# Model/observation comparisons with dual-polarization radar data on a number of severe convective cases

**Cloé DAVID**[1], C. Augros[1], B. Vie[1], F. Bouttier[1]

PROM meeting, Leipzig, 24 – 26 July 2024

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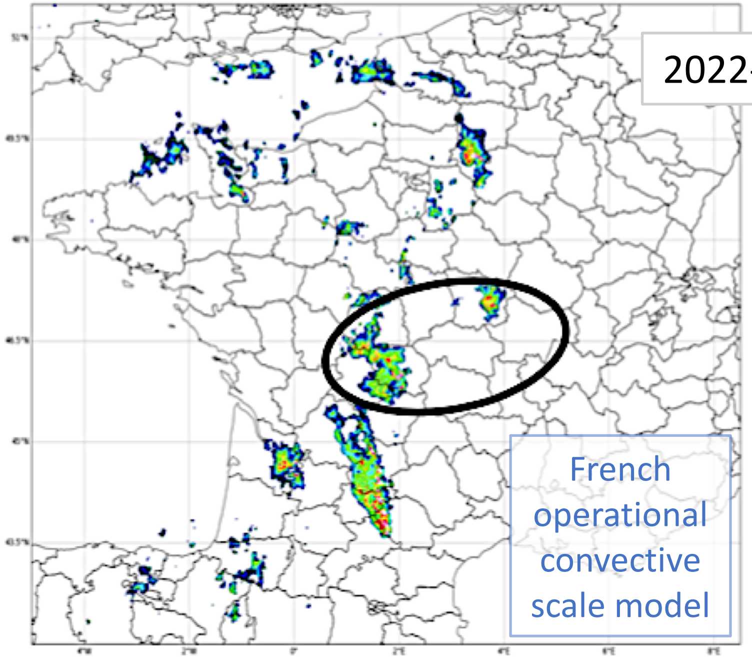
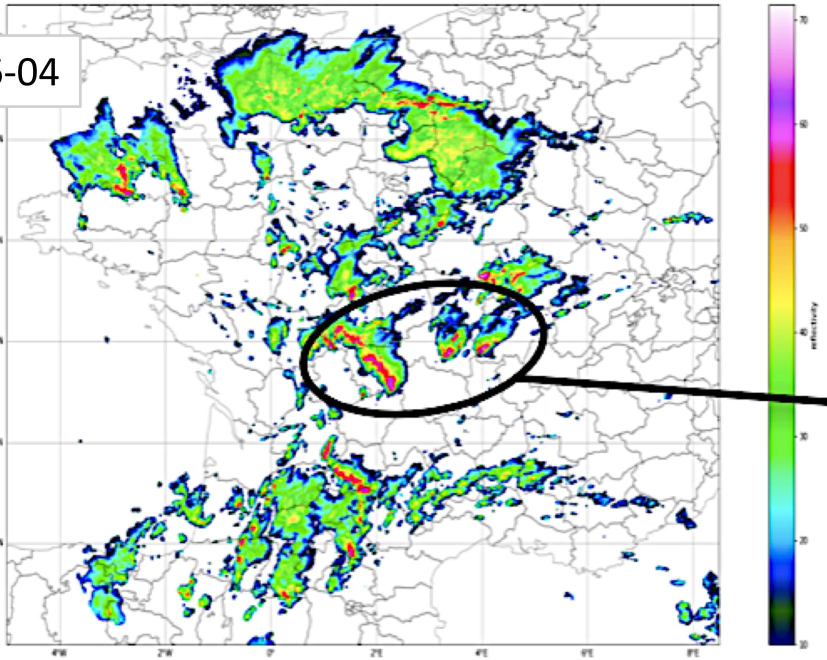
# Context

AROME forecast issued at 00Z
925 hPa reflectivity at 23 UTC




radar reflectivity observed at 23:00 UTC



June 4th, 2022 tweet


- What can we do to improve thunderstorm forecast ?
  - increase model resolution
  - improve assimilation systems
  - use more complex microphysics schemes
  - assimilate new observations

PhD : Contribution of polarimetric observations to enhance thunderstorm forecasting with the LIMA microphysics scheme

# Objectives

## Contribution of polarimetric observations to enhance thunderstorm forecasting with the LIMA microphysics scheme

Main questions :

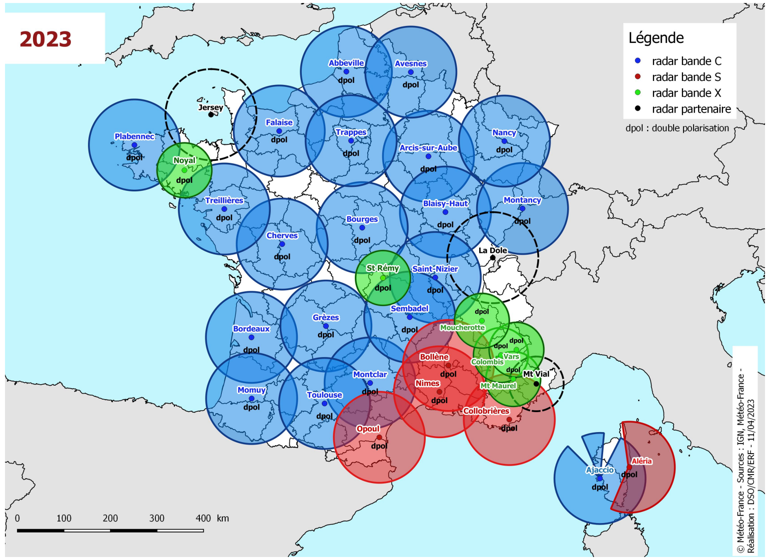
1. Is the model able to reproduce polarimetric signatures and especially $Z_{DR}$ columns ?
2. What are the statistical differences between observations and model coupled to different microphysics schemes ?

# In this presentation…

- Data and pre-processing
- Methodology
- Qualitative comparisons
- Statistic evaluation
- Conclusions and perspectives

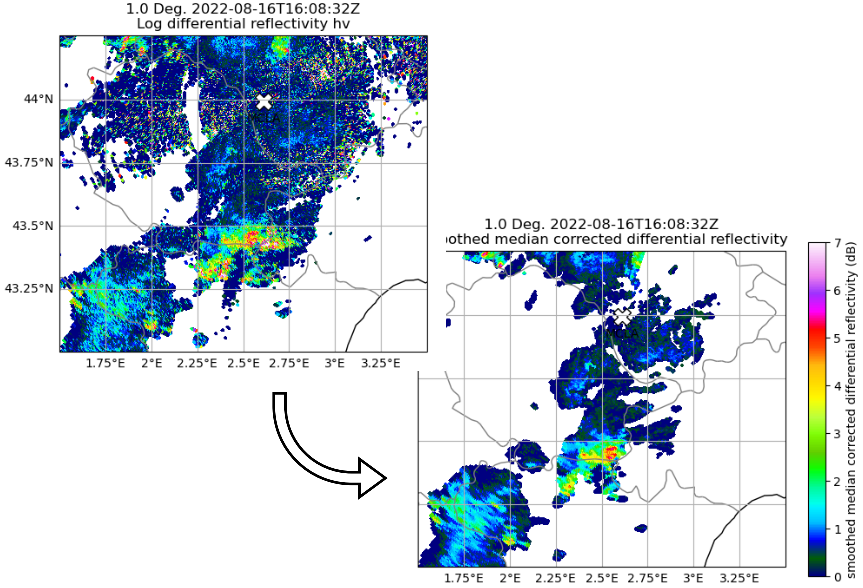
# Data and pre-processing

## Observations



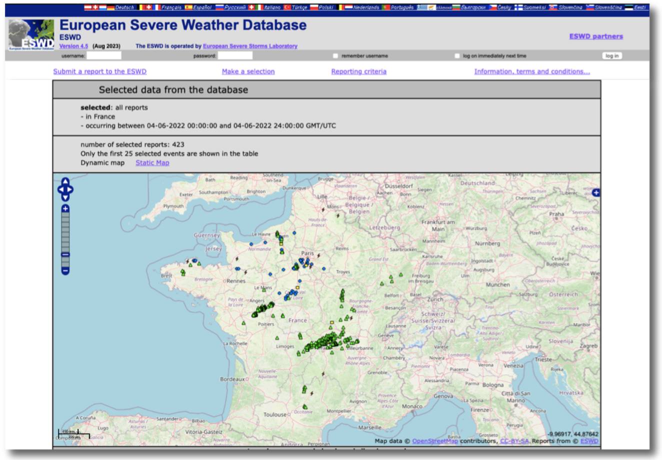

**Radar data**

- ➢ Full dual polarization radar network
- ➢ Mostly C band radars
- ➢ Complete coverage over France
- ➢ 360° scans at 6 elevation angles
- ➢ Native resolution : 240 m / 0.5°




**Radar data pre-processing**

1. Removing non meteorological echoes
2. Noise reduction (applying a median filter on 3 gates and 3 azimuths)
3. Interpolation into a cartesian grid




**Quality controlled crowd source observations (ESWD)**

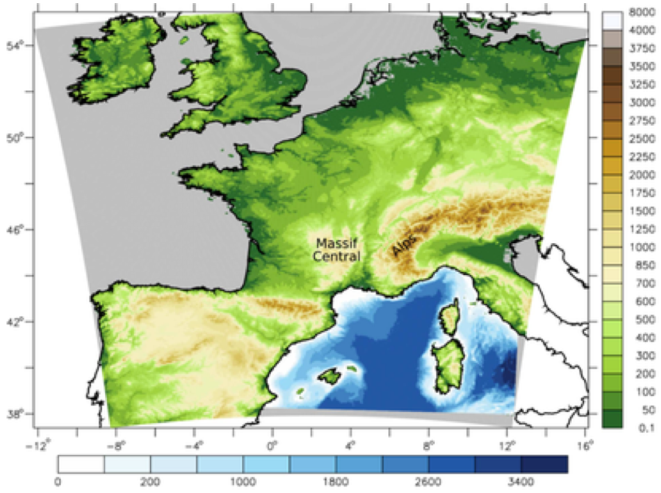
ESSL website

European Severe Weather Database (ESWD)

# Data and pre-processing

## Model

Sauvage et al, 2020 (fig 1)




**AROME* model**

- non-hydrostatic & limited area
- deep convection resolving
- 90 vertical levels
- 1.3 km horizontal resolution
- 13 prognostic variables
- ICE3 microphysics

***** **A**pplication of **R**esearch to **O**perations at **ME**soscale

# Data and pre-processing

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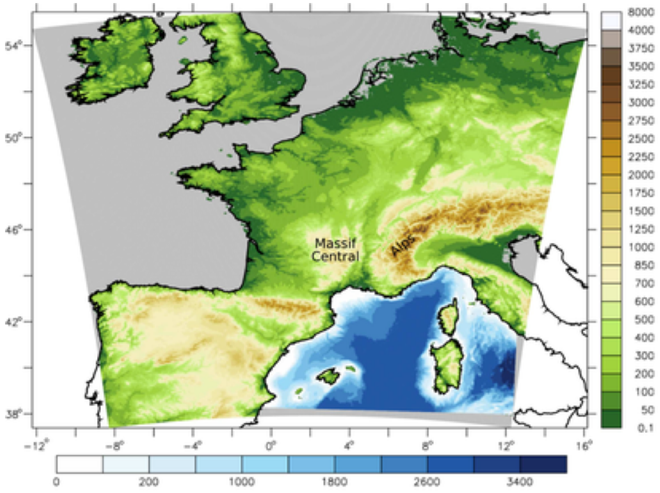


