Which ice microphysical processes might explain the typical radar signatures in the Dendritic Growth Layer?

Leonie von Terzi, Stefan Kneifel (LMU Munich)

Christoph Siewert, Axel Seifert, Fabian Jakub (DWD)

Davide Ori (Uni of Cologne)

The Dendritic Growth Layer (DGL)

- What is the DGL? Why is it important?

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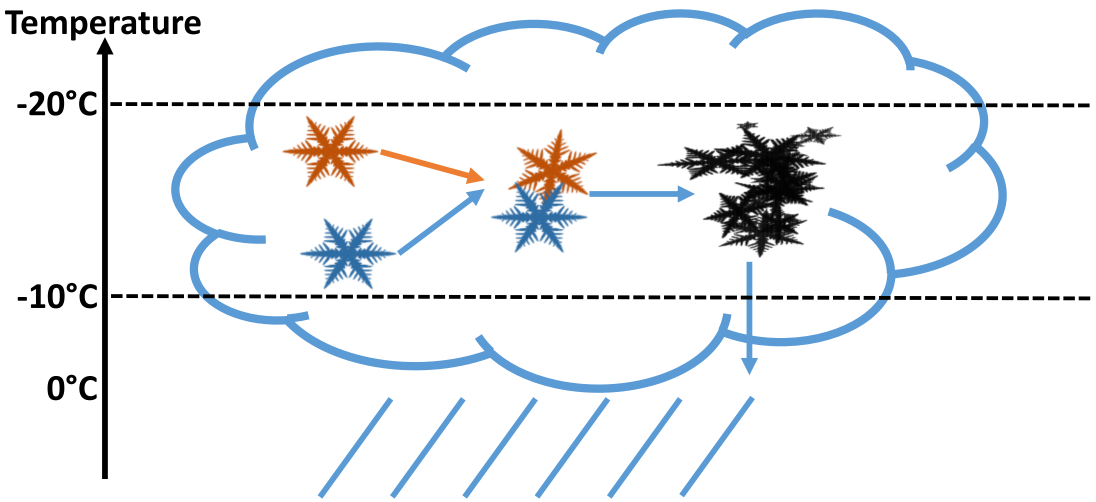

The Dendritic Growth Layer (DGL)

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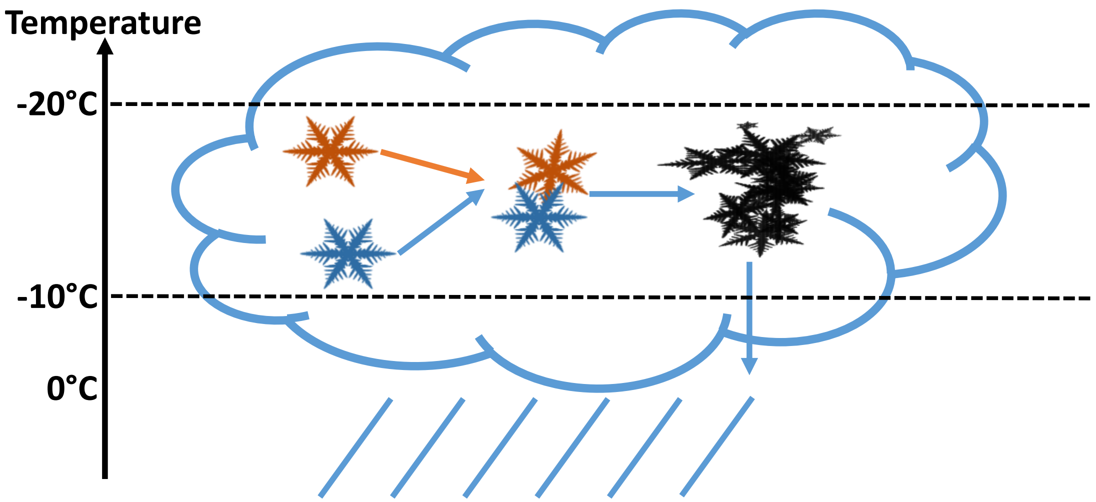

Leonie von Terzi, l.terzi@lmu.de

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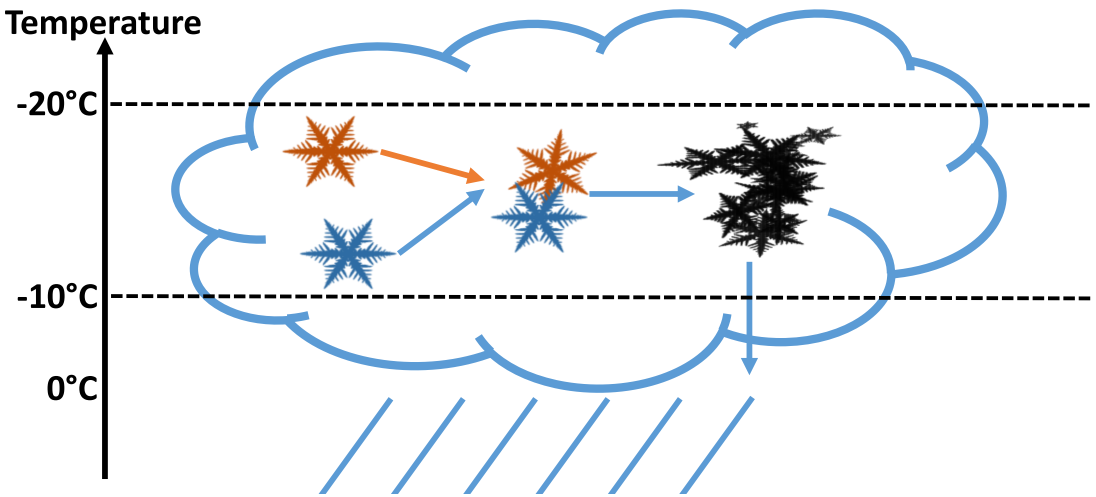

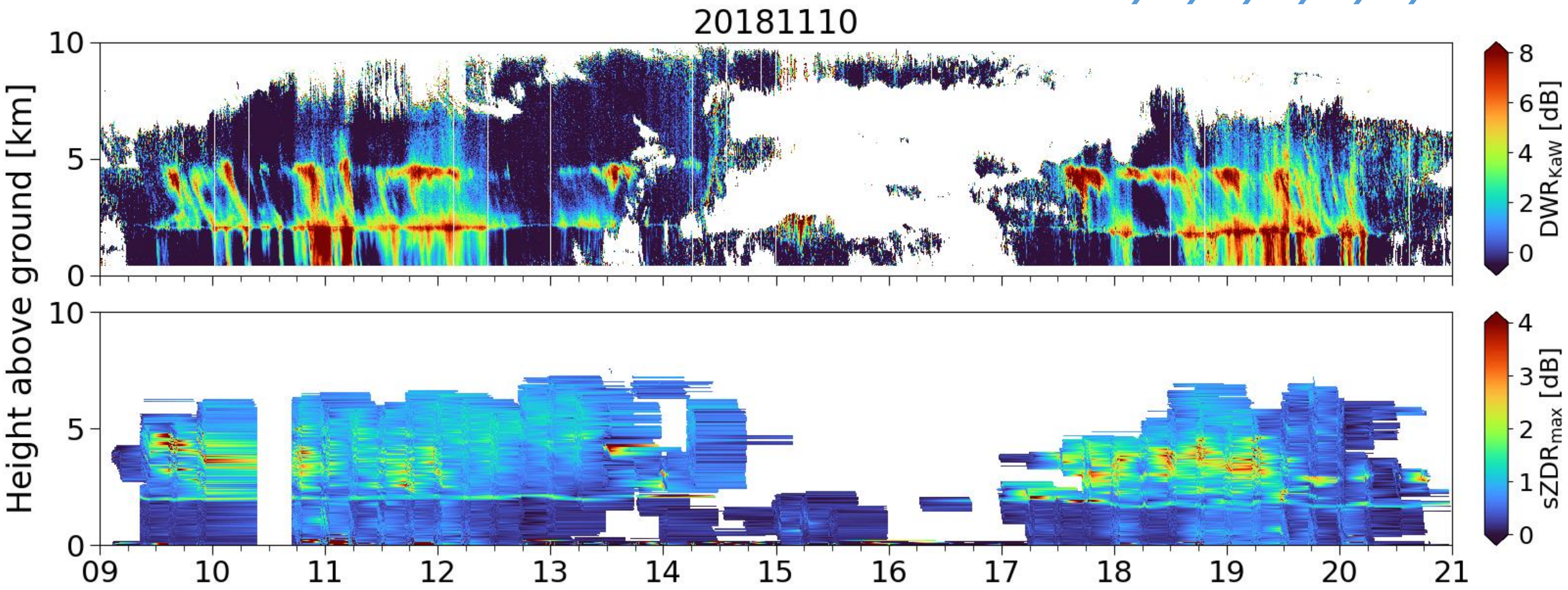

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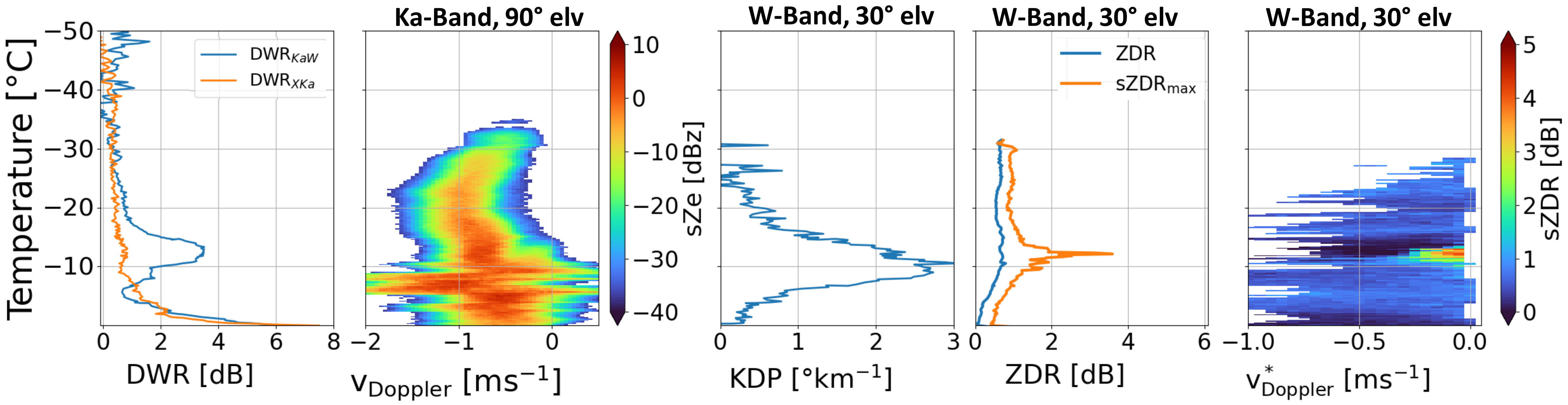
The Dendritic Growth Layer (DGL) – a typical case study:



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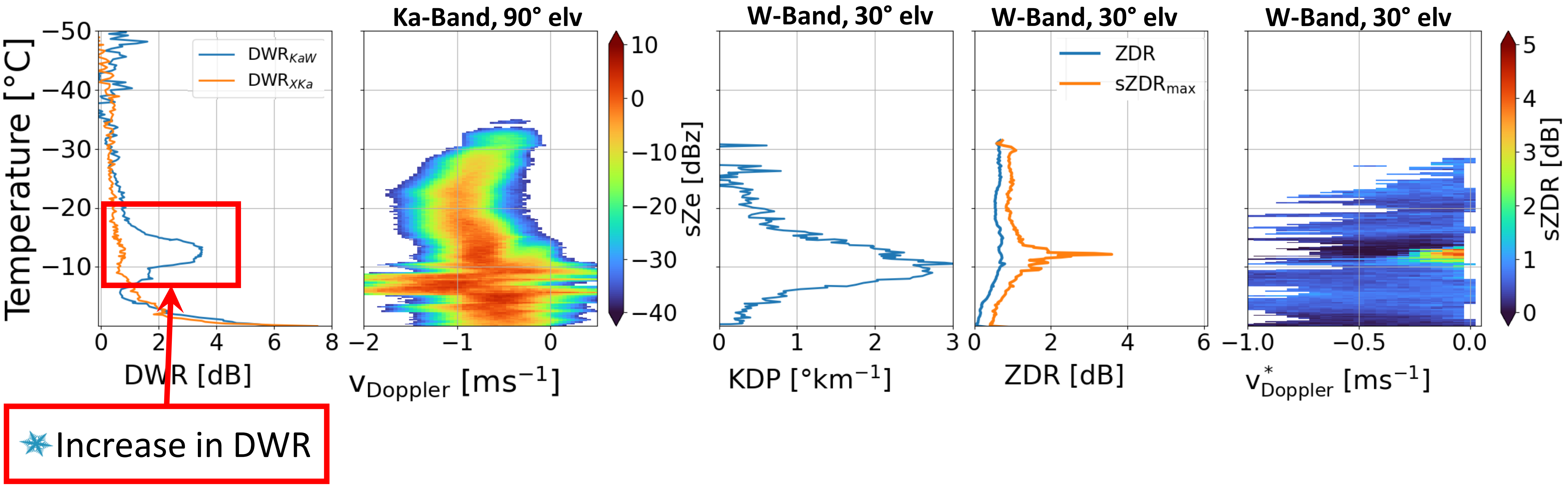

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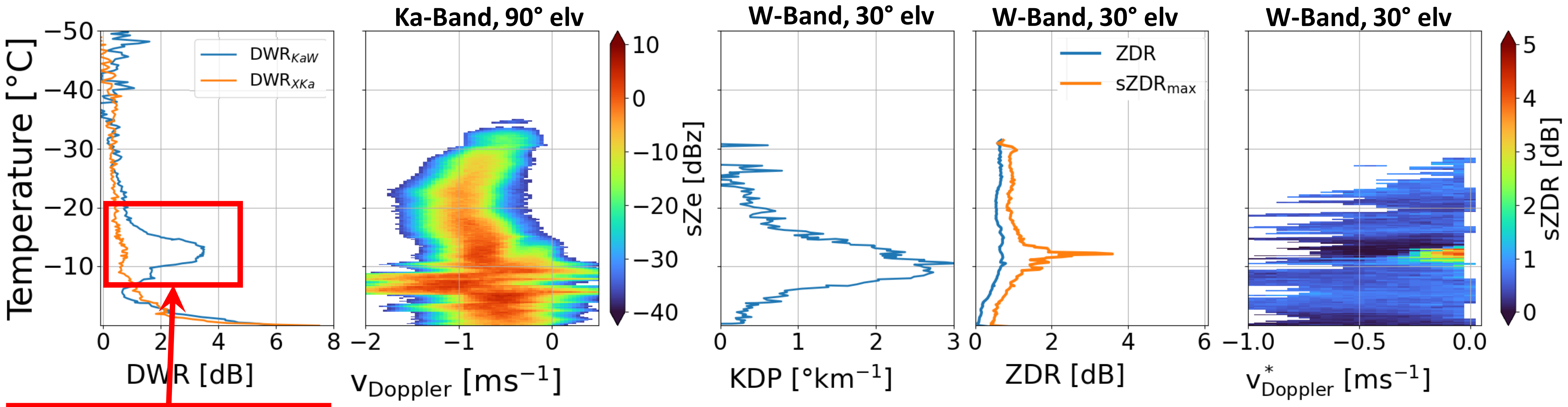

Increase in DWR

→ aggregation

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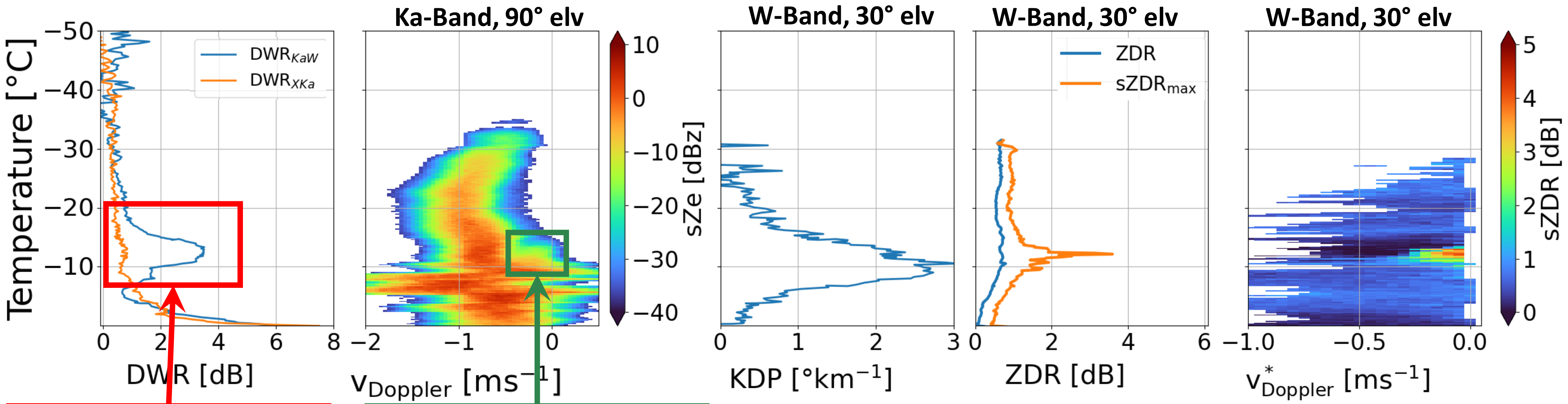

Increase in DWR

2nd mode in Doppler spectrum

→ aggregation

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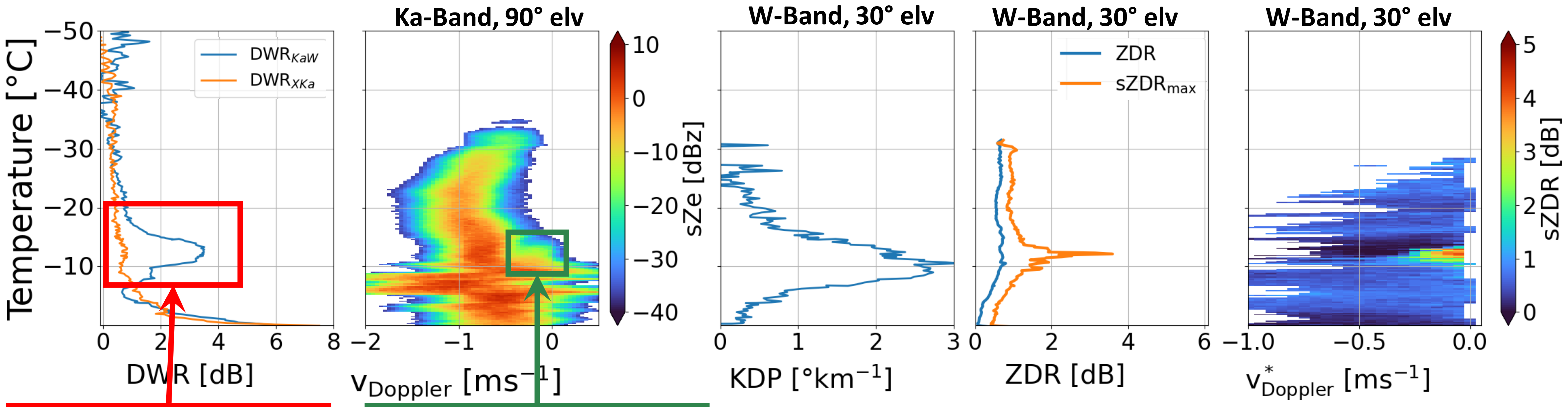

Increase in DWR

2^{nd} mode in Doppler spectrum

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→ New ice particles?

