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

with polarimetric radar observations

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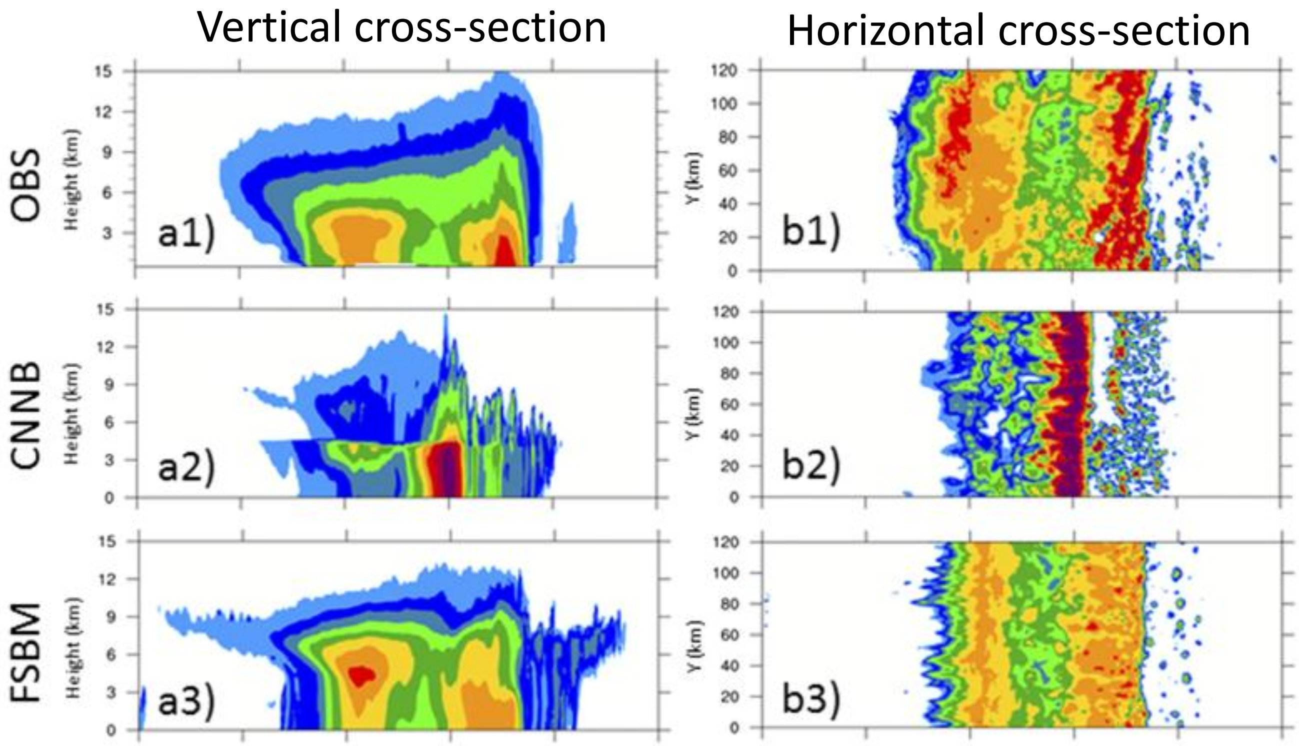
Introduction

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



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

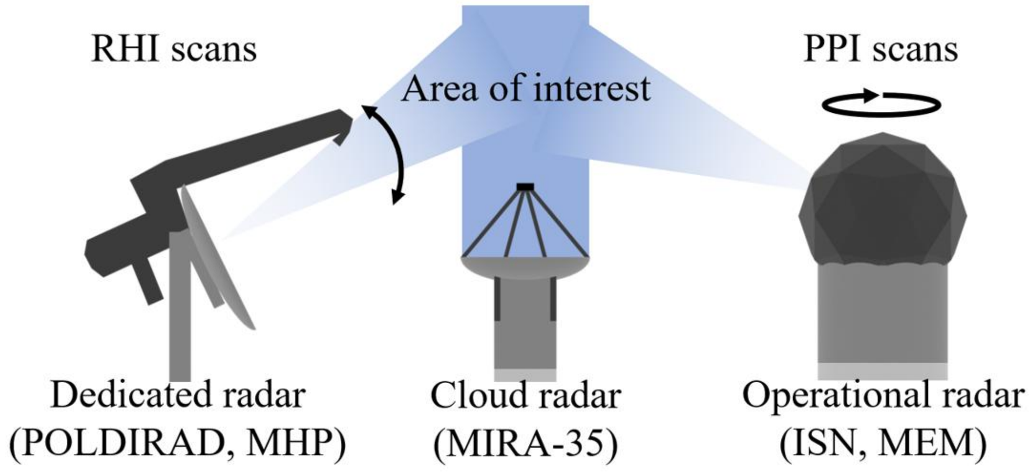
Introduction

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*)

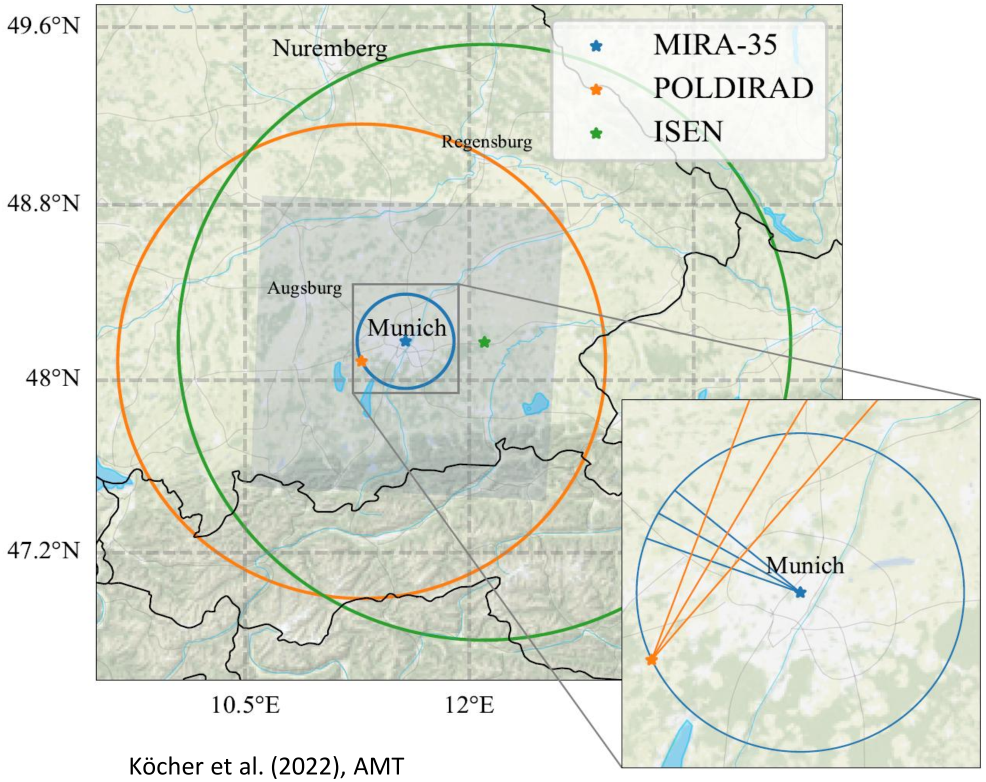
- Strongly sensitive to particle shape
- $Z_{DR} = 10 \cdot \log(\frac{Z_H}{Z_V})$

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

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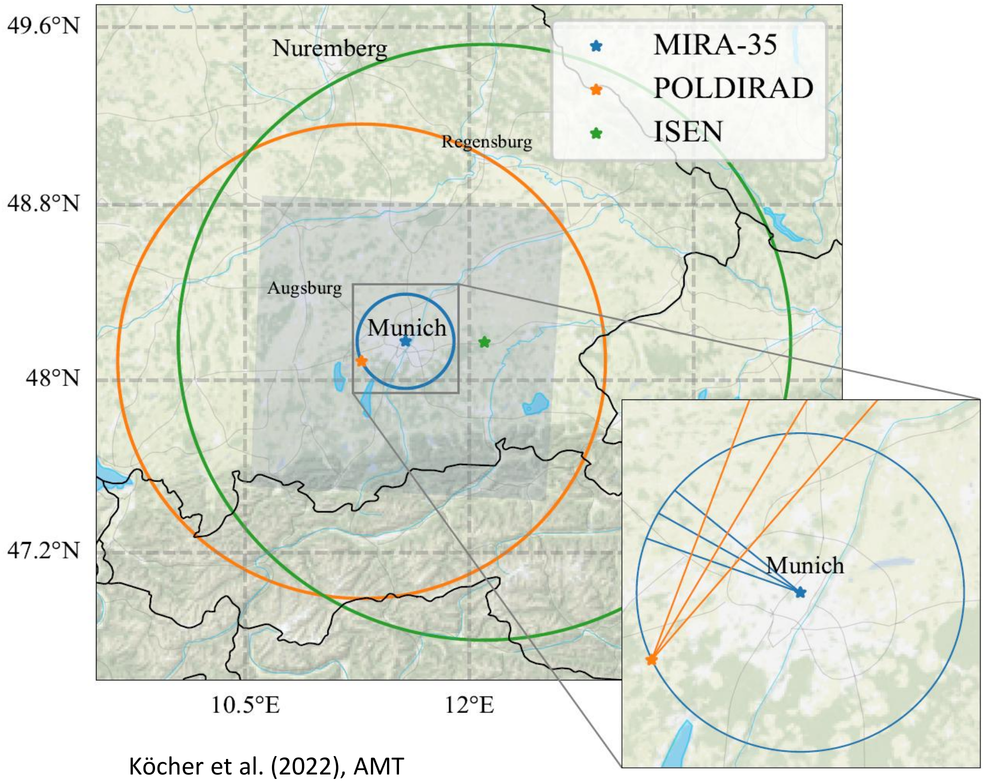