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**Microphysics**

| Scheme | Prognostic variables | |
|---|---|---|
| ICE3 | r (cloud, rain, graupel, snow, ice) | Pinty and Jabouille, 1998 |
| ICE4 | r (cloud, rain, graupel, snow, ice, **hail**) | Pinty and al., 2002 |
| LIMA | r (cloud, rain, graupel, snow, ice, hail) + N (**cloud, rain, ice**) | Vié et al., 2016 |

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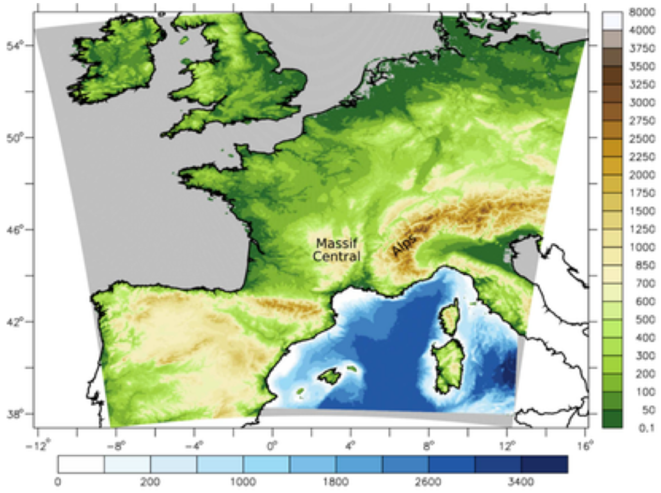
# Data and pre-processing

## Model

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### Model data pre-processing : application of a radar forward operator

*Augros et al., 2016*

- Simulates dual-pol radar variables $Z_H$, $Z_{DR}$, $K_{DP}$ and $\rho_{HV}$
- Hydrometeors = oblate spheroids (T-matrix scattering)
- Axis ratio : following *Ryzhkov et al., 2011*
- Oscillation is neglected
- Particle Size Distribution and mass diameter laws inherited from ICE3 or LIMA
- Dielectric function : Debye (rain) or Maxwell Garnett (combination of ice, air and water) ; single sphere

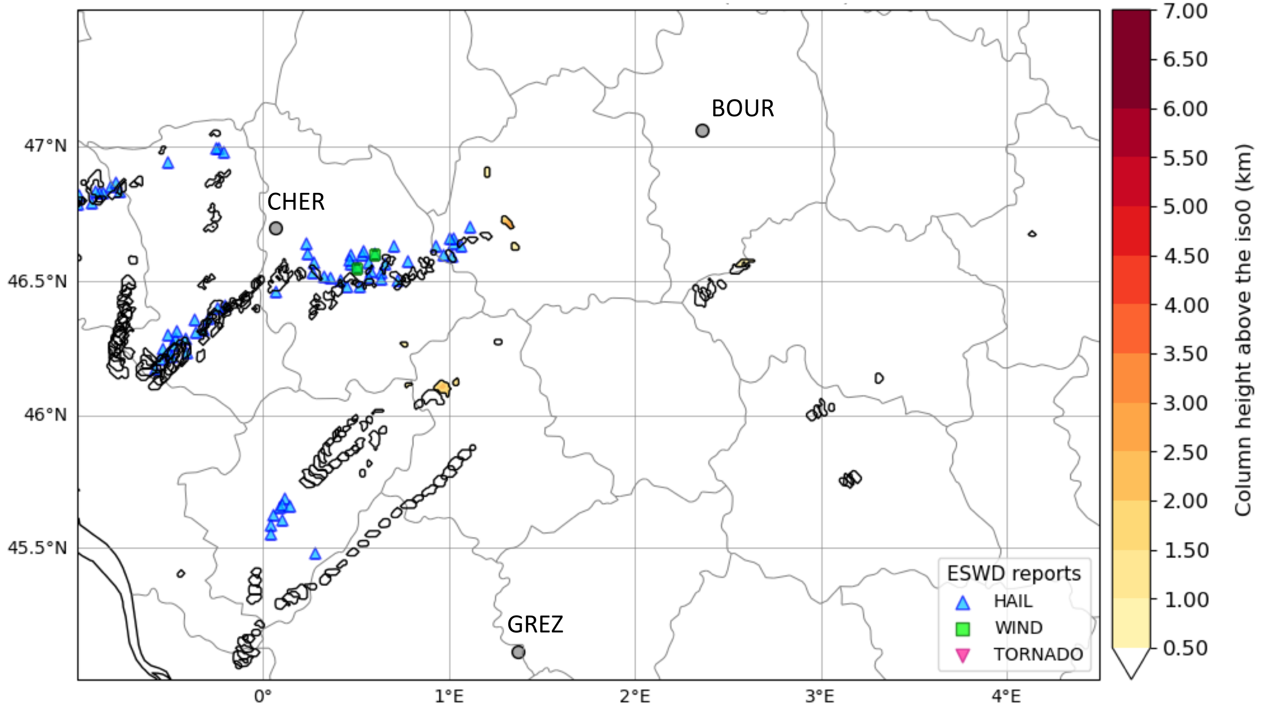


* **A**pplication of **R**esearch to **O**perations at **ME**soscale

# Methodology

→ Implementation of an automatic $Z_{DR}$ column depth computation followed by a tracking algorithm.

Accumulated 500 m column contours (solid black) + column depth value at 20:35 UTC – 22-05-2022




**Legend :**

Hail locations from ESWD website : https://eswd.eu

Column contour at the corresponding timestep if filled

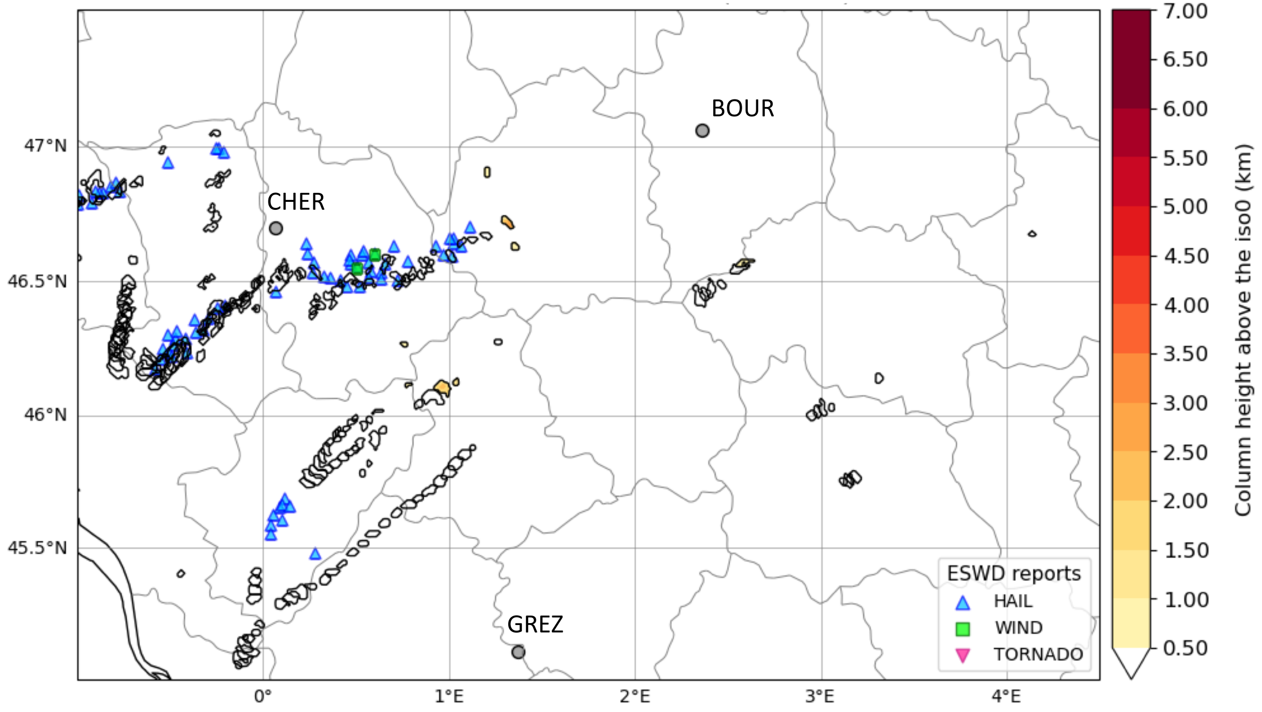
# Methodology

→ Implementation of an automatic $Z_{DR}$ column depth computation followed by a tracking algorithm.

→ Work on **34 convective days of 2022** for a total of 45 case studies (objective selection).


Corsica tempest : 224 km/h wind, 5 deaths

Accumulated 500 m column contours (solid black)
+ column depth value at 20:35 UTC – 22-05-2022




**Legend :**

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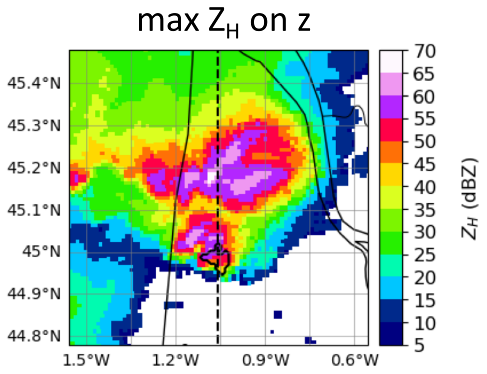
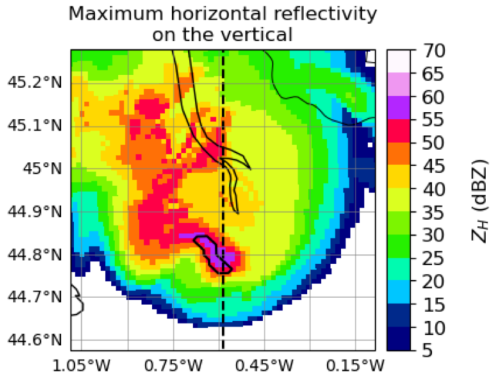
# Qualitative comparisons

20-06-2022 18:00 UTC

observations




AROME
+ ICE3




AROME
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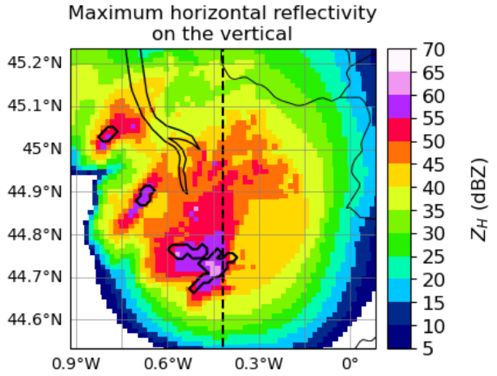



Reflectivity $Z_H$ :

