SPP 2115

The AROME-MesoNH radar dual-polarization radar forward operator

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CNRM UMR 3589

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Convective-scale models at Météo France

➤ 2 **non-hydrostatic convection resolving** atmospheric models at Météo-France / CNRM

AROME
operational use since 2008
(Seity et al, 2011)

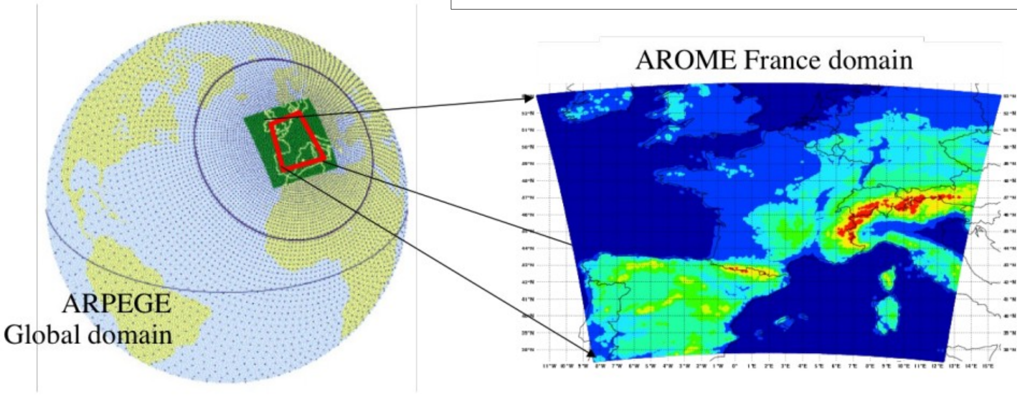
- horizontal resolution : 1.3 km / 90 vertical levels
- time step of 50 s
- Coupled to global model ARPEGE every hour (lateral conditions)
- 3DVar assimilation system adapted from ARPEGE/IFS's

MesoNH
limited area **research** model
(Lac et al, 2018)

- LES to mesoscale horizontal resolution options
- coupled to the surface model SURFEX (surface/ atmosphere interactions : vegetation, city, ocean, lake)
- Allows a multi-scale approach through a grid-nesting technique

Share same microphysics options

- **ICE3** (1-moment) : cloud liquid water, rain, graupel, snow, ice crystals => operational use in AROME
- **LIMA** (2-moment for rain, cloud water and ice crystals)



Meso-NH
mesoscale non-hydrostatic model

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History of radar forward operators at CNRM and Météo France

- Radar forward operator versions for **AROME** and **MesoNH** (2003-2022)

<table>
<tr><th colspan="3">AROME</th></tr>
<tr><td rowspan="6">Caumont 2006, 2010 Wattrelot 2014</td><td>variables</td><td>zh, vr</td></tr>
<tr><td>scattering</td><td>Rayleigh</td></tr>
<tr><td>geometry</td><td>beam pattern, PPIs</td></tr>
<tr><td>microphysics</td><td>ICE3 (1-moment)</td></tr>
<tr><td>code</td><td>f90 inline</td></tr>
<tr><td>application</td><td>* 1D+3D Var zh oper assimilation
* 3D-EnVar direct zh assimilation
(Martet et al, 2024 => future operational version)</td></tr>
<tr><td rowspan="4">Augros 2018</td><td>variables</td><td>zh, zdr, kdp, rhohv</td></tr>
<tr><td>scattering</td><td>Tmatrix (lookup tables)</td></tr>
<tr><td>geometry</td><td>model grid</td></tr>
<tr><td>code</td><td>python offline</td></tr>
<tr><td>Le Bastard 2018</td><td colspan="2">Augros 2018 + new mixed phase model
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<tr><td rowspan="5">Richard 2003</td><td>variables</td><td>zh</td></tr>
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<tr><td>scattering</td><td>Rayleigh, Rayleigh spheroids or Mie</td></tr>
<tr><td>geometry</td><td>beam pattern, PPIs, attenuation</td></tr>
<tr><td>code</td><td>f90 inline</td></tr>
<tr><td>Augros 2016</td><td colspan="2">Caumont 2006 + zdr, kdp, rhohv
Tmatrix (lookup tables) f90 inline, S, C, X bands</td></tr>
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operational version (Maud Martet CNRM/GMAP) - fortran
research version (Clotilde Augros CNRM/GMME) - python

History of radar forward operators at CNRM and Météo France

- Radar forward operator versions for **AROME** and **MesoNH** (2003-2022)

