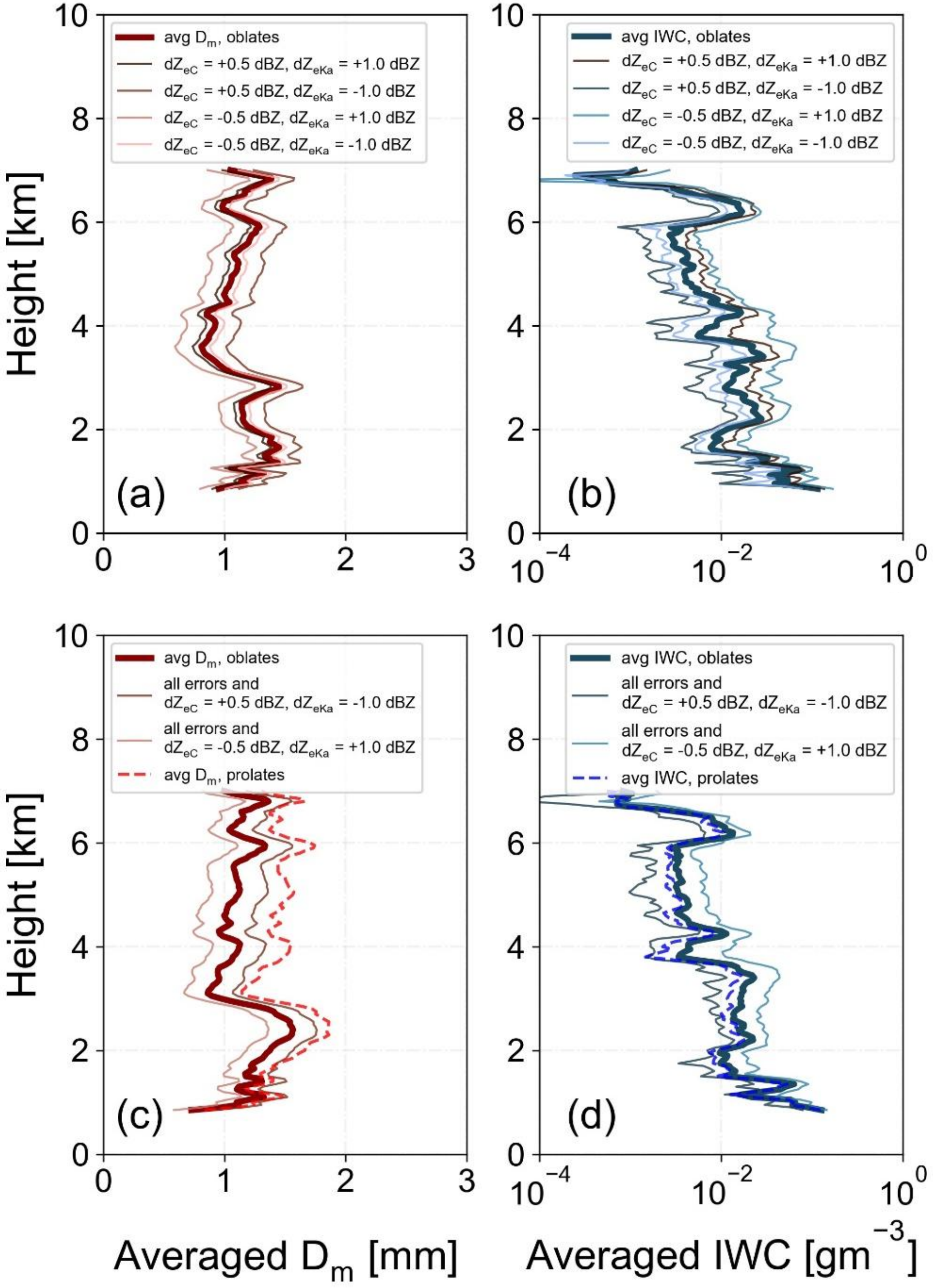
Retrieval results

red and blue shades: calibration error combinations for POLDIRAD (±0.5 dBZ) and MIRA-35 (±1.0 dBZ)

Retrieval results + spatiotemporal and beam width errors

dashed lines: results for horizontally aligned prolate ice spheroids

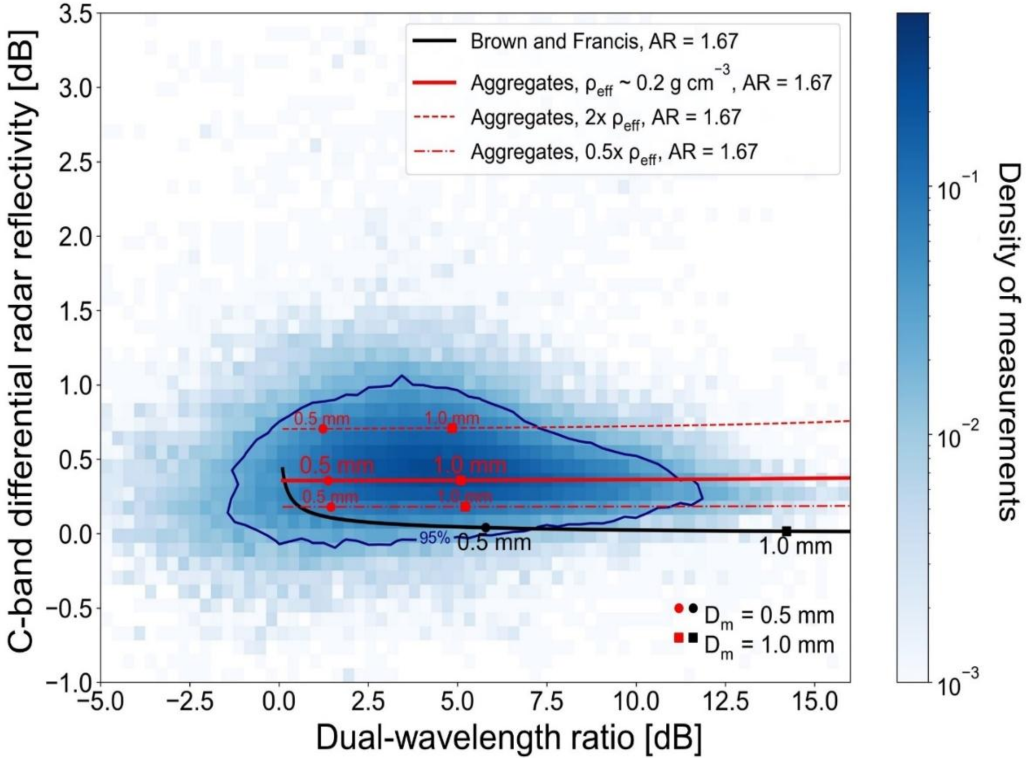
Mismatch errors can locally lead to significant differences.
Calibration uncertainty significant for the whole profile.
Shape assumption equally significant for the retrieval of D_m and less important for the retrieval of IWC.

