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Retrieving riming in arctic mixed phase clouds from collocated remote sensing and in situ aircraft measurements during ACLOUD

abstract:

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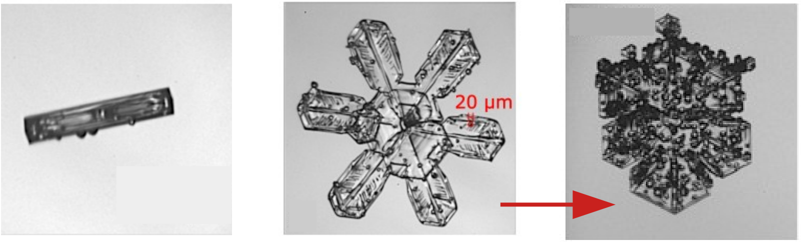
ARCTIC MIXED PHASE CLOUDS (MPC)

- **Ice** crystals + supercooled **liquid** water droplets
- **Long life times** (Morrison et al., 2012)
- **Ice** crystal formation & **growth** processes still poorly understood

Riming

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

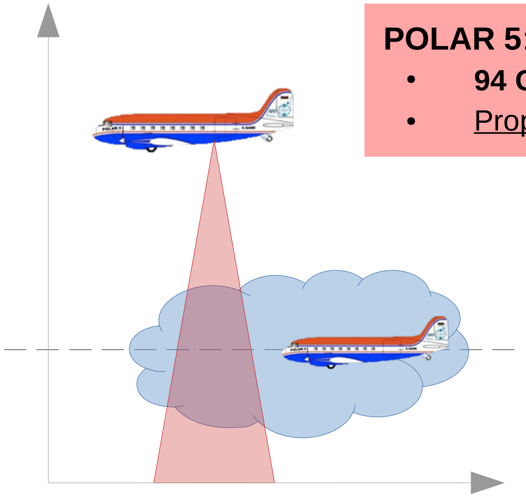


Figures from Waitz et al., 2021

Reseach Question: **How can we derive a measure for riming from combined airborne radar and in situ measurements?**

Arctic **CL**oud **O**bservations **U**sing airborne measurements during polar **D**ay - **ACLOUD**

- (AC)3 **aircraft** measurement campaign
- **May/June** 2017, Longyearbyen/Svalbard
- Collocated flights with **Polar 5 & 6**



POLAR 5: remote sensing
- **94 Ghz FMCW radar**
- Property: **Z_e**

PAMTRA
- **P**assive and **A**ctive **M**icrowave radiative **TRA**nsfer tool (Mech et al., 2020)

POLAR 6: optical cloud probes
- **S**mall **I**ce **D**etector (**SID-3**), **C**loud **D**roplet **P**robe (**CDP**), **C**loud **I**maging **P**robe (**CIP**)
- Properties: **PSD**, **circularity** (CIP)

