Latest Result of Including ZDR Column for Enhanced Radar Data Assimilation using OSSE at German Weather Service (DWD)

Kobra Khosravian, Jana Mendrok, Alberto De Lozar, Klaus Stephan and Ulrich Blahak

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Bonn, Germany

What are ZDR and the ZDR Column? And How will the ZDR column be assimilated?

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

ZDR (Differential Reflectivity) is a radar parameter that measures the difference in reflectivity between horizontally and vertically polarized radar beams.

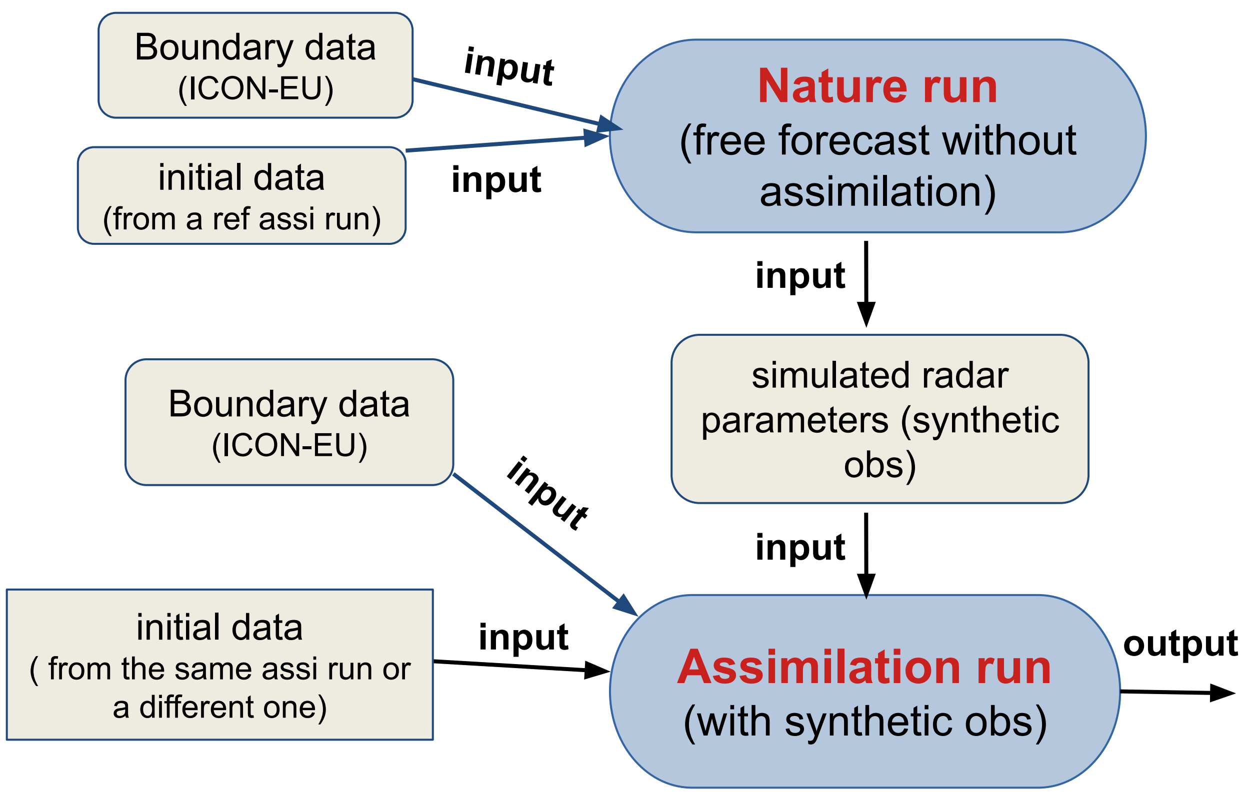
- It mainly depend on particle shapes, sizes, and orientations.
- Higher ZDR values indicate horizontally oriented particles (like raindrops), while lower or negative values suggest spherical particles (like hail or cloud droplets).

ZDR Column:

- The **ZDR column** is a column within a thunderstorm where high ZDR values are observed.
- Typically indicating the presence of large, horizontally oriented raindrops.
- This column is usually extended above the freezing level.
- It can signal the early stages of hail growth.

OSSE is an assimilation experiment where instead of real observations, synthetic observations are used.

- **Synthetic observations** are calculated by applying a forward operator to a so-called nature run.
- **Nature run**: a model run without data assimilation.

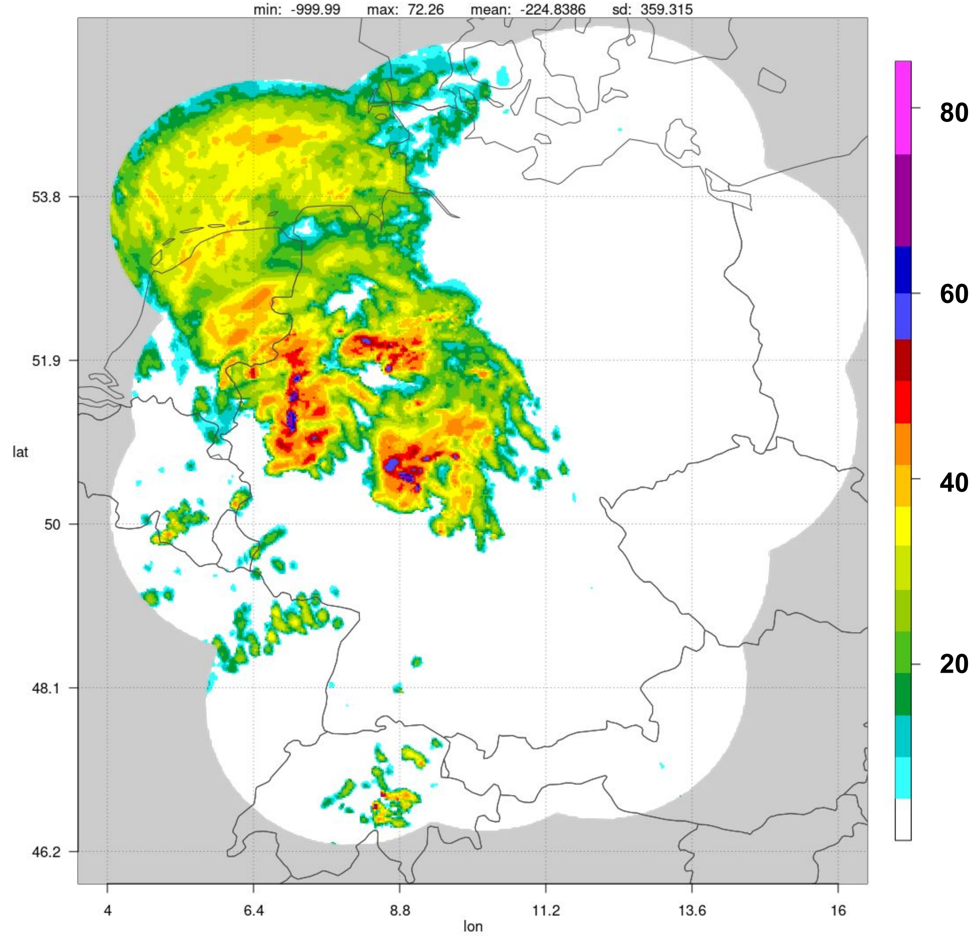


Compare the assimilated data with synthetic observation to analyse the effect of assimilation of the radar data

Case Study - 20 May 2022
Tornado in Paderborn, Germany

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Radar Reflectivity of German Radar Network
layer 1 (0.5 degree) at 15 UTC (17 LOC)



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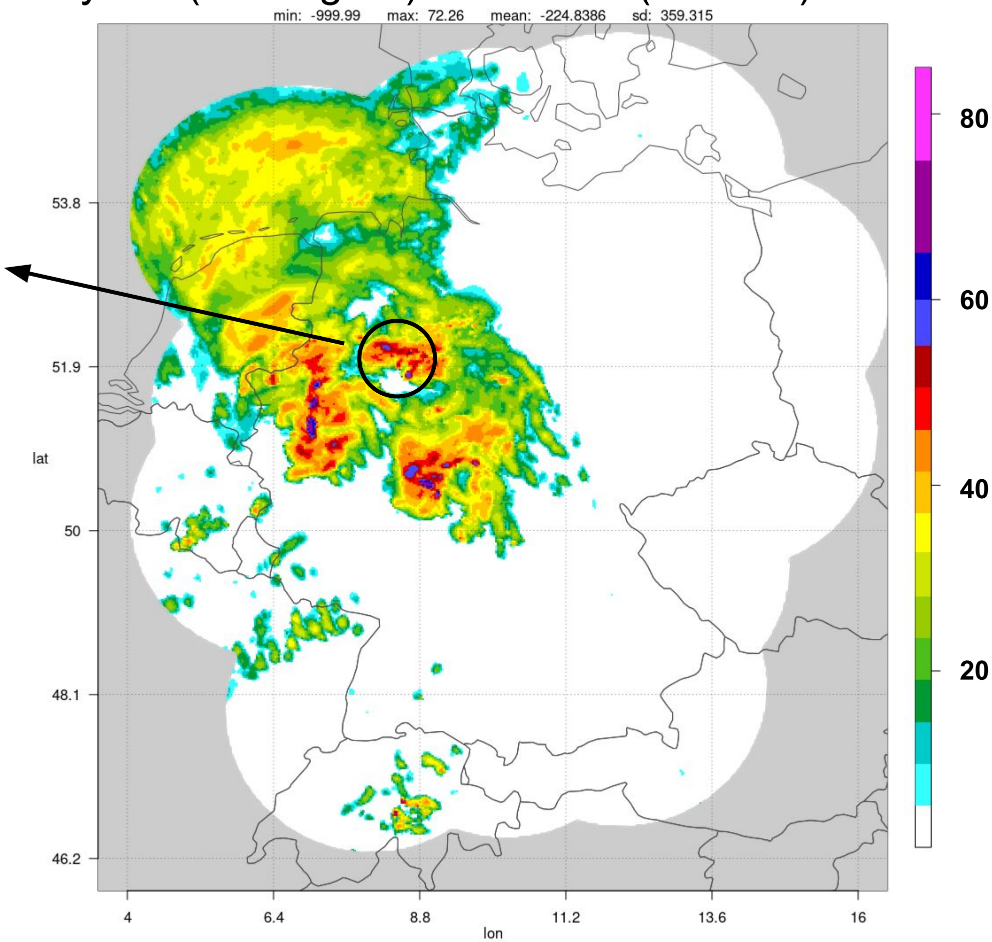
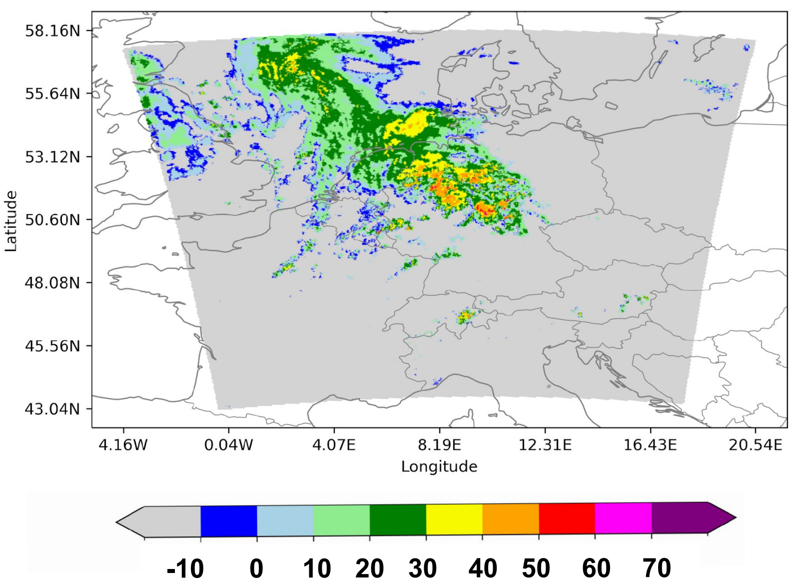


- The nature run:
  - Started from **07 UTC** and had **9-h pre-run** before using the simulated reflectivity to make the synthetic observation.
  - The **ICON-RUC** (~2 km resolution) with **2-mom microphysics** (including 5 hydrometeors, rain, snow, graupel, hail and ice cloud) was used in the nature run
  - The initial data came from a 2-mom experiment **(ICON-RUC)**.
  - The boundary condition provided from **ICON-EU**.