AROME		
Caumont 2006, 2010 Wattrelot 2014	variables	**zh, vr**
	scattering	**Rayleigh**
	geometry	**beam pattern, PPIs**
	microphysics	**ICE3 (1-moment)**
	code	**f90 inline**
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MesoNH		
Richard 2003	variables	zh
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	geometry	**model grid**
	microphysics	**ICE3 (1-moment)**
	code	f90 inline
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➔ **Numerous versions, adapted to 2 different models, with fortran or python languages : very difficult to maintain !**

operational version (Maud Martet CNRM/GMAP) - fortran
research version (Clotilde Augros CNRM/GMME) - python

Since 2023 : new single version operadar

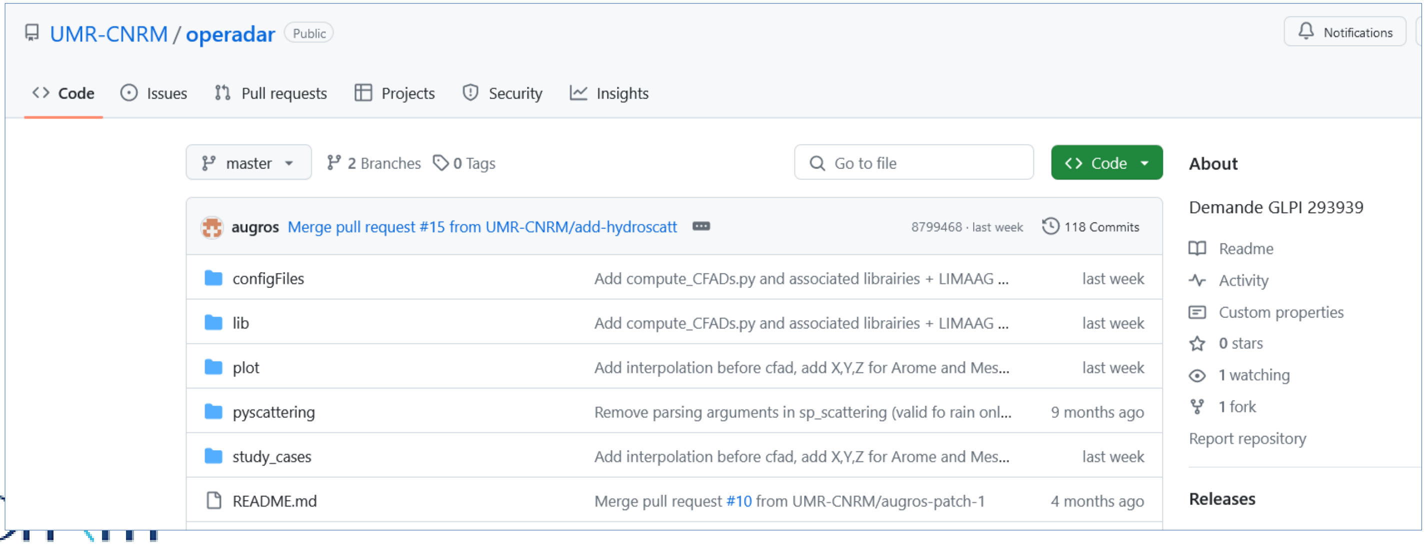
- Development of a **new single version for research** valid for **AROME** and **MesoNH** (co-developers: C. Augros and C. David)

- **2 steps :**

  1. **Tmatrix tables generation** (fortran 77 + fortran 90 codes based on Mischenko 1994)
     https://opensource.umr-cnrm.fr/projects/dpolsimul

  2. **Dual polarimetric variables computation** in the model grid for Meso-NH or AROME models (python code)

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



operadar step 1 : Tmatrix tables generation

➢ For a range of **temperatures**, **elevation angles**, **liquid water fraction** (for graupel only), and spherical equivalent **diameter**, estimation of :

- aspect ratio r
- dielectric constant
- maximum diameter Dm + partially melted equivalent diameter (Deq)
- computation of scattering coefficients from T-matrix routine