Köcher et al. (2022), AMT

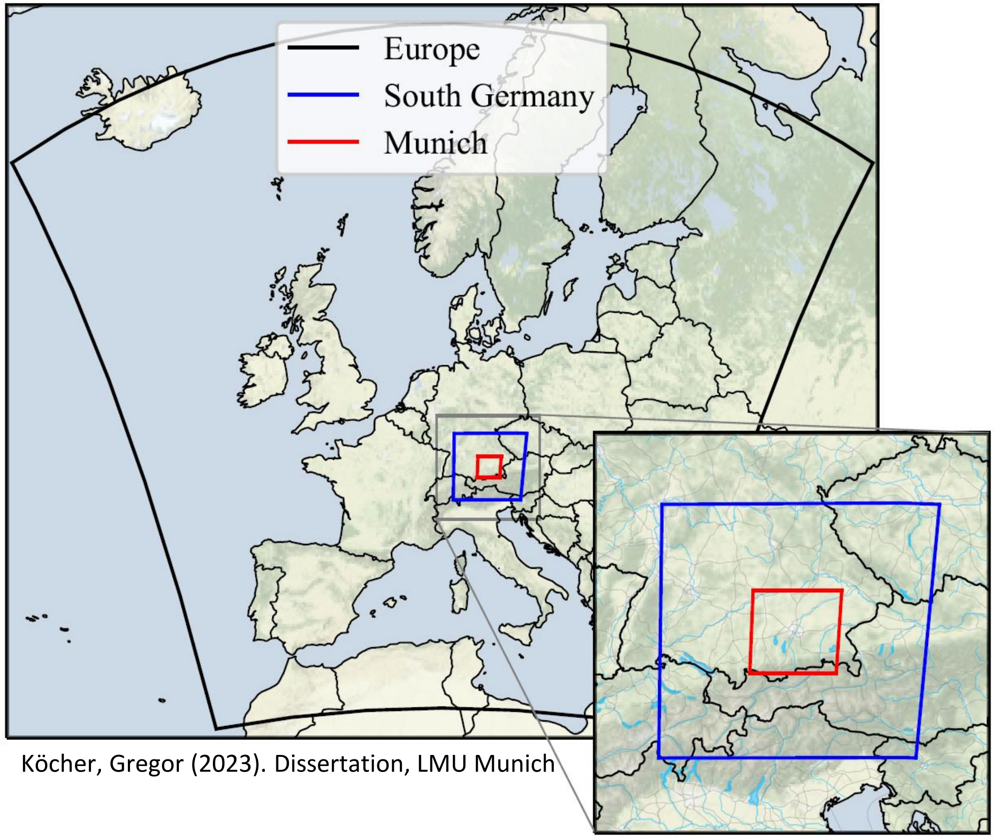
30 convection days

> 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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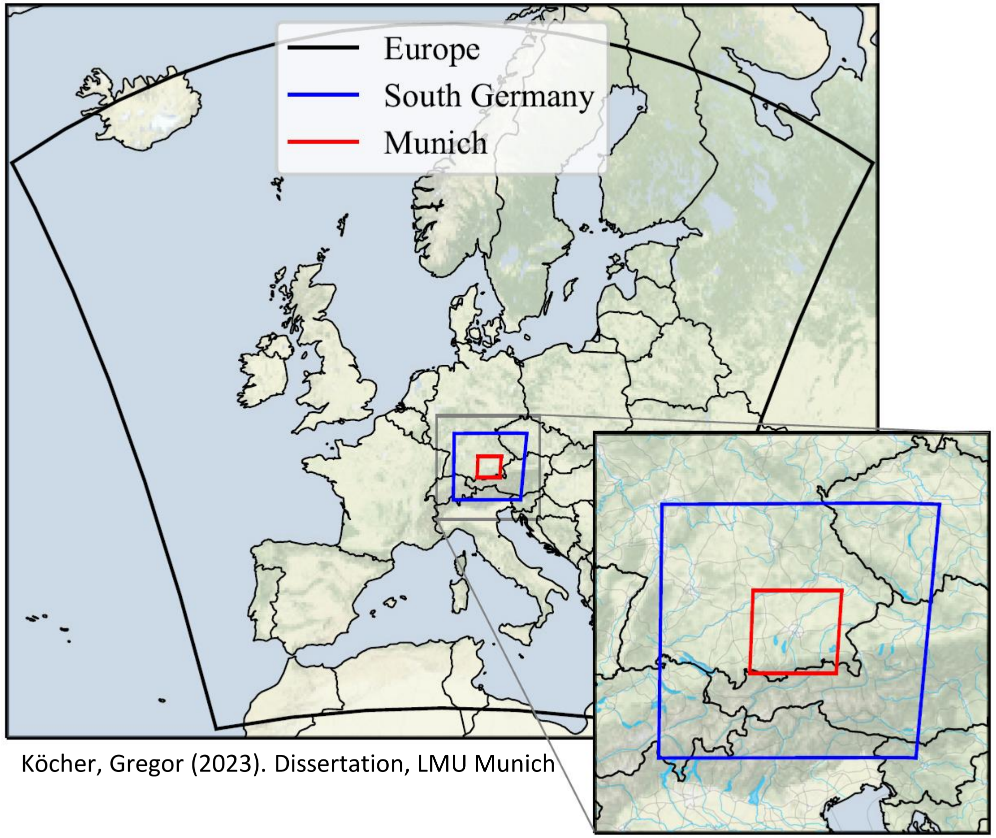
The microphysics

- **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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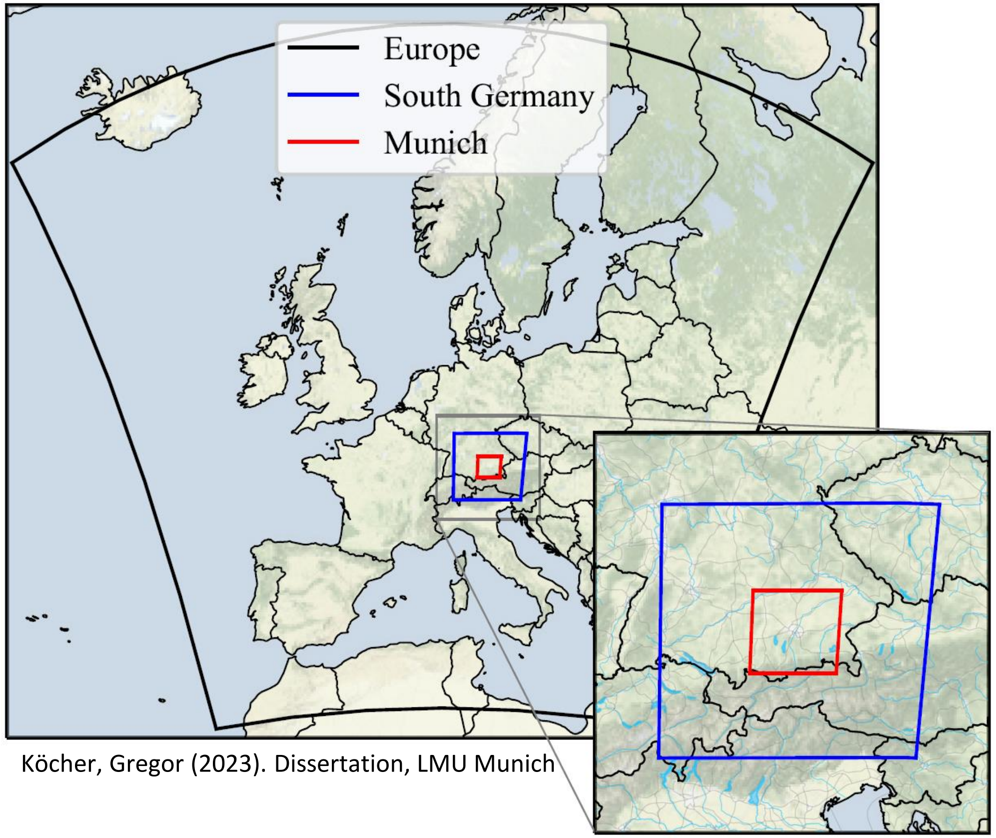
Comparison to observations

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



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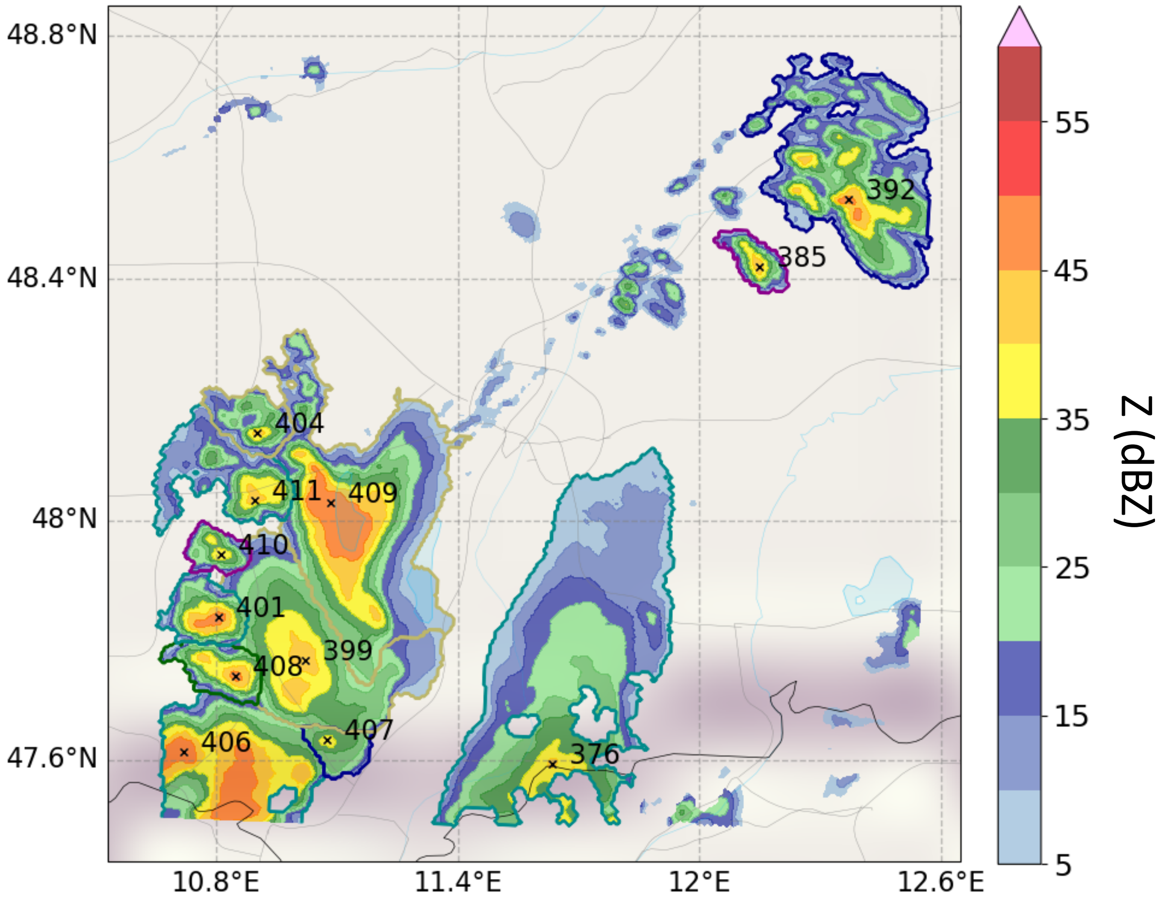
Automatic Cell Tracking

