17th Apr 2024 | AS1.11 | EGU24-7424

Characterizing the influence of riming on the spatial variability of ice water content in mixed-phase clouds using airborne data

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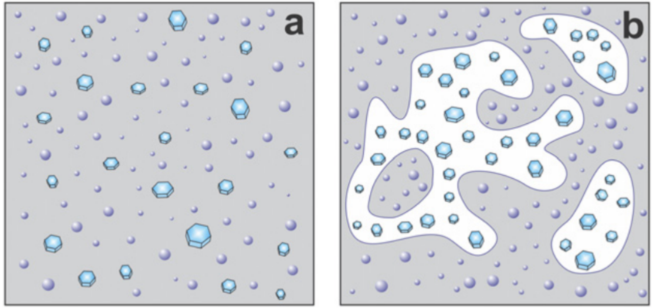
[4]Faculty of Aerospace Engineering, Delft University of Technology, the Netherlands
[5]Institute for Geophysics and Meteorology, University of Cologne, Germany
[6]NSF National Center for Atmospheric Research, USA

Abstract & slides:

Sharing is encouraged

[1] Deng et al. (2024)

Ice water content (IWC) clustering in mixed-phase clouds (MPC)



Adapted from Korolev et al. (2017)

- Liquid droplets and ice particles often mixed heterogeneously → **hydrometeor clusters**

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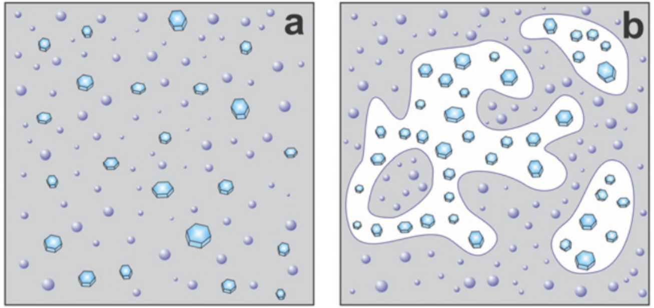

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- Liquid droplets and ice particles often mixed heterogeneously → **hydrometeor clusters**
  - Larger sclaes (few km)
    - Dominate ice inhomogeneity [1]
    - Due to ice formation and growth processes

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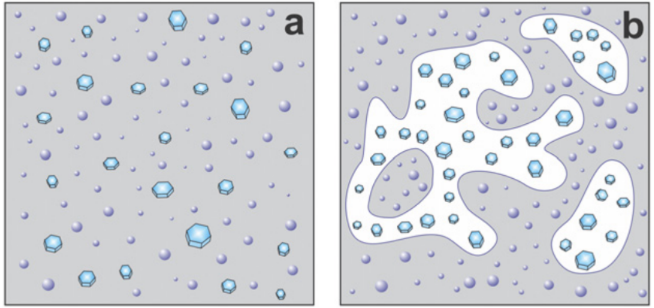

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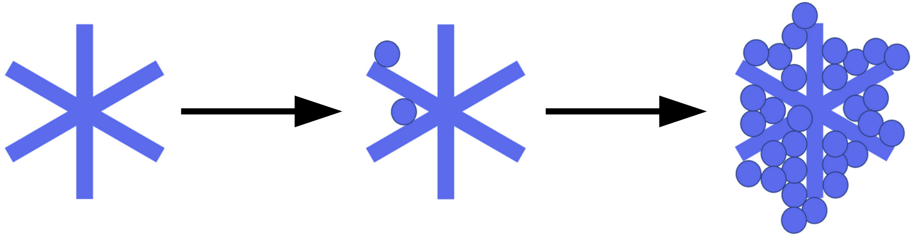
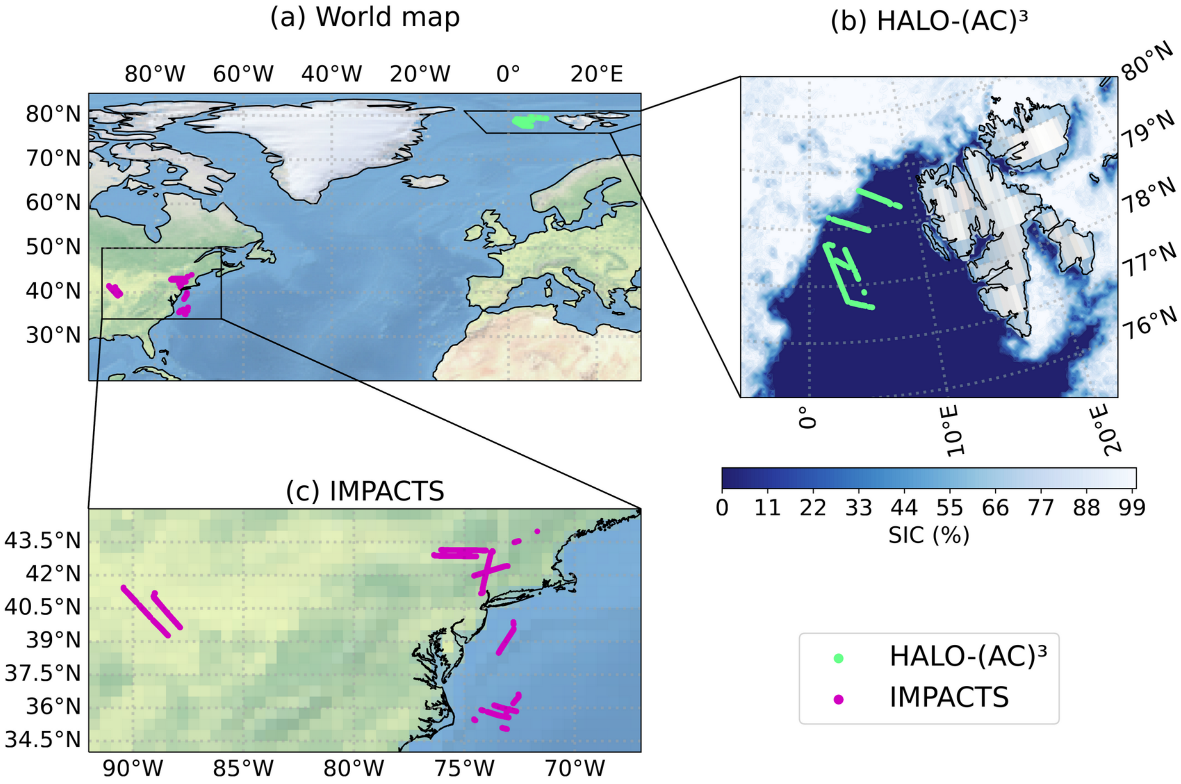
<u>Research question:</u>

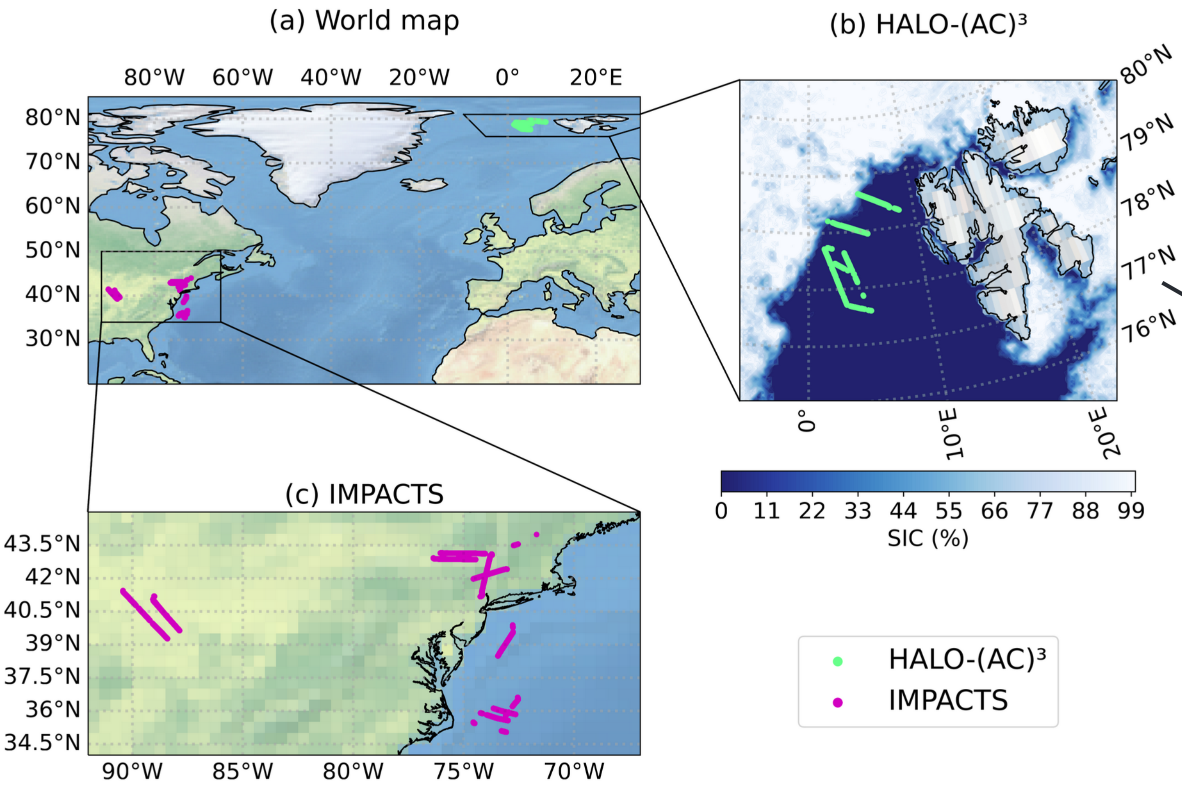
- **What is the influence of riming on spatial variability of ice in MPC?**



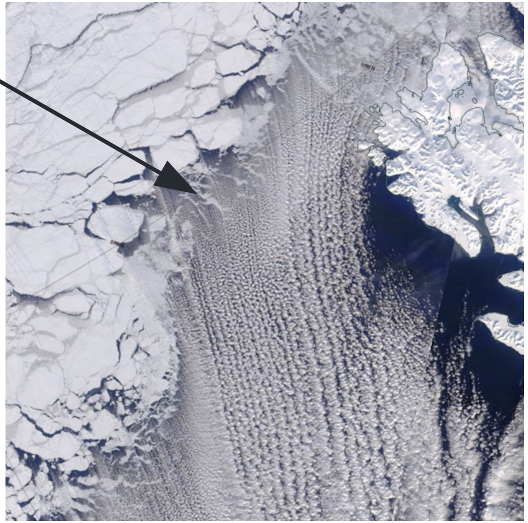
(Collocated) Flights during IMPACTS & HALO-(AC)^3



(Collocated) Flights during IMPACTS & HALO-(AC)³



Cloud streets during HALO-(AC)³



https://worldview.earthdata.nasa.gov/

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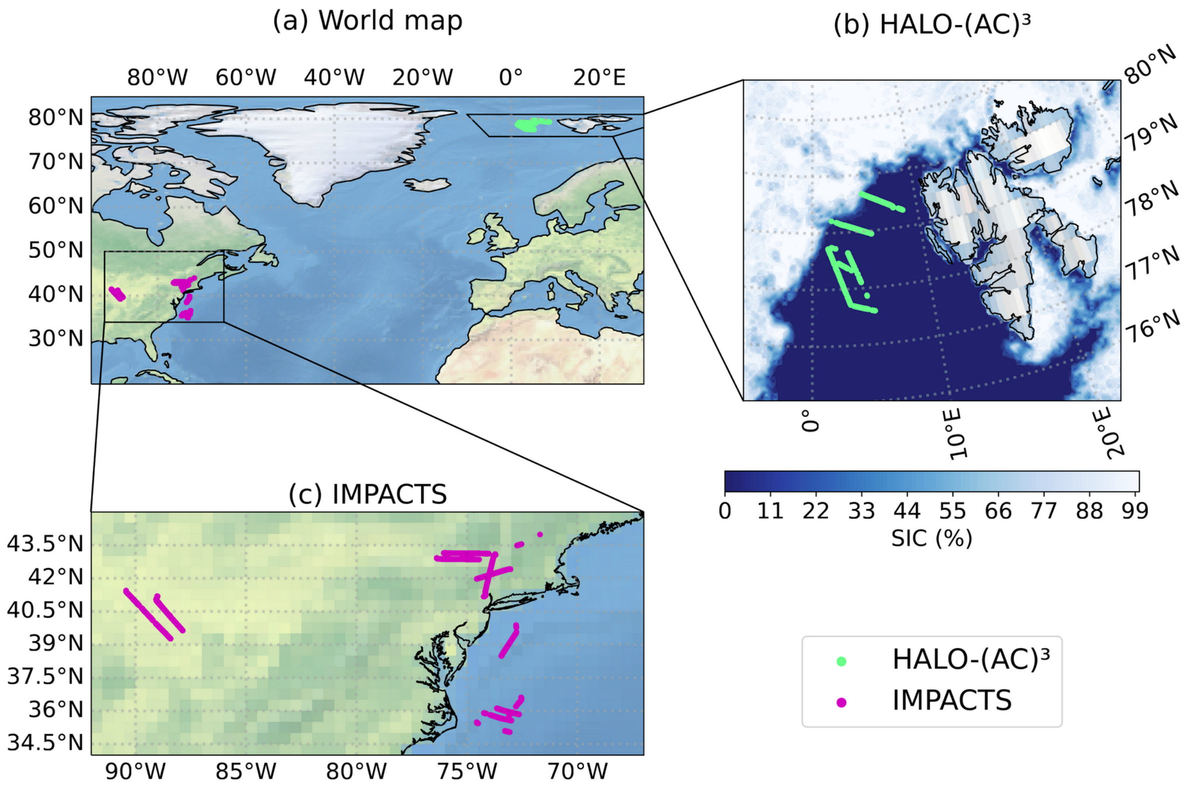

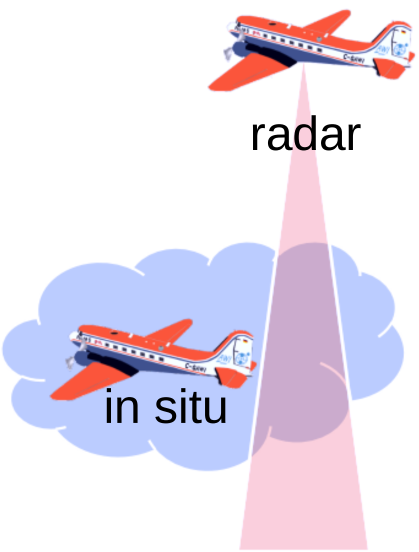

Research question: **What is the influence of riming on spatial variability of ice in MPC?**

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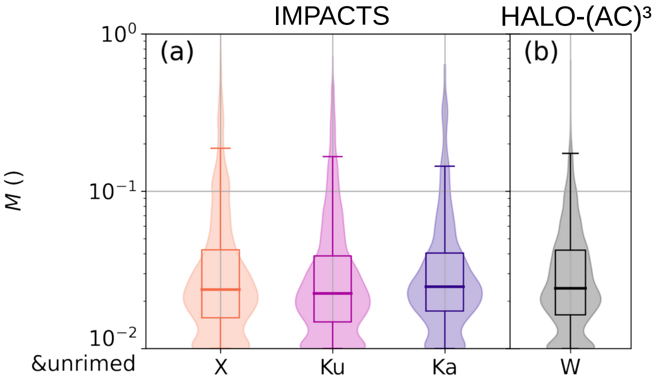
I. Riming occurence

II. IWC variability

[2] Seifert et al. (2019)

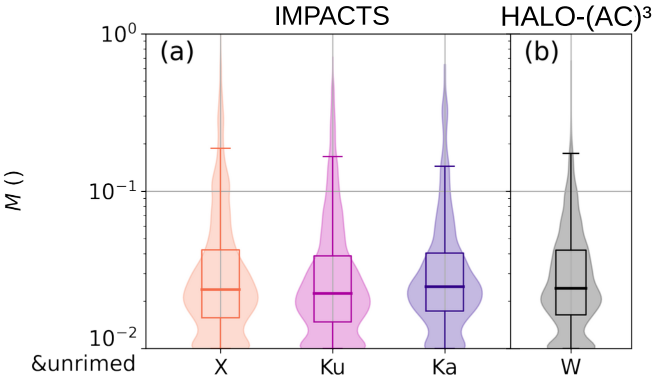
How much riming occured?



- Similar amount of riming during both campaigns:
  - Lots of lightly rimed particles
  - Few heaviliy rimed particles
- M … normalized rime mass [2]

[2] Seifert et al. (2019)
[3] Maherndl et al. (2023)

How much riming occured? **What is the impact on IWC?**



- Similar amount of riming during both campaigns:
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- **IWC** calculated by integrating the product of **ice particle mass** and **number**
  - Accounting for riming → mass parameterization for rimed particles
  - Neglecting riming → mass parameterization for unrimed particles

[3]

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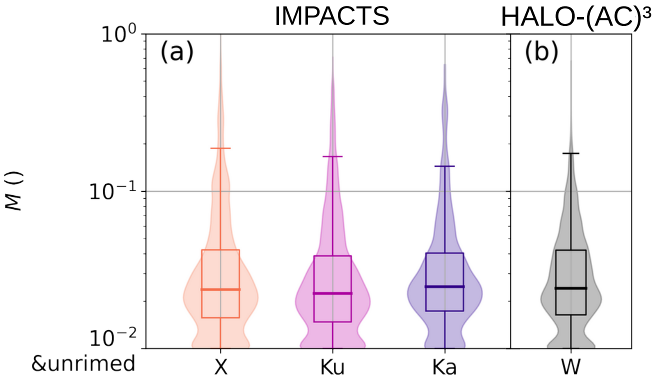

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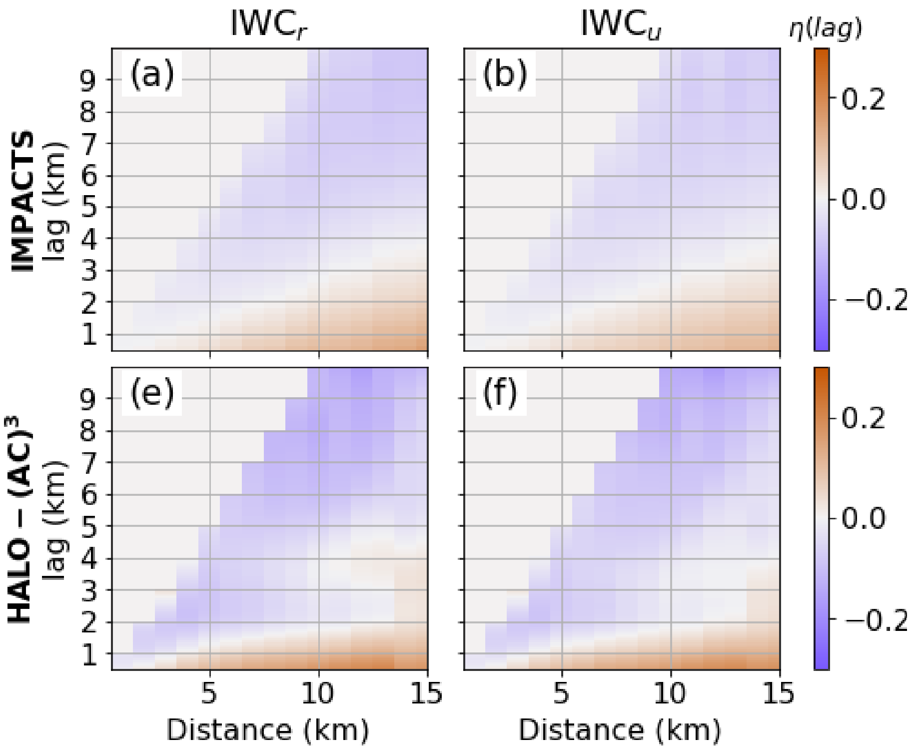
- **66 %** and **63 % of IWC due to riming** during IMPACTS and HALO-(AC)³, respectively

Research question: **What is the influence of riming on spatial variability of ice in MPC?**

I. Riming occurence

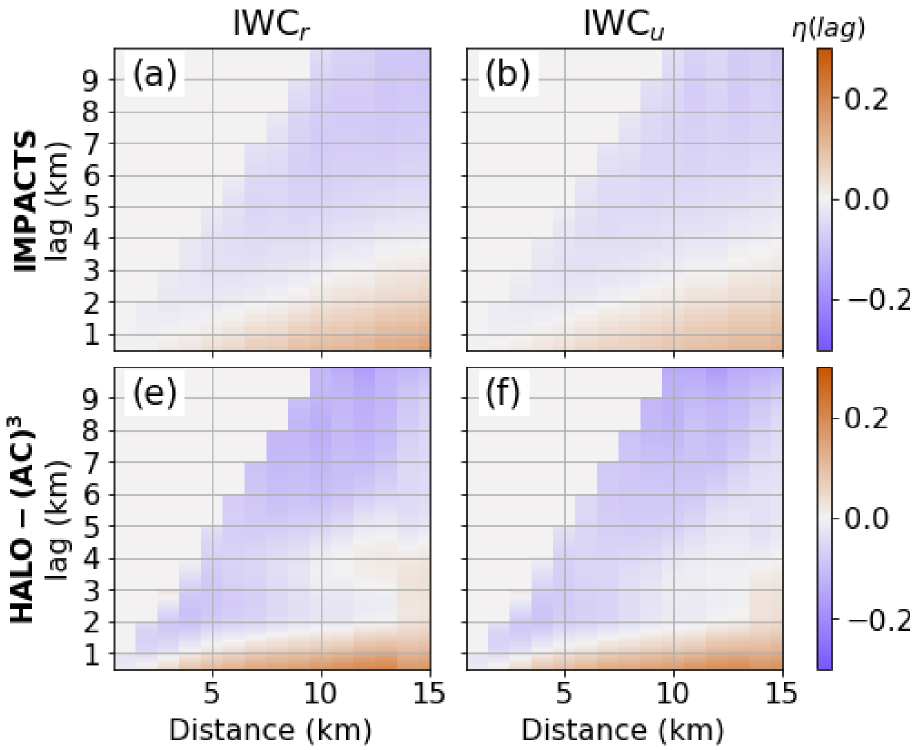
II. IWC variability

Ice cluster spatial scales



- Pair correlation function η
  - IWC cluster probability

Ice cluster spatial scales



- Pair correlation function η
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- IWC calculated:
  - Accounting for riming **IWC$_r$**
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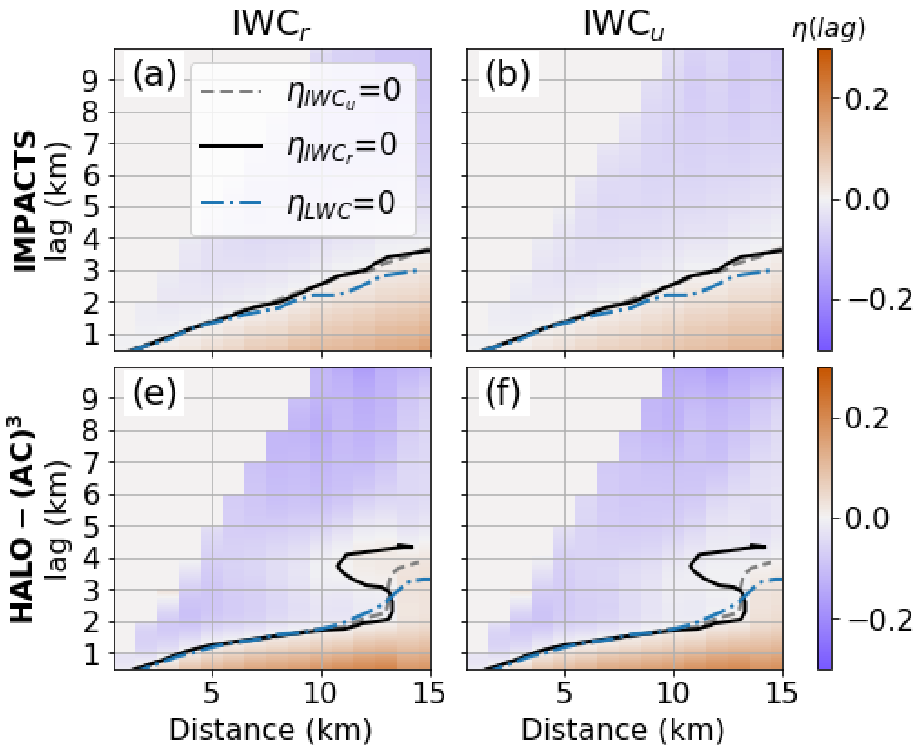
- Flight segments with fixed **distance *x*** km
- Calculate **average *η*** as function of **lag *y*** km

Ice cluster spatial scales



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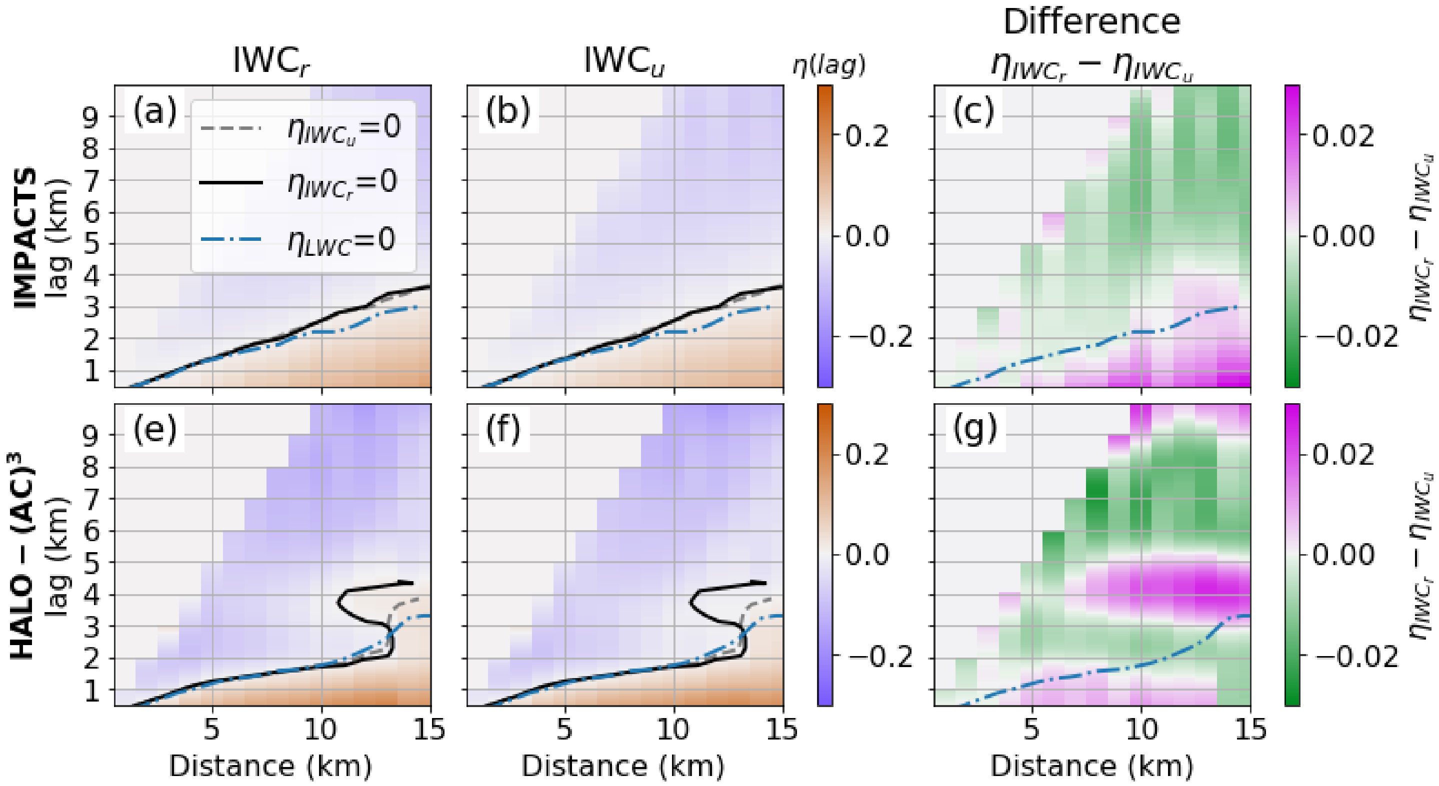

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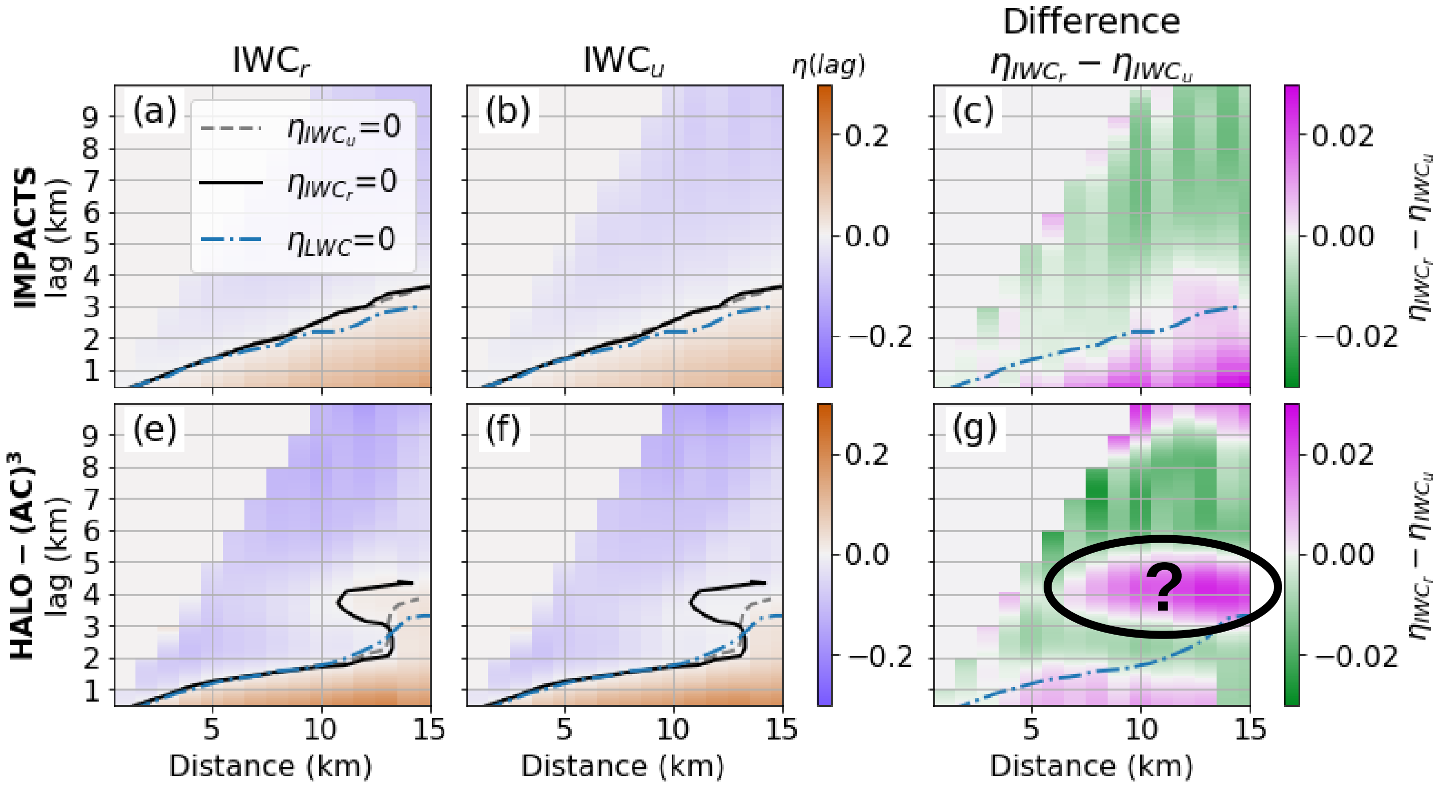

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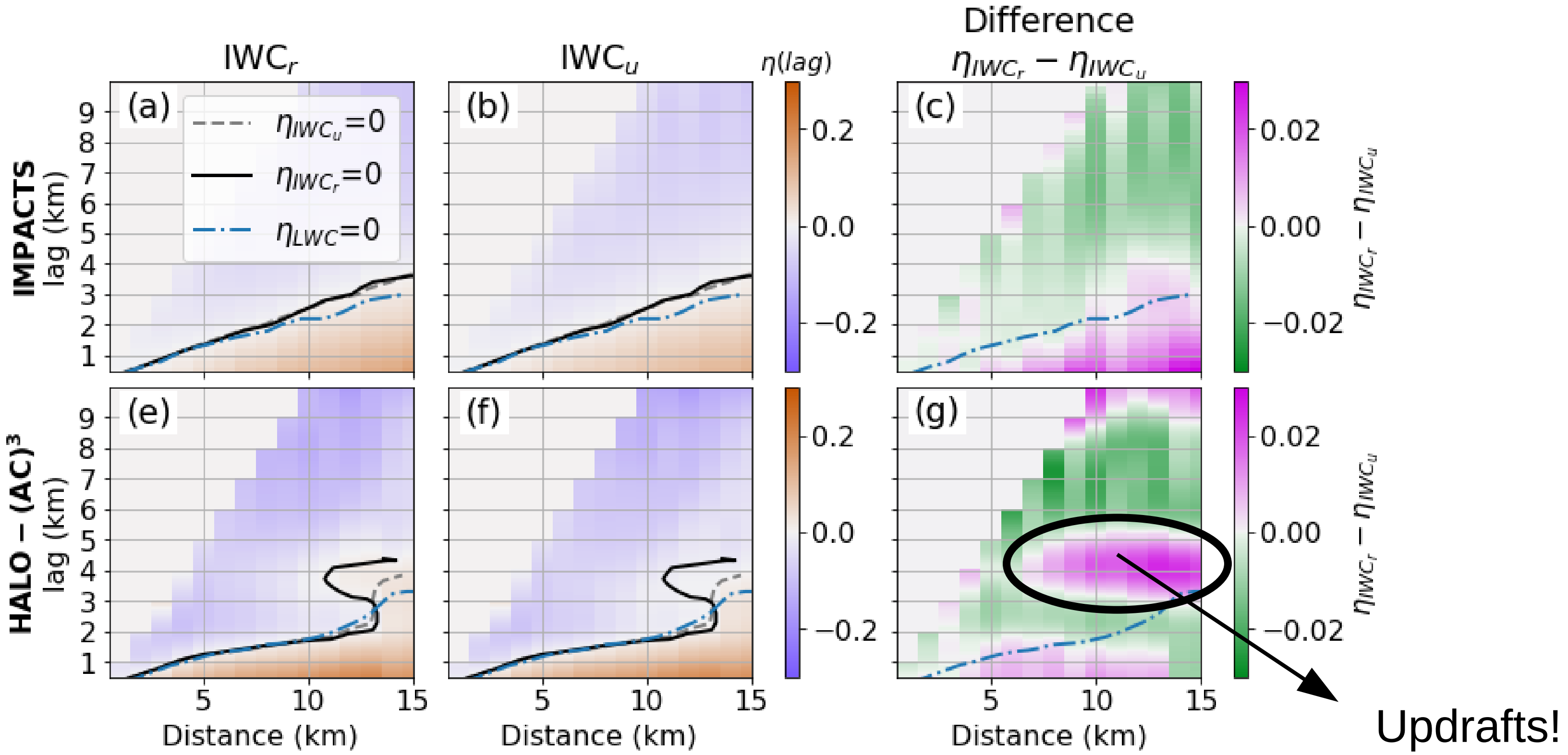
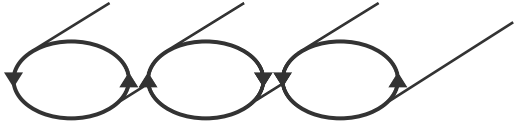
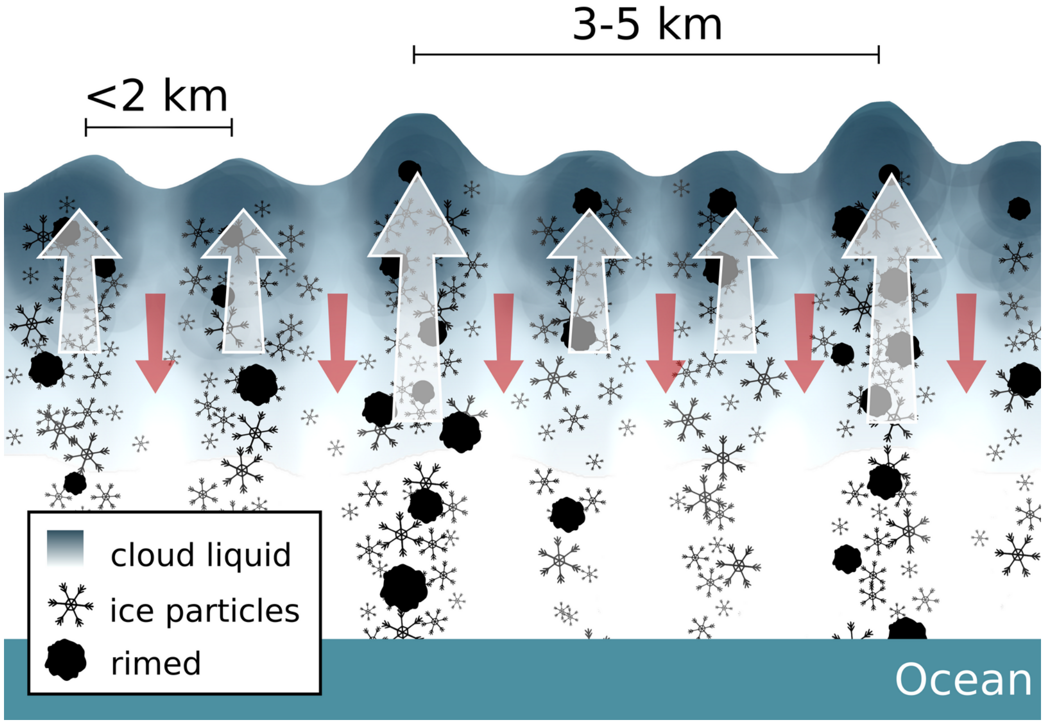
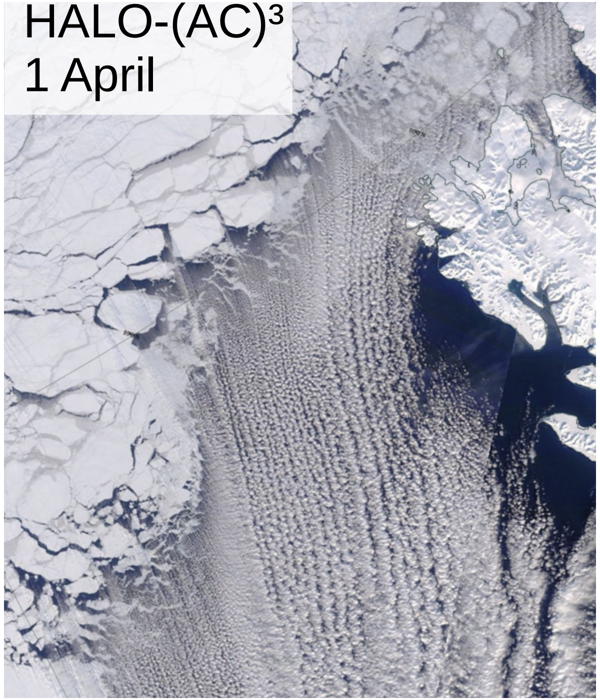


IWC variability & riming

Updrafts → enhanced riming → additional ice clustering







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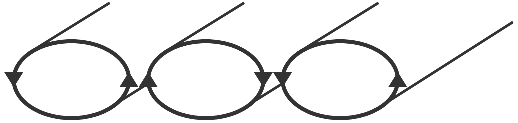
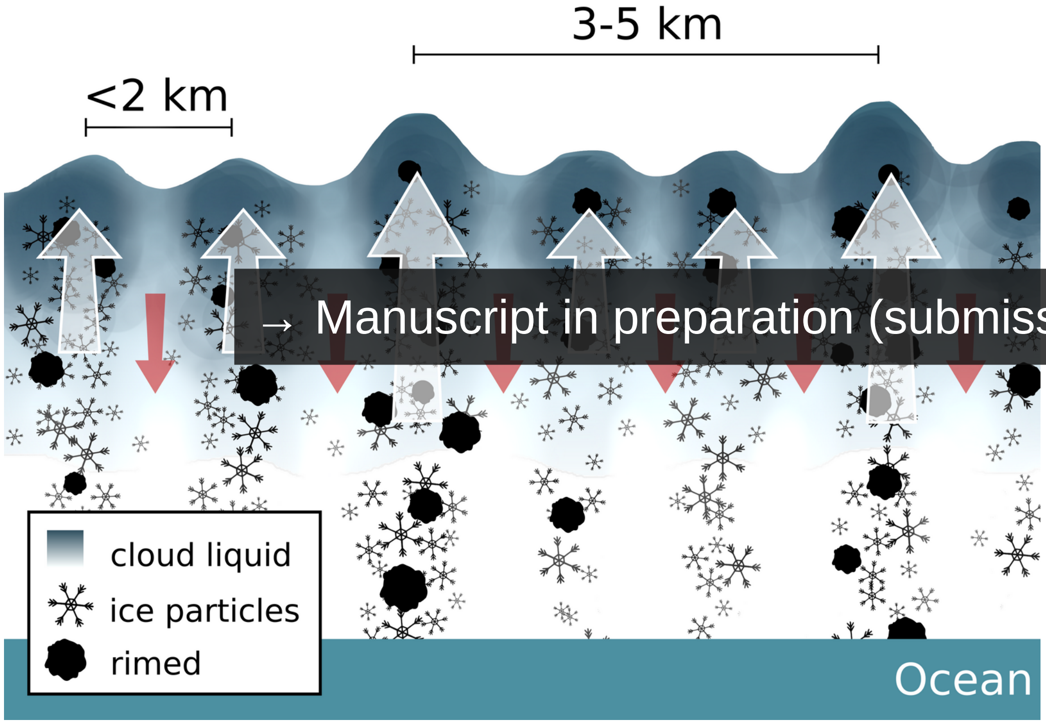
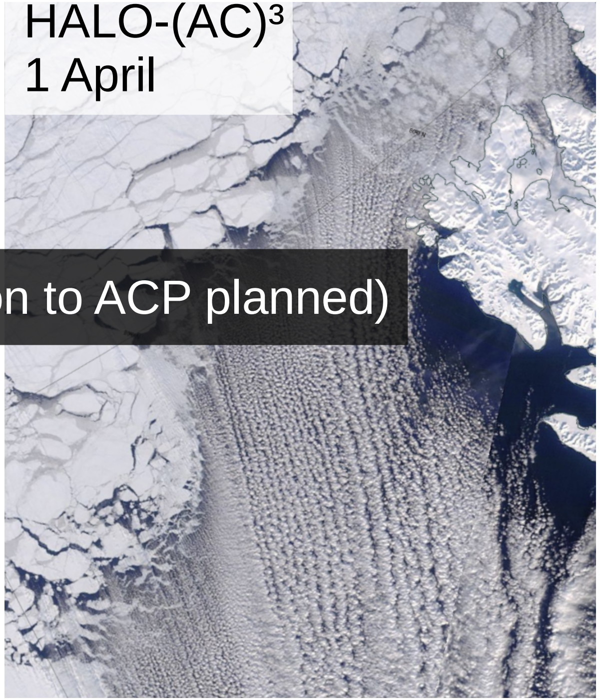




→ Manuscript in preparation (submission to ACP planned)



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THANK YOU

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research group **drOPS**
clou**D** and p**R**ecipitation **O**bservations for **P**rocess **S**tudies

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Abstract & slides:

REFERENCES

[1] Deng, Y., Yang, J., Yin, Y., Cui, S., Zhang, B., Bao, X., Chen, B., Li, J., Gao, W., and Jing, X.: Quantifying the Spatial Inhomogeneity of Ice Concentration in Mixed-Phase Stratiform Cloud Using Airborne Observation, Atmospheric Research, 298, 107 153, ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2023.107153 , 2024.

[2] Seifert, A., Leinonen, J., Siewert, C., and Kneifel, S.: The geometry of rimed aggregate snowflakes: A modeling study, Journal of Advances in Modeling Earth Systems, 11, 712–731, https://doi.org/10.1029/2018MS001519, 2019.

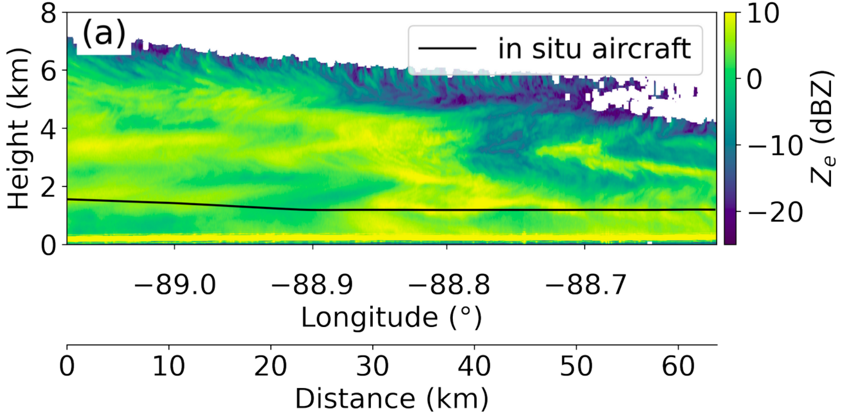
[3] **Maherndl, N.**, Maahn, M., Tridon, F., Leinonen, J., Ori, D. and Kneifel, S.: A riming-dependent parameterization of scattering by snowflakes using the self-similar Rayleigh–Gans approximation, Quarterly Journal of the Royal Meteorological Society, 149(757), 3562–3581, https://doi.org/10.1002/qj.4573, 2023.

[4] **Maherndl, N.**, Moser, M., Lucke, J., Mech, M., Risse, N., Schirmacher, I., and Maahn, M.: Quantifying riming from airborne data during the HALO-(AC)3 campaign, Atmospheric Measurement Techniques, 17, 1475–1495, https://doi.org/10.5194/amt-17-1475-2024 , 2024.

APPENDIX

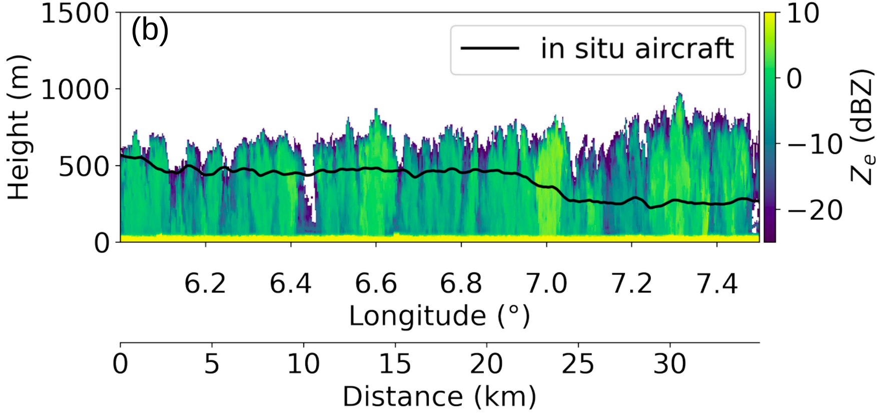
„Typical“ clouds during:

IMPACTS



- Deep mid-latitude winter storms
- Cloud tops 6-8 km

HALO-(AC)³



- Shallow Arctic cold air outbreak roll clouds
- Cloud tops often below 1 km

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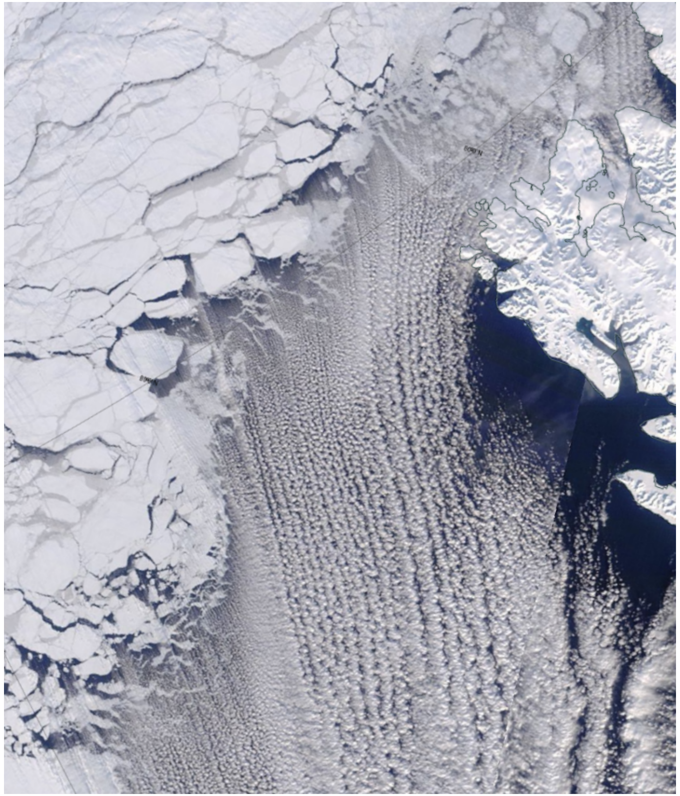
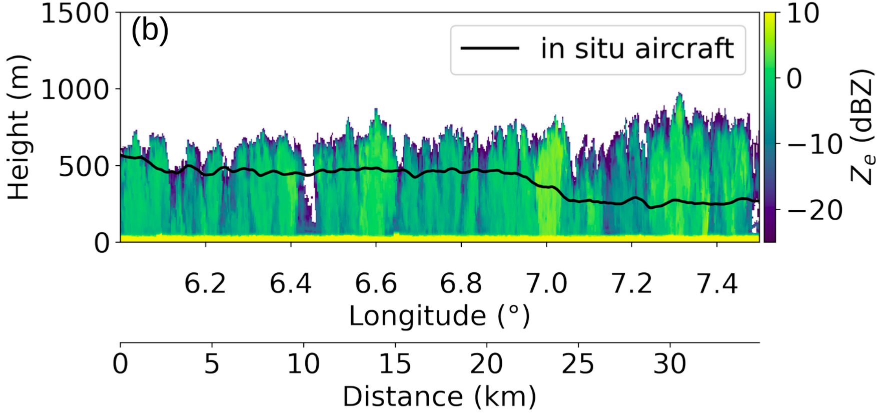


HALO-$(AC)^3$



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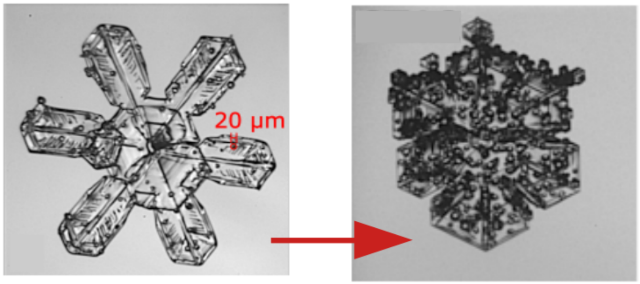
D_{max} ... maximum dimension (m)
m_{rime} ... rime mass (kg)
m_g ... mass of D_{max} equivalent graupel (kg)
ρ_{rime} ... rime density $(700\ kg/m^3)$

Riming in arctic mixed-phase clouds (MPC)

- Supercooled **liquid** droplets freeze onto **ice** crystals
- Research mainly qualitative

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

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



Adapted from Waitz et al. (2022)

[3] Maherndl et al. (2023)
[4] Maherndl et al. (2024)

Collocated radar and in situ data:

In situ: cloud probes

Particle size distributions

Radar forward simulator **(PAMTRA)**

riming-dependent parameterization [3] for ice particle properties

Z_e = function(M)

Simulated Z_e
at in situ flight altitude

Find M such that =

Remote sensing: radar

Measured radar reflectivity Z_e
at in situ flight altitude

► combined method [4]

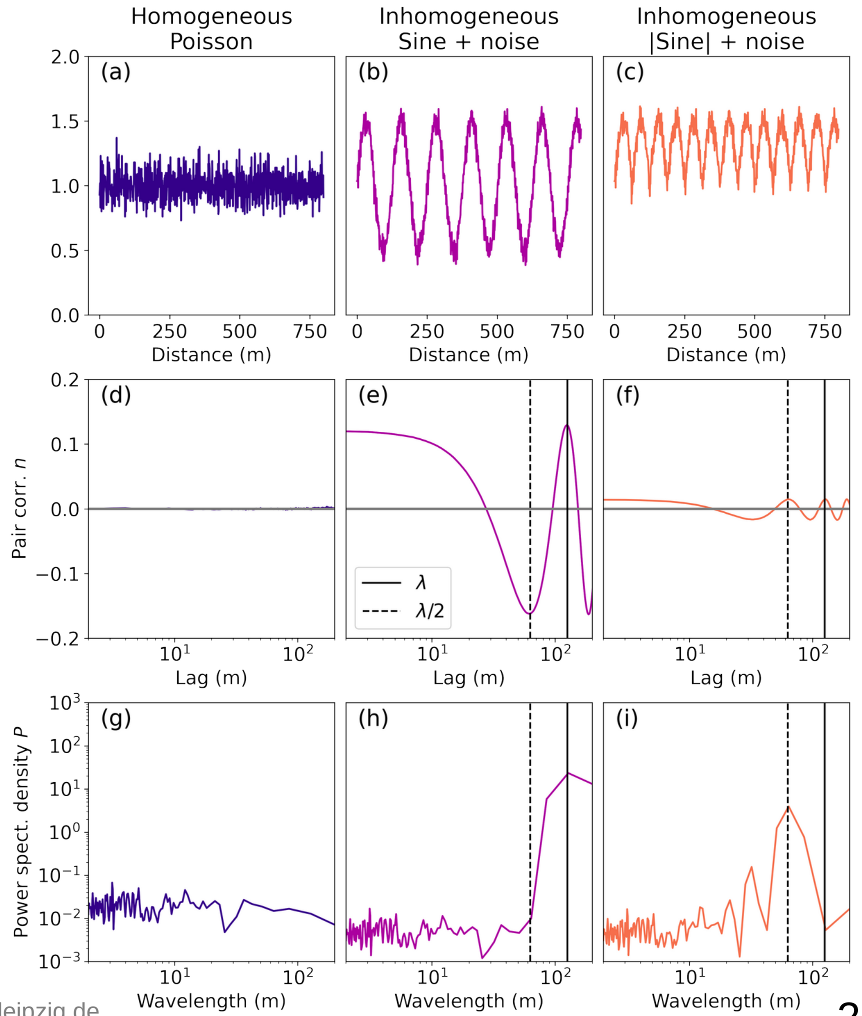
How to quantify spatial variability?
→ **Pair Correlation Function (PCF)**

- Defined as:

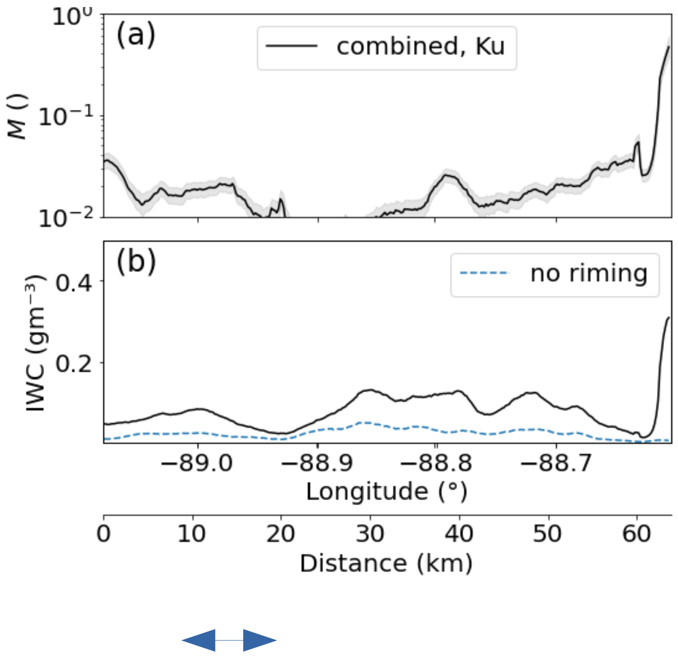
$$\eta(r) = \frac{\overline{P(0)P(r)}}{(\overline{P})^2} - 1,$$

where P(0) is the parameter at a given point, P(r) the parameter at the lag r from that point and P the average.

- P … number of ice particles N_i or IWC
- $\eta > 0$ → occurance of clustering
- $\eta = 0$ → homogeneous Poisson



Ice cluster spatial scales: example flight segment

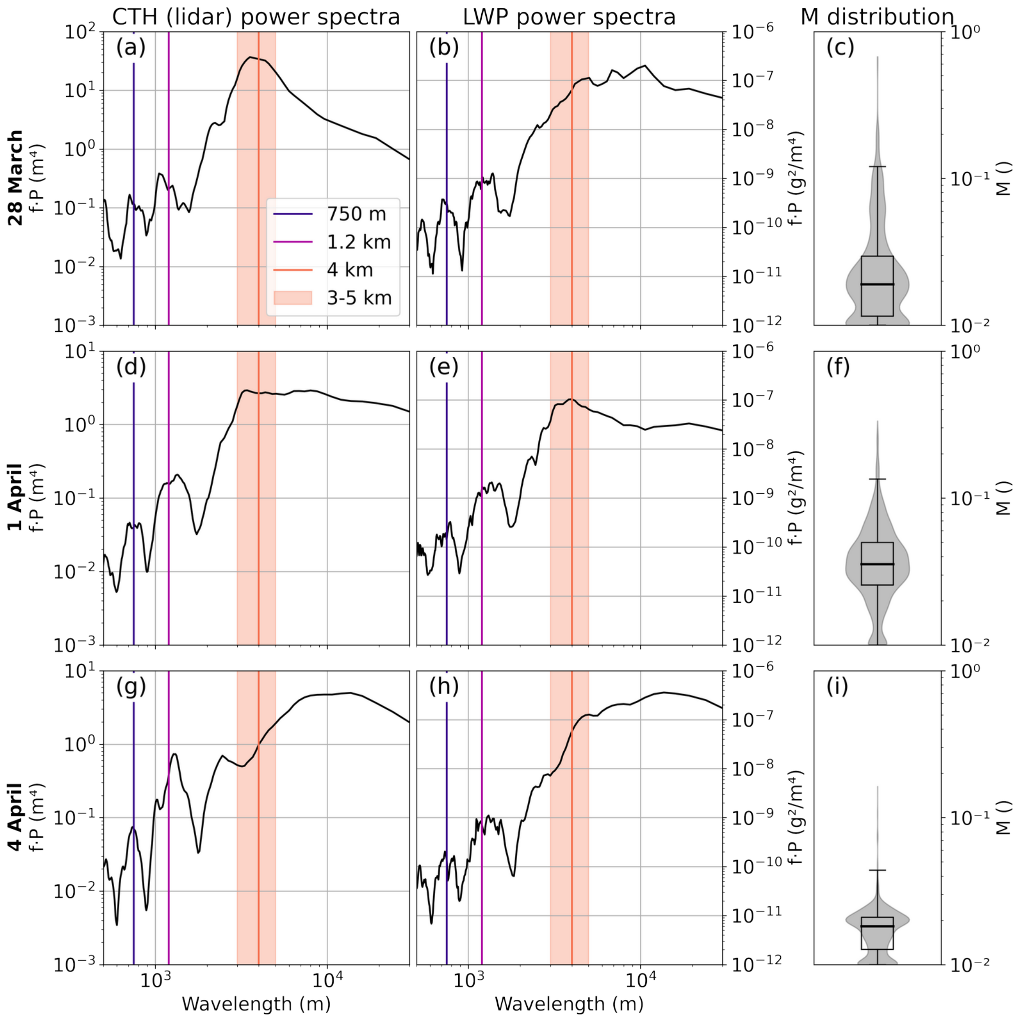


e.g., 10 km segments

- IWC calculated from PSD and mass-size relation
  - Accounting for riming **IWC_r**
  - Neglecting riming **IWC_u**
- Flight segments → random subsegments with **distance x** km
  - Calculate pair correlation as function of **lag y** km

Why does riming enhance ice clustering at 3-5 km scales during HALO-(AC)³?

- CTH as proxy for updraft regions
- On days with more riming → updrafts at 3-5 km
- Not necessarily higher LWP



Detailled summary and outlook

What is the influence of riming on spatial variability of ice in MPC?

1) Increases probability of ice clusters
   - Mid-latitude & Arctic: regions with liquid and ice → riming → increase in ice mass
   - Arctic: updraft regions of cloud streets

2) Arctic cloud streets: additional ice clusters at 3-5 km scales ← enhanced riming in mesoscale updraft regions

Manuscript in preparation (submission to ACP planned)