
Supercell approaching Toulouse seen from Météo France site 25/06/2025, photo @Marc Mandement

# Improving AROME NWP Polarimetric Radar Simulations: Selection of Optimal Microphysics and Enhancement of the Radar Forward Operator

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# Motivation

- **Accurate initialization** of **NWP models** via data assimilation → crucial for reliable forecasts.
- **Radar observations** = key contributors in km-scale NWP data assimilation systems
- **AROME-France assimilation system**:

Current:

- ❑ **3DEnVar** (*Brousseau et al., 2025*), preprint https://doi.org/10.5194/egusphere-2025-2642
- ❑ **reflectivity assimilated** via Bayesian humidity retrievals (*Caumont et al 2010, Wattrelot et al 2014*)

Future:

- ❑ **4DEnVar + hydrometeors** in the control variable
- ❑ **direct assimilation** of radar reflectivity
- ❑ Rayleigh scattering forward operator **with TL/AD** (*Maud Martet's work*)

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- **Polarimetric radar observations**:
  - Preliminary Zdr and Kdp data assimilation studies with AROME (*Augros et al., 2018, Thomas, et al. 2020*)
  - But : **not yet operationally** assimilated in AROME-France
  - Require **more accurate simulation of polarimetric variables** via:
    - reliable **polarimetric radar forward operators (PRFO)**
    - accurate **microphysics scheme** in the NWP model

# Objectives

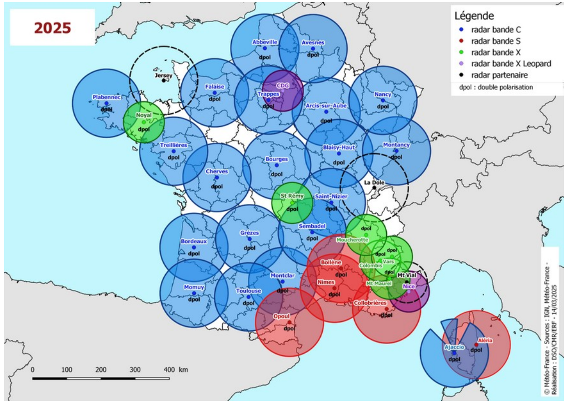
1. **Evaluate polarimetric radar simulations using AROME**:
   - with **ICE3 (1-moment)** & **LIMA (2-partial moment)** microphysics schemes
   - using existing polarimetric radar PRFO (Augros et al, 2016)
   - focus on **severe convective cases**

2. **Implement & evaluate new options** in:
   - the polarimetric radar forward operator
   - the microphysics schemes

# Data overview

🗓️ **Case selection**

- 34 convective days in France (2022)
- selected for hail >= 2 cm occurrence via **ESWD** database (*Dotzek et al., 2009*)

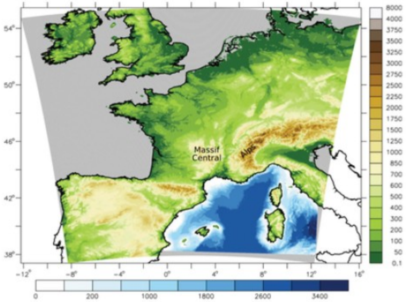



📡 **Radar observations (ARAMIS network – Météo-France)**

- 33 Doppler dual-pol radars S, C, X => in this study: use of C and S bands only
- Variables used: **ZH, ZDR, KDP**
- Quality-processed from operationnal polarimetric processing chain (*Figueras et al. 2012*)
- **Interpolated to 3D Cartesian grid** (1 km horizontal, 0.5 km vertical) using **Py-ART** (*Helmus and Collis, 2016*)

🌀 **AROME-France NWP model**

- 1.3 km resolution, 90 vertical levels, re-forecasts with 5-min outputs (*Seity et al 2011, Brousseau et al 2016*)
- Two microphysics schemes:
  - **ICE3** (*Pinty and Jabouille, 1998):* operational, **1-moment** for cloud droplets, rain, snow, graupel, ice crystals):
  - **LIMA** (*Vié et al. 2016):* research, **partial 2-moment** for cloud droplets, rain, ice crystals



