EGU23-5000:

Airborne observations of riming in arctic mixed-phase clouds during HALO-$(AC)^3$

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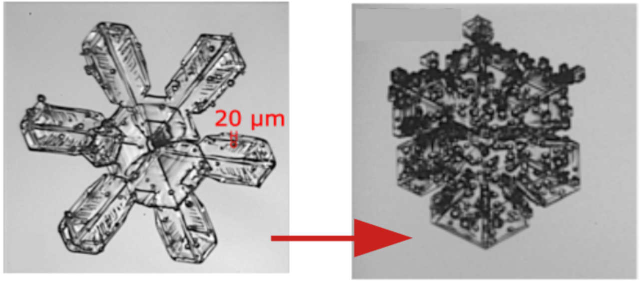
Sharing is encouraged

abstract & slides

Riming in arctic mixed-phase clouds (MPC)

- Supercooled **liquid** droplets freeze onto **ice** crystals
- Impact on
  - density, shape, mass, fall speed, scattering properties, …
- Research mainly qualitative



Adapted from Waitz et al. (2022)

D_{max} … maximum dimension (m)
m_{rime} … rime mass (kg)
m_g … mass of D_{max} equivalent graupel (kg)
ρ_{rime} … rime density $(700\ kg/m^3)$

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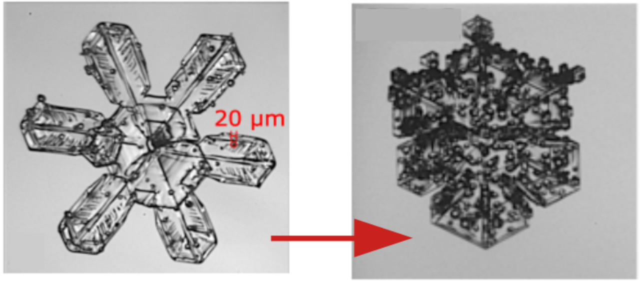
- In this study:
  - **Normalized rime mass M** (Seifert et al., 2019)

$$M = \frac{m_{rime}}{m_g}$$

$$m_g = \frac{\pi}{6} \rho_{rime} D_{max}^3$$



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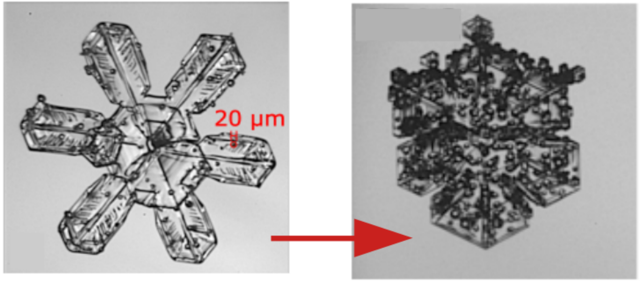

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How can we derive M from airborne radar and in situ measurements?

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Ice particle properties depend on riming

Normalized rime mass $M = \frac{m_{rime}}{m_g}$

Interlinked with:

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- Mass size relationship $m(D_{max}) = a_m \cdot D_{max}^{b_m}$
- Particle shape
- Scattering properties
  - Self-Similar Rayleigh-Gans Approximation (SSRGA) (Hogan and Westbrook, 2014; Hogan et al., 2017)

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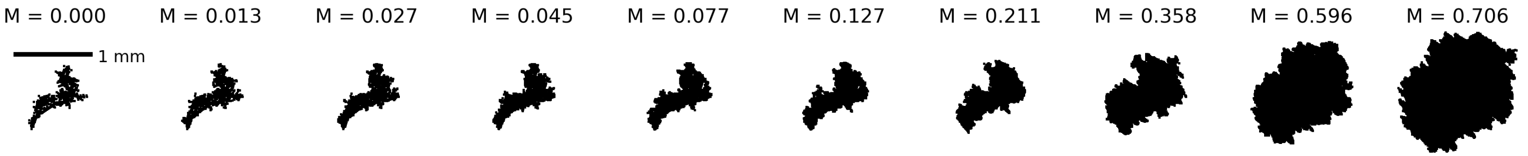
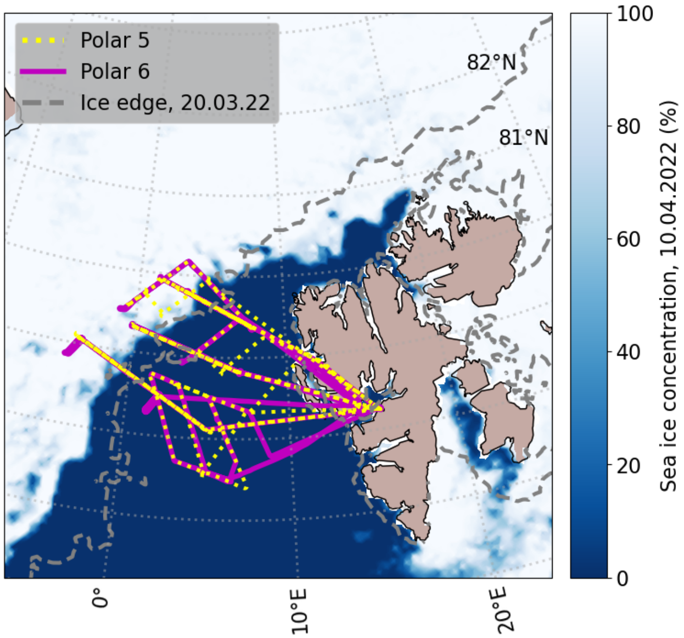
► Parameterizations based on model calculations (Maherndl et al., 2023a, b)