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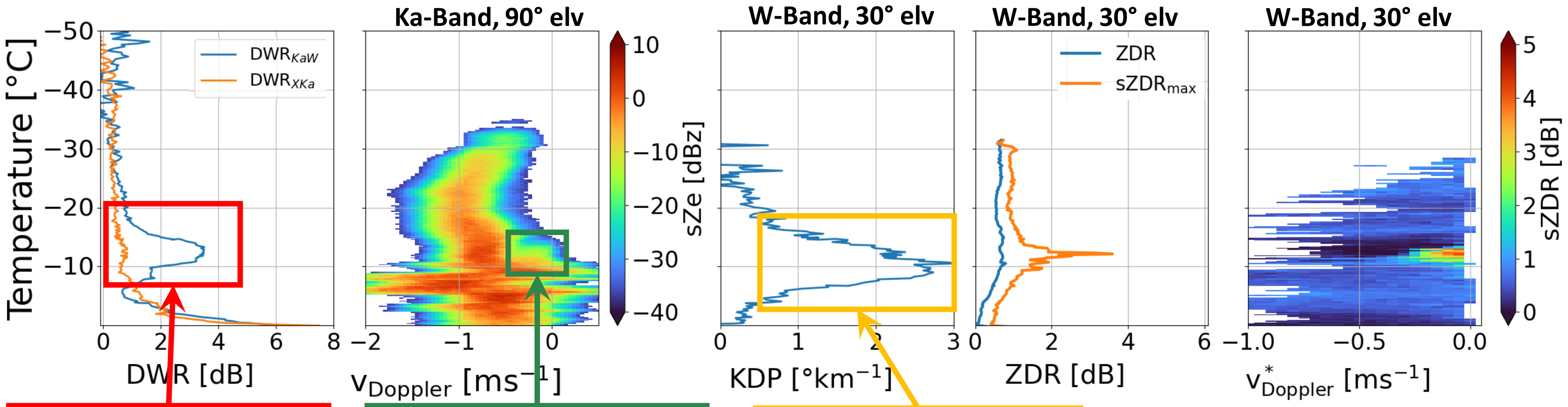
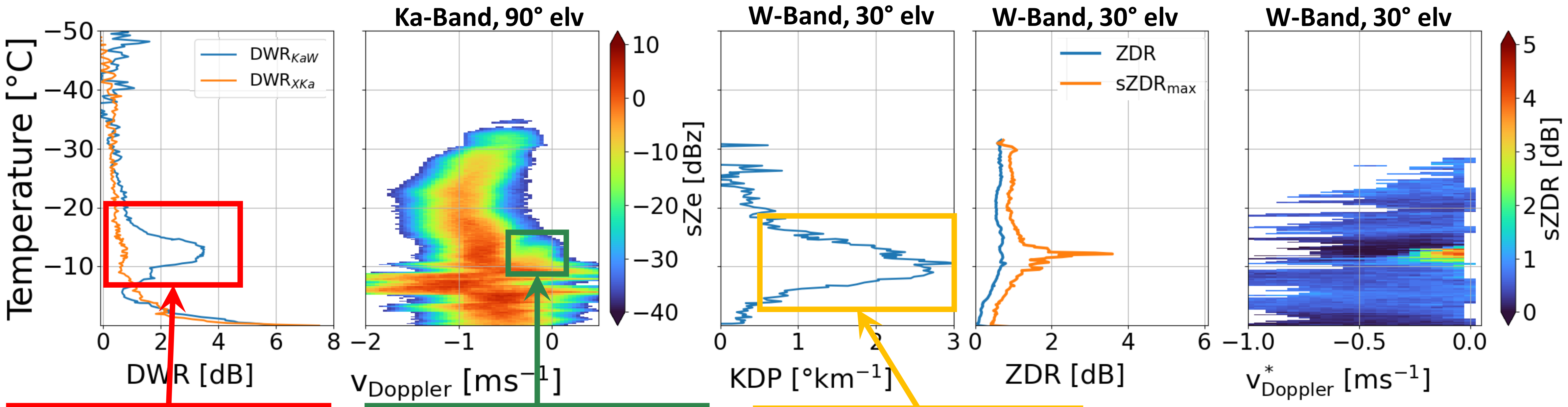


- Increase in DWR
- 2nd mode in Doppler spectrum
- Increase in KDP

→ aggregation

→ New ice particles?

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



Increase in DWR

→ aggregation

2nd mode in Doppler spectrum

→ New ice particles?

Increase in KDP

→ Ice concentration or size increases?

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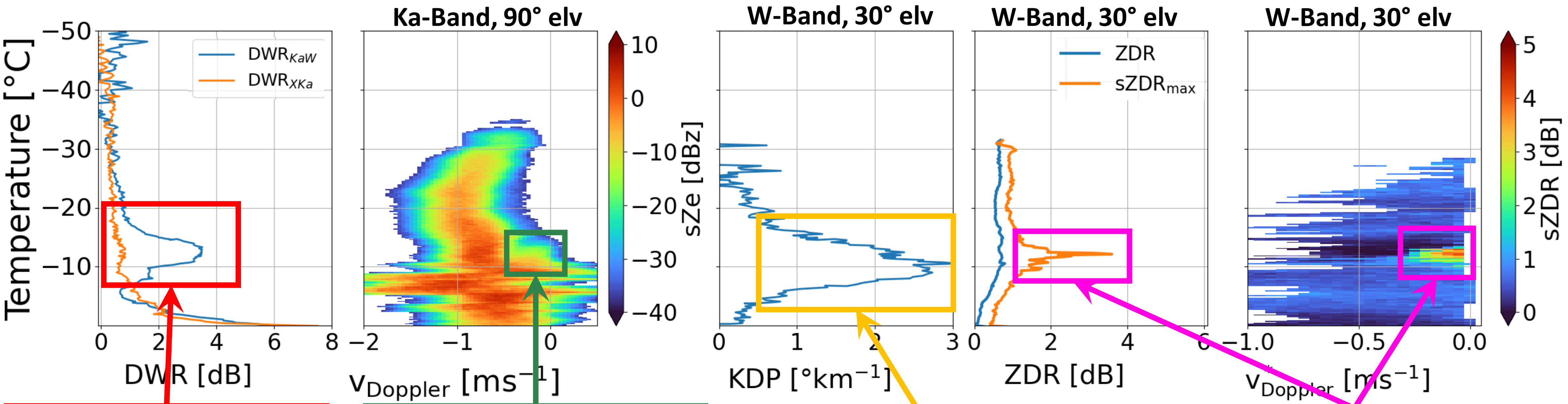


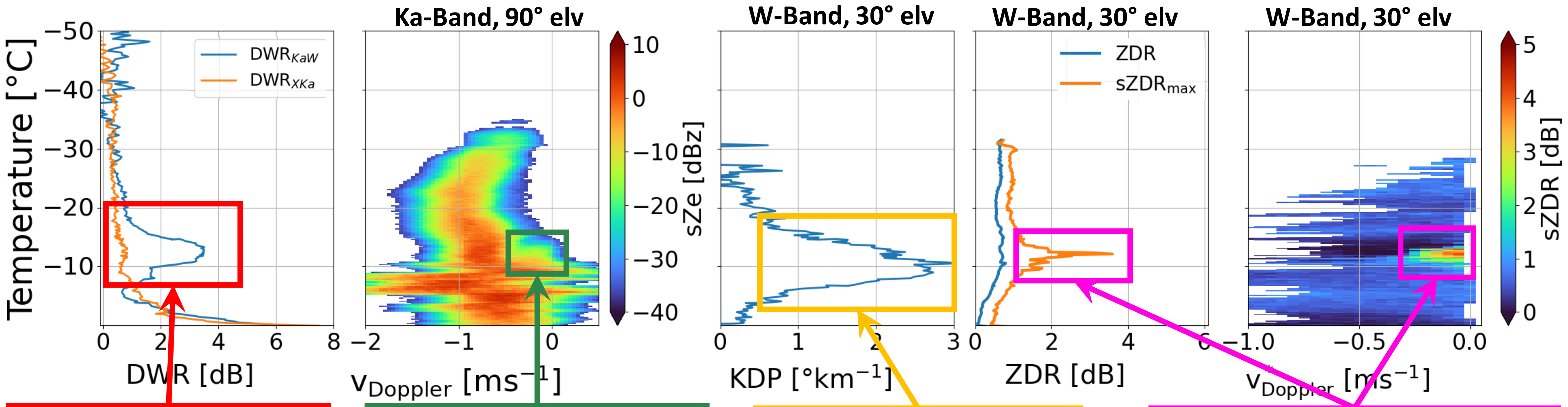
- Increase in DWR
- 2nd mode in Doppler spectrum
- Increase in KDP
- Increase in sZDR$_{max}$

→ aggregation

→ New ice particles?

→ Ice concentration or size increases?

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



- Increase in DWR
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- 2nd mode in Doppler spectrum
  → New ice particles?
- Increase in KDP
  → Ice concentration or size increases?
- Increase in sZDR$_{max}$
  → Plate-like ice crystals are growing

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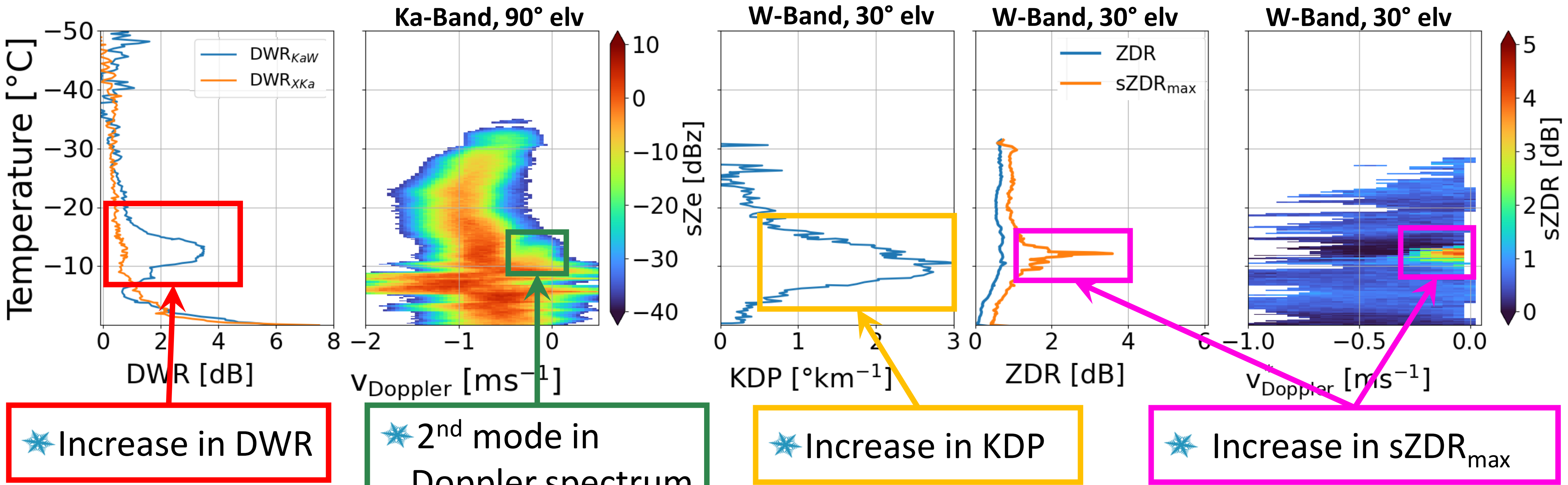

→ aggregation

→ New ice particles?

→ Ice concentration or size increases?

→ Plate-like ice crystals are growing

- How are the new ice particles generated?
- Shouldn‘t aggregation reduce concentration? How can KDP increase then?