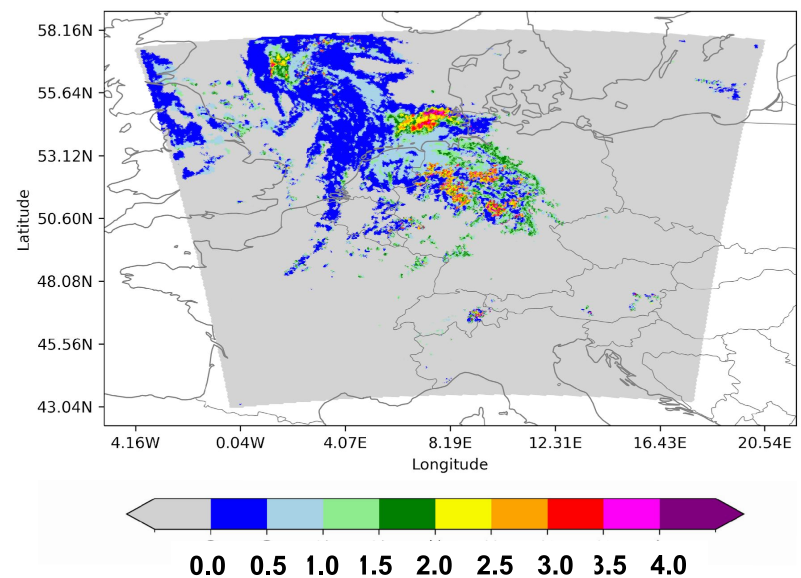
To analyze and detect the ZDR column, both **ZDR** and **reflectivity** were output **over the model grid points** on **D2 domain**.

Reflectivity and ZDR output at 16 UTC
over model gridpoint and model level
(a model level close to the surface)

Reflectivity (DBZ)



Differential Reflectivity (ZDR)



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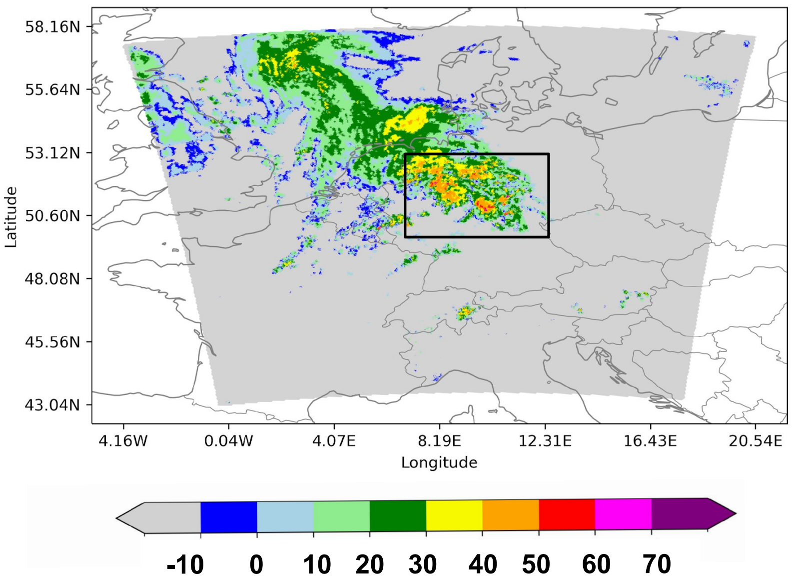

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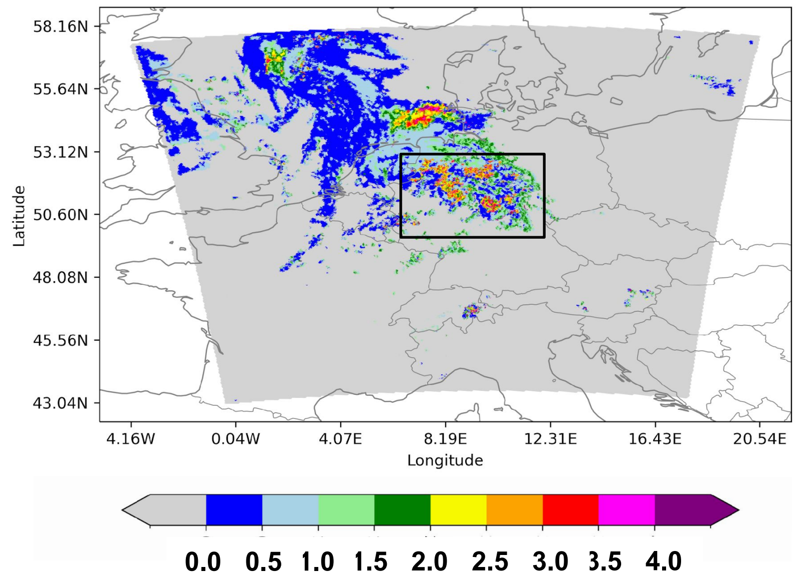
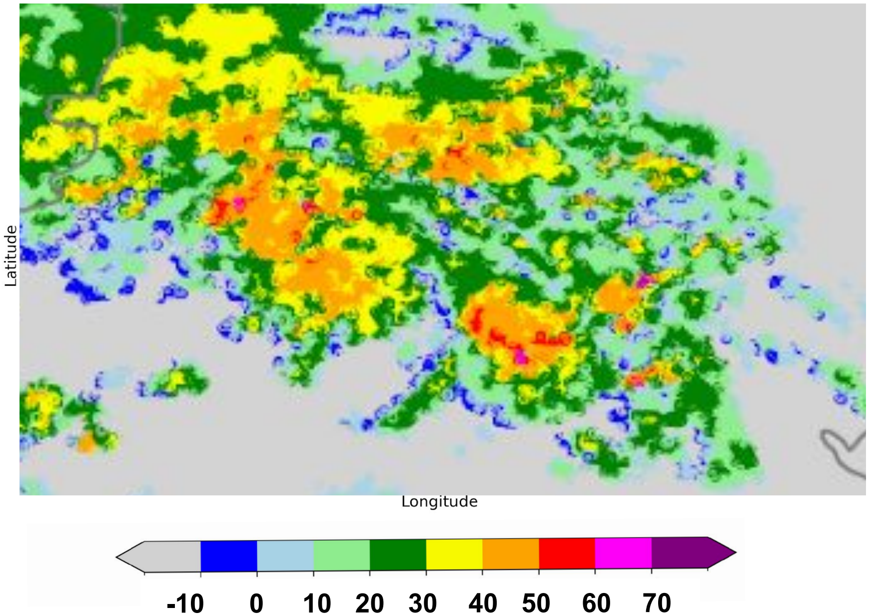


Select Specific ZDR Columns for Further Analysis

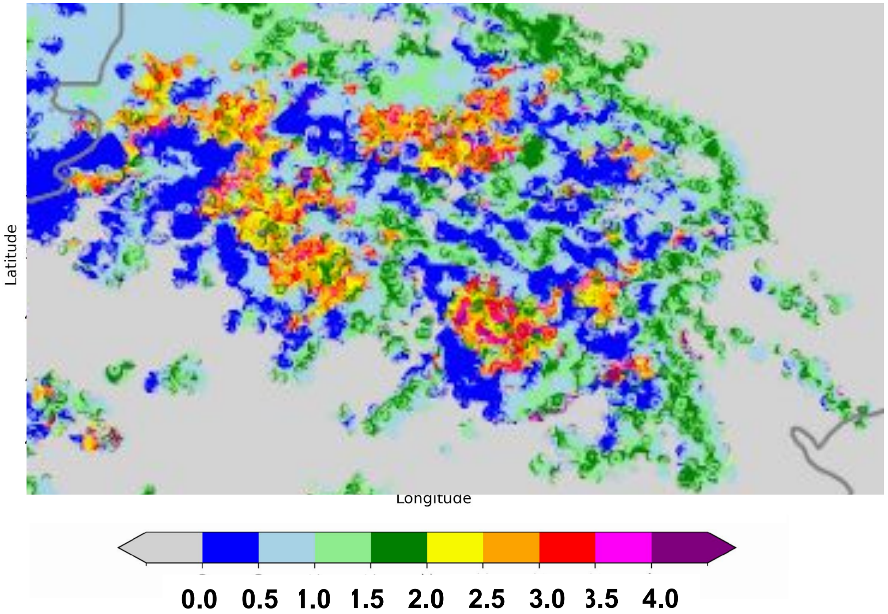
Selected ZDR columns:

- First identifies the 0°C temperature level,
- Then detects columns where the **reflectivity** is **greater than 25 dBZ** both **0.5 km** below and above the 0°C line, and the **ZDR** is greater than **0.5 dB**.

Reflectivity (DBZ)



Differential Reflectivity (ZDR)



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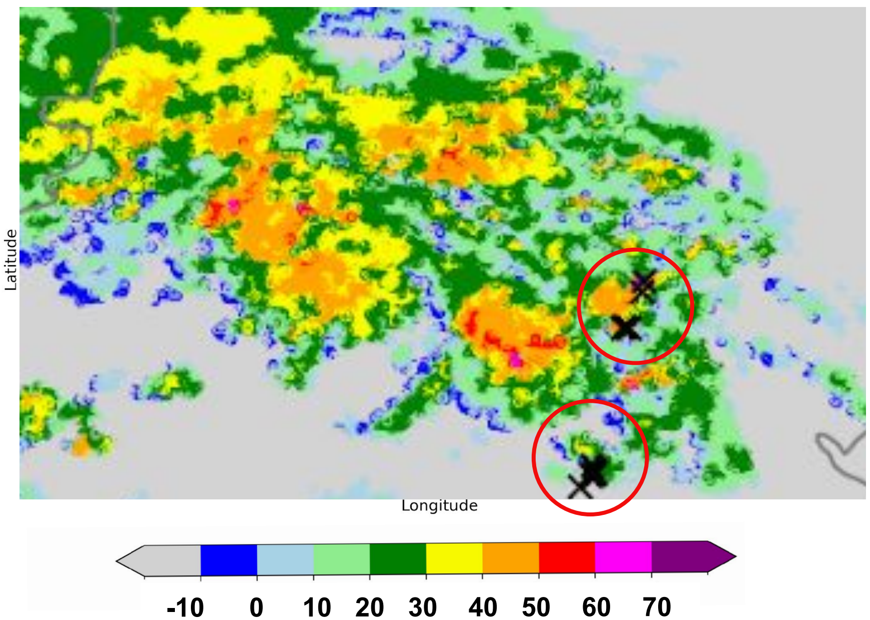
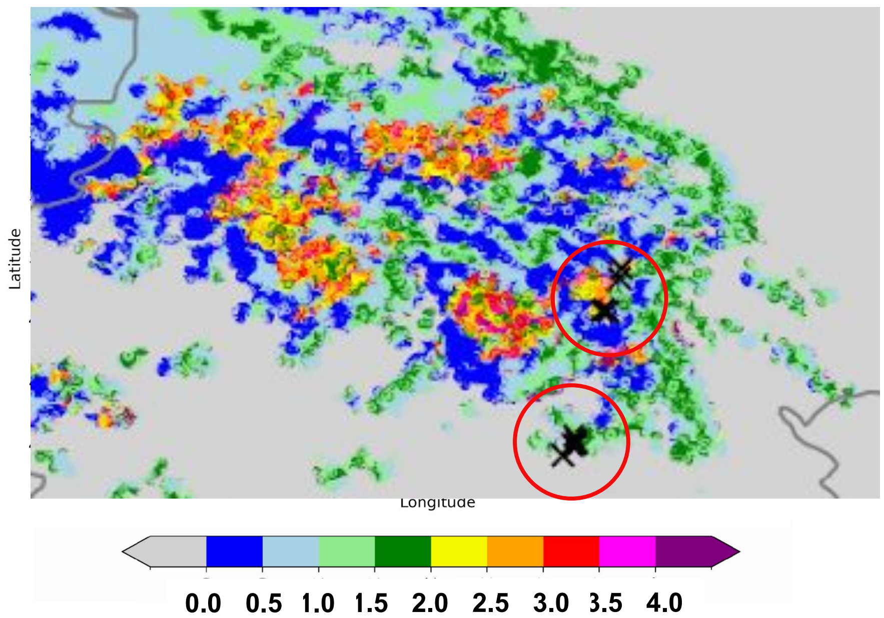
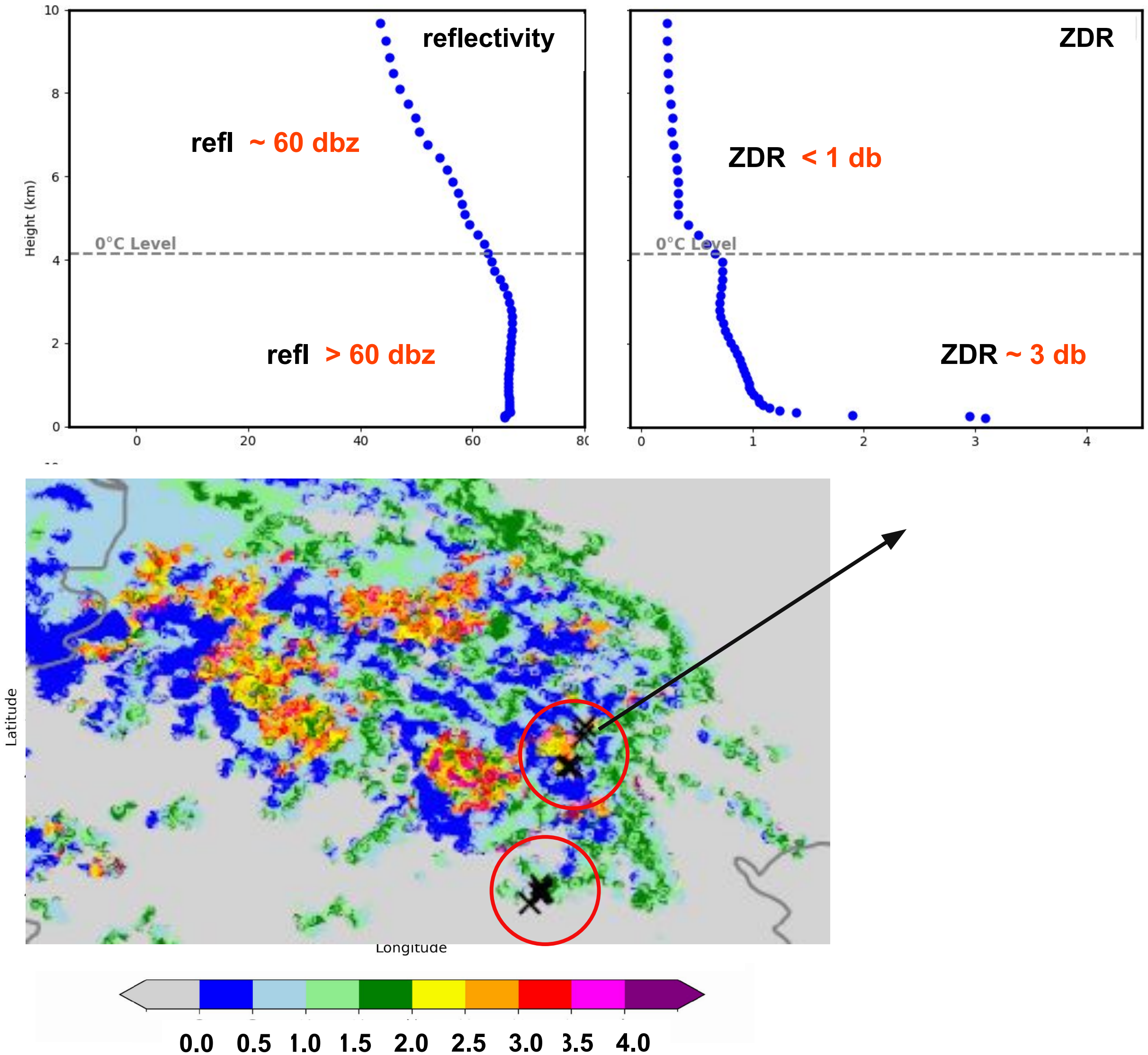