→ lowest intensities with ICE3

→ less intense convective core

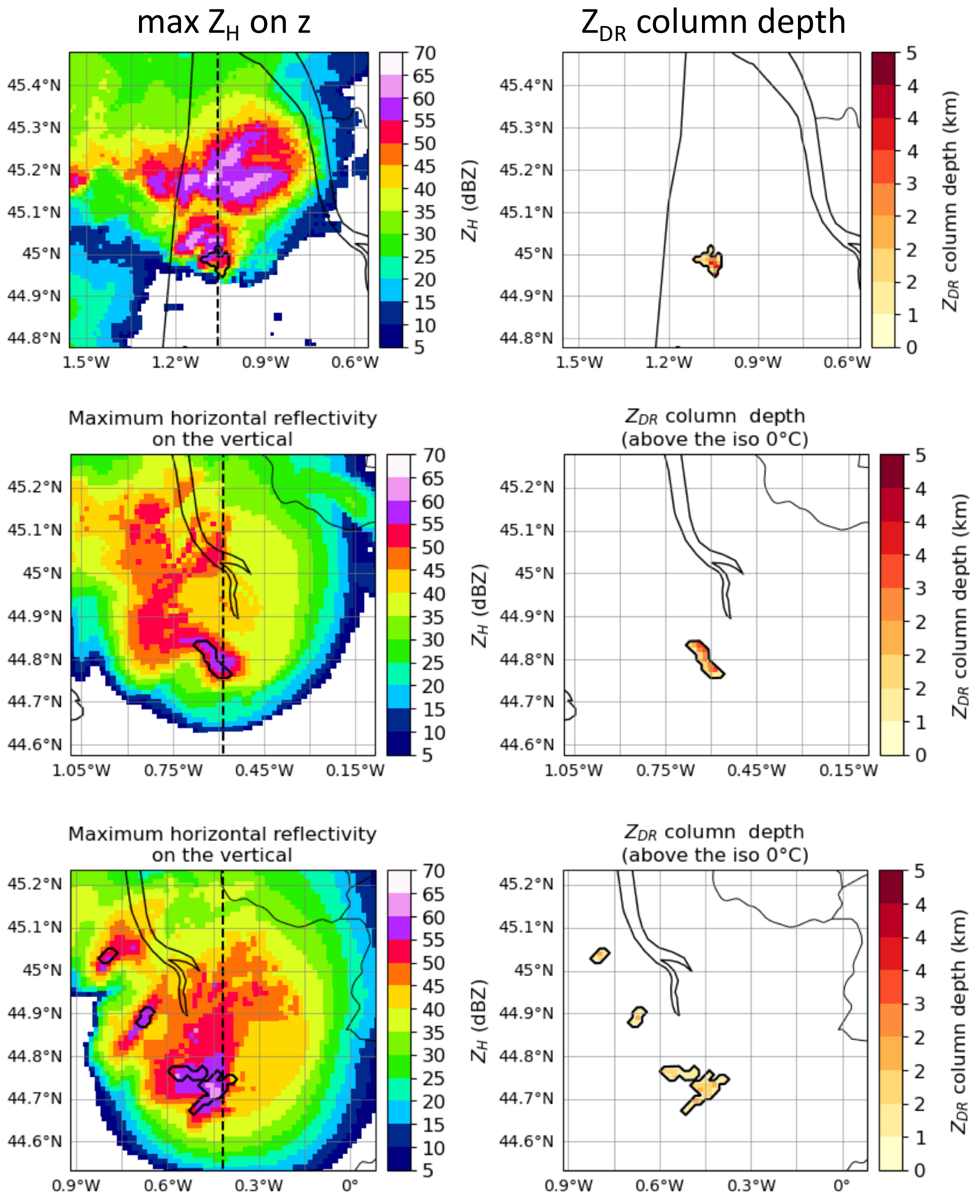
# Qualitative comparisons

20-06-2022 18:00 UTC

observations

AROME + ICE3

AROME + LIMA




Reflectivity $Z_H$ :

- → lowest intensities with ICE3
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$Z_{DR}$ column depth :

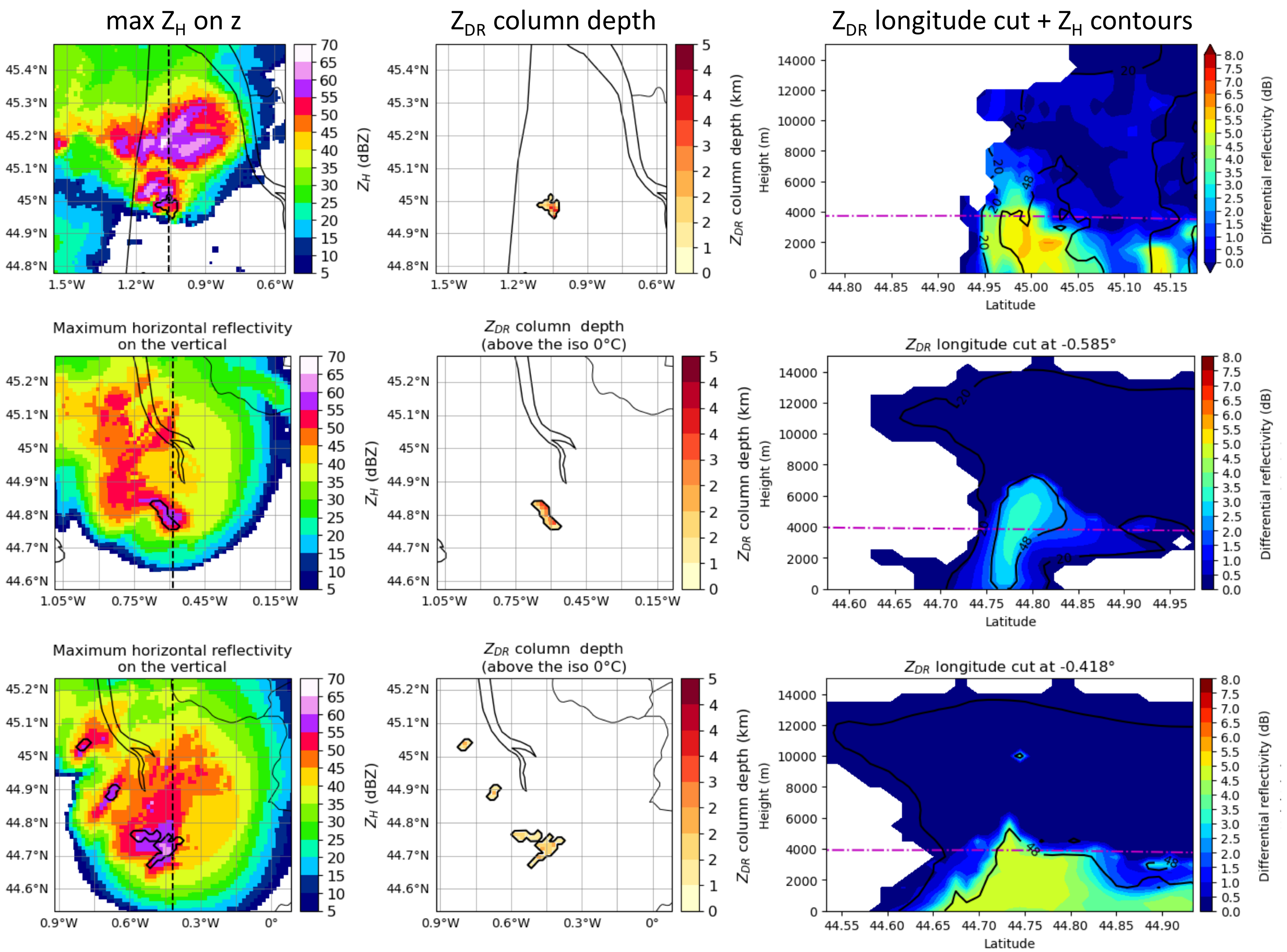
- → higher with ICE3
- → good structure reproduction

# Qualitative comparisons

observations

AROME + ICE3

AROME + LIMA

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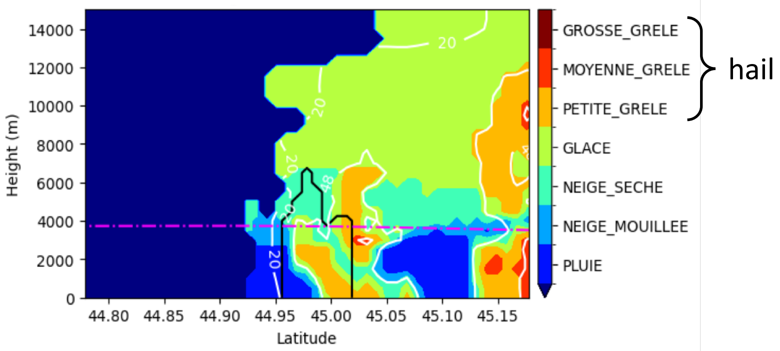
## Differential reflectivity $Z_{DR}$ :

→ LIMA more realistic values

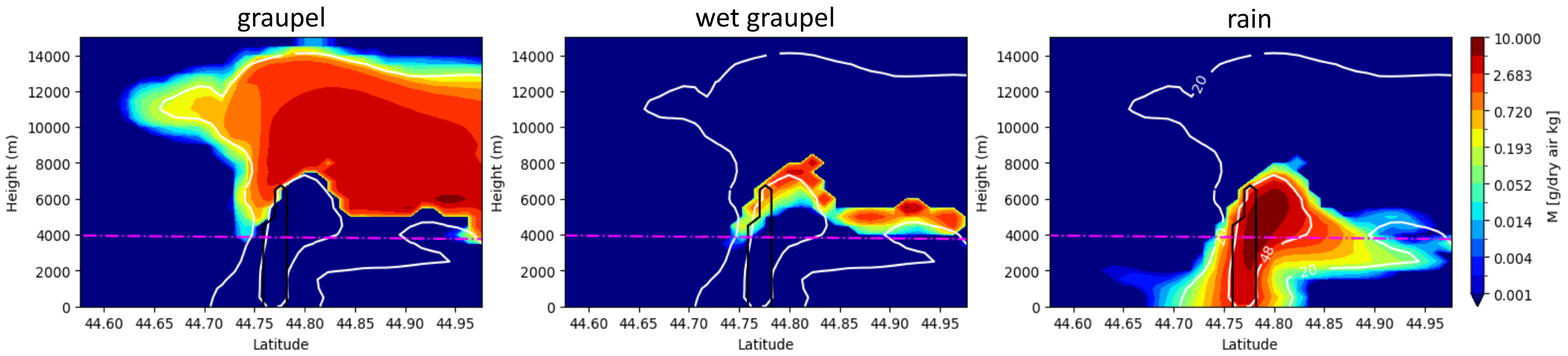
# Qualitative comparisons

20-06-2022 18:00 UTC

observations




AROME + ICE3

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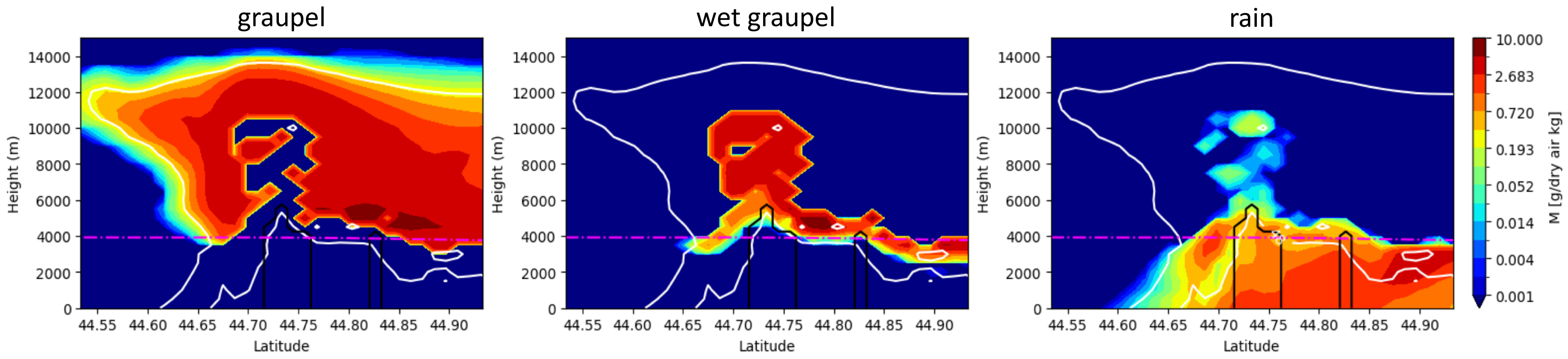