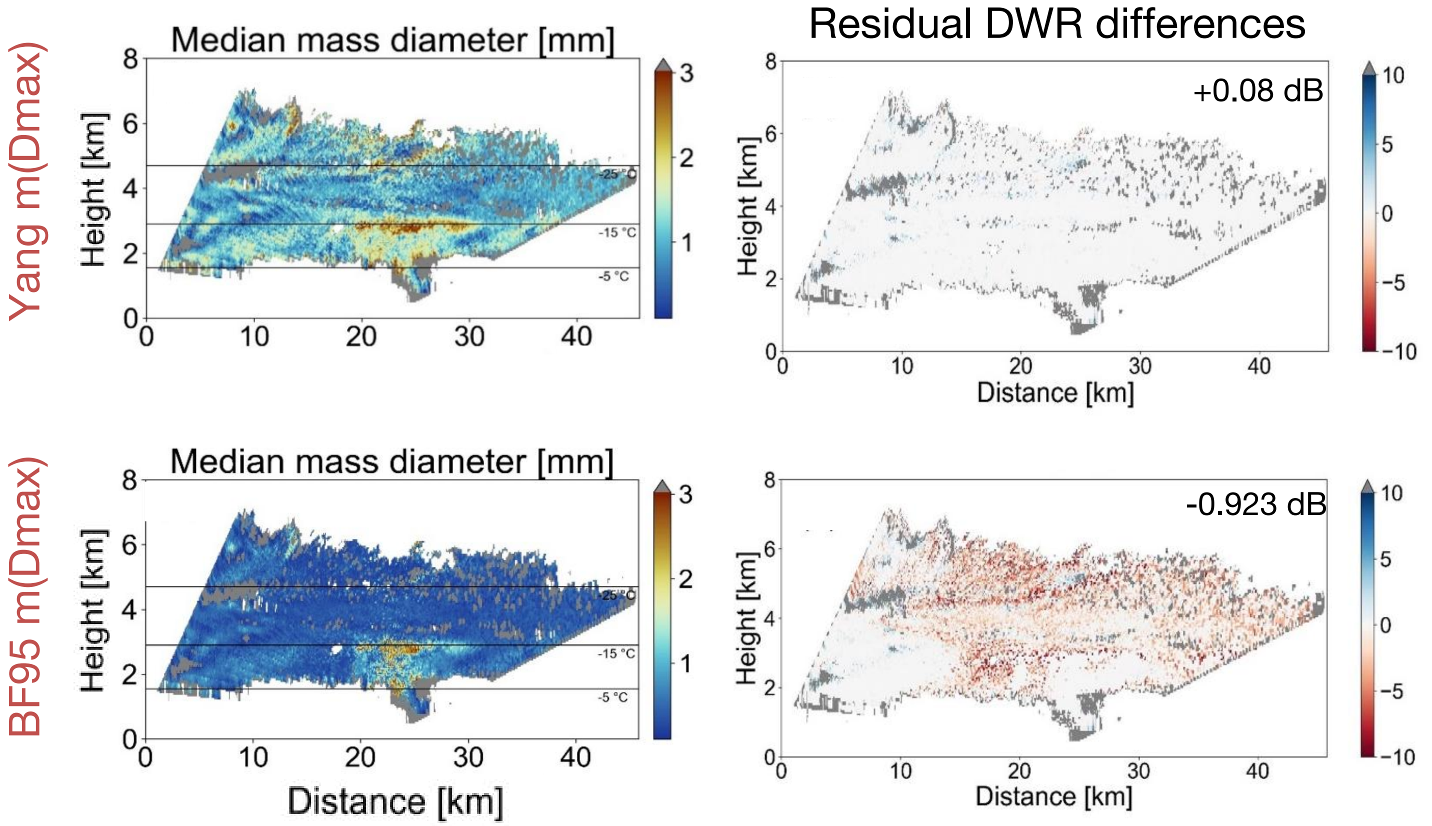


RQ3: Sensitivity studies

Mass-size relation

low elevation angles 0°–5°

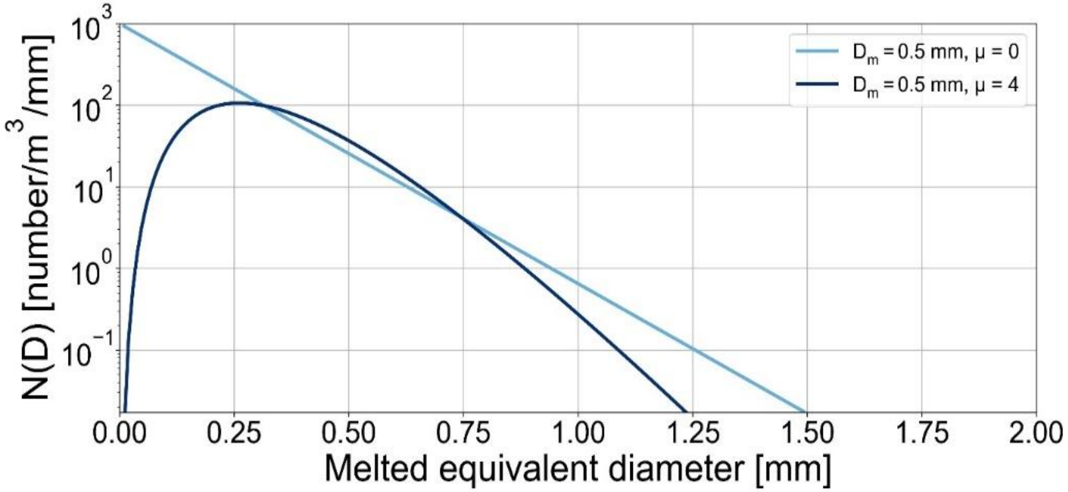




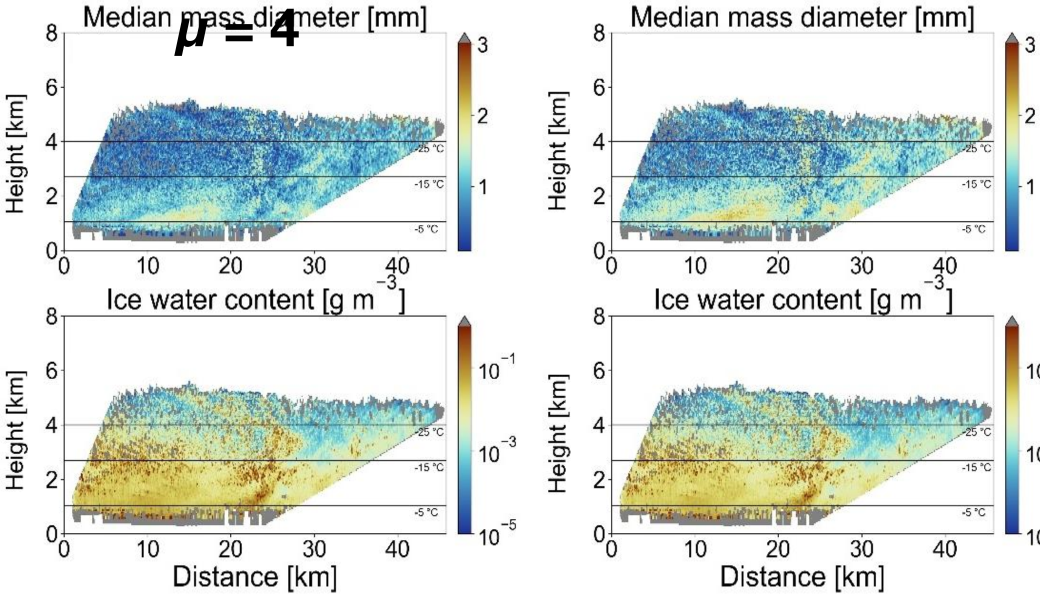