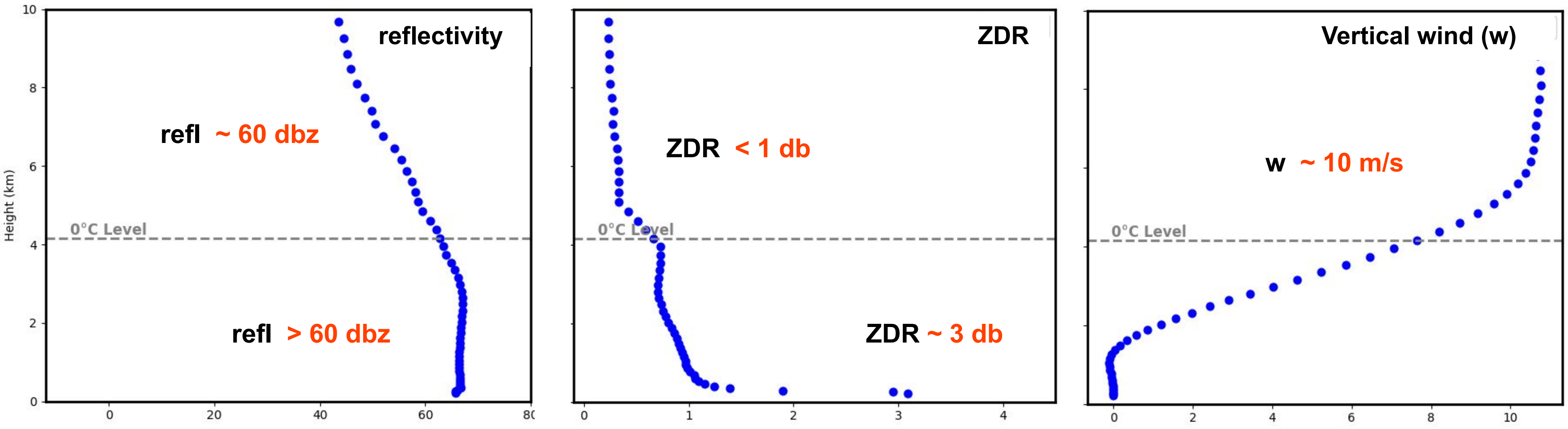
Differential Reflectivity (ZDR)

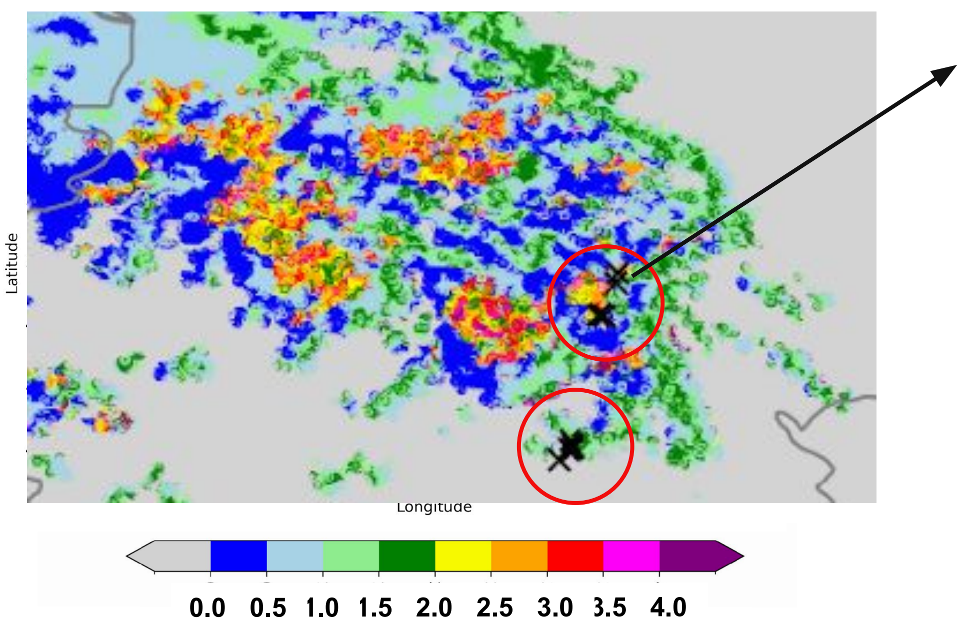


Analyzing the selected ZDR Column



Analyzing the selected ZDR Column





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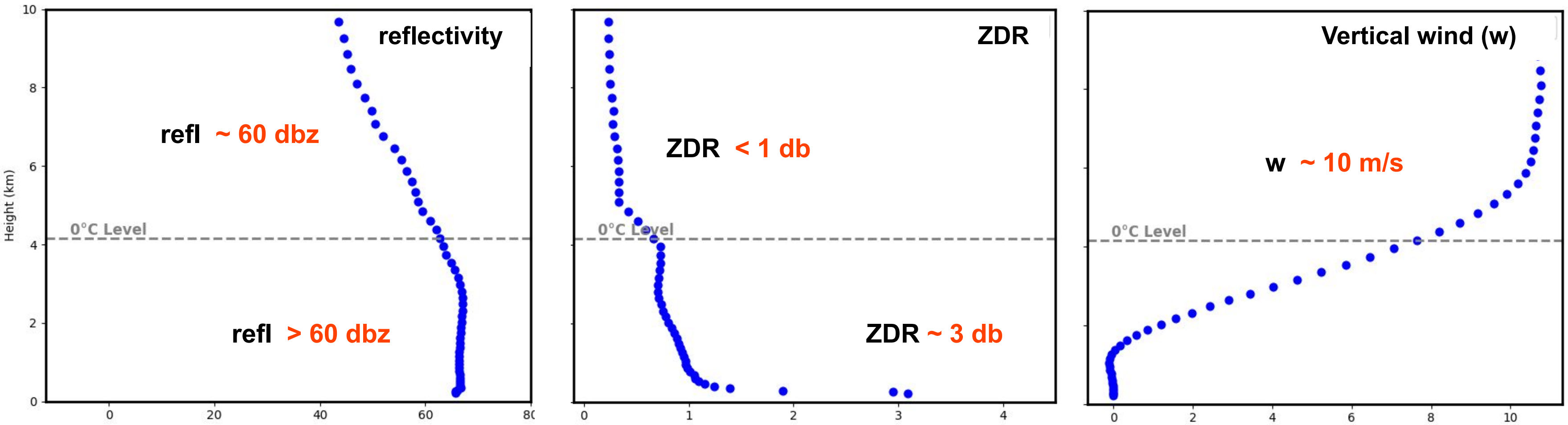