(Collocated) Flights during HALO-(AC)³

- March / April 2022, Svalbard



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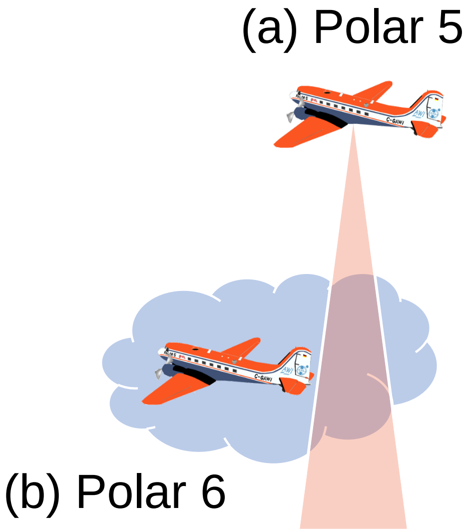

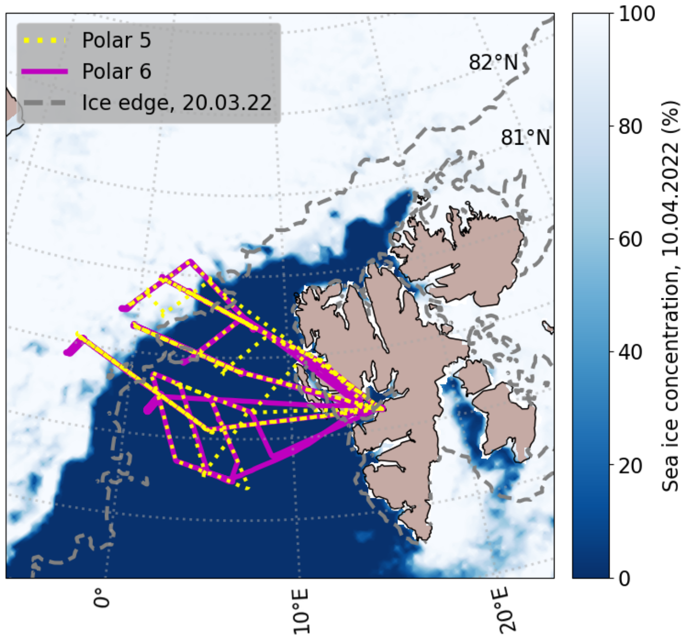

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(a) Polar 5

(b) Polar 6

Radar

(a) Remote sensing → Polar 5

- 94 GHz FMCW radar
- Property: reflectivity Z_e

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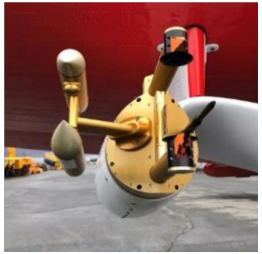
Radar

CDP+CIP



PIP

(a) Remote sensing → Polar 5

- 94 GHz FMCW radar
- Property: reflectivity Z_e

(b) Cloud probes → Polar 6

- **CDP, CIP, PIP**
- Properties:
  - **PSD** (CDP+CIP+PIP)
  - **area**, **perimeter** (CIP+PIP)

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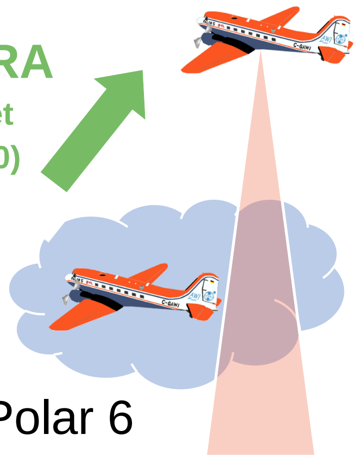
(a) Polar 5

PAMTRA

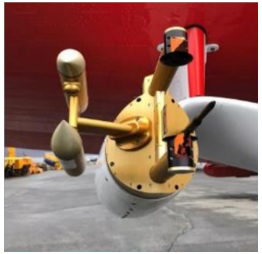
(Mech et al., 2020)



(b) Polar 6

Radar

CDP+CIP



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Methods

I. COMBINED RETRIEVAL

II. IN SITU SHAPE

Step 1

Polar 5: radar

Radar reflectivity Z_e

Polar 6: cloud probes

PSD_{ice} and PSD_{liquid}

Step 2

Polar 5: radar

Radar reflectivity Z_e

Polar 6: cloud probes

PSD_{ice} and PSD_{liquid}

Collocated data set:

- Max. temporal offset 5 min
- Max. spatial offset 5 km
- Moving average 30 s

Step 3

Collocated data set:
- Max. temporal offset 5 min
- Max. spatial offset 5 km
- Moving average 30 s

Polar 5: radar

Radar reflectivity Z_e

Polar 6: cloud probes

PSD_{ice} and PSD_{liquid}

↓

Radar forward simulator **(PAMTRA)**

- Liquid:
  - Mie scattering, spheres
- Ice:
  - Parameterizations depending on M

↓

Simulated Z_e at Polar 6 flight altitude

Step 4

Collocated data set:

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- Max. spatial offset 5 km
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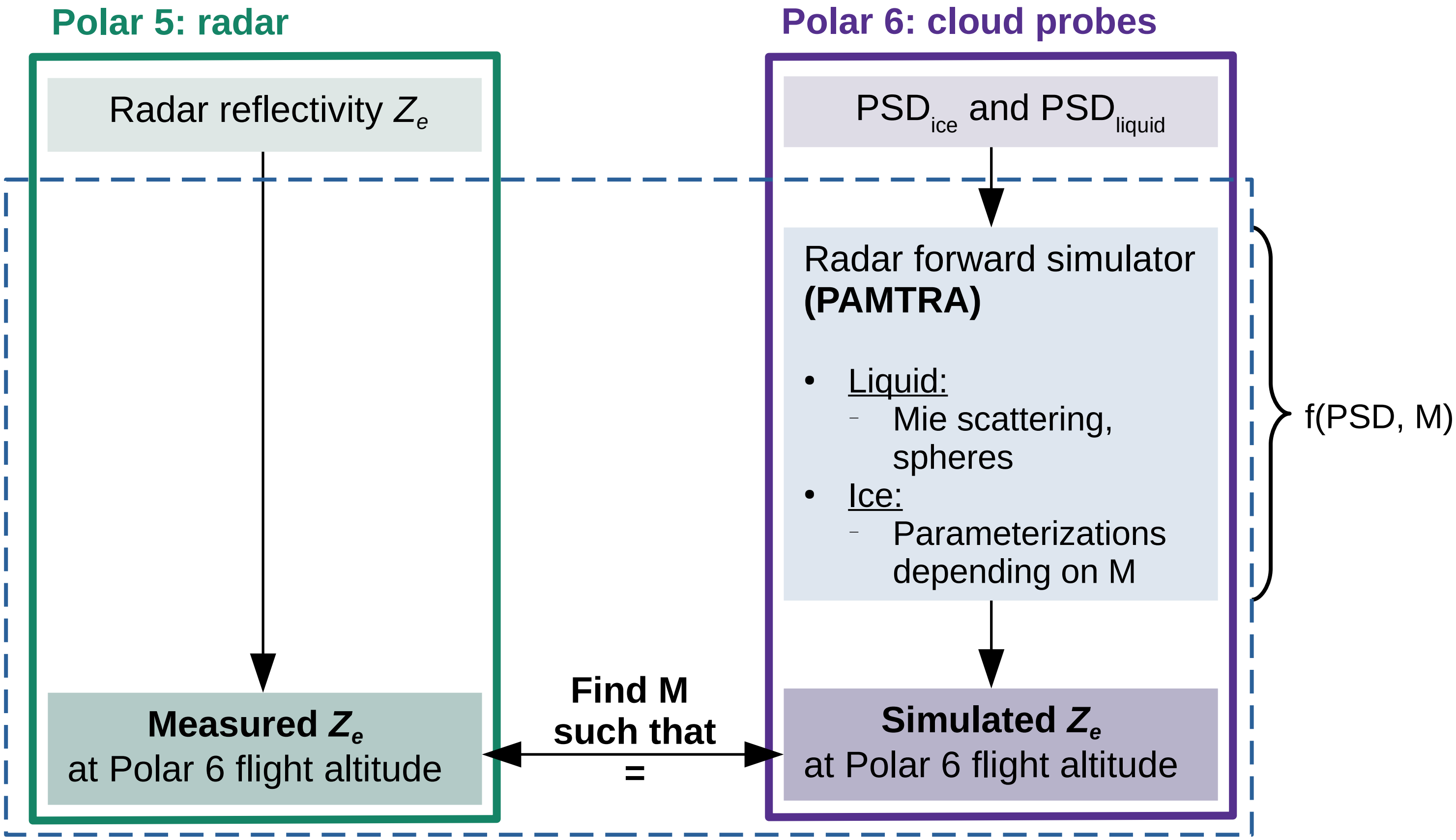

Methods

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II. IN SITU SHAPE

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Particle shape as proxy for riming

- The rounder the more riming
- **Complexity χ** (Garrett and Yuter, 2014)