## Reflectivity $Z_H$ :

→ lowest intensities with ICE3

→ less intense convective core

## $Z_{DR}$ column depth :

→ higher with ICE3

→ good structure reproduction

## Differential reflectivity $Z_{DR}$ :

→ LIMA more realistic values

## Hydrometeor contents :

→ coexistence of graupel and rain at high altitudes

→ ICE3 high rain content

# In this presentation…

- [x] Data and pre-processing
- [x] Methodology
- [x] Qualitative comparisons
- [ ] Statistic evaluation
- [ ] Conclusions and perspectives

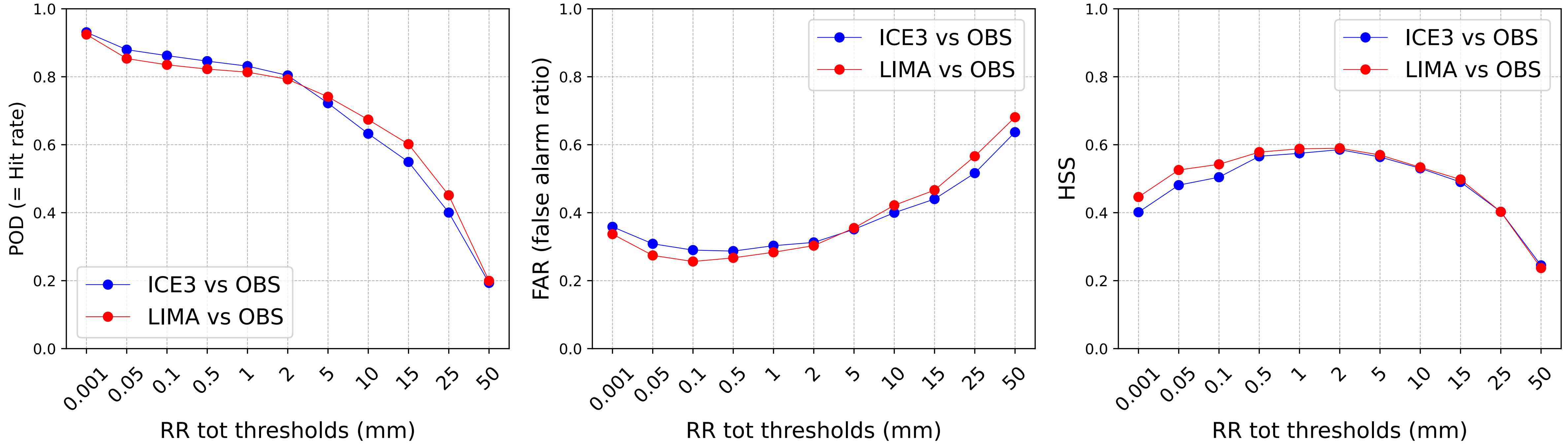
# Evaluation of AROME microphysics : new results

## Cumulative rainfall

➢ “classic” evaluation with POD, FAR and HSS scores calculation for multiple RR thresholds

**METHOD**

- ✓ OBS from ANTILOPE QPE
- ✓ France domain divided into 50 x 50 km boxes
- ✓ Contingency table : Q99 value in each box compared to RR threshold
- ✓ RR tot → the total period is constrained to the duration of each observed event



# Evaluation of AROME microphysics : new results

## Cumulative rainfall

- "classic" evaluation with POD, FAR and HSS scores calculation for multiple RR thresholds
- bootstrap statistical significance testing applied to score differences between LIMA and ICE3

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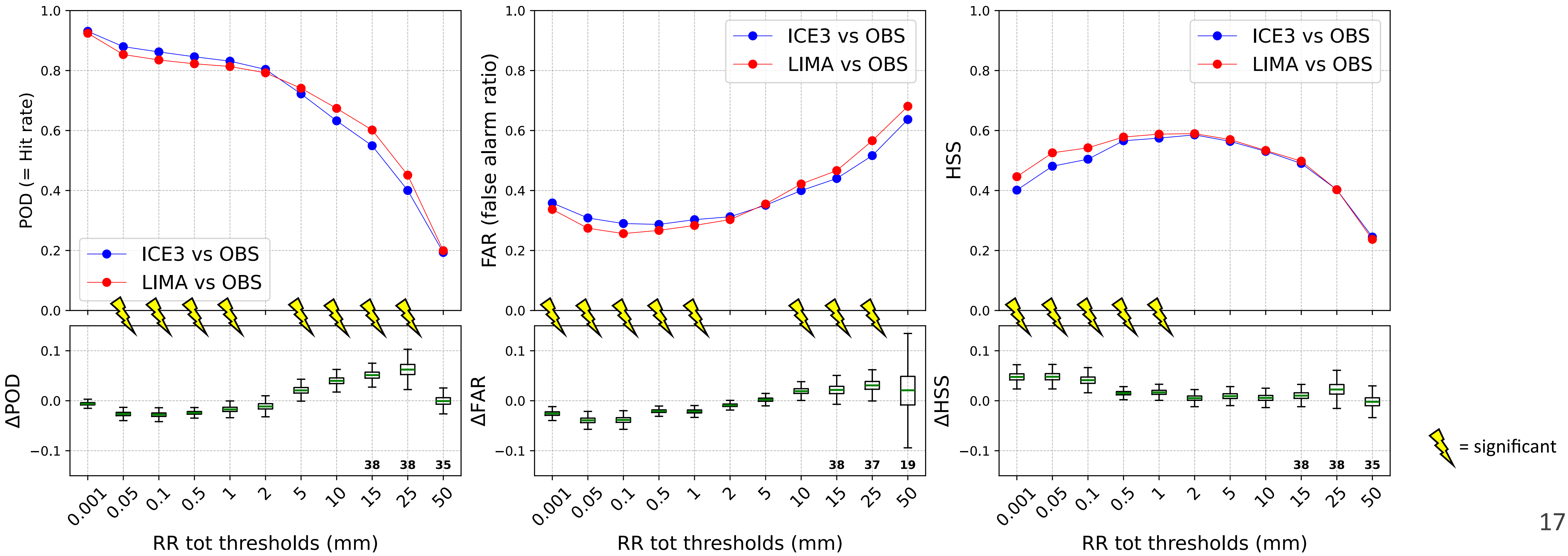

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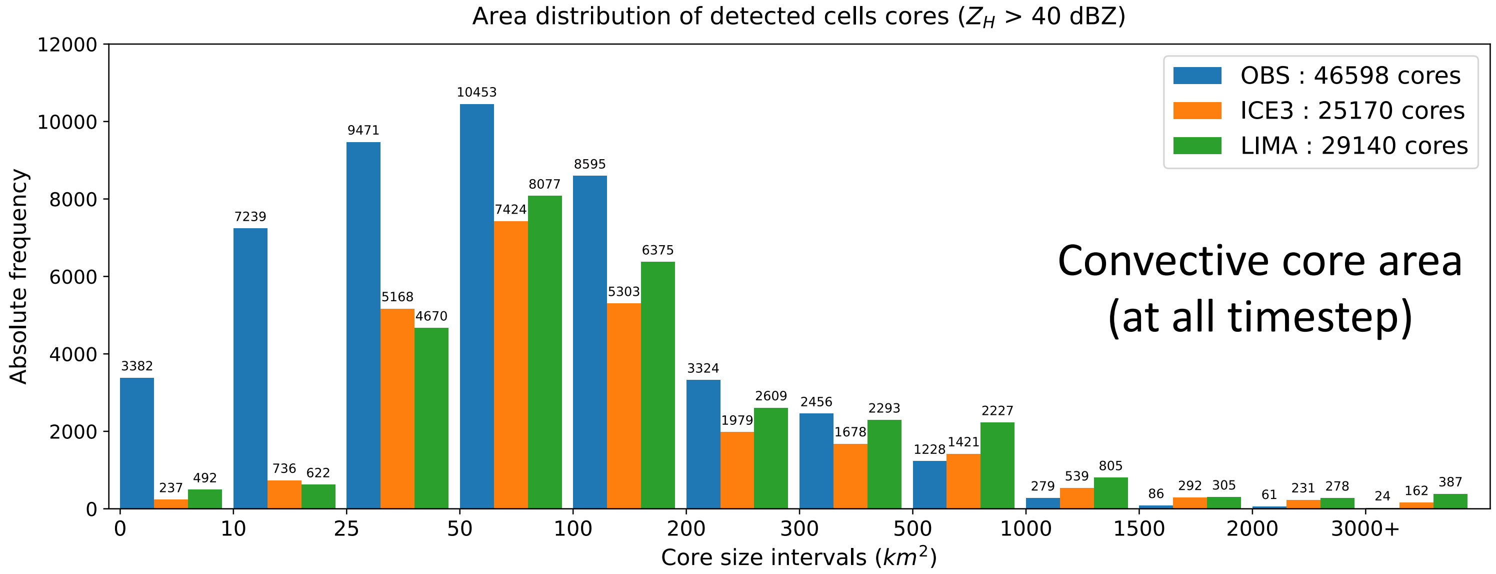