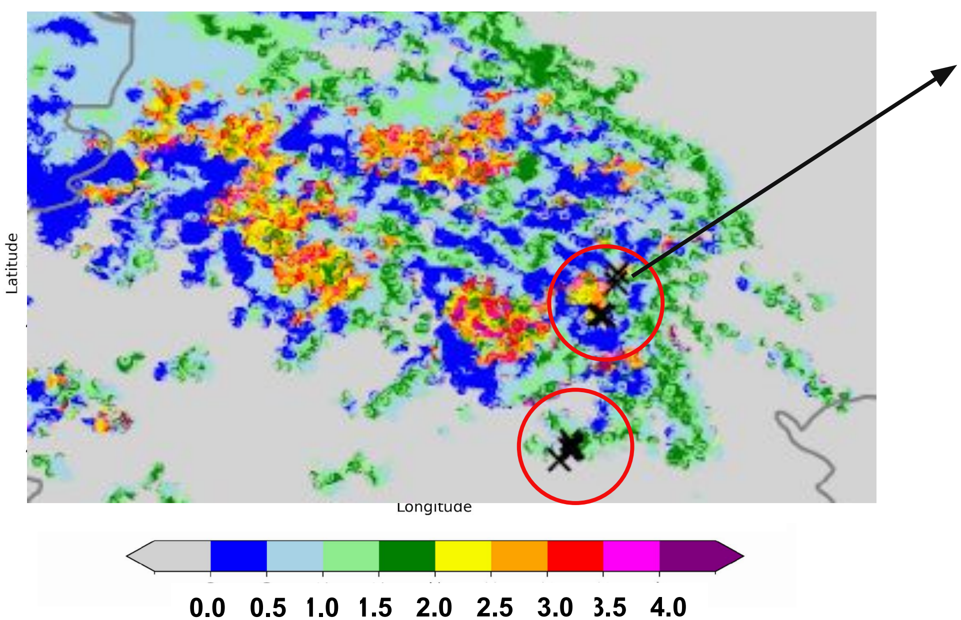

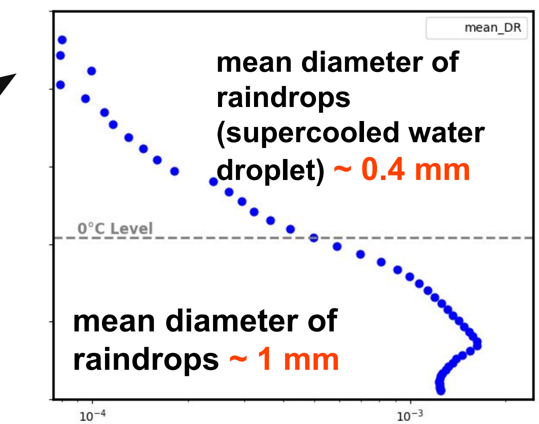

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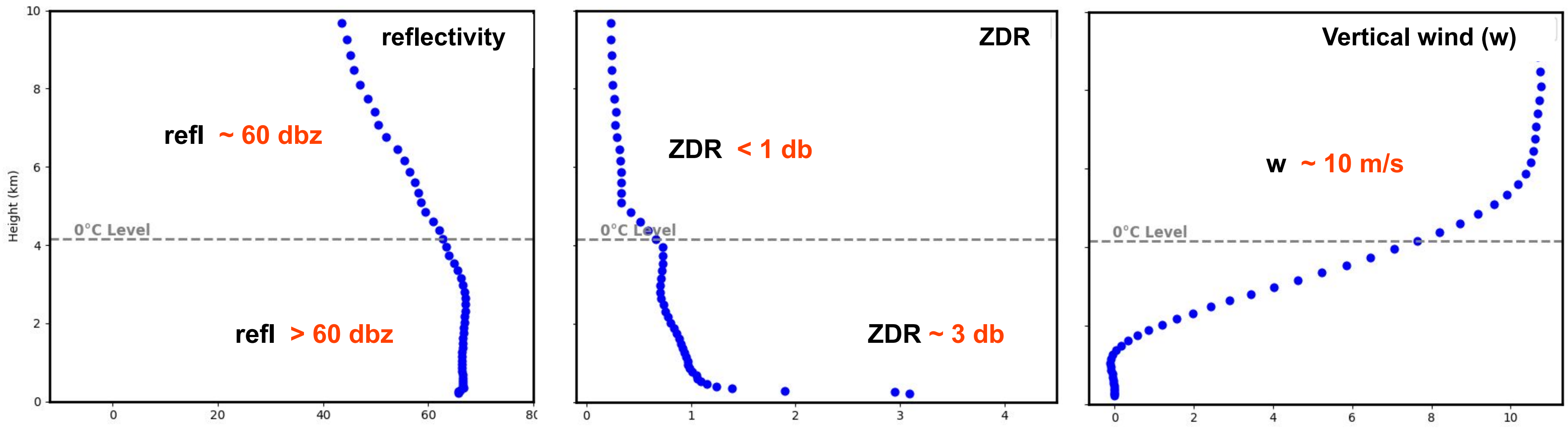
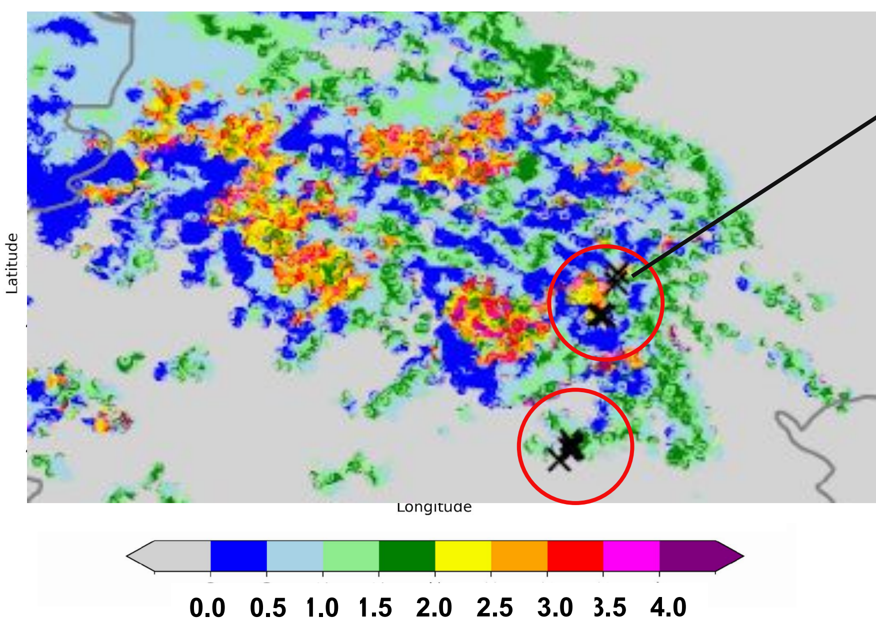
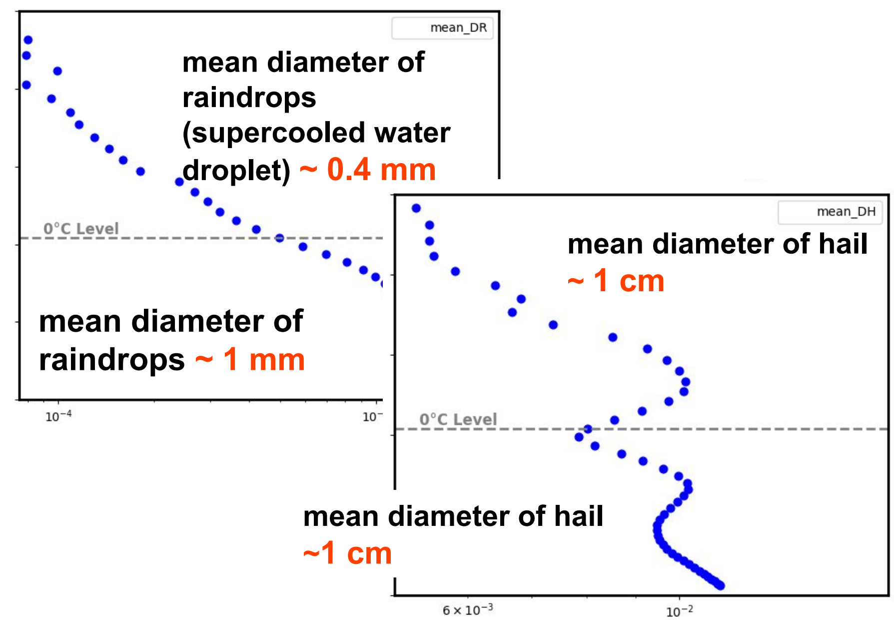
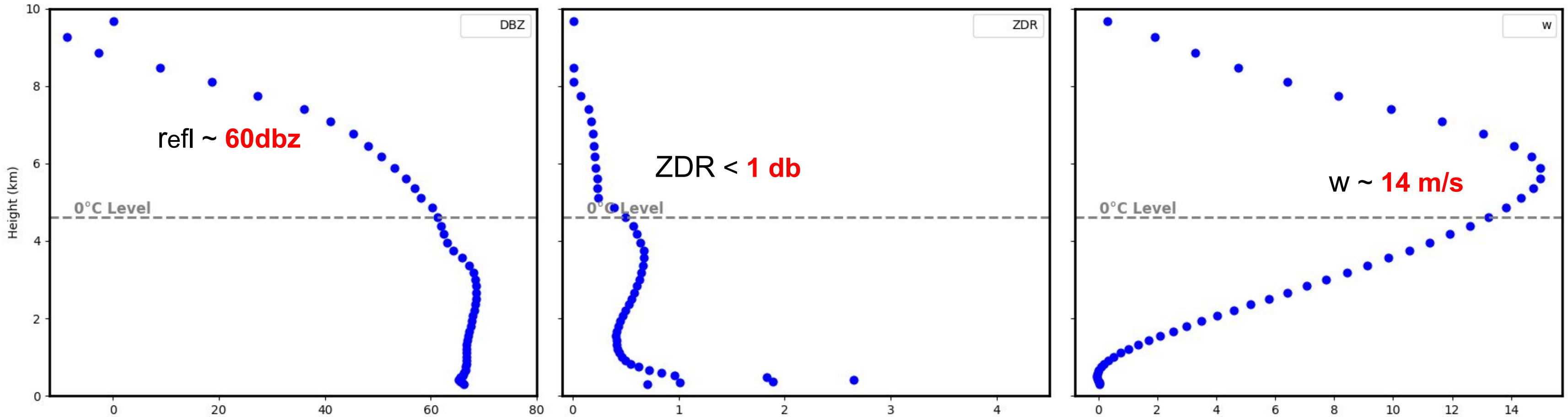
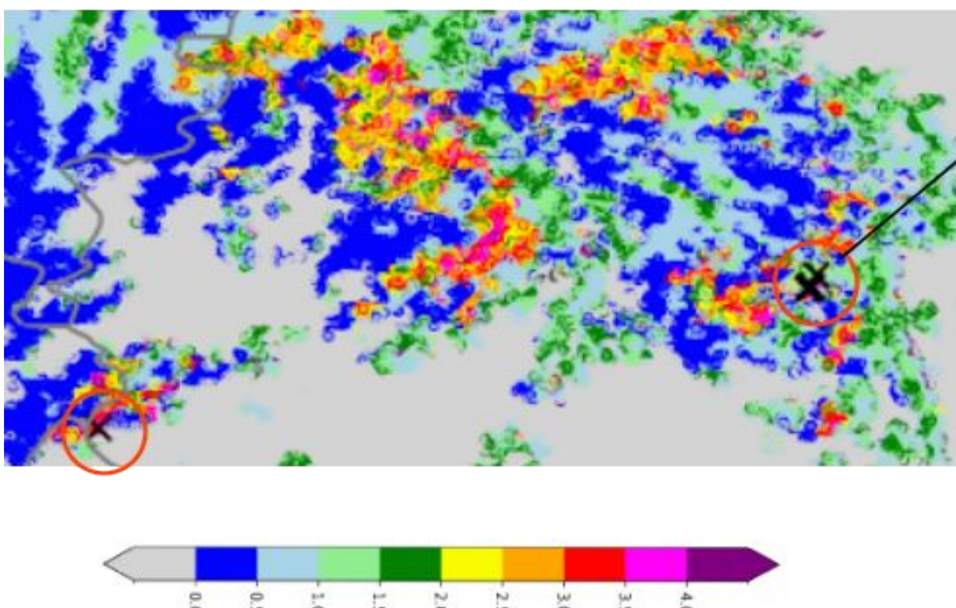


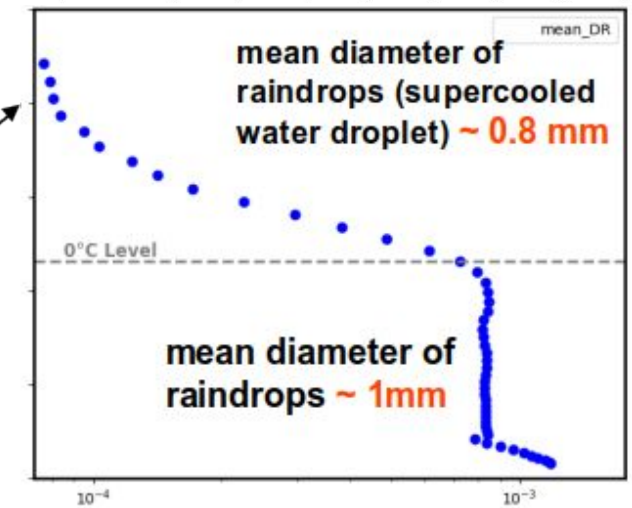




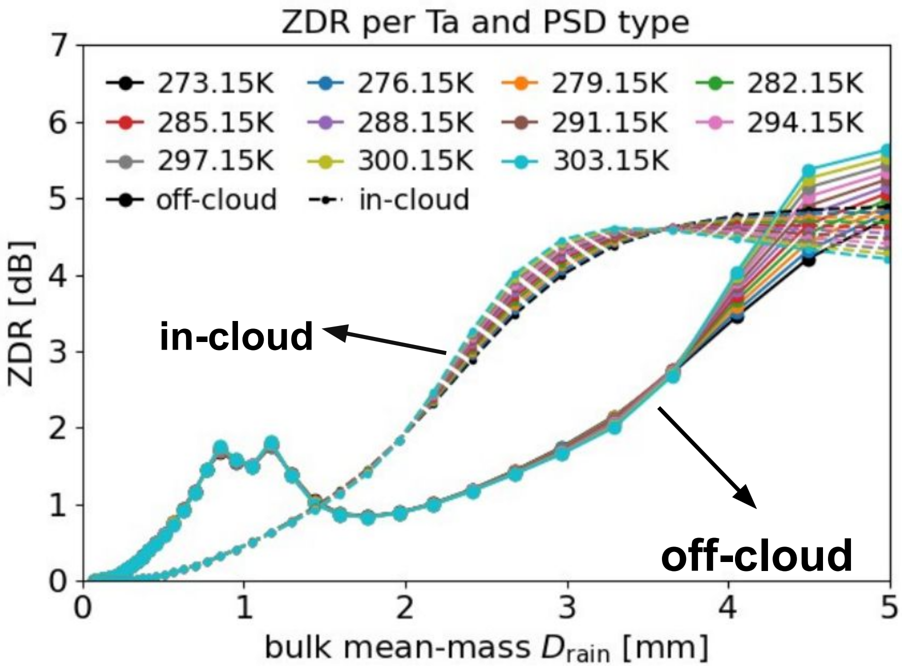
Improving the mean-mass of rain diameter after modifying model microphysics





