PROM-FRAGILE:

Exploring the role of **FRAG**mentation of ice particles by combining super-part**I**cle modeling, **L**aboratory studies and polarim**E**tric radar observations

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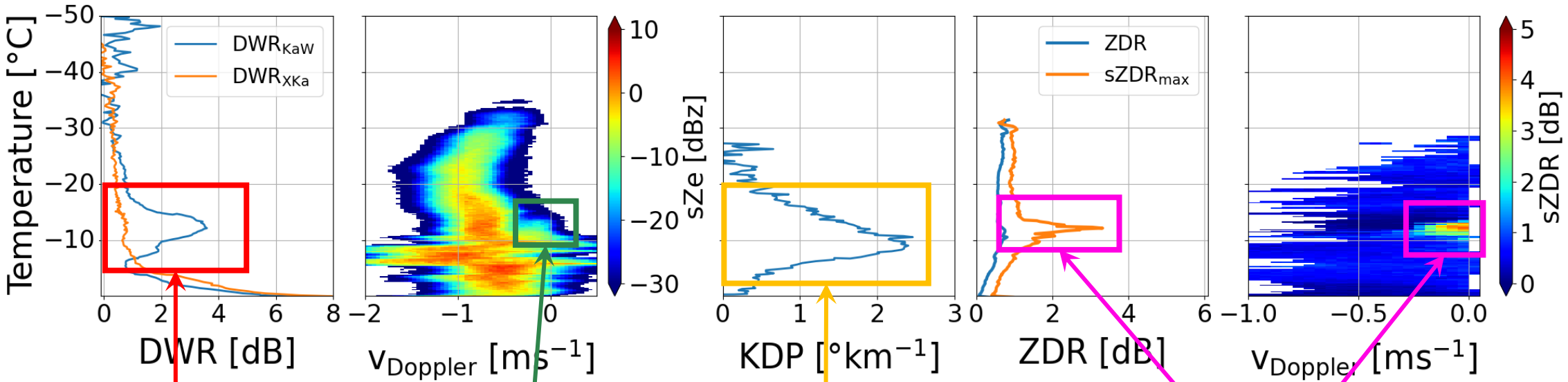
What happened since our last meeting?

- Clouds containing ice workshop – Poster presentation
- Snowfall workshop – Talk
- AMS annual meeting – Invited talk
- Lots of science – paper in preparation, to be submitted to JGRA soon:

Investigating ice microphysical processes in the dendritic growth layer by combining Monte-Carlo Lagrangian particle modelling with multi-frequency polarimetric radar observations

Leonie von Terzi [1],Christoph Siewert [2], Axel Seifert [2], Davide Ori [3], Stefan Kneifel [1]

The Dendritic Growth Layer (DGL) – a typical case study:



- Increase in DWR → aggregation
- Second mode in Doppler spectrum
- Increase in KDP
- Increase in sZDRmax

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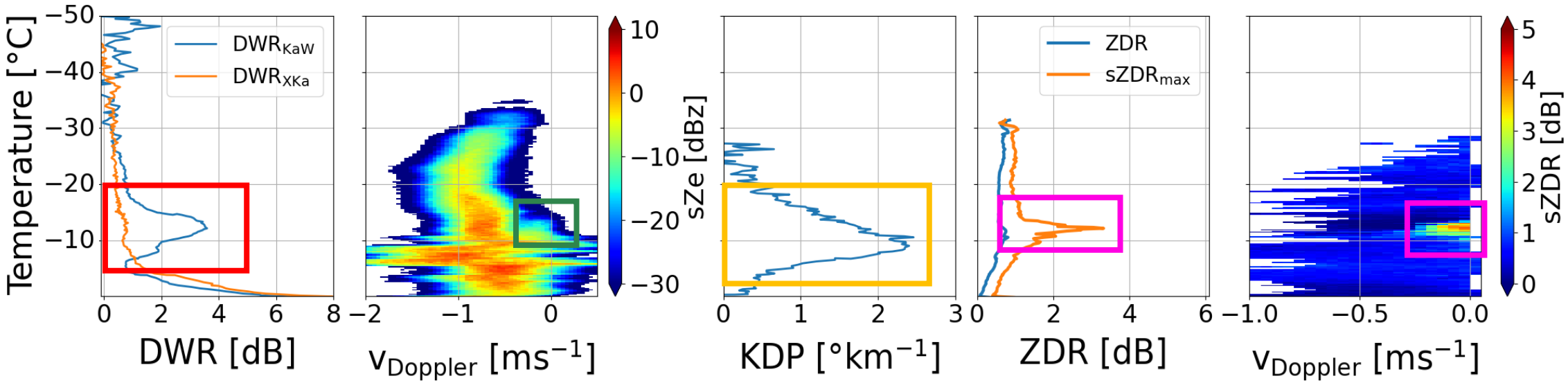

<u>Hypotheses</u>:

1. Primary nucleation in DGL produces plate-like particles which grow rapidly in DGL
2. Secondary ice production (Fragmentation) in DGL produces fragments of ice particles
3. Small ice crystals sedimenting from above which grow plate-like rapidly in DGL

The Lagrangian Monte-Carlo particle model McSnow

Radar only sees **effect** of ice microphysical processes (IMP) on the observed particle distribution, **not the IMP themselves!**

→ Let‘s combine observations with model in which current knowledge of IMP can be implemented

<u>Lagrangian Particle Models:</u>

- predict motion and evolution of individual particles

<u>Monte-Carlo approach</u>:

- group particles with similar microphysical properties into super-particles

McSnow predicts evolution of super-particles due to

- Deposition
- Aggregation
- Riming
- Secondary ice production
  - i.e. fragmentation
- Sedimentation

McSnow simulations

Hypotheses:

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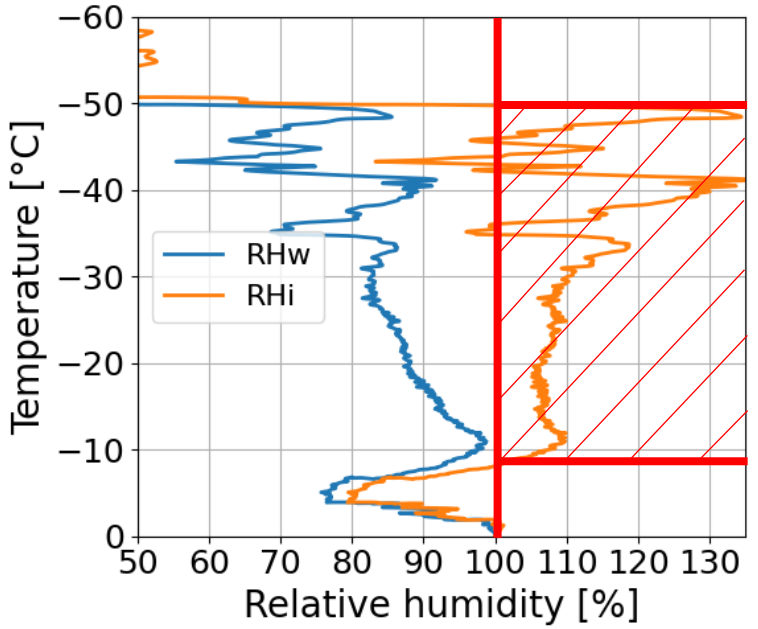
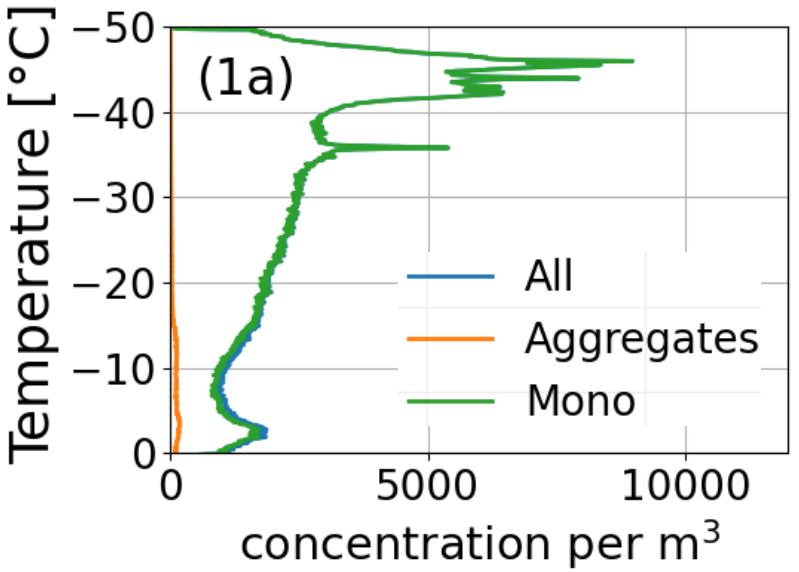
McSnow simulation