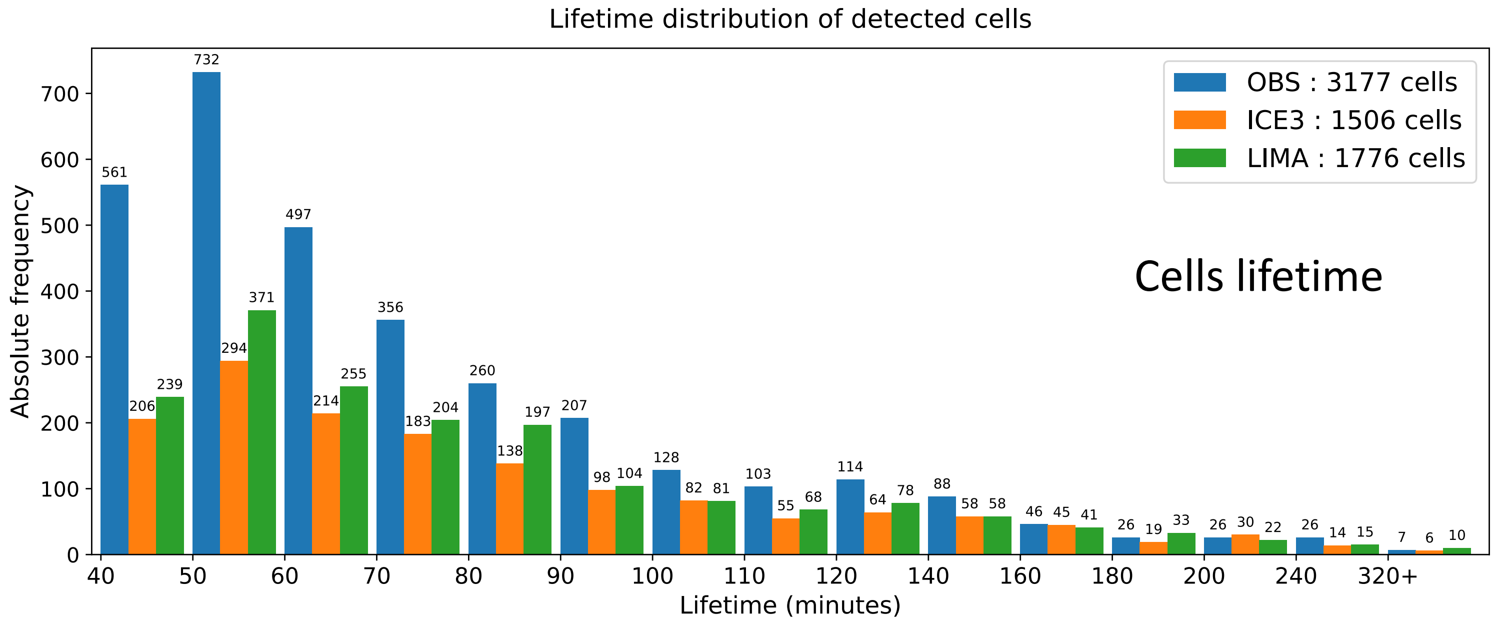


## Cell’s characteristics

- No big differences between ICE3 and LIMA (same order of magnitude)
- Models fail to reproduce small structures and short-lived cells

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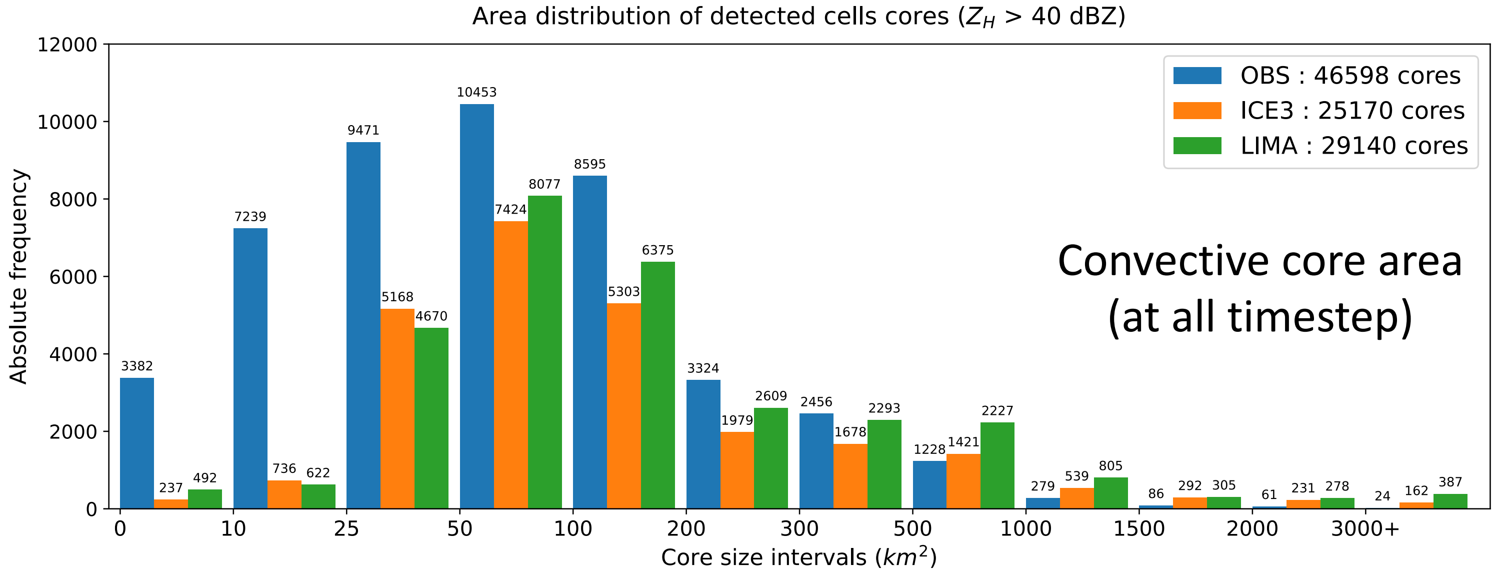
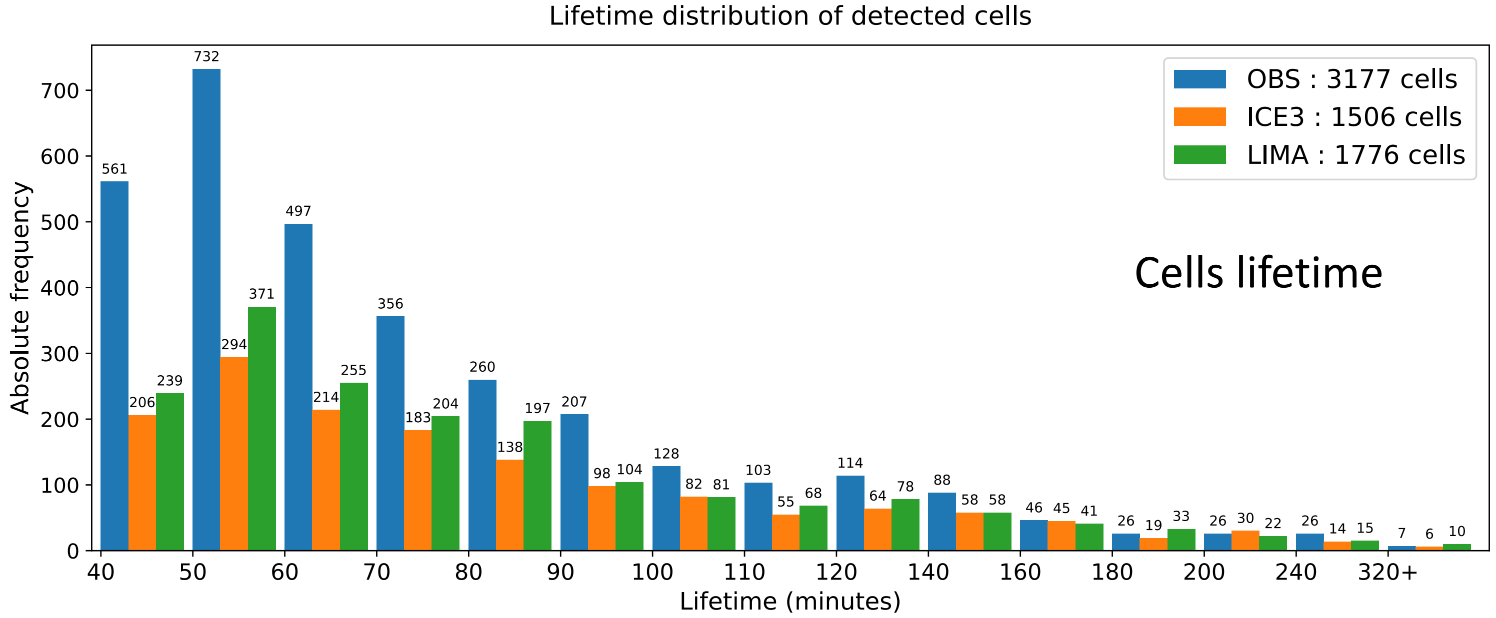



## Cell's characteristics

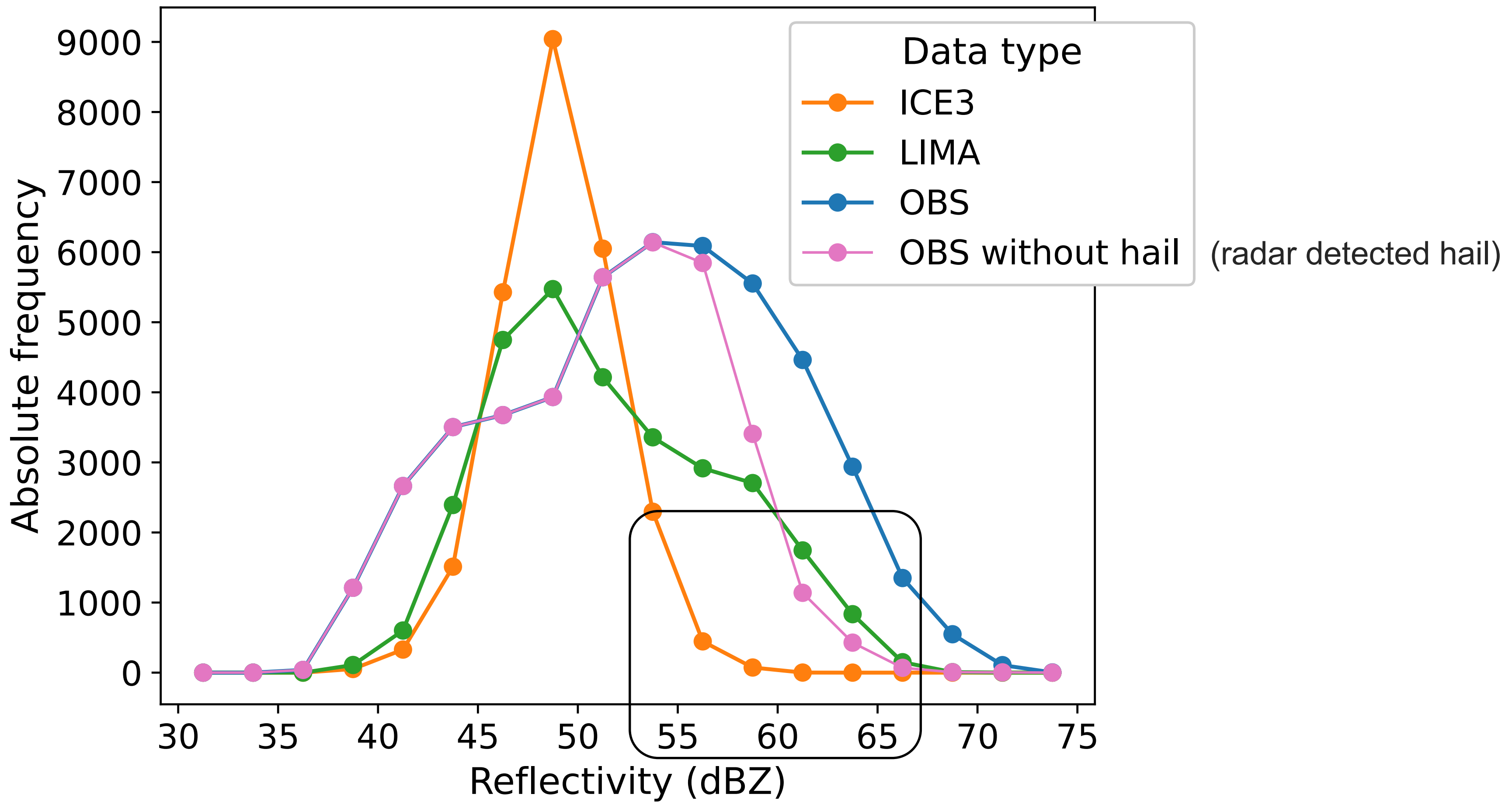
- No big differences between ICE3 and LIMA (same order of magnitude)
- Models fail to reproduce small structures and short-lived cells

| | OBS | ICE3 | LIMA |
|---|---|---|---|
| Total number of detected cells | 3177 | 1506 | 1776 |
| Mean cell lifetime (min) | 75'20'' | 83'45'' | 82'21'' |
| Proportion of cells with a $Z_{DR}$ column | 43.8 % | 26,8 % | 44.5 % |