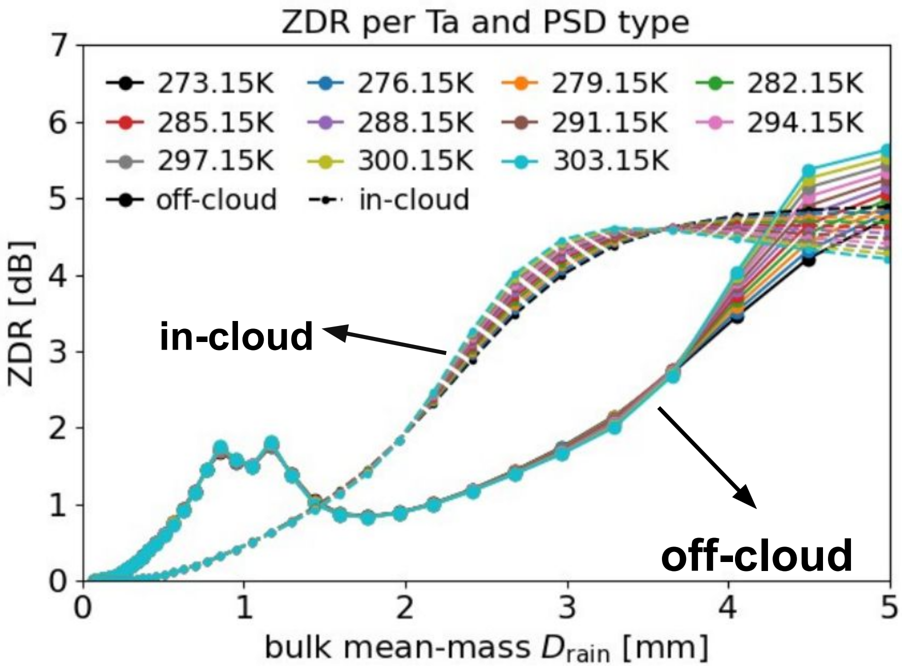


µ-D relation in-cloud and off-cloud



plots from J. Mendrok

μ-D relation in-cloud and off-cloud

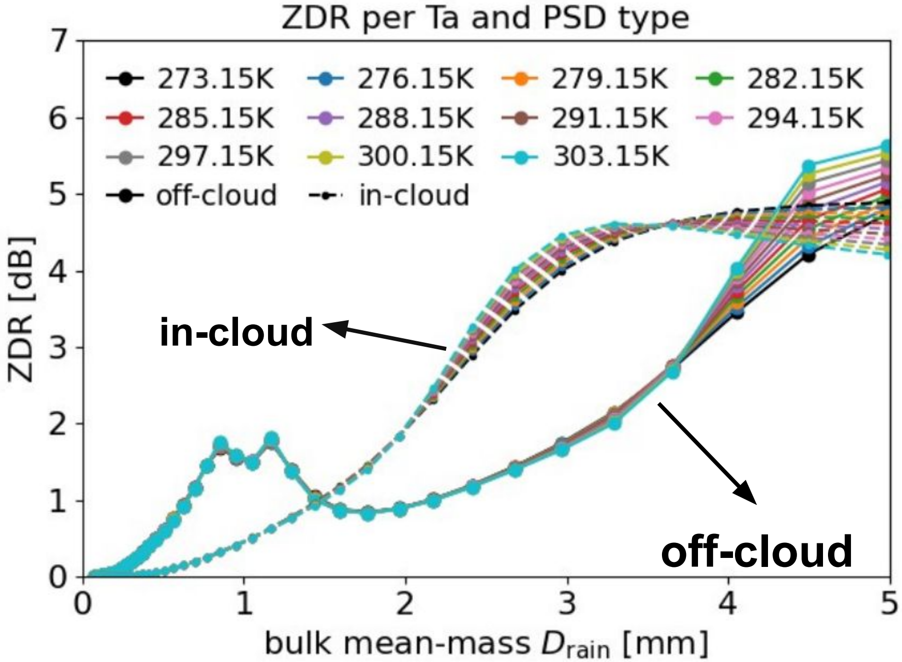


drop-size distribution defined based on the modified gamma distribution:

$$n(x) = N_0 x^{\mu} \exp(-\Lambda x^{\gamma})$$

plots from J. Mendrok

μ-D relation in-cloud and off-cloud



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plots from J. Mendrok

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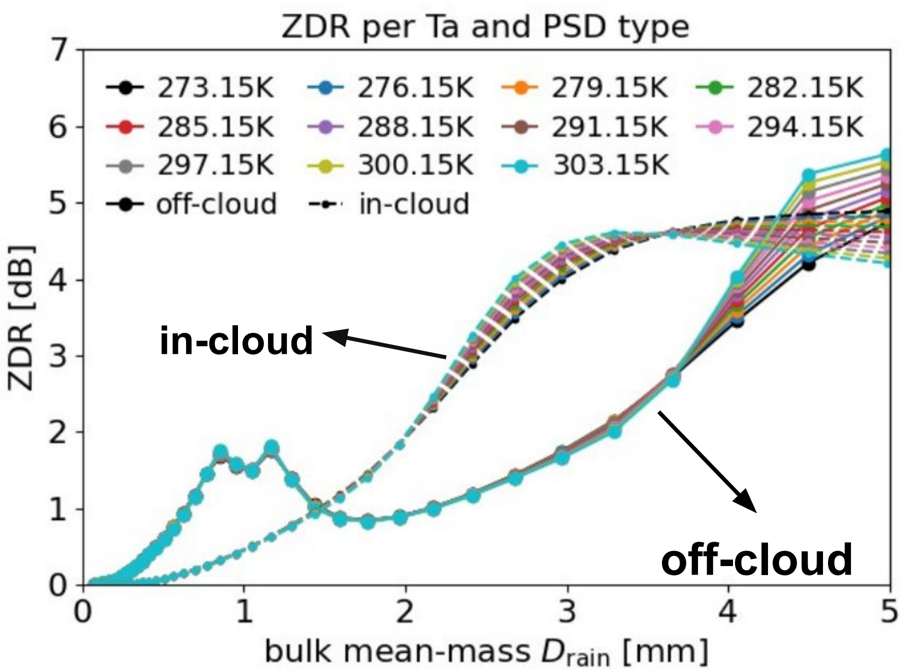

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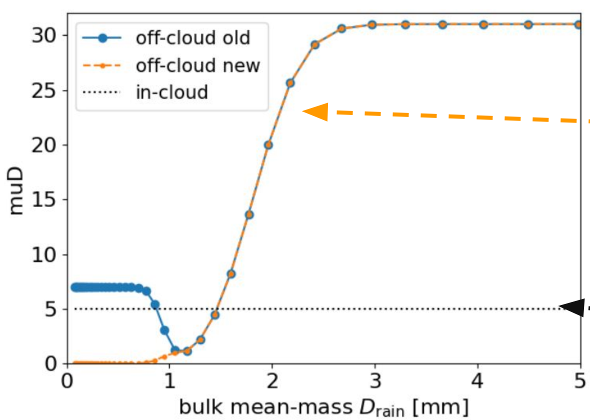

off-cloud

$$\mu = C_0 \times \tanh[C_1 \times (D_{\text{mean}} - D_{\text{ref}})]^2 + 1$$

with C0 and C1 defined separately for cases when Dmean < Dref & Dmean > Dref

in-cloud

$$\mu = 5$$

plots from J. Mendrok

Improving the mean-mass of rain diameter after modifying model microphysics

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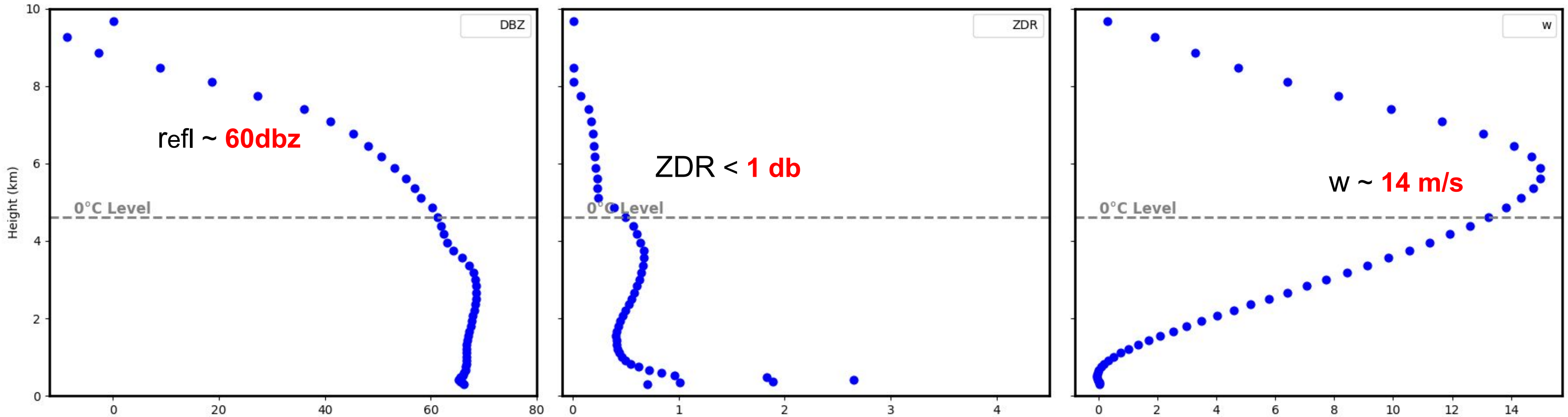