Multiscale Structure and Evolution of an Oklahoma Winter Precipitation Event

R. Jeffrey Trapp, David M. Schultz, Alexander V. Ryzhkov, and Ronald L. Holle

Print Publication: 01 Mar 2001

DOI: https://doi.org/10.1175/1520-0493(2001)129<0486:MSAEOA>2.0.CO;2

Observations of supercooled water and secondary ice generation by a vertically pointing X-band Doppler radar

I Zawadzki, F Fabry, W Szyrmer

Deriving Mixed-Phase Cloud Properties from Doppler Radar Spectra

Matthew D. Shupe, Pavlos Kollias, Sergey Y. Matrosov, and Timothy L. Schneider

Print Publication: 01 Apr 2004

DOI: https://doi.org/10.1175/1520-0426(2004)021<0660:DMCPFD>2.0.CO;2

S-Band Dual-Polarization Radar Observations of Winter Storms

Patrick C. Kennedy and Steven A. Rutledge

Print Publication: 01 Apr 2011

DOI: https://doi.org/10.1175/2010JAMC2558.1

13B.2 DUAL-POLARIZATION WEATHER RADAR OBSERVATIONS OF SNOW GROWTH PROCESSES

Dmitri Moisseev [1], Elena Saltikoff [2], Matti Leskinen [1]

[1]*Dep. of Physics, University of Helsinki, Helsinki, Finland*
[2]*Finnish Meteorological Institute, Helsinki, Finland*

High-Resolution Vertical Profiles of X-Band Polarimetric Radar Observables during Snowfall in the Swiss Alps

Marc Schneebeli, Nicholas Dawes, Michael Lehning, and Alexis Berne

Print Publication: 01 Feb 2013

DOI: https://doi.org/10.1175/JAMC-D-12-015.1

Polarimetric Signatures above the Melting Layer in Winter Storms: An Observational and Modeling Study

Jelena Andrić, Matthew R. Kumjian, Dušan S. Zrnić, Jerry M. Straka, and Valery M. Melnikov

Print Publication: 01 Mar 2013

Polarimetric Radar Observations in the Ice Region of Precipitating Clouds at C-Band and X-Band Radar Frequencies

R. Bechini, L. Baldini, and V. Chandrasekar

Print Publication: 01 May 2013

DOI: https://doi.org/10.1175/JAMC-D-12-055.1

11A.6 Observations of snow growth by a vertically pointing radar

Wednesday, 18 September 2013: 11:45 AM
Colorado Ballroom (Peak 4, 3rd Floor) (Beaver Run Resort and Conference Center)

Isztar Zawadzki, McGill University, Montreal, QC, Canada

Connecting Microphysical Processes in Colorado Winter Storms with Vertical Profiles of Radar Observations

ROBERT S. SCHROM AND MATTHEW R. KUMJIAN

Department of Meteorology, The Pennsylvania State University, University Park, Pennsylvania

(Manuscript received 19 November 2015, in final form 3 May 2016)

A Dual-Polarization Radar Hydrometeor Classification Algorithm for Winter Precipitation

Elizabeth J. Thompson, Steven A. Rutledge, Brenda Dolan, V. Chandrasekar, and Boon Leng Cheong

Print Publication: 01 Jul 2014

DOI: https://doi.org/10.1175/JTECH-D-13-00119.1

Polarimetric Radar Signatures of Dendritic Growth Zones within Colorado Winter Storms

Robert S. Schrom, Matthew R. Kumjian, and Yinghui Lu

Print Publication: 01 Dec 2015

DOI: https://doi.org/10.1175/JAMC-D-15-0004.1

A Polarimetric Analysis of Ice Microphysical Processes in Snow, Using Quasi-Vertical Profiles

Erica M. Griffin, Terry J. Schuur, and Alexander V. Ryzhkov

Print Publication: 01 Jan 2018

DOI: https://doi.org/10.1175/JAMC-D-17-0033.1

JGR Atmospheres

Research Article | Free Access

Dual-polarization radar signatures in snowstorms: Role of snowflake aggregation

Dmitri N. Moisseev, Susanna Lautaportti, Jani Tyynela, S. Lim

First published: 11 December 2015 | https://doi.org/10.1002/2015JD023884 | Citations: 78

JGR Atmospheres

Research Article | Free Access

Toward Exploring the Synergy Between Cloud Radar Polarimetry and Doppler Spectral Analysis in Deep Cold Precipitating Systems in the Arctic

Mariko Oue, Pavlos Kollias, Alexander Ryzhkov, Edward P. Luke

First published: 06 February 2018 | https://doi.org/10.1002/2017JD027717 | Citations: 28

Polarimetric Radar Variables in the Layers of Melting and Dendritic Growth at X Band—Implications for a Nowcasting Strategy in Stratiform Rain

Silke Trömel, Alexander V. Ryzhkov, Brandon Hickman, Kai Mühlbauer, and Clemens Simmer

Print Publication: 01 Nov 2019

DOI: https://doi.org/10.1175/JAMC-D-19-0056.1

Ice microphysical processes in the dendritic growth layer: a statistical analysis combining multi-frequency and polarimetric Doppler cloud radar observations

Leonie von Terzi[1], José Dias Neto[2], Davide Ori[1], Alexander Myagkov[3], and Stefan Kneifel[1,4]

[1]Institute of Geophysics and Meteorology, University of Cologne, Cologne, Germany
[2]Department of Geosciences and Remote Sensing, Delft University of Technology, Delft, the Netherlands
[3]Radiometer Physics GmbH, Meckenheim, Germany
[4]Meteorological Institute, Ludwig-Maximilians University Munich, Germany

Correspondence: Leonie von Terzi (lterzi@uni-koeln.de)

Received: 7 April 2022 – Discussion started: 11 April 2022
Revised: 24 August 2022 – Accepted: 25 August 2022 – Published: 13 September 2022

NOVEMBER 2022 DUNNAVAN ET AL. 1685

Radar Retrieval Evaluation and Investigation of Dendritic Growth Layer Polarimetric Signatures in a Winter Storm

EDWIN L. DUNNAVAN,[a,b] JACOB T. CARLIN,[a,b] JIAXI HU,[a,b] PETAR BUKOVČIĆ,[a,b] ALEXANDER V. RYZHKOV,[a,b] GREG M. MCFARQUHAR,[a,c] JOSEPH A. FINLON,[d] SERGEY Y. MATROSOV,[e,f] AND DAVID J. DELENE[g]

[a] *Cooperative Institute for Severe and High-Impact Weather Research and Operations, Norman, Oklahoma*
[b] *NOAA/OAR National Severe Storms Laboratory, Norman, Oklahoma*
[c] *School of Meteorology, University of Oklahoma, Norman, Oklahoma*
[d] *Department of Atmospheric Sciences, University of Washington, Seattle, Washington*
[e] *Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado*
[f] *Physical Sciences Laboratory, NOAA, Boulder, Colorado*
[g] *Department of Atmospheric Sciences, University of North Dakota, Grand Forks, North Dakota*

(Manuscript received 19 October 2021, in final form 29 June 2022)

Status: this preprint is open for discussion and under review for Atmospheric Chemistry and Physics (ACP).

Investigating KDP signatures inside and below the dendritic growth layer with W-band Doppler Radar and in situ snowfall camera

Anton Kötsche, Alexander Myagkov, Leonie von Terzi, Maximilian Maahn, Veronika Ettrichrätz, Teresa Vogl, Alexander Ryzhkov, Petar Bukovcic, Davide Ori, and Heike Kalesse-Los

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

Hypotheses:

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

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

The 1D Lagrangian Monte-Carlo particle model McSnow

→**Let‘s combine observations with a model in which current knowledge of IMP can be implemented** (Brdar and Seifert, JAMES, 2017)

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McSnow predicts evolution of super-particles due to

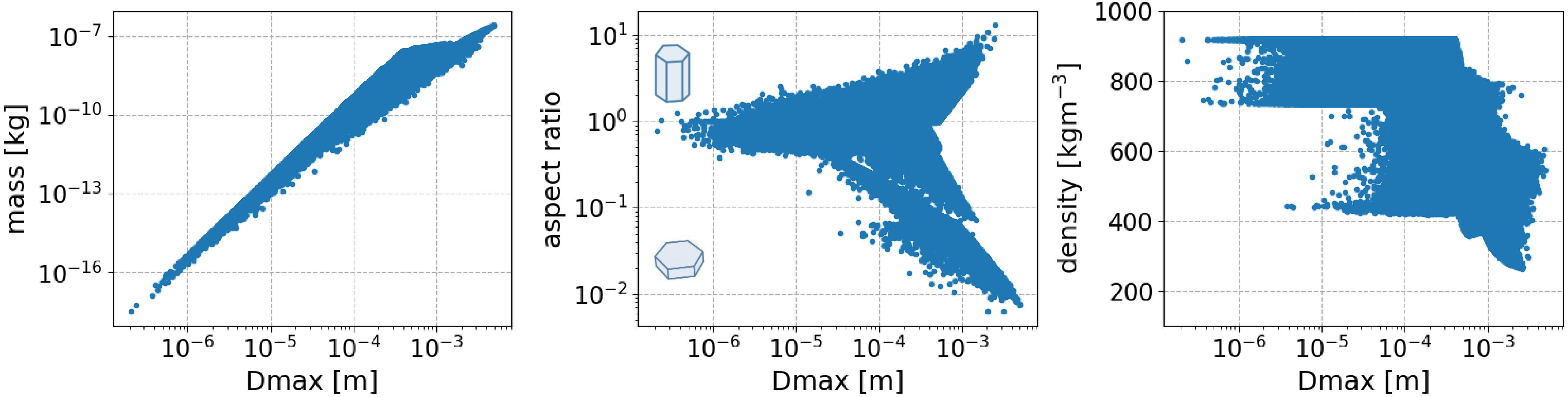
- Deposition → **habit prediction** (Welss et al., JAMES, 2024)
- Aggregation
- Riming
- Secondary ice production
  - i.e. fragmentation

Forward simulations: DDA LUTs

- „Problem“: McSnow has freely evolving particle properties:

Forward simulations: DDA LUTs

- „Problem“: McSnow has freely evolving particle properties:



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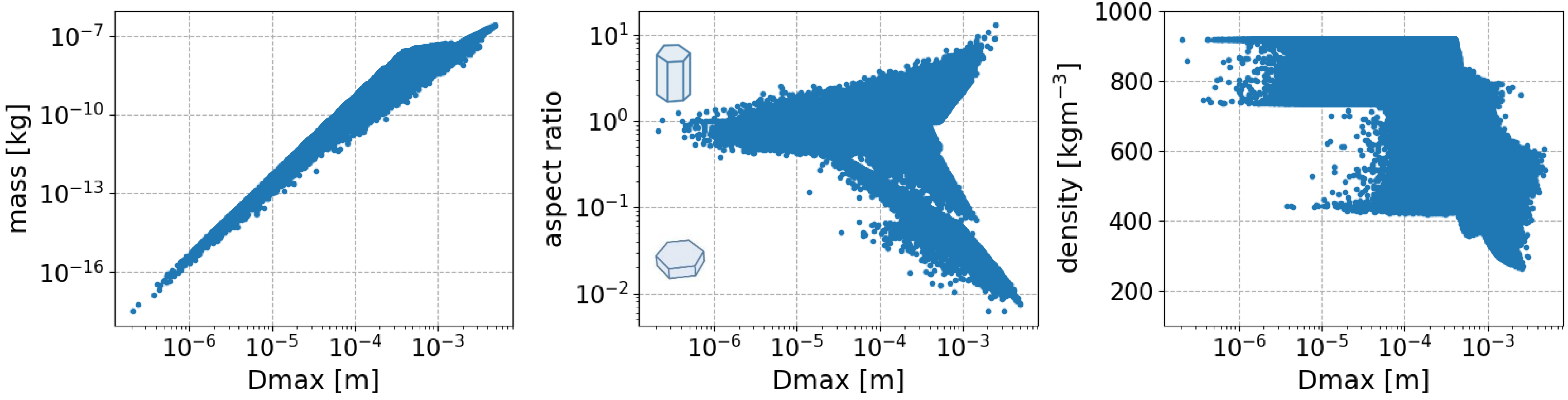

- We want to <u>consistently</u> forward simulate into Radar Space!