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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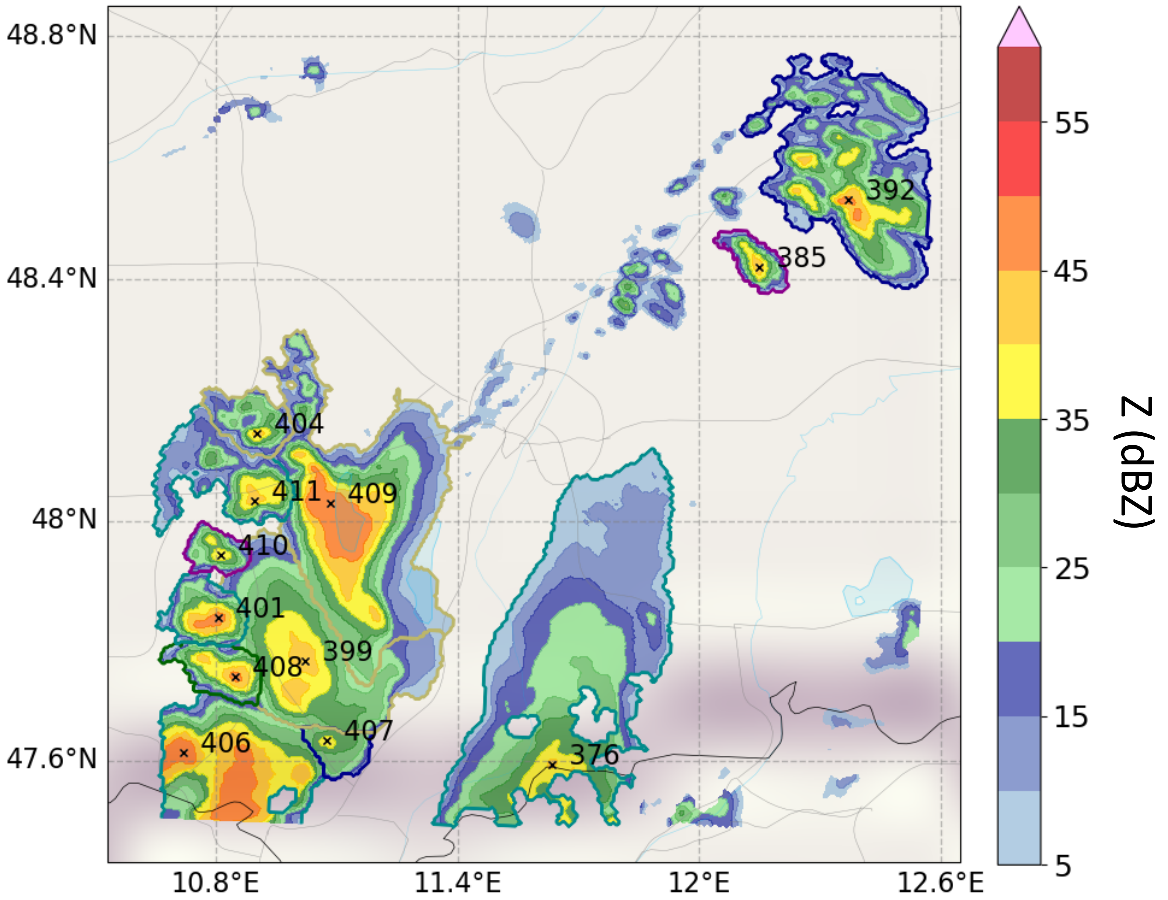
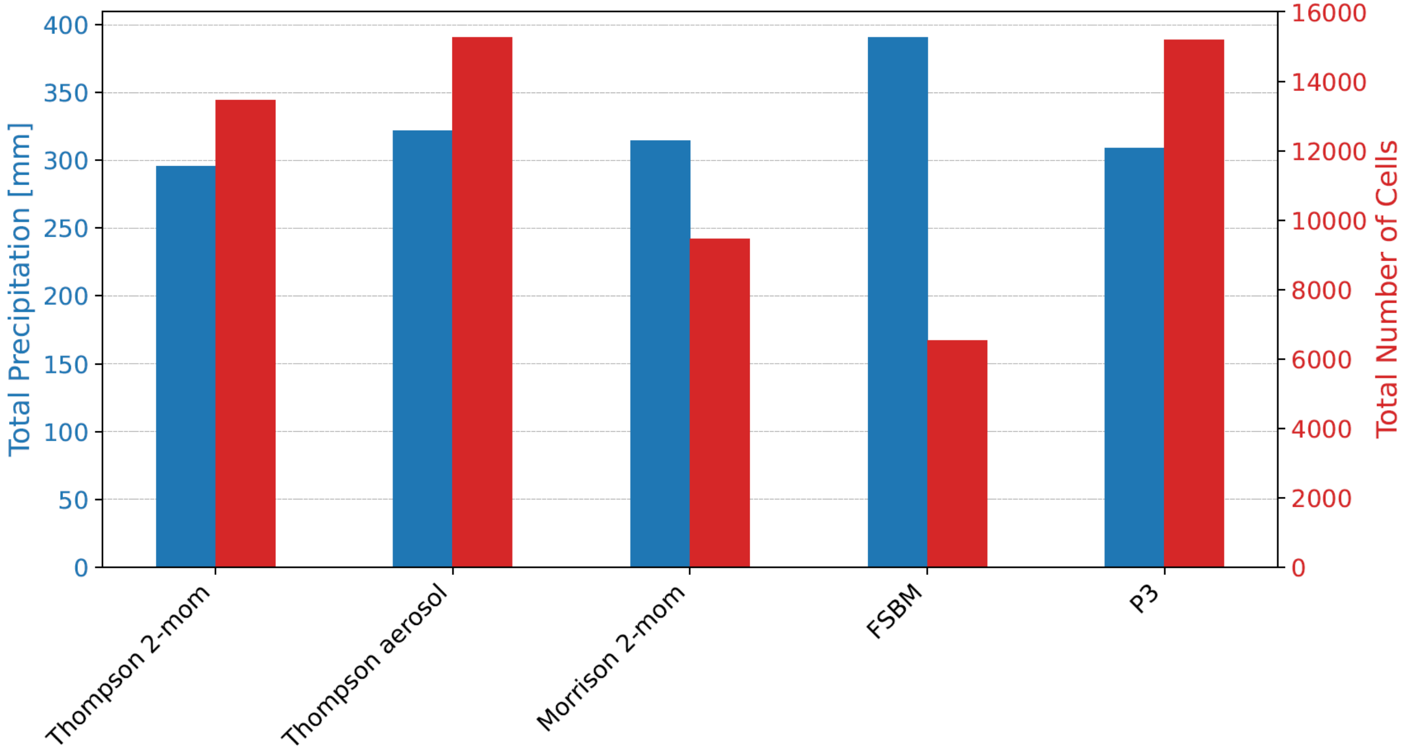


Works for **simulation** and **observation** alike

Spatial distribution: microphysics



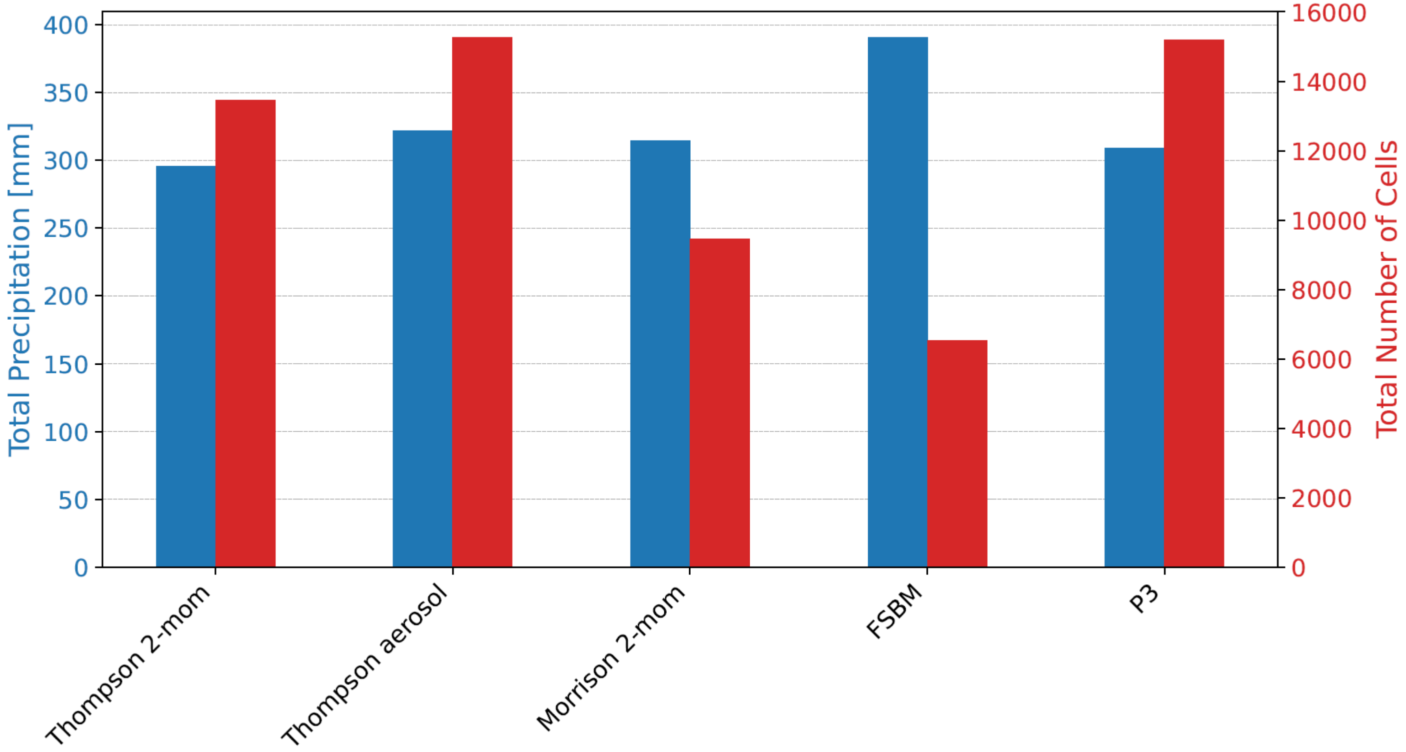
Dataset

- **30 days** of convection
- **5 microphysics** schemes

What do you see

- In blue: **Total surface precipitation**
- In red: **Total number of identified convective cells**

Spatial distribution: microphysics



Total surface precipitation:
Similar

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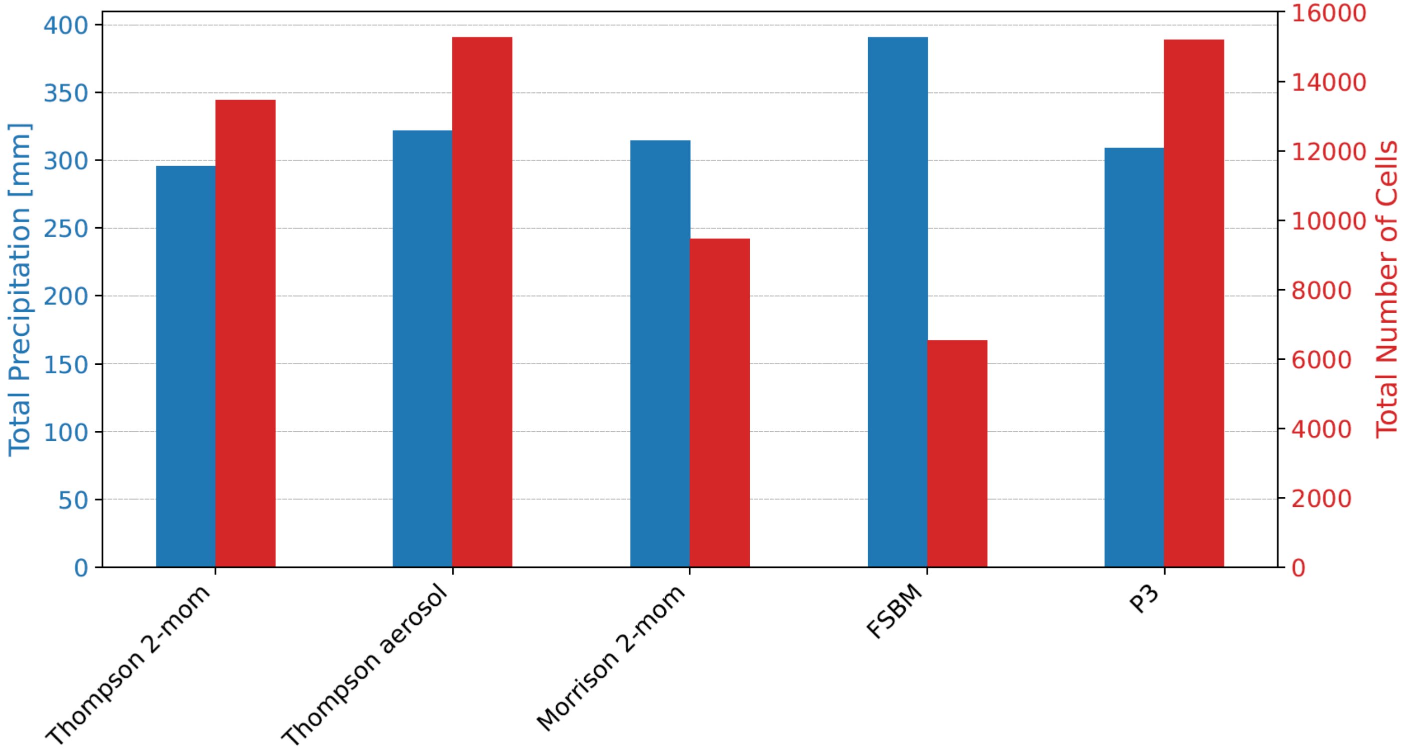