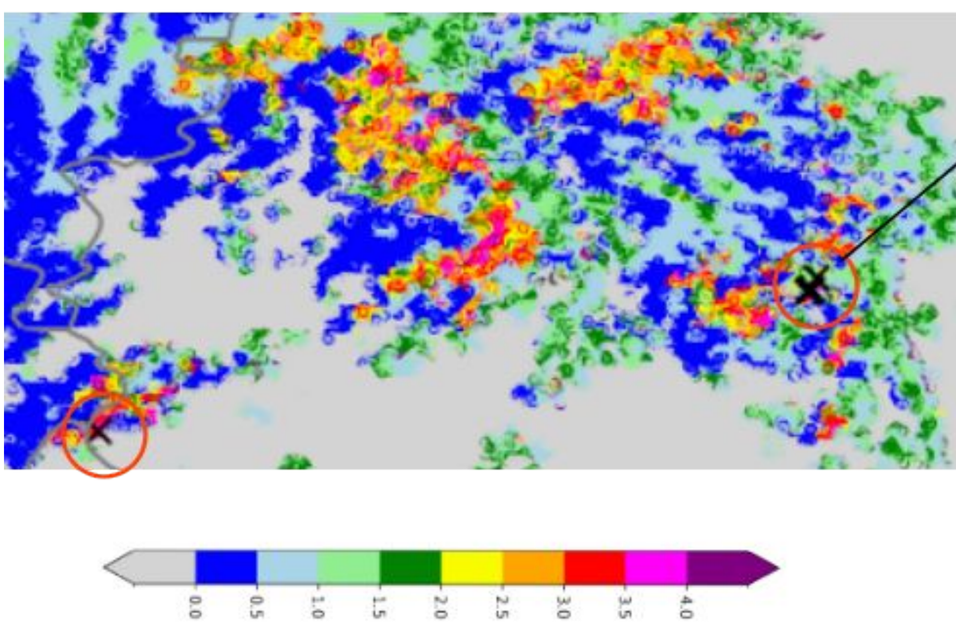

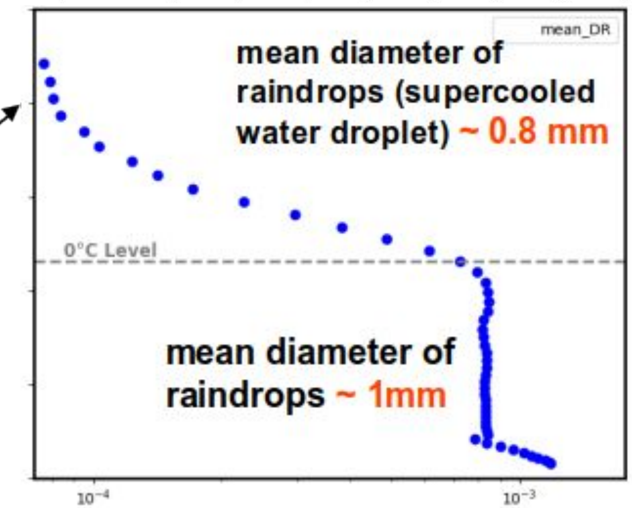

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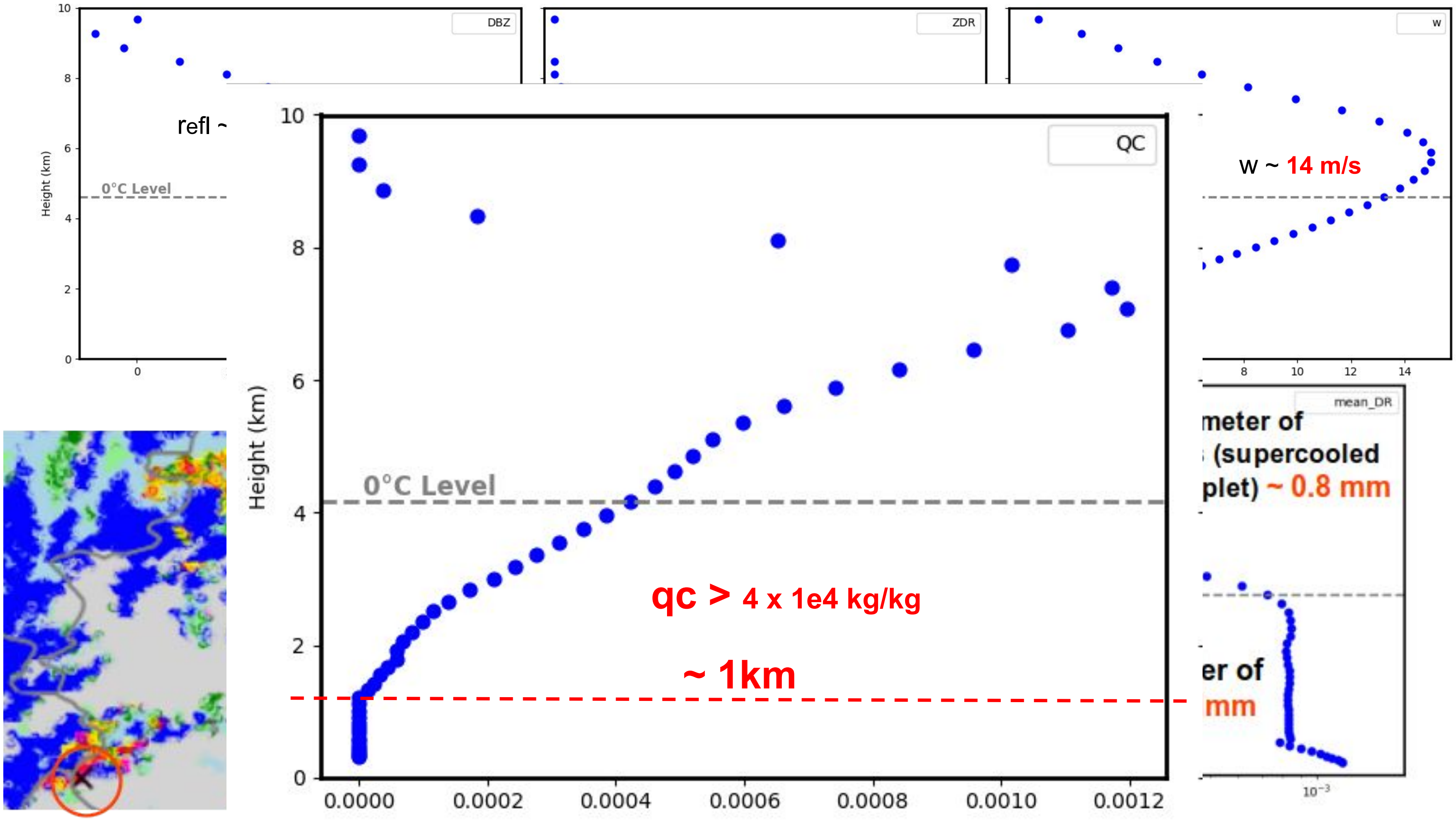

Investigate changing the μ of in-cloud μ-D relation

modified Gamma distribution:

$$n(x) = N_0 x^{\mu} \exp(-\Lambda x^{\gamma})$$

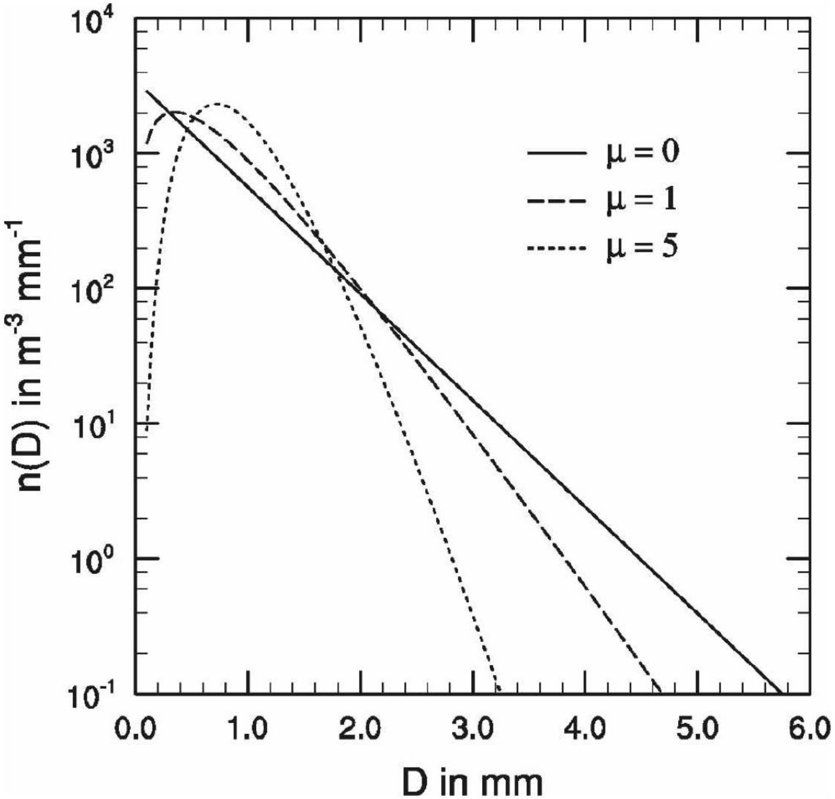

FIG. 1. Drop size distributions $n(D)=N_0 D^{\mu} e^{-\lambda D}$ for different shape parameters μ at a constant mean volume diameter of D_m = 1 mm and rainwater content L_r = 1 g m^{-3}.

From Seifert A., 2008

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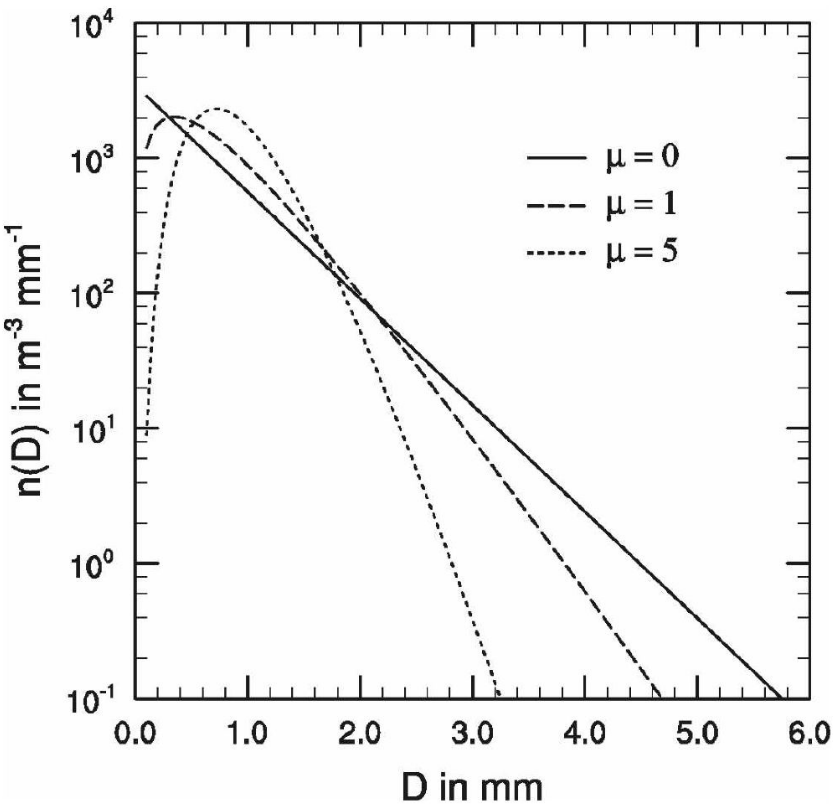
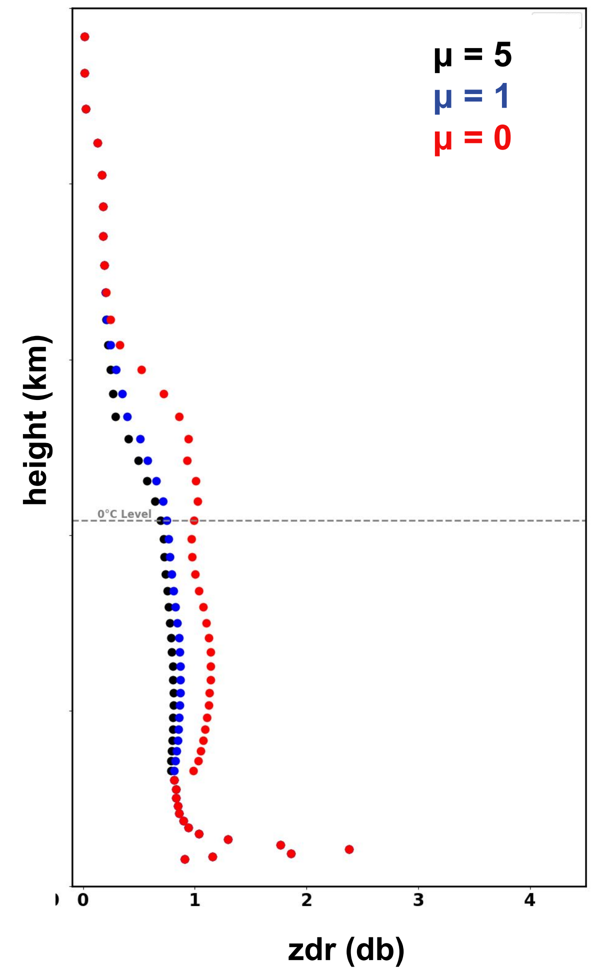


FIG. 1. Drop size distributions $n(D) = N_0 D^{\mu} e^{-\lambda D}$ for different shape parameters μ at a constant mean volume diameter of D_m = 1 mm and rainwater content L_r = 1 g m^{-3}.

ZDR profile

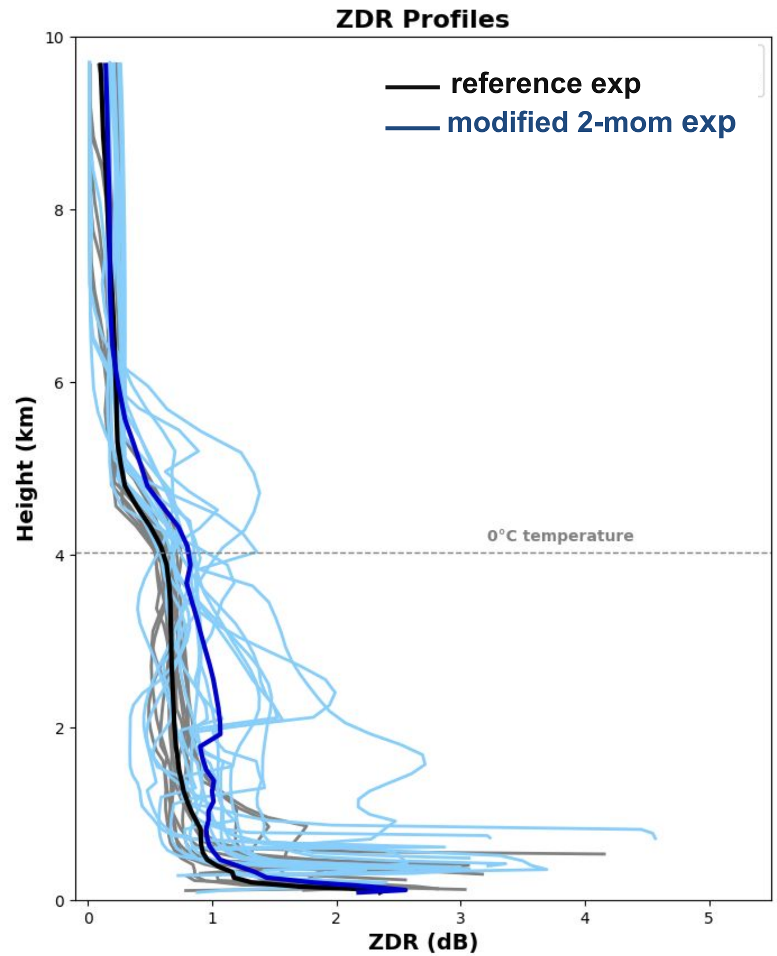


From Seifert A., 2008

Applying Microphysics Modifications to Improve ZDR Profiles

Microphysics modifications include:

- Doubling the collision efficiency of rain droplets
- Slowing the freezing process
- Forcing small cloud droplets to remain within the cloud for further growth
- **Setting the parameter μ to 0 for in-cloud rain distribution**



Applying Microphysics Modifications + EMVORADO modification to Improve ZDR Profiles

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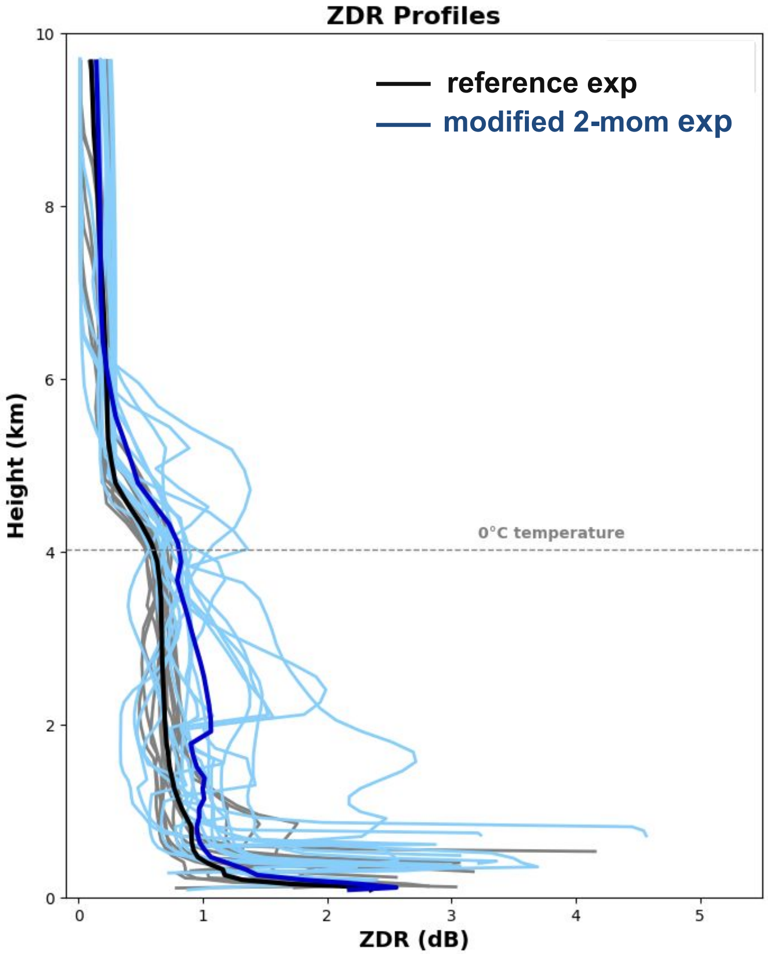
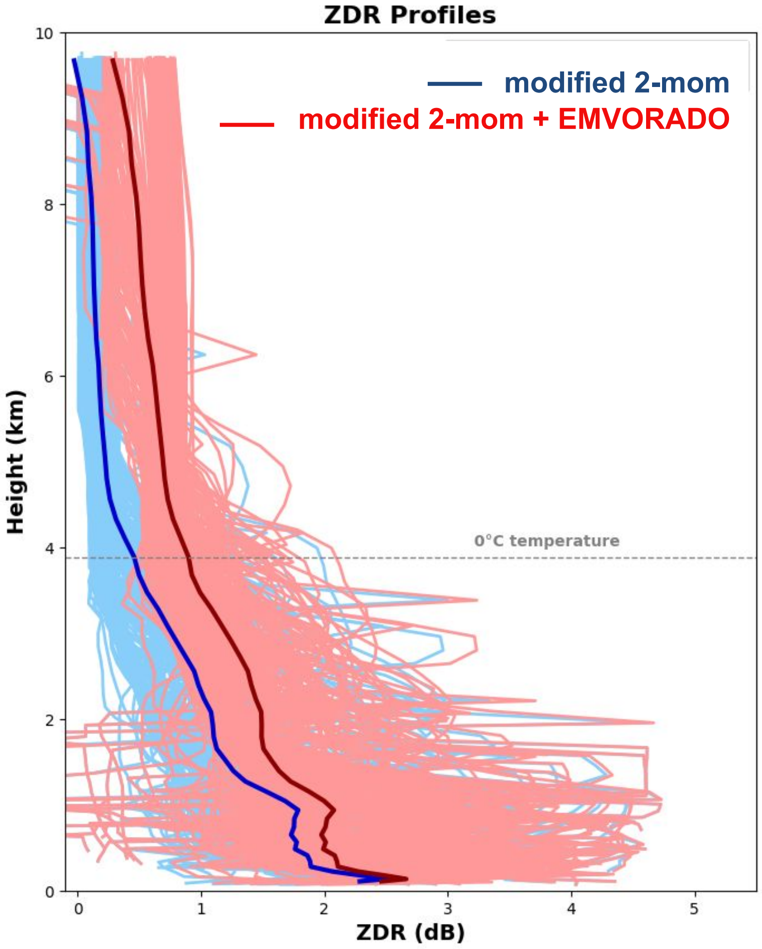




Summary and Outlook

Summary:

- The OSSE system has been successfully tested and implemented for radar reflectivity, showing promising results. It is now ready for implementation in ZDR column assimilation.
- ZDR output over model gridpoint has undergone quality control and is now suitable for use in defining the ZDR column.
- The ICON 2-moment microphysics and EMVORADO schemes were analyzed and modified to improve the ZDR column, particularly above the melting layer. The modified ZDR column now allows for a more realistic definition of the ZDR column by applying more appropriate thresholds compared to observed ZDR data.

Next Steps:

- Define the ZDR column as a new observation object within the assimilation system.

Thank you for your attention

Dr. Kobra Khosravian
German Weather Service
(Data Assimilation Group)
Address: Frankfurter Str. 135 63067 Offenbach
Tel: +49 (69) 8062-3186
E-Mail: kobra.khosravianghadikolaei@dwd.de

backup slides

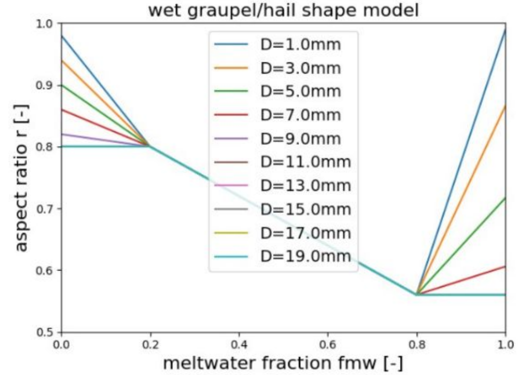
The aspect ratio relation of dry and wet hail/graupel

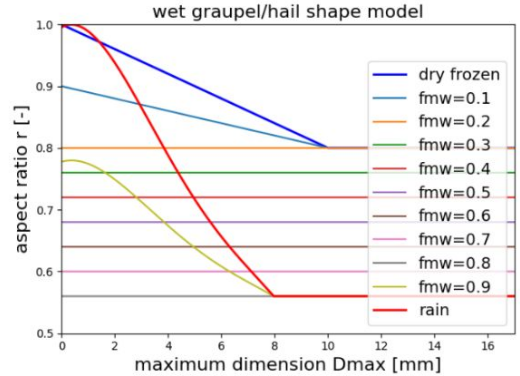
shape

- **rain**: $r_w = 0.9951 + 0.025\,10D - 0.036\,44D^2 + 0.005\,303D^3 - 0.000\,249\,2D^4$ > 0.56

- **dry** graupel/hail:
$$r_{gh} = 1.0 - 0.02D \quad \text{if} \quad D < 10\,\text{mm}$$
$$r_{gh} = 0.8 \quad \text{if} \quad D > 10\,\text{mm}$$

- **wet** graupel/hail:
$$r_m = r_{gh} - 5.0(r_{gh} - 0.8)f_{mw} \quad \text{if} \quad f_{mw} < 0.2$$
$$r_m = 0.88 - 0.40f_{mw} \quad \text{if} \quad 0.2 < f_{mw} < 0.8$$
$$r_m = 2.8 - 4.0r_w + 5.0(r_w - 0.56)f_{mw} \quad \text{if} \quad f_{mw} > 0.8.$$





Plots form J. Mendrok

Changing some settings related to the hail and graupel in EMVORADO

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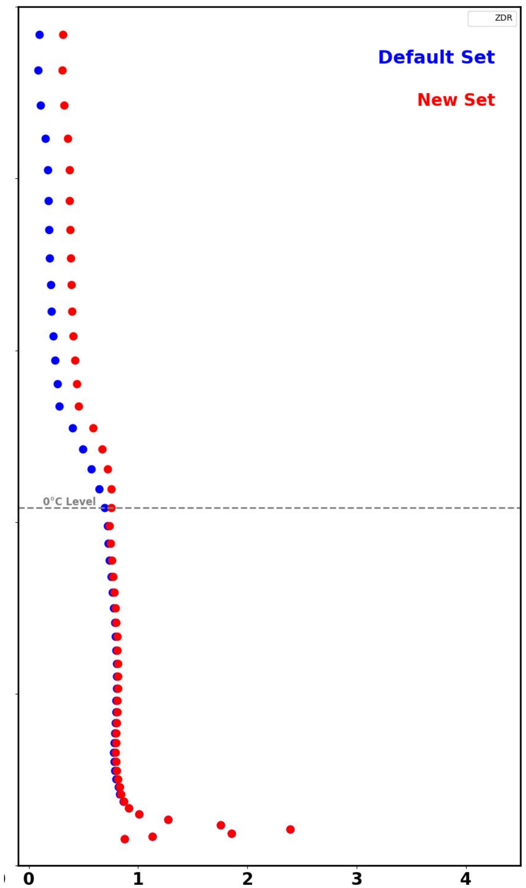
Changing the aspect ratio

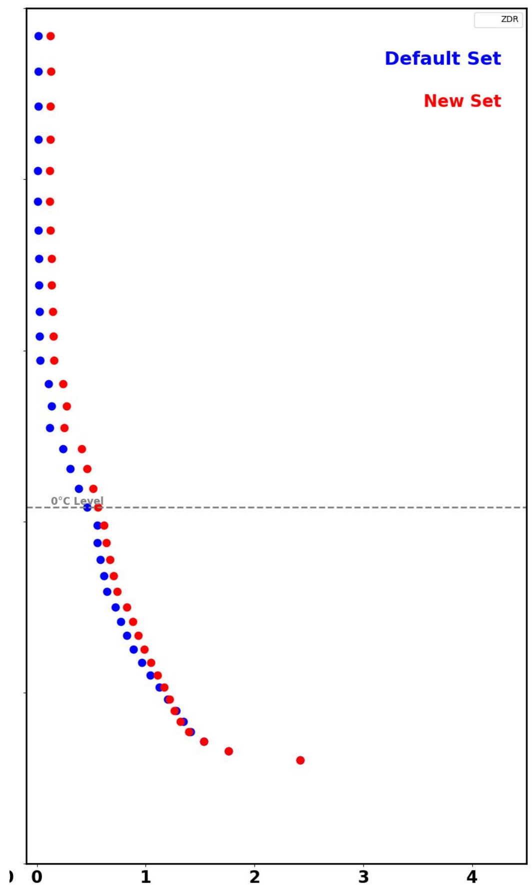
Default setting: 0.8<AR dry Hail <1.0

New setting: 0.7<AR dry Hail <0.8



Default setting: 0.8<AR dry Graupel <1.0

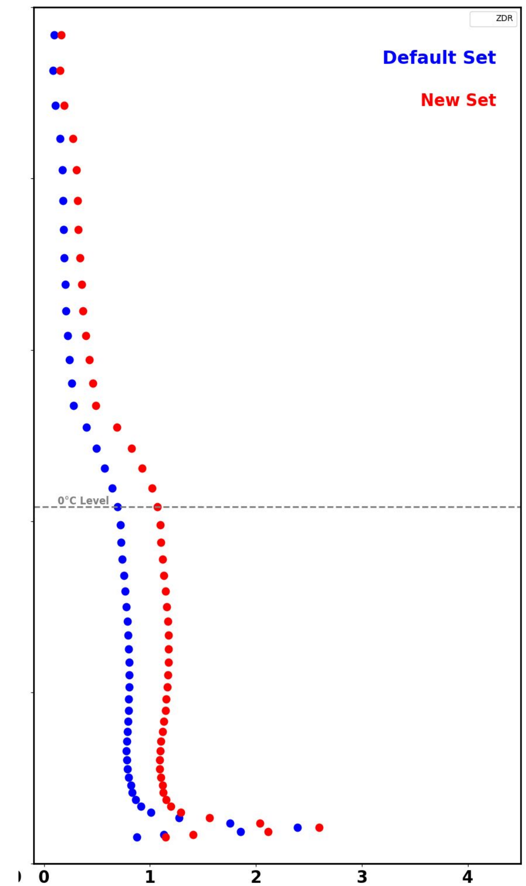
New setting: 0.7<AR dry Graupel <0.8

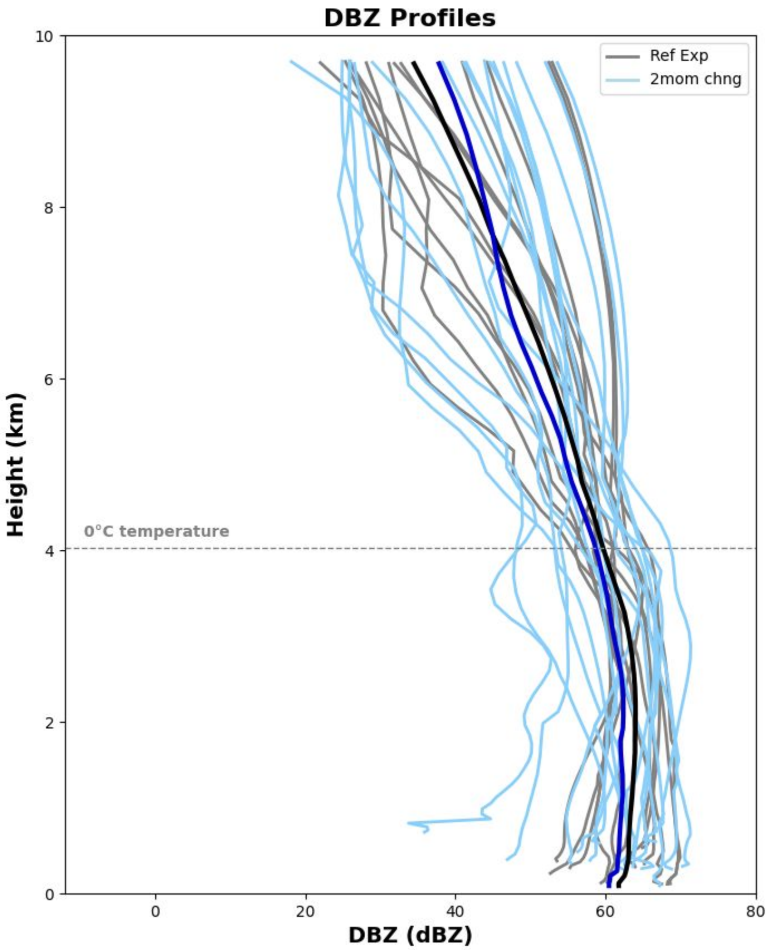


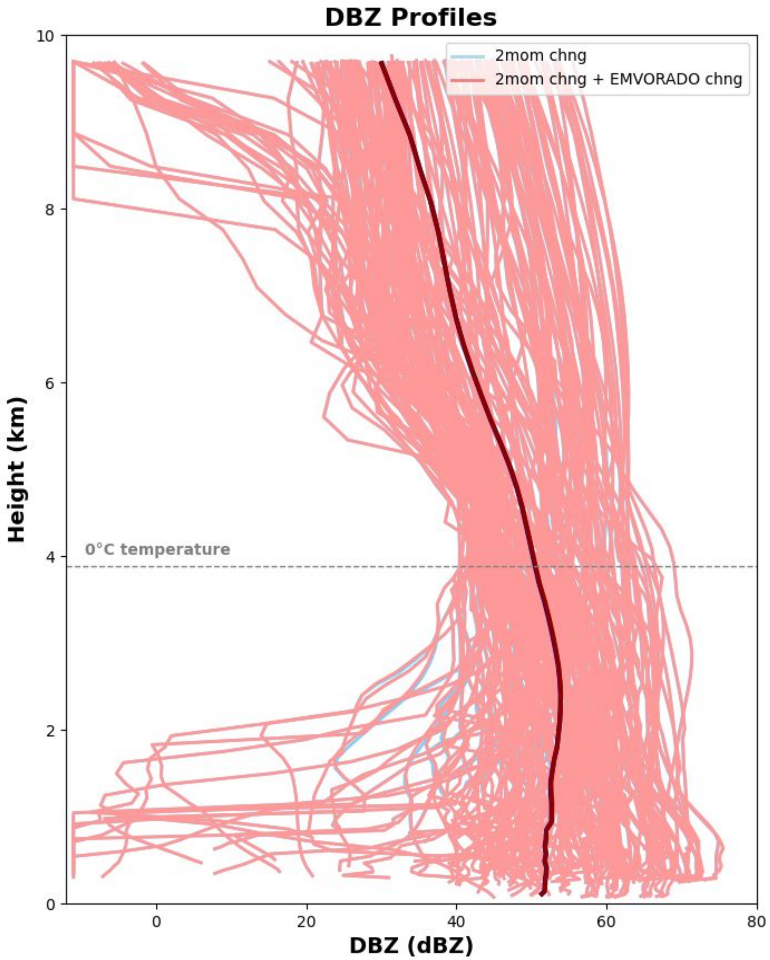
Changing the canting angle

Default setting: h%sig=40

New setting: h%sig=30



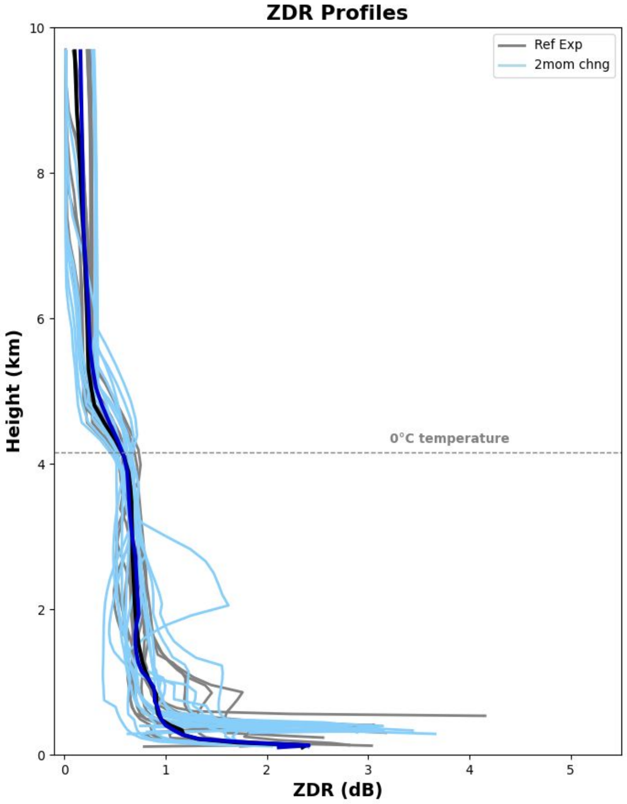

DBZ Profiles
Ref Exp
2mom chng
0°C temperature
Height (km)
DBZ (dBZ)
0
2
4
6
8
10
20
40
60
80

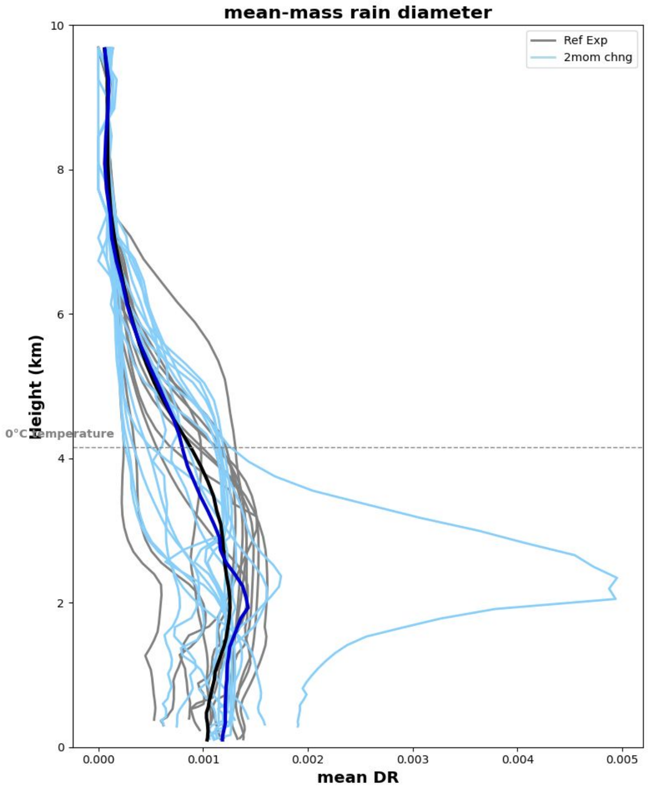

DBZ Profiles
2mom chng
2mom chng + EMVORADO chng
0°C temperature
Height (km)
DBZ (dBZ)
0
2
4
6
8
10
20
40
60
80

Modifications in Model Microphysics to Enhance the Diameter of Supercooled Water Droplets

We applied several modifications to the model's microphysics to investigate their impact on water droplet size. As an example:

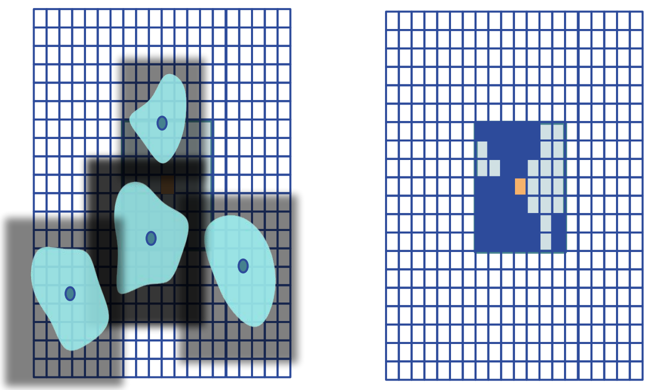
- Increasing the **probability collision of rain droplet** by a factor of 2





The Idea/The Method for Data Assimilation

Object Assimilation



$$\mathrm{FBS} = \frac{1}{N} \sum_i \sum_j \left(F^{ij}_{\mathrm{obs}} - F^{ij}_{\mathrm{mod}}\right)^2$$

$$\mathrm{FSS} = 1 - \frac{\mathrm{FBS}}{\mathrm{FBS}_{\mathrm{ref}}}$$

Fractions Skill Score

FSS considers how close we get to obs at a certain **threshold** and **spatial scale**.

Idea: we can actually just assimilate ***F***, i.e. :

define an **Object** by a threshold
define a **neighborhood box** for gridding
create **obs** and **model equivalents**
feed it to the assimilation system and see what happens

From L. Neef