A statistical evaluation of convective cloud microphysics in a numerical weather prediction model

with polarimetric radar observations

Gregor Köcher[1], Tobias Zinner[1], Florian Ewald[2], Christian Heske[2]

1: Meteorologisches Institut, Ludwig-Maximilians-Universität, Munich, Germany (LMU)

2: Deutsches Zentrum für Luft- und Raumfahrt, Oberpfaffenhofen, Germany (DLR)

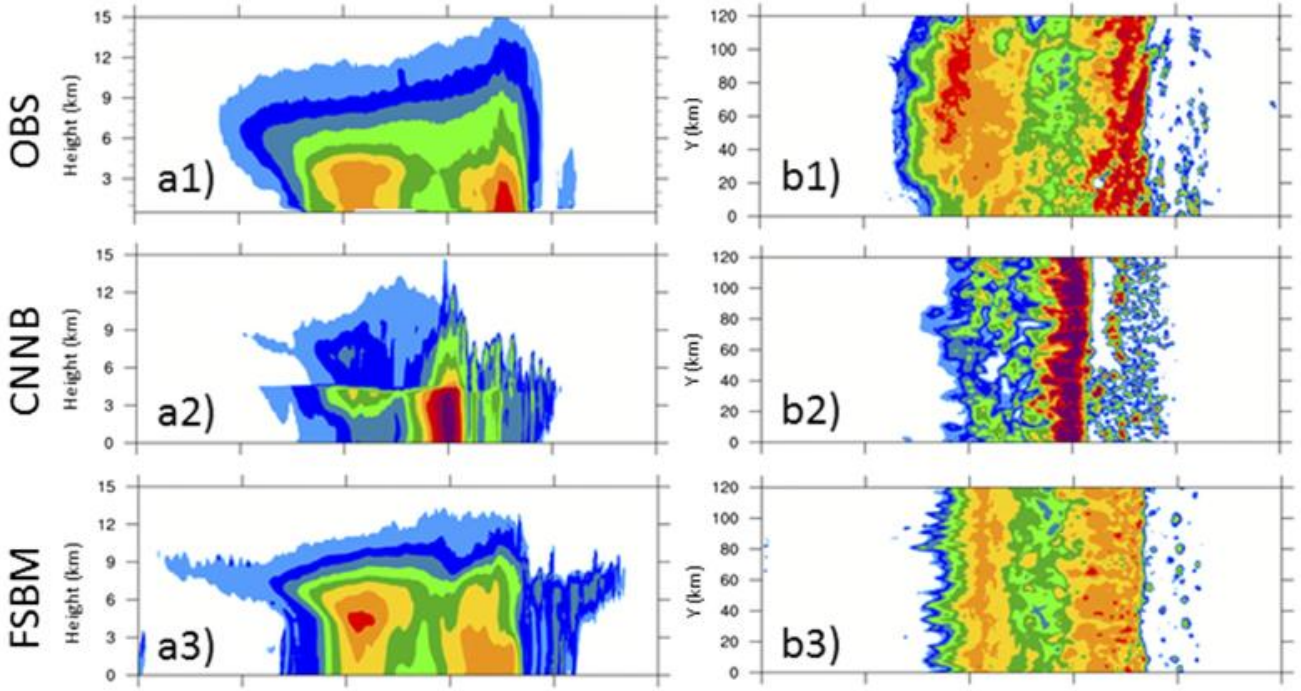
Email: gregor.koecher@physik.uni-muenchen.de

Introduction

Problem: NWP struggles to correctly simulate **spatial distribution** and **intensity** of convective and stratiform parts in convective systems

Vertical cross-section

Horizontal cross-section



Xue et al. (2017), AMS

Microphysics

- Influences **structure** and **development** of convection
- Determines **transport** from convective updraft into stratiform precipitation parts
- Controls **sedimentation speed** through ice density
- **Hard** to **observe** on high level of detail

Convection

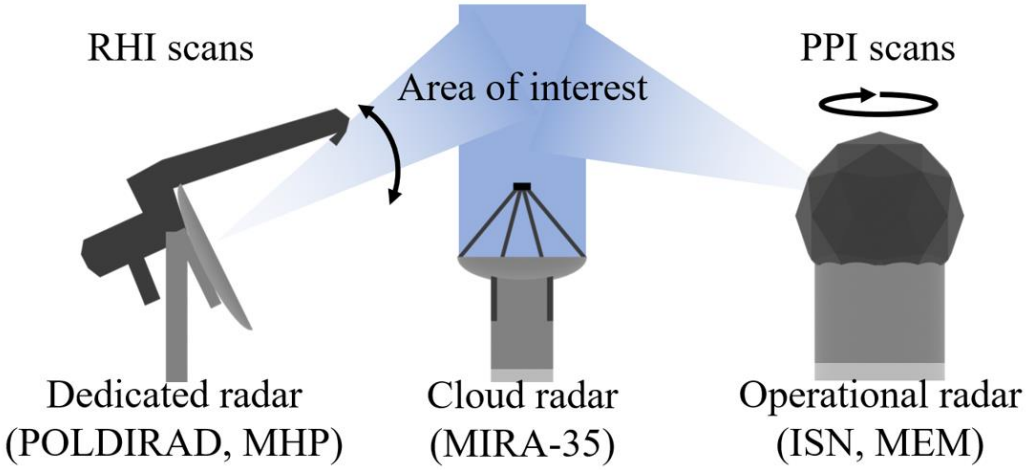
- Can **vary** strongly from case to case
- Requires **statistics** over large data set

Introduction

Approach: Statistical comparison of simulated and observed polarimetric radar signals to evaluate microphysics during spatio-temporal development of thunderstorms

Substantial **variability** in thunderstorm development → **Statistical** approach over large data set

Microphysics hard to observe on high level of detail → **Polarimetric / Multifrequency radar:** Sensitive to particle shape, size, phase…



Comparison in **observation** space

Combining radar network data with **vertical** pointing cloud radar (Christian Heske, DLR)

Radar quantities

Reflectivity (*Z*)

- Sensitive to particle number, size, phase, and density

Differential reflectivity (*ZDR*)

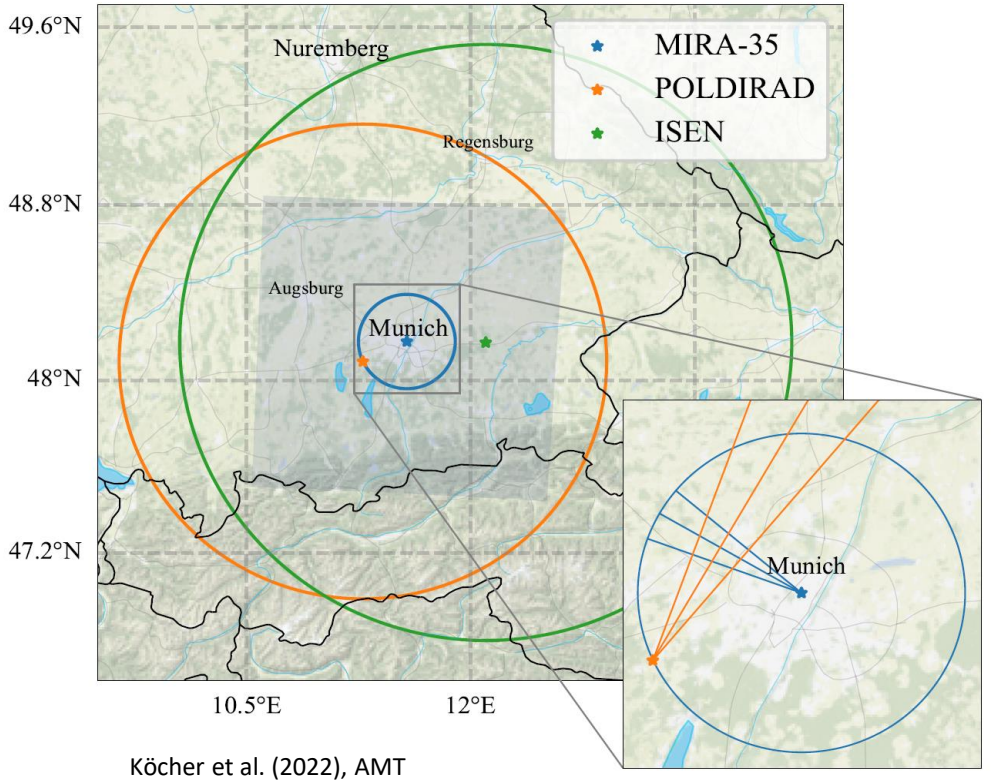
- Strongly sensitive to particle shape
- $Z_{DR} = 10 \cdot \log(\frac{Z_H}{Z_V})$

Dual-wavelength ratio (*DWR*)

- Strongly sensitive to particle size
- $DWR = dBZ_C - dBZ_{Ka}$

Other quantities

- Specific differential phase (*KDP*)
- Linear Depolarization Ratio (*LDR*)
- Copolar correlation coefficient (*RHOhv*)
- Doppler Velocity (*Vel*)



Köcher et al. (2022), AMT

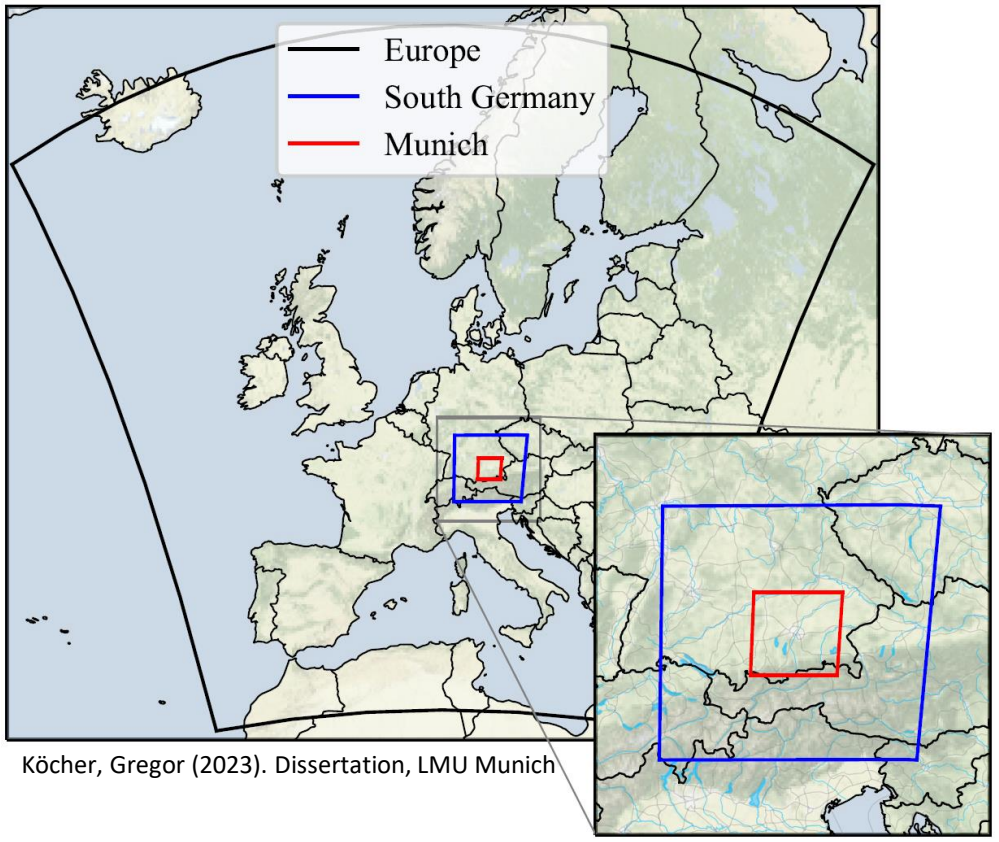
30 convection days

> 1000 convective cells

Model Setup

The model

- **WRF:** Weather Research and Forecasting Model (Skamarock et al., 2019)
- Regional numerical weather prediction model (NWP)