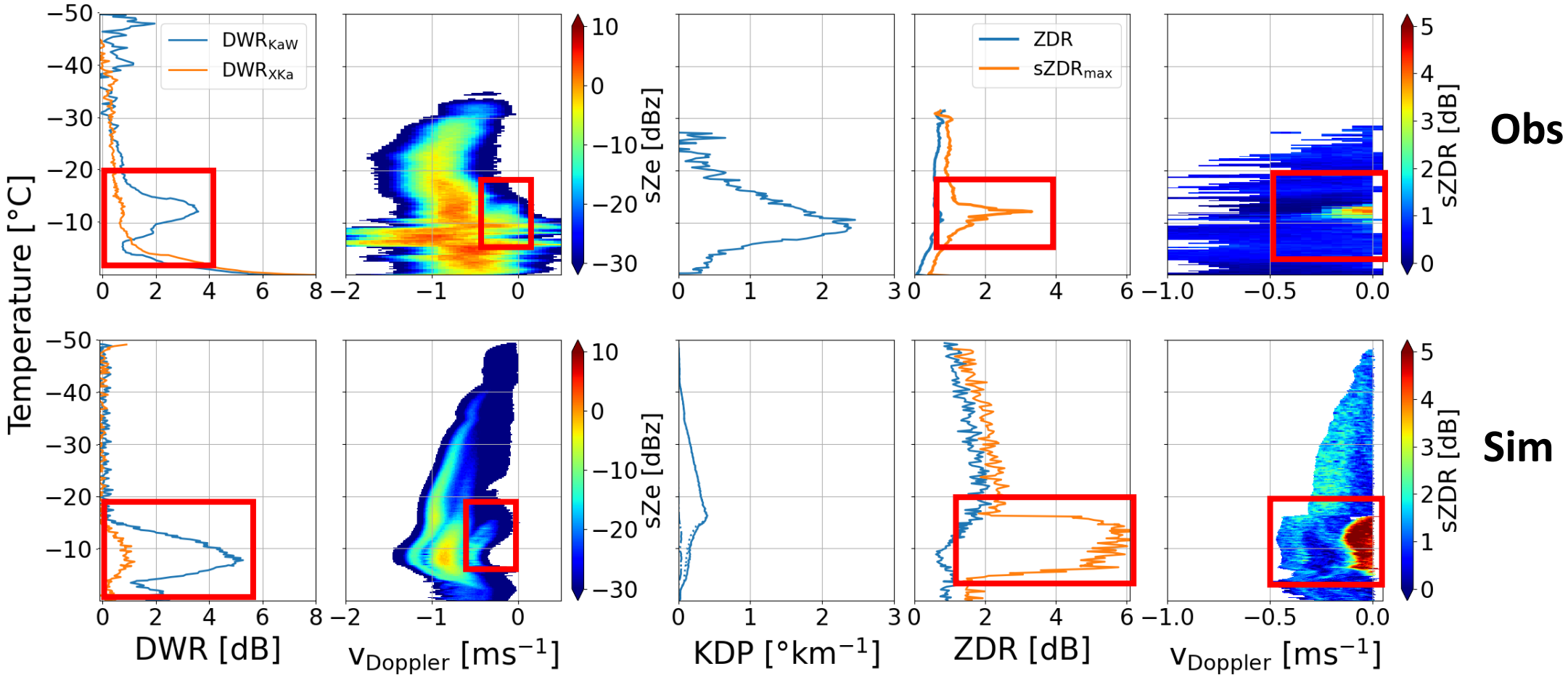
1. <u>Primary nucleation in DGL produces plate-like particles</u>

- We do not have information about INP concentration or ice particle concentration
- Assumption:
  - We have ice nucleation everywhere where $\mathrm{RH_{ice}} > 100\%$
  - Ice number concentration is governed by INP concentration which could be expected in Jülich
- Ice nucleation means: initialisation of ice particles with $\mathrm{D} = 10\mu\mathrm{m}$ and aspect ratio $= 1$



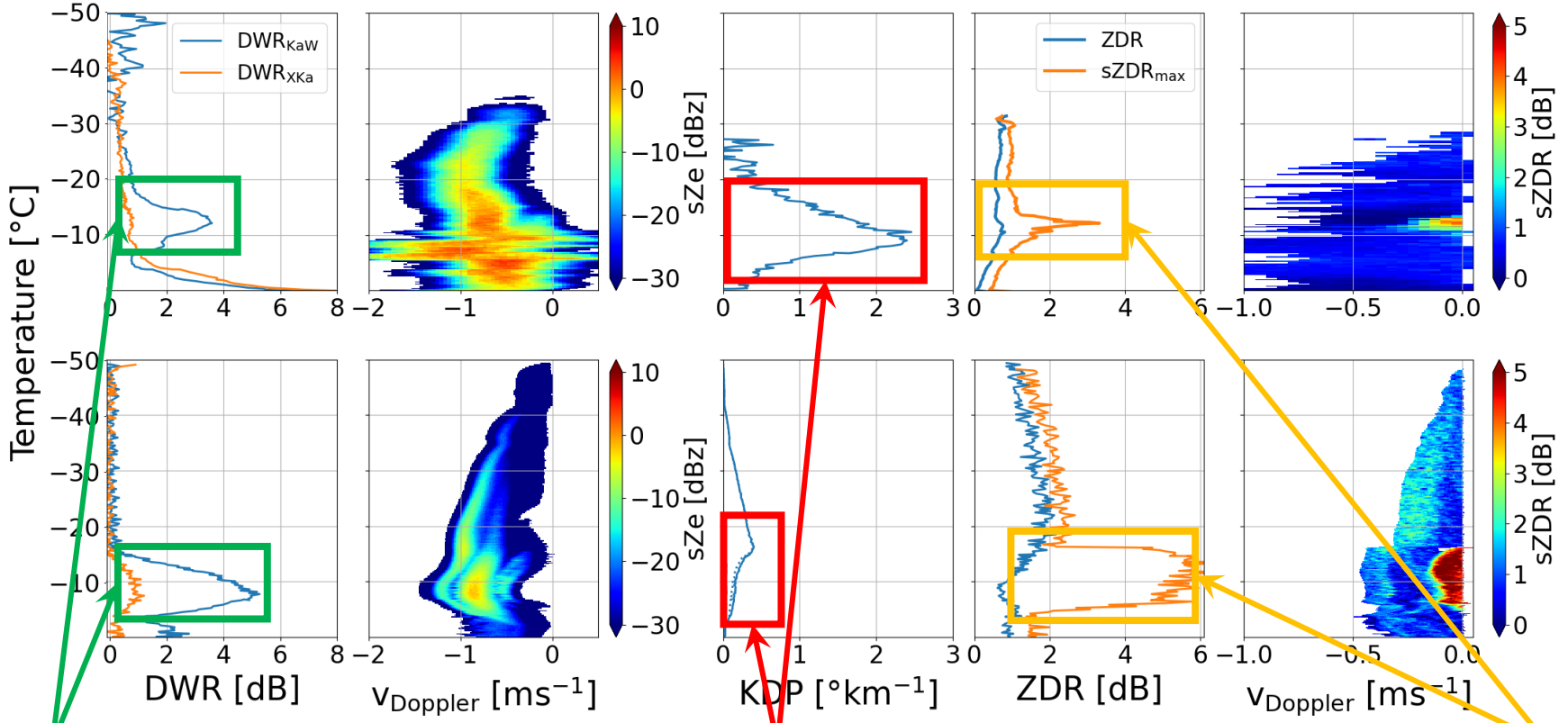


1. Primary nucleation in DGL produces plate-like particles



- McSnow is able to reproduce (most of) the important radar variables!
- What are the differences? Why are they there?

1. Primary nucleation in DGL produces plate-like particles



- Strength of DWR in DGL is similar
- DWR peak:
  - at wrong temperature
  - too strong

→ Is sublimation at correct height?