# Data overview

🔁 **Radar forward operator :** *Augros et al. (2016)*, enhanced by *Le Bastard (2019)*

- **T-matrix scattering**: hydrometeors as oblate spheroids (*Mishenko and Travis, 1994*)
- **Axis ratio**:
  - graupel, wet graupel following *Ryzhkov et al. (2011)*
  - dry snow : D < 8mm: AR=1-0.025D, D >=8 mm: AR=0.75
  - ice : spheres
- **Oscillation:** neglected
- **Particle Size Distributions** and **mass-diameter** laws inherited from ICE3 or LIMA
- **Mixed phase model** for wet graupel :
  - graupel transferred to wet graupel category if coexists with rain
  - wet fraction Fw= Mr / (Mg + Mr)
- **Dielectric function**:
  - Debye (rain)
  - Maxwell Garnett (combination of ice, air and water)

https://github.com/UMR-CNRM/operadar

ZH, ZDR and KDP after integration over PSD (ICE3, 1-moment), for T=0°C

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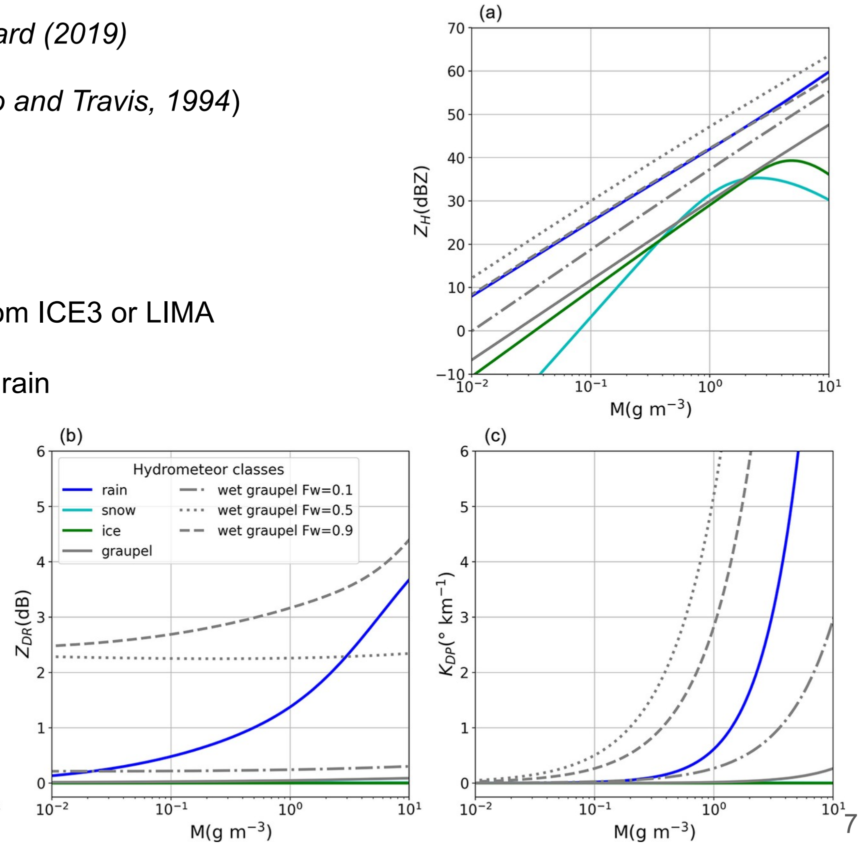