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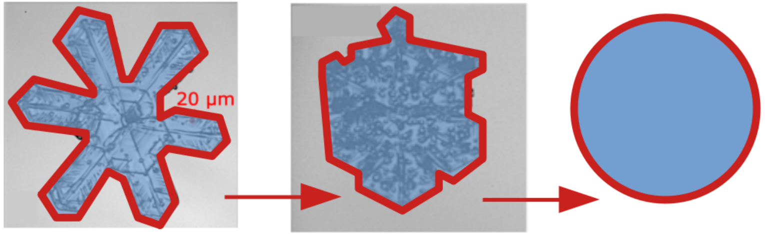

Figures from Waitz et al., 2021

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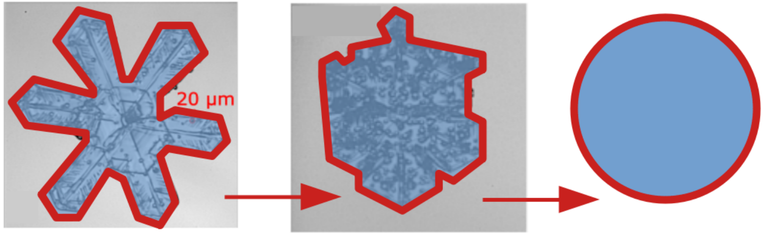


Figures from Waitz et al., 2021

- Empirical relation of **χ** to **M** and **size (D_{max})** derived from simulated rimed aggregates (of dendrites)

But: method can only applied to particles larger 14 px

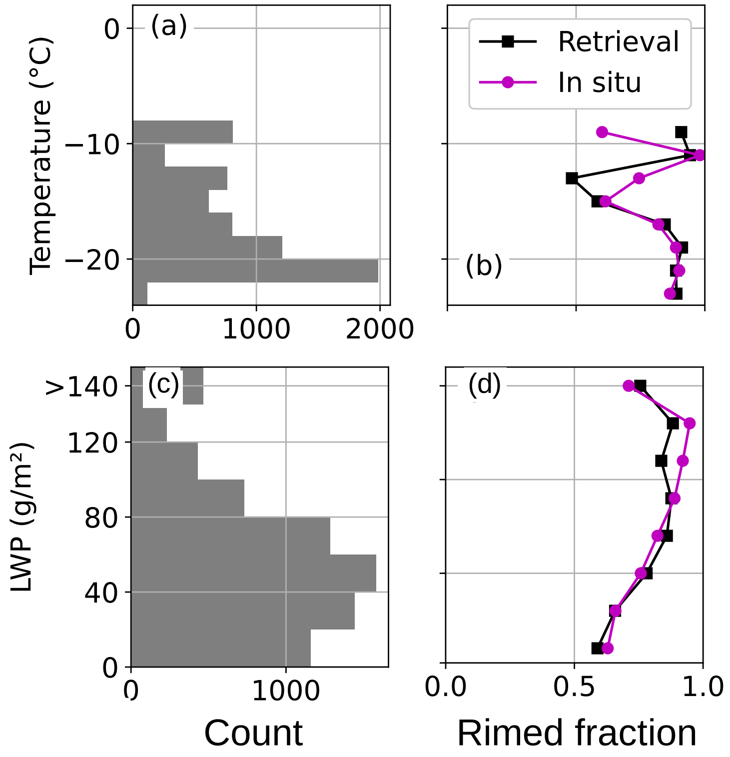
Results

RIMING DURING HALO-(AC)³

Occurance of riming

Only collocated segments

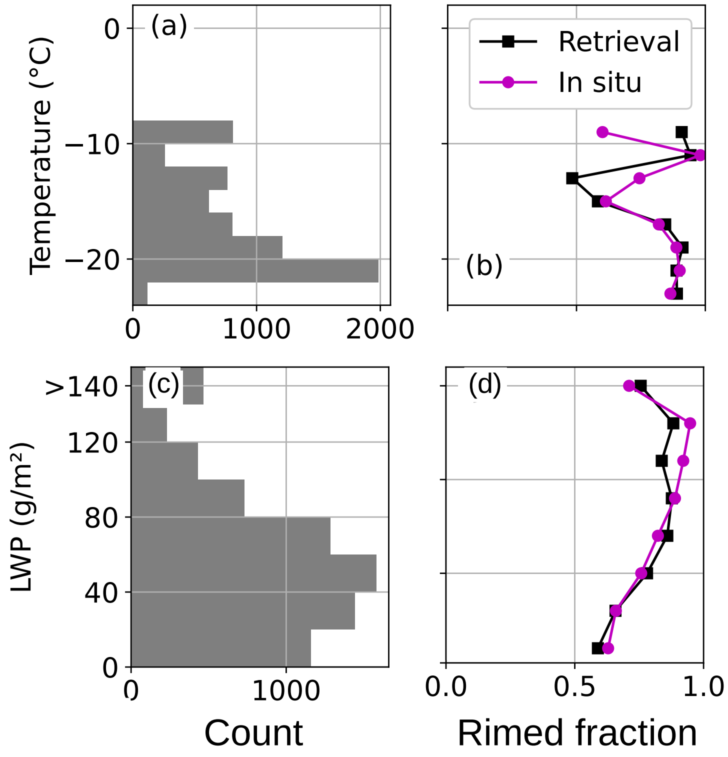
- Rimed fractions (M ≥ 0.01)
  - **Combined:** 77 %
  - **In situ:** 75 %