Köcher, Gregor (2023). Dissertation, LMU Munich

Munich Domain with a grid spacing of **400 m**

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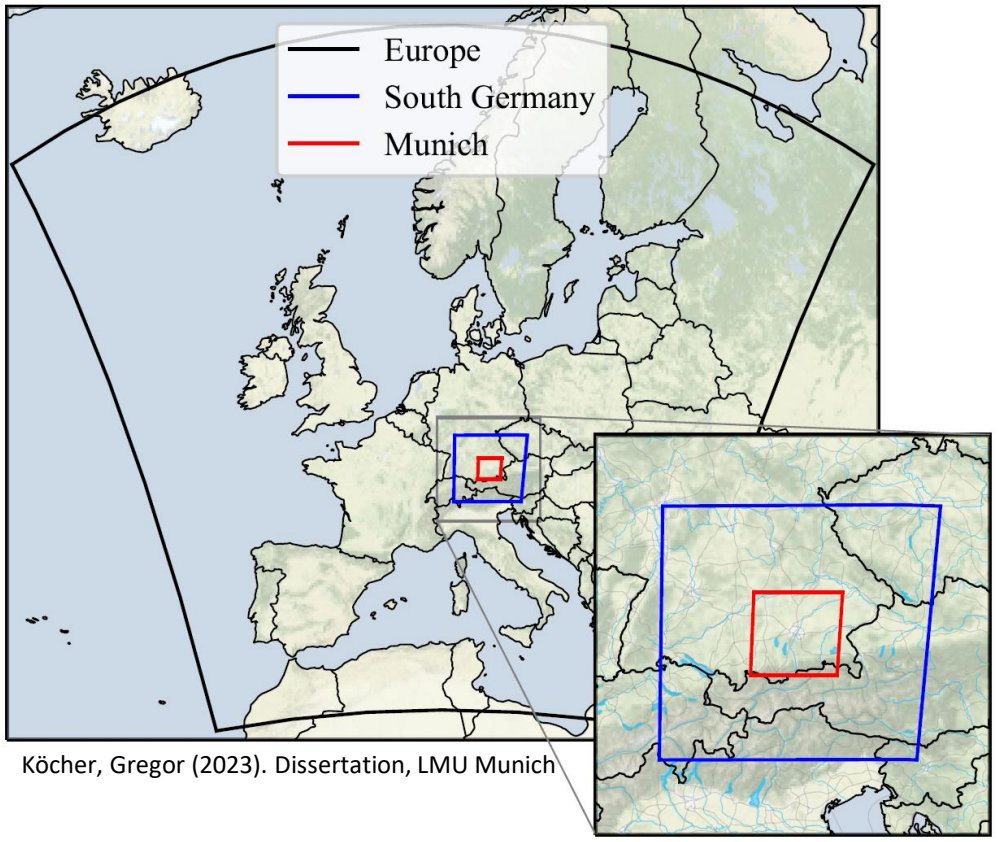
The microphysics

- **Bulk** (Thompson 2-mom, Morrison 2-mom, Thompson 2-mom aerosol aware)
- **Spectral Bin** (Shpund 2019)
- **P3** (Morrison and Milbrand 2015)



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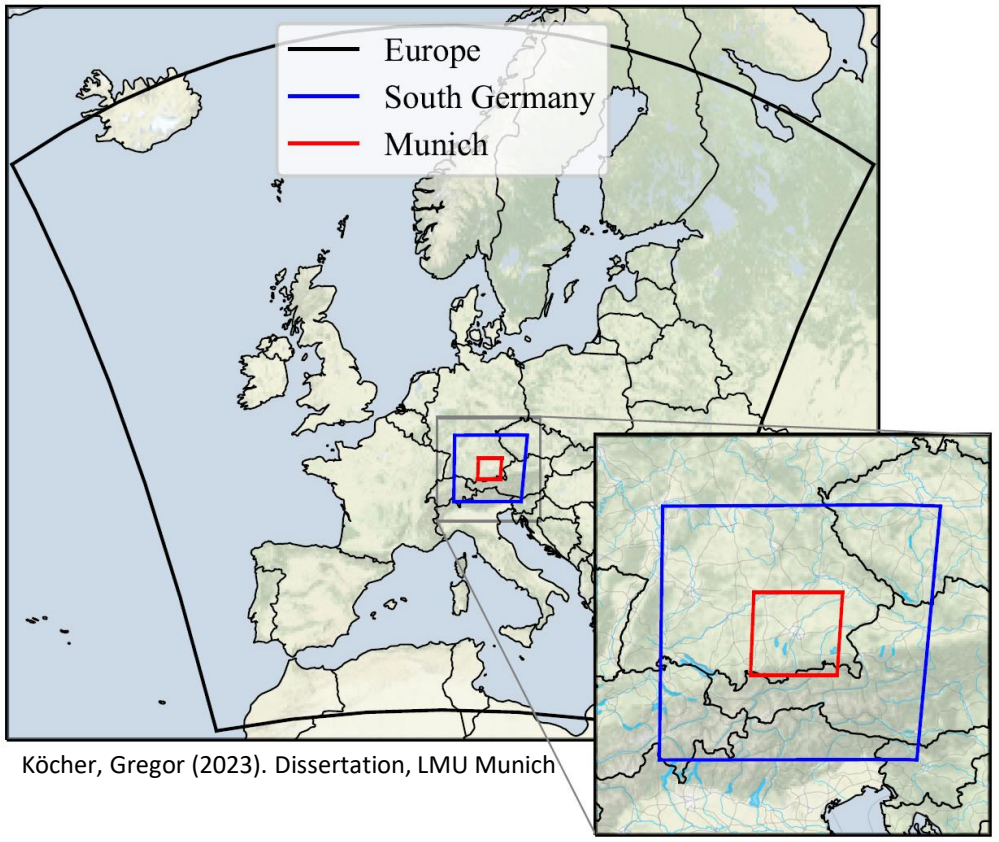
Comparison to observations

- With polarimetric radar forward operator
- **CR-SIM:** Cloud Resolving Model Radar Simulator (Oue et al., 2020)



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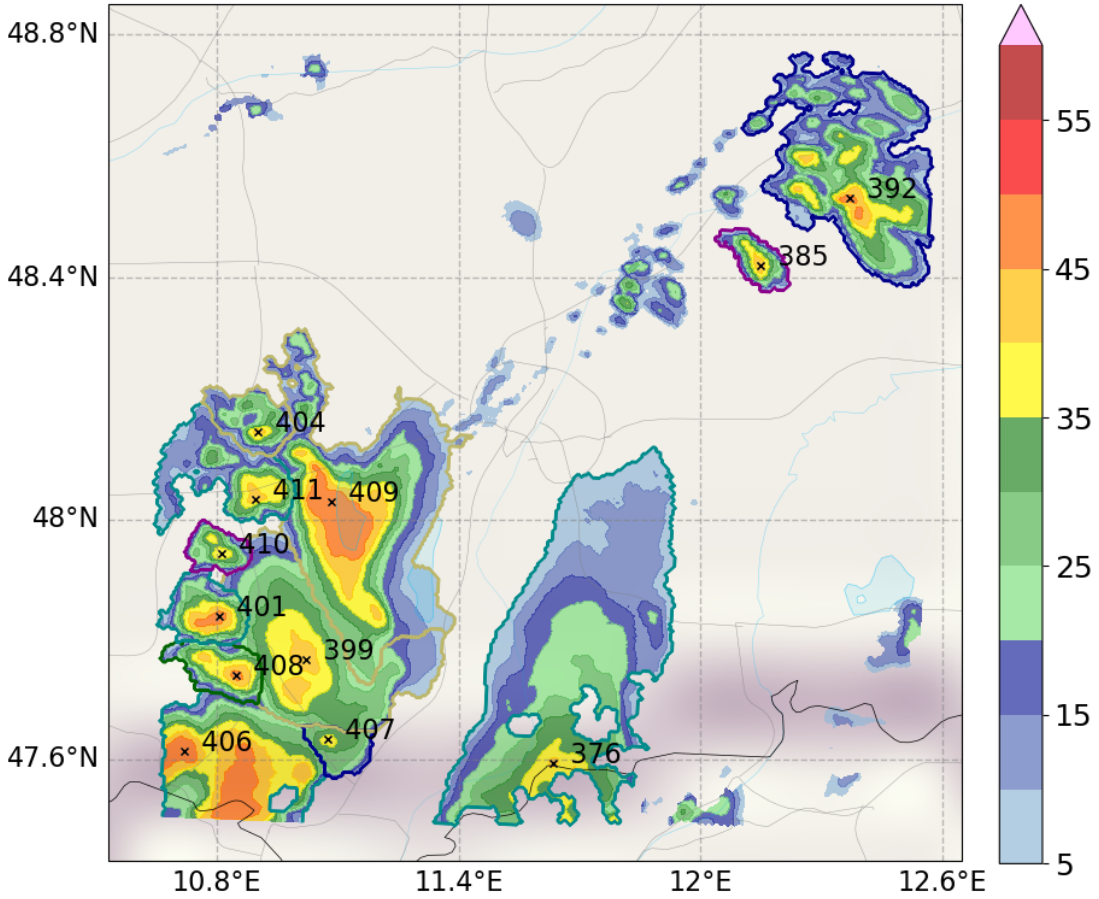
Automatic Cell Tracking

Problem: Tracking of convective cells with their associated stratiform precipitation

Solution: Tobac (Tracking and Object-Based Analysis of Clouds, Heikenfeld et al., 2019)



Tobac

- Feature **identification** based on reflectivity
- Assigns stratiform precipitation based on **watershedding** technique
- **Links** features to tracks with **trackpy**

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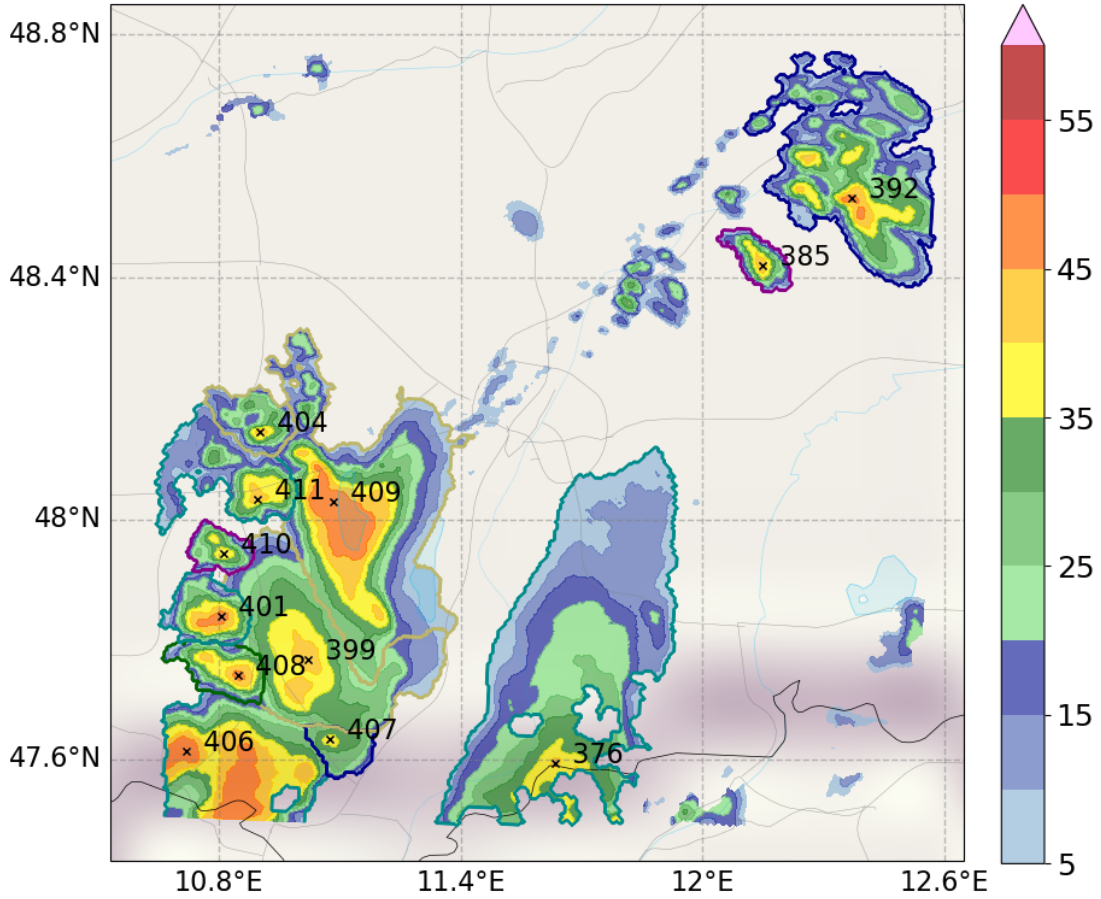