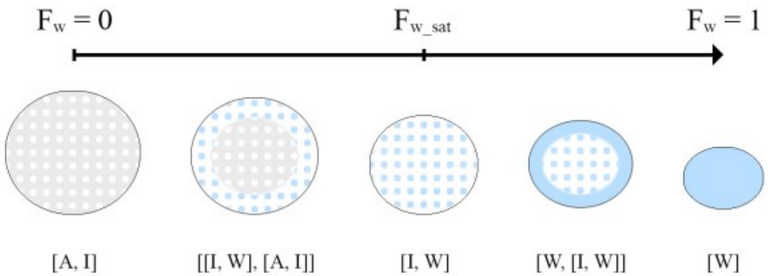
	Rain	Ice	Snow	Dry graupel	Wet graupel
Axis ratio	$r_r = f(D)$ Brandes et al (2002)	$r_i = 1$	$r_s = \begin{cases} 1 - \frac{1-0.75}{8-0} D & \text{si } D \leq 8 \text{ mm} \\ 0.75 & \text{si } D > 8 \text{ mm} \end{cases}$ or $r_s = 0.7$ Borderies et al (2018)	$r_g = \begin{cases} 1 - 0.02D & \text{if } D \leq 10 \text{ mm} \\ 0.8 & \text{if } D > 10 \text{ mm} \end{cases}$ or $r_g = 0.8$ Borderies et al (2018)	$r_{wg} = \begin{cases} r_g - 5.0(r_g - 0.8)F_w & \text{if } F_w \leq 0.2 \\ 0.88 - 0.40F_w & \text{if } 0.2 < F_w \leq 0.8 \\ 2.8 - 4.0r_w + 5.0(r_w - 0.56)F_w & \text{if } F_w > 0.8 \end{cases}$ Ryzhkov et al (2011)
Dielectric constant	Debye model (Liebe, 1991)	Maxwell Garnett (MG) :ice inc in air matrix	MG (ice inclusions in air matrix)	MG (ice inclusions in air matrix)	MG (combination of ice / water / air matrix and inclusions)

➢ Integration over the **Particle Size Distribution** (from the model microphysics scheme)

operadar step 1 : Tmatrix tables generation

Mixed phase model : wet graupel

- Mwg = Mg (graupel is completely transfered to « wet graupel » when it coexists with rain)
- Mass water fraction (with wet graupel) estimated as **Fw=Mg/(Mg+Mr)**
- Partially melted equivalent diameter (Deq) estimation
  - Decrease of the « melted equivalent diameter » as water first soaks air cavities (reducing the volume)
  - Building of a water shell once cavities are fully soaked



Description of the melting process (Le Bastard, 2019)

- Dielectric constant : particle successively considered as a matrix of water-saturated graupel (matrix of ice with water inclusions) with dry graupel inclusions (matrix of air with ice inclusions), and as a matrix of water with water-saturated graupel (matrix of ice with water inclusions).
- estimation of the fall velocity of the wet specie (graupel) from rain and solid hydrometeor fall velocities
- Combination of the liquid and solid parts of the distribution following Szyrmer and Zawadzki (1999) and used by Wolfensberger and Berne (2018) and Le Bastard (2019)

$$N(D_{eq}) = (1 - F_w)\frac{v_{ss}}{v_w}N_{ss}(D_{eq}) + F_w\frac{v_r}{v_w}N_{rr}(D_{eq})$$

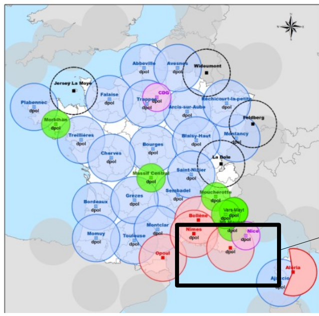
operadar step 2 : dual-pol variables

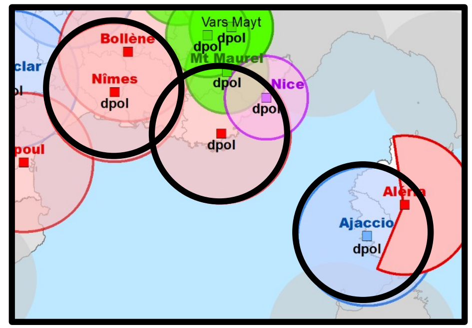
- **Main program steps : operad.py**
  - import config file
  - read tmatrix tables
  - read model variables (arome or mesonh)
  - compute radar geometry (to be completed)
  - mixed phase parametrisation (compute wet graupel content and wet fraction)
  - loop over hydrometeors
    - extract scattering coefficients for each type (tmat table interpolation)
    - single type dual-pol variable computation and save
  - compute dual-pol variables for all hydrometeors and save

- **Subdirectories :**
  - lib/ (read_arome.py, read_mesonh.py, read_tmatrix.py, save_dpolvar.py ...)
  - conf/
  - plot/ (plot_2Dmaps.py, plot_CFADs.py)

Application example : Corsica derecho 18/08/2022

Observation data





- 3 radars : Nimes, Collobrieres, Ajaccio
- Radar data preprocessing (non meteorological echo filtering, attenuation correction…)
- Interpolation in a 3D grid using PyArt
  1 km x 1km x 500m