Tetoni et al. (2022), AMT

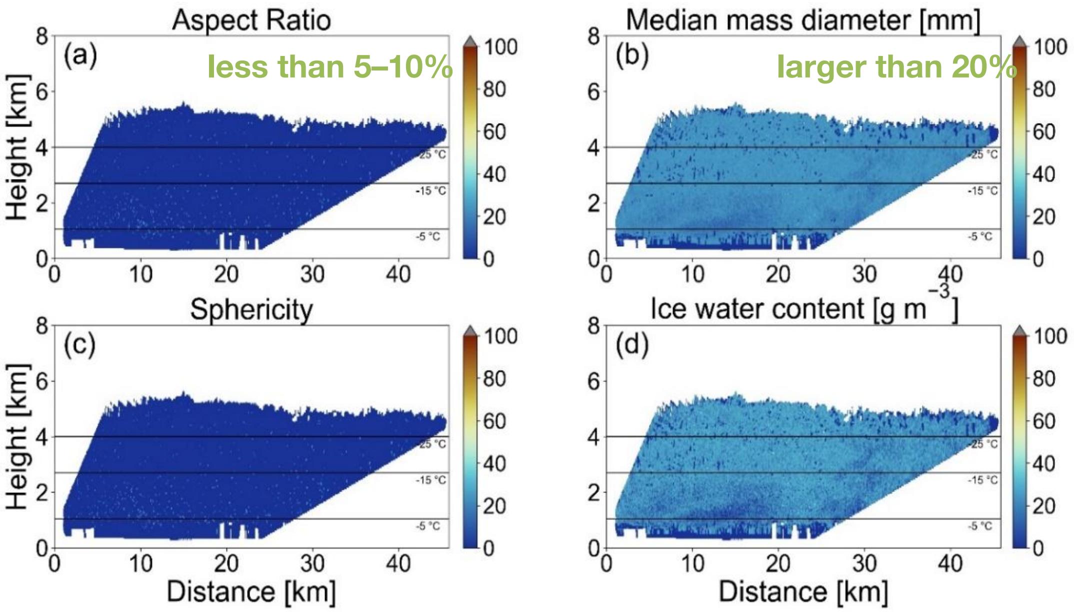
RQ3: Sensitivity studies

Particle size distribution



$$difference = \frac{|result_{\mu=4} - result_{\mu=0}|}{result_{\mu=0}} \cdot 100\ \%$$