Works for **simulation** and **observation** alike

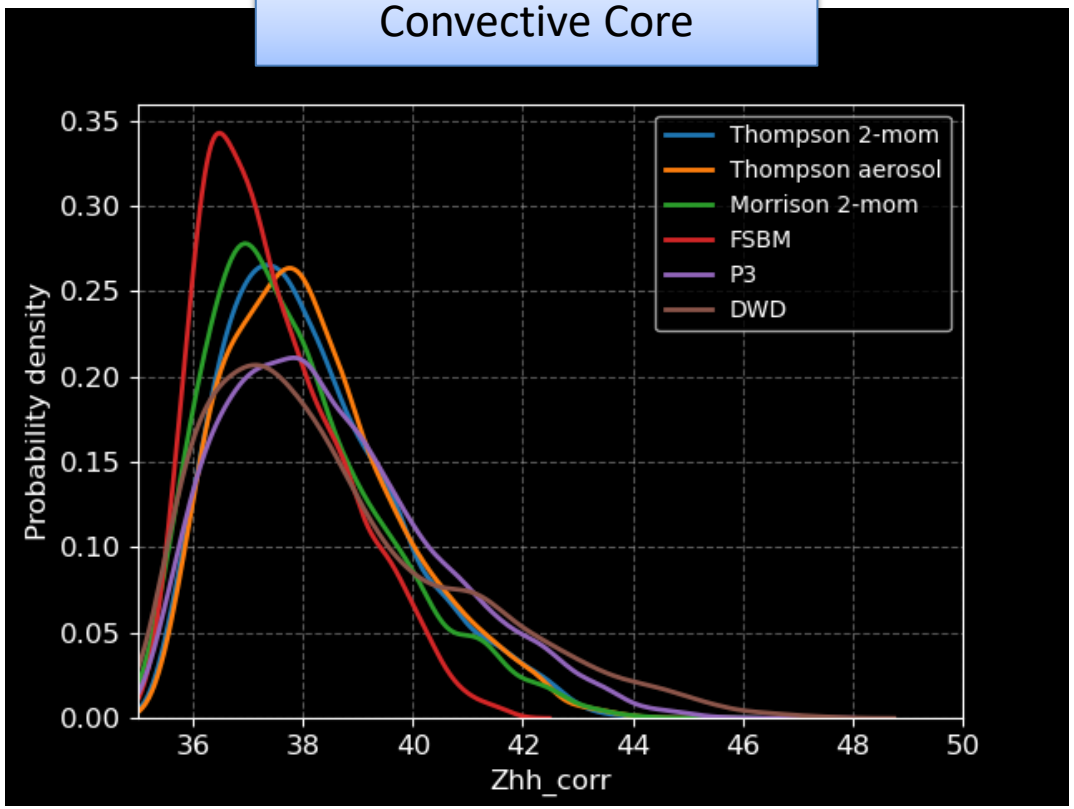
Statistical comparison of radar signals

Height:
1.5 km

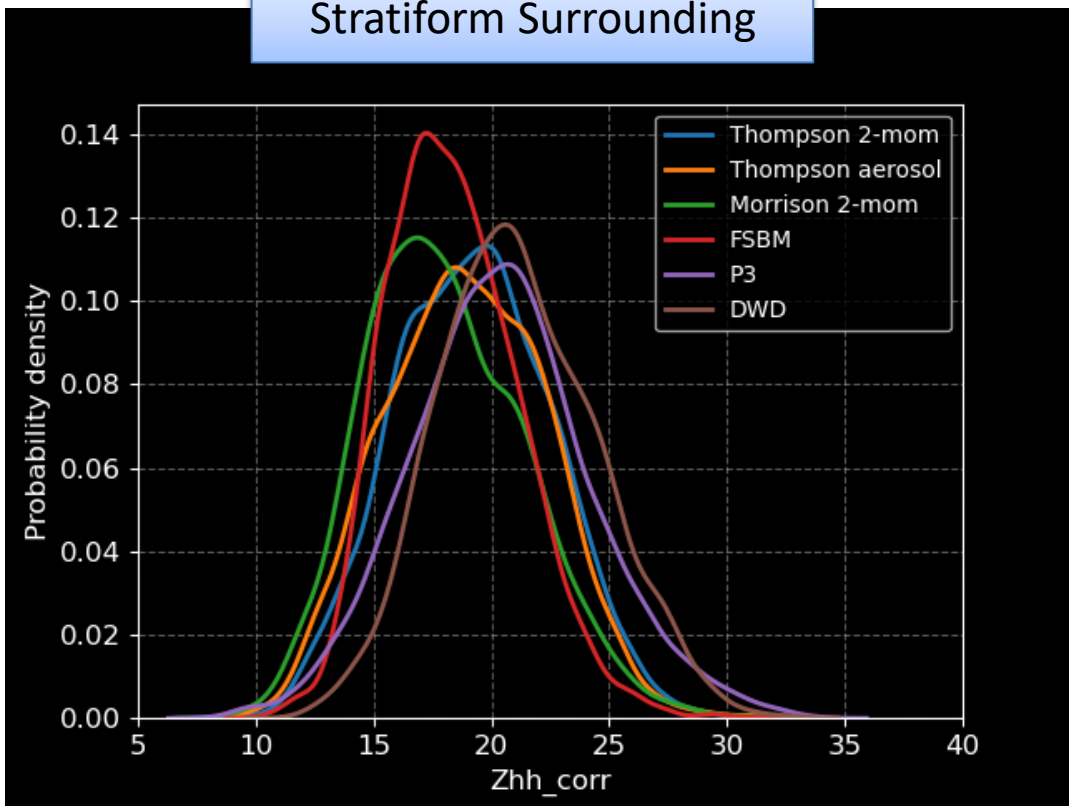
Precipitation signal close to the ground

Variable:
Reflectivity

Convective Core



Stratiform Surrounding



Reflectivity (dBZ)

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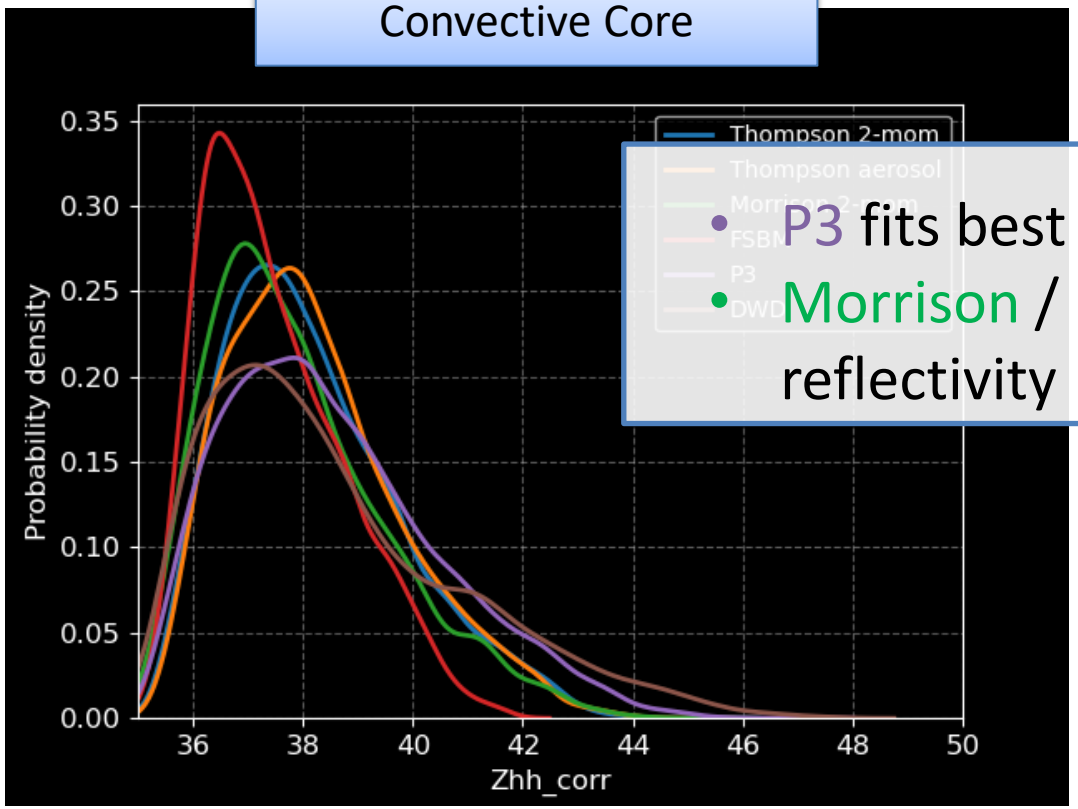

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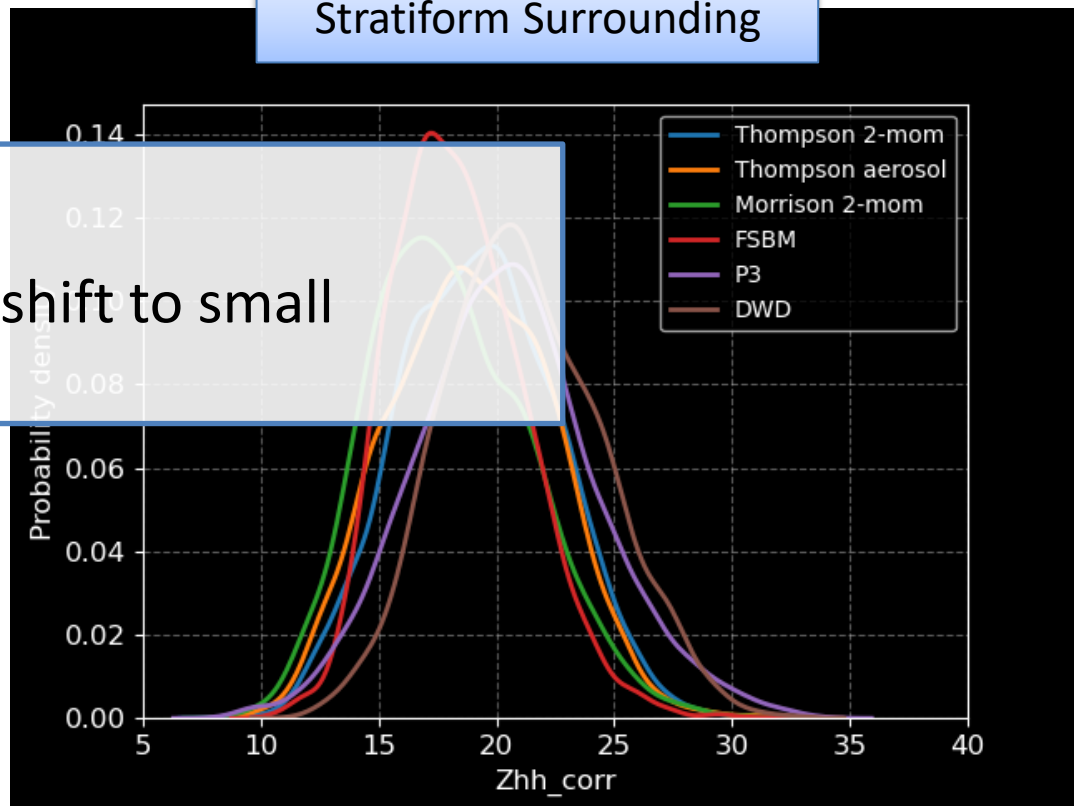

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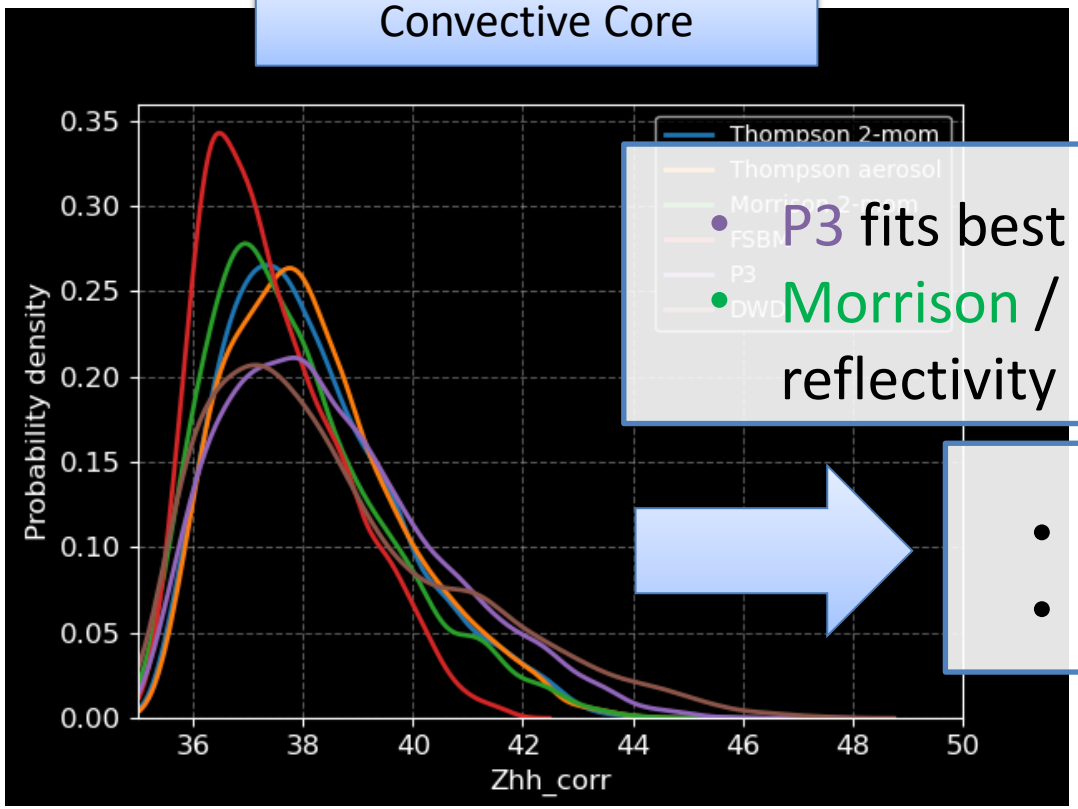