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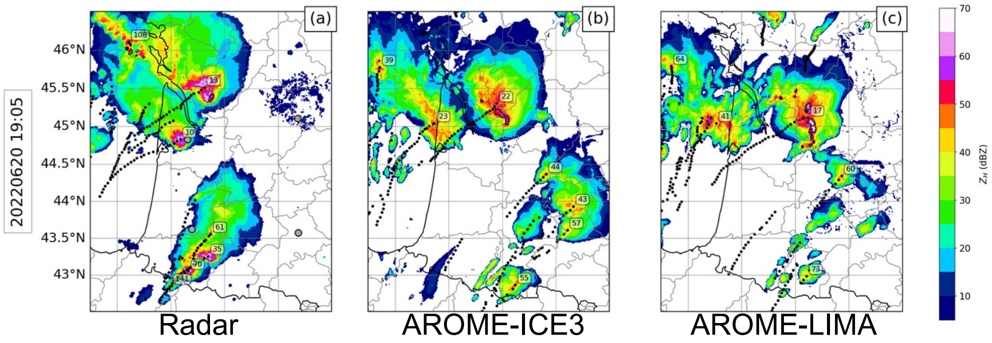
# Methodology

- **Traditional evaluation**: quantitative precipitation forecast evaluation

- **Object-oriented framework:**
  - Storm cell detection & tracking: **tobac** Python package (*Sokolowsky et al., 2024*)
  - Cell cores analysed with max Zh = 40 dBZ

- **ZDR column detection** :
  - adapted from *Snyder et al (2015)*, *Kuster et al (2019)*
  - Zdr threshold : 2dB, Zh threshold: 25 dBZ
  - vertical continuity is imposed
  - applied on **observed** and **simulated Zdr** 3D Cartesian grids

Example of max Zh maps with cell centroid tracks



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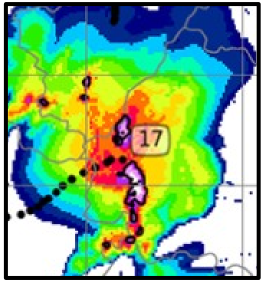


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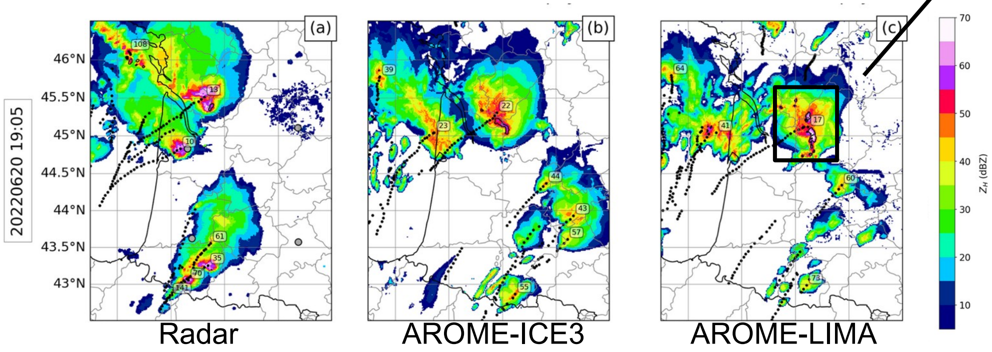
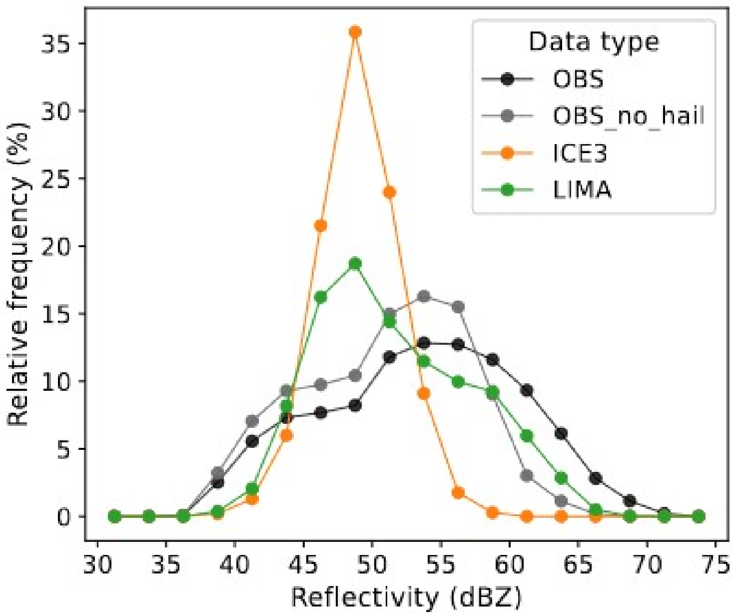