Occurance of riming

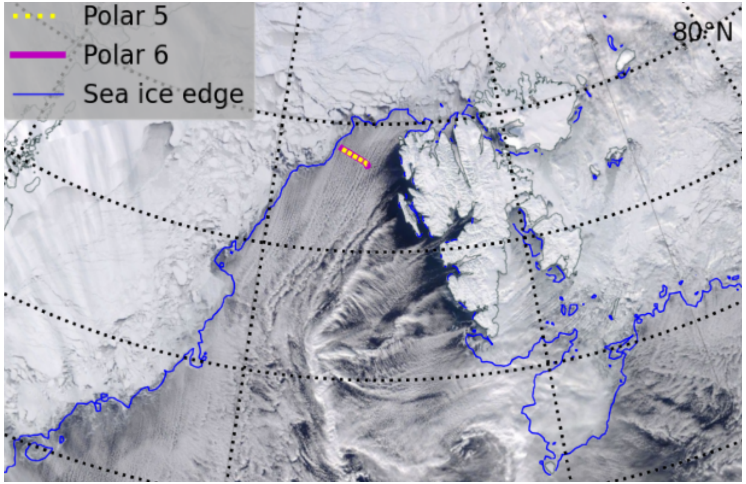
Only collocated segments

- Rimed fractions (M ≥ 0.01)
  - **Combined:** 77 %
  - **In situ:** 75 %
- Mean
  - **Combined:** 0.027
  - **In situ:** 0.028
- Median [25 %, 75 % quantiles]
  - **Combined:** 0.018 [0.010, 0.032]
  - **In situ:** 0.016 [0.009, 0.028]



Case study

- **01 April** ~ 11:25 – 11:35 UTC:
- Collocated flight segment over open ocean



MODIS Terra (NASA worldview)

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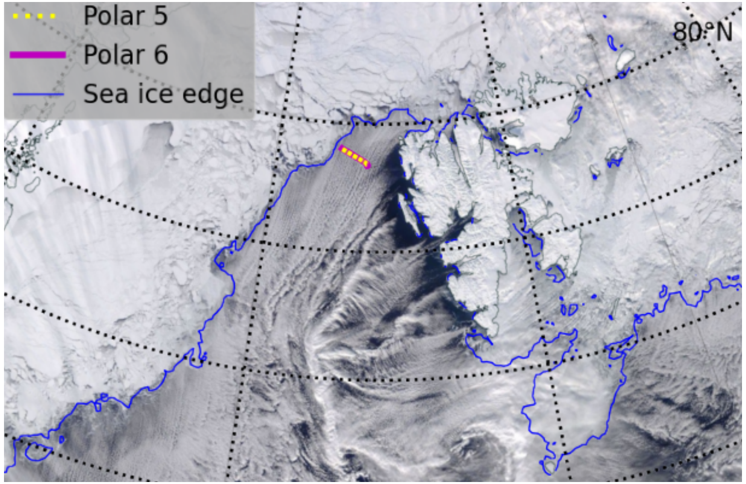

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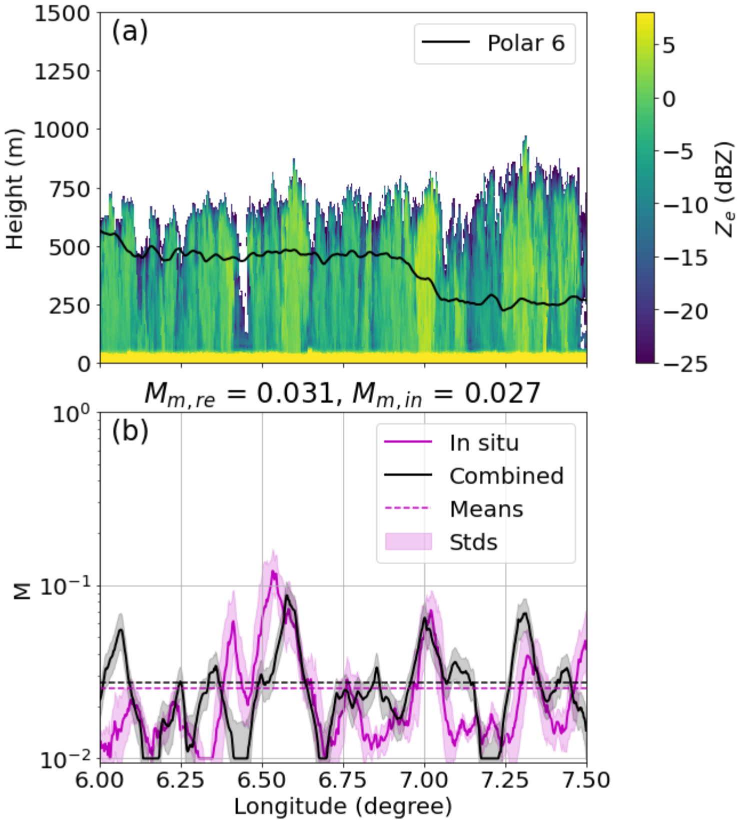