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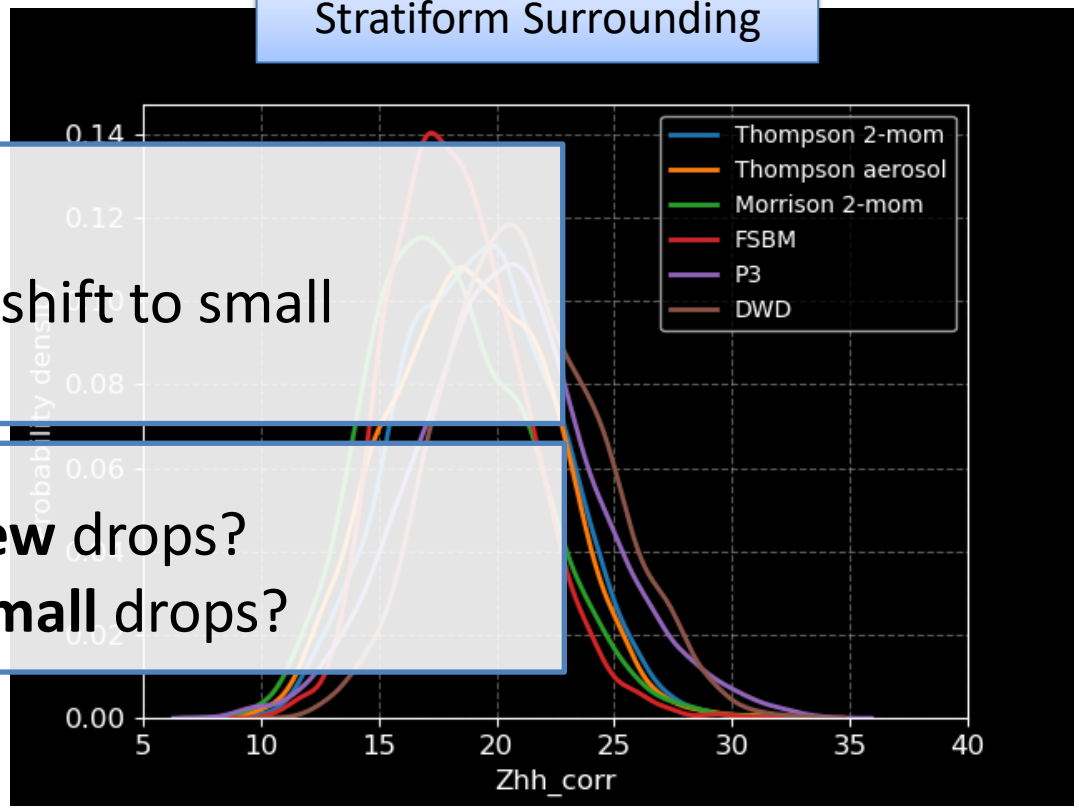

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- Too **few** drops?
- Too **small** drops?

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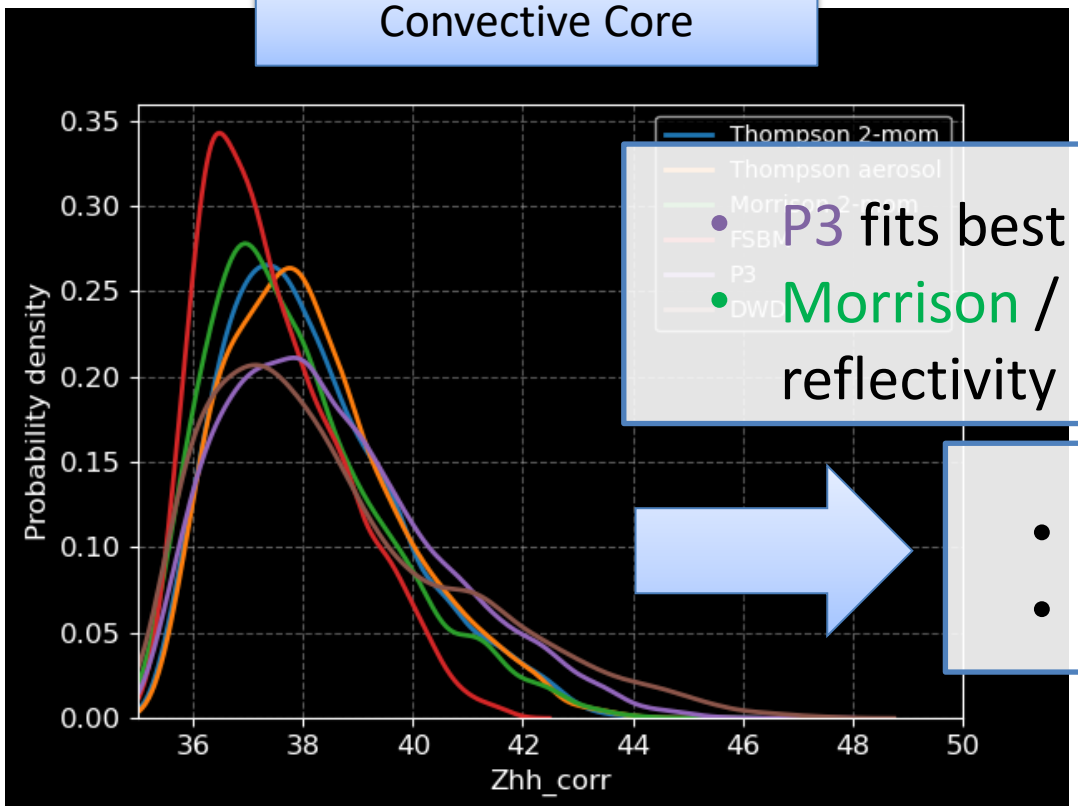

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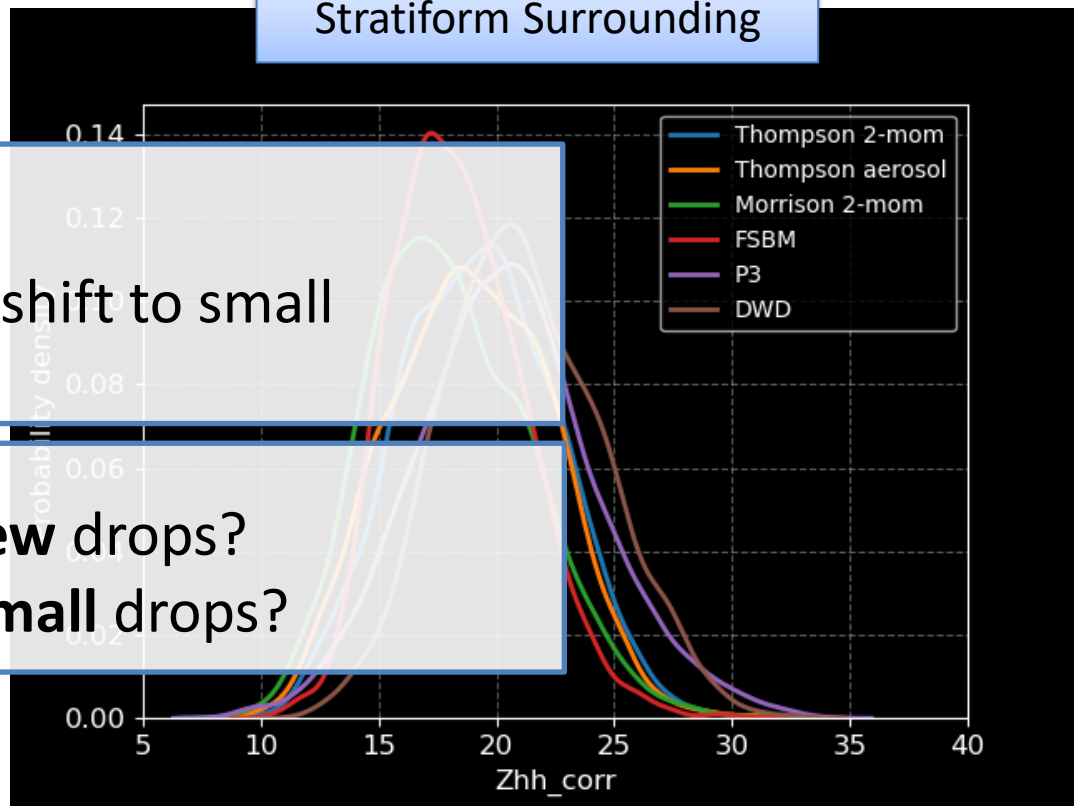

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Reflectivity (dBZ)

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Variable:
Differential Reflectivity

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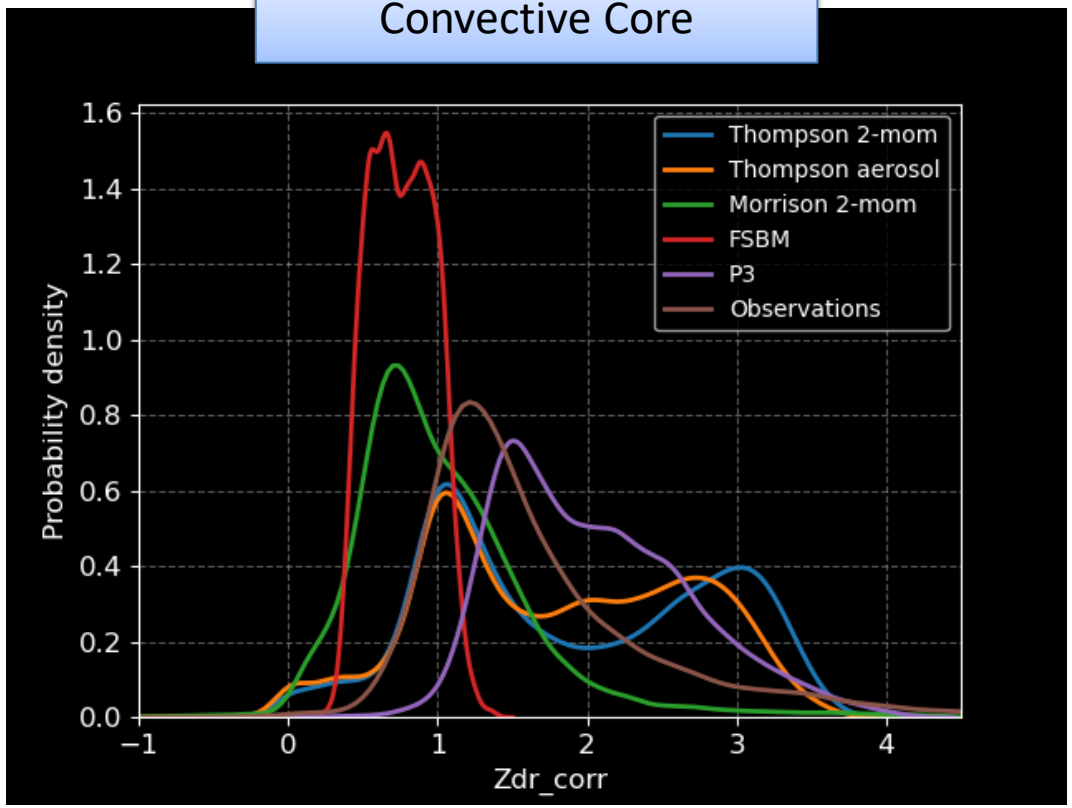