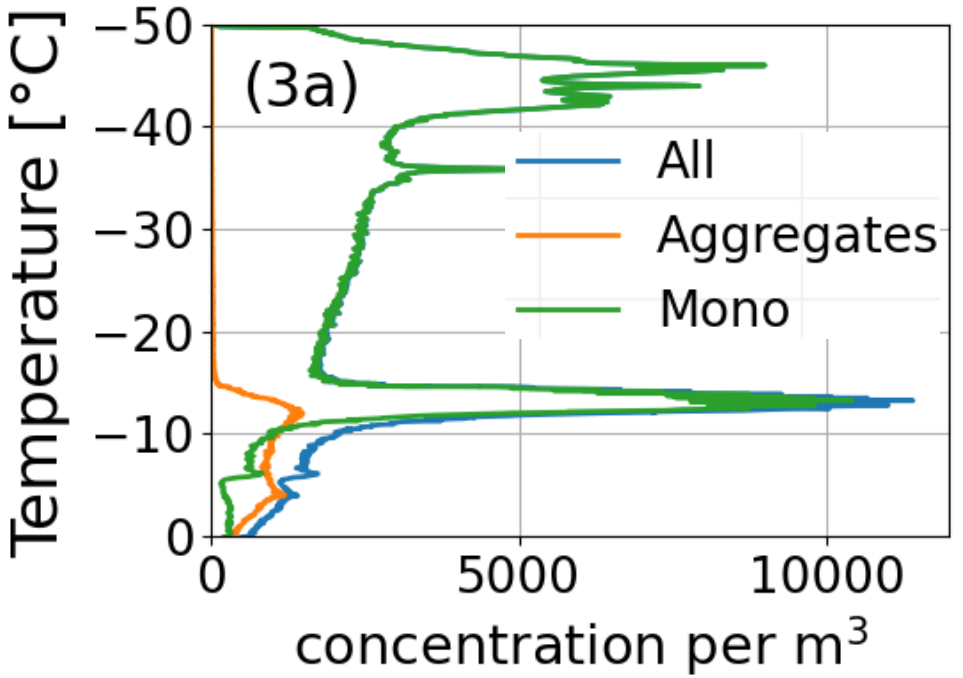
- Strength of KDP is massively underestimated
- Concentration (and size) of particles underestimated?

- Strength of sZDRmax is overestimated
  - no wobbling of particles assumed
- Peak of sZDRmax is too wide
  - Aggregation is not fast enough?
  - Does turbulence play a role?

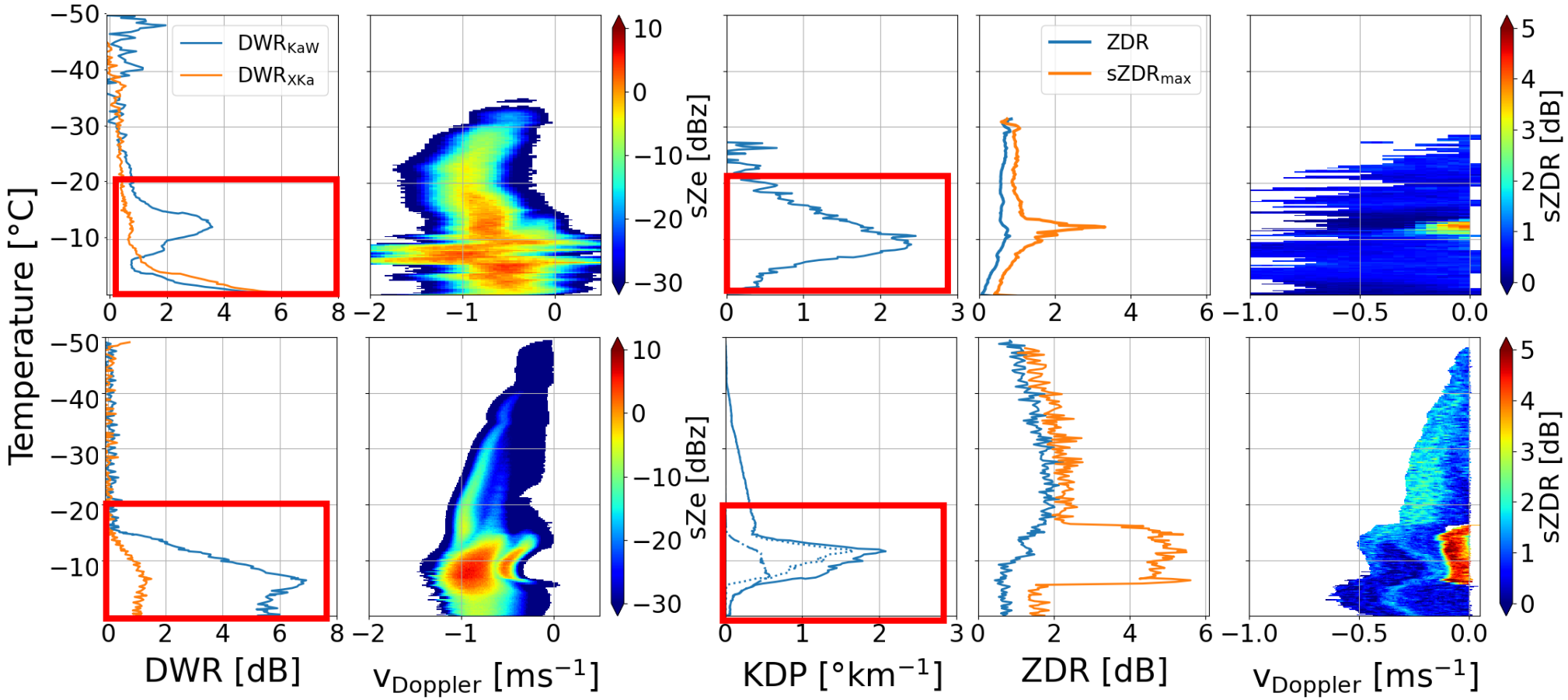
McSnow simulation

2. Secondary ice production (collisional fragmentation) in DGL produces fragments of ice particles

- Same simulation setup as in 1st hypothesis
- In addition: new fragmentation scheme based on Grzegorczyk et al. 2023 and Takahashi 1995:
  - Fragmentation happens during collision if:
    - Collision kinetic energy $> 10^{-9} J$
    - Ambient temperature between -12 and -18°C
  - Maximum number of fragments per fragmentation event: 20
  - Number of fragments is temperature dependent with maximum at -15°C
  - Size of fragments follows exponential PSD according to Grzegorczyk with mode of PSD $= 70 \mu$m



2. Secondary ice production – collisional fragmentation



Obs

Sim

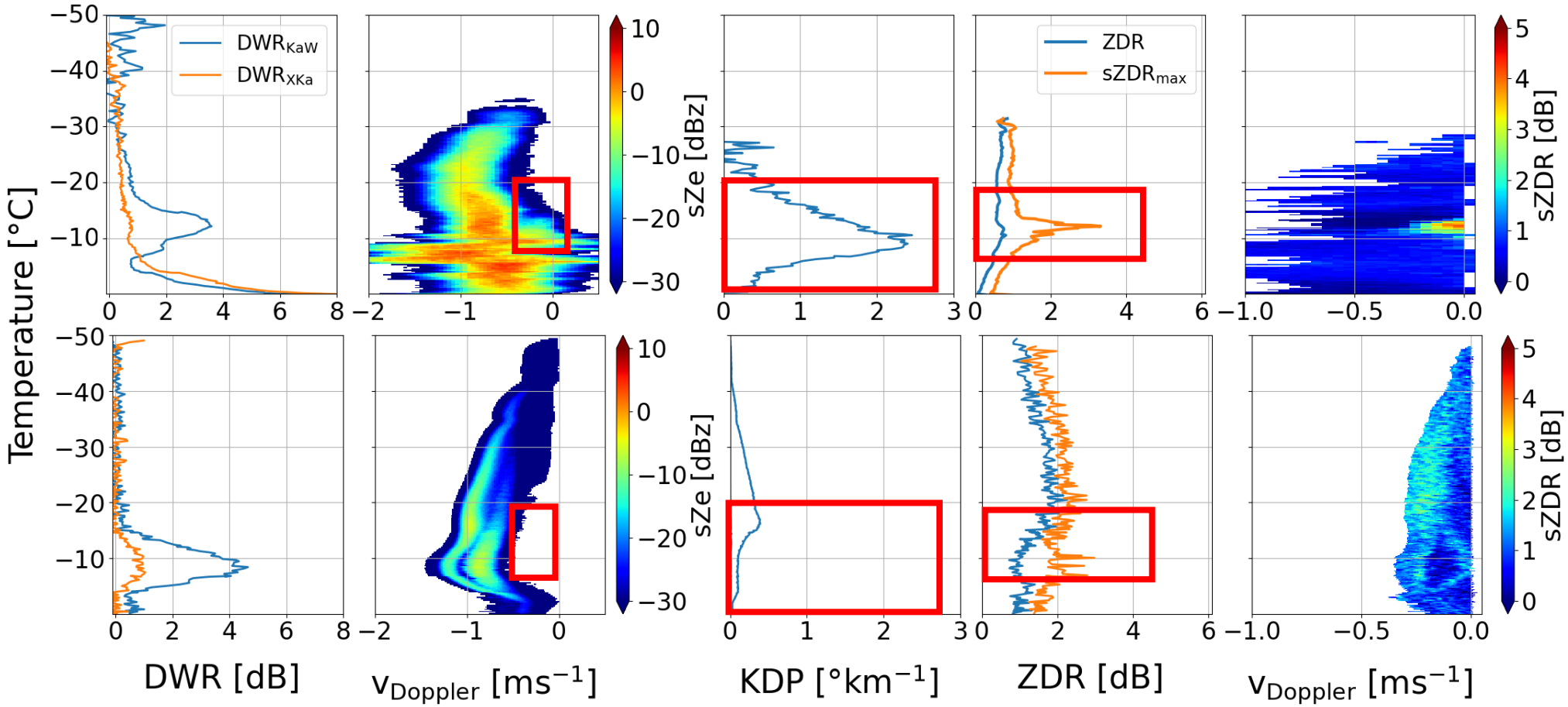
- Maximum of KDP is matching
- DWR is overestimated