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What do you see

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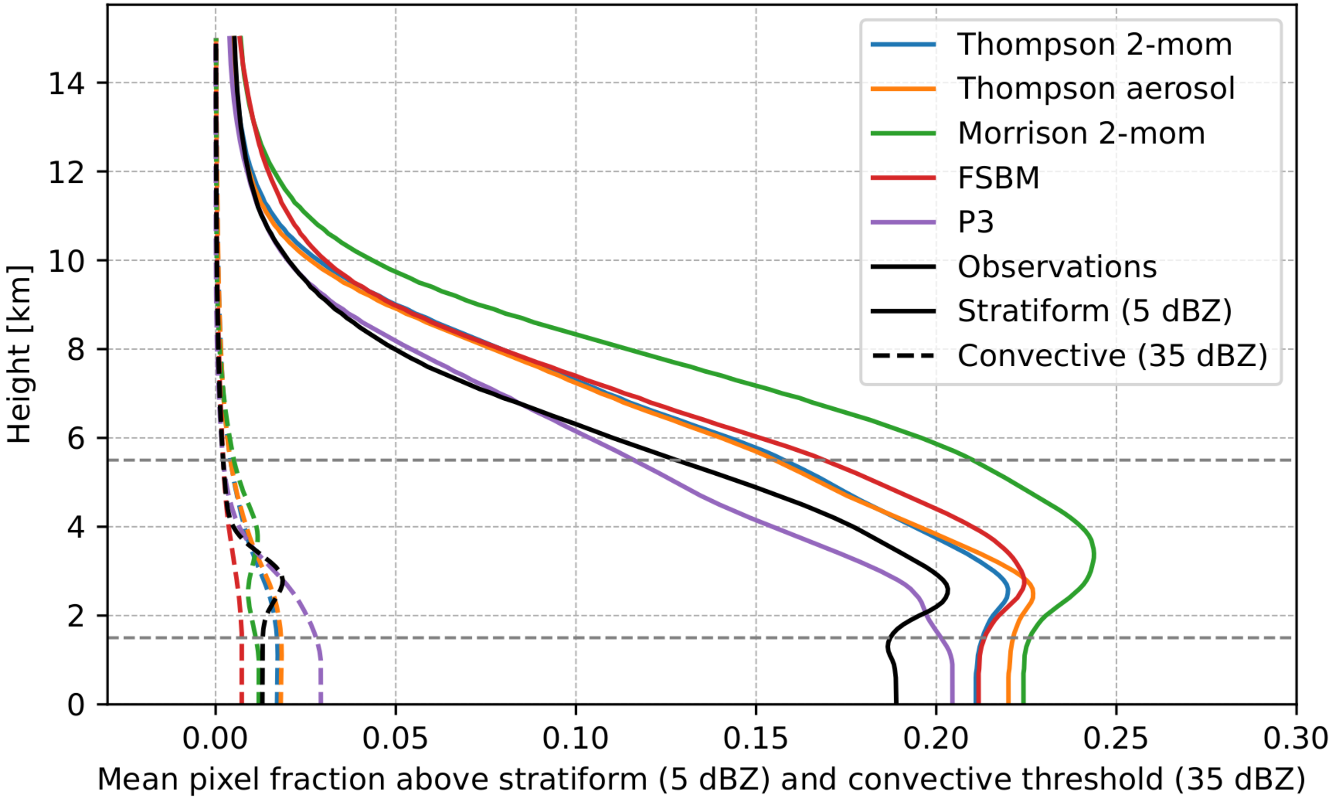
Total surface precipitation:
Similar

Number of convective cells:
Different

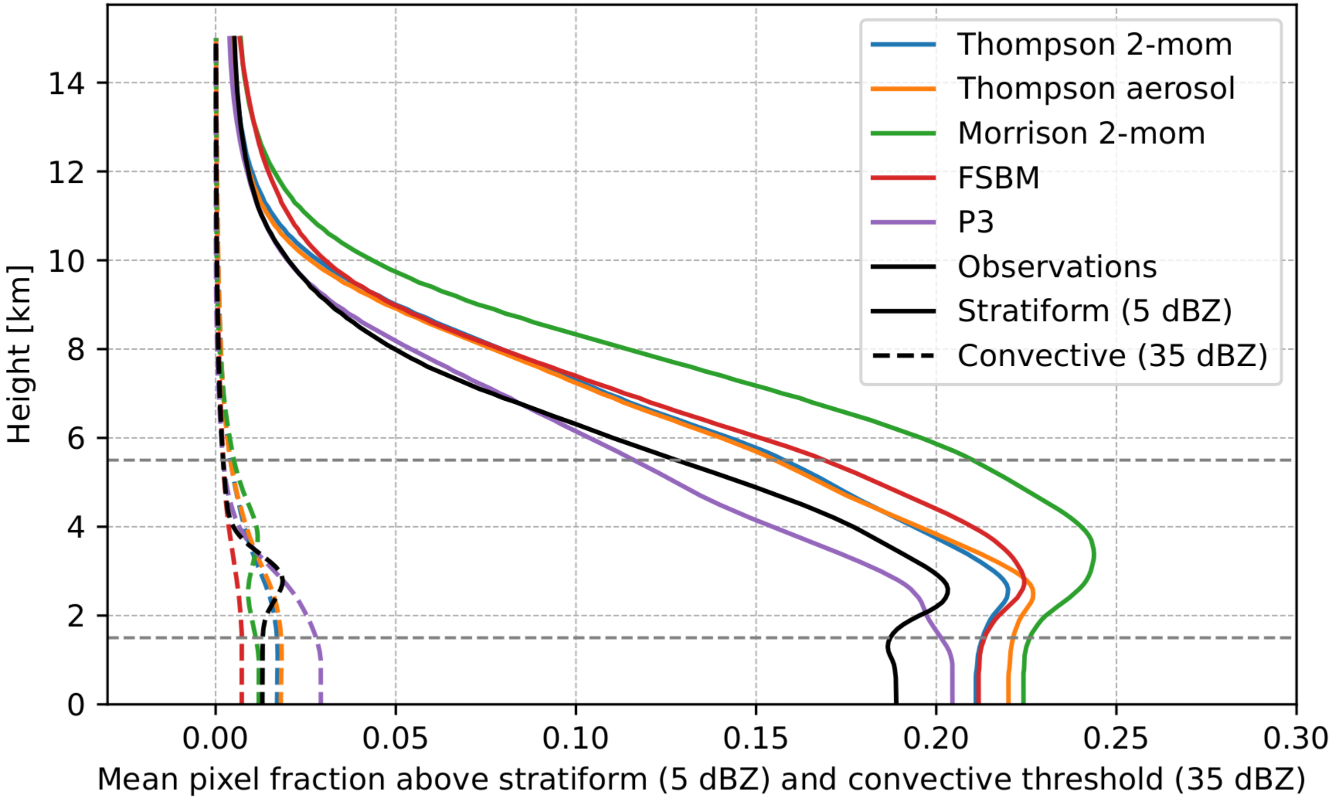
Spatial distribution: Vertical



What do you see?

- **Fraction** of **pixels** above **5** and **35 dBZ** with height
- Proxy for precipitation **coverage**
- Radar observations in **black**, simulations in color

Spatial distribution: Vertical



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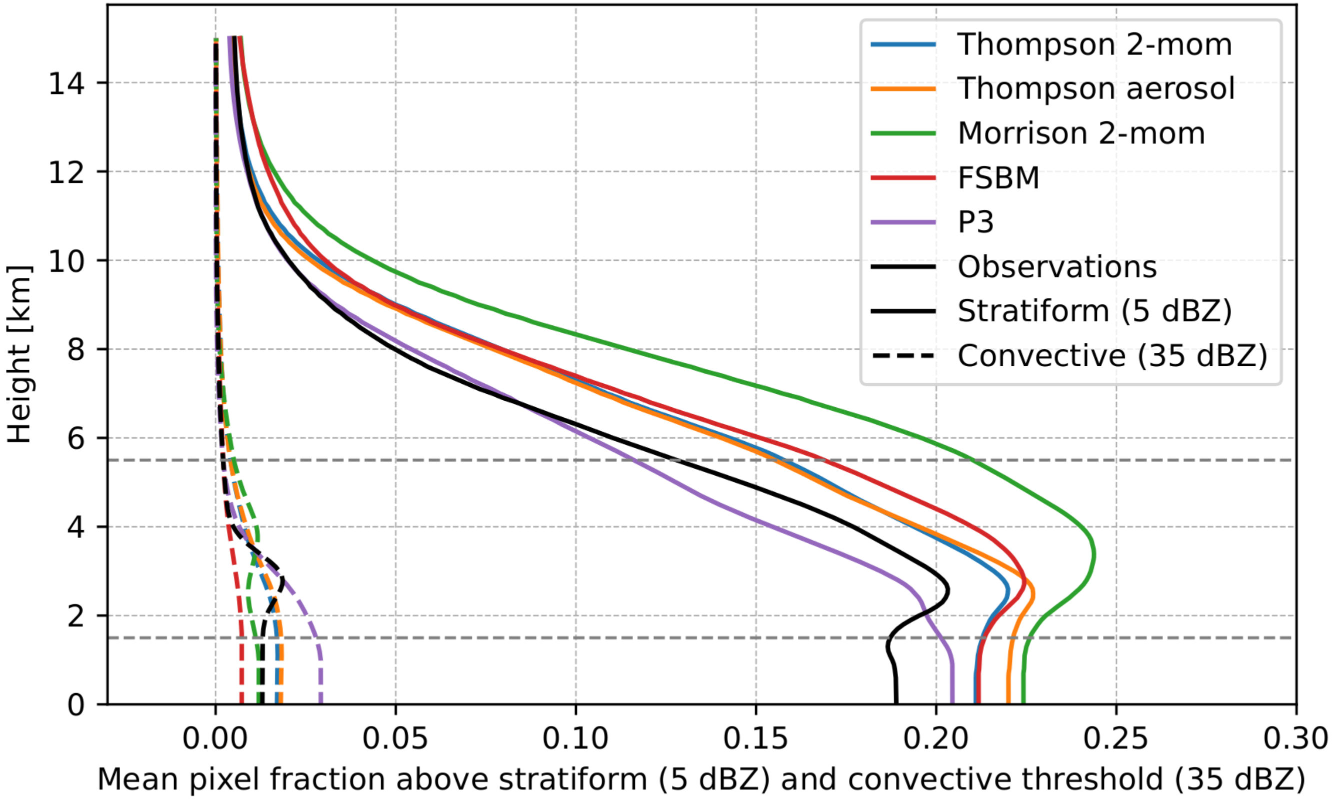
- **Morrison:** Too high stratiform (5 dBZ) **coverage**
- **P3: Close to observations** at upper heights
- **P3: Unrealistic strong increase** of convective coverage below 3 km