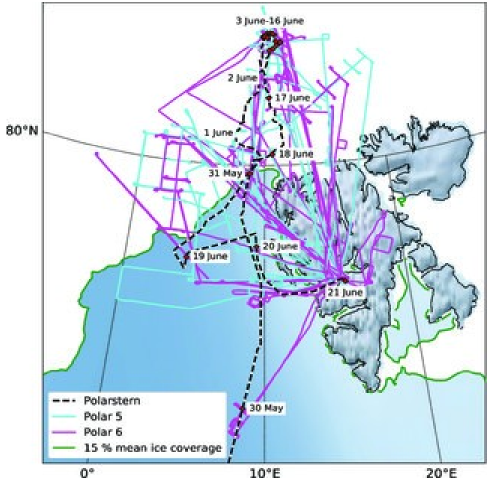


Figure from Wendisch et al., 2019

Figure: https://www.awi.de/expedition/flugzeuge/polar-5-6.html

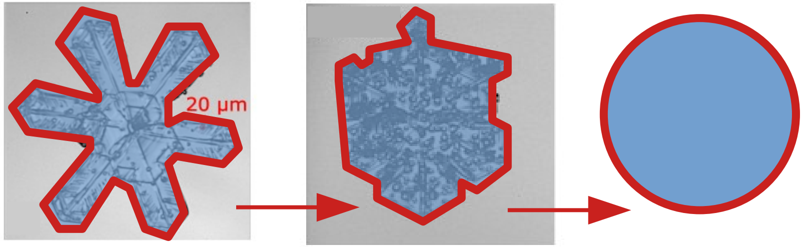
D_{max} ... maximum dimension (m)
m_{rime} ... rime mass (kg)
m_g ... mass of D_{max} equivalent graupel (kg)
ρ_{rime} ... rime disity $(700\, kg/m^3)$

HOW TO OBTAIN A MEASURE FOR RIMING?

Normalized rime mass M (Seifert et al., 2019) $M = \frac{m_{rime}}{m_g}$ $m_g = \frac{\pi}{6} \rho_{rime} D_{max}^3$

Interlinked with:

- **Mass size relationship** $m(D_{max}) = a_m \cdot D_{max}^{b_m}$
- Particle shape: $circularity = \frac{perimeter^2}{4\pi area}$
- Scattering properties
  - **S**elf-**S**imilar **R**ayleigh-**G**ans **A**pproximation (**SSRGA**) (Hogan and Westbrook, 2014; Hogan et al., 2017) → 5 parameters: $\alpha_{eff}, \kappa, \beta, \gamma, \zeta_1$



Figures from Waitz et al., 2021

→ **model calculations...**

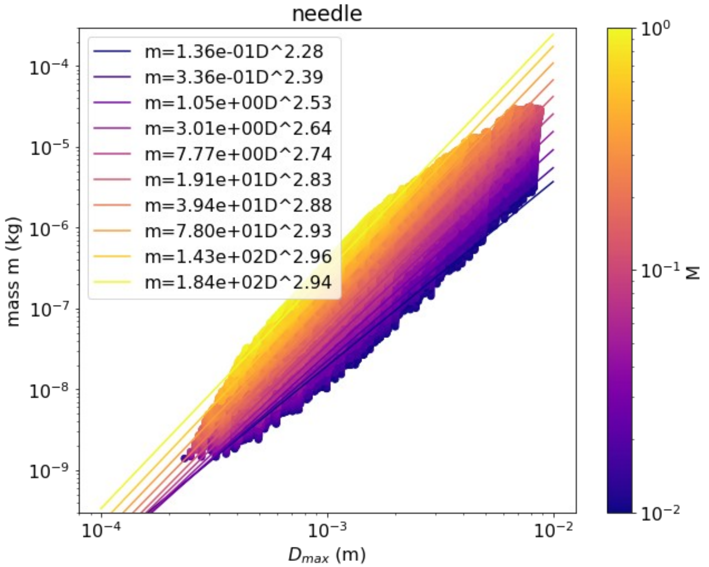
MODEL CALULATIONS

M=0 M=0.01 M=0.05 M=0.1 M=0.3

<u>Aggregation and riming model</u>

(Leinonen, 2013; Leinonen & Moisseev, 2015; Leinonen & Szyrmer, 2015)

- Aggregation followed by riming
- Allows to observe growth history of individual snowflakes
- Monomer crystals from exponential PSD with mean diameter of 100 / 200 µm
  - Dendrites, needles, plates, rosettes or columns
- Resolution 20 µm



<u>snowScatt</u> (Ori et al., 2021)

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

empirical relations

$$\alpha_{eff}, \kappa, \beta, \gamma, \zeta_1 \Leftrightarrow M$$

RETRIEVING M WITH OPTIMAL ESTIMATION

- Find $\boldsymbol{a_m}$, $\boldsymbol{b_m}$, $\boldsymbol{M}$ such that measured and simulated $\mathbf{Z_e}$ match
- Use measured **circularity** to contrain problem

Prior from model calculations

Forward operator:

(1) **PAMTRA** → $\mathbf{Z_e}$

- $m(D_{max}) = a_m \cdot D_{max}^{b_m}$
- In-situ PSD
- Mie and SSRGA(*M*)

(2) **Slope** $k = p_1 \cdot \log(M) + p_2$

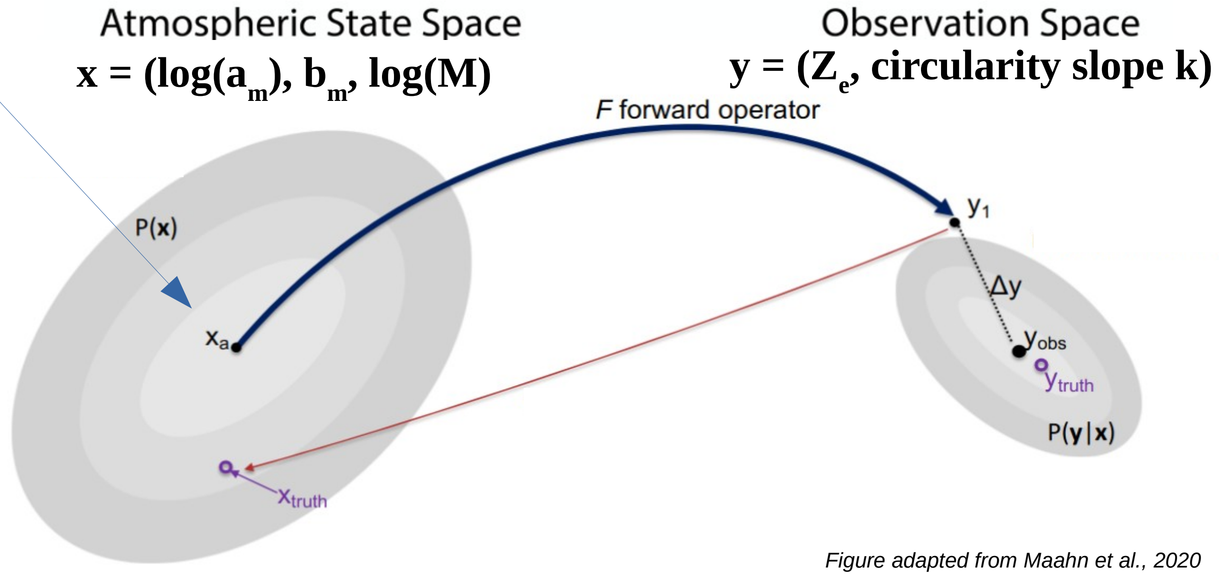
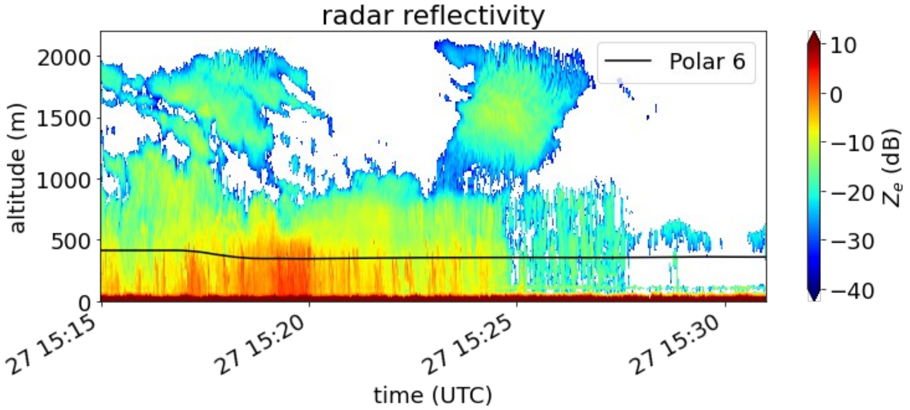