Simulations configurations

AROME

- horizontal resolution : 1.3 km / 90 vertical levels
- time step of 50 s
- 00:00 UTC run of 18 August 2022
- Microphysics : ICE3 (one moment)

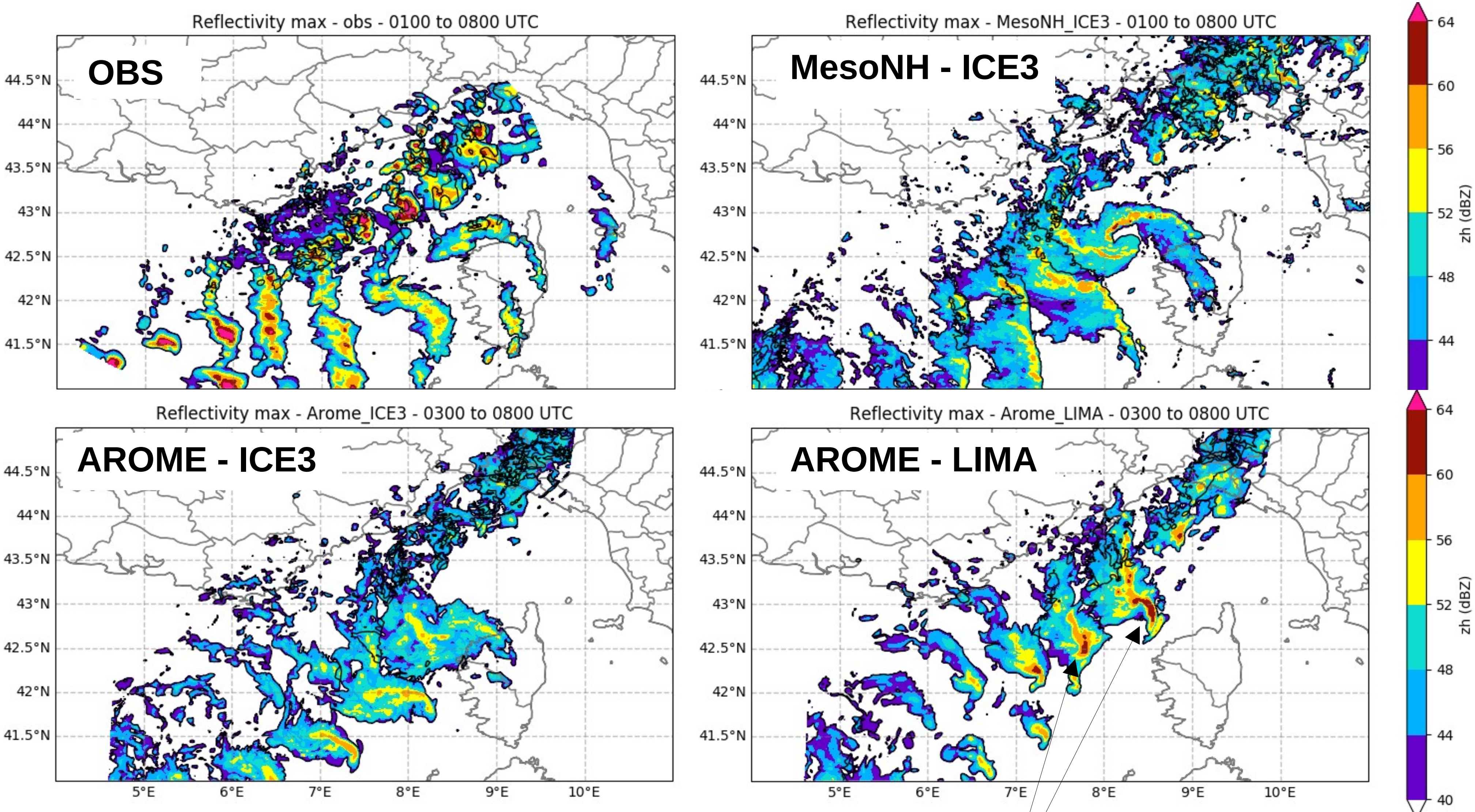
MesoNH

- horizontal resolution : 1 km / AROME vertical levels
- time step : 1,5 s
- initial and lateral conditions given by the AROME 00:00 UTC run of 18 August 2022
- Microphysics : ICE3 and LIMA (2-moments)

Dual-pol radar forward operator : operadar

Application : Corsica derecho 18/08/2022