Spatial distribution: Vertical



Low **Morrison** precipitation intensity

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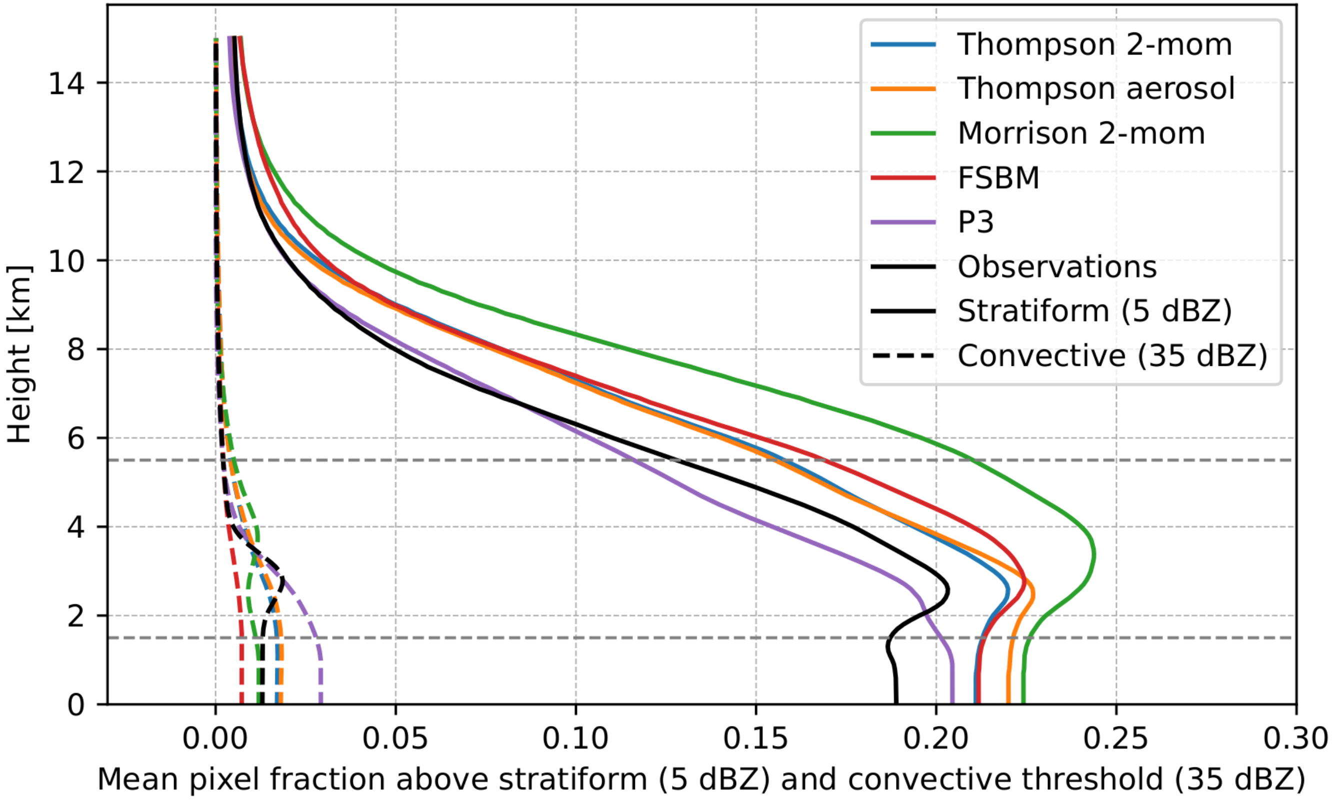

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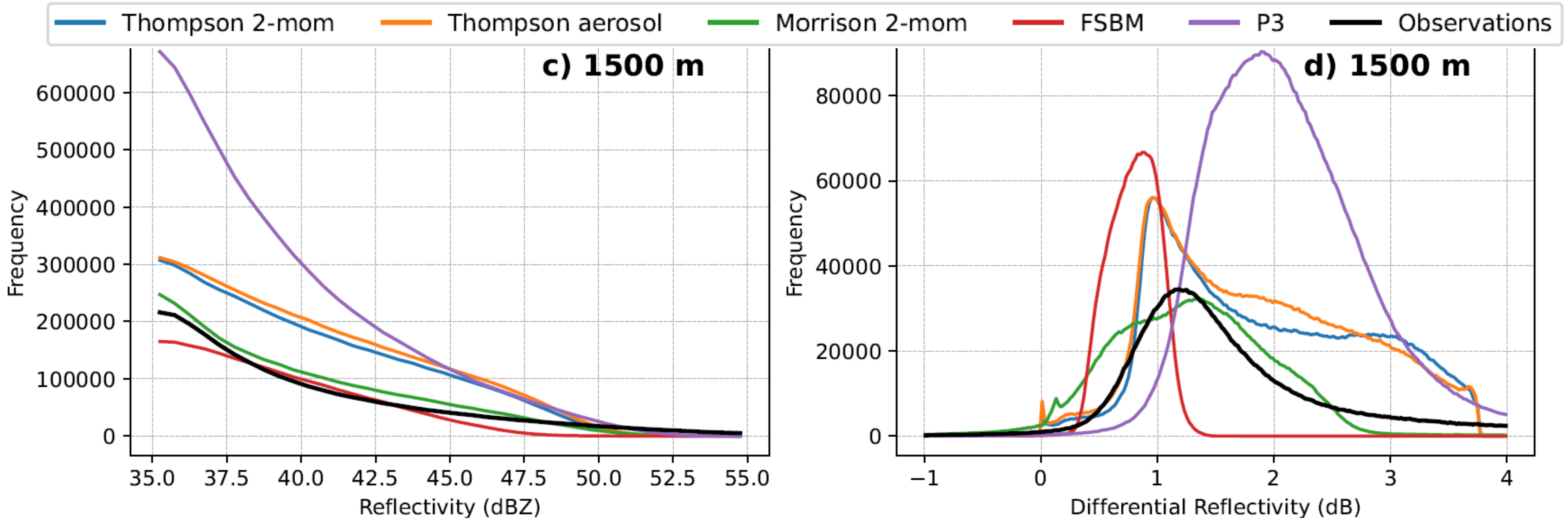
Low **Morrison** precipitation intensity

What is happening for **P3?**

Radar signals: Convective Core

Histograms of simulated and observed (differential) reflectivity



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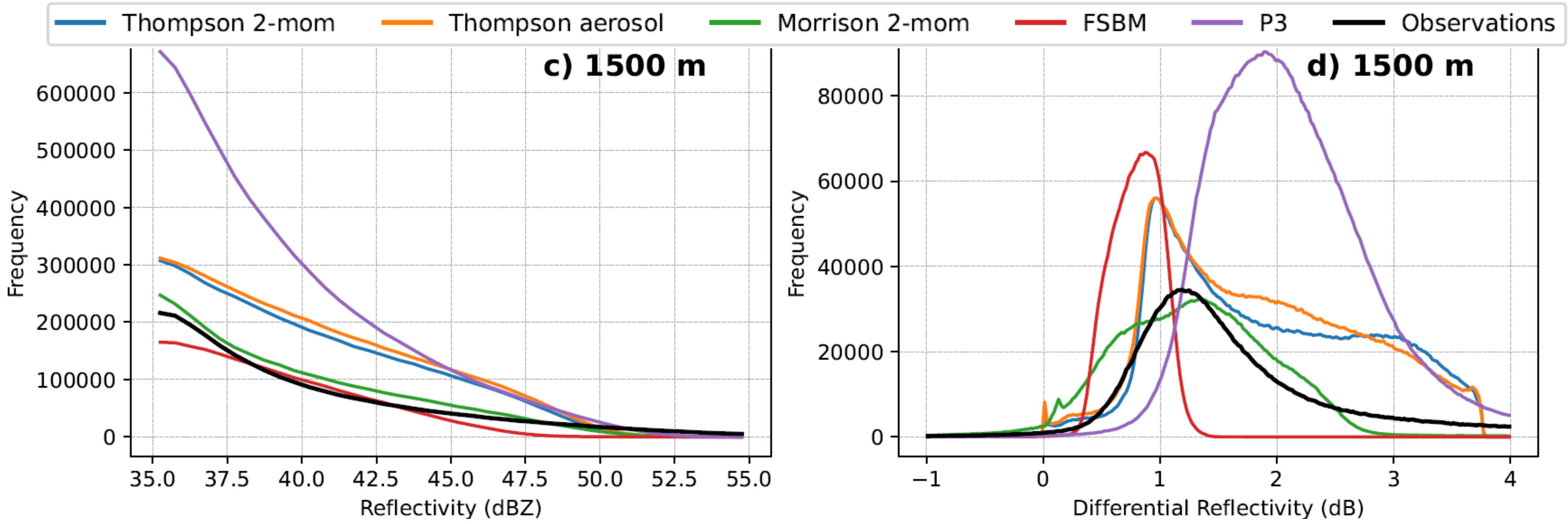

- Too **high ZDR** in **P3**
- Too **high Z** in **P3**

Radar signals: Convective Core

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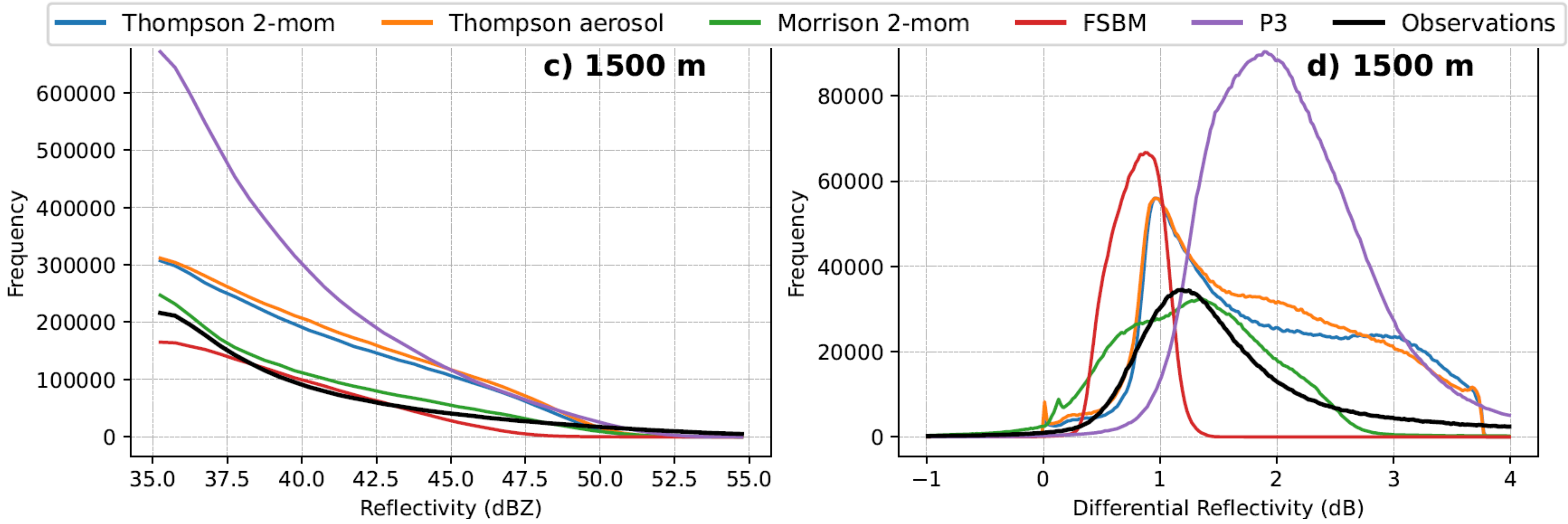

- Too **high ZDR** in **P3**
- Too **high Z** in **P3**

P3 rain drops too large!