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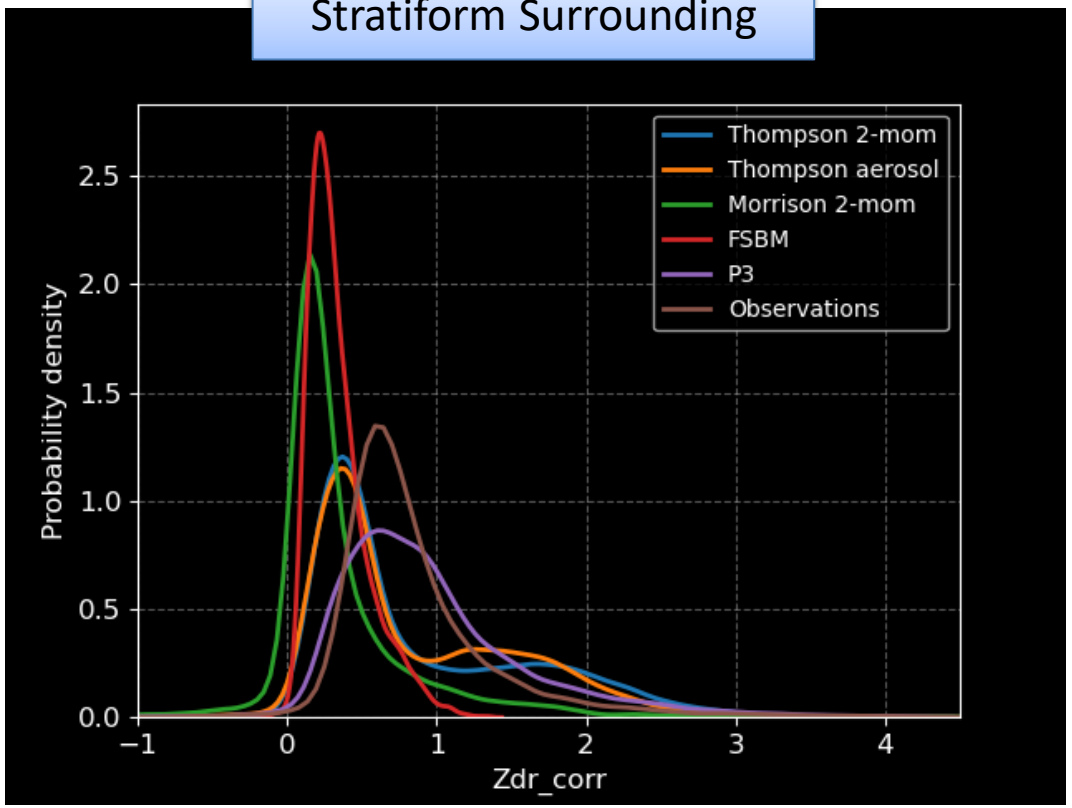

Differential Reflectivity (dB)

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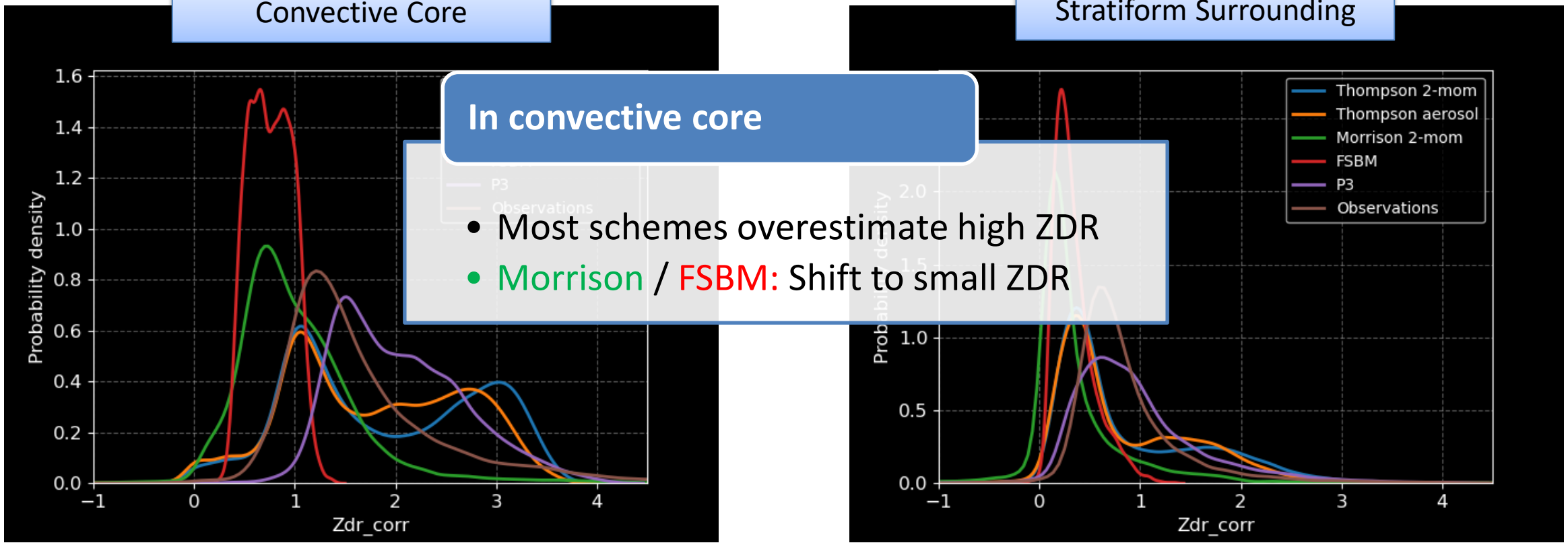

In convective core

- Most schemes overestimate high ZDR
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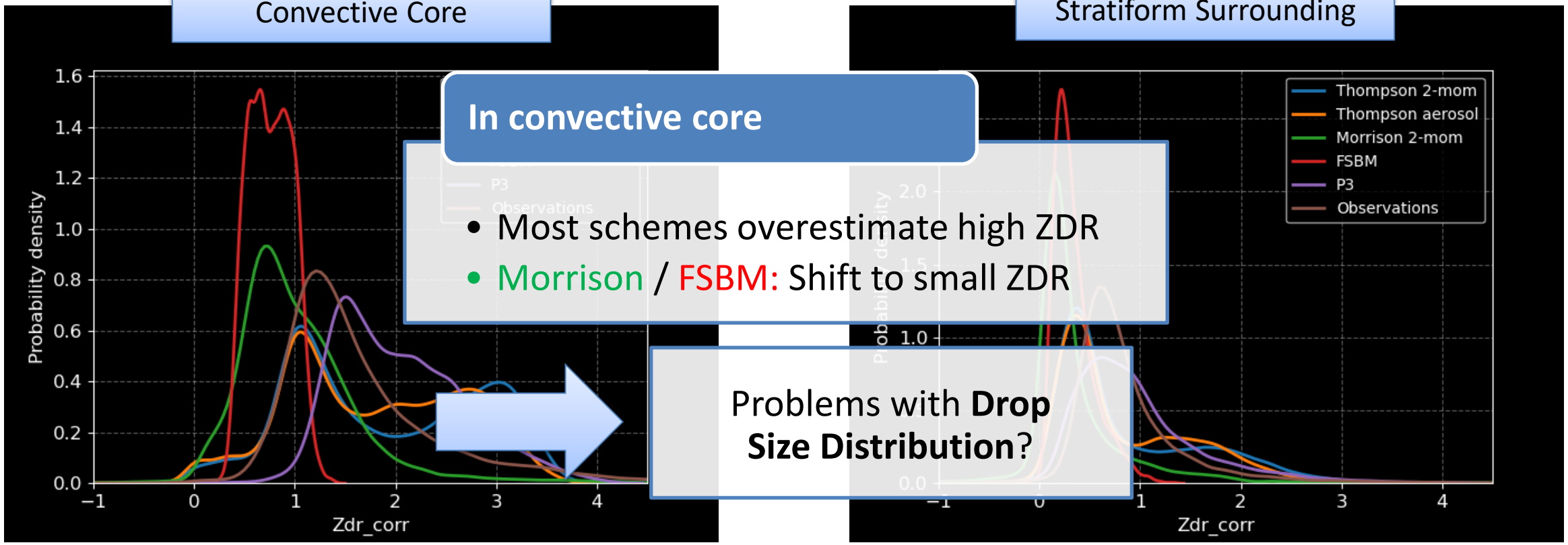

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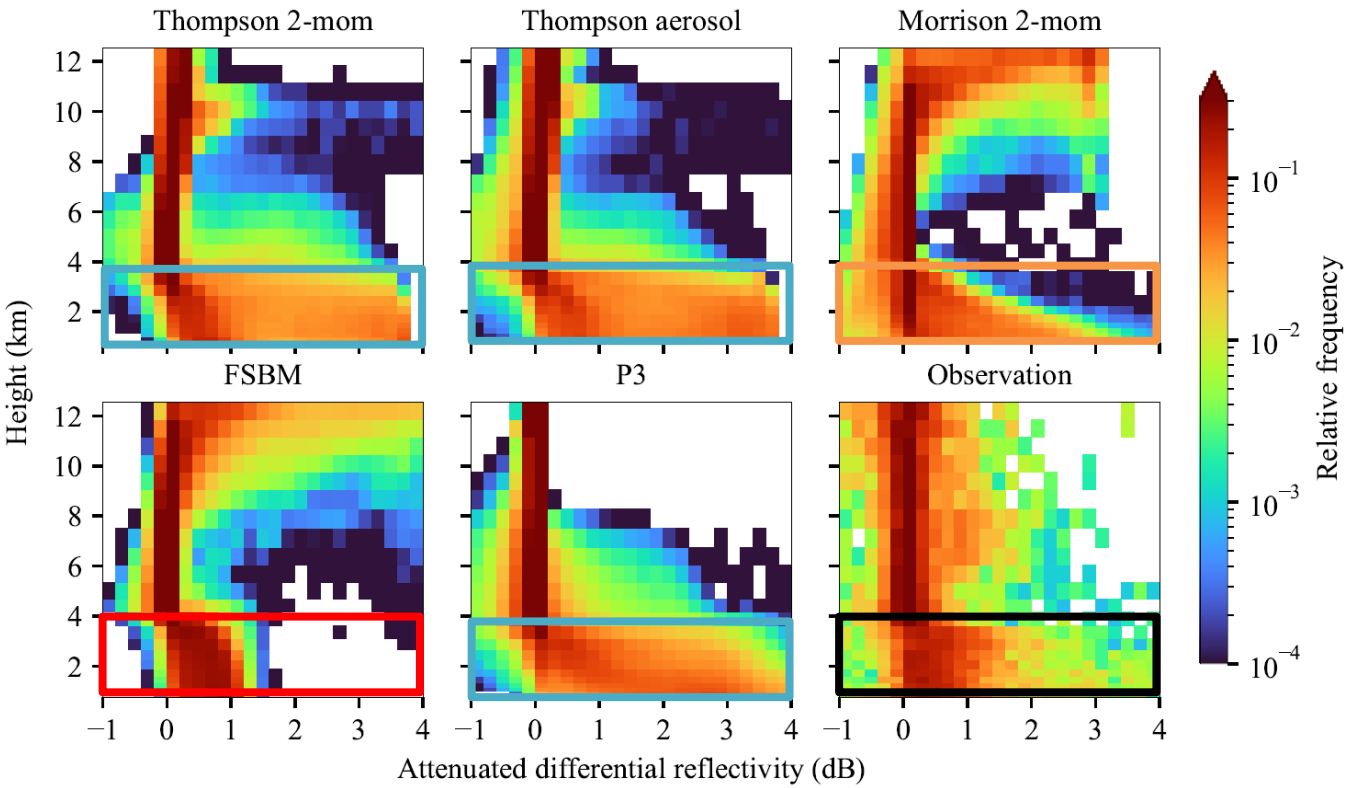
Problems with **Drop Size Distribution**?