McSnow simulation

3. Small ice crystals sedimenting from above grow plate-like

- Difference to 1st simulation setup: only nucleation at $T < -20°C$

3. Only ice nucleation at $T < -20°C$



- Without ice nucleation (primary or secondary) we do not have polarimetric signatures in DGL and also no second mode in the Doppler spectrum

Summary – which hypothesis is most likely?

	DWR	2nd mode in Doppler spectrum	KDP	sZDRmax
Primary nucleation @ $RH_{ice} > 100\%$				
Primary nucleation + fragmentation				
Primary nucleation @ $T < -20°C$				

Outlook

- Orientational averaging of ice particles is currently running (see talk of Davide and Soumi?)
  - This could decrease the polarimetric variables (which is needed in case of sZDRmax)
- We need more laboratory experiments in order to constrain
  - Temporal dependence of fragmentation
  - Shape of fragments
  - …

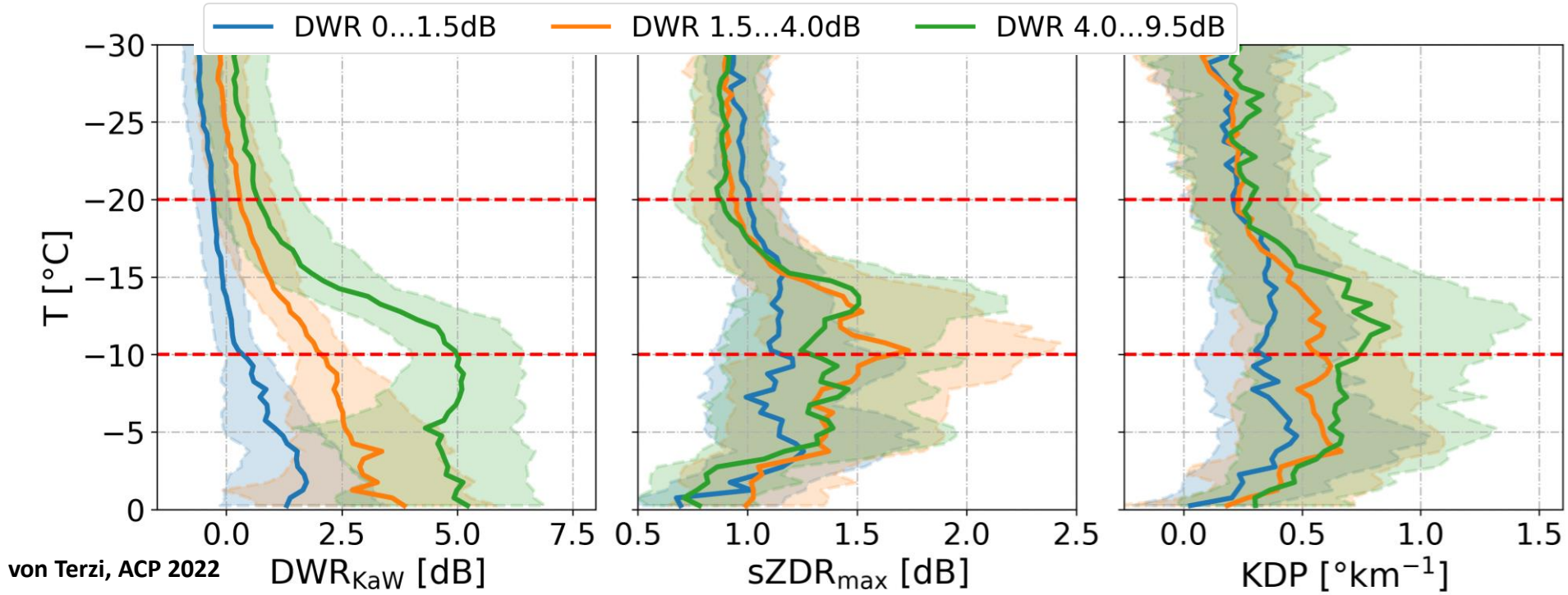
  → Talk by Sudha

Take Home messages:

1. The second mode in the Doppler spectrum as well as the increase in sZDRmax appear to be a direct result of new production of ice particles within the DGL (primary and secondary).
2. Fragmentation is needed in order to produce the large increase in KDP.
3. Ice crystals sedimenting into the dendritic growth layer do not explain the main DGL features.