# Evaluation of AROME microphysics : new results

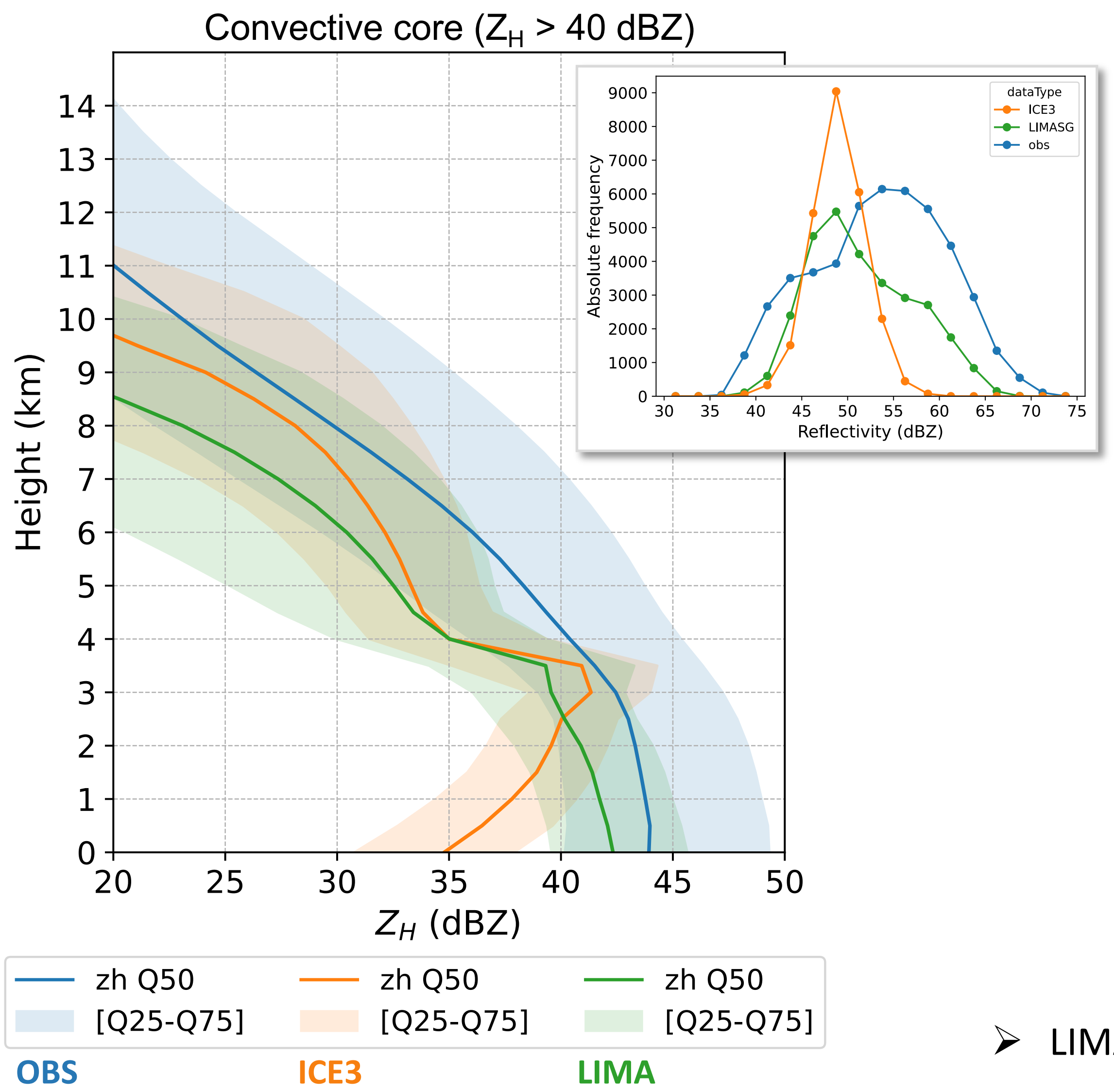
## Reflectivities

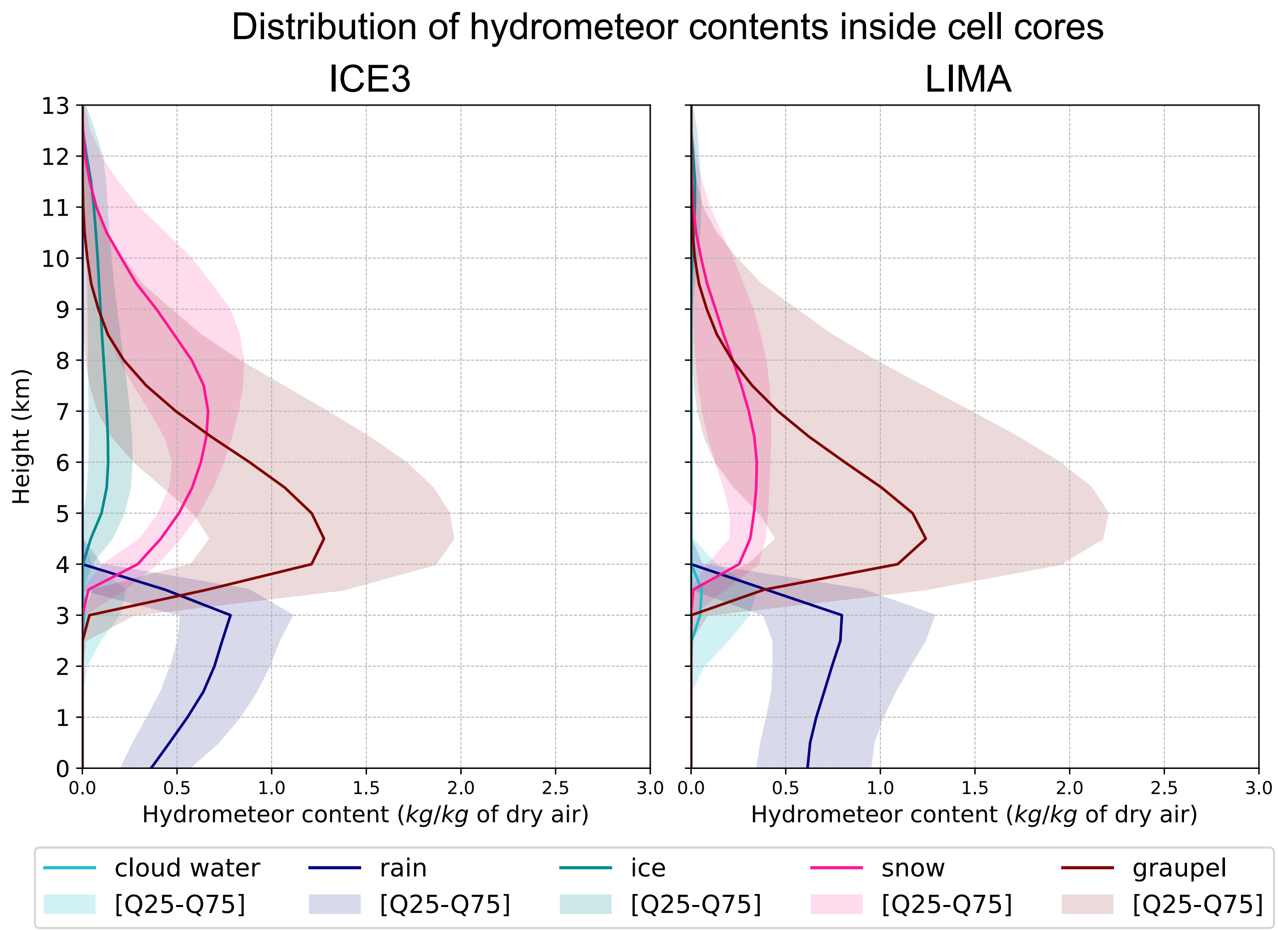
Distribution of the maximum ($Z_H$)



# Evaluation of AROME microphysics : new results

## Reflectivities

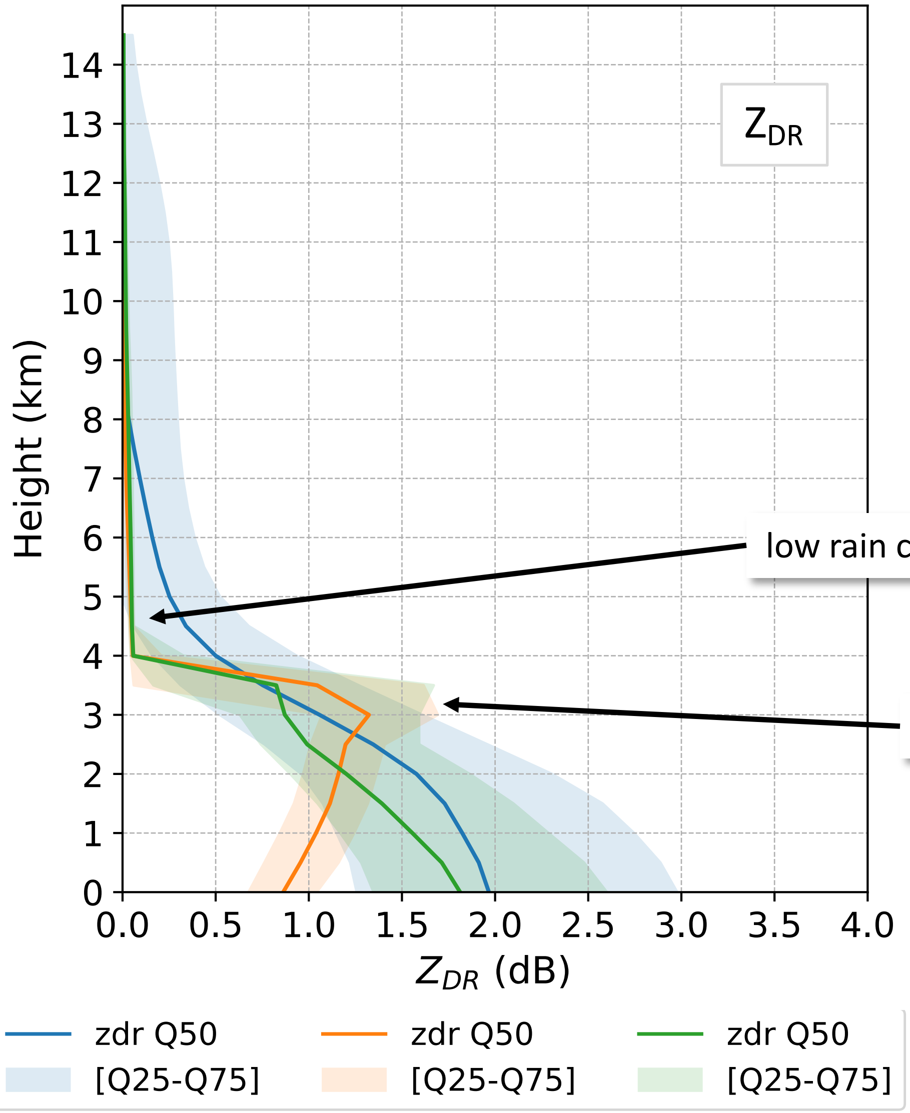



- LIMA better simulates high $Z_H$ under the iso-0°C (in the rain)