Radar signals: Convective Core

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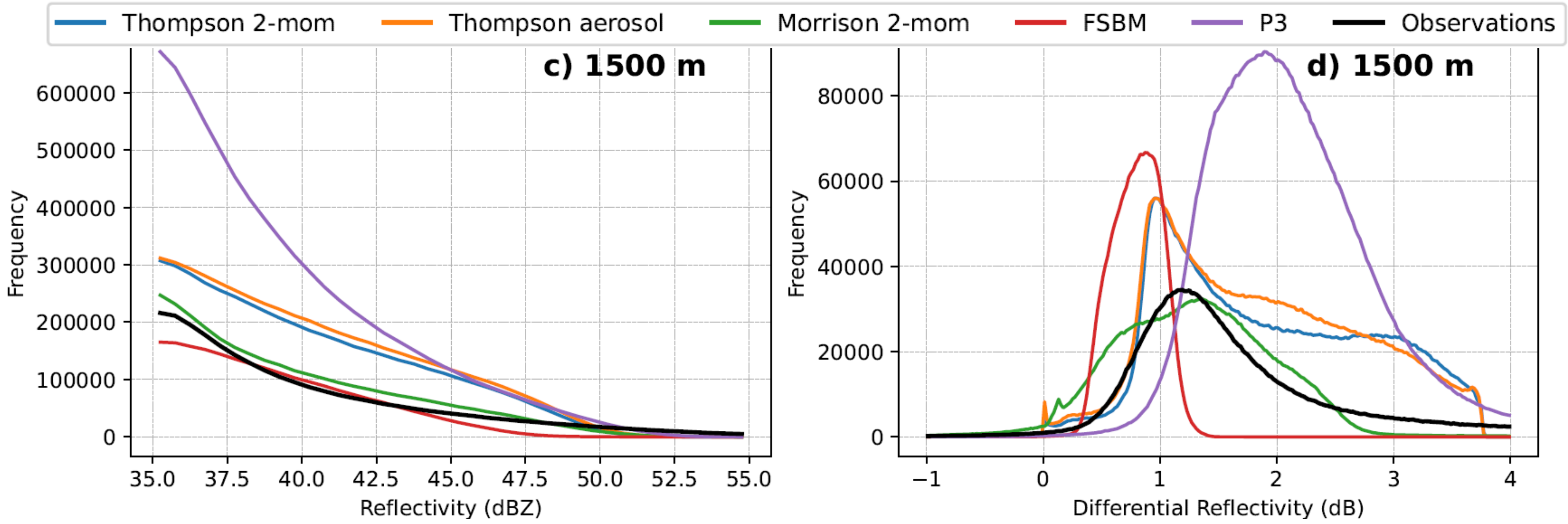

- Too **high (low) ZDR** in P3 (**FSBM**)
- Too **high (low) Z** in P3 (**FSBM**)

P3 rain drops too large!

FSBM rain drops too small!

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**)

Spatial distribution of precipitation

- **Too much convective coverage** in **P3** below 3 km
- **Morrison: Too much stratiform coverage** at all heights

Particle size distributions

- In convective core: **P3** produces **too large rain drops**
- In stratiform region: **Morrison** and **FSBM** **too small rain drops**

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

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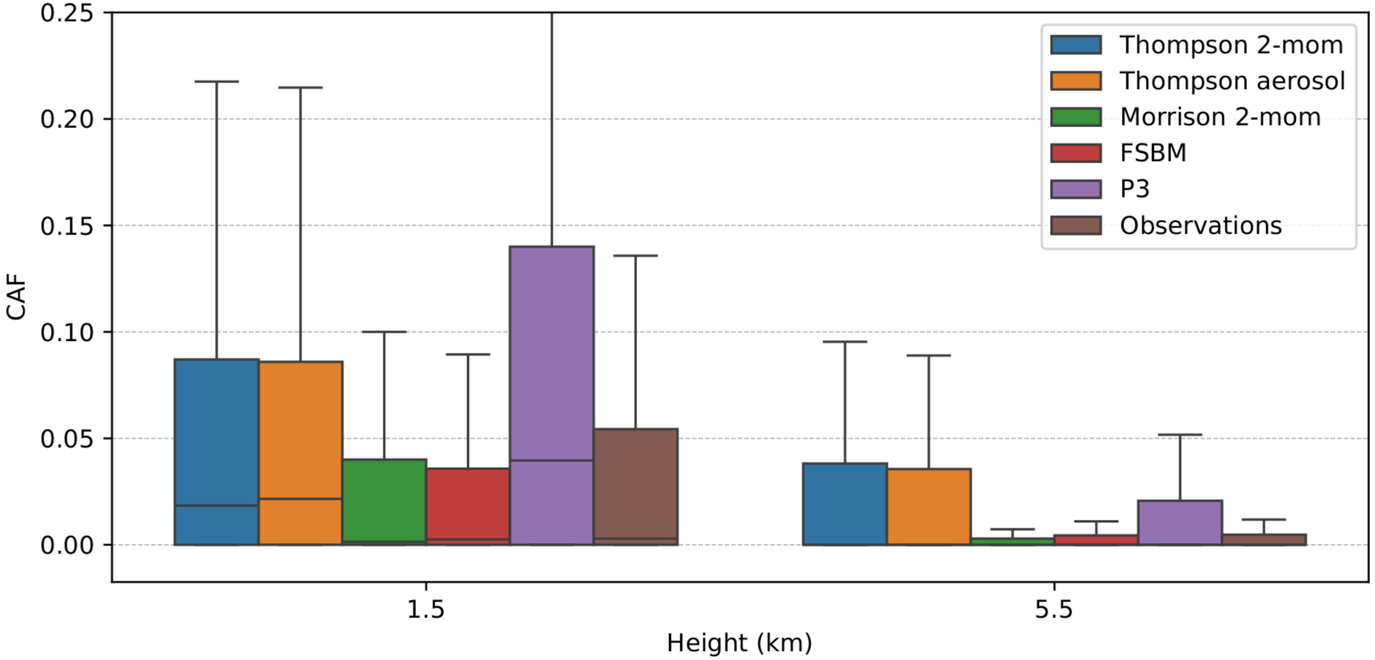
Spatial distribution: Horizontal

CAF (Convective Area Fraction)

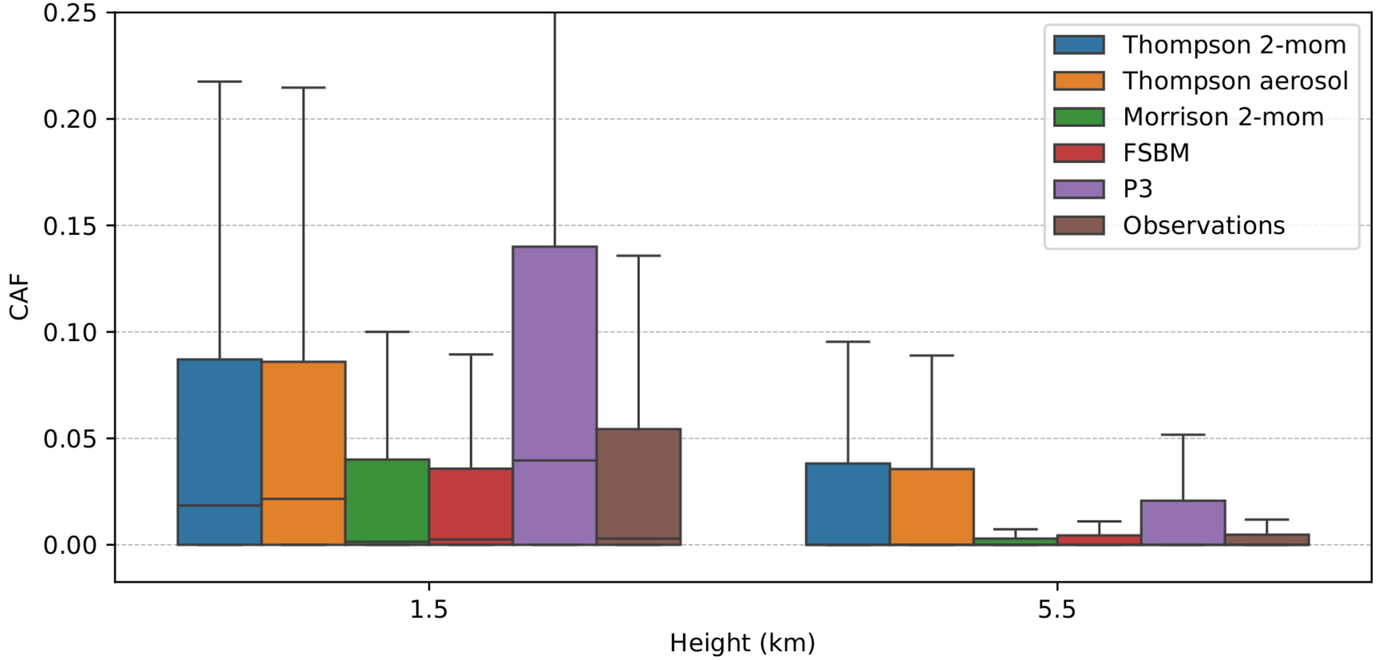


What do you see?

- Boxplots of **CAF** at **1.5** and **5.5 km** height
- Observations in **brown**, simulations in **color**

Spatial distribution: Horizontal

CAF (Convective Area Fraction)



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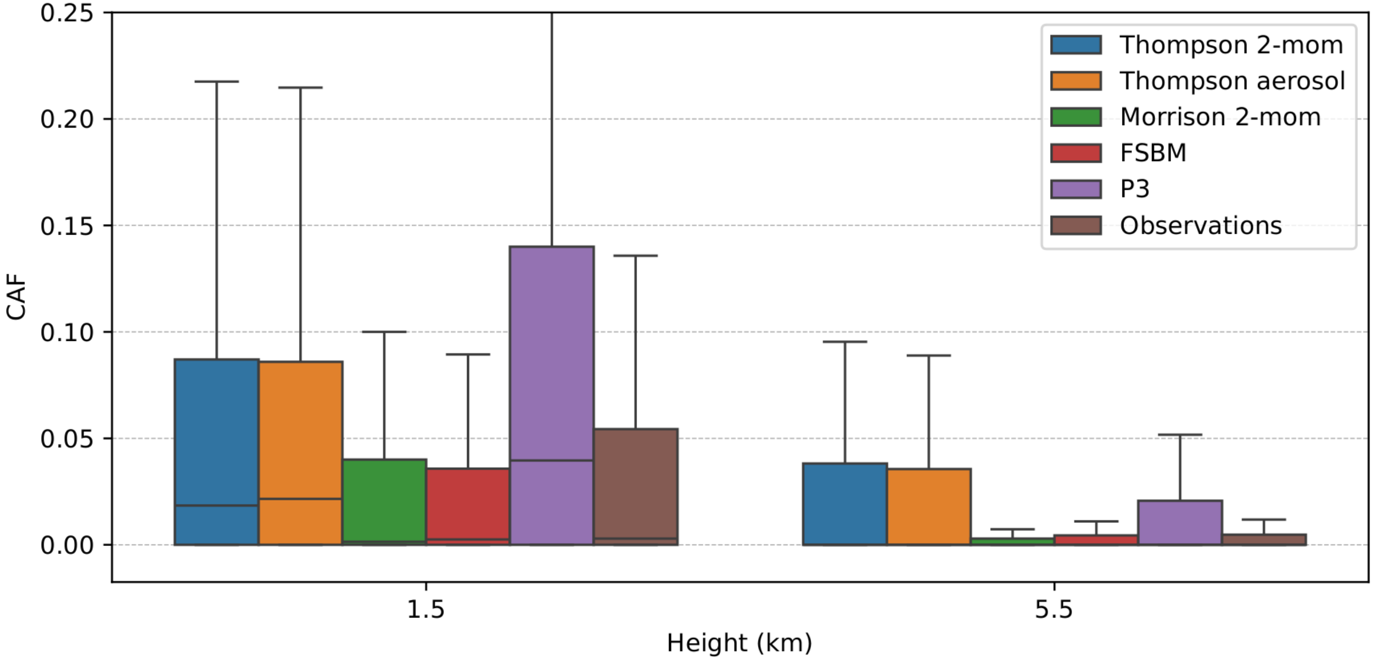
Microphysics