Forward simulations: DDA LUTs

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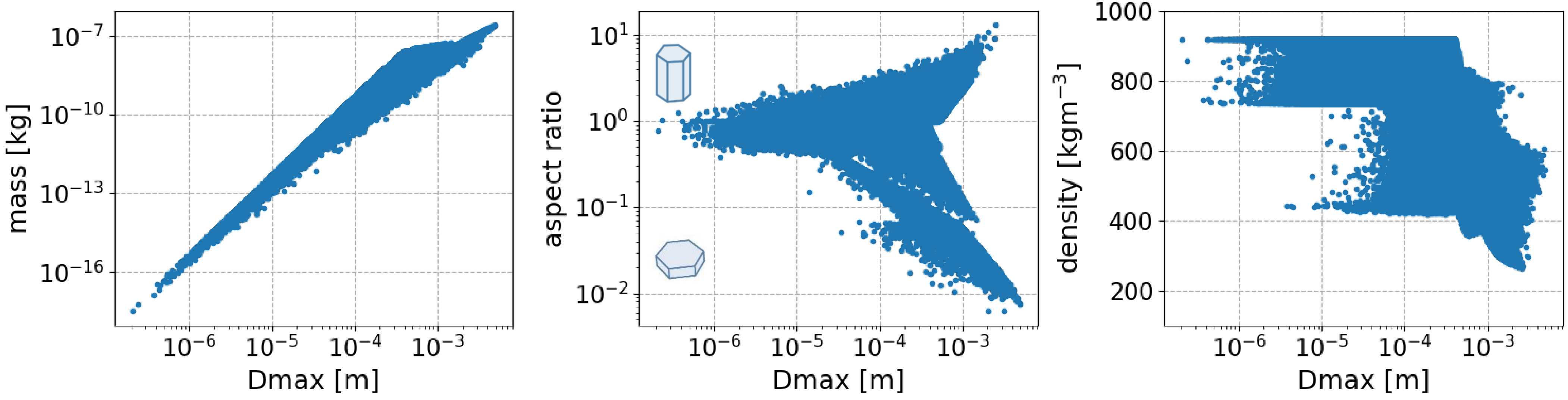


- We want to consistently forward simulate into Radar Space!
- Solution: DDA LUTs of a large variety of ice particles (approx. 3100 particles)
  - Dendritic ice crystals
  - Columnar ice crystals
  - Aggregates with varying monomer habits and riming degree

Hypotheses

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

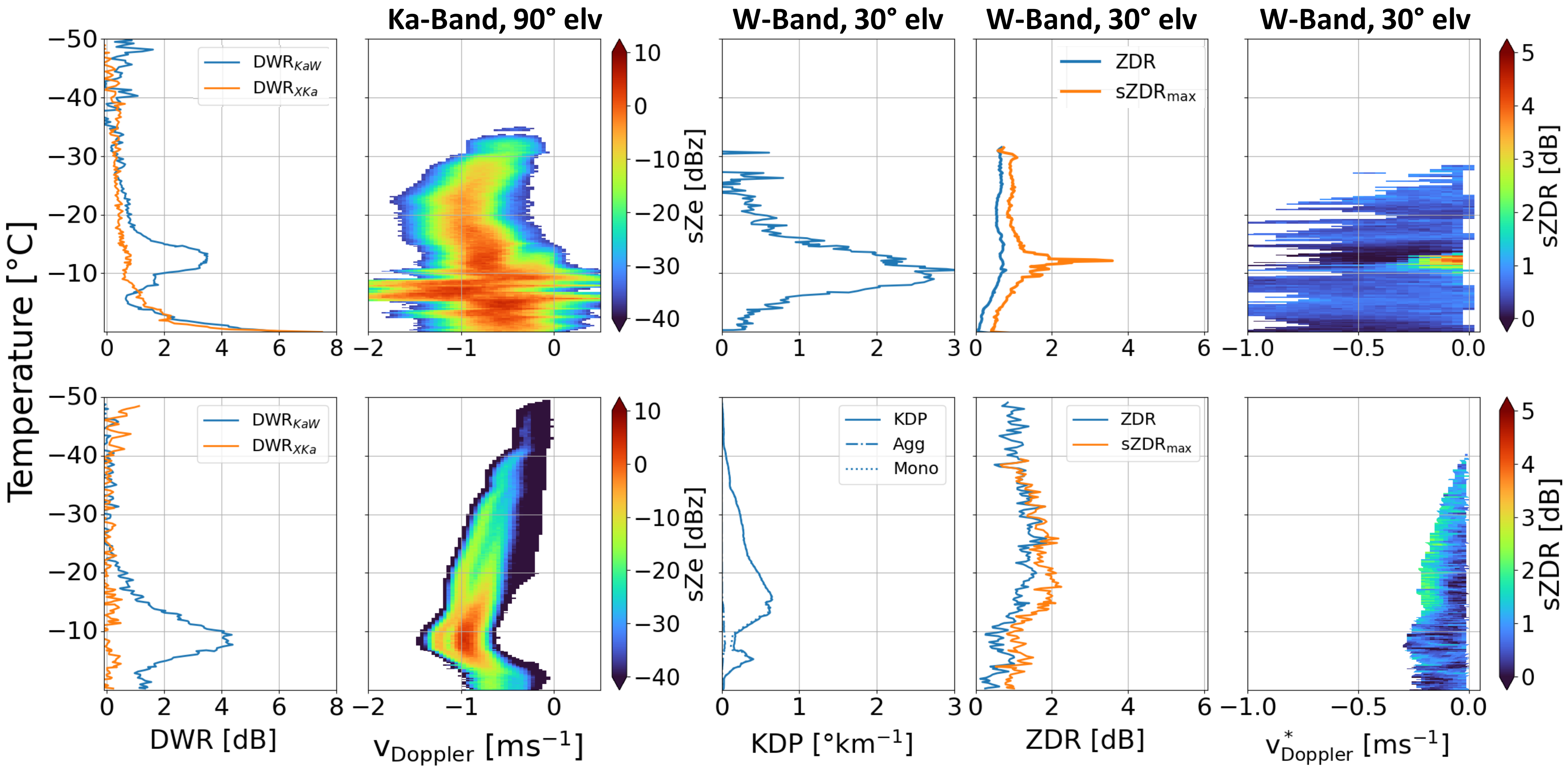
Leonie von Terzi, l.terzi@lmu.de

McSnow simulation setup

1. Small ice crystals sedimenting from above

- Assumption:
  - Average $\mathrm{RH_i} = 5\%$ (from Radiosonde data)
  - Ice nucleation at $-20°\mathrm{C} < T < -50°\mathrm{C}$,
    concentration increasing from $1\mathrm{L}^{-1}$at $-20°\mathrm{C}$ to $20\mathrm{L}^{-1}$ $-50°\mathrm{C}$
- Ice nucleation: initialisation of ice particles with $\mathrm{D} = 10\mu\mathrm{m}$, aspect ratio $= 1$, ice density
- After nucleation: particles can evolve freely due to depositional growth, aggregation,…

3. Only ice nucleation at $T < -20°C$



Observation

Simulation

Leonie von Terzi, l.terzi@lmu.de

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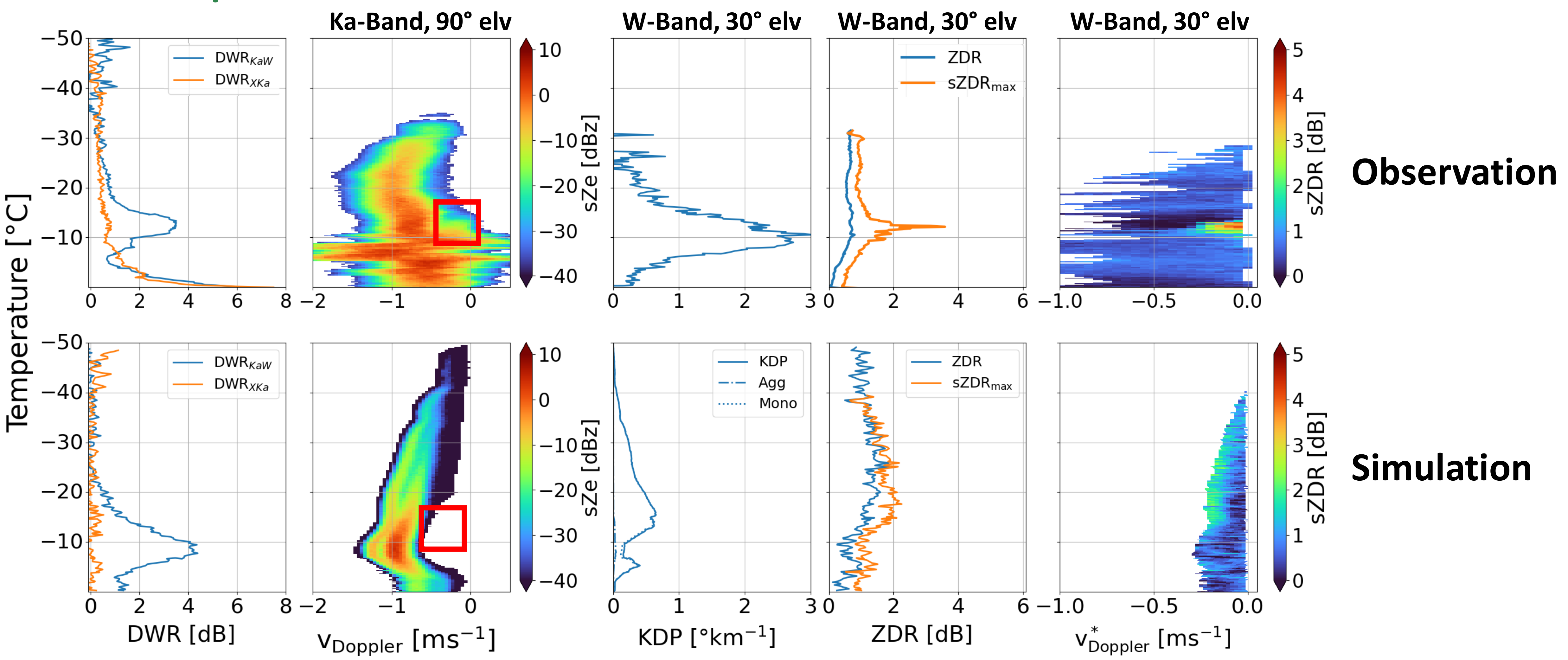