Anhang

Multi-month spectral polarimetric multi-frequency radar dataset

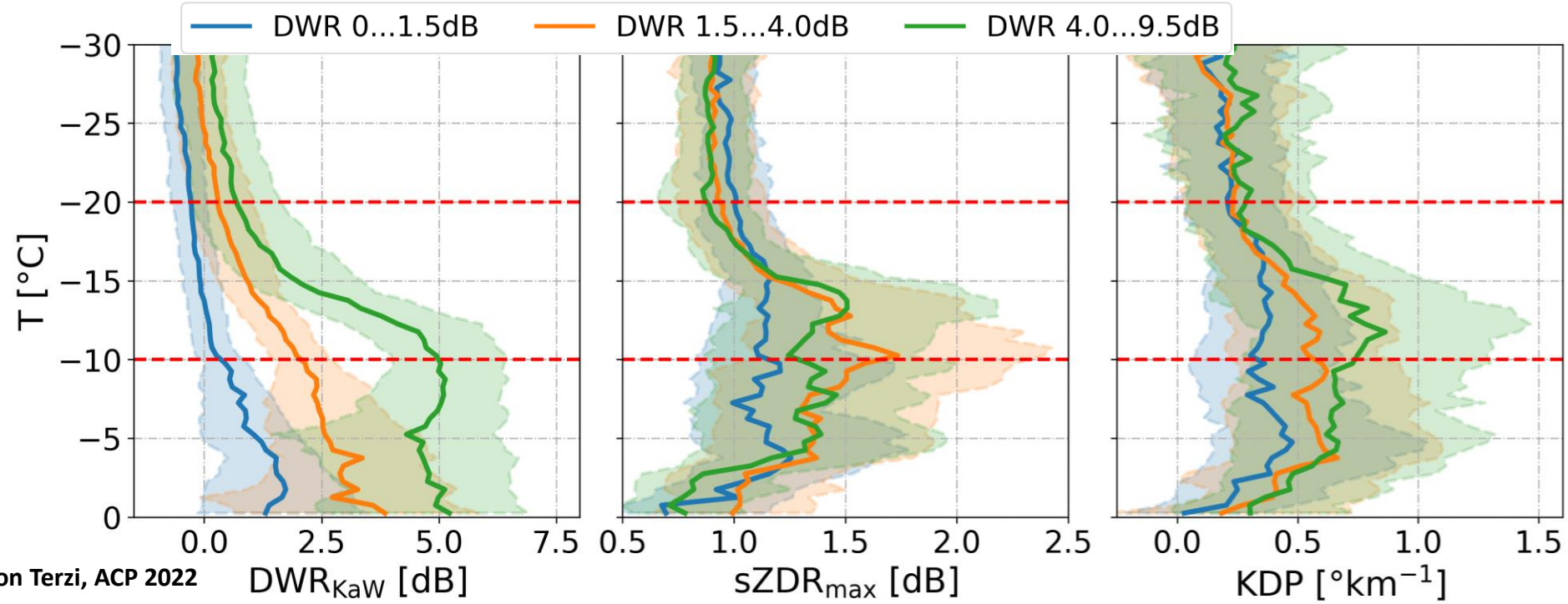


von Terzi, ACP 2022

<u>The dendritic growth layer is know for:</u>

- Increase in DWR
  → **aggregation**
- Increase in sZDRmax
- Increase in KDP

Multi-month spectral polarimetric multi-frequency radar dataset



von Terzi, ACP 2022

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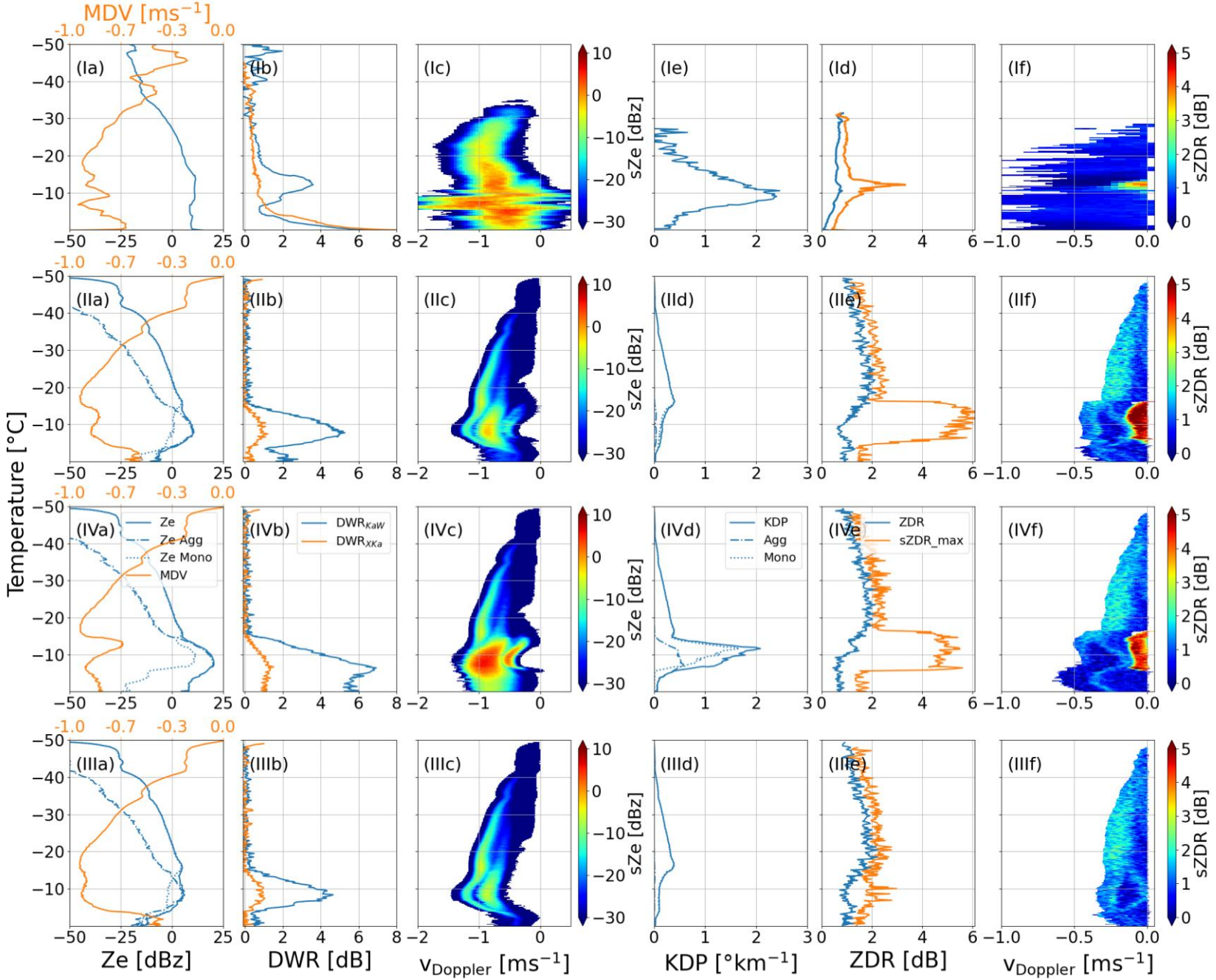