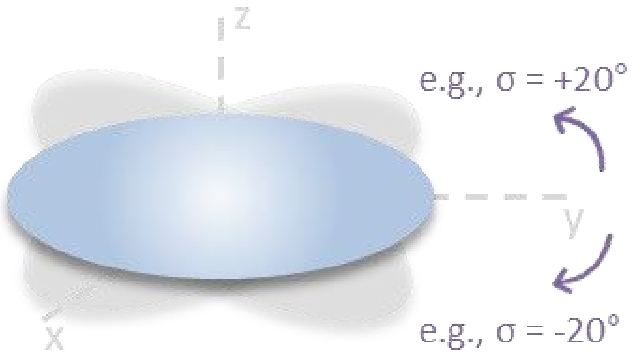




Tetoni et al. (2022), in preparation

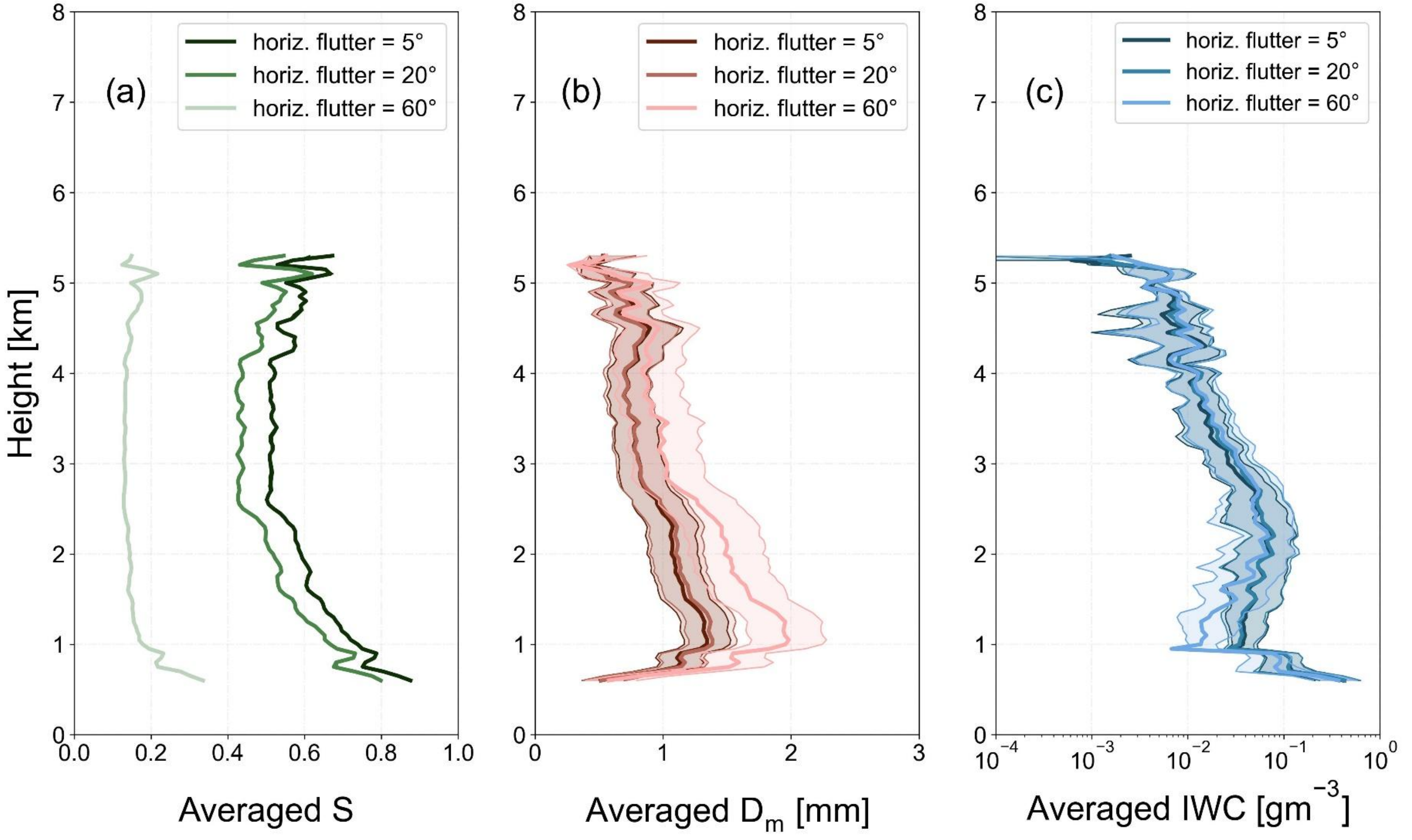
RQ3: Sensitivity studies

Horizontal flutter of ice particles



Average tumbling (σ) of ice particles while falling.

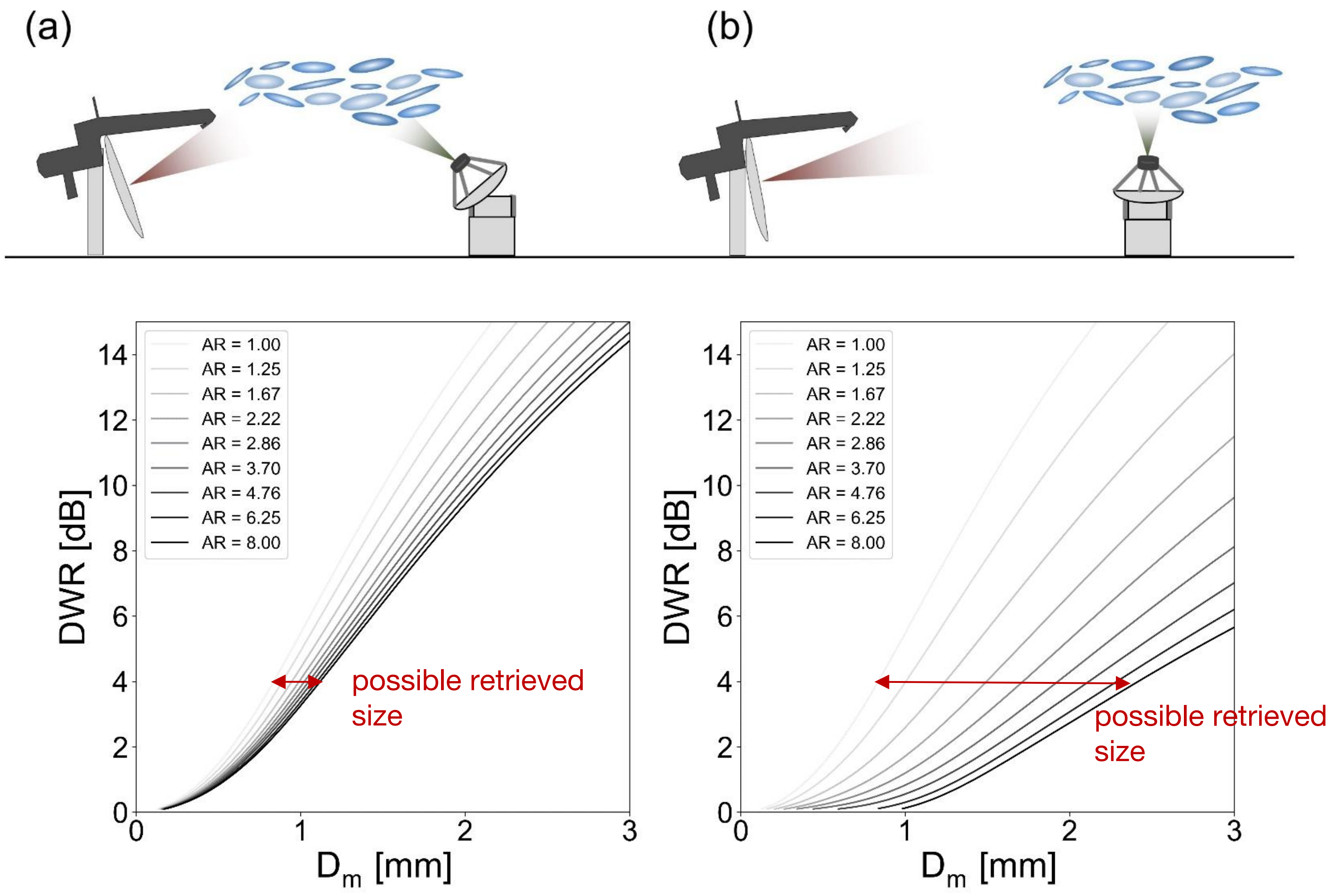
(e.g., σ = 2°–23° according to Melnikov, 2017)



Tetoni et al. (2022), in preparation

RQ3: Sensitivity studies

Contribution of polarimetry



Above MIRA-35:

- the ambiguity for the different AR values is larger
- ZDR constrains the shape
- ZDR helps in the size retrieval

Tetoni et al. (2022), AMT

Take-home message

RQ1: Synergy of multiwavelength and polarimetry is possible!

polarimetric measurements, **aspect ratio** can be constrained
ZDR provides **shape** information and **contributes to the size** retrieval **above cloud radar**

RQ2,3: Simple particle model seems to work but the assumptions for ice spheroids should be carefully selected!

m(Dmax): **most substantial**, need the most representative to be found.

PSD: **effect** on the retrieved **size and mass**, low impact on the retrieved shape.

horizontal flutter: **large effect on shape** for large tumbling, also affects the size and mass.

oblate or prolate: **significant for the size retrieval**, less important for the mass retrieval.

Some of these assumptions will be constrained in IcePolCKa Phase II.

Publications

1. Tetoni, E., Ewald, F., Hagen, M., Köcher, G., Zinner, T., and Groß, S.: Retrievals of ice microphysical properties using dual-wavelength polarimetric radar observations during stratiform precipitation events, Atmos. Meas. Tech., 15, 3969–3999, https://doi.org/10.5194/amt-15-3969-2022, 2022.