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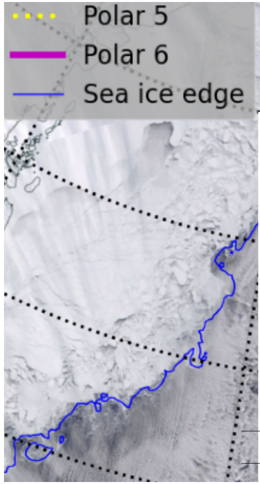

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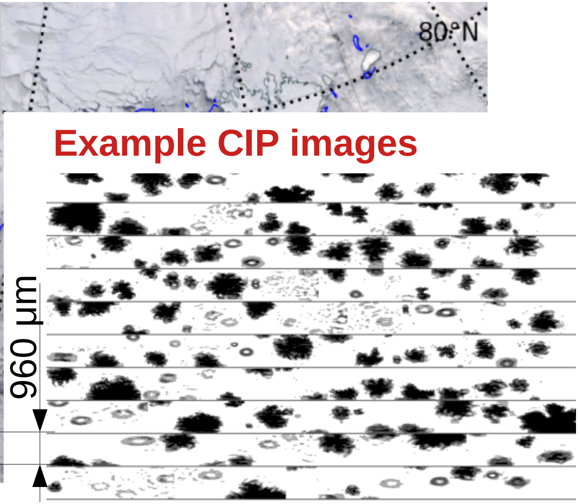

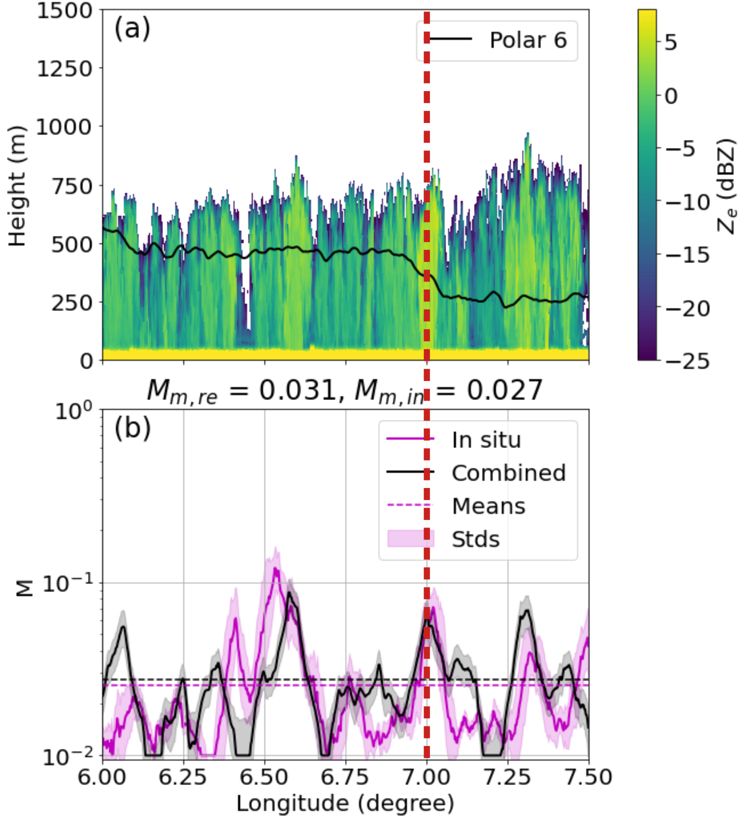

Summary

- Two methods to derive normalized rime mass M:
  - **Combined method** (radar + in situ PSD retrieval)
  - **In situ method** (in situ shape)

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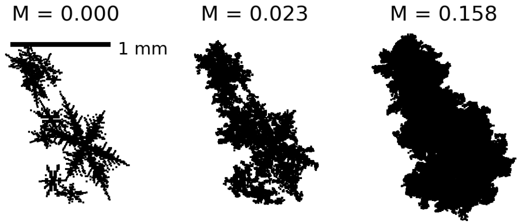
- Generated large data set of simulated rimed aggregates
  - Parameterizations of physical and scattering properties as function of M
  - **Maherndl et al., 2023a** (QJRMS, in revision)
  - **Maherndl et al., 2023b** (zenodo data set)



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Manusscript to be submitted to AMT soon

