Operation Hydrometeors I+II

–

The DWD contribution:
Polarimetric radar operator & Numerical modelling

Kobra Khosravian, Jana Mendrok, Ulrich Blahak
Deutscher Wetterdienst

Operation Hydrometeors

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Wetter und Klima aus einer Hand

- Phase 1:

  „An efficient volume scan polarimetric radar forward **OPERA**tor to **improve the representaTION of HYDROMETEORS** in the COSMO model"

- Phase 2:

  „Synergy of an efficient polarimetric radar **OPERA**tor and advanced classification to **improve the representaTION of HYDROMETEORS** in the ICON model"

Outline

➔ [Jana] Phase 1 summary:

- Polarimetric radar operator EMVORADO: Status
- Polarimetric radar based ICON/COSMO evaluation: Results

➔ [Kobra] Phase 2:

- New (2-mom ICON) microphysics
- Outlook

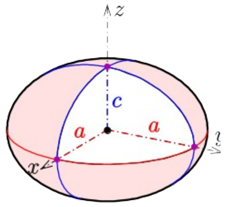
Polarimetric radar operator: Status summary

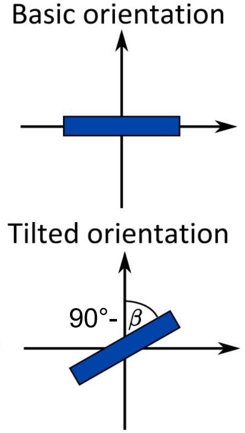
- Approach: add polarimetry to EMVORADO, but **keep existing core features & characteristics**
  - consistent model coupling, sensor (network) modelling
  - hydrometeor property assumptions (e.g. morphology, melting state)
  - speed (→bulk scattering lookup-tables)

Polarimetric radar operator: Status summary

- Approach: add polarimetry to EMVORADO, but **keep existing core features & characteristics**
  - consistent model coupling, sensor (network) modelling
  - hydrometeor property assumptions (e.g. hydrometeor morphology & melting state)
  - speed (→bulk scattering lookup-tables)
- Added scattering model option: **T-Matrix + angular moments**
  - **default:** shape (AR), orientation (σ_β), melt fraction dependence from **Ryzhkov et al. (2011)**

liquid	rain	ice	snow	graupel, hail	
Rayleigh	oblate spheroids	oblate spheroids	oblate spheroids	oblate spheroids	shape
-	Brandes (2002) f(deg4-in-D)	Matrosov (1996) thick plates aD^b	1.0-0.02*D 0.8 (D>10mm)	1.0-0.02*D 0.8 (D>10mm)	AR
-	10°	10°	40°	40°	σ_β
-	-	both: lin. in f_m to rain	both: lin in f_m to rain	AR: lin. in f_m between AR_{wet}=[AR_{dry},0.8,0.48,AR_{rain}] for f_m=[0,0.2,0.8,1] σ: lin. in f_m to rain	melting behaviour (f_m=mass melt fraction)



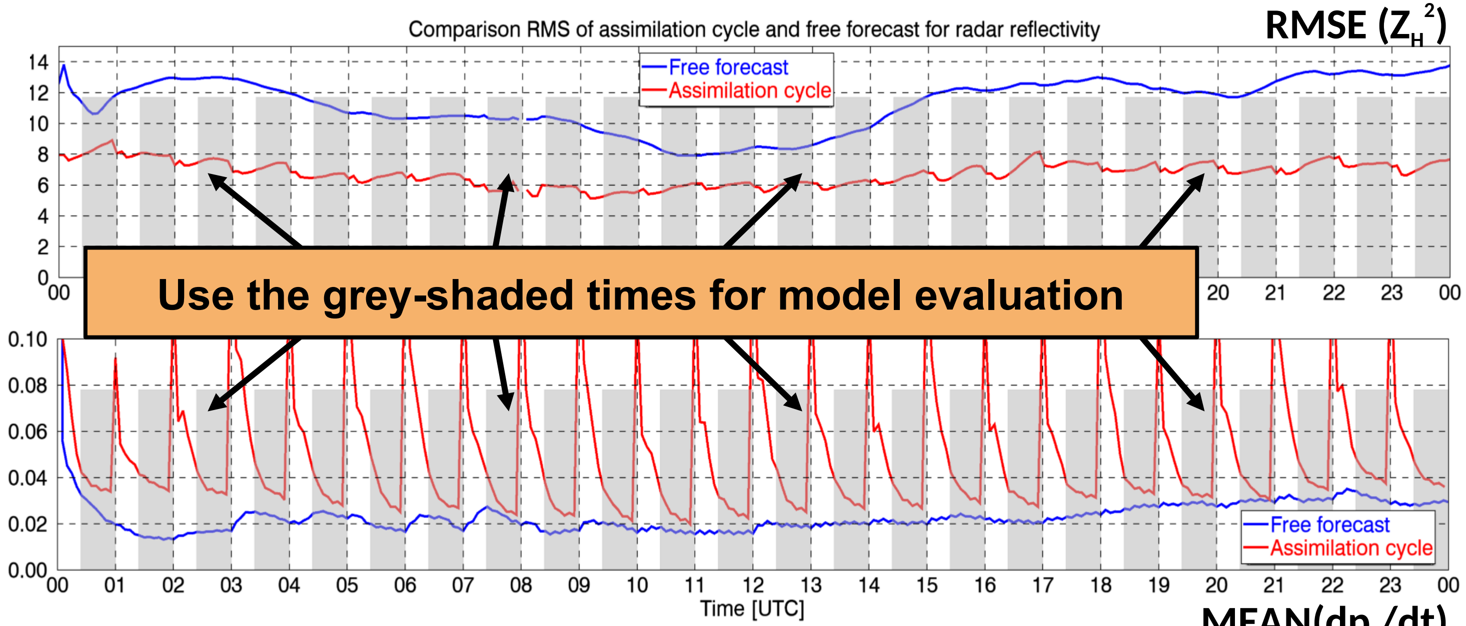


Model evaluation: Method I [skip]

- ➔ Model data best suitable for comparison/evaluation
  - Represent the weather situation
    - match in space & time
  - Options:
    - (long-running) free forecasts
      + model characteristics
      - model-reality divergence
    - frequent **data assimilation**
      + better model-reality agreement
      - model-inconsistent DA states
- ➔ (our) Solution:
    - frequent DA (1h), but avoid spin-up time range (~20min)
      - data gaps :-/

= measure of model-reality match

RMSE (Z_H^2)



MEAN(dp_s/dt)

= measure of model „imbalance“

Model evaluation: Method II [skip]

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➔ Model data best suitable for comparison/evaluation

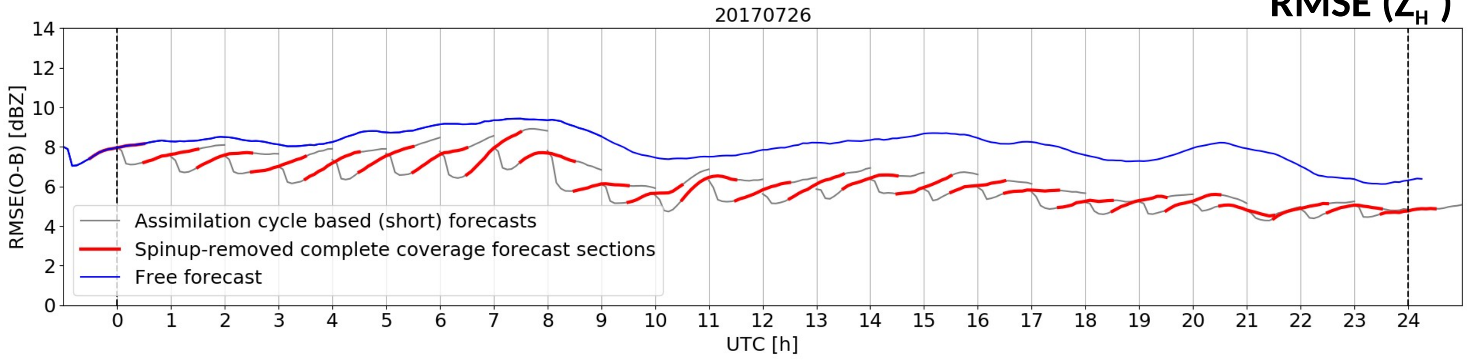
- Represent the weather situation
  - match in space & time
- Options:
  - (long-running) free forecasts
    + model characteristics
    - model-reality divergence
  - frequent **data assimilation**
    + better model-reality agreement
    - model-inconsistent DA states

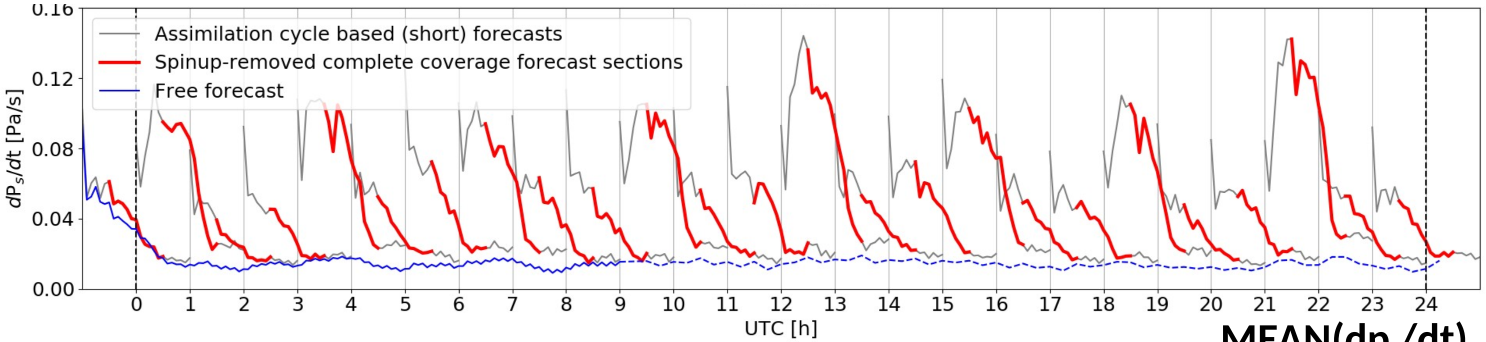
➔ (our final) Solution:

- hybrid: 1h-DA + 2h forecasts & use non-overlapping 1h-sections (e.g. min30-90)
  + model-consistent
  + gap-free
  - discontinuous
- all together 10 case days (5conv + 4strat + 1mixed)
  - precip & volume scans of DWD‘s 17-station C-band radar network

= measure of model-reality match

RMSE (Z_H^2)





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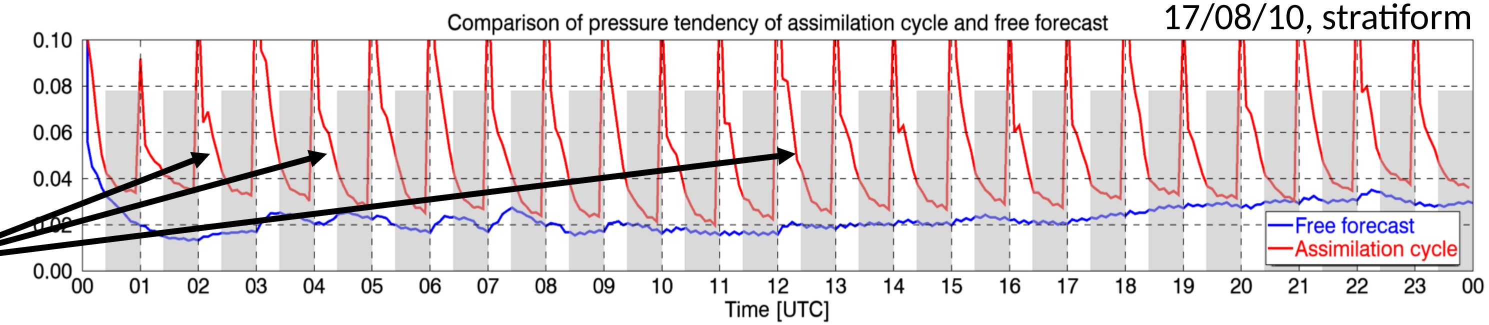
Example: 17/07/26, stratiform

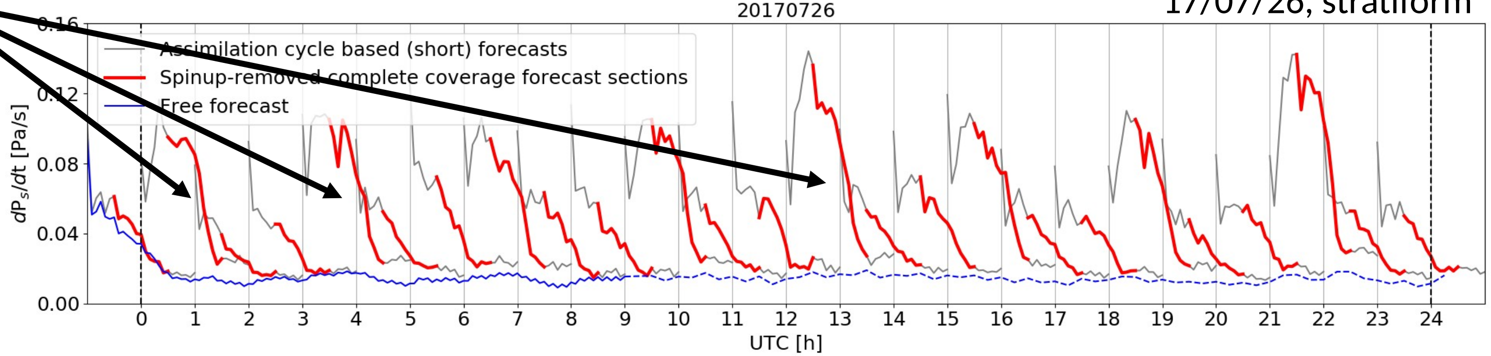
Model evaluation: Method III – spinup issues [skip]

17/08/10, stratiform



Why are the spinup times so different?

17/07/26, stratiform



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→ Boundary conditions: (upper boundary) nudging

- asimilation mode: w/ nudging
- forecast mode: no nudging

Upper boundary nudging requires a lot more data to be kept for subsequent time steps.

→ We keep(?) as (quasi-)operationally done, ie as shown above.

Model evaluation: Results I – Case studies

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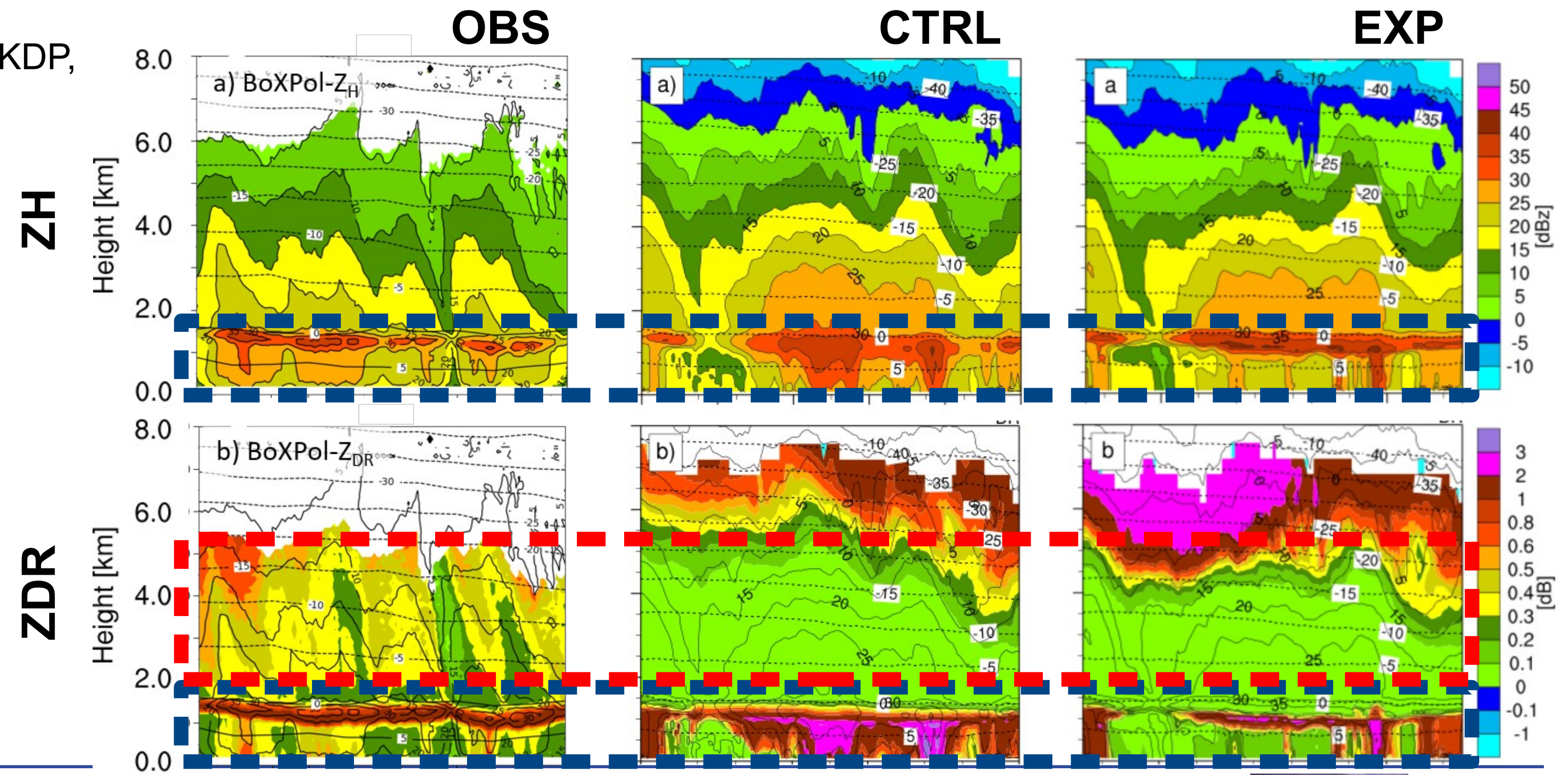
➔ Obs: **Quasi-Vertical Profiles** (QVP) of stratiform event by the Bonn polarimetric X-band radar

➔ Model: COSMO **2-mom microphysics**, free forecast
EXP: w/ modifications of T_{gr} and D_{ice}

➔ FO: stratiform-tuned setup case (melting scheme)

Shrestha et al., 2022

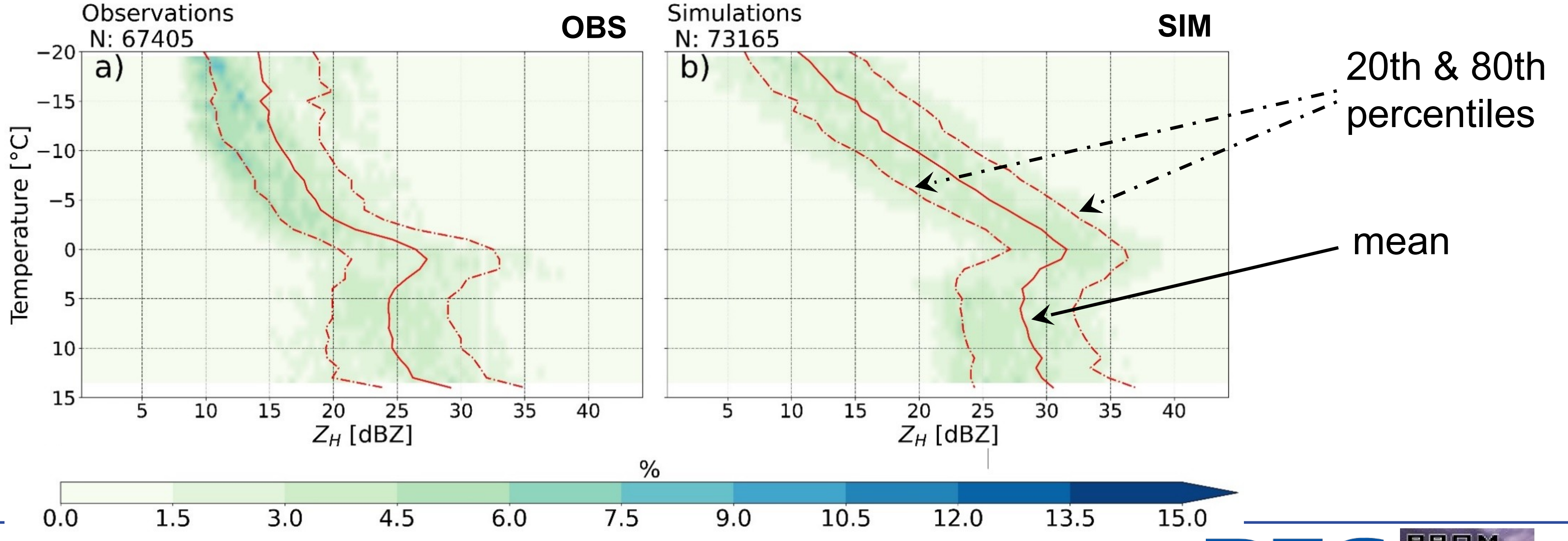
- **above ML: lack of pol. signals** (also KDP, RHV)
  - ice-snow-partitioning? lack of secondary ice?
    → mod. D_{ice}: **inconclusive**
  - **FO assumption on**
    - (snow) shape & orientation?
    - **(snow) morphology**
- **below ML: high ZH and ZDR**
  - signat. from melting graupel
  - resulting from **too much & too large graupel** in general
    → mod. T_{gr}: **O-B improved**



Model evaluation: Results II – Polarimetric radar statistics

➔ Statistics of **stratiform events from 10 case days** of (dominantly) stratiform and convective weather in summer/fall of 2017 and 2018

- Obs: **QVPs** (12°) from entire DWD C-band network, indiv. filtered for stratiformity (→ Scharbach) **summarized into** Contoured Frequency Temperature Diagrams (**CFTD**)
- Model: ICON-D2 w/ **2-mom microphysics & adapted T_{gr}**
  min30-90 forecasts from hourly assimilation of synop. and radar data
- FO: (quasi-)operational RUC/SINFONY setup



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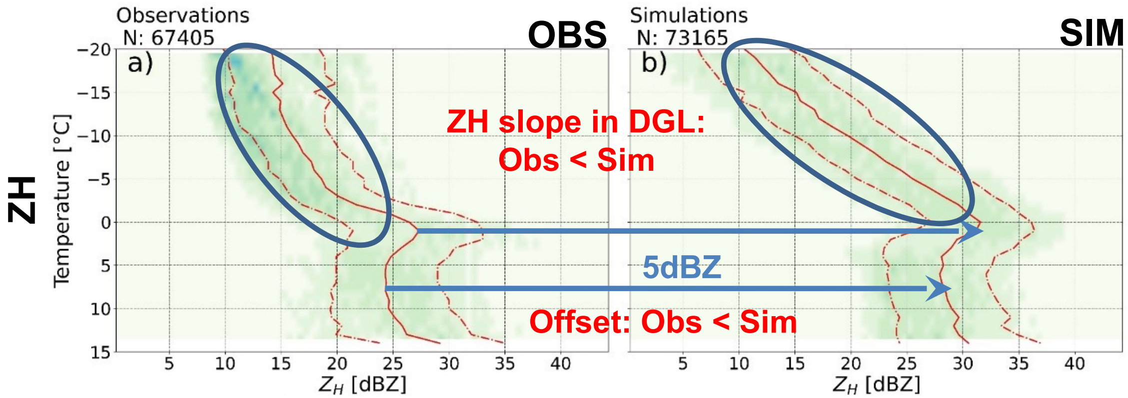
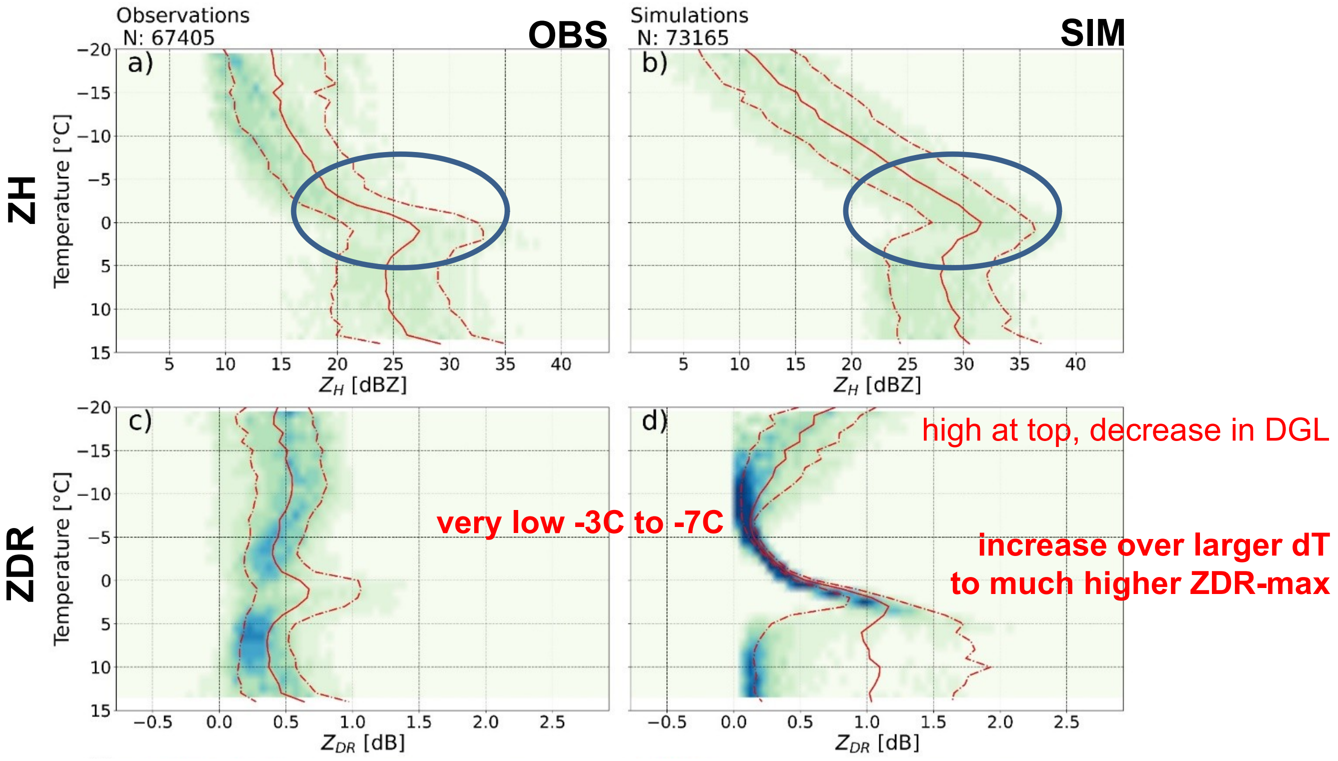


higher ZH slope in SIM suggestive of too few, but too large (and fast growing) hydrometeors

(too much and too large) graupel present even after T_{gr} adjustment

presence of graupel as such might be (one of the) reason(s) for ZH offset otherwise **ZH below ML quite okay**

Model evaluation: Results II – Polarimetric radar statistics



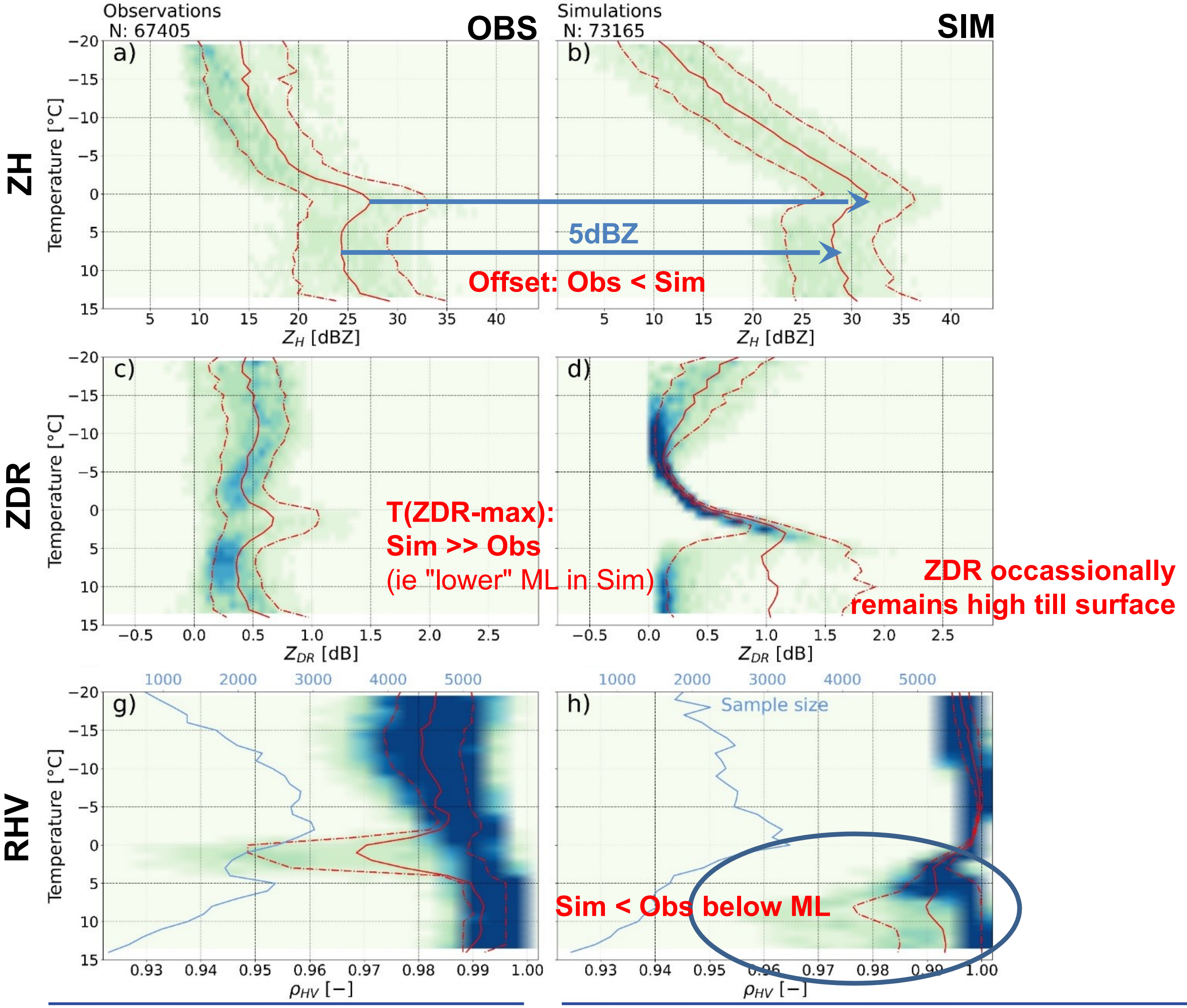
(too much and too large) graupel present
even after T_{gr} adjustment

FO allows graupel to be „wet“ at T<0C
(ie above ML)

causes smooth transition of scatt. properties
(e.g. ZH-, ZDR-) over large T-range:
"smeared out" brightband

responsible for entire ZDR enhancement
at T<0C
makes up–to some degree–for the lack
in snow ZDR

Model evaluation: Results II – Polarimetric radar statistics



(too much and too large) graupel present

"surviving" to quite high temperatures in model **(below ML)**

FO sets melt fraction to reach 1.0 (all liquid) at highest graupel T even for large sizes

shape (and orientation) transitions to rain equivalents with increasing melt fraction

ie, FO melting scheme and FO shape parametrization make **graupel** at high(er) T **appear as (super-)large raindrops**

large & very unspherical: **large ZDR**

mix of (fully & partly) melted graupel and actual rain = increased diversity in particle "appearance": **low RHV**

Phase 1 summary

- EMVORADO extended to state-of-the-art polarimetric radar FO
- Evaluation of COSMO/ICON w/ 2-moment microphysics:
  - Polarimetric signatures above ML missing: snow morphology → PRISTINE
  - Excessive graupel production
    - mitigated (only) to certain degree by adjustment of T_{gr}
    - spotlighted in polarimetric parameters by EMVORADO melting scheme
      - above-ML "wetting"
      - below-ML apparent "superdrops"

Outline

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➔ **[Kobra] Phase 2:**

- New (2-mom ICON) microphysics
- Outlook

Some of the main problems in the old settings

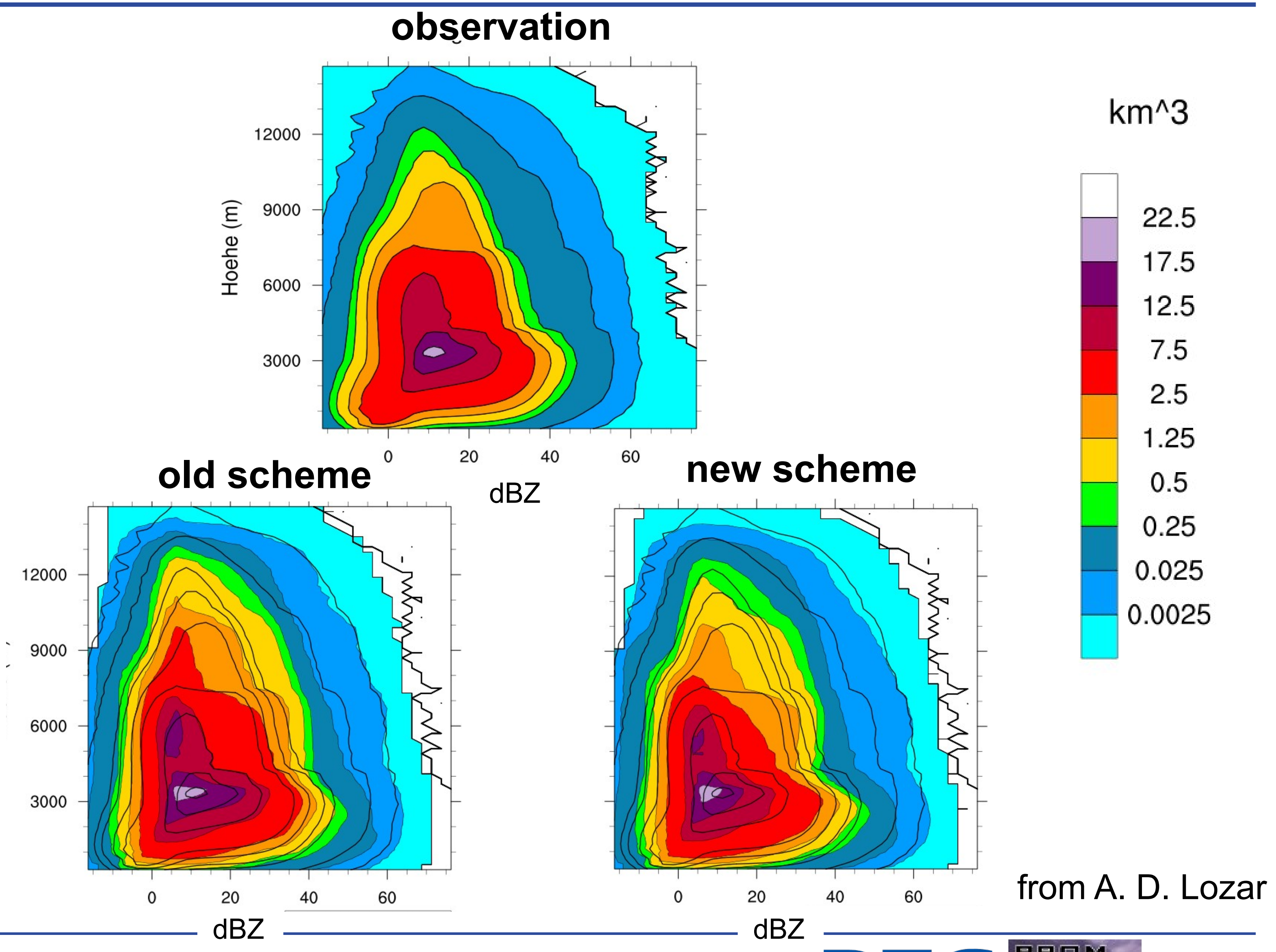
- ➔ Overestimation in simulated radar reflectivity compared to the observed reflectivity particularly for the higher thresholds in convective cases
- ➔ The lower/worse verification scores in the winter time (for both reflectivity and precipitation) since the model has been never tuned (such as tuning of snow microphysics) for the winter time.
- ➔ Delay in the convection initiation as well as missing of convective cases (rarely happens)
- ➔ Higher reflectivity but lower precipitation probably due to the not well-defined Z-R relation

Study the effect of new defined microphysics in ICON

on forecasted output (reflectivity) in the experiment without data assimilation (hindcast exp.)

Main changs in new scheme:

- **Reduced collision efficiency of graupel by 50%.**
- Faster graupel velocity according to Heims et al.
- Graupel can form for T > -3
- Lower limit of Connley et al. for snow sticking efficiency.
- Reduced Snow velocity (similar to M. Karrer)
- Increased collisions for wet graupel (T>-3)



from A. D. Lozar

Study the effect of new defined microphysics in ICON

on forecasted output (reflectivity and precipitation) in the experiment with data assimilation

Running long-term experiments to comparison between old and new scheme:

settings of experiment:

- ✓ICON-D2 with **2-mom** microphysics
- ✓Assimilation of **3D radar data** and conventional observation (such as Radio soundings (**TEMP**), Aircraft measurements (**AIREP**), **SYNOP** stations, **Wind profile**, **BUOY**) + **LHN**
- ✓Run the forecast cycles for every **3h** with the **lead time of 12h**

Study the effect of new defined microphysics in ICON
on forecasted output (reflectivity and precipitation) in the experiment with data assimilation

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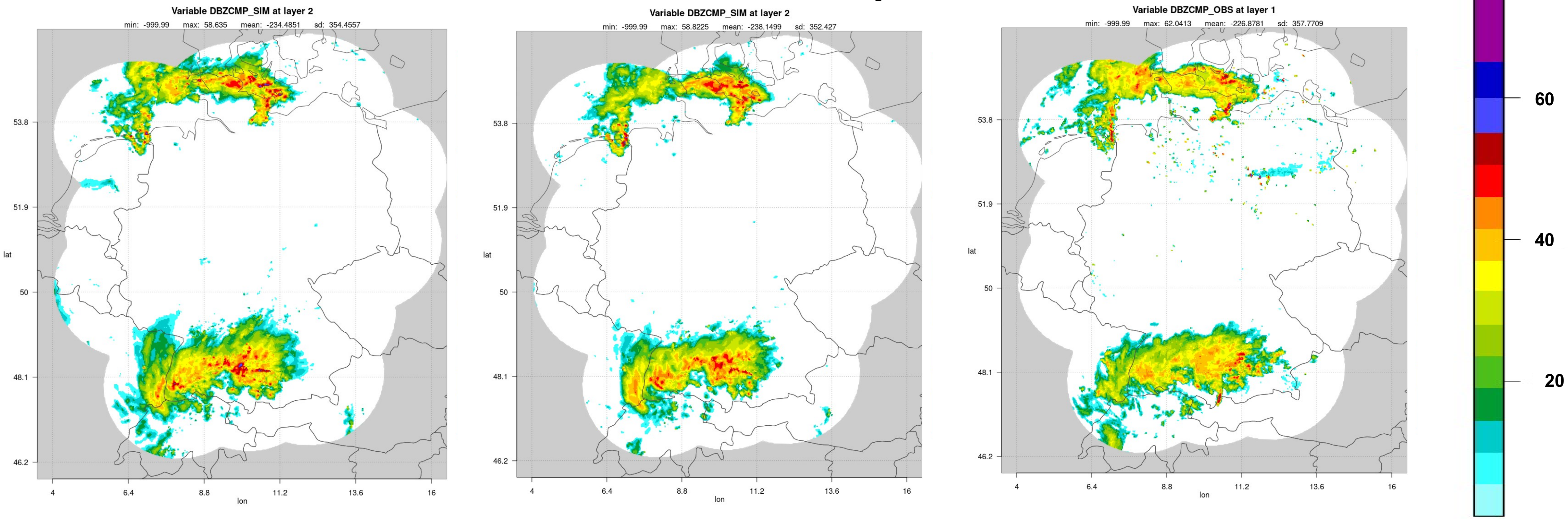
→ Winter time **02 until 13 Dec 2022**

→ Summer time **16 Aug until 04 Sep 2022**

✓Run the forecast cycles for every **3h** with the **lead time of 12h**

Reflectivity (ZH) plots
composite plot from German radar network of elevation 0.5°

old scheme Simulated reflectivity | **new scheme Simulated reflectivity** | **observation**



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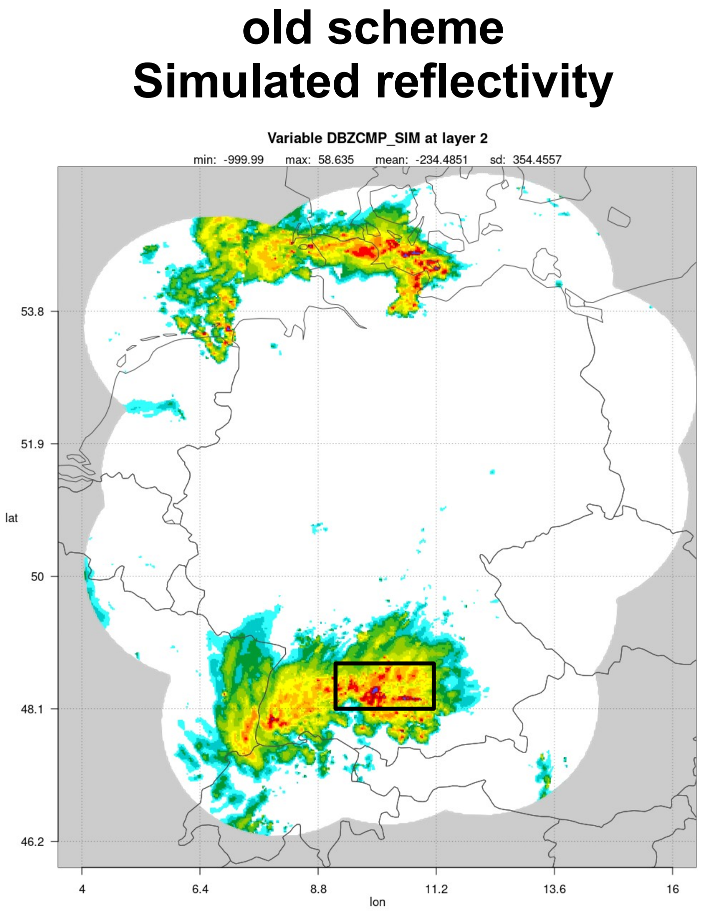

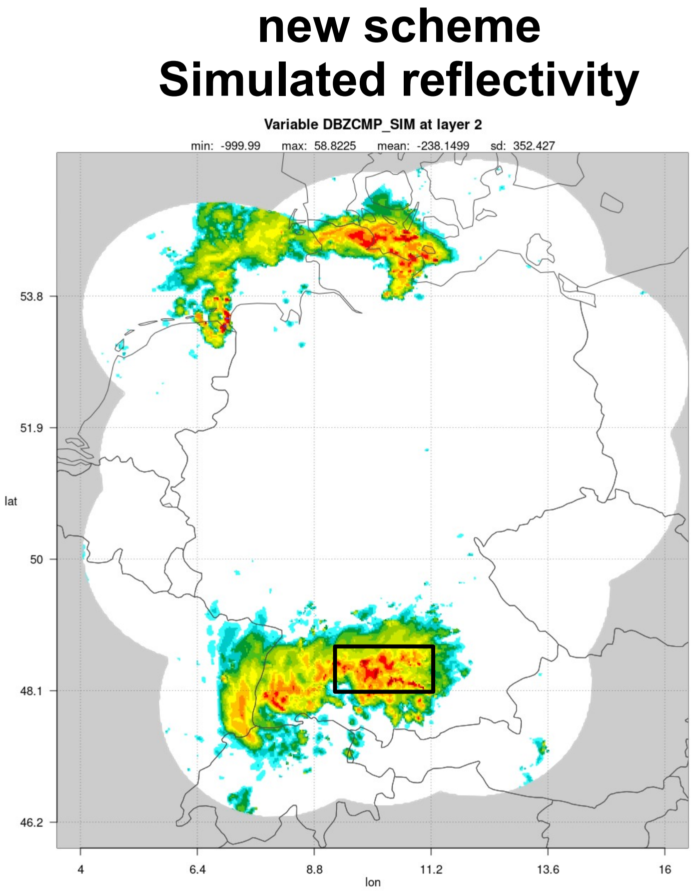

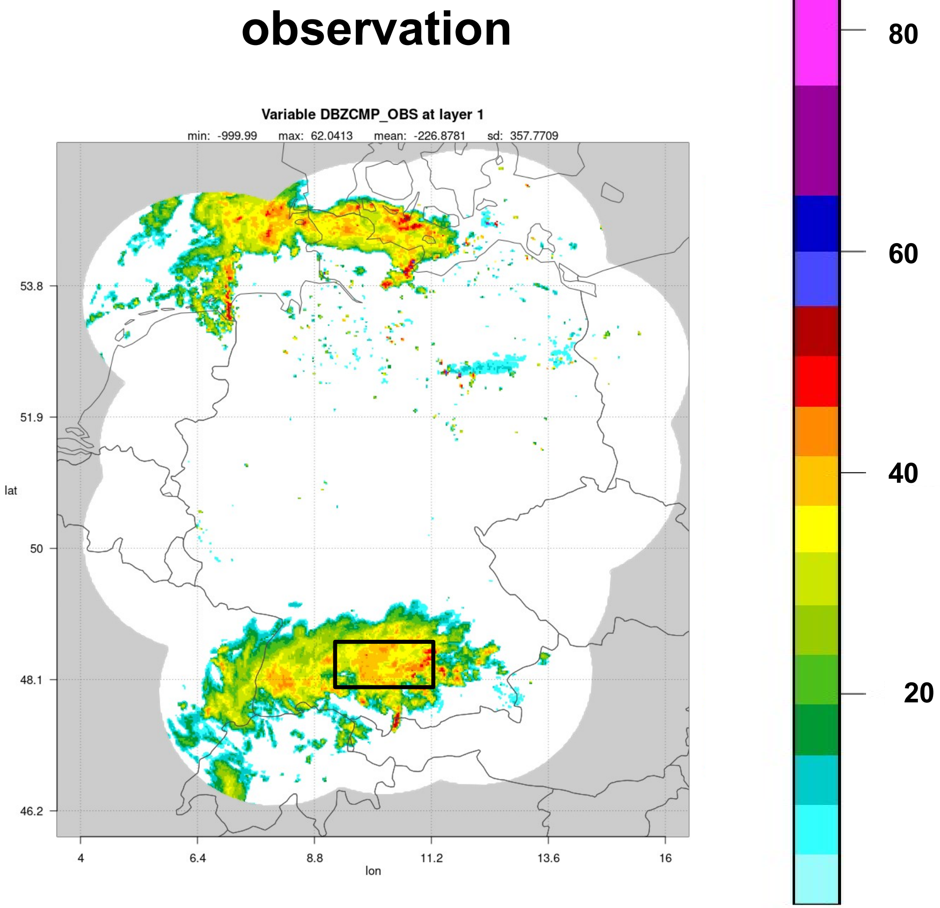

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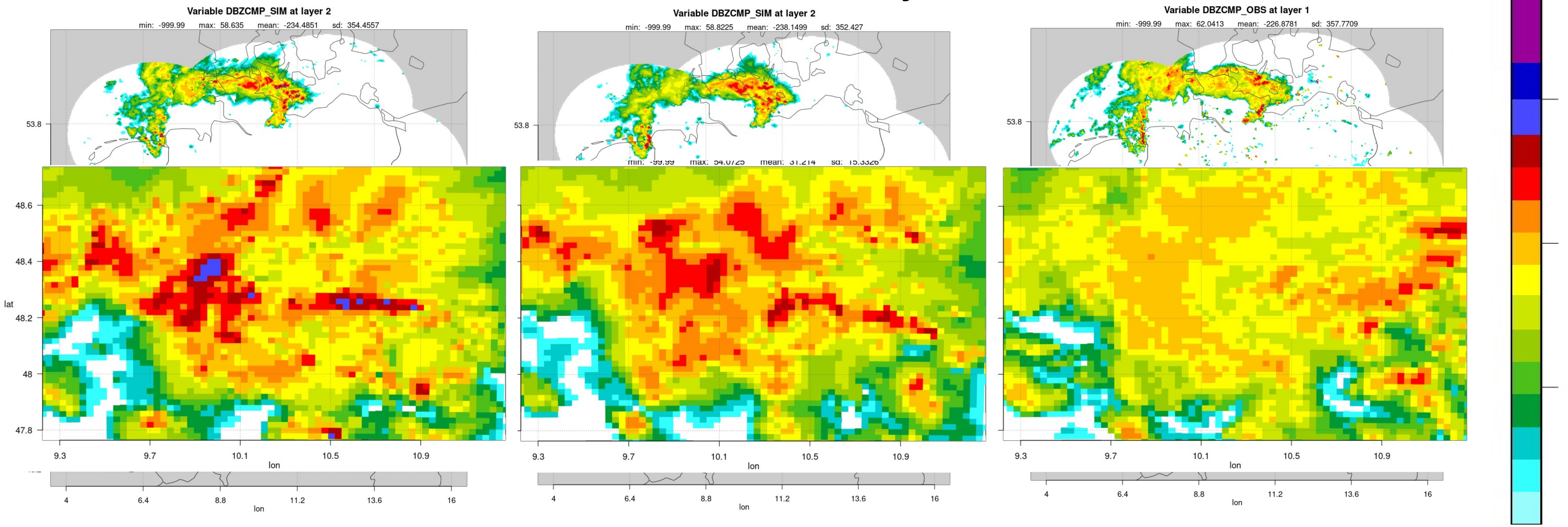
old scheme Simulated reflectivity | **new scheme Simulated reflectivity** | **observation**



PROM SPP 2115

Reflectivity (ZH) plots
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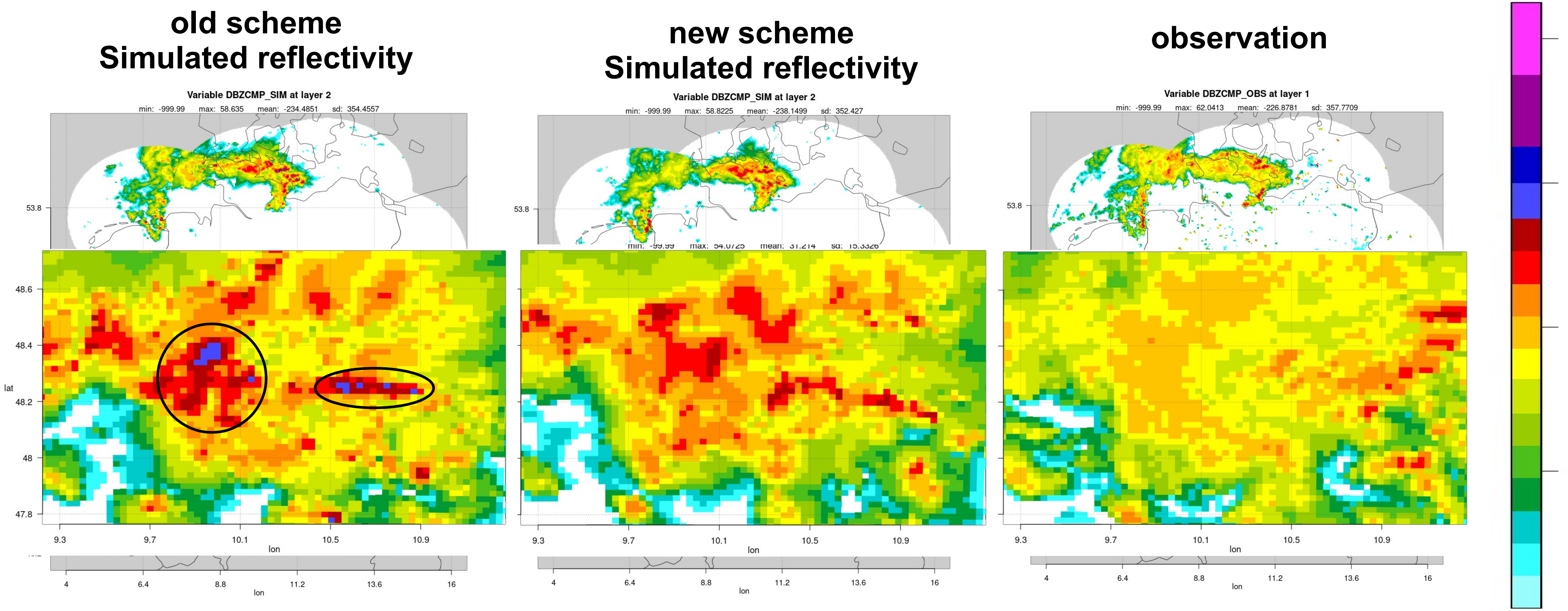

Reflectivity (ZH) plots
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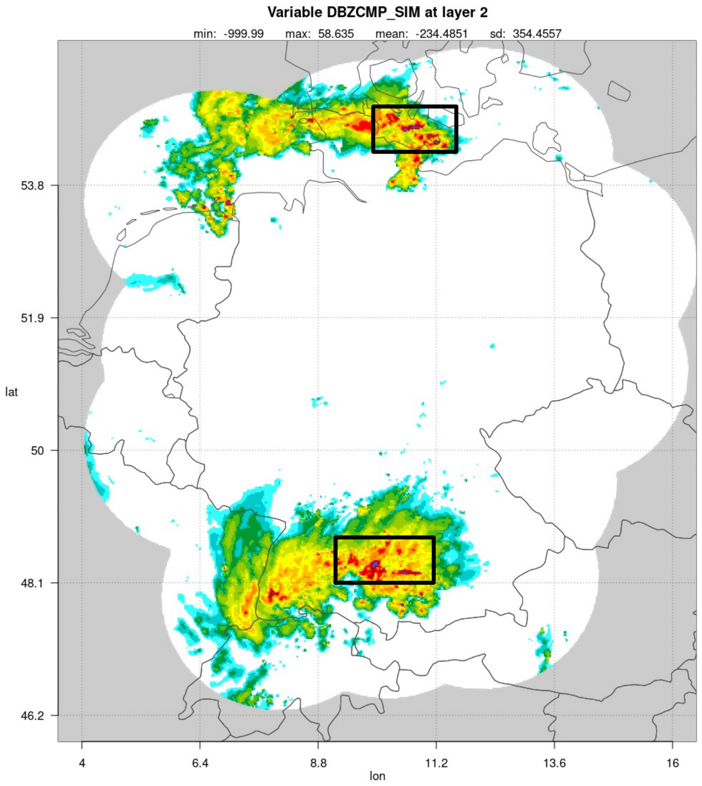
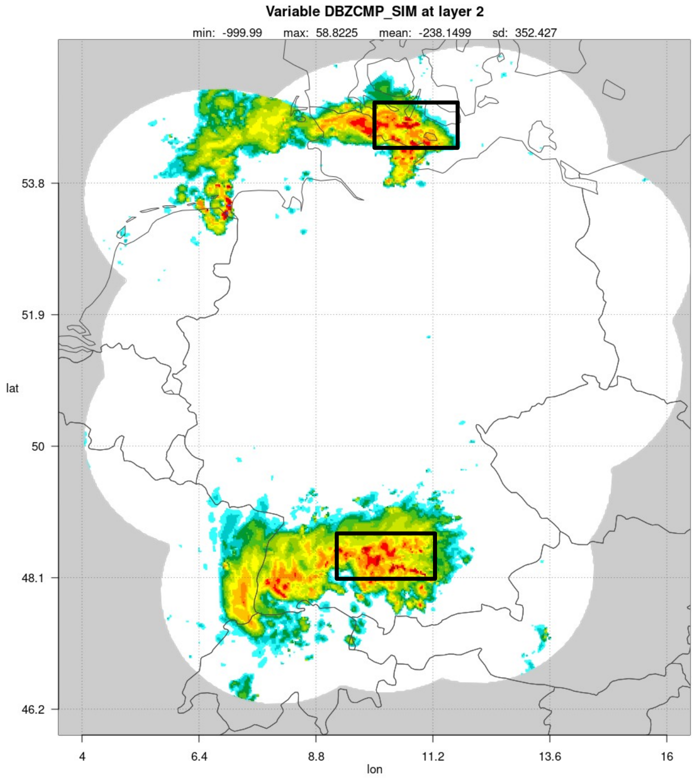
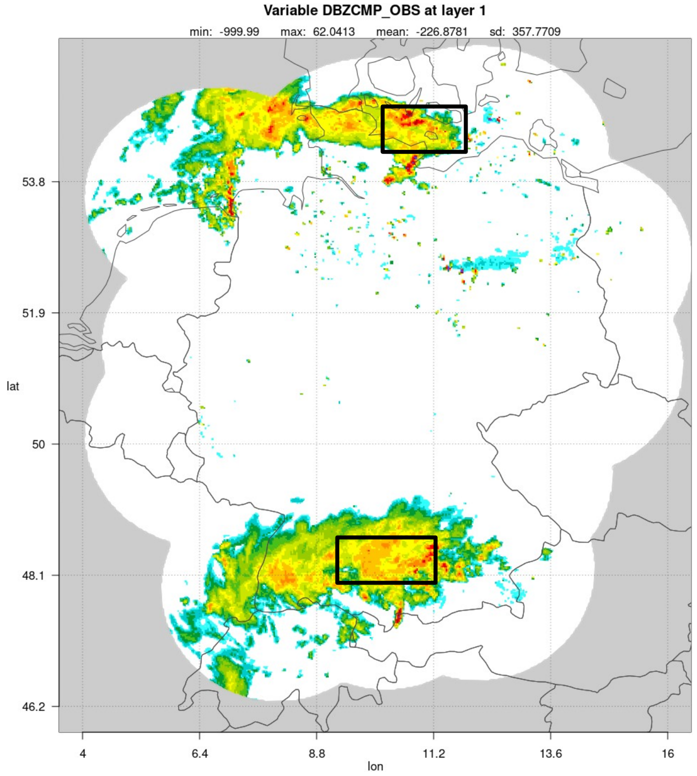
**old scheme
Simulated reflectivity**

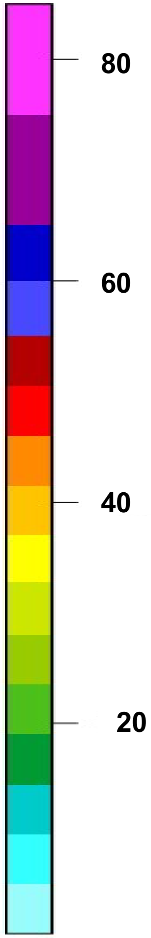


**new scheme
Simulated reflectivity**



observation





Reflectivity (ZH) plots
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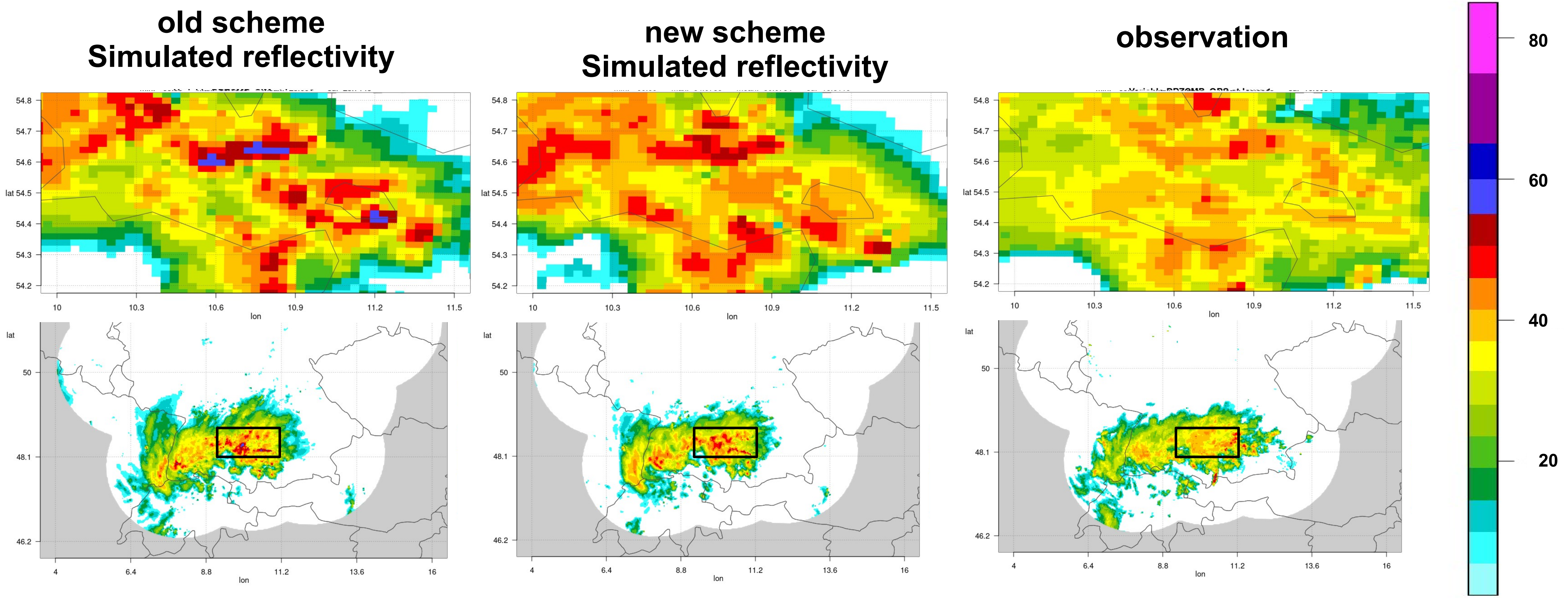

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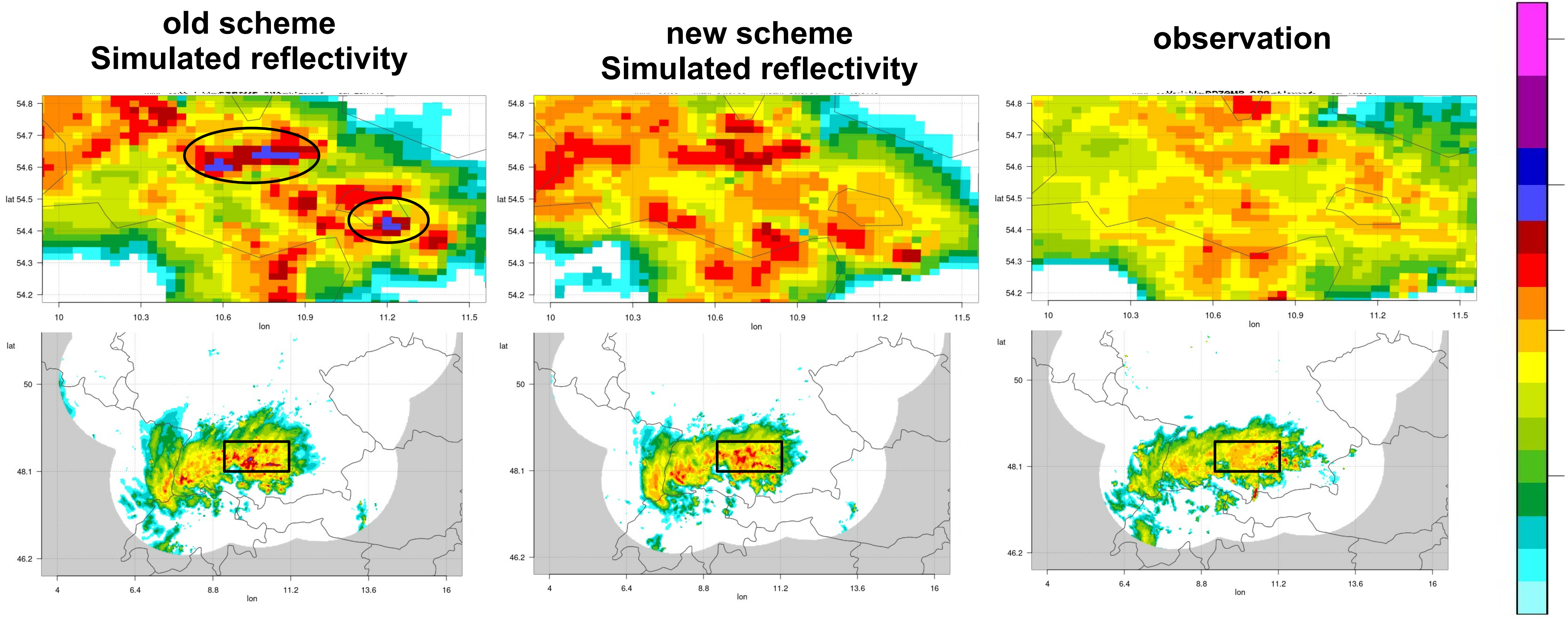


Sommer time

16 Aug until 04 Sep 2022

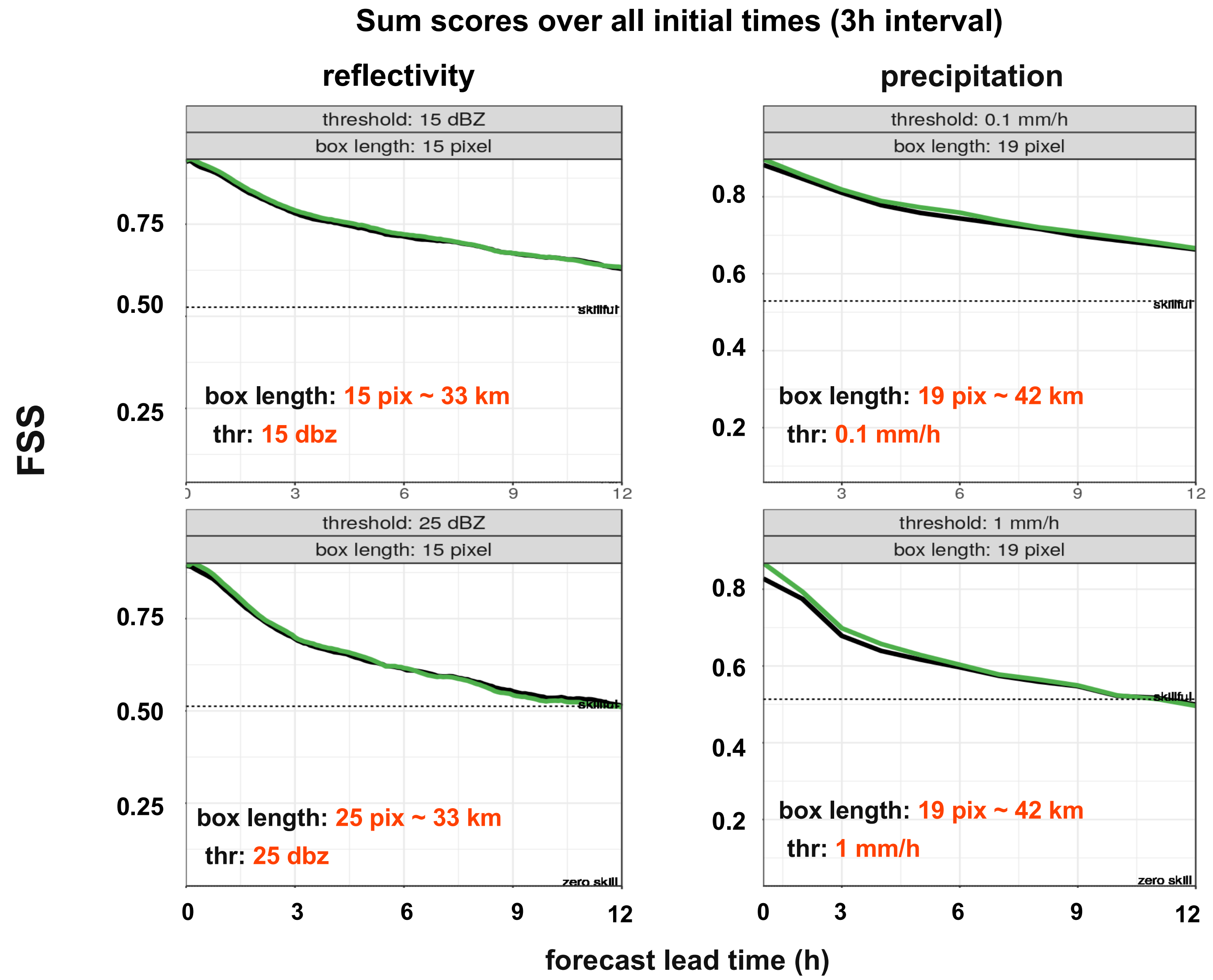
(161 forecast cycles)

Verification:

Neighborhood-based using franktinol skill scores (FSS)

Reflectivity and precipitation verification_Fractional Skill Score (FSS) over Germany - from 16 Aug to 04 Sep 2022

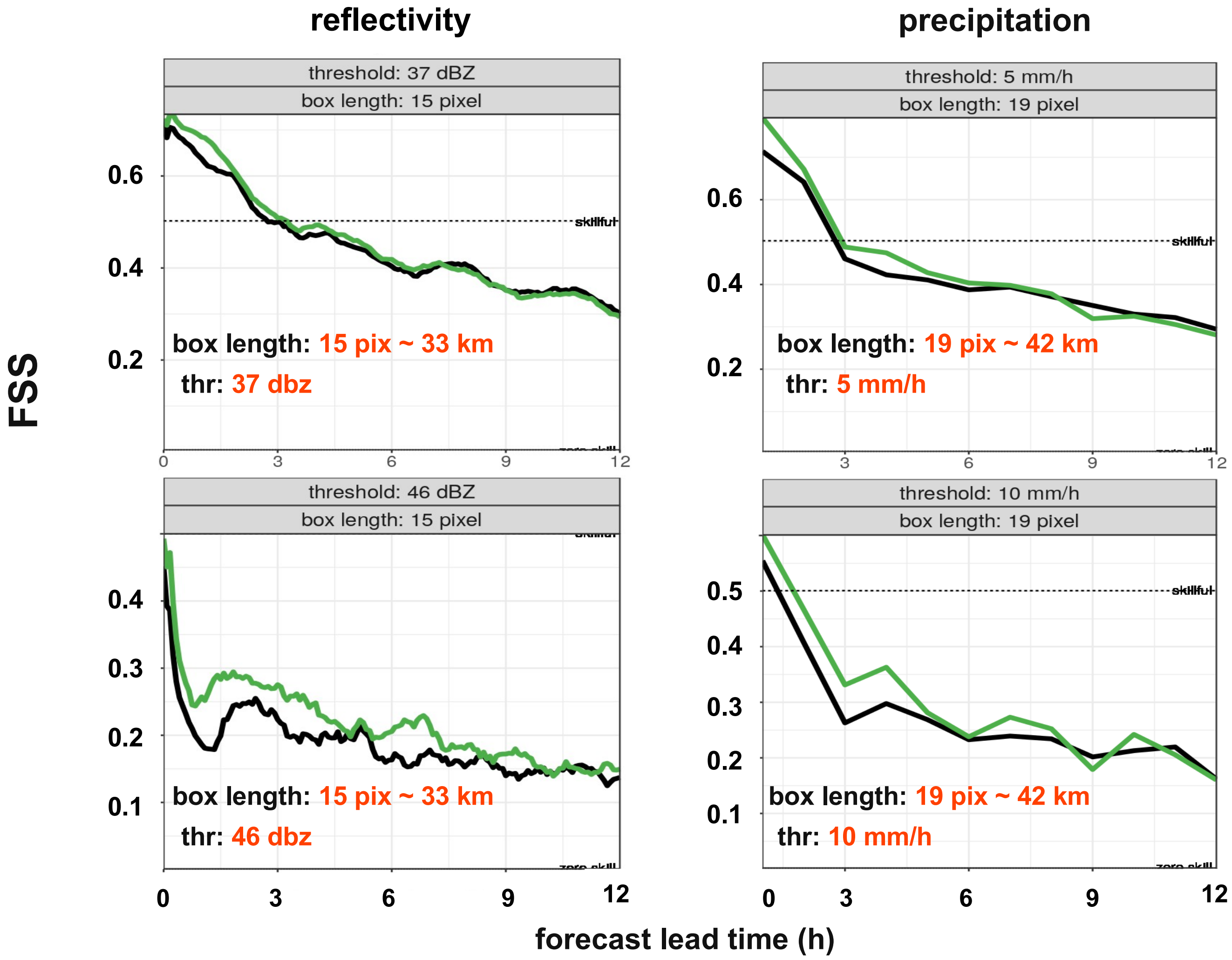
Old scheme
New scheme (less sticky)



Reflectivity and precipitation verification_Fractional Skill Score (FSS) over Germany - from 16 Aug to 04 Sep 2022

Sum scores over all initial times (3h interval)

Old scheme
New scheme (less sticky)



Winter time
02 until 13 Dec 2022
(104 forecast cycles)

Verification:

Neighborhood-based using franktinol skill scores (FSS)

Reflectivity and precipitation verification_Fractional Skill Score (FSS) over Germany - from 2 to 13 Dec 2022

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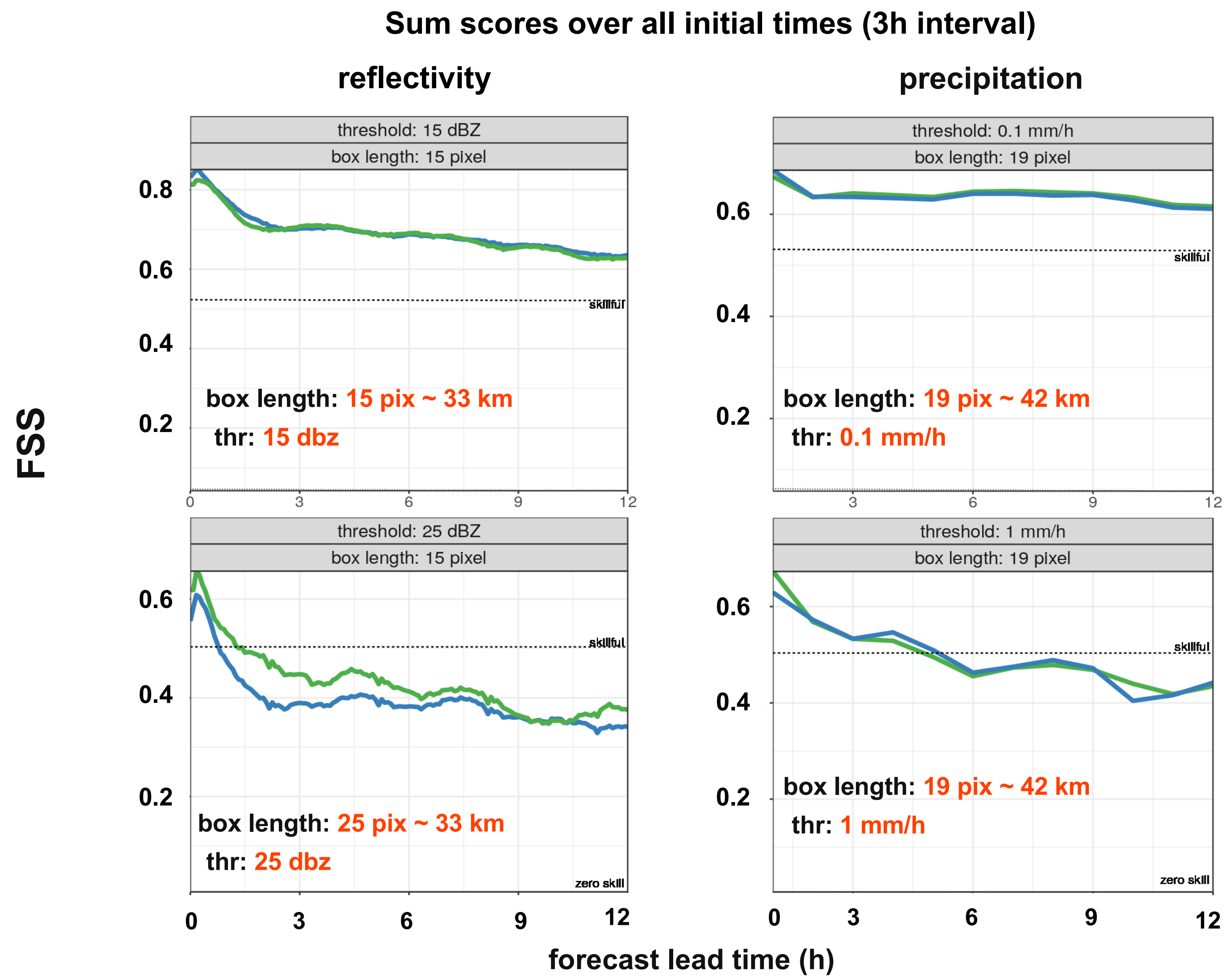
Old scheme
New scheme (less sticky)



Summary and outlook

The new microphysics scheme (less sticky) shows a good improvement in the simulated reflectivity particulary for the higher thresholds

- The new scheme need to be tested to see its effect on the polarimetric variables (such as ZDR)

First steps in ZDR column assimilation

- Find the ZDR column in the observed ZDR
- Compared the ZDR column of the observed one with the simulated ones from EMVORADO
- Applying the ZDR column assimilation for the ideal case

Thank you for your attention

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Backup slides

Polarimetric forward operator: Status summary

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- → Computational speed: **parallelization + bulk scattering lookup tables**
  - tabulation of additive components per hydrometeor class
  - over total (1mom) or mean (2mom) bulk mass q_x + ambient temperature T + max. melting temperature T_m
- → **Example: online in ICON-LAM** on DWD's NEX-SX Aurora HPC (128 vector processors)
  - D2-domain, 2-mom microphysics, 6 hydromet. classes
  - **24h** free **forecast** with **5' output** of **10-elev. volume scans** for **16** DWD C-band **radars** **(= 289 radar output times)**

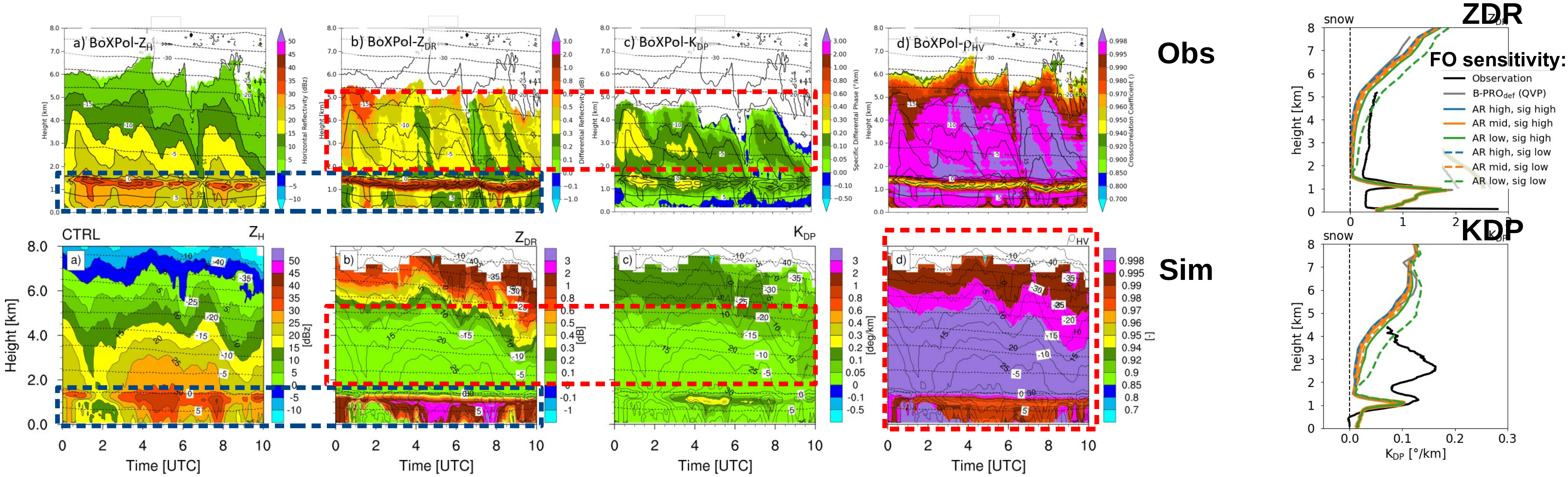
Configuration	EMVORADO time [s] (incl. MPI comm.)	Total model time [s]	Increase [%]
CTRL (no EMVORADO)	-	680	-
E1: **Mie** (look-up), pencil beam, dBZ + v_r	15*	695	**2.2**
E2: T-matrix (look-up), pencil beam dBZ + all dualpol moments + v_r	**28***	**708**	**4.1**
E3: E2 + **vertical beam function smoothing** (5 auxiliary rays for quadrature)	51*	736	8.2

→ Computing time polarimetry (E2), one 5'-step, all 16 German C-band stations:
28 s / 289 = 0.1 s

* if the look-up tables already exist; additional time to pre-compute look-up tables, depends on platform, may vary from few minutes to several days

Polarimetric extention: Applications & Challenges

- Model evaluation (Shrestha et al., 2021):
  - COSMO 2-mom of stratiform rain event, observed with X-band pol. radar at Bonn, Germany



- FO uncertainties & shortcomings:
  - shape & orientation: choice of parametrizations, natural variability
  - suitability of homogeneous models for fluffy, low effective density particles, eg snow aggregates

Polarimetric extention: (DA) Challenges

→ FO uncertainties (non-**polarimetry** specific)

- **Particle model, shape & orientation**
- Effective medium approximation of refractive index
- Melting scheme

- Understanding of the measurement process: **beam smoothing of pol. parameters** (Z-weighted?)

→ Technical

- LUT calc time consuming
  (but: calculated once & re-used; then as fast as Mie/Rayleigh!)
- Memory requirements (5-10 times Mie)

- Lacking implementation of superobbing & feedback files

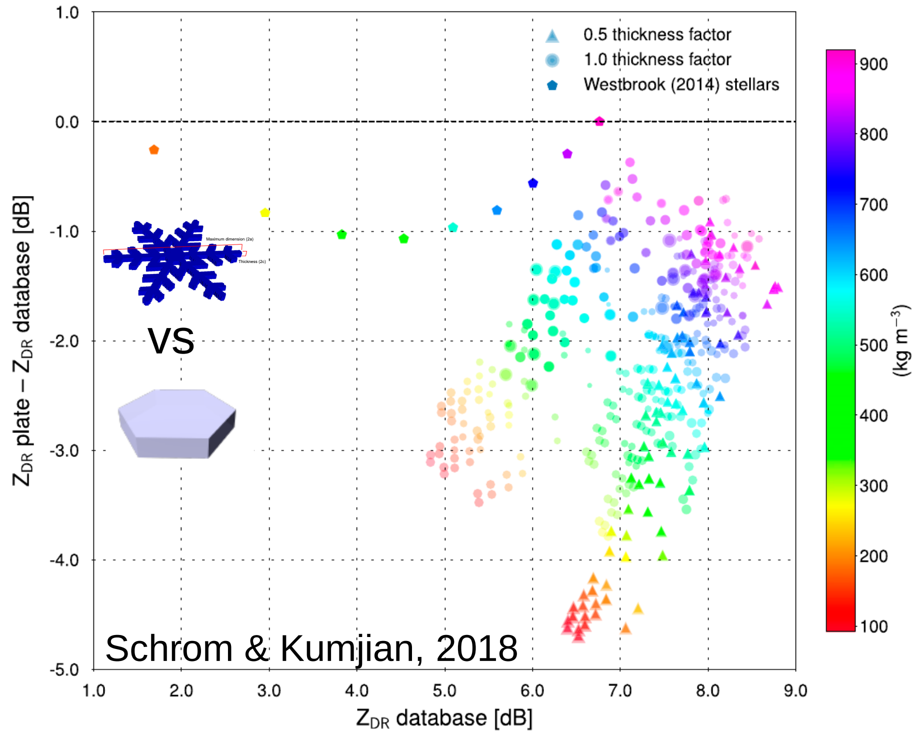


FIG. 3. As in Fig. 1, but for Z_{DR}. The size of the markers indicating the Westbrook (2014) particles are enlarged for the purposes of interpretation and therefore do not correspond in scale to the size of the markers depicting the Lu et al. (2016) branched planar crystals.

Reduced density approach

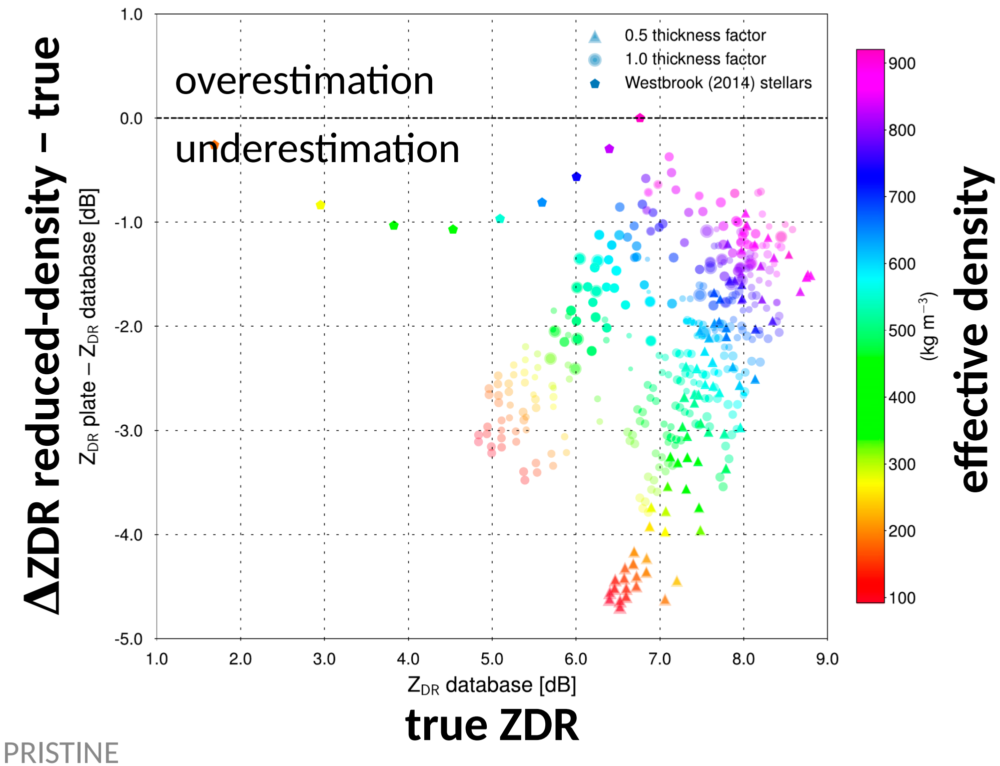
SPP 2115

Probably the most popular approach to setup particles consistent to model constraints (keeping m, D, and aspect ratio unchanged) with T-Matrix suitable shapes.

T-Matrix based simulations show a **consistent deficit** in terms of **polarimetric response** in the dendritic growth layer where large, “fluffy” particles prevail.

Schrom & Kumjian (2018)

- assessed errors in polarimetric scattering properties of homogeneous reduced-density particles as proxies of branched planar crystals (both from DDA)
- found persistent underestimation of ZDR, the worse the less dense
- provided detailed explanation for the **role of internal structure** from dipole interactions



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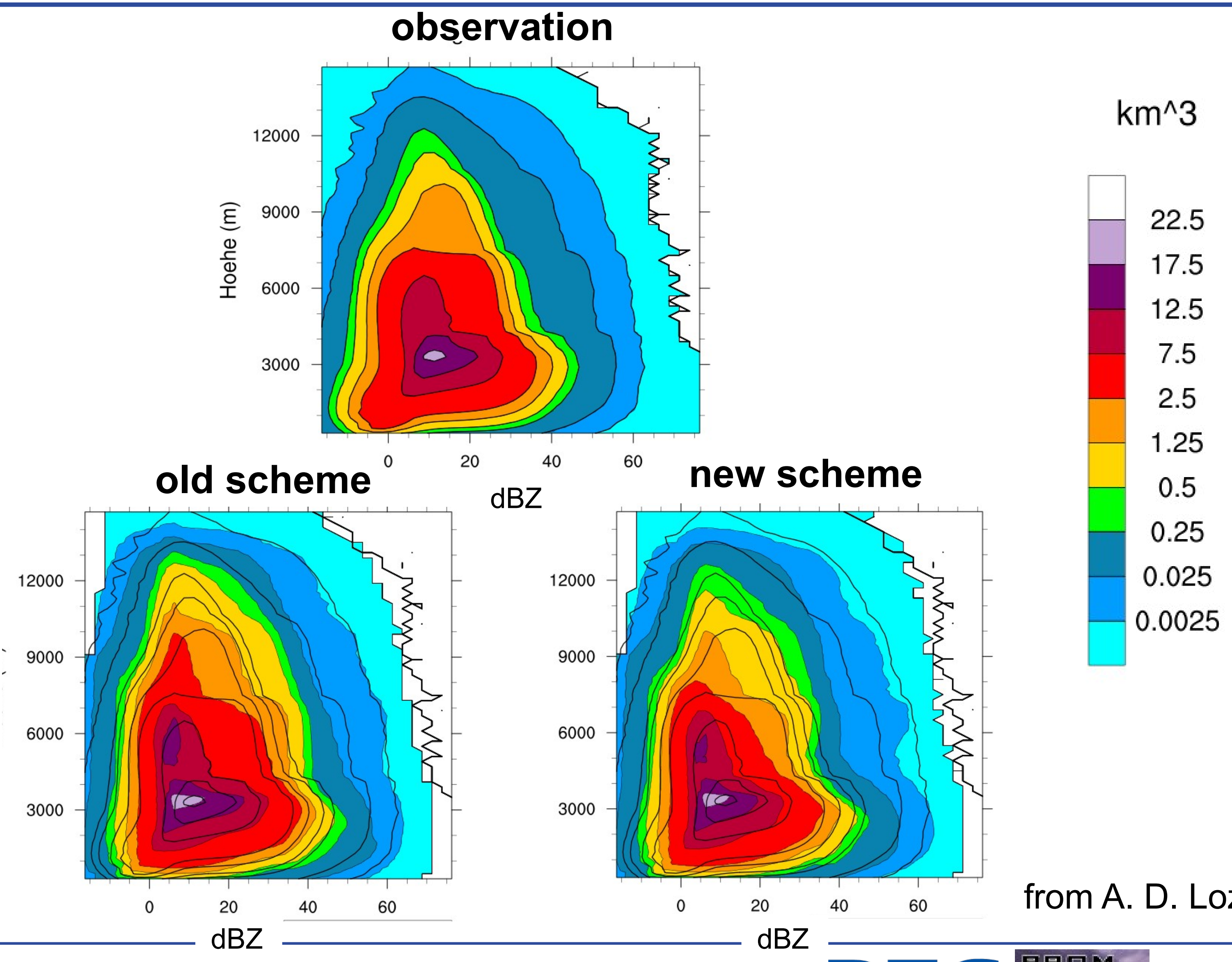
- Graupel can form for T > -3
- Lower limit of Connley et al. for snow sticking efficiency.



from A. D. Lozar

Radar setting

Some radar data seting in 3D radar data assimilation:

- ✓Using **5** radar beams (**1.5, 3.5, 5.5, 8** and **12** degree)
- ✓Horizontal loc: **16 km**
- ✓Vertical loc: **0.07 Lnp** (vertically increasing)
- ✓Vertical profile for the reflectivity observation error