17 = cell identification
black contours = Zdr columns

# Convective Cell Intensity



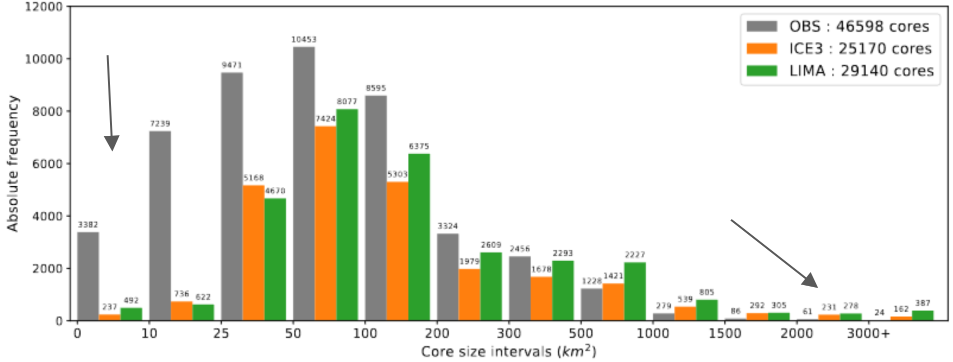

**Max reflectivity per cell:**

- **Observed** peak: ~55 dBZ
- ICE3 & LIMA peaks: ~48.5 dBZ
- LIMA **better reproduces the largest reflectivities** (>60 dBZ) : comparable to largest observed reflectivity values with no radar detected hail

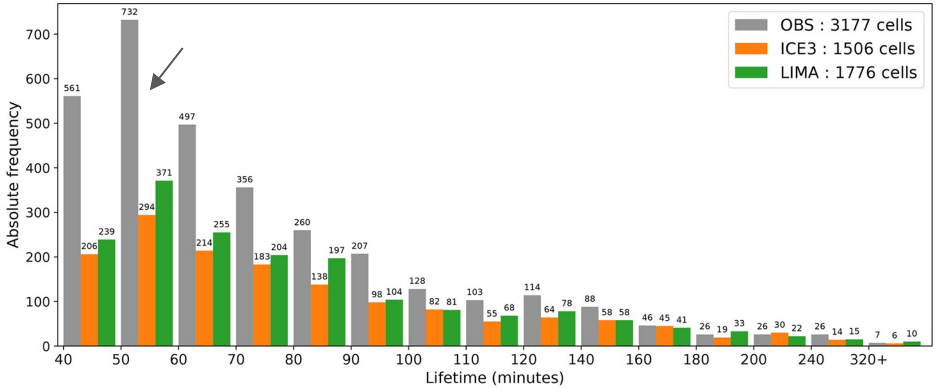
➡️ improved performance in simulating intense cores with LIMA due to **2-moment rain (larger drops)**

# Convective Cell Size and Duration

Distribution of Cell core sizes




Distribution of Cell core lifetimes




**Number of cells cores (ZH ≥ 40 dBZ):**

- Underestimated by both ICE3/LIMA

**Cells' core sizes:**

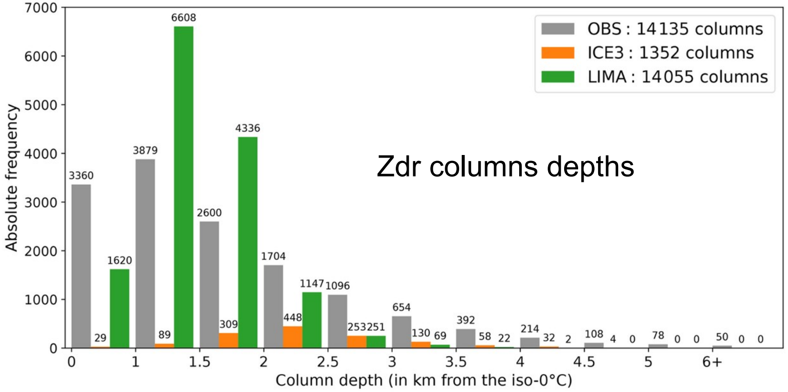
- **Underestimation of small cells sizes** (< 50 km²)
- Overestimation of very large cells sizes (> 1000 km²)