2. Tetoni, E., Ewald, F., Hagen, M., +++, and Groß, S.: Sensitivity studies on developing an ice microphysics retrieval using dual-wavelength and polarimetric radar observations, in preparation.

3. Köcher, G., Zinner, T., Knote, C., Tetoni, E., Ewald, F., and Hagen, M.: Evaluation of convective cloud microphysics in numerical weather prediction models with dual-wavelength polarimetric radar observations: methods and examples, Atmos. Meas. Tech., 15, 1033–1054, https://doi.org/10.5194/amt-15-1033-2022 , 2022.

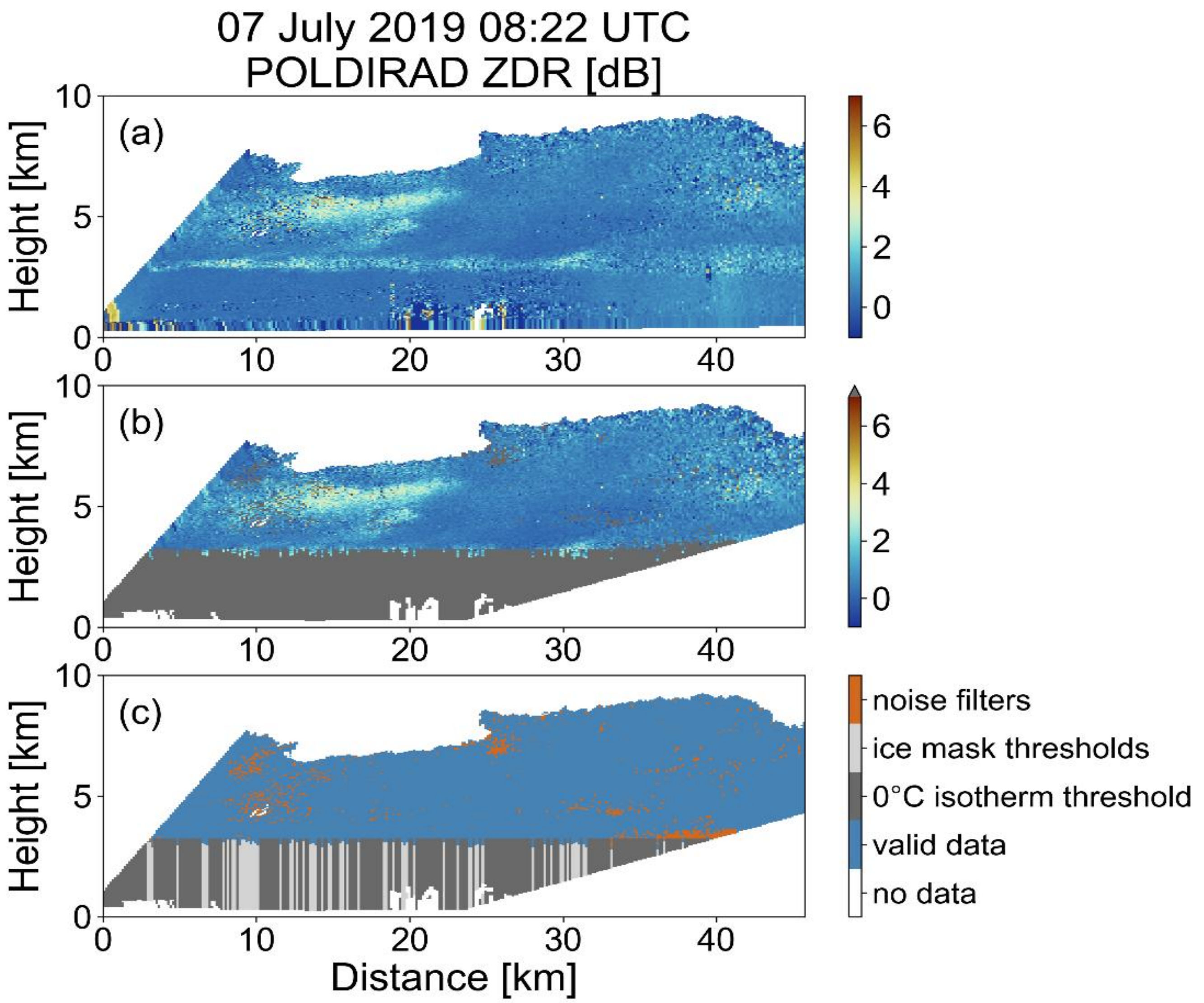
4. Trömel, S., Simmer, C., Blahak, U., Blanke, A., Doktorowski, S., Ewald, F., Frech, M., Gergely, M., Hagen, M., Janjic, T., Kalesse-Los, H., Kneifel, S., Knote, C., Mendrok, J., Moser, M., Köcher, G., Mühlbauer, K., Myagkov, A., Pejcic, V., Seifert, P., Shrestha, P., Teisseire, A., von Terzi, L., Tetoni, E., Vogl, T., Voigt, C., Zeng, Y., Zinner, T., and Quaas, J.: Overview: Fusion of radar polarimetry and numerical atmospheric modelling towards an improved understanding of cloud and precipitation processes, Atmos. Chem. Phys., 21, 17291–17314, https://doi.org/10.5194/acp-21-17291-2021 , 2021.

Thank you for your attention!

RQ1: Combination of two spatially separated radars

Filtering and preprocessing of data

- stratiform cases
  Large features captured by both radar beam
- snowfall cases
  Negligible hydrometeors attenuation
  (also at Ka-band).
- gaseous attenuation
  (ITU formulas + ECMWF ERA5)
- ice mask
- other error sources
  azimuthal calibration, random and systemati
  absolute radiometric calibration
  (±0.5 dBZ POLDIRAD, ±1.0 dBZ MIRA-35)