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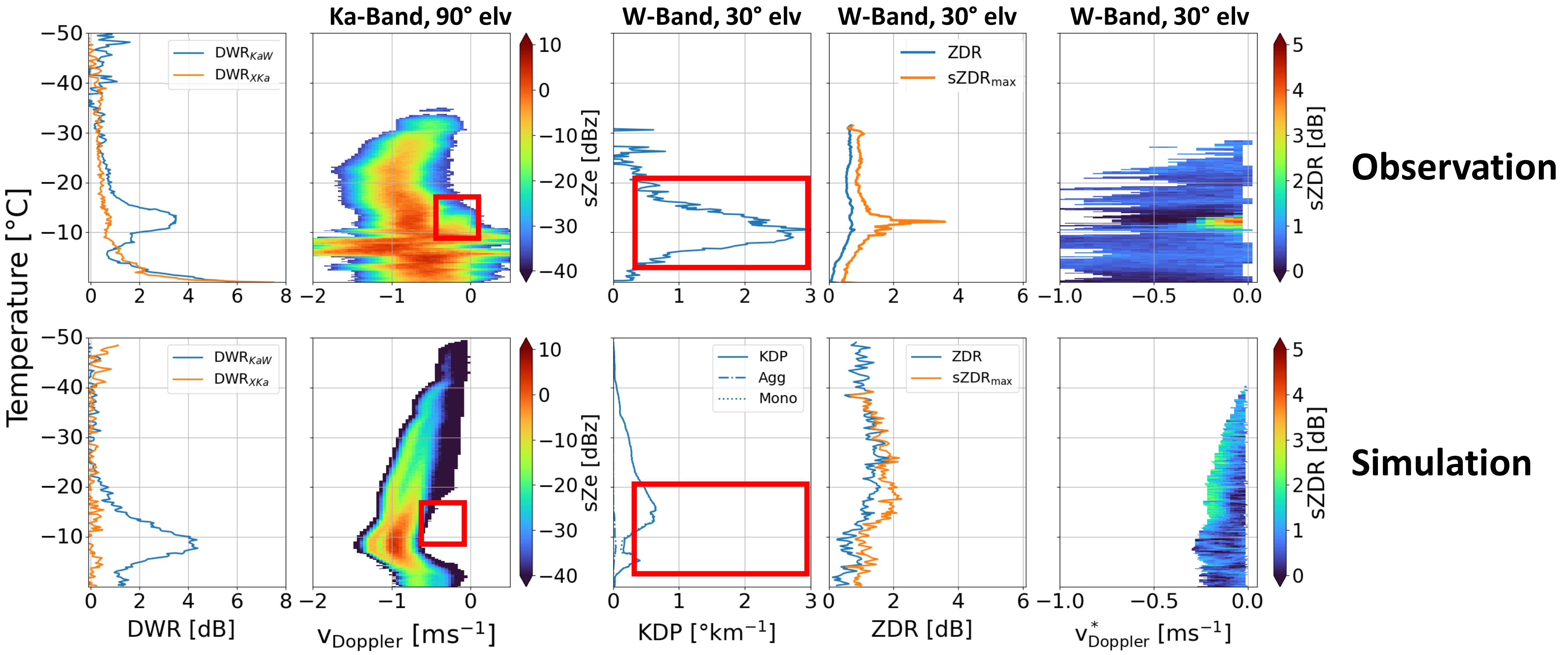

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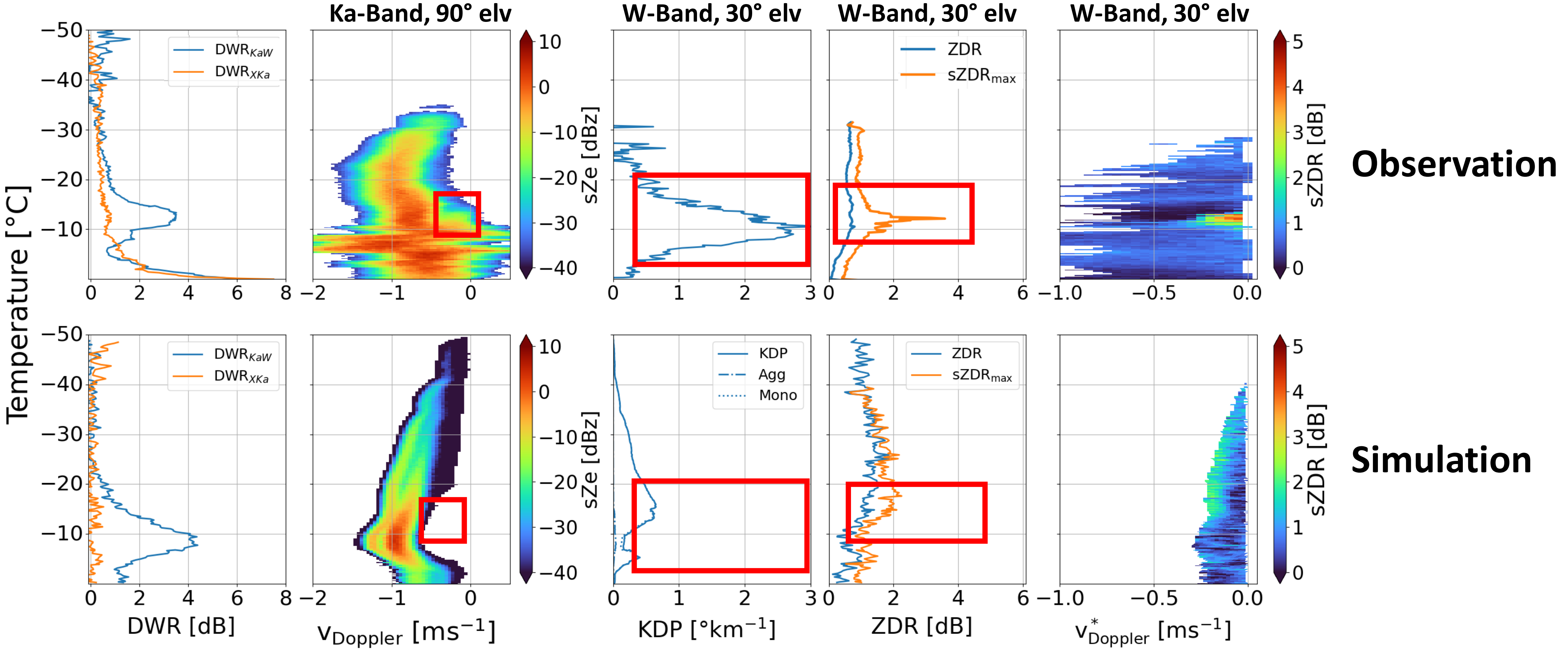

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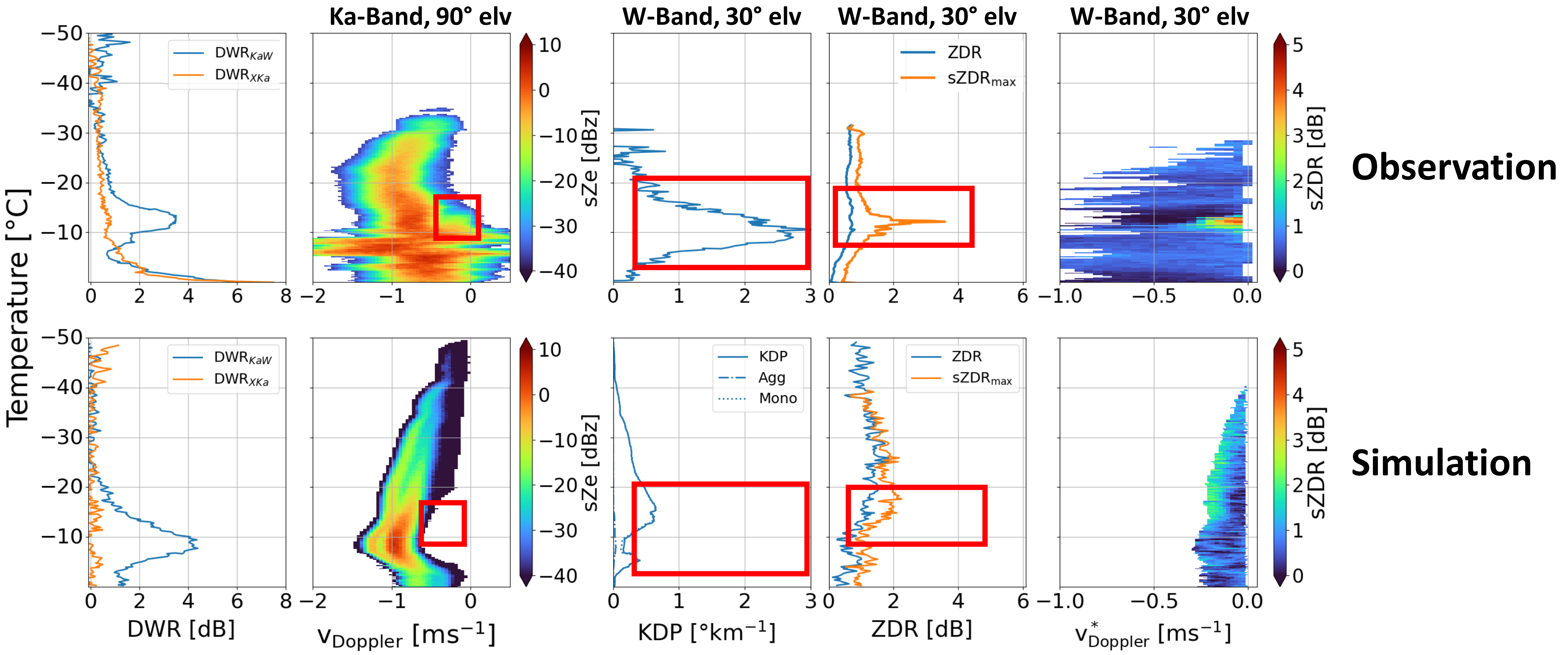

- Without ice nucleation (primary or secondary) we do not have a second spectral mode, and also no polarimetric signatures in DGL!