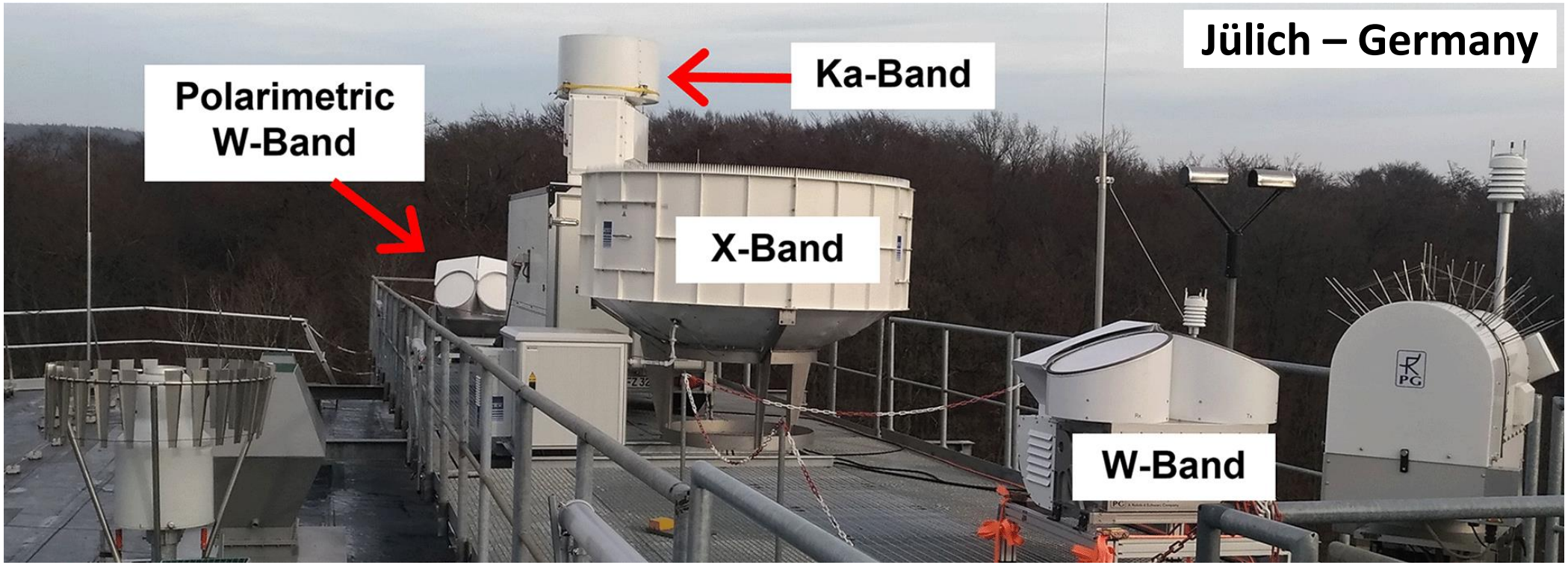
Obs

Primary nucleation
@ $RH_{ice} > 100\%$

Primary nucleation
+ Fragmentation

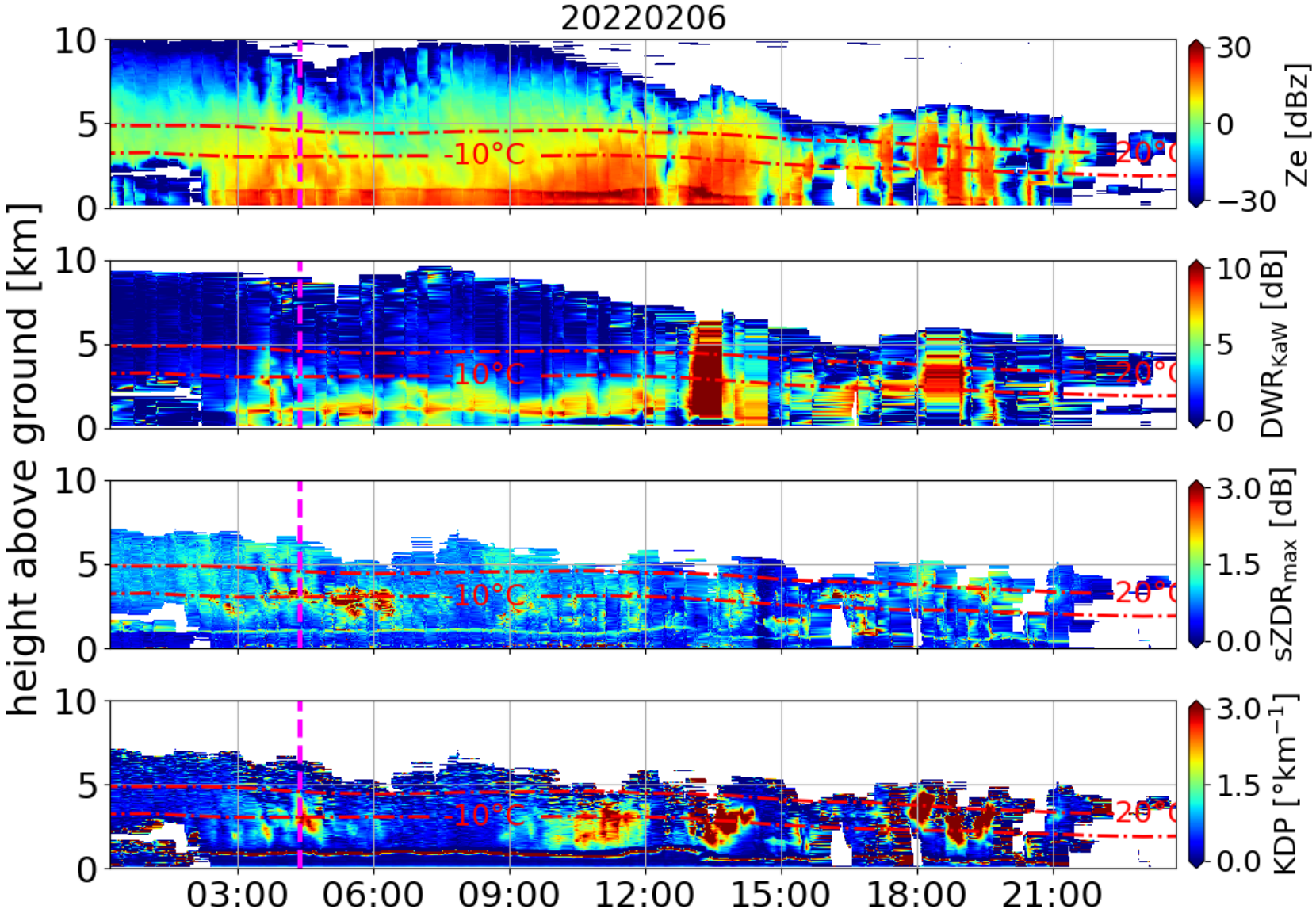
Primary nucleation
@ $T < -20°C$

Two radar campaigns:



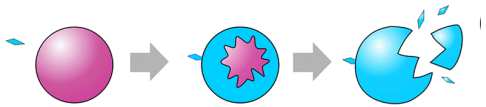
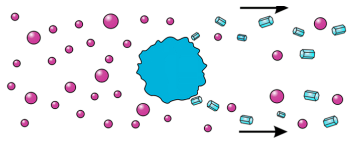
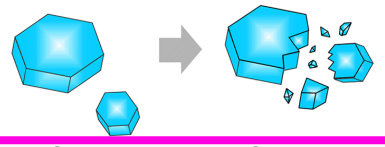
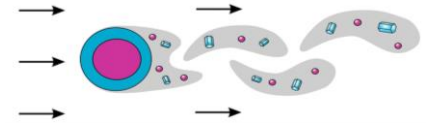
1. Tripex-pol
   - Nov 2018 – Jan 2019
   - Zenith X, Ka, W-Band
   - Scans pol. W-Band
   - 15 Radiosondes
2. Tripex-pol-scan
   - Dec 2021 – Feb 2022
   - Zenith X-Band
   - Scans with pol. W-Band and Ka-Band
   - 50 Radiosondes

The Dendritic Growth Layer – a case study:



Why Fragmentation?

- Status of SIP research: (as in talk from Korolev at ICCP 2021)

Description	Mechanism	# Lab works	Lab studies quantification	# years	simulations
	**Droplet fragmentation during freezing**	35	Work-in-progess (ongoing)	69	Early stage
	**Splintering during riming (HM process)**	22	Work-in-progess (ongoing)	61	Yes physical mechanism under debate
	**Fragmentation during ice-ice collision**	2	Work-in-progess (deeply hybernated)	49	Early stage
	**Fragmentation during sublimation**	9	Work-in-progress (deeply hibernated)	47	Early stage
	**Activation of INPs in transient supersaturation**	5	Not attempted	49	no

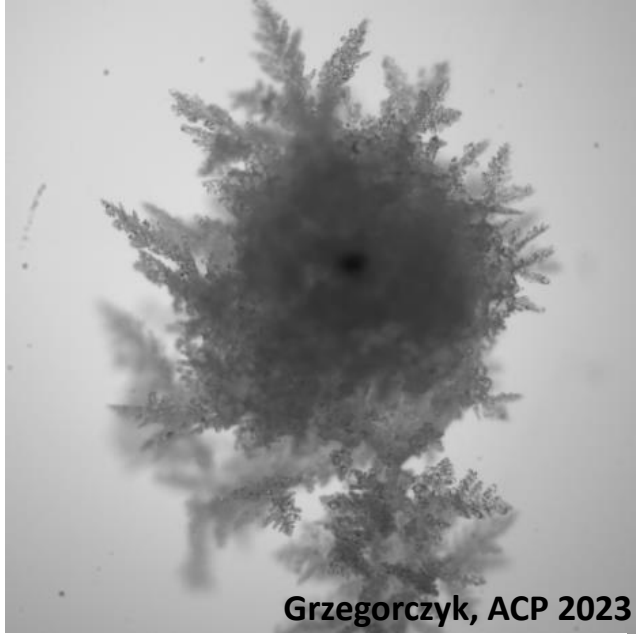
Why Fragmentation?

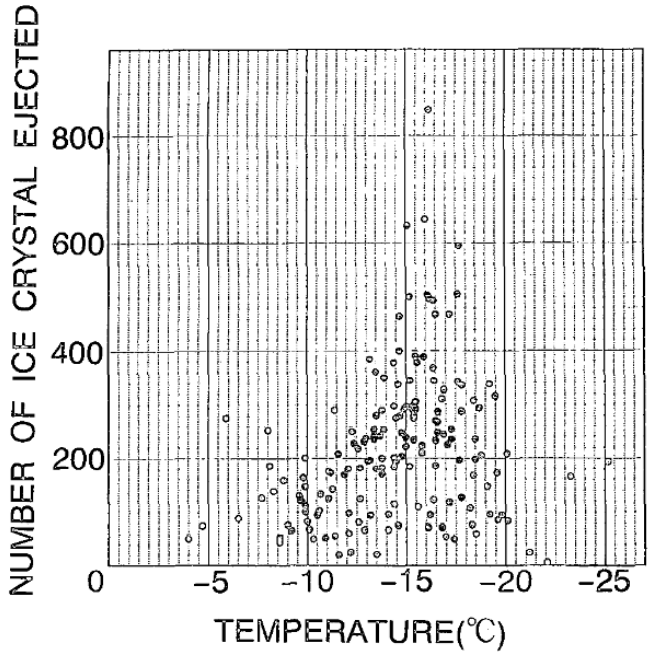
Fragmentation:

- Fragile dendritic arms growing on ice particles and aggregates
- Arms break off during collisions
- Potential to be active over wide parameter range (not like other SIP)

Problem:

- Very little understanding


Grzegorczyk, ACP 2023



Takahashi 1995

Outlook McSnow simulations

- Fragmentation produces 2. Mode with reasonable sZDR
  - KDP is too small – can we produce more fragments?
  - Which conditions are most favourable for fragmentation?
- Are there other explanations for 2. Mode?
  - Local enhancement of relative humidity
    → INP get activated and new ice crystals are formed

- Both hypothesis are currently investigated in more detailed with a statistical approach!