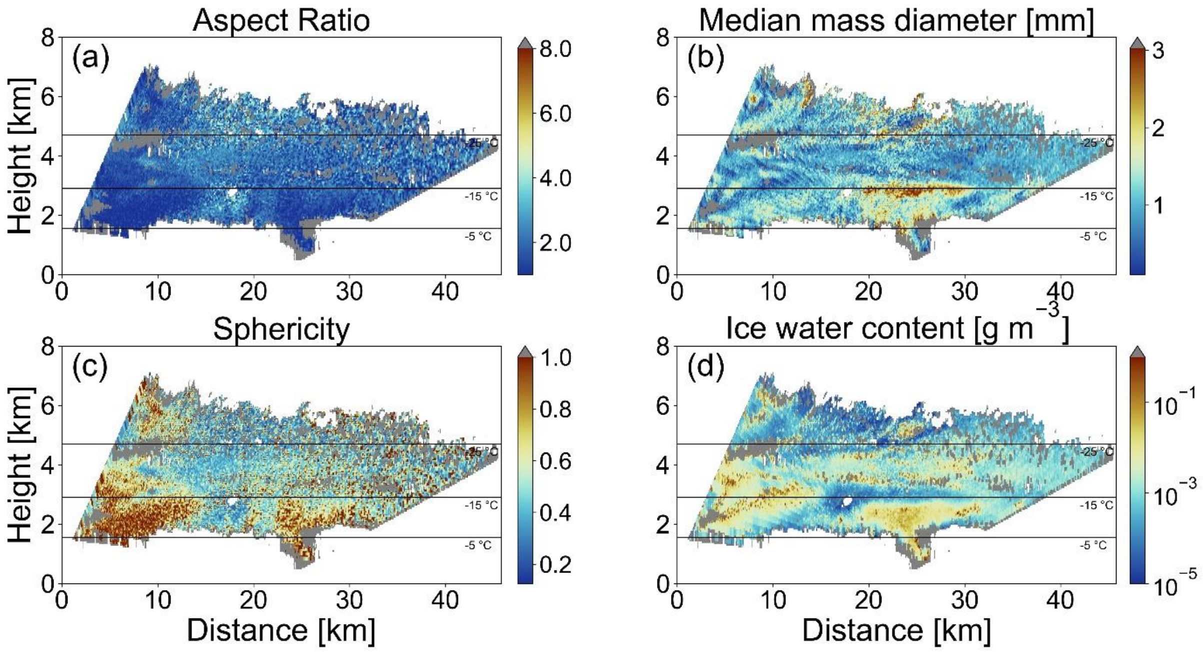
Tetoni et al. (2022), AMT

RQ3: Sensitivity studies

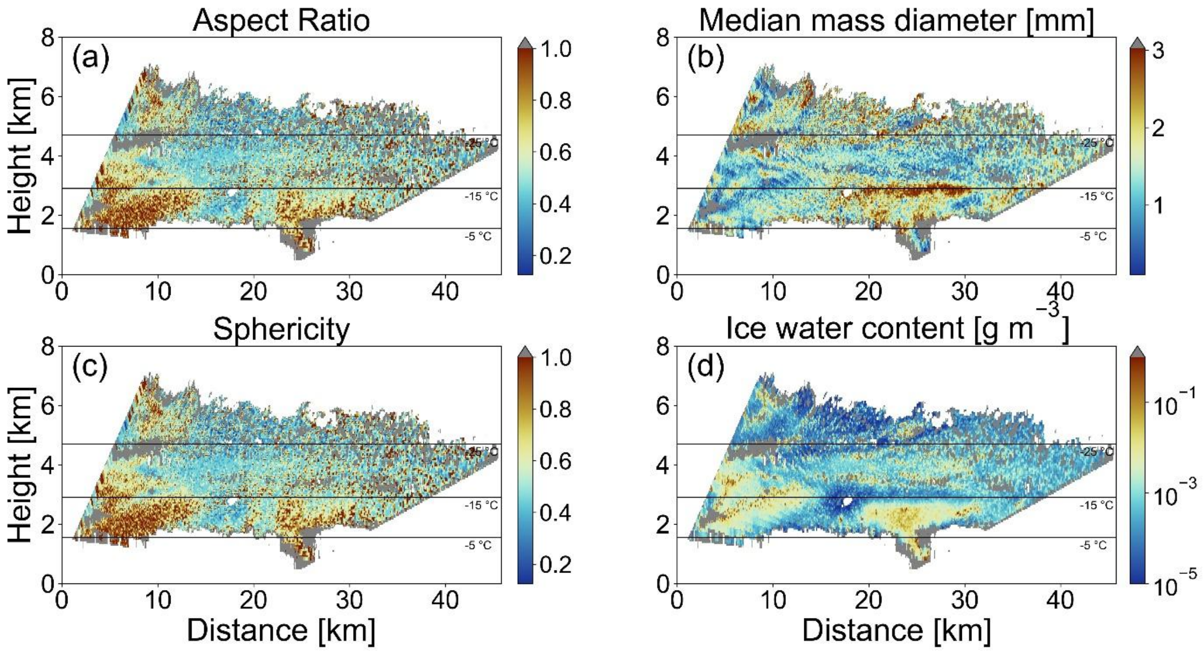
Oblate or prolate assumption

Yang m(Dmax)
Exponential PSD

Oblate ice spheroids



Prolate ice spheroids



Shape assumption	Parameter	RMSE
Oblates	DWR	0.50 dB
	ZDR	0.19 dB
	Z_e	0.20 dB
Horizontally aligned prolates	DWR	0.61 dB
	ZDR	0.25 dB
	Z_e	0.36 dB

Oblate ice spheroids that follow aggregates m(Dmax) and an exponential PSD can better explain our radar measurements.

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Tetoni et al. (2022), AMT

RQ3: Sensitivity studies

Mass-size relation

The averaged IWP data from MODIS (Platnick, S., Ackerman, S., King, M. et al., 2017) was found IWP ~ 90 g m^{-2} .

Ice Water Path (IWP) integrated from IWC.