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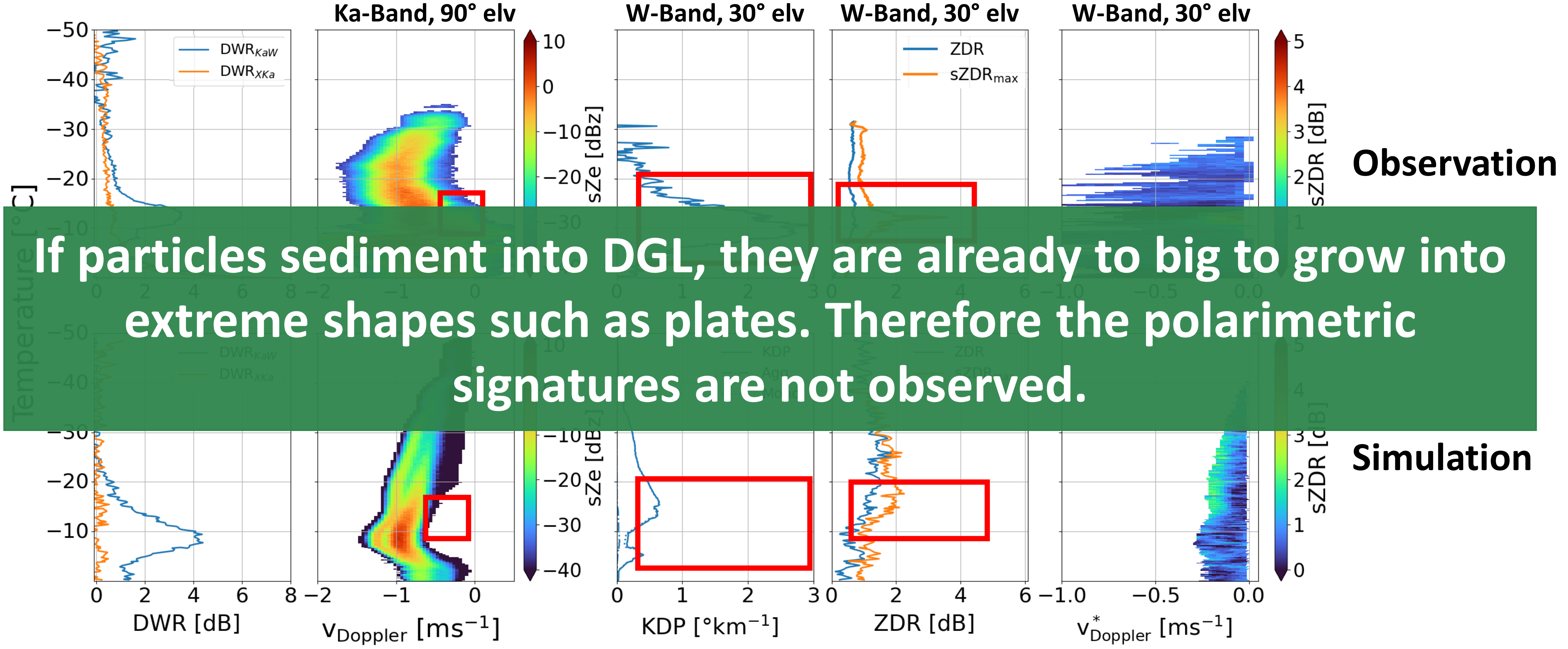

If particles sediment into DGL, they are already to big to grow into extreme shapes such as plates. Therefore the polarimetric signatures are not observed.

- Without ice nucleation (primary or secondary) we do not have a second spectral mode, and also no polarimetric signatures in DGL!

Hypotheses

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

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

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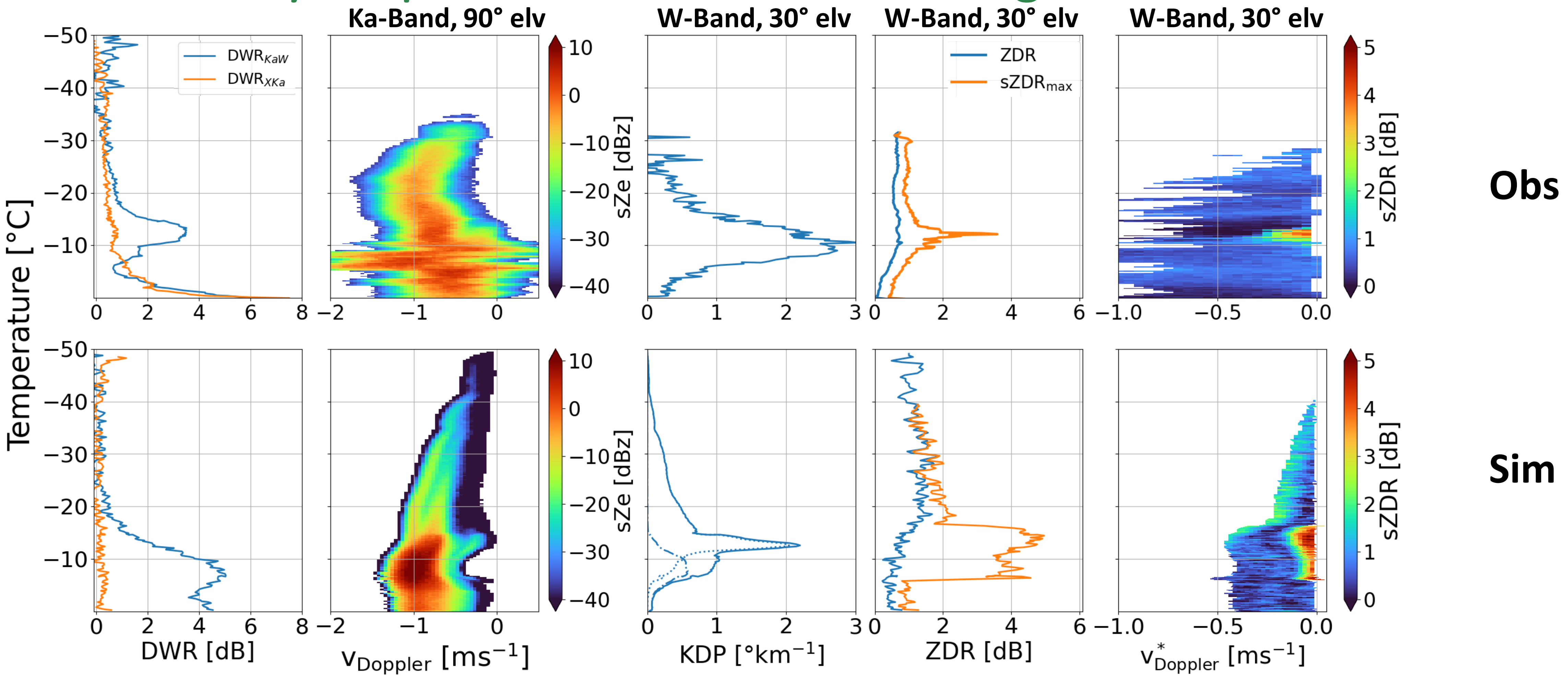
1. Small ice crystals sedimenting from above grow plate-like

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

- Same setup as in first hypothesis
- New fragmentation scheme based on Grzegorczyk et al. 2023 **(see talk by Miklós Szakall, Thu 16:15, Session 2 A)** and Takahashi 1995

2. Secondary ice production – collisional fragmentation



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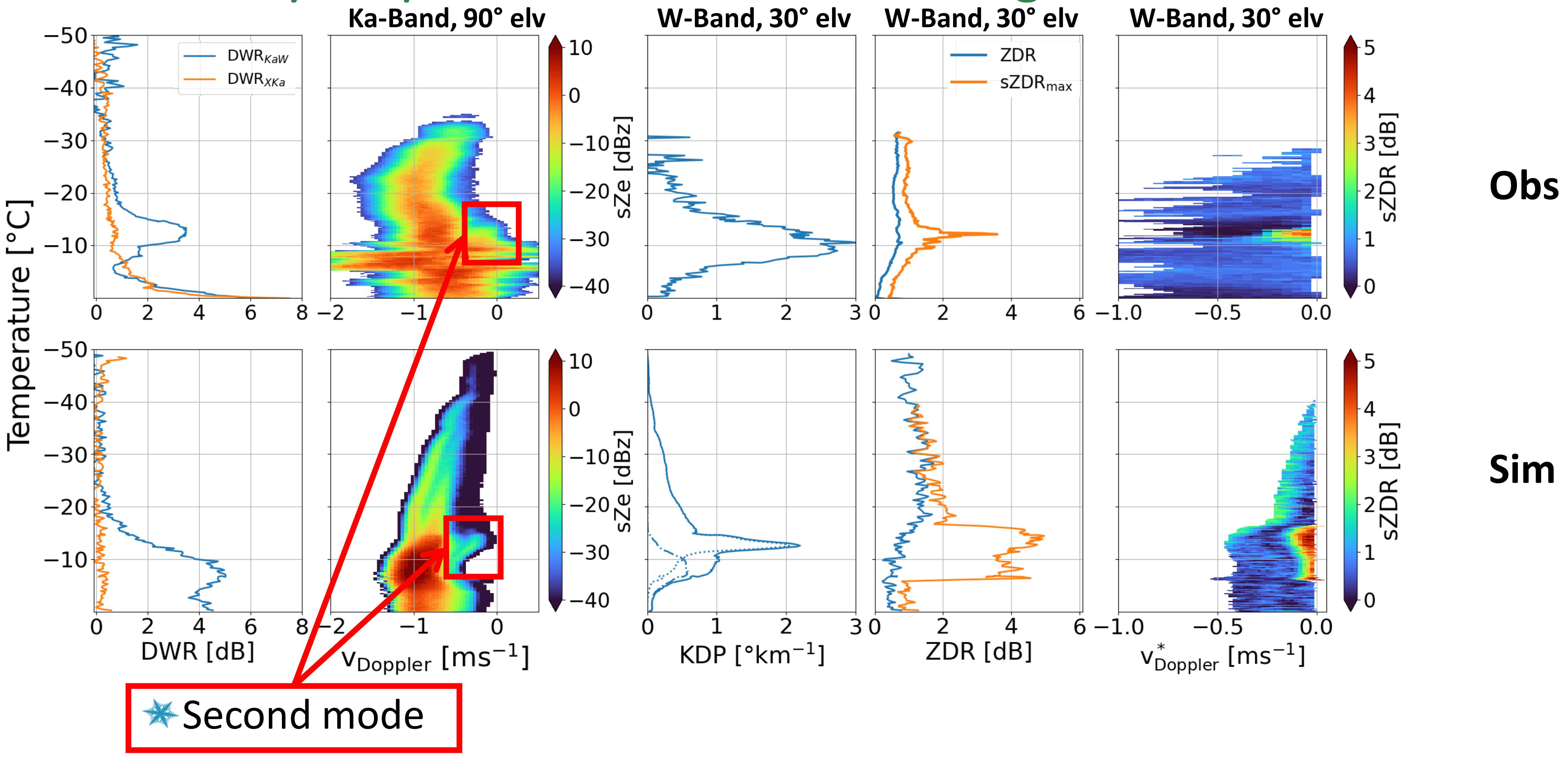