Differential Reflectivity (dB)

Comparing to phase 1



Köcher et al. (2022), AMT

Differential reflectivity (ZDR)

- Sensitive to particle shape
- Proxy for **size** of rain

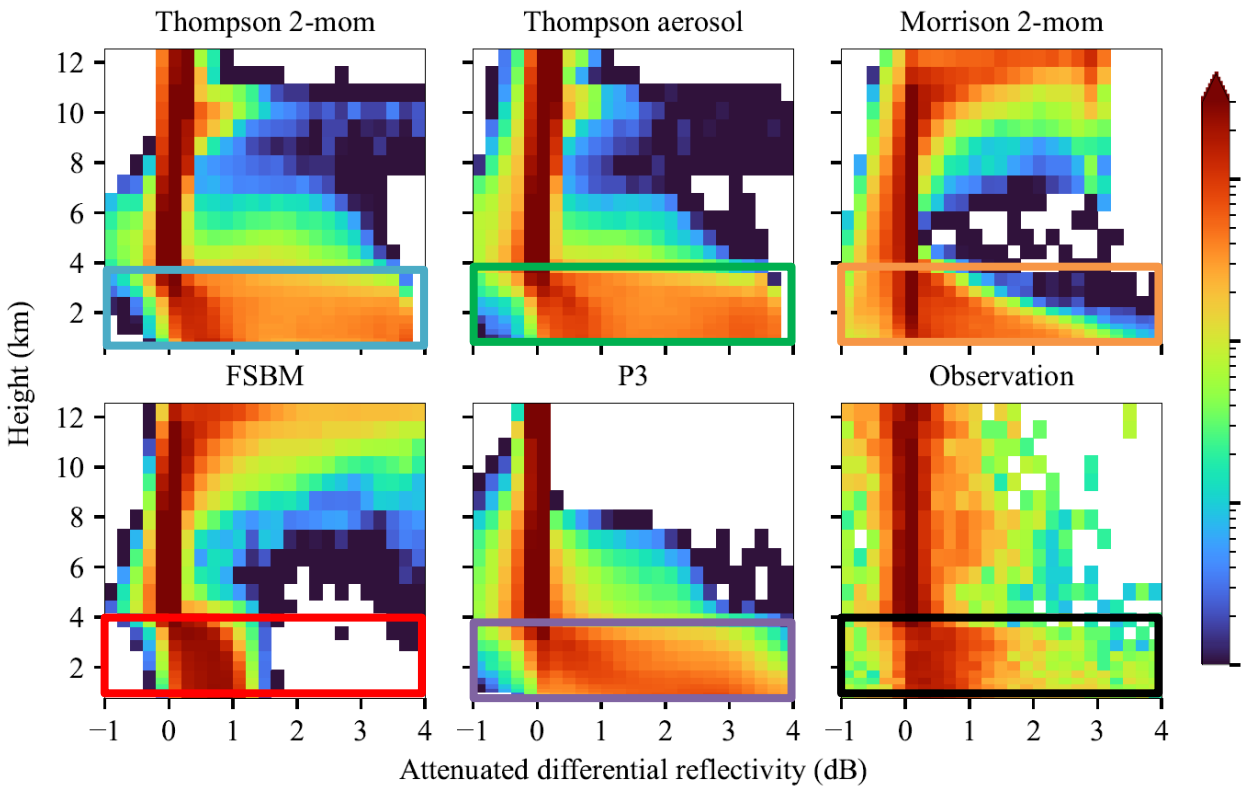
Most models

- Have **too large** ZDR spread
- **Too many** large drops

FSBM

- **Better** captures high density at **low** ZDR
- Does **not show** any **high** ZDR

Comparing to phase 1



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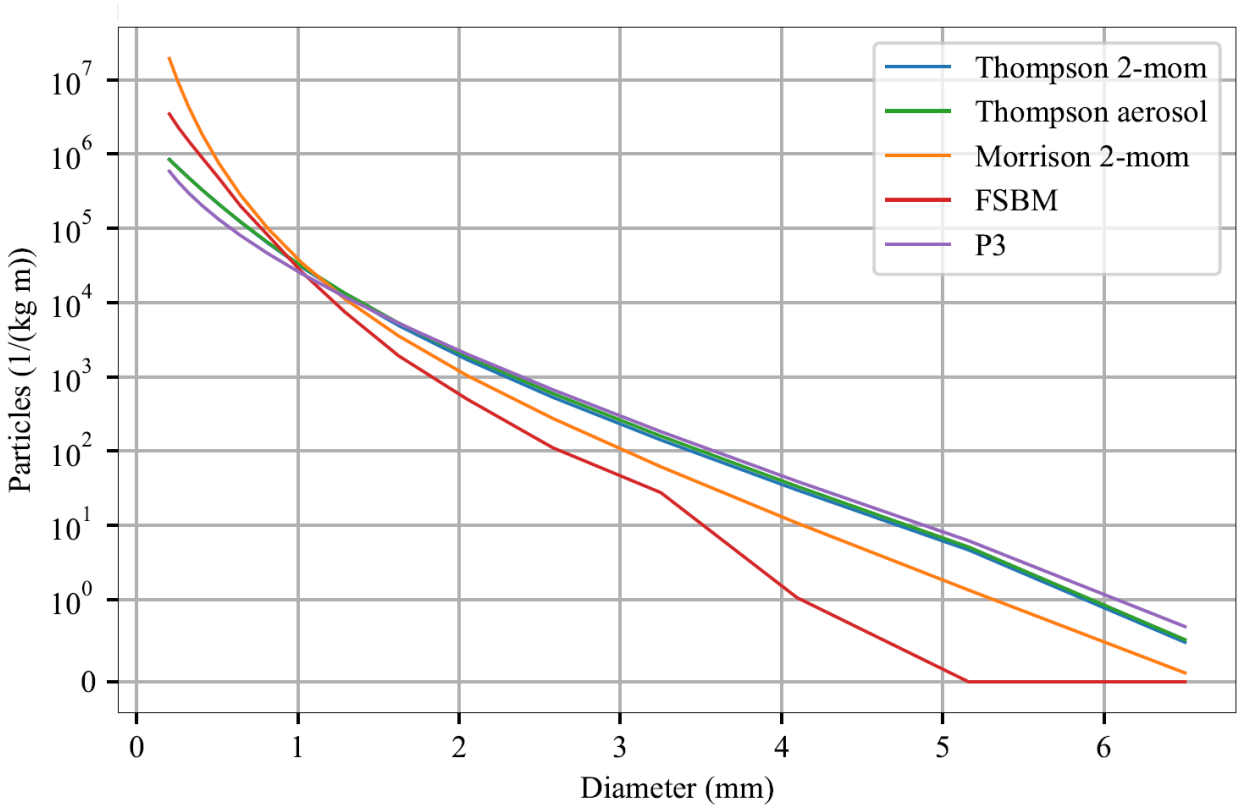


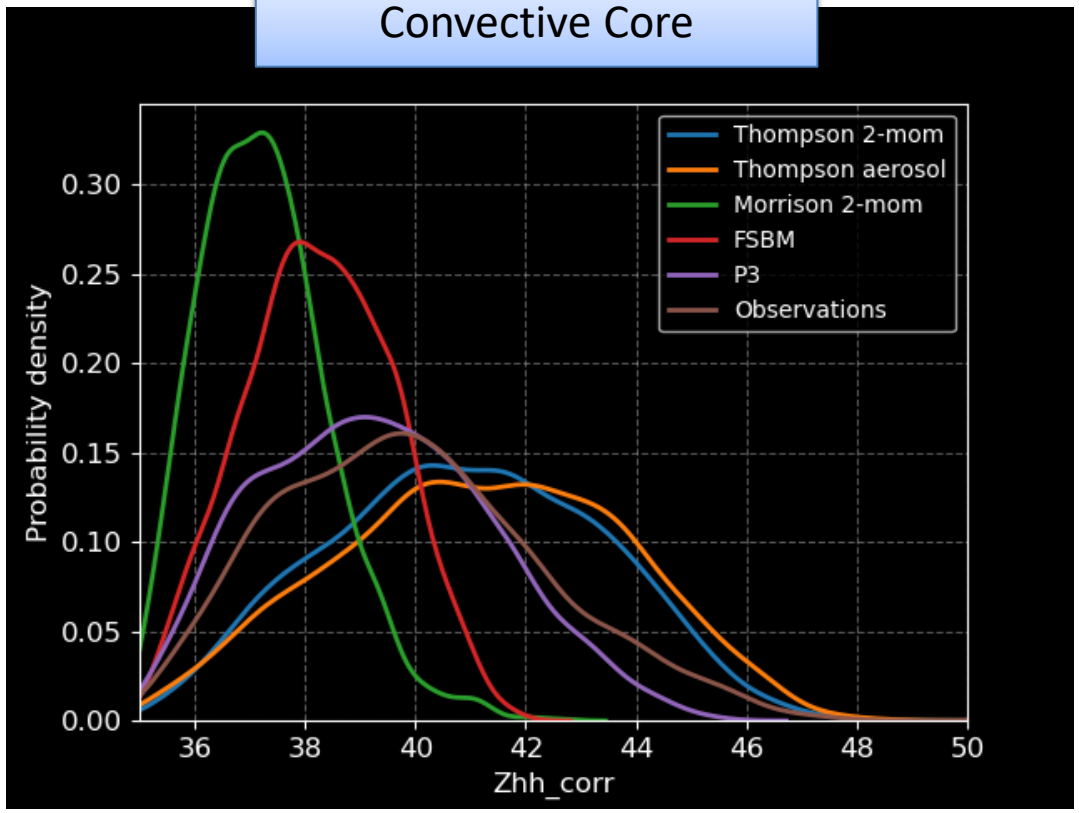
Statistical comparison of radar signals

Height:
5.5 km

Precipitation signal at upper heights

Variable:
Reflectivity

Convective Core



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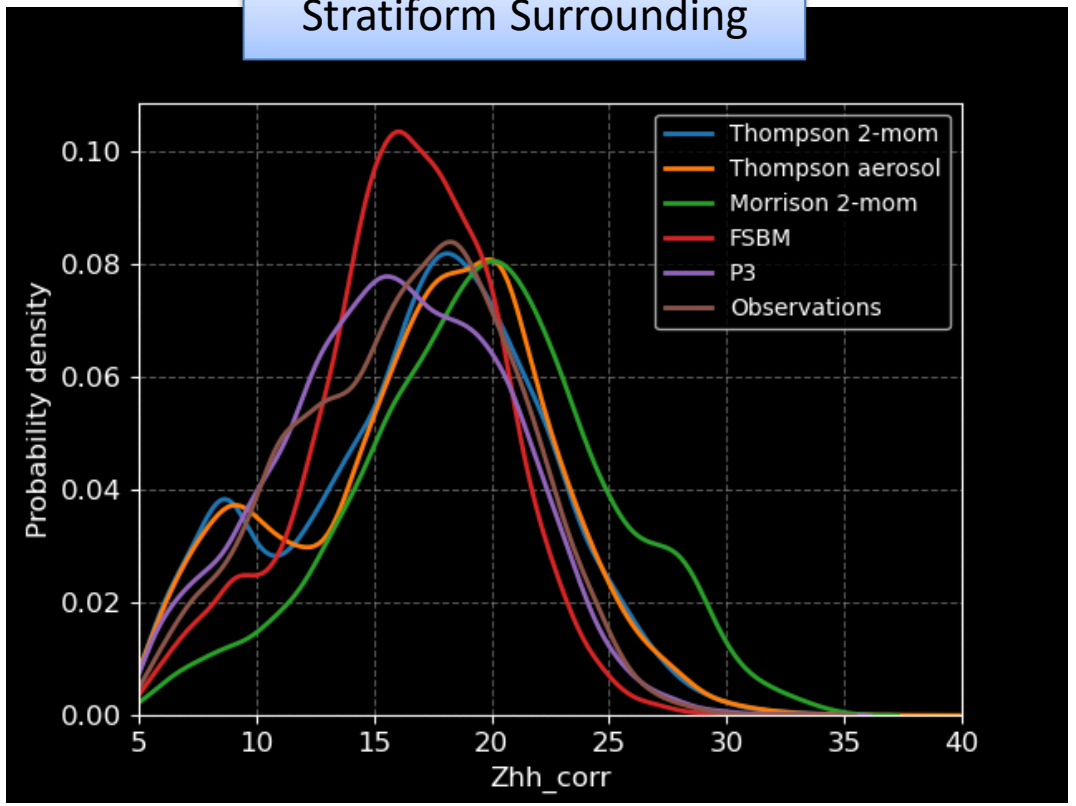

Reflectivity (dBZ)