IWP ~ 46 g m^{-2}

0.5x aggr ρ_{eff}

better agreement when ρ_{eff} = 1x ρ_{eff} aggregates

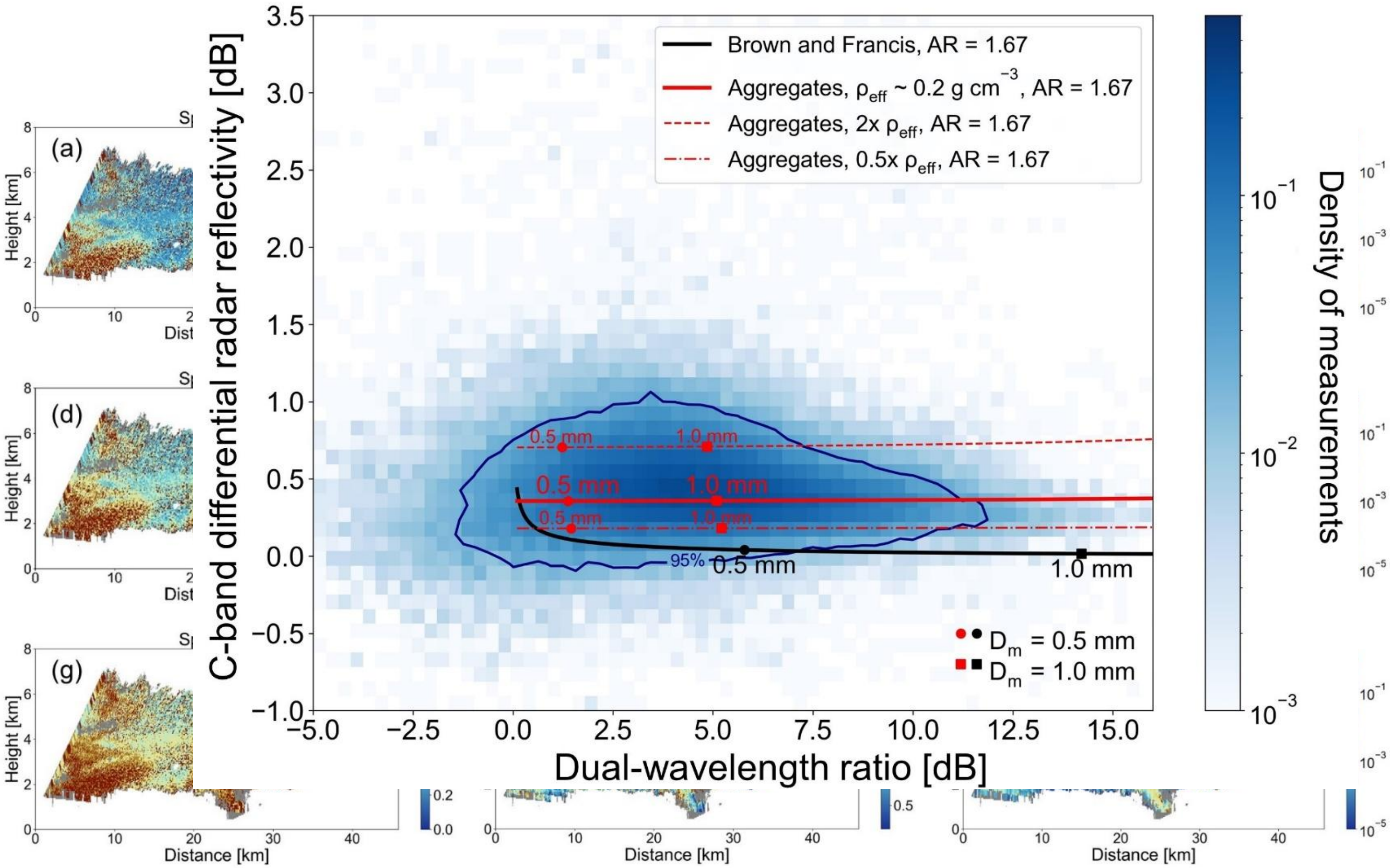
IWP ~ 83 g m^{-2}

1x aggr ρ_{eff}

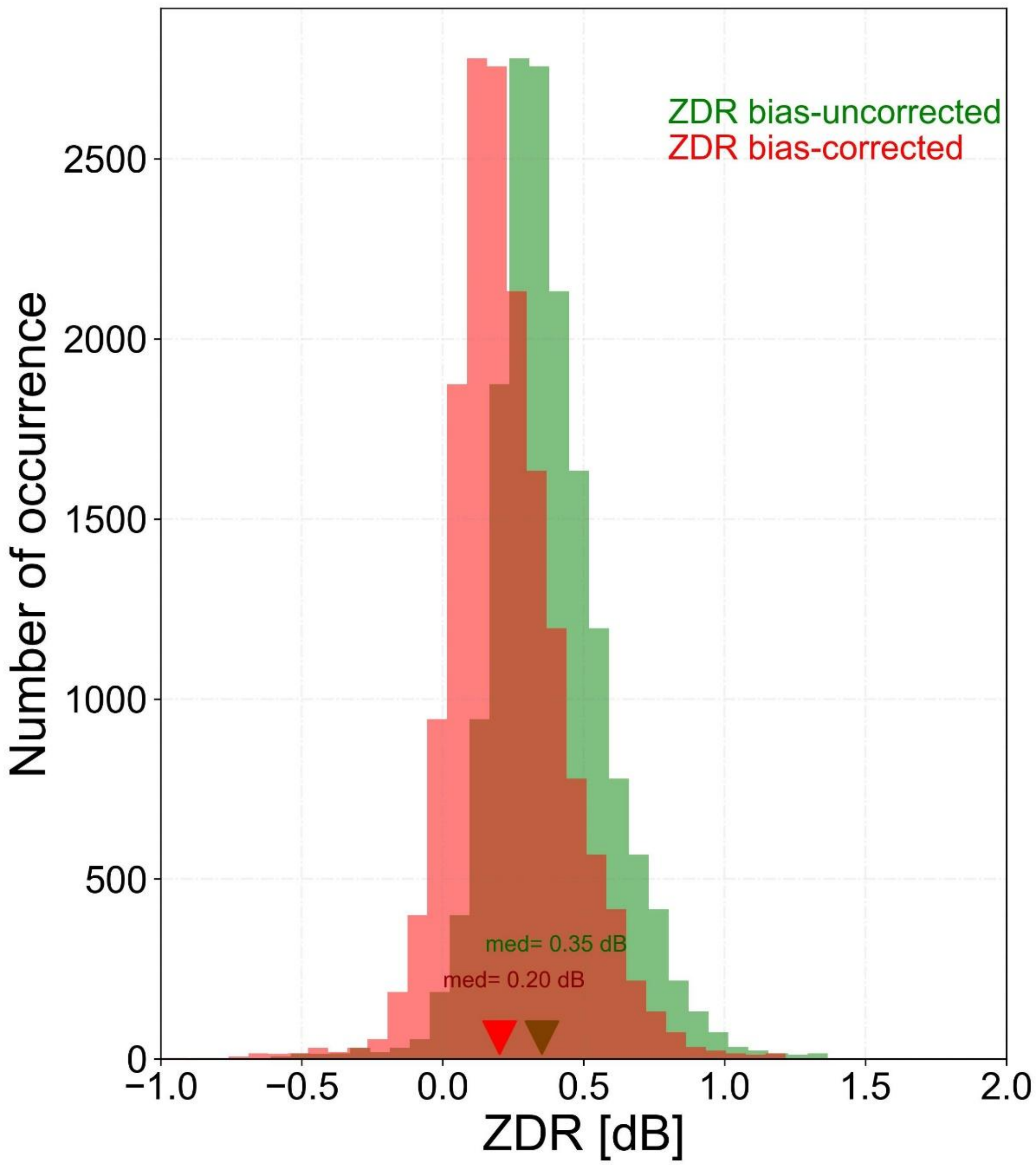
IWP ~ 137 g m^{-2}

2x aggr ρ_{eff}

low elevation angles 0°–5°



Tetoni et al. (2022), AMT



Tetoni et al. (2022), AMT

ZDR bias:

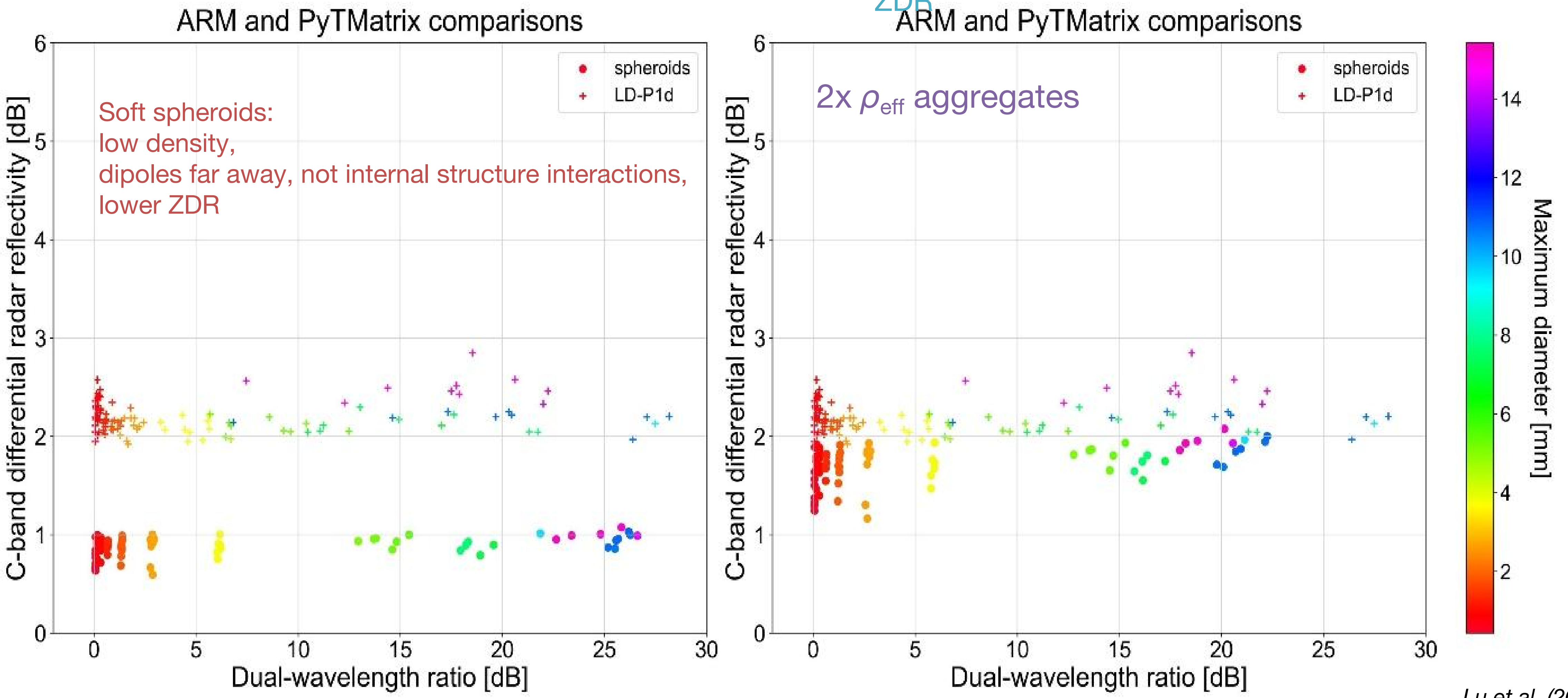
additional calibration validation following the Ryzhkov and Zrnic (2019) approach

Measurements were filtered for large Ze regions and intermediate temperatures for dry and large aggregates

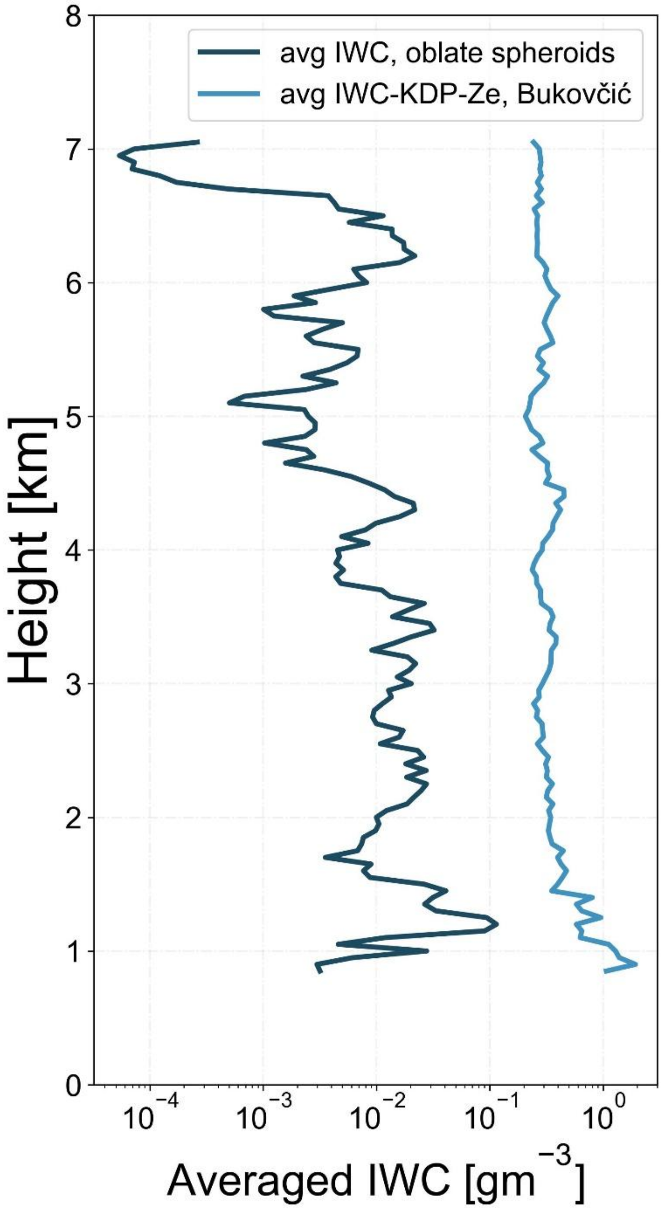
RQ3: Sensitivity studies

Spheroid model

Our soft spheroids showed 1 dB lower values than ARM. Doubled ρ_{eff} spheroids could match ARM ZDR



Lu et al. (2016)



$$\mathrm{IWC}(K_{\mathrm{DP}}, Z) = 0.71 K_{\mathrm{DP}}^{0.65} Z^{0.28}$$

Bukovčić et al. (2018)

We used our C-band radar KDP along with Z_e to calculate IWC and IWP.

Bukovčić yields a much higher mean IWP (~ 2308 g m^{-2}) compared to our IWP (~ 80 g m^{-2}).

Their method would assume a much smaller melted equivalent particle diameter (~300 µm vs. our retrieved ~1 mm).