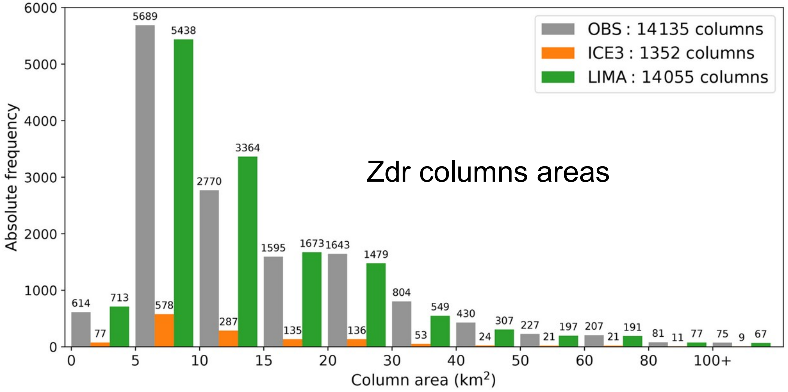
**Cells' core lifetimes:**

- AROME with both schemes **miss short-lived cells**

Partly due to the larger explicit model resolution (~ 9Δx = 11 km, Ricard et al. 2012) // 1 km for radar grid

# Zdr columns: depth and area distributions




**LIMA** :

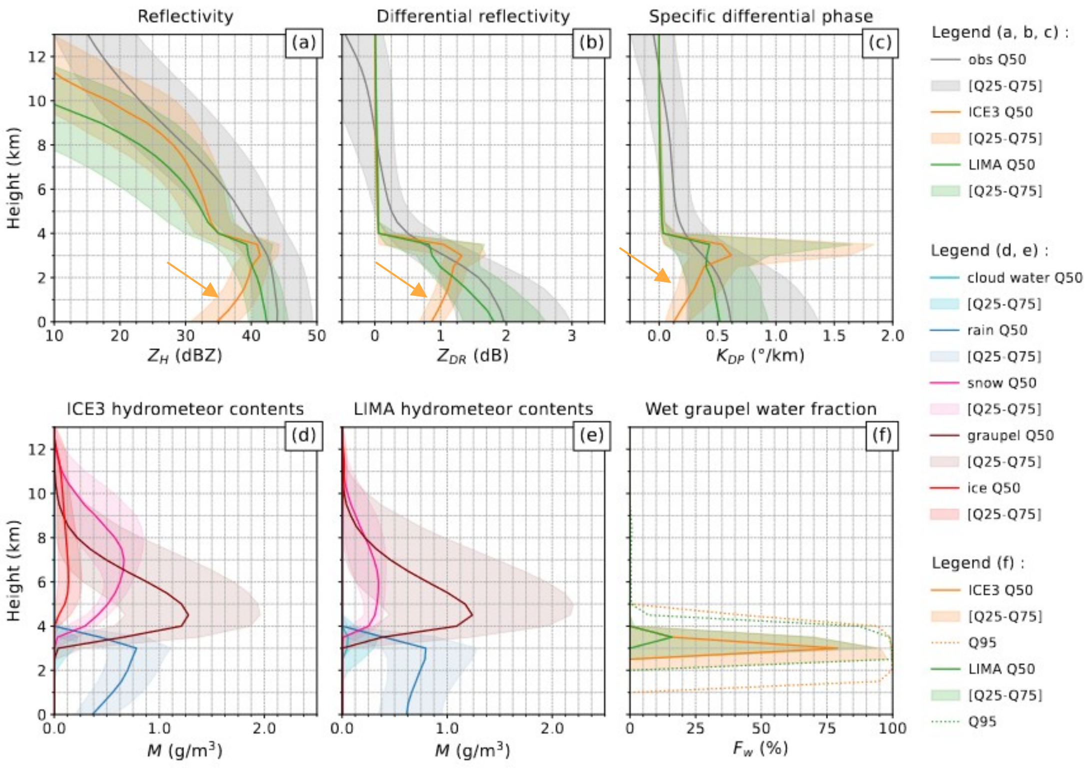
- remarkable **similar number of simulated Zdr columns compared** to **observations**
- miss the lowest depths (< 1 km) and areas (< 5 km$^2$)
- not able to simulate the Zdr columns with depths above 3.5 km