- **Two groups**: Smaller and larger median CAFs
- **Smaller** CAFs: **Morrison 2-mom**, **FSBM**, **radar observations**
- **Larger** CAFs: **Thompson 2-mom**, **Thompson aerosol**, **P3**

Spatial distribution: **Horizontal**

CAF (Convective Area Fraction)



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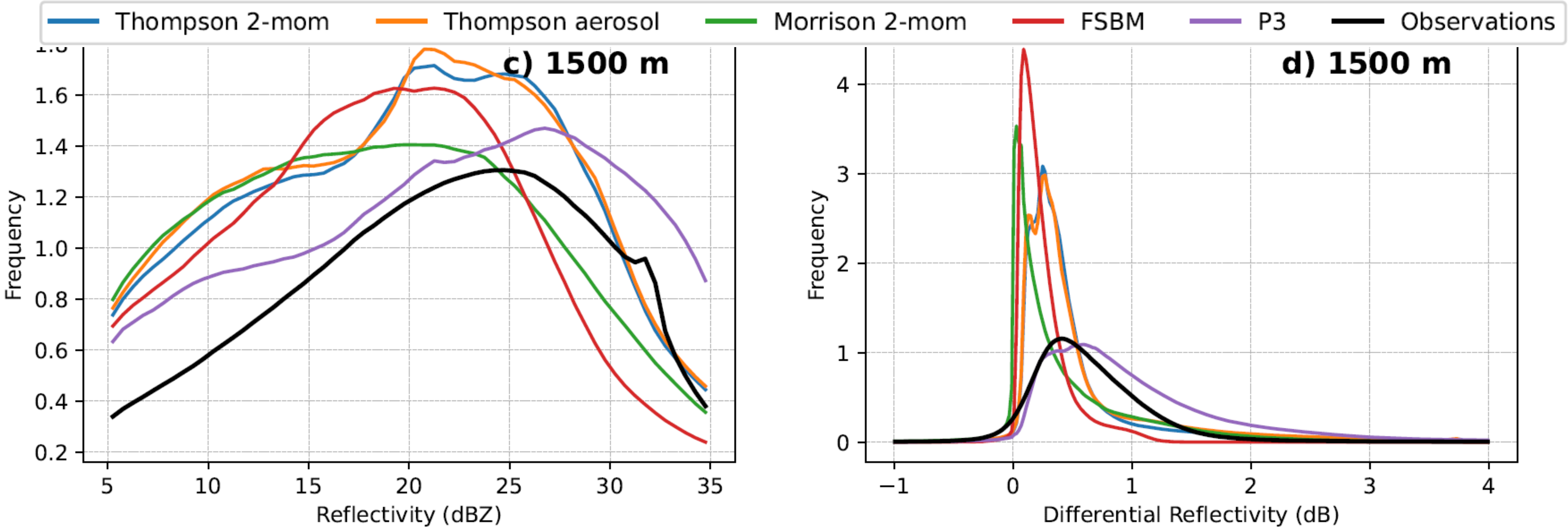
P3 much too high CAF at 1.5 km!

Radar signals: Stratiform

Histograms of simulated and observed (differential) reflectivity

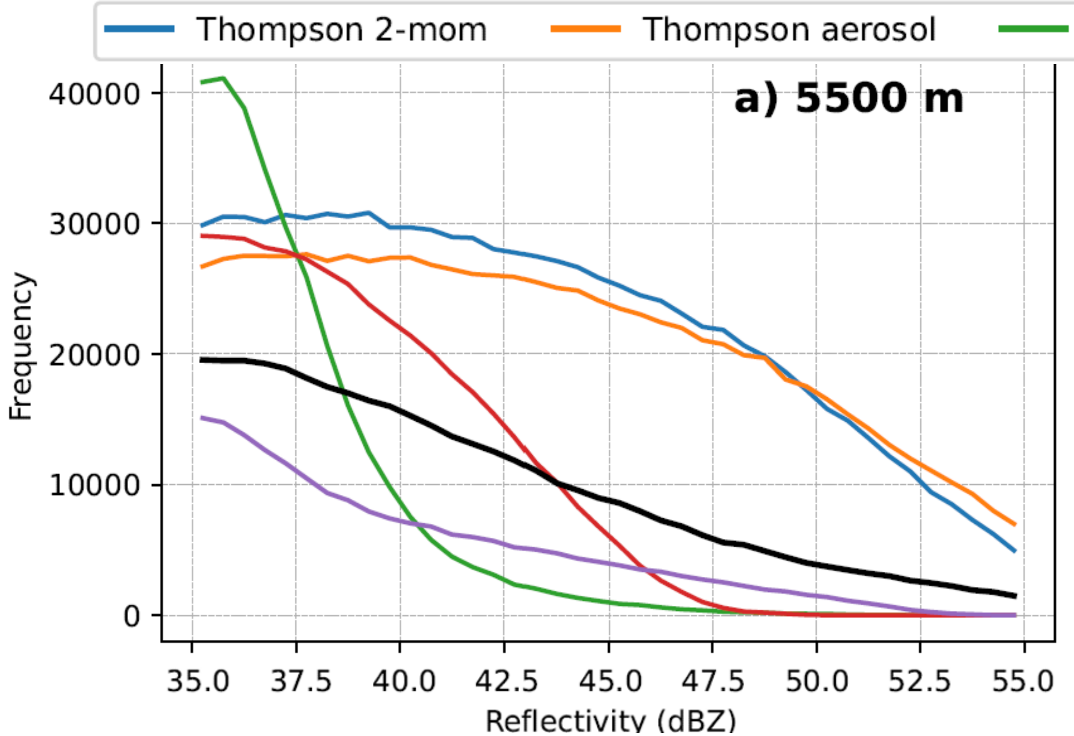


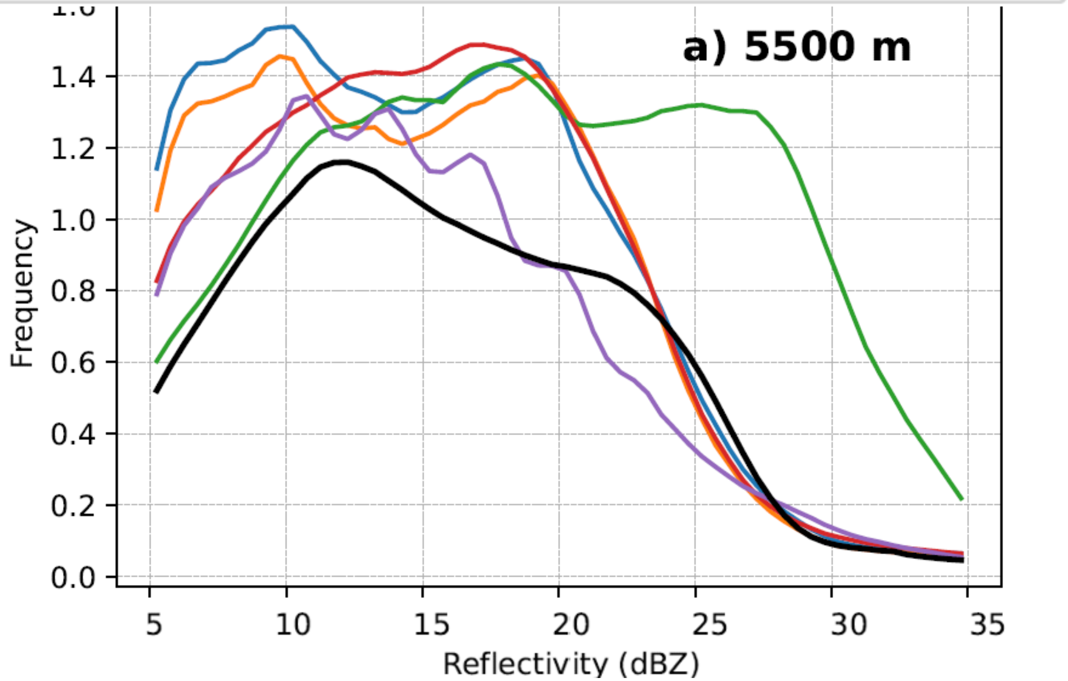
- **P3 ZDR fits** much **better** compared to convective cores
- All **other schemes** too **low ZDR**
- **FSBM** and **Morrison low Z bias**

Radar signals: ICE

Convective Core

Stratiform

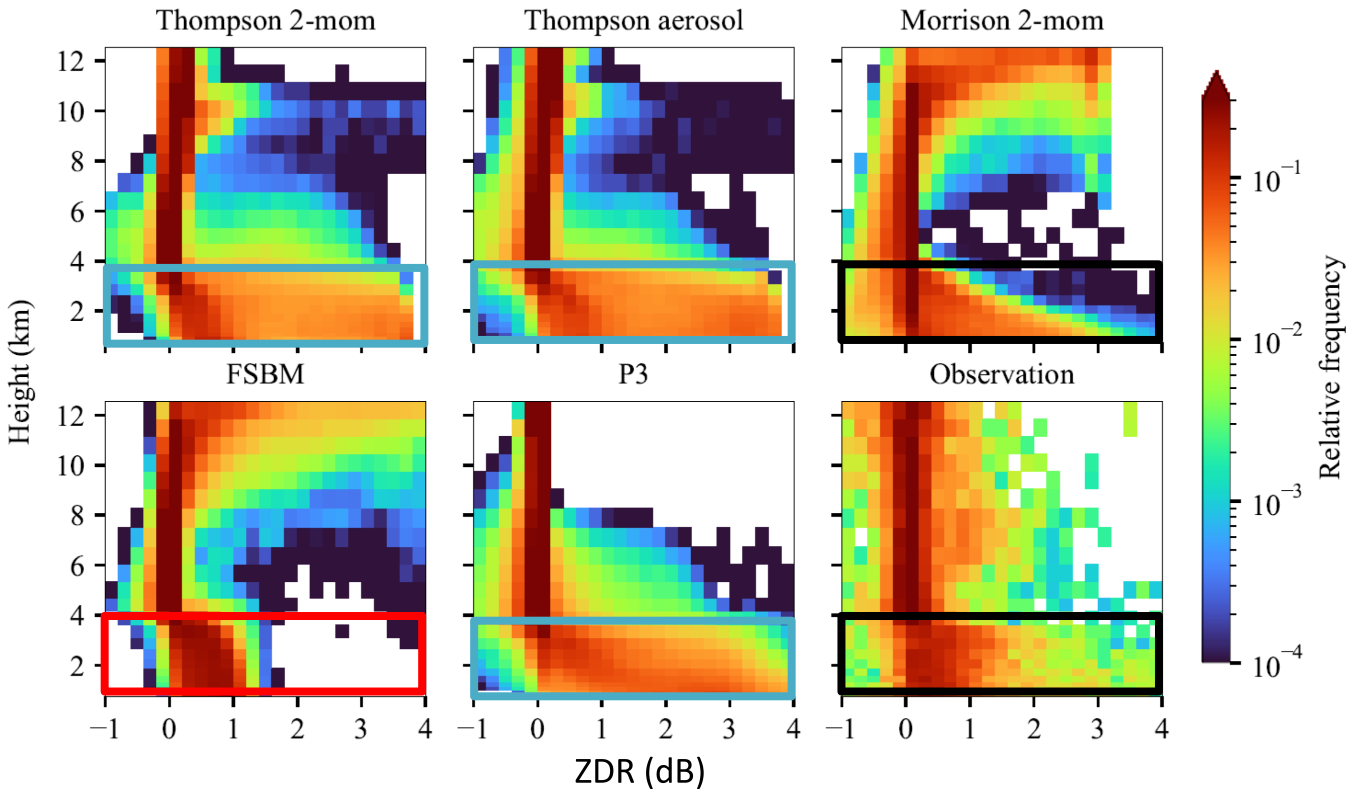




- **Low bias** in P3 → **Opposite** to **1.5 km**
- **High bias** in Thompson 2-mom and Thompson aerosol → **Same** as in **1.5 km**

- **High bias** in Morrison reflectivity
  → **Opposite** to **1.5 km** stratiform region

Statistical comparison of radar signals



Köcher et al. (2022), AMT

Differential reflectivity (ZDR)

- Sensitive to particle shape
- Proxy for size of rain

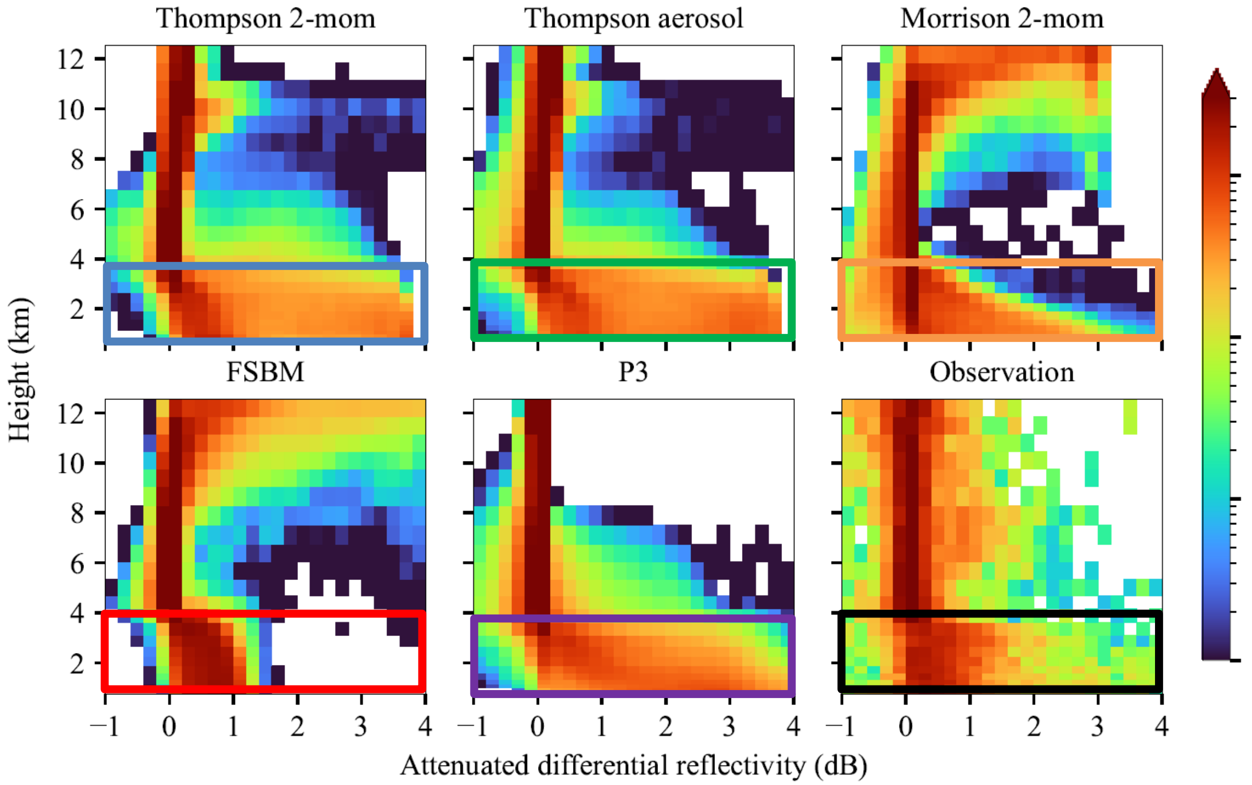
Most models

- Have too large ZDR spread
- Too many large drops

FSBM

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

Statistical comparison of radar signals



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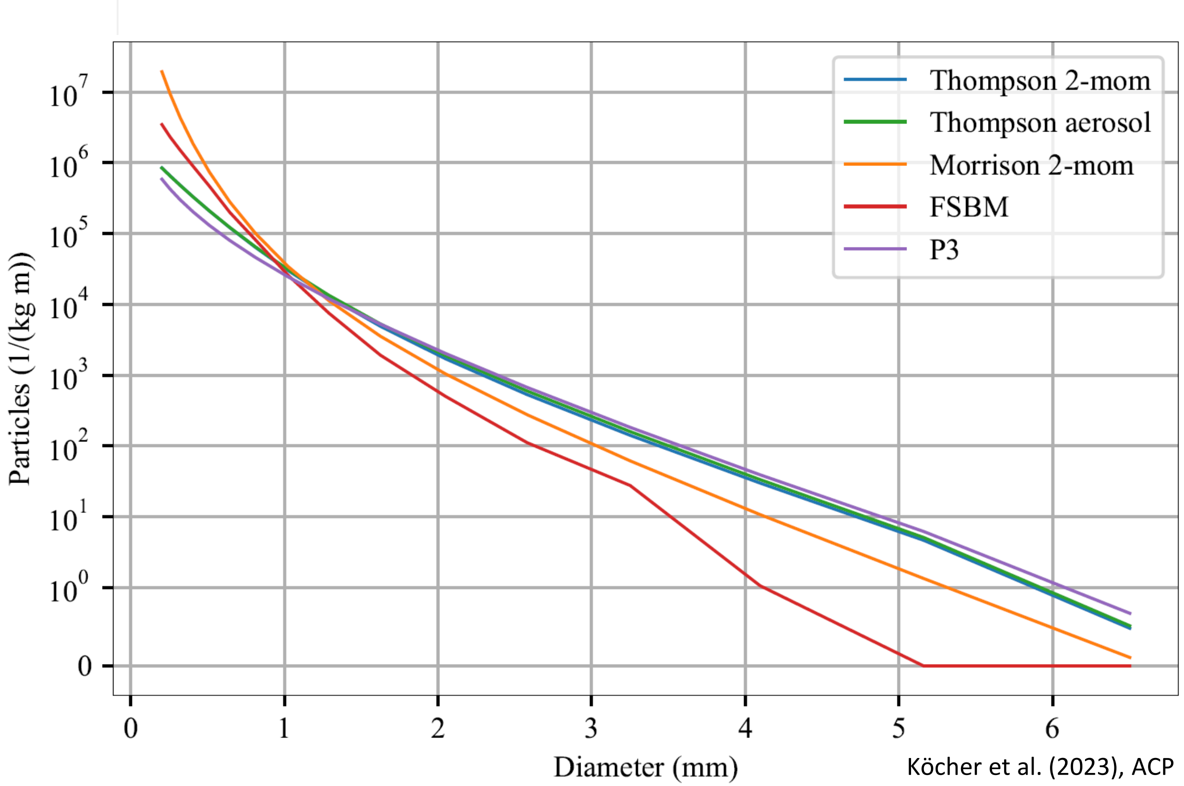
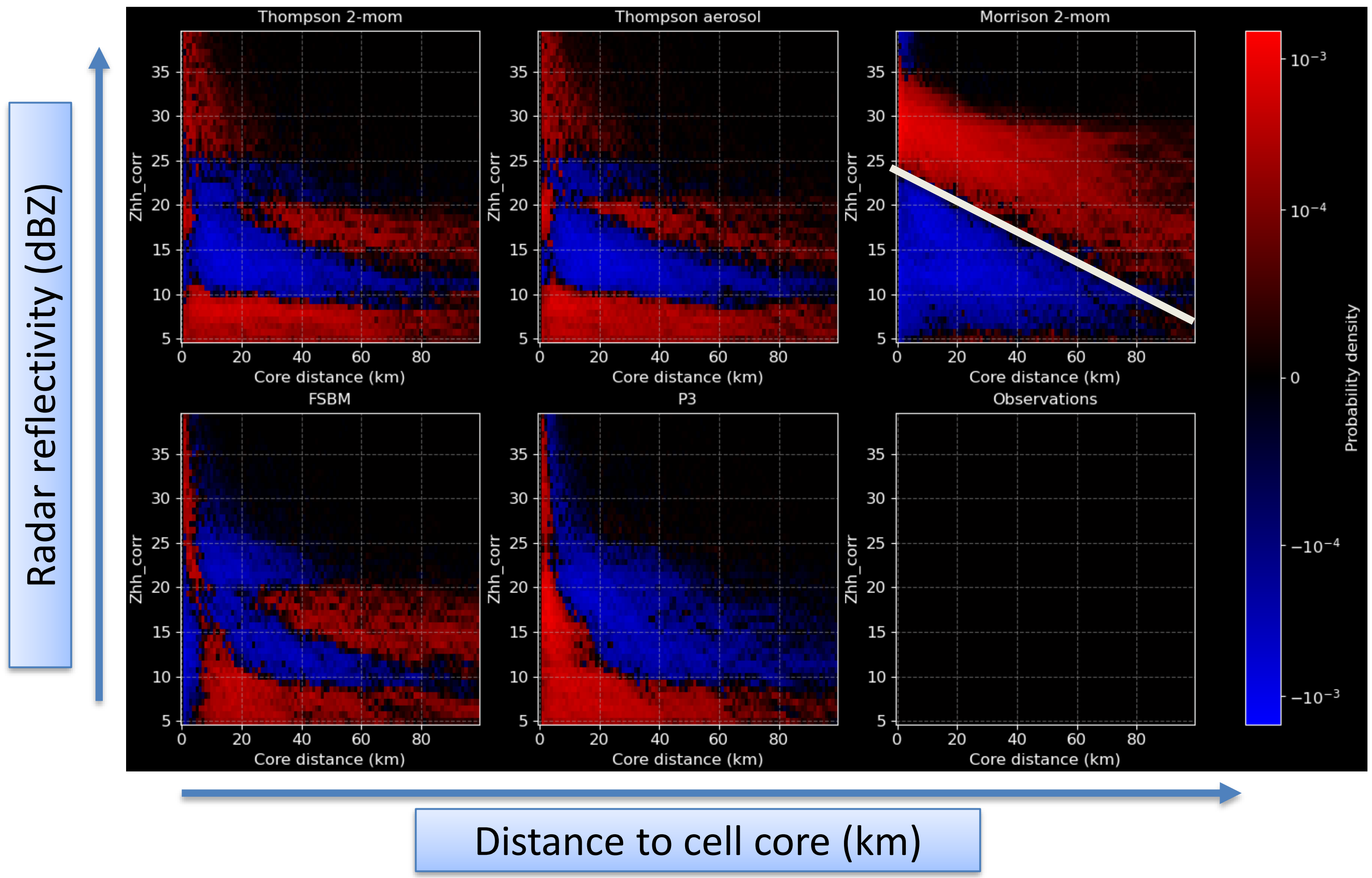


Köcher et al. (2023), ACP

Too few large rain drops!
In FSBM (and Morrison)

Towards spatio-temporal development



Height:
5.5 km

Variable:
Reflectivity

What do you see?

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

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