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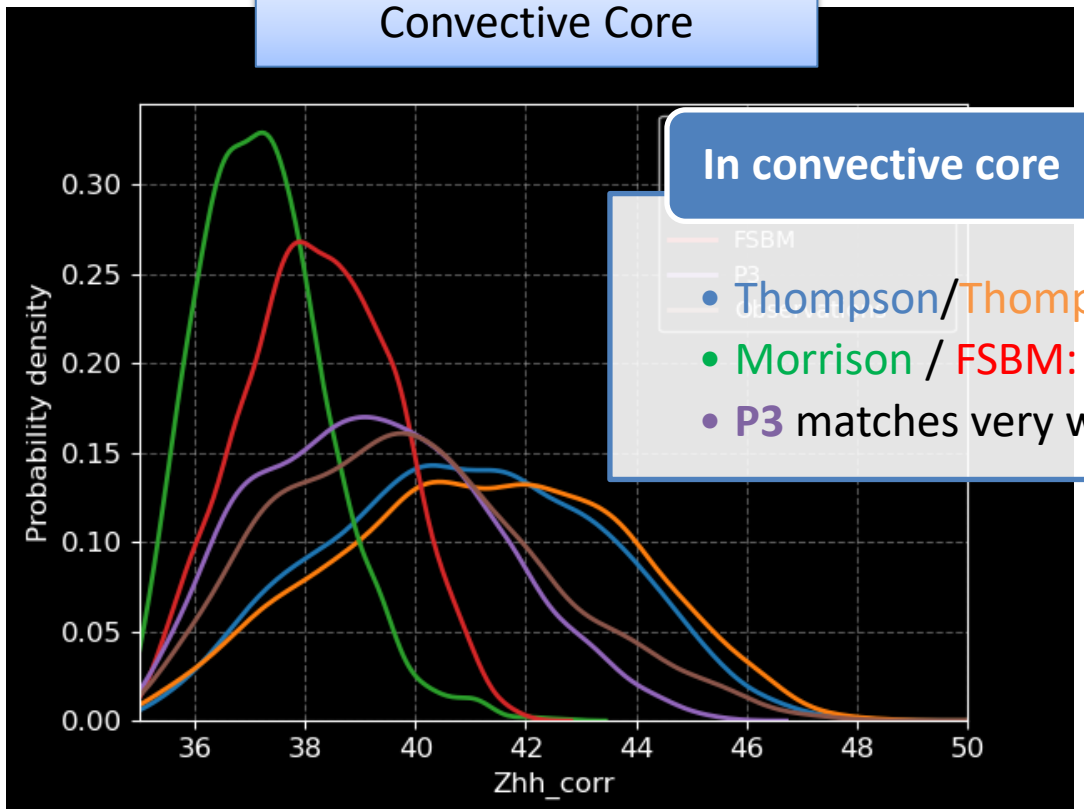

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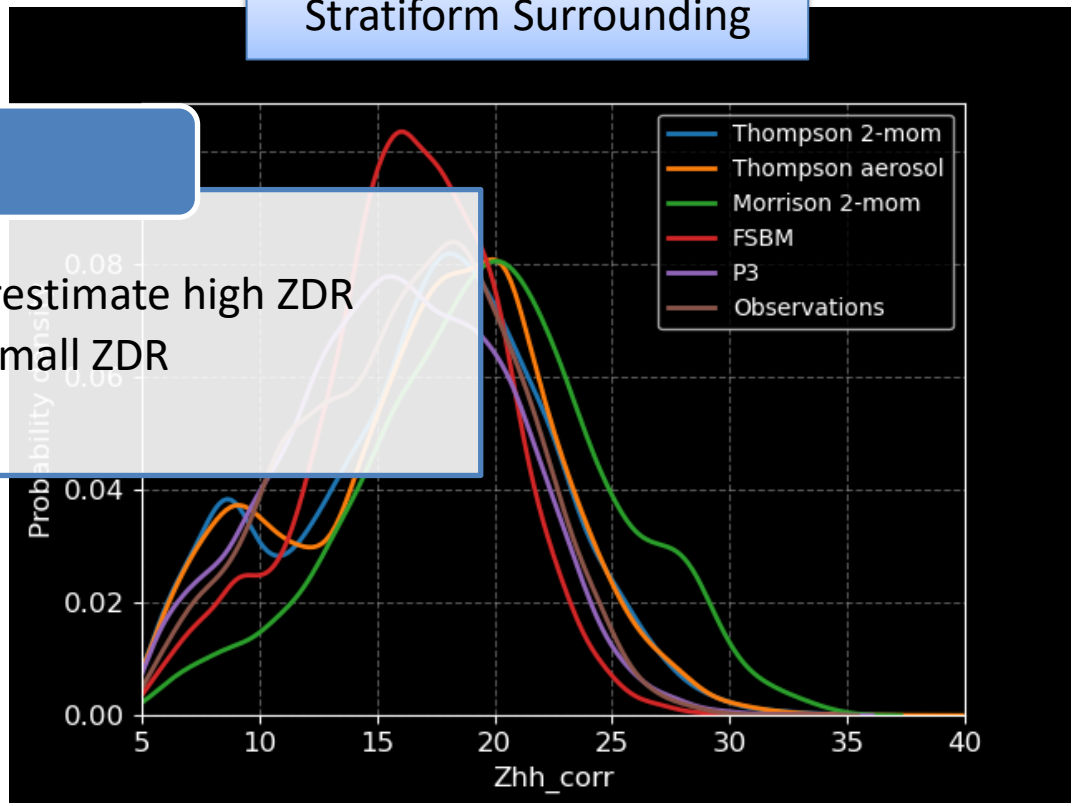

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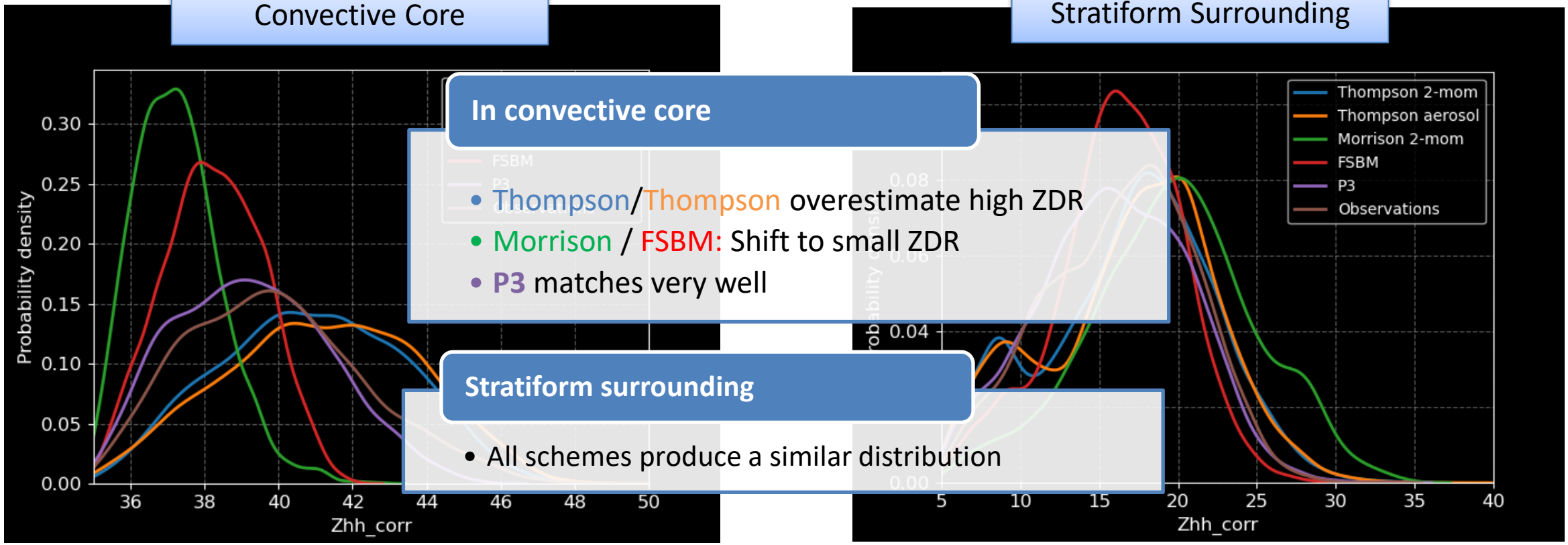

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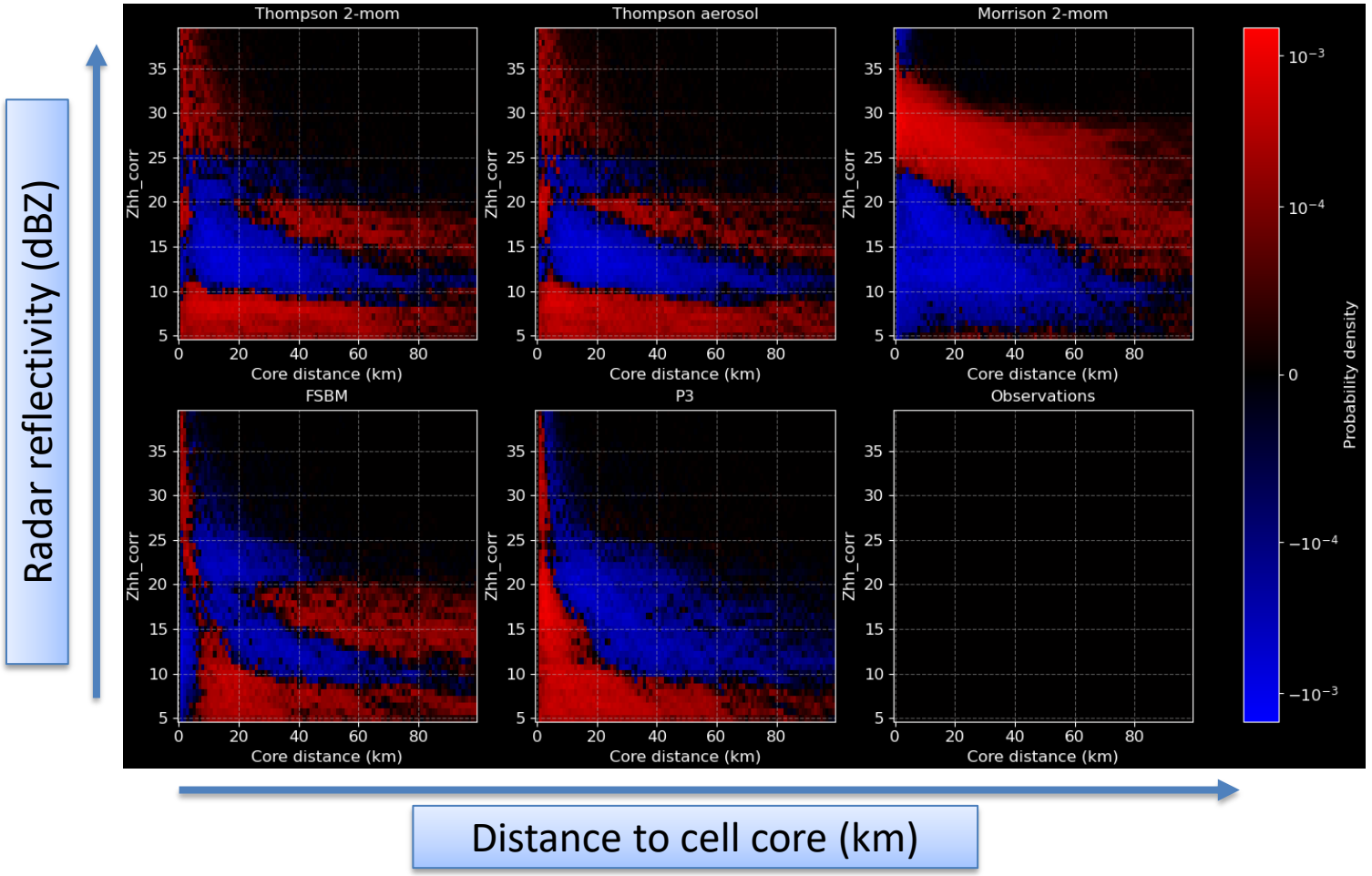
Stratiform surrounding

- All schemes produce a similar distribution

Reflectivity (dBZ)

Towards spatio-temporal development



Height:
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What do you see?