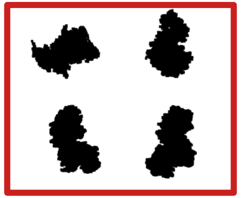
Figure adapted from Maahn et al., 2020

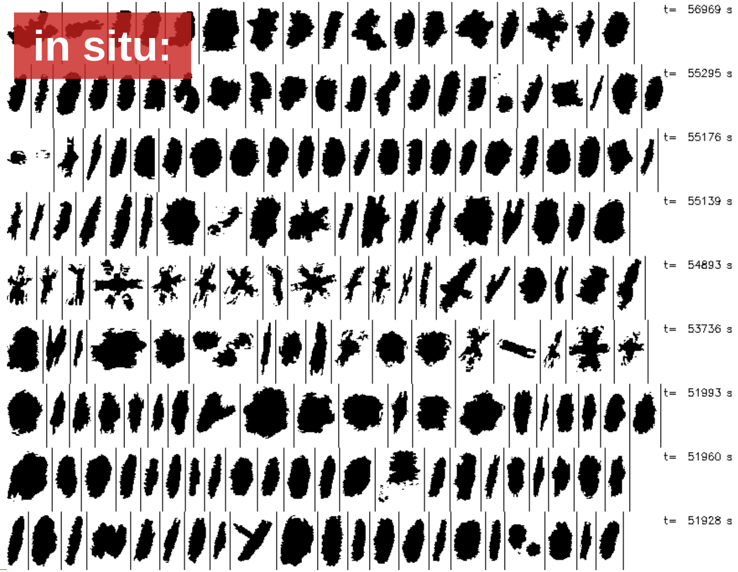


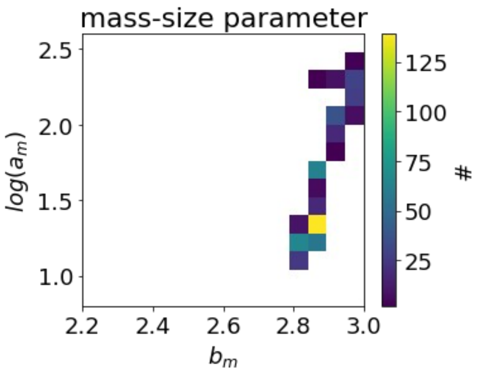
ACLOUD CASE STUDY 1

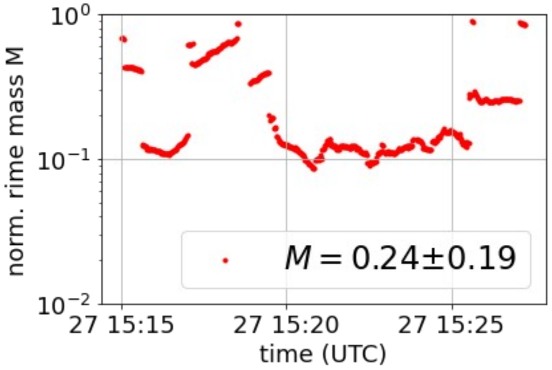
- <u>Flight 07</u>: 27.05.2017, 15:15-15:35 UTC
- In situ images show signatures of **riming**
- Retrieval results:
  - Realistic *M* values
  - a_m, b_m high compared to literature

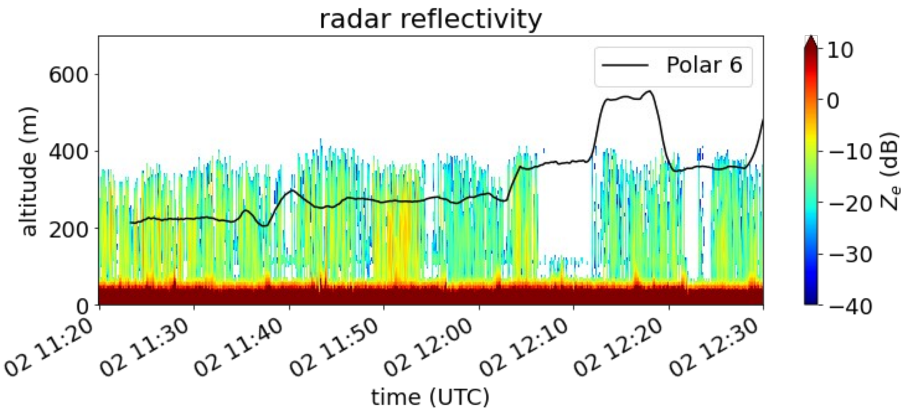
model:







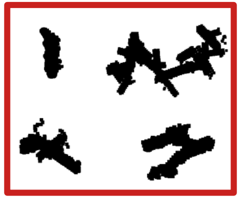


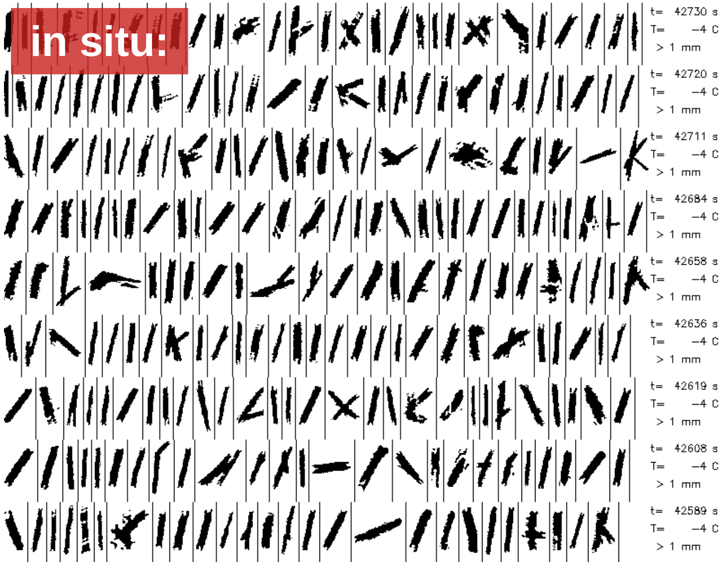


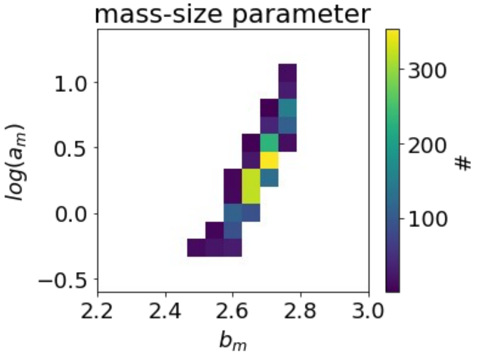
ACLOUD CASE STUDY 2

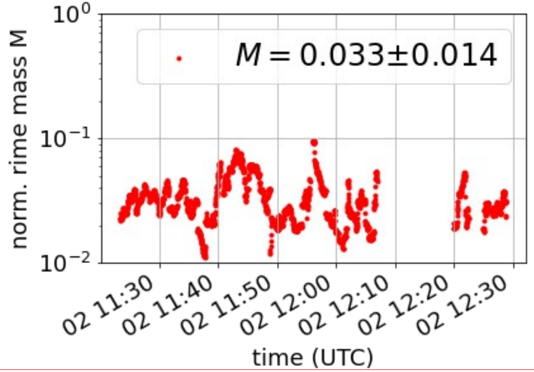
- <u>Flight 11</u>: 02.06.2017, 11:20-12:30 UTC
- In situ images show rather **unrimed** particles
- Retrieval results:
  - Realistic *M* values
  - a_m, b_m high compared to literature

model:









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FLUXES TRANSPORT CLOUDS SURFACE ARCTIC AMPLIFICATION (AC)³

SUMMARY

- Combined **airborne radar** and **in situ** measurements to determine amount of **riming** during ACLOUD
  - **Normalized rime mass *M***
- Model calculations to derive **empirical relations** between *M* and SSRGA & mass size parameter
  - Publication in work
- **Retrieval** of normalized rime mass *M* based on **optimal estimation** (work in progress)

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