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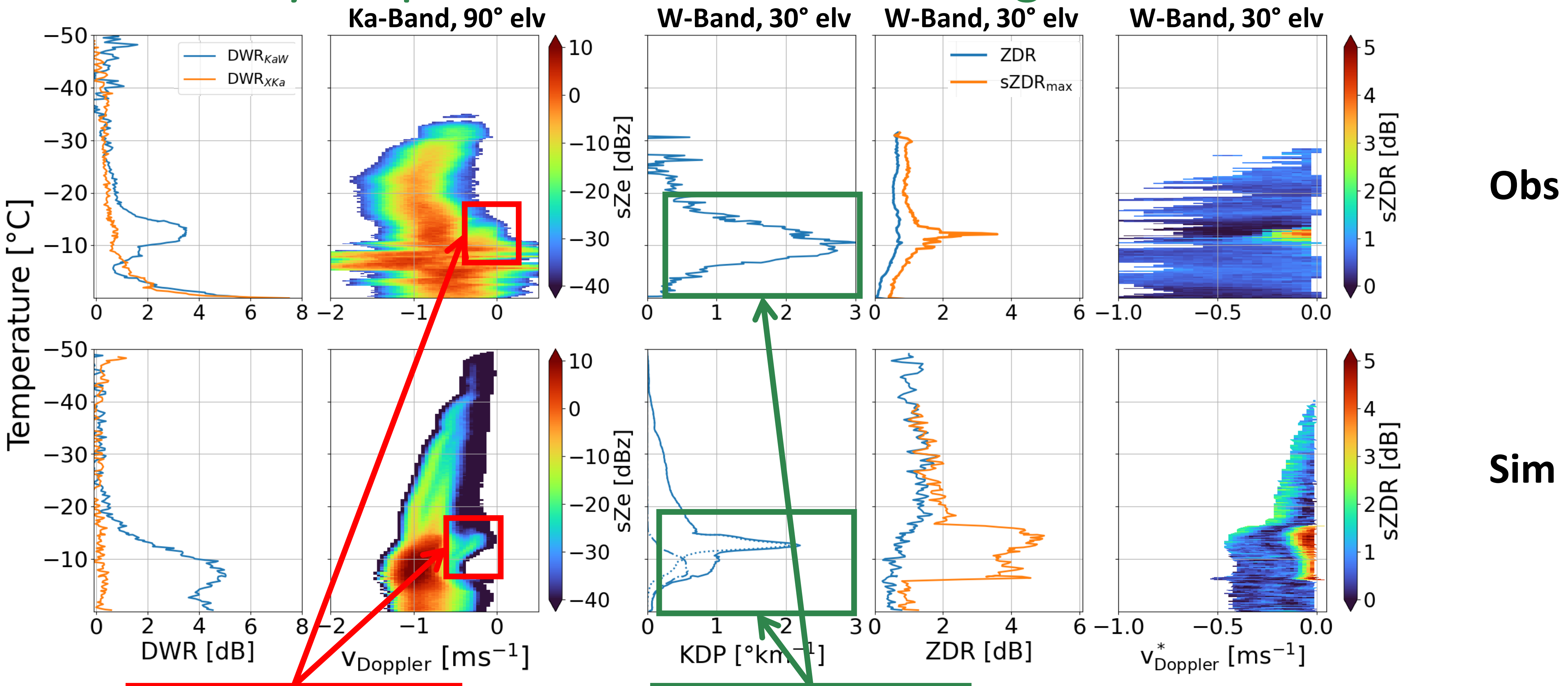
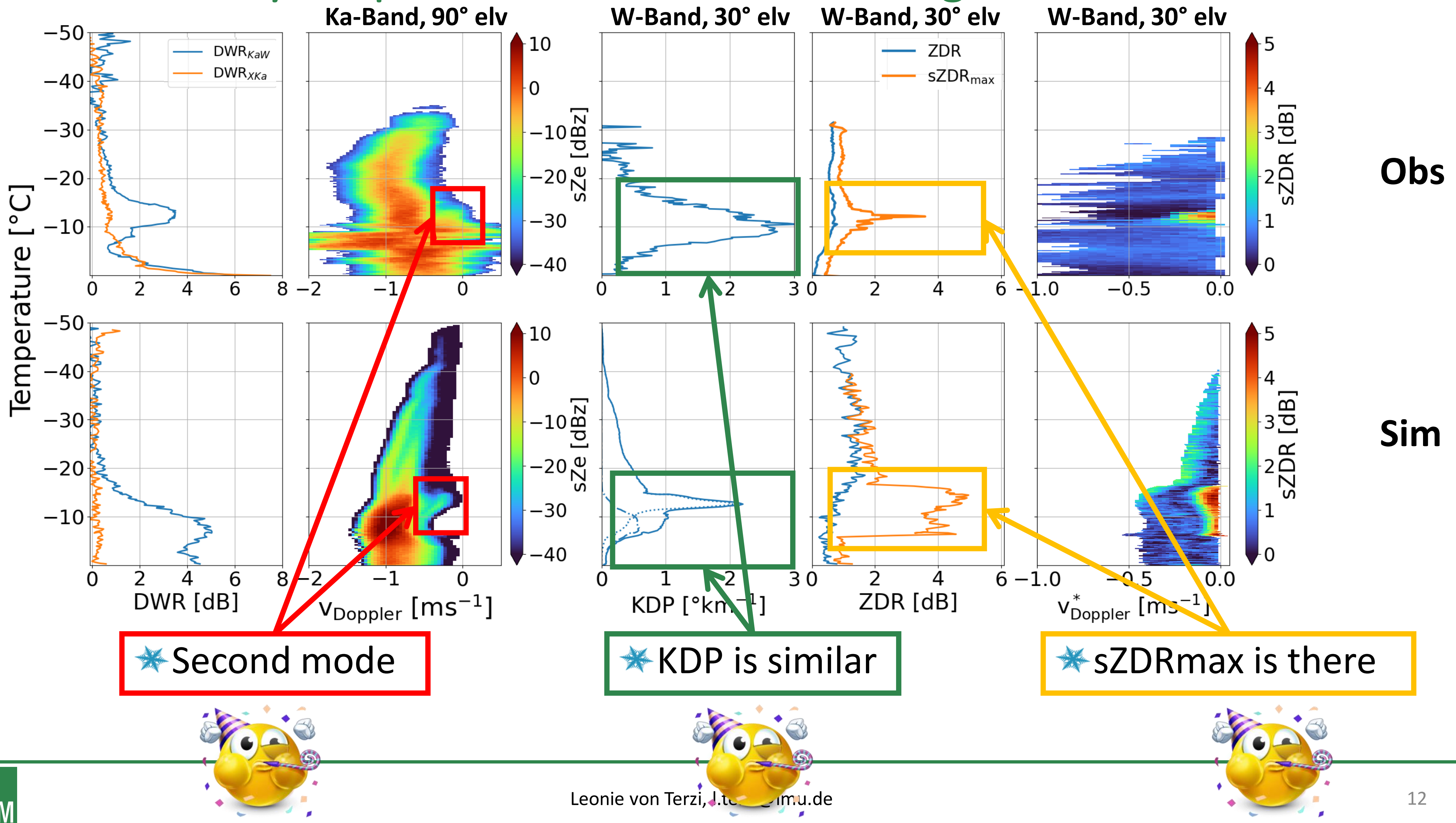


Second mode

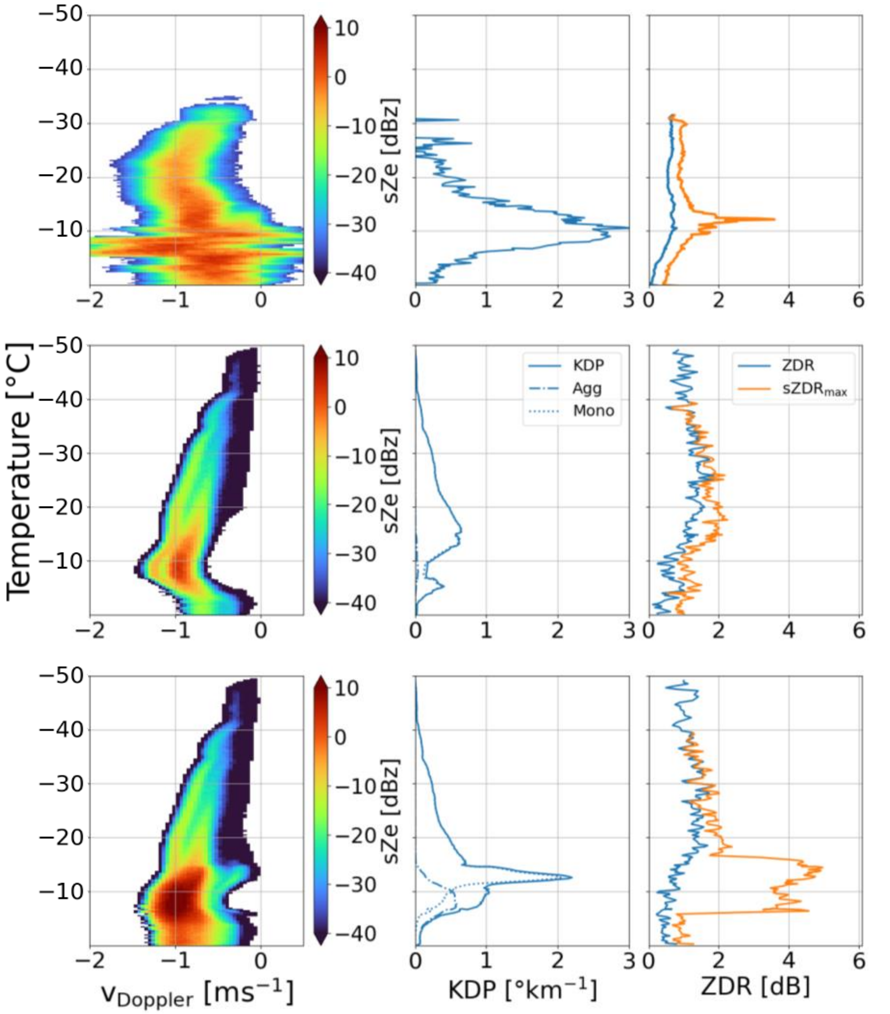
KDP is similar

2. Secondary ice production – collisional fragmentation



Which ice microphysical properties might explain the typical radar signatures in the dendritic growth layer?

- Ice particles sedimenting into the DGL do not grow plate-like
- We need a production mechanism close to -15°C for enhanced ZDR and KDP in the DGL!
- Fragmentation is a promising candidate



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Combining „research“ models, laboratory studies and radar observations can help to close current knowledge gaps!