Conclusions

- Observations show an increase in number concentration in DGL alongside second mode and enhanced sZDR
- Simulations indicate that second mode might be more likely related to fragmentation than new INP activation

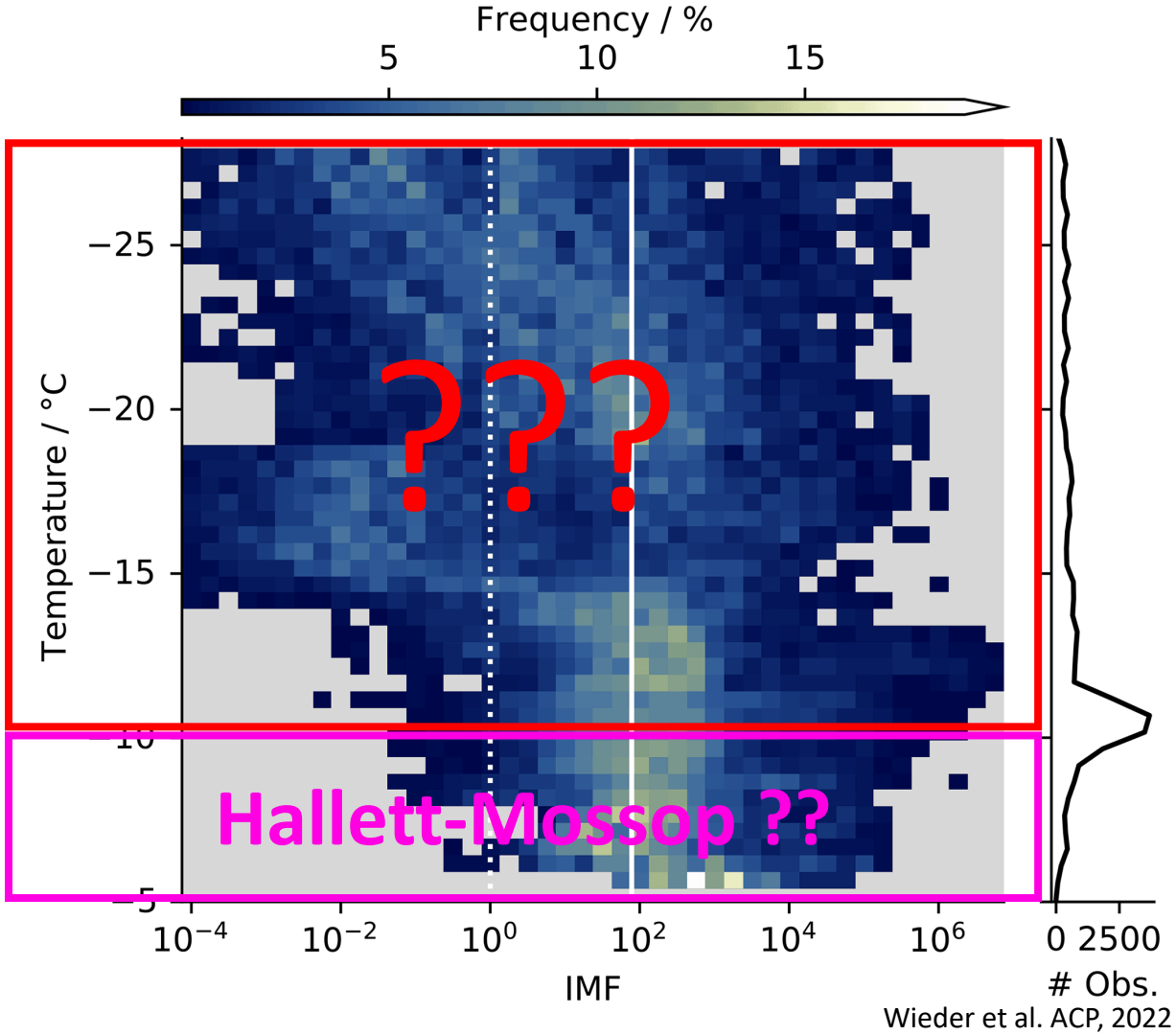
… of course more simulations are needed to investigate in a more objective way…

… more information on fragmentation is needed to constrain fragmentation scheme in McSnow …

Why Fragmentation?

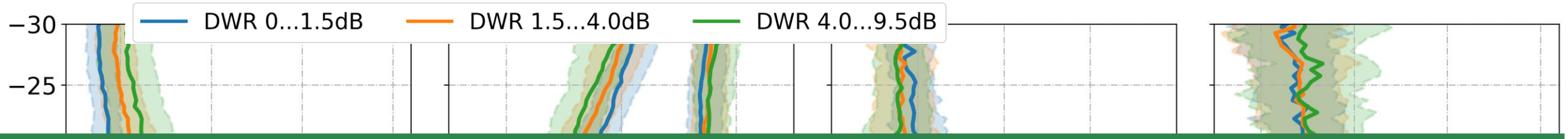
- factor 10 to 100 more ice particles (IP) observed than ice nucleating particles (INP) measured
- E.g. ice multiplication factor $\mathrm{IMF} = \frac{N(IP)}{N(INP)}$

→ Secondary ice production (SIP)



Wieder et al. ACP, 2022

Multi-month spectral polarimetric multi-frequency radar dataset



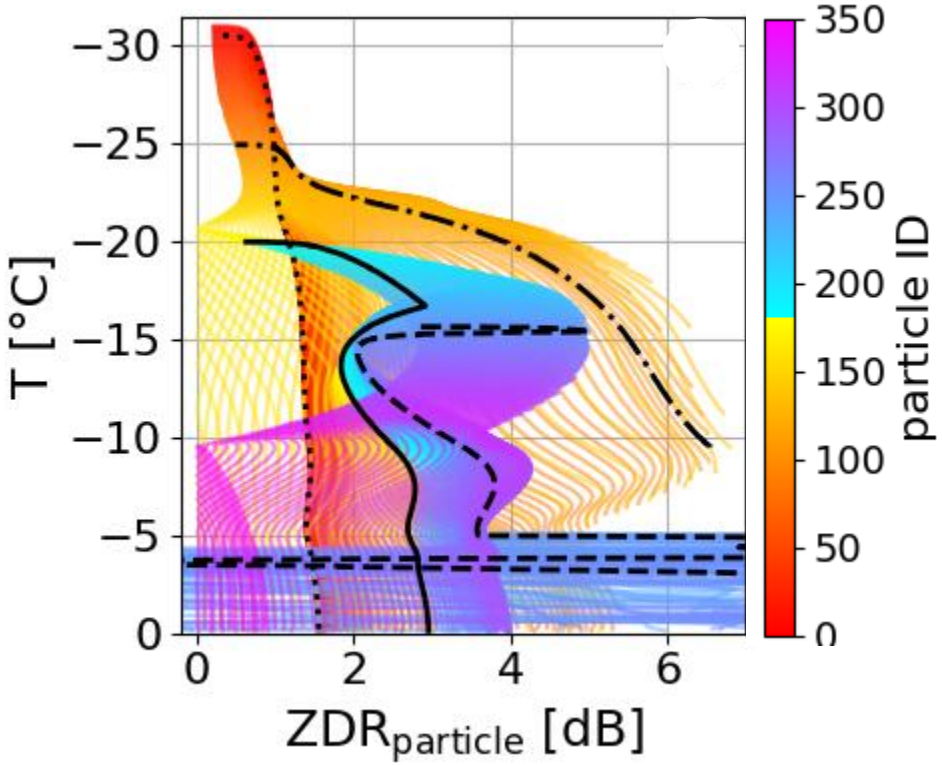
Radars only observe the **effect** of microphysical processes, **not the processes themselves**!!

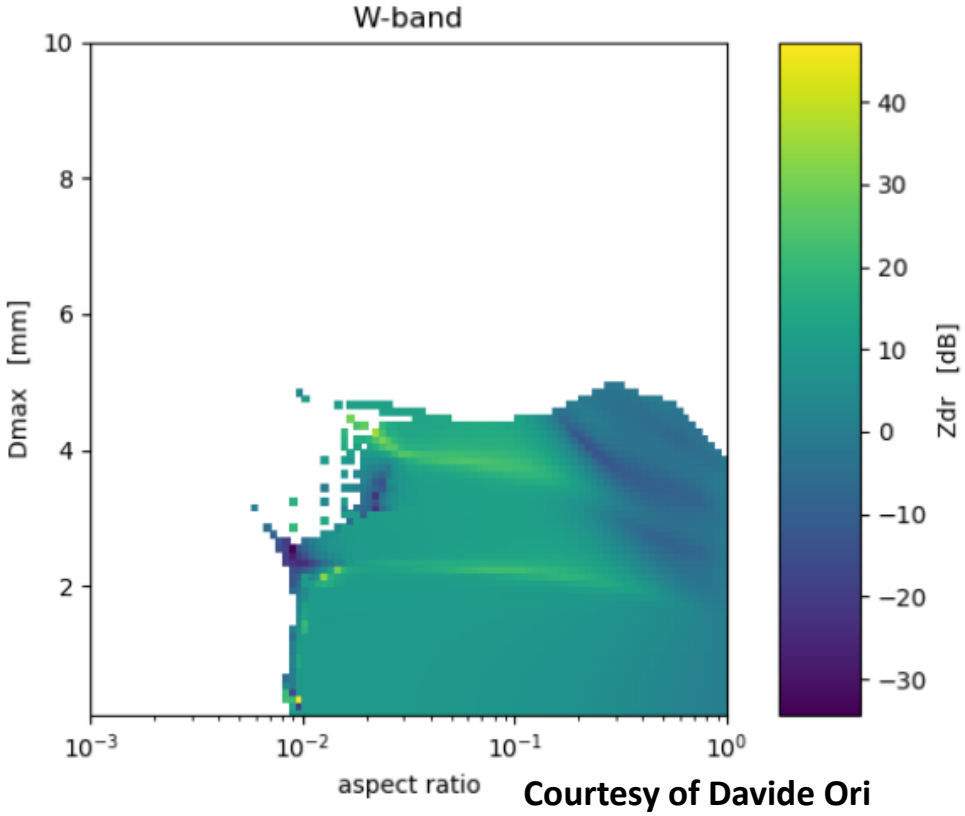
→ Model where current knowledge of microphysical processes is implemented and hytpothesis can be tested