- **2D histogram** of radar / model **differences**
- **Red:** Too frequently simulated
- **Blue:** Too rarely simulated

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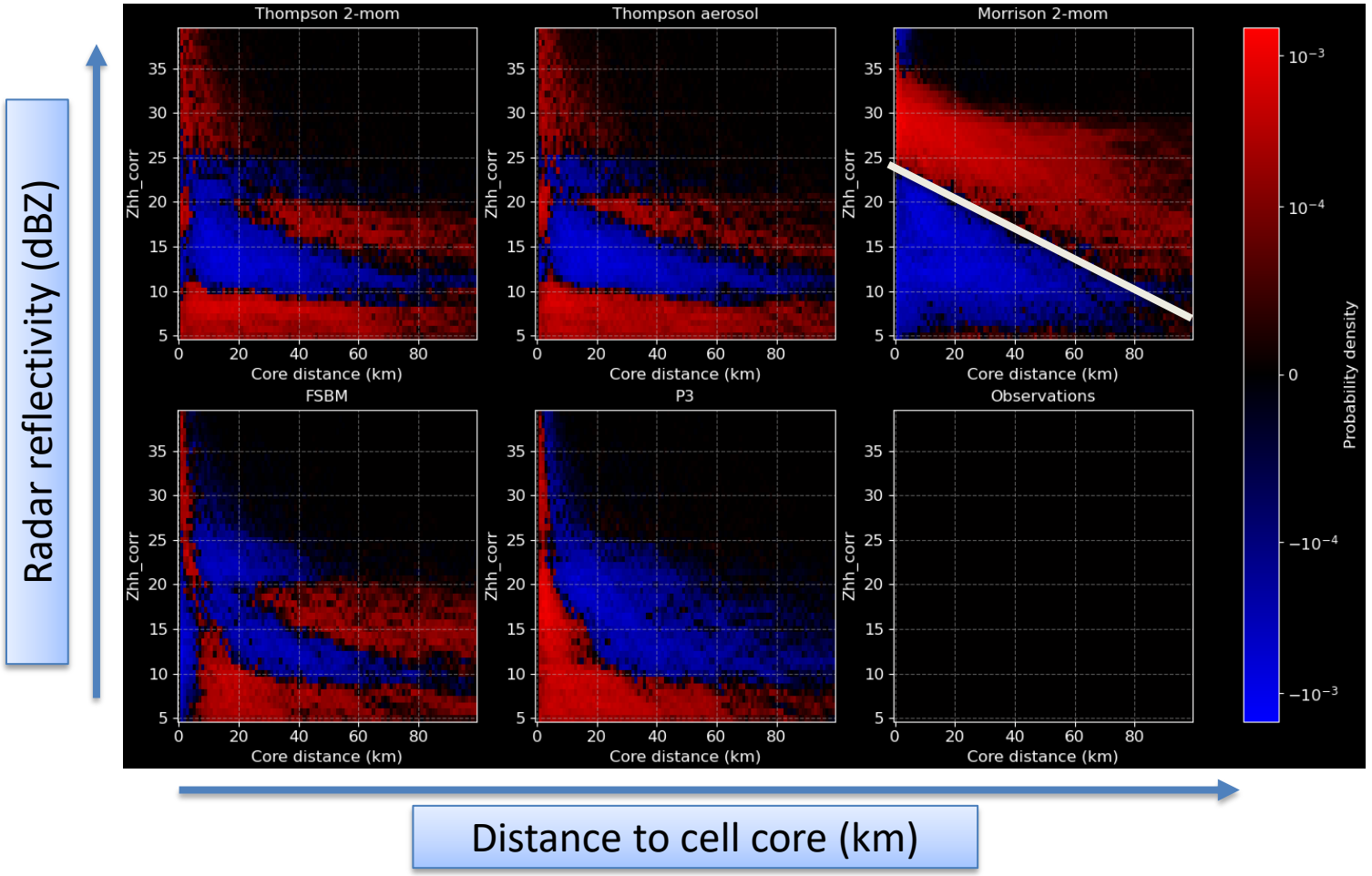

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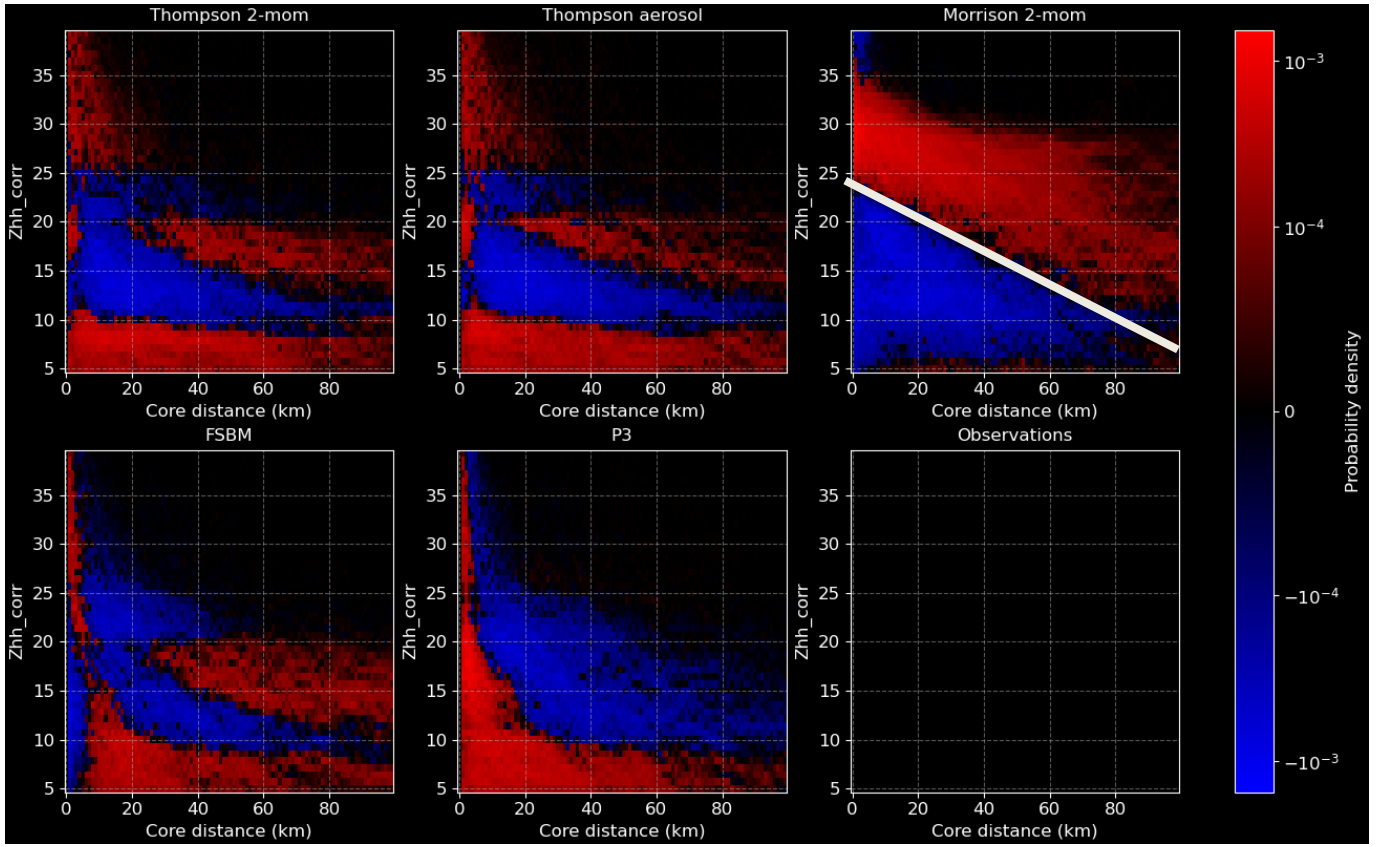

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„Error“ depends on **distance** to cell core and on **MP-scheme**

Summary

Polarimetric radar observations

- Sensitive to **particle properties** (shape, size, density, …)
- Useful tool for evaluation of model **microphysics**

Statistical evaluation

- On objective based **convective cell basis**
- Using an automated cell-tracking algorithm (**Tobac**)

Microphysical results

- Most schemes: too **many** large rain drops
- Morrison/FSBM: too **few** large rain drops

Spatio-temporal development (experimental)

- Strongly influenced by **microphysics** scheme
- Mean radar signals depend on **cell core distance**

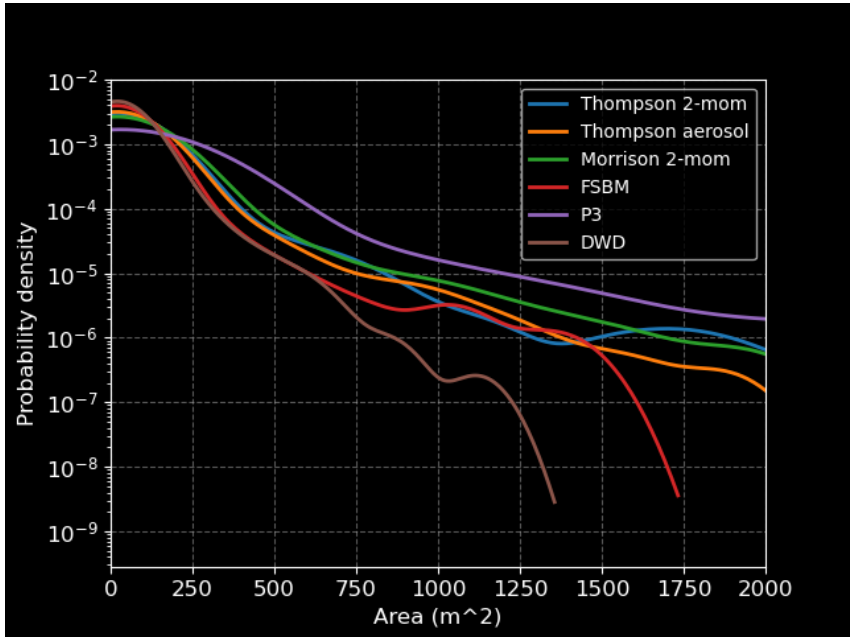
Köcher, G., Zinner, T., Knote, C., Tetoni, E., Ewald, F., and Hagen, M. (2022): Evaluation of convective cloud microphysics in numerical weather prediction models with dual-wavelength polarimetric radar observations: methods and examples, Atmos. Meas. Tech., 15, 1033–1054, https://doi.org/10.5194/amt-15-1033-2022

Köcher, G., Zinner, T., and Knote, C. (2023): Influence of cloud microphysics schemes on weather model predictions of heavy precipitation, Atmos. Chem. Phys., 23, 6255–6269, https://doi.org/10.5194/acp-23-6255-2023

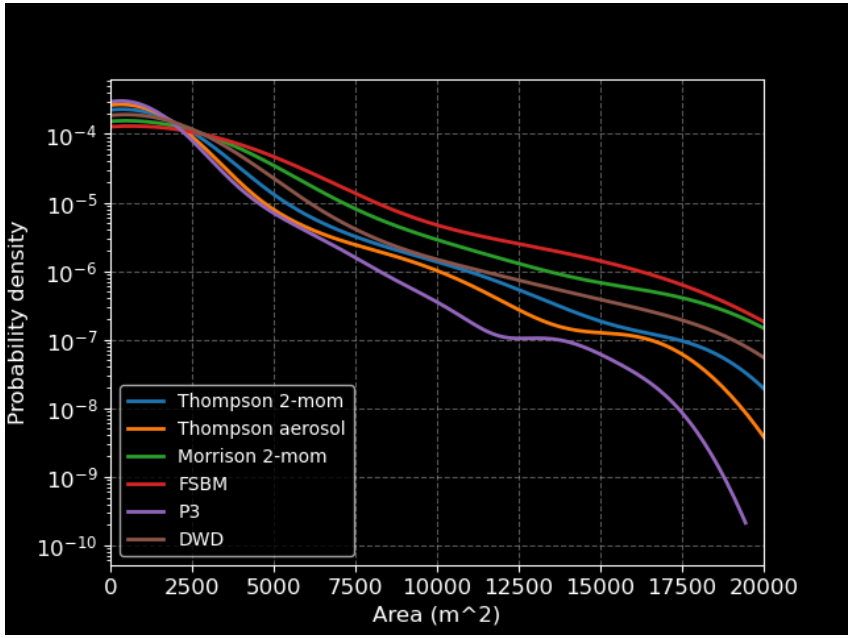
Köcher, Gregor (2023): Convective cloud microphysical parameterizations in a numerical weather prediction model: an evaluation with polarimetric radar observations. Dissertation, LMU München: Faculty of Physics, https://doi.org/10.5282/edoc.32170

Statistics of convective characteristics

Convective Core



Stratiform Surrounding



What do you see?

- Mean area of convective core / stratiform precipitation at 1.5 km
- Probability density over 30 days

Microphysics

- Influences distribution of stratiform / convective parts
- **P3:** least area in stratiform region, highest in convective core

Analysis of area, intensity at upper heights

Transport from convective core outwards