**ICE3** :

- strong **underestimation of the number of Zdr columns**
- but is able to simulate depths until 4.5 km

➡️ less Zdr columns in ICE3, but slightly more intense (more rainwater available at negative temperatures within the columns leads to higher graupel wet fraction => higher Zdr )

# Vertical Profiles (CFADs): ZH, ZDR, KDP




**Below melting level (~0–3 km):**

- ICE3 strongly underestimates ZDR & KDP (likely over-evaporation)
- LIMA matches observations much better (larger raindrops → better ZDR) thanks to prognostic raindrop concentration → more realistic DSD

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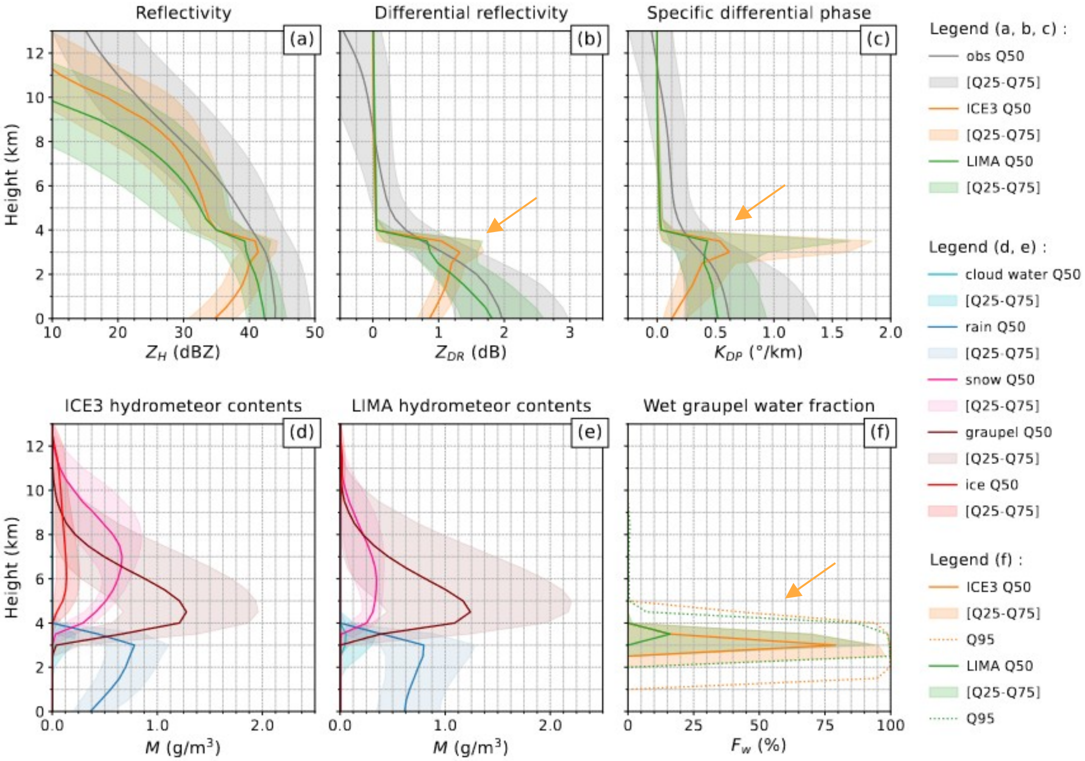