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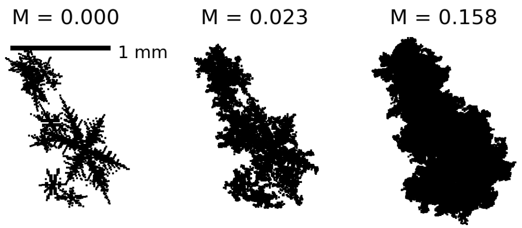

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THANK YOU

Nina Maherndl
Institute for Meteorology (LIM)
research group **drOPS**
clou**D** and p**R**ecipitation **O**bservations for **P**rocess **S**tudies

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References

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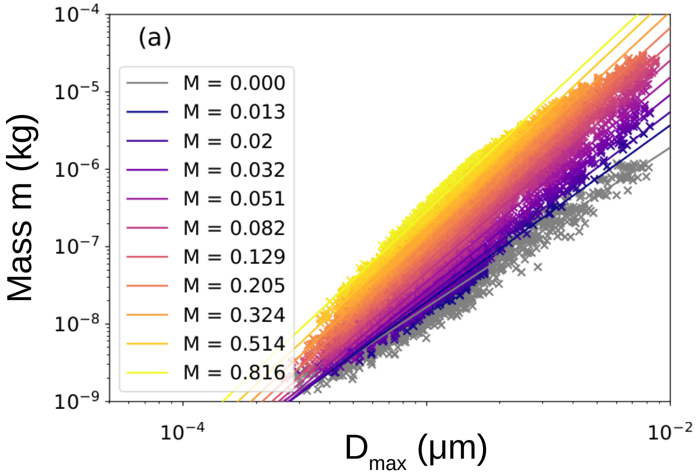
Appendix

I. PARAMETERIZATIONS
II. IN SITU METHOD
III. COMPARISION

Model calculations

Aggregation and riming model (Leinonen, 2013; Leinonen & Moisseev, 2015; Leinonen & Szyrmer, 2015)

- Monomer crystals
  - From exponential PSD (mean 100 / 200 µm)
  - Resolution 20 µm
- Aggregation followed by riming



snowScatt (Ori et al., 2021)

- Derive SSRGA parameters for modeled snowflakes for different amounts of riming

empirical relations

SSRGA parameter $\Leftrightarrow M$

Results summarized in Maherndl et al. (2023) → in revision (QJRMS)

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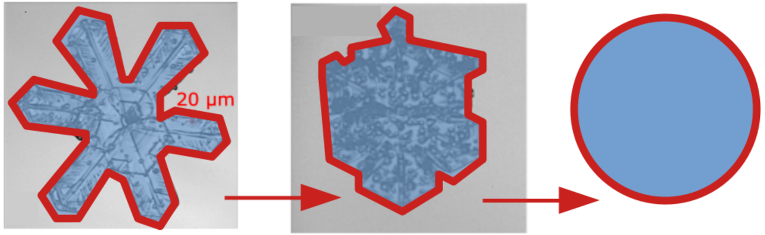

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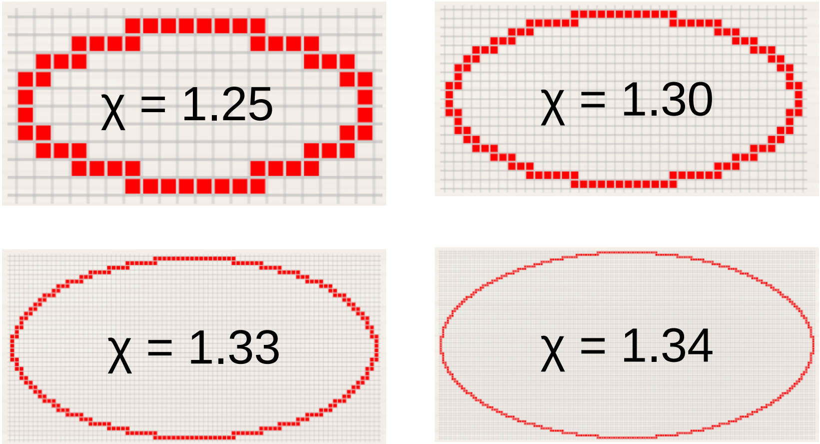

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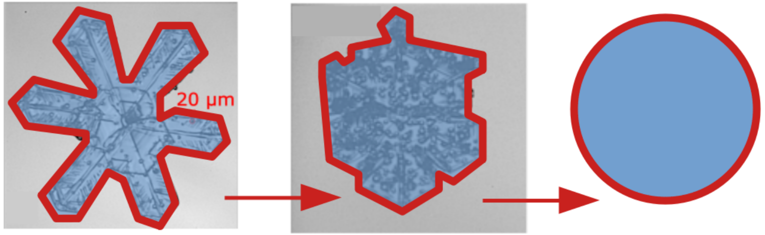