- Do ice – ice collisions in the DGL cause fragmentation?
- Ice nucleating particles (INP) get activated and produce new primary ice

Forward simulations: from T-matrix to DDA

- Tmatrix has a convergence problem!

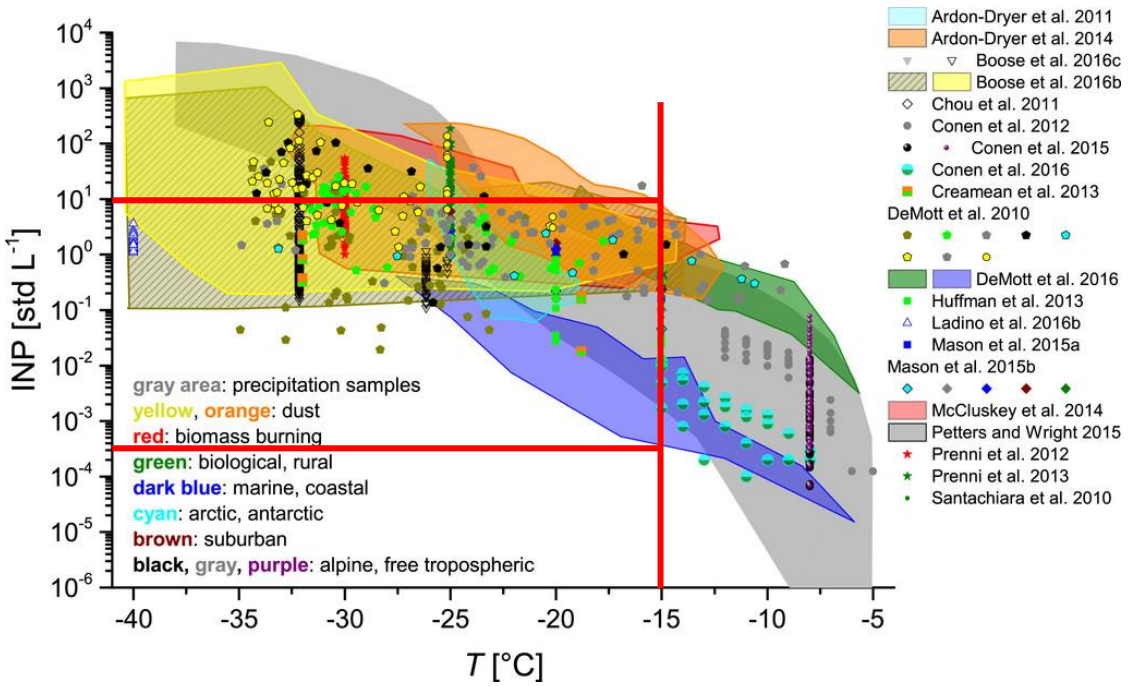




Courtesy of Davide Ori

Are new INP activated in DGL?

- Mode of aggregates from above
- Second nucleation layer in DGL
- Nucleation rate was adapted to have 2-3 L^{-1} ice crystals in the second mode
- McSnow mit habit prediction (Welss, JAMES 2023)
- Atmosphere setup:
  - Temp: const. Lapse rate
  - Rhi: 105% (median of radiosonde observations)



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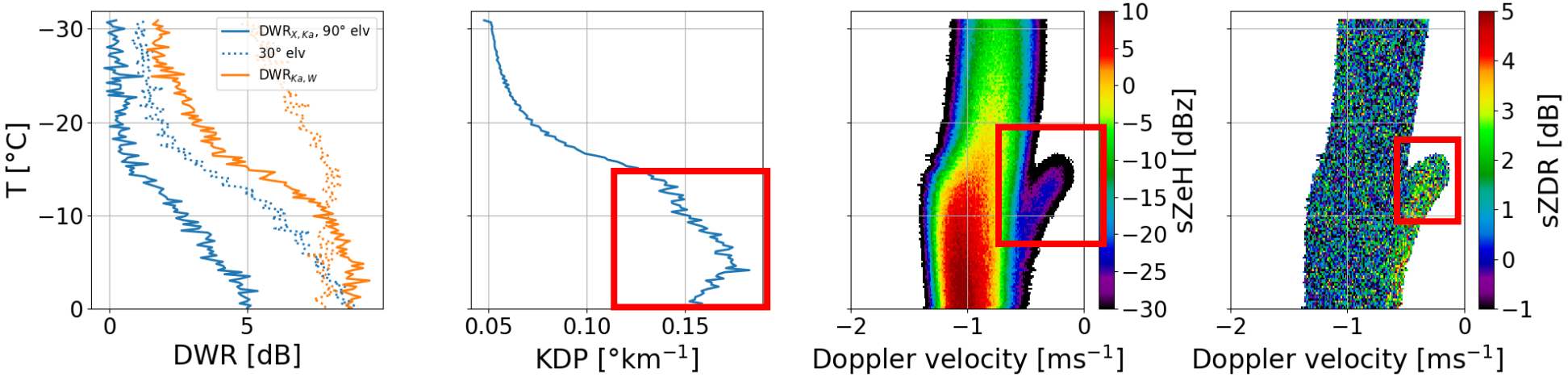

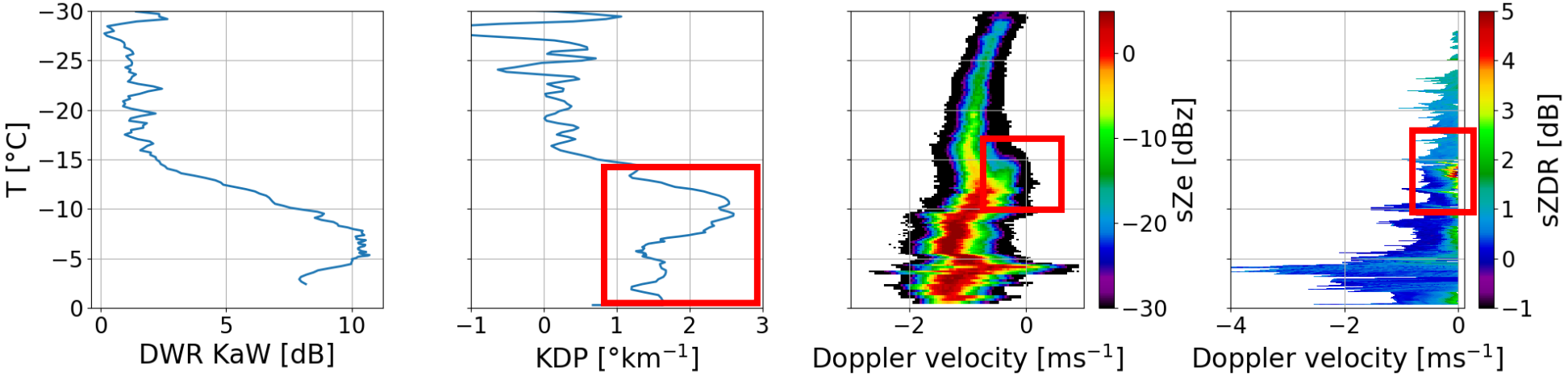

Simulation

- KDP too small
- → not enough particles?
- sZDR too small
- → aspect ratios too large or asymmetric
- Particles not small enough?

Observation