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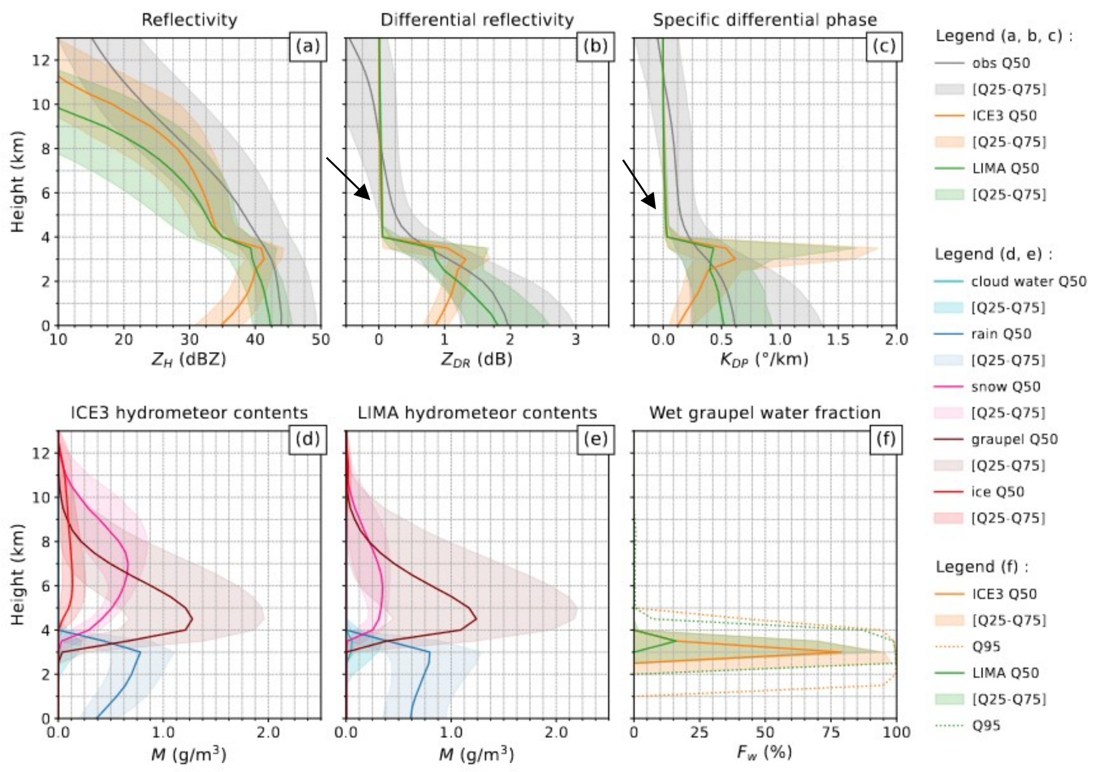


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**Above melting layer:**

- ZDR & KDP quickly drop to zero in both schemes
- Forward operator limitations ?

# Conclusions & Outlook

✅ **Comprehensive Model Evaluation**
Evaluation conducted on convective cases using two microphysics schemes: ICE3 (one-moment) and LIMA (partially two-moment).

✅ **AROME QPF Scores** (not shown)
No significant difference observed between the two microphysics schemes.

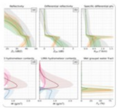
✅ **LIMA Strengths**
Better simulation of Zh, Zdr, and Kdp in convective rain
Zdr columns occurrence, width, and lifetime.

❌ **PRFO Limitations**
ZDR and KDP values too weak above the melting layer.

David et al. (2025)

Research article | 11 Aug 2025

Improved simulation of thunderstorm characteristics and polarimetric signatures with LIMA two-moment microphysics in AROME



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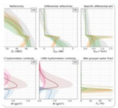

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🔮 **Ongoing Investigation**
Sensitivity to axis ratio, oscillation, and mass-diameter relations.

**At Météo-France**
Ongoing evaluation of AROME-LIMA with different configurations over longer periods, incorporating all standard NWP scores and radar CFADs (collab. with Benoît Vié and Clément Strauss)