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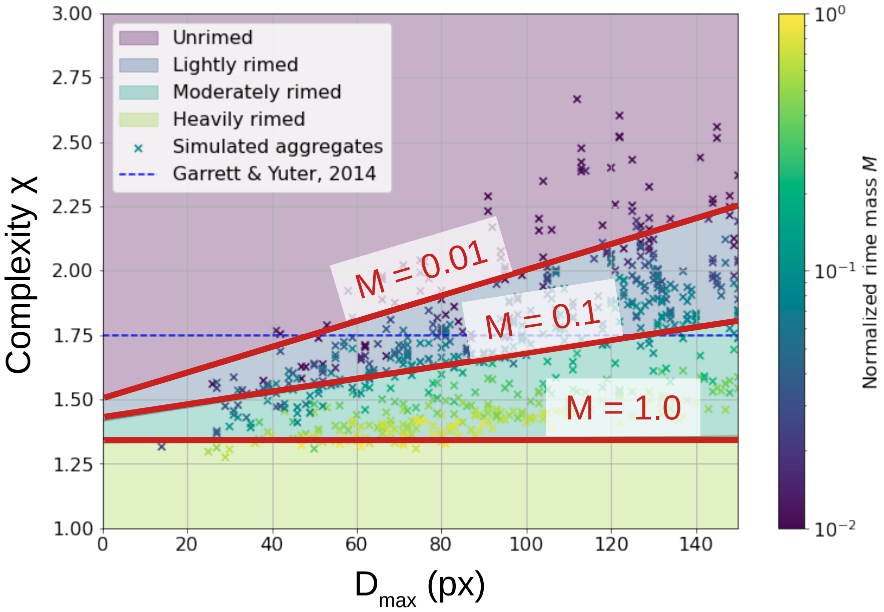

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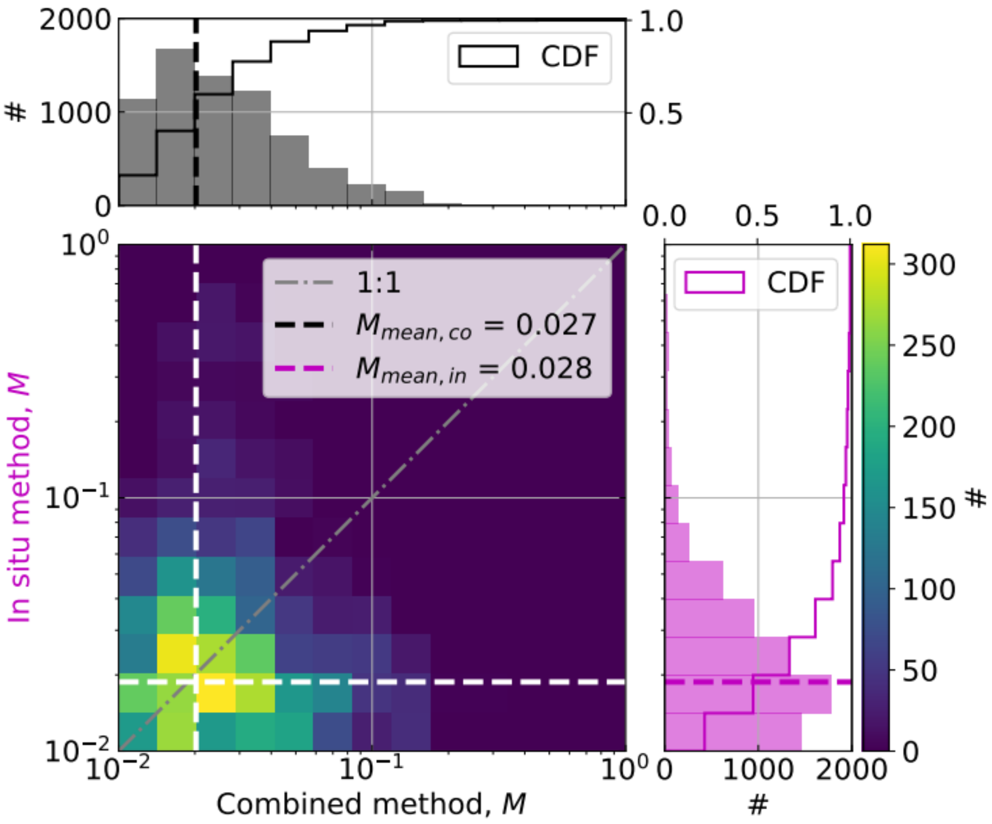
Comparison

Only collocated segments

- 2d histogram
- Individual distributions
- CDF … cumulative distribution function



Comparison of methods

	Combined method	**In situ method**
Polar 5 instruments and data	MiRAC: • Radar reflectivity $\mathbf{Z_e}$	-
Polar 6 instruments and data	CDP, CIP and PIP: • Combined **PSD**	CIP and PIP: • **Area** • **Perimeter**
Particle size range	2 – 6400 µm	210 – 960 µm, 1400 – 6400 µm
Collocation	yes	no
Limitations	In situ measurements need to be representative of radar volume	Needs good statistics >7 particles per second in size range