# Evaluation of AROME microphysics : new results

## Polarimetric variables

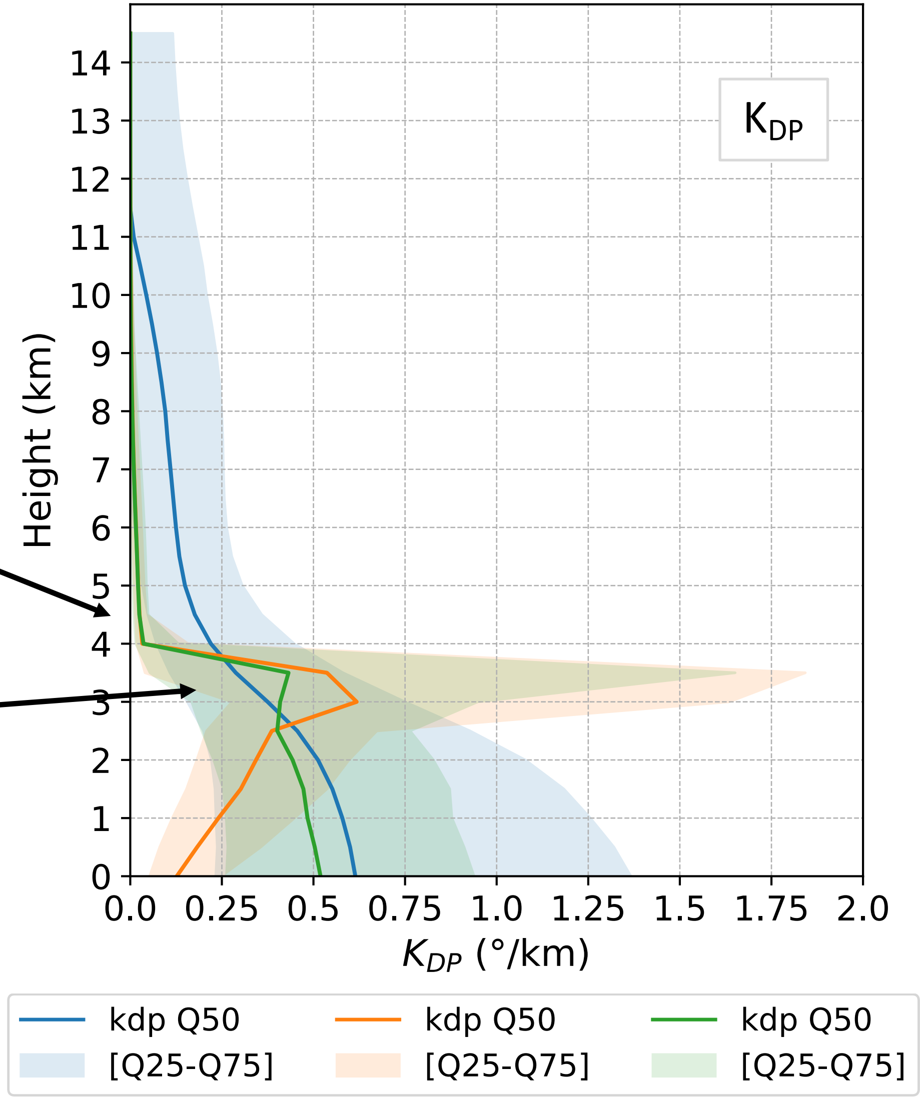



Distributions of $Z_{DR}$ and $K_{DP}$ inside the cell cores

**OBS** **ICE3** **LIMA**

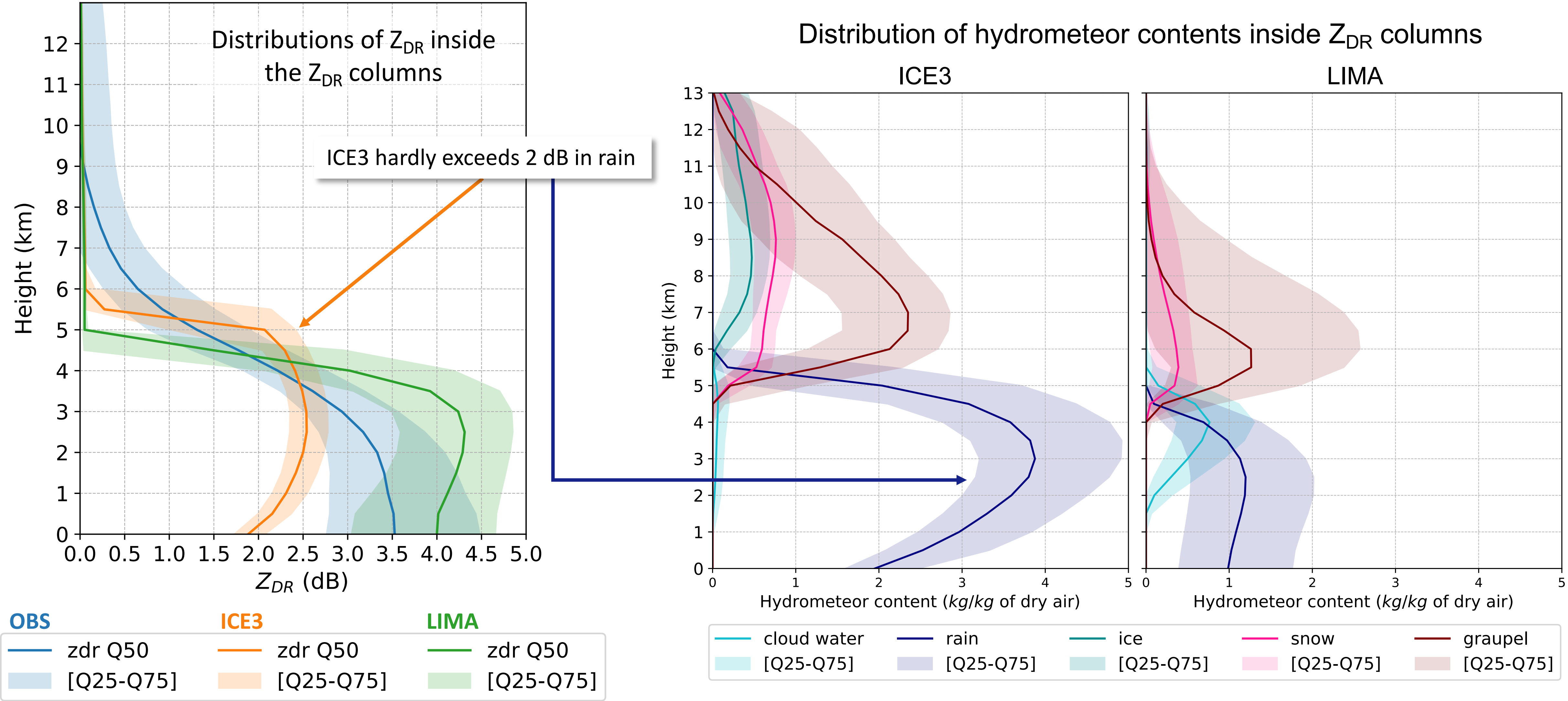
low rain content –> low mixed phase

bright band overestimated



# Evaluation of AROME microphysics : new results

## Spotlight on $Z_{DR}$ columns



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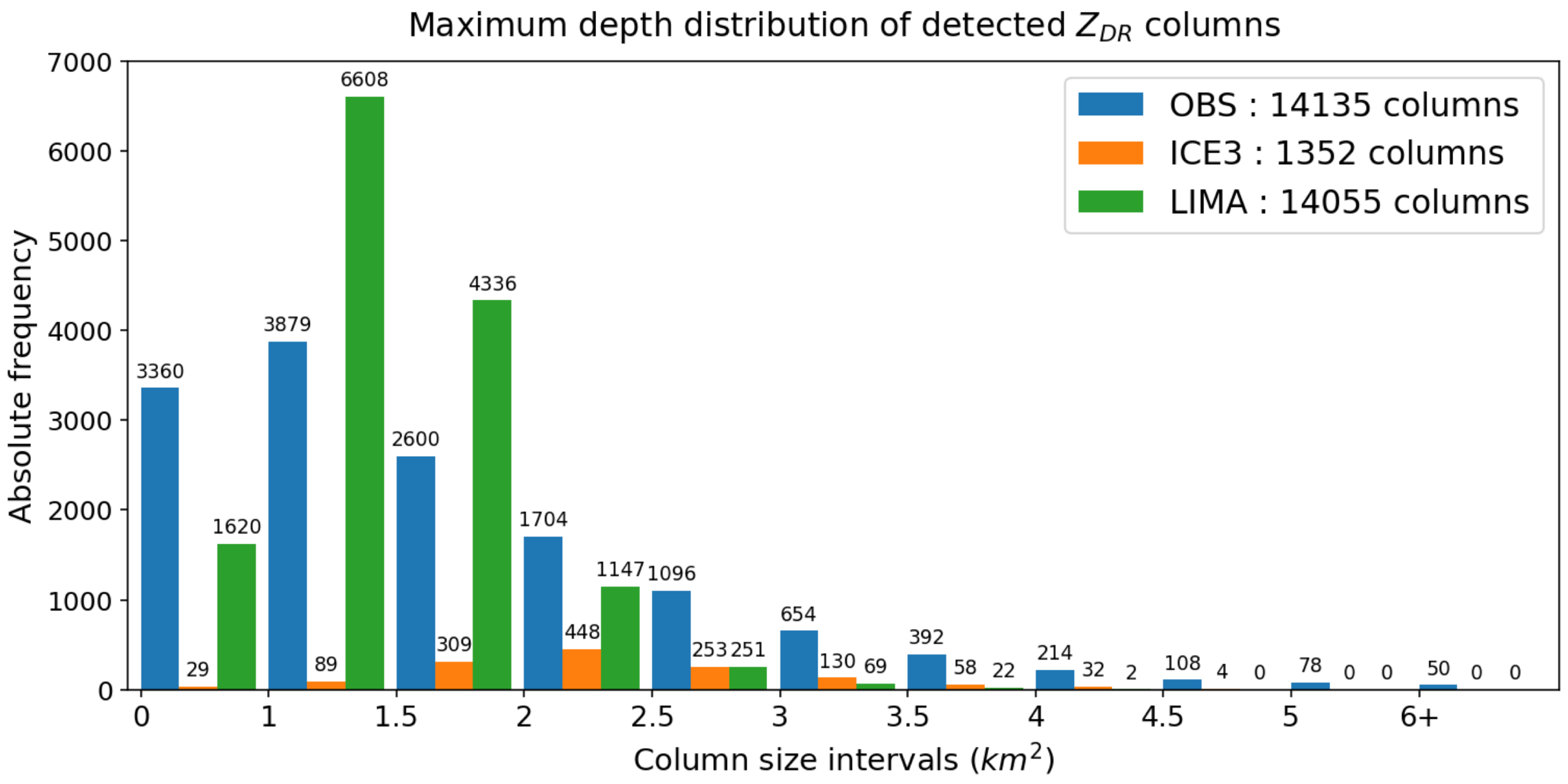
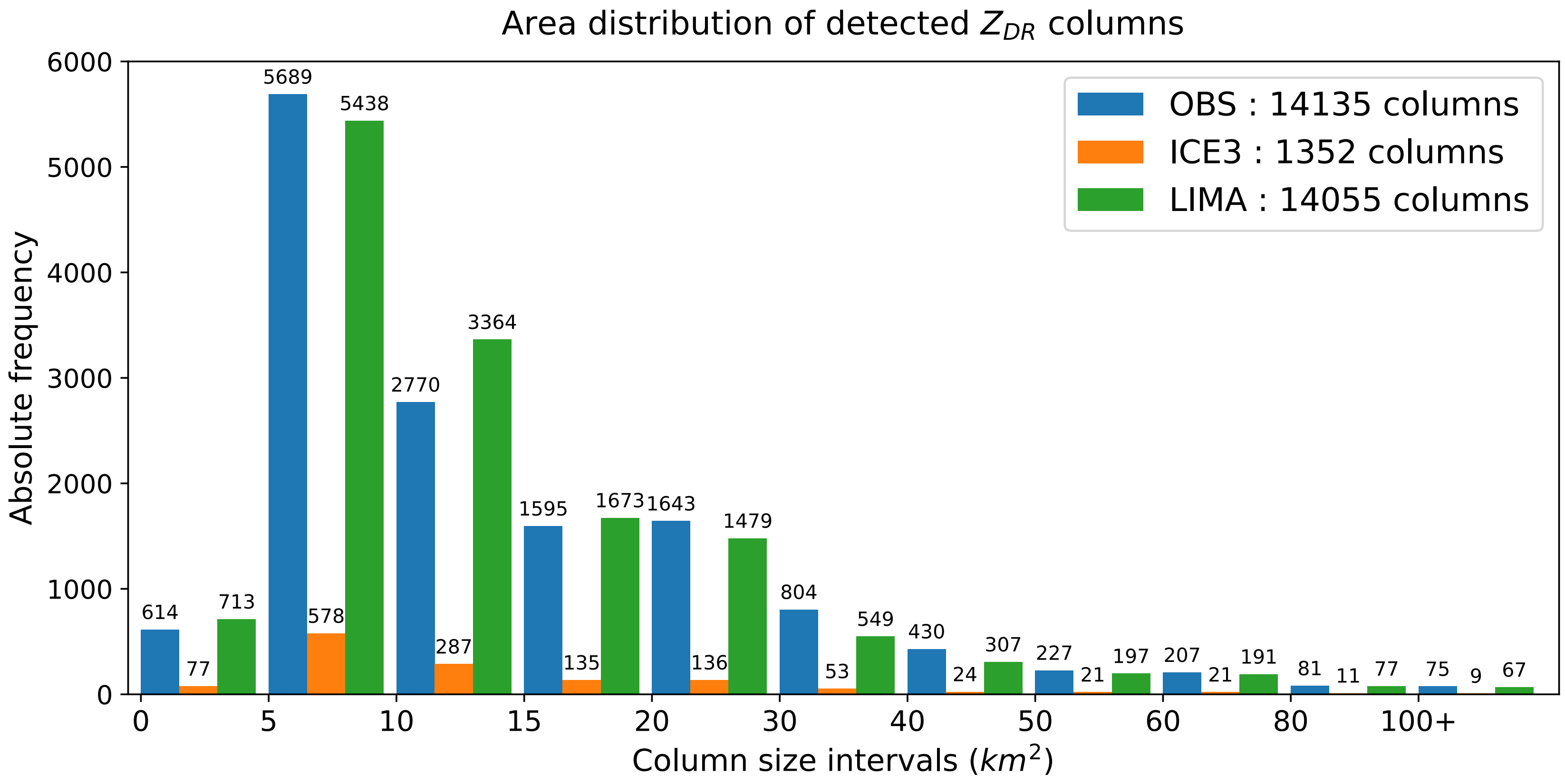
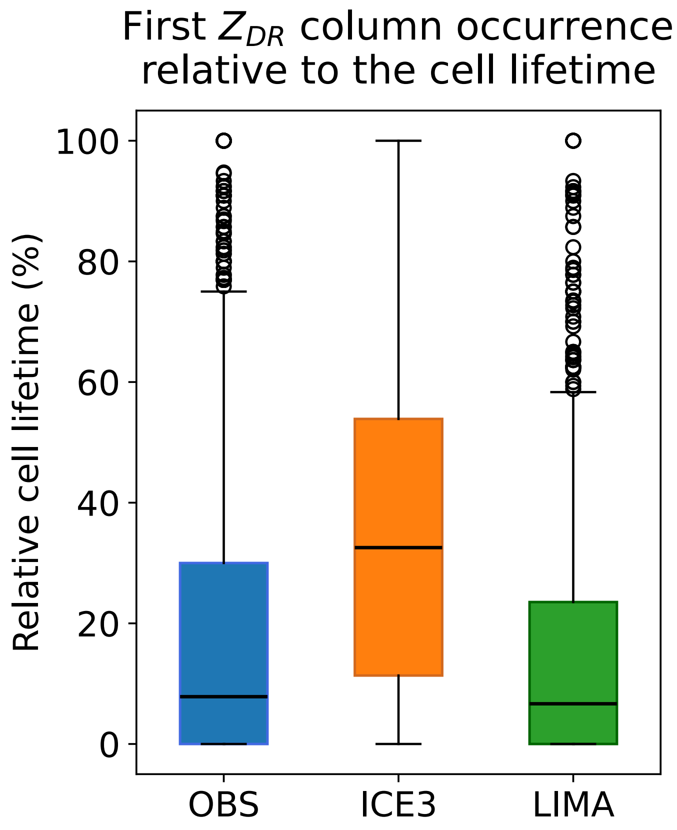



ICE3 succeed to produce high ZDRC contrary to LIMA !

# Evaluation of AROME microphysics : new results

## Spotlight on $Z_{DR}$ columns



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- ☐ Conclusions and perspectives

# Conclusions and perspectives

## Conclusions

- Statistical evaluation of 34 convective days of 2022.
- Global approach and object-based framework.
- *Precipitations* : quite neutral impact (little improvement on low RR ?).
- *Cells characteristics* : no big difference between ICE3 and LIMA. Overall the model struggle to simulate small cells.
- $Z_H$ : ICE3 fail to produce high values under the iso-0°C → too much evaporation.
- $Z_{DR}$ *and* $K_{DP}$ : LIMA far better than ICE3 under the iso-0°C. Some issues in the ice phase due to low ice contents in LIMA (which then reflects in the radar forward operator).
- $Z_{DR}$ *columns* : LIMA's best success in this work. Almost the same characteristics than obs, same amount, very good temporality…

Paper submitted soon (AMT Copernicus)

# Conclusions and perspectives

## Perspectives

1. Improve the *Augros et al. (2016)* radar forward operator
   - ➢ Mixed phase :
     - implementing a 2-layers spheroids T-matrix code (following Ryzhkov et al., 2011, 2013).
     - Implementing a variation of the proportion of water as a function of diameter for mixed phase species (Dawson et al., 2014).
     - Implementing different options to estimates the mixed phase content (Augros et al., 2016 ; Jung et al., 2008 ; Wolfensberger et al., 2018 ; Liu et al., 2024).
   - ➢ Ice crystals :
     - Modifying the shape of ice crystals from sphere to oblate spheroids.

2. Test another version of LIMA scheme, relying on Wurtz et al., 2021 :
   - 2-moments for liquid hydrometeors and 1-moment for ice phase.
   - Same nucleation formula and autoconversion as ICE3.
   - Different snow PSD.
   - Lower computation cost (diagnostic ice concentration, no aerosols to form crystals, etc) → a better candidate for operational use ?

ongoing work

# Thank you for your attention !

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PROM meeting, Leipzig, 24 – 26 July 2024

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# References

**Radar forward operator :**


- Augros, C., Caumont, O., Ducrocq, V., Gaussiat, N. and Tabary, P. (2016), Comparisons between S-, C- and X-band polarimetric radar observations and convective-scale simulations of the HyMeX first special observing period. Q.J.R. Meteorol. Soc., 142: 347-362. https://doi.org/10.1002/qj.2572
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***tobac* (Tracking and Object-Based Analysis of Clouds) Python package :**


- Heikenfeld, M., Marinescu, P. J., Christensen, M., Watson-Parris, D., Senf, F., van den Heever, S. C., and Stier, P.: tobac 1.2: towards a flexible framework for tracking and analysis of clouds in diverse datasets, Geosci. Model Dev., 12, 4551–4570, https://doi.org/10.5194/gmd-12-4551-2019, 2019.
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**Microphysics :**


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- Wurtz, J., Bouniol, D., Vié, B. & Lac, C.(2021) Evaluation of the AROME model's ability to represent ice crystal icing using in situ observations from the HAIC 2015 field campaign. Q J R Meteorol Soc, 147: 2796–2817. Available from: https://doi.org/10.1002/qj.4100

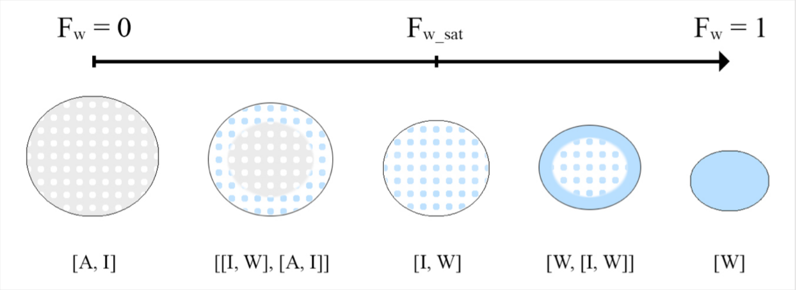
# Appendix : the Augros et al. radar forward operator

| **Main features** *Augros et al., 2016* |
|---|
| ➢ Simulates dual-pol radar variables $Z_H$, $Z_{DR}$, $K_{DP}$ and $\rho_{HV}$ |
| ➢ Hydrometeors = oblate spheroids (T-matrix scattering) |
| ➢ Axis ratio : following *Ryzhkov et al., 2011* |
| ➢ Oscillation is neglected |
| ➢ Particle Size Distribution / mass diameter laws : ICE3 / LIMA |
| ➢ Dielectric function : Debye (rain) or Maxwell Garnett (combination of ice/air/water) (single sphere) |

**Mixed phase model : wet graupel and wet hail**

- graupel and hail = considered wet if coexists with rain
- liquid water fraction $F_w$ of wet hail and/or wet graupel estimated as :

$$F_w = \frac{M_r}{M_r + M_g + M_h}$$




Melting process for graupel (Le Bastard, 2019)