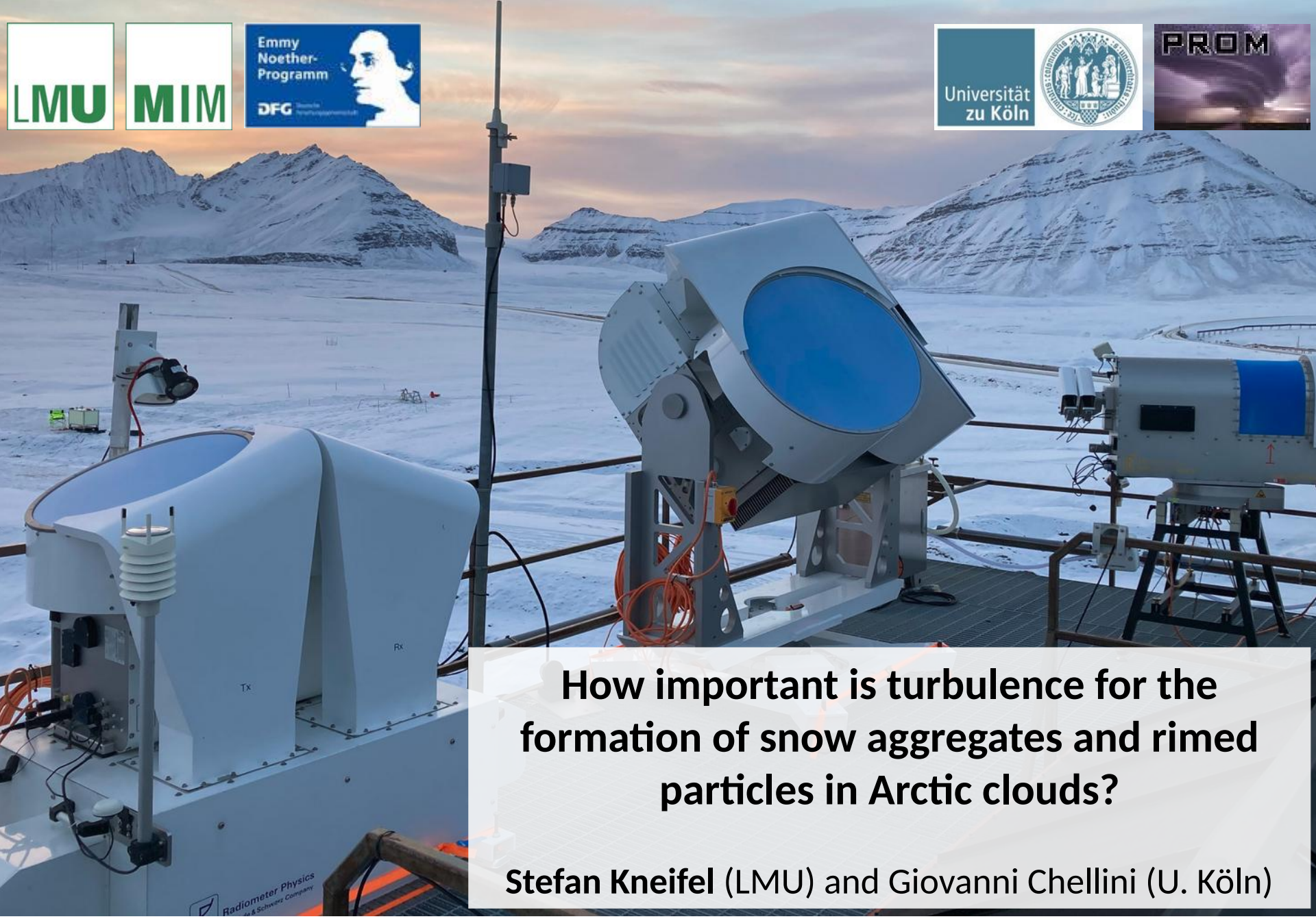
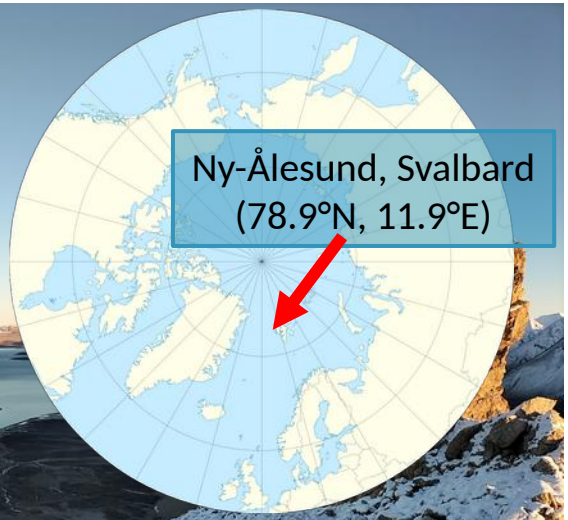


How important is turbulence for the formation of snow aggregates and rimed particles in Arctic clouds?

Stefan Kneifel (LMU) and Giovanni Chellini (U. Köln)

AWIPEV site, Ny-Ålesund, Svalbard



ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Universität zu Köln

Data collected at German-French Research Site AWIPEV

Research Project: Arctic Amplification AC³ (www.ac3-tr.de)

94-GHz FMCW radar

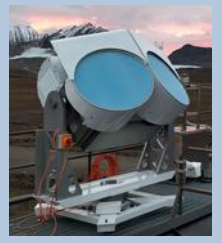
24-GHz Micro-Rain radar

Microwave radiometer

since Sep 2017

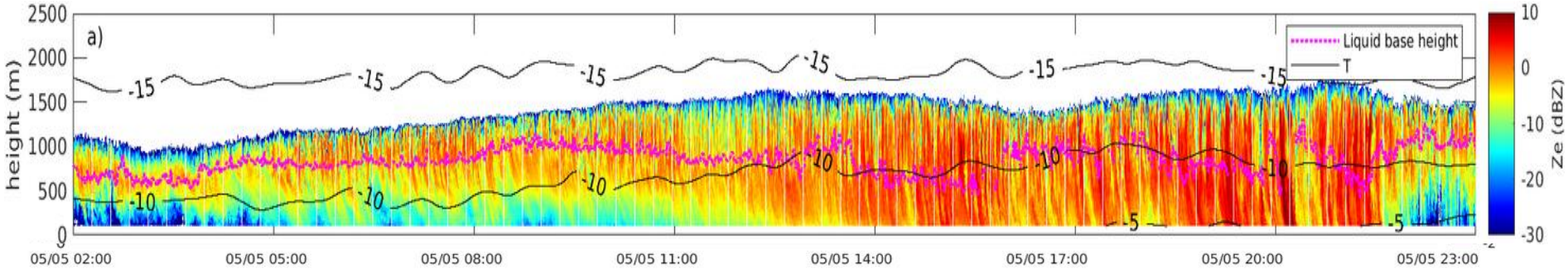
Ceilometer

35-GHz dual-pol FMCW radar



since Oct 2021

Arctic Mixed-Phase Clouds (A-MPCs)



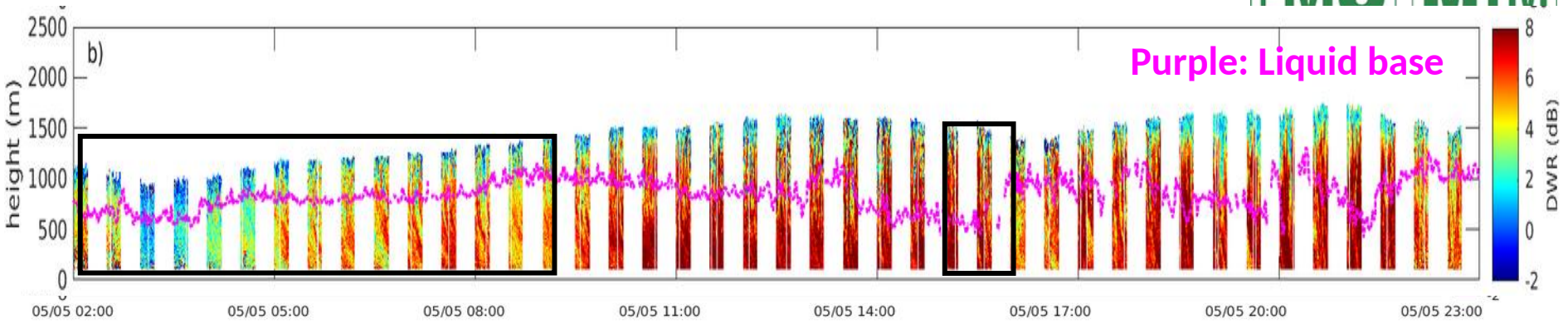
A-MPCs and precipitation

- Liquid droplets at cloud top, maintained by turbulence
- Precipitation is **sink for moisture and INP**
- Simulations showed: Whether MPC precipitates or not can drastically alter its lifetime and spatio-temporal evolution

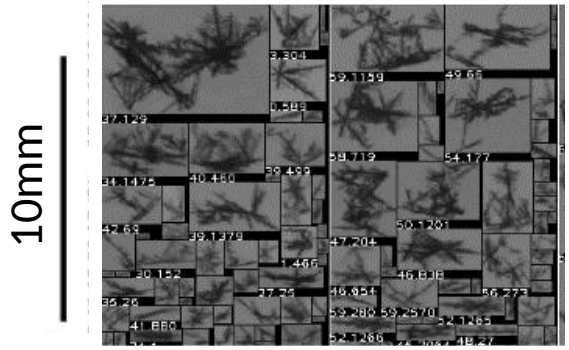
Selection criteria

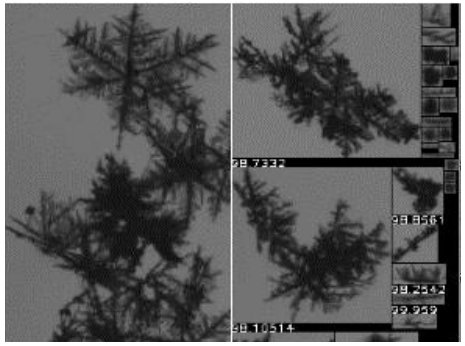
- Cloud-top height < 2500 m
- Liquid and ice coexisting (from Cloudnet target classification)
- Minimum duration 1 hour (with gaps allowed)

Dual-Wavelength Ratio (DWR)



- Ratio of linear reflectivity factors or in dB: **$DWR_{Ka,W} = Ze_{Ka} - Ze_{W}$**
- **Strongly related to mean particle size → Indicator for aggregation**

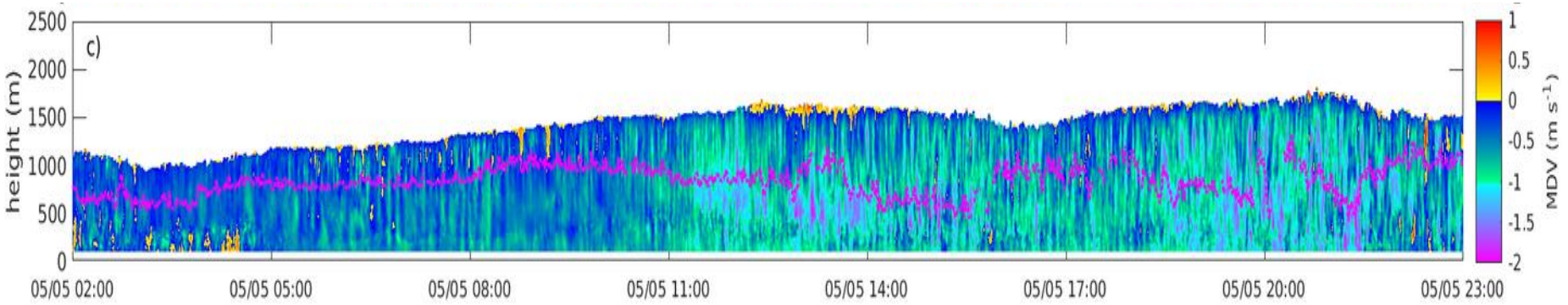




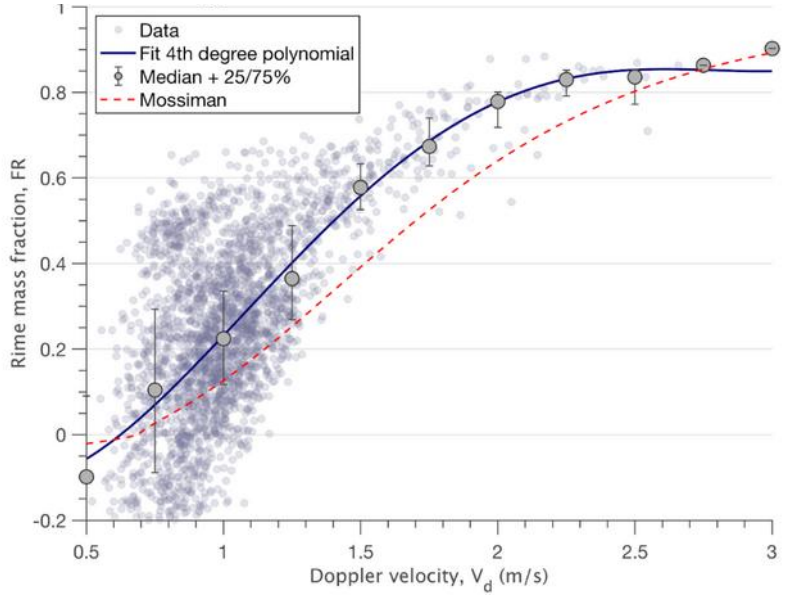
Video In-Situ Snowflake Imager VISSS (Maahn et al., 2023)

- DWR due to differential attenuation negligible as liquid is mostly on the top and water vapor content is low

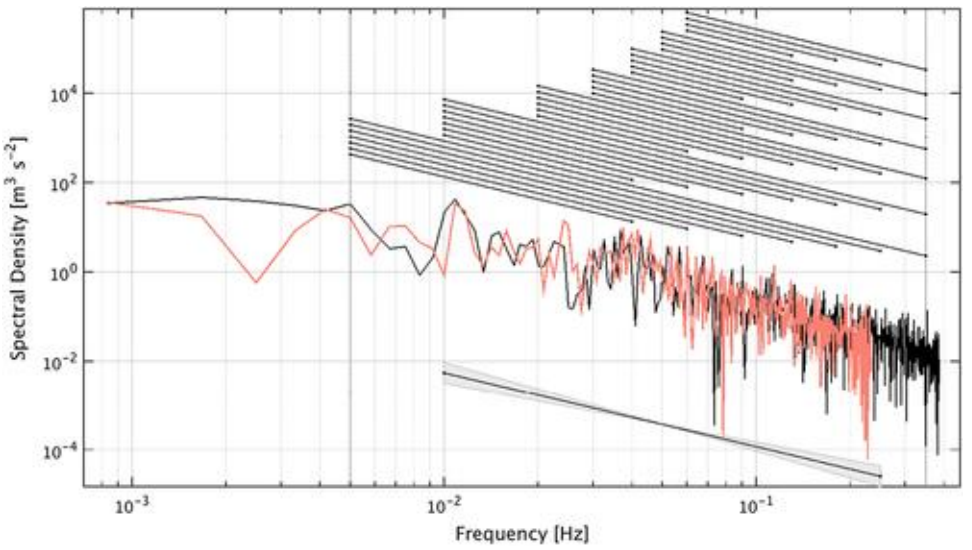
Mean Doppler velocity (MDV)



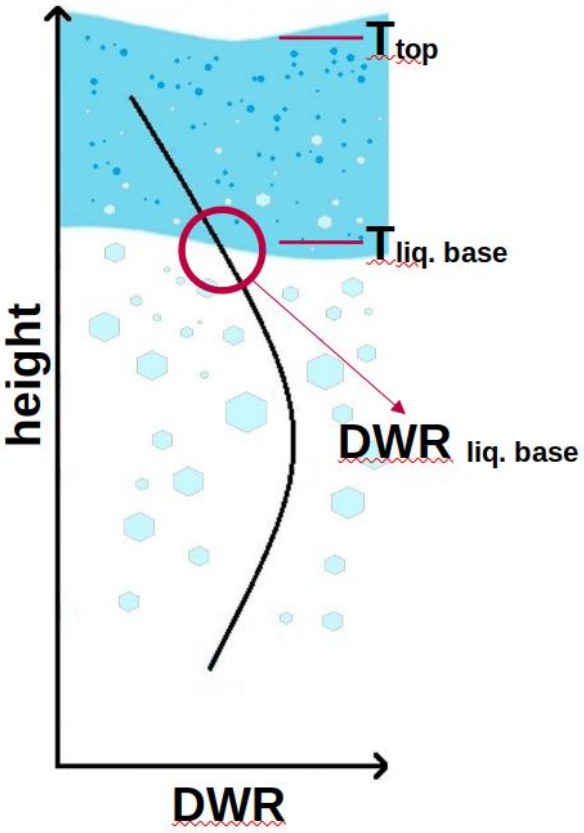
Detection of riming
(Kneifel&Moisseev, JAS, 2020)

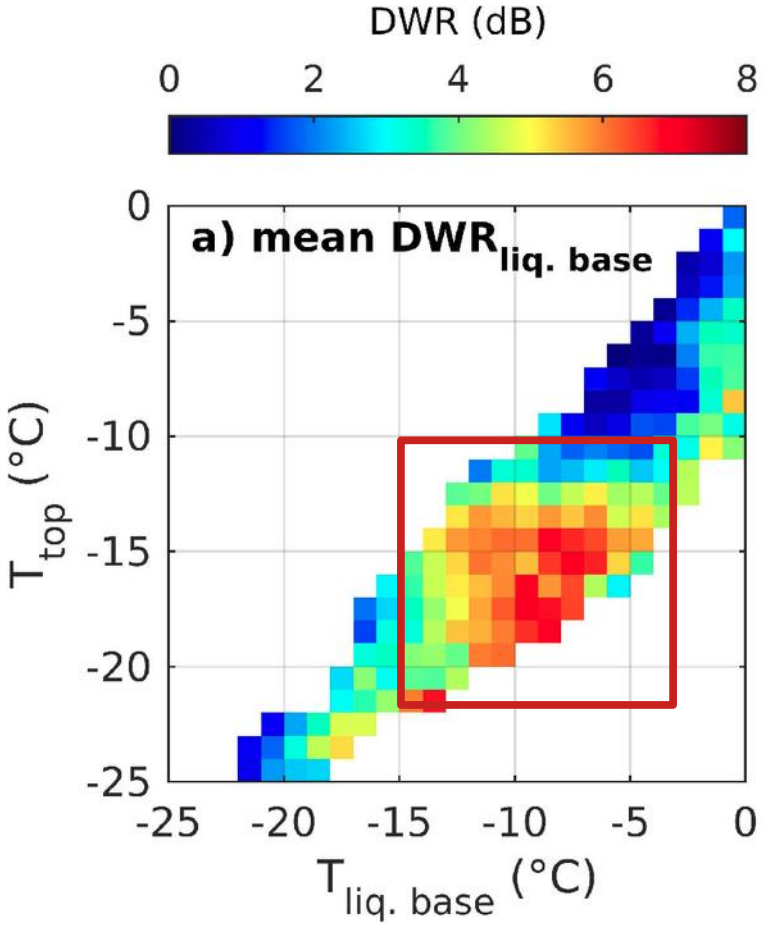


Eddy Dissipation Rate Retrieval
(Borque et al., JGR, 2016)



Under which conditions do we find aggregation or riming in A-MPCs?

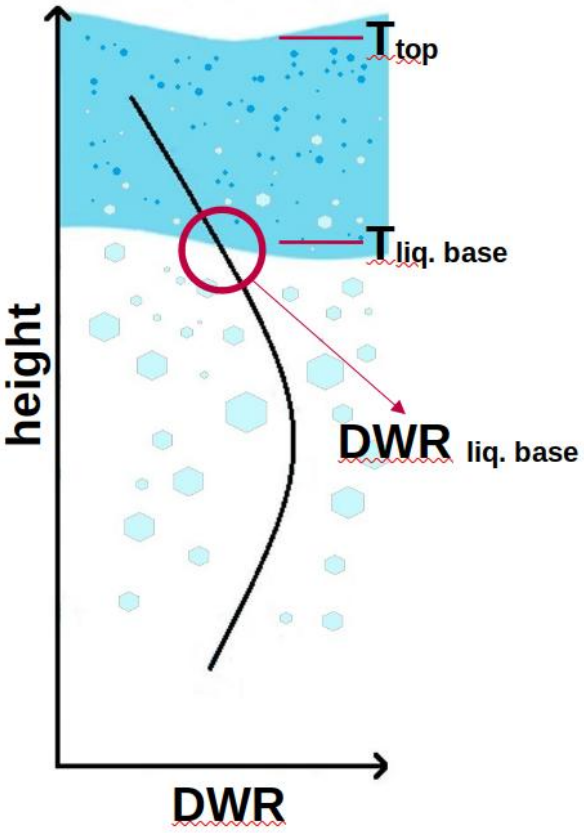


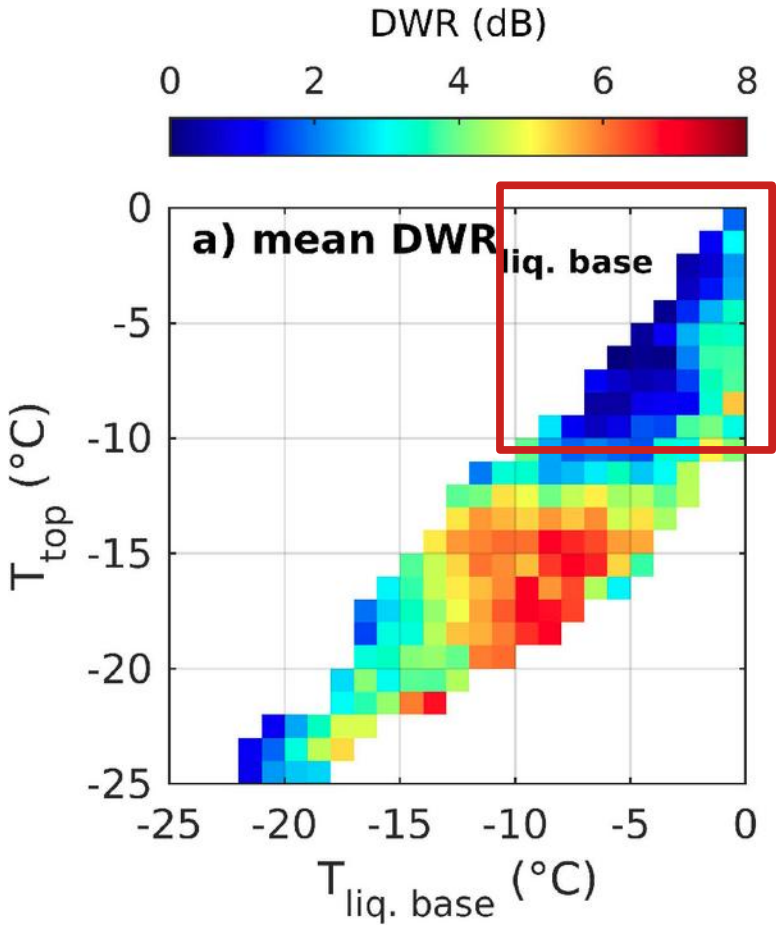


Large aggregates mainly if the liquid layer is, at least partly, at T between -20 and -12°C

(Chellini et al., JGR, 2022)

Under which conditions do we find aggregation or riming in A-MPCs?





No large particles when CTT > -10°C

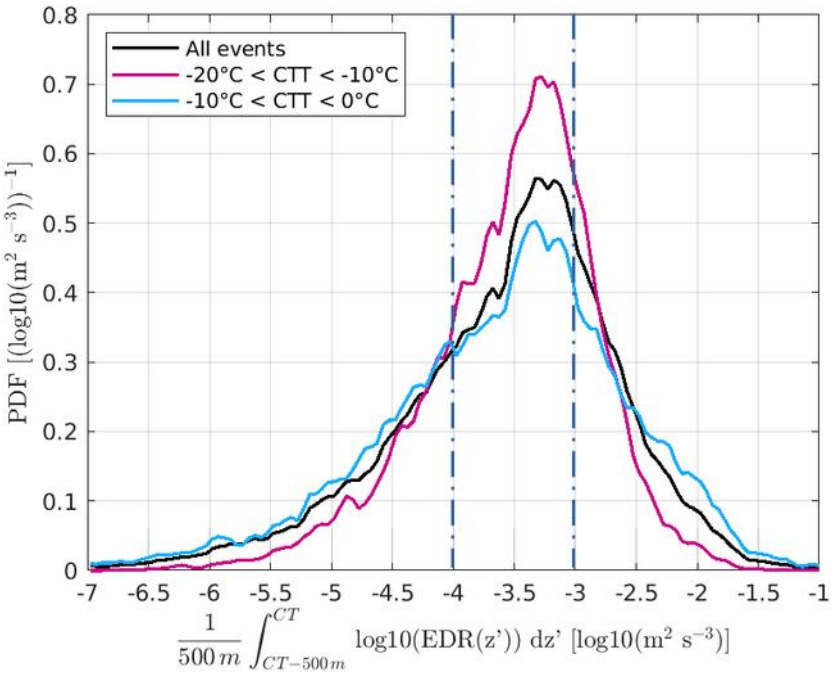
But: Larger MDV as in the dendritic growth zone

(Chellini et al., JGR, 2022)

Analysis idea: Use A-MPCs to study impact of turbulence on collisional processes

Riming and aggregation are both collisional processes

- Possible effects of turbulence:
  - Clustering, collisions more likely
  - Broader velocity spectrum
  - More collisions, higher impact energy



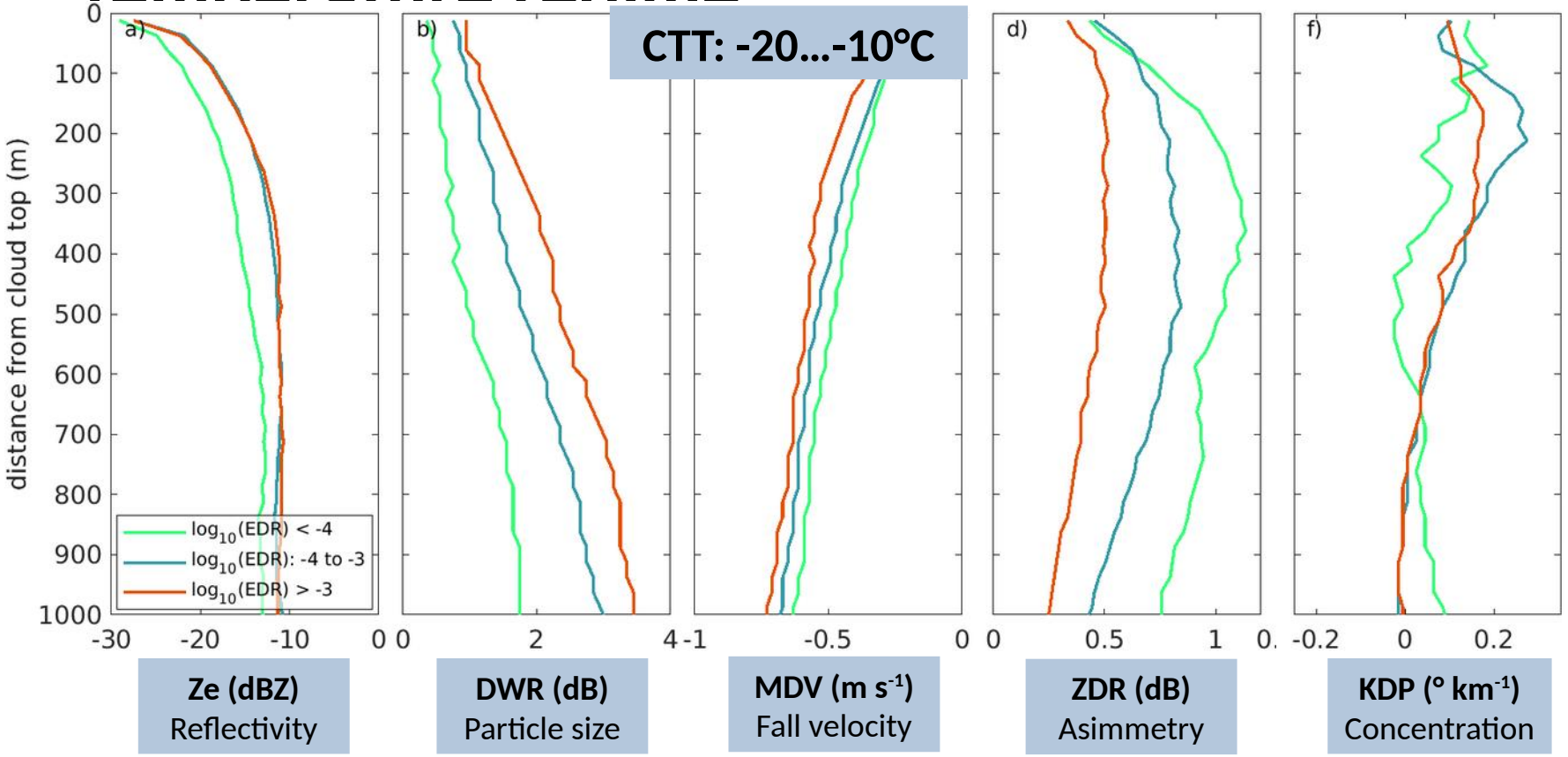
<u>Events classified based on:</u>

- CTT:
  - -20 to -10°C → aggregation and riming
  - > -10°C → predominantly riming

- Average EDR in uppermost 500 m:
  - < 10^{-4} m^2 s^{-3} → low
  - between 10^{-4} and 10^{-3} m^2 s^{-3} → intermediate
  - > 10^{-3} m^2 s^{-3} → high

Impact of turbulence in the aggregation dominated temperature regime

(Chellini & Kneifel, GRL, 2024)

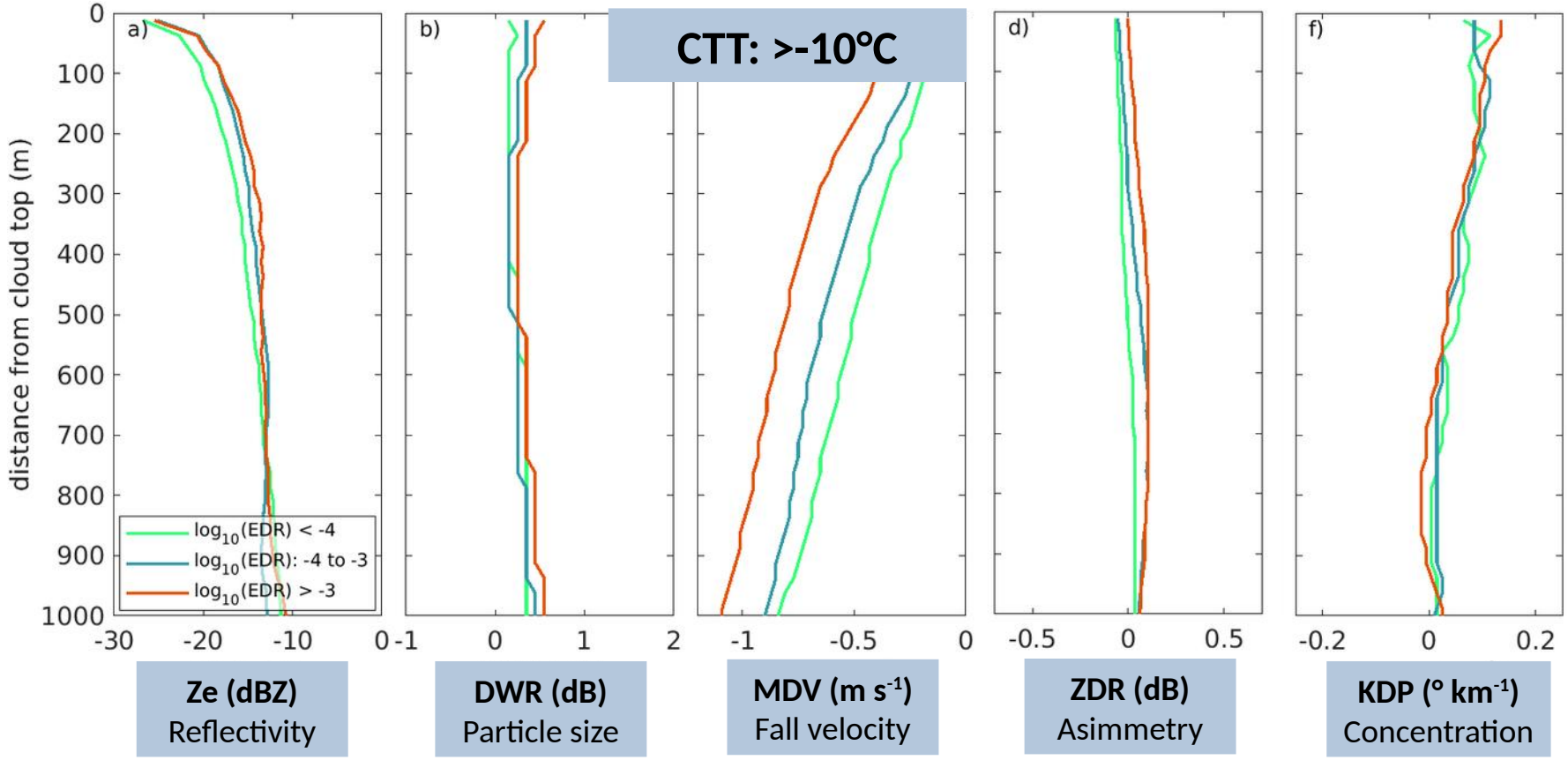


Higher EDR correlated with:

- Larger, more spherical particles, low velocity ⇒ larger aggregates
- Increasing KDP ⇒ higher fragmentation due to higher collision rates?

Impact of turbulence in the riming dominated temperature regime

(Chellini & Kneifel, GRL, 2024)

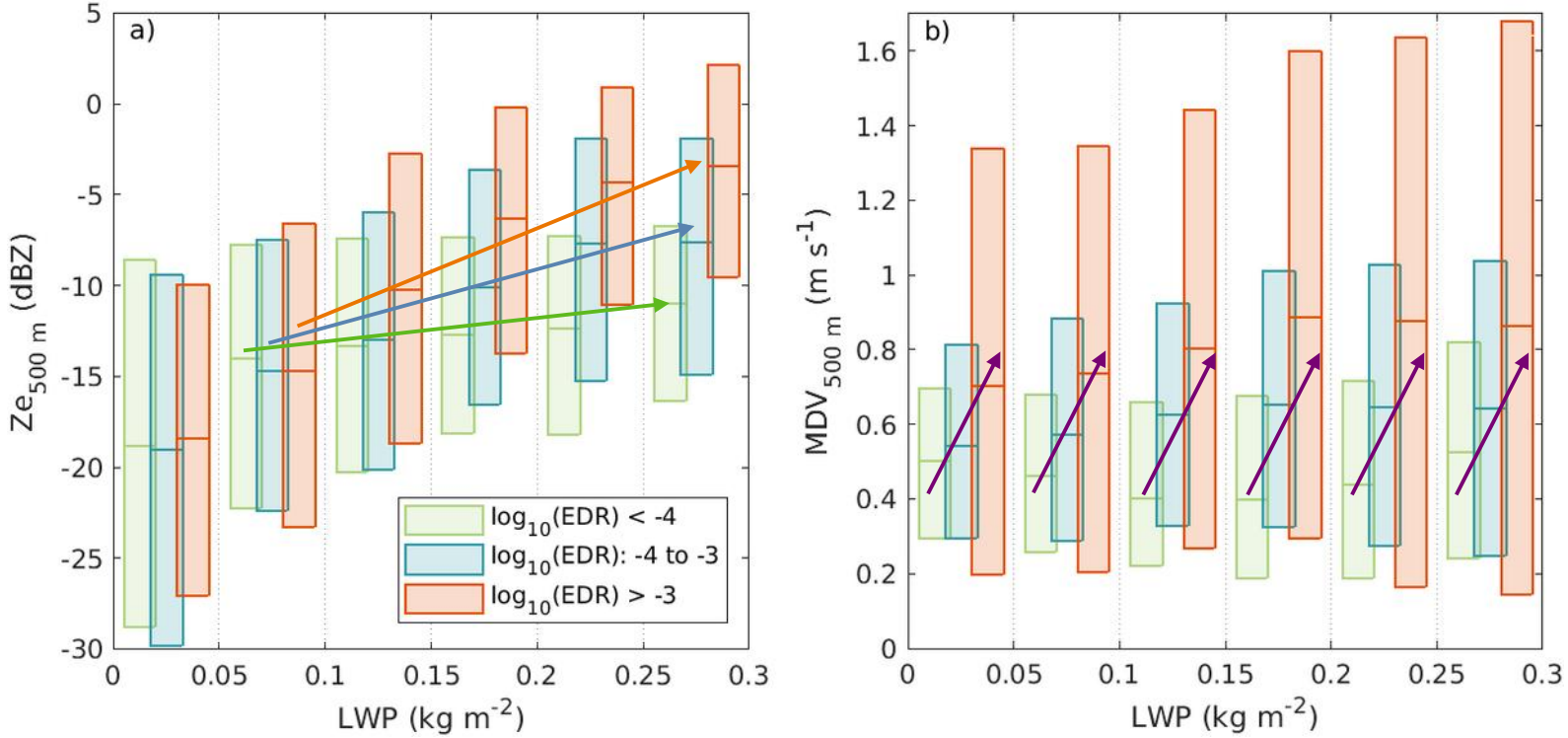


Higher EDR correlated with:

- Higher MDV but similar DWR ⇒ particles potentially more rimed

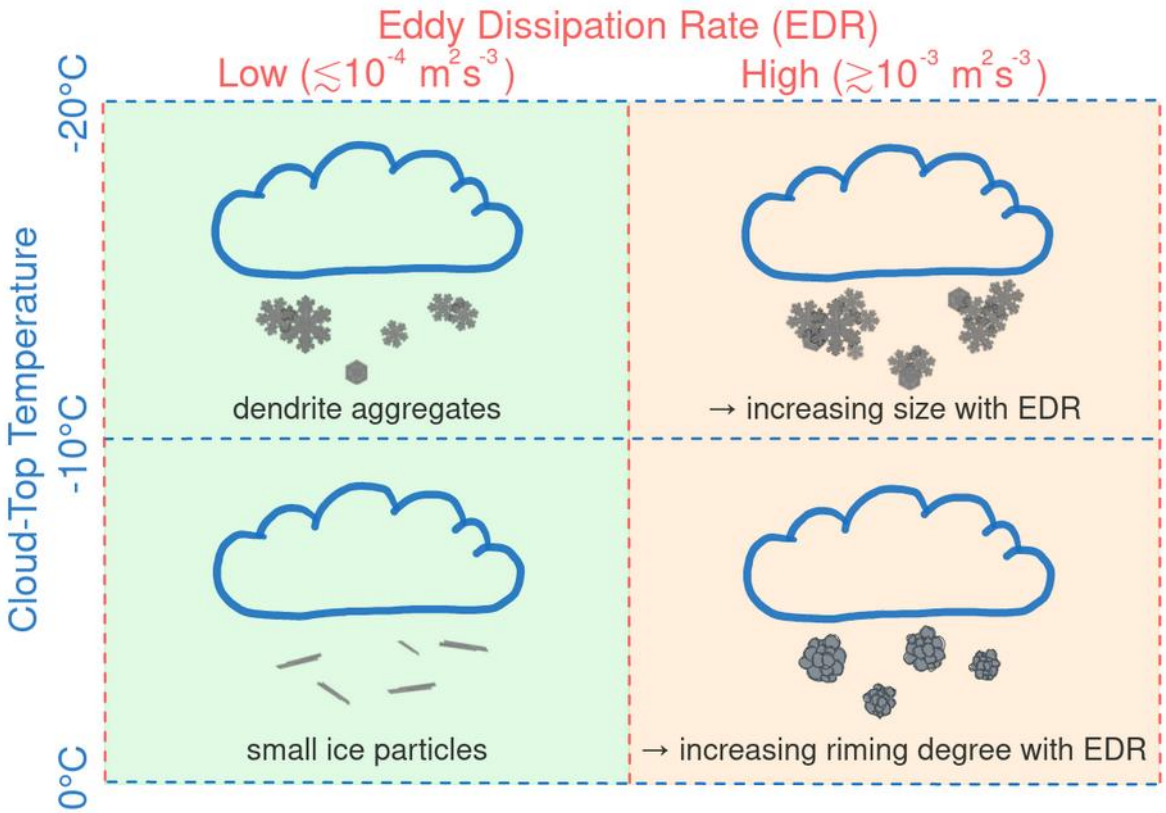
Dependency of riming on turbulence and liquid water path (LWP)

(Chellini & Kneifel, GRL, 2024)



1) **MDV and Ze increase with LWP <u>and</u> EDR**
2) **increasing LWP alone doesn't increase MDV** or Ze in the low EDR class (green)
→ **turbulence seems to be a necessary ingredient for riming in A-MPCs!**

Conclusions



Liquid-layer temperature determines major ice-growth processes

Aggregation:

- At temperatures compatible with dendritic growth
- Increasing EDR linked with increasing collision rates
  → larger particles and enhanced secondary ice

Riming:

- At temperatures > -10°C
- Turbulence key component to trigger riming

Further reading: G. Chellini, PhD thesis, available https://kups.ub.uni-koeln.de/72320/

Backup Slides

Study 1:

- Chellini et al. (2022) - ***Ice Aggregation*** *in Low–Level Mixed–Phase Clouds at a High Arctic Site: Enhanced by Dendritic Growth and Absent Close to the Melting Level* - JGR:A

Study 2:

- Chellini et al. (2023) - *Low-level mixed-phase clouds at the high Arctic site of Ny-Ålesund: a comprehensive long-term* ***dataset of remote sensing observations*** - ESSD

Study 3:

- Chellini and Kneifel (2024) - ***Turbulence as a key driver of ice aggregation and riming*** *in Arctic low-level mixed-phase clouds, revealed by long-term cloud radar observations* - GRL

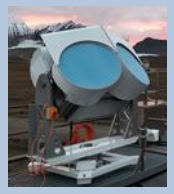
94-GHz cloud radar:

24-GHz precip. radar:

Sep 2017 - Feb 2021
cases: 1042

94-GHz cloud radar:

35-GHz dual-pol cloud radar:



Oct 2021 - Dec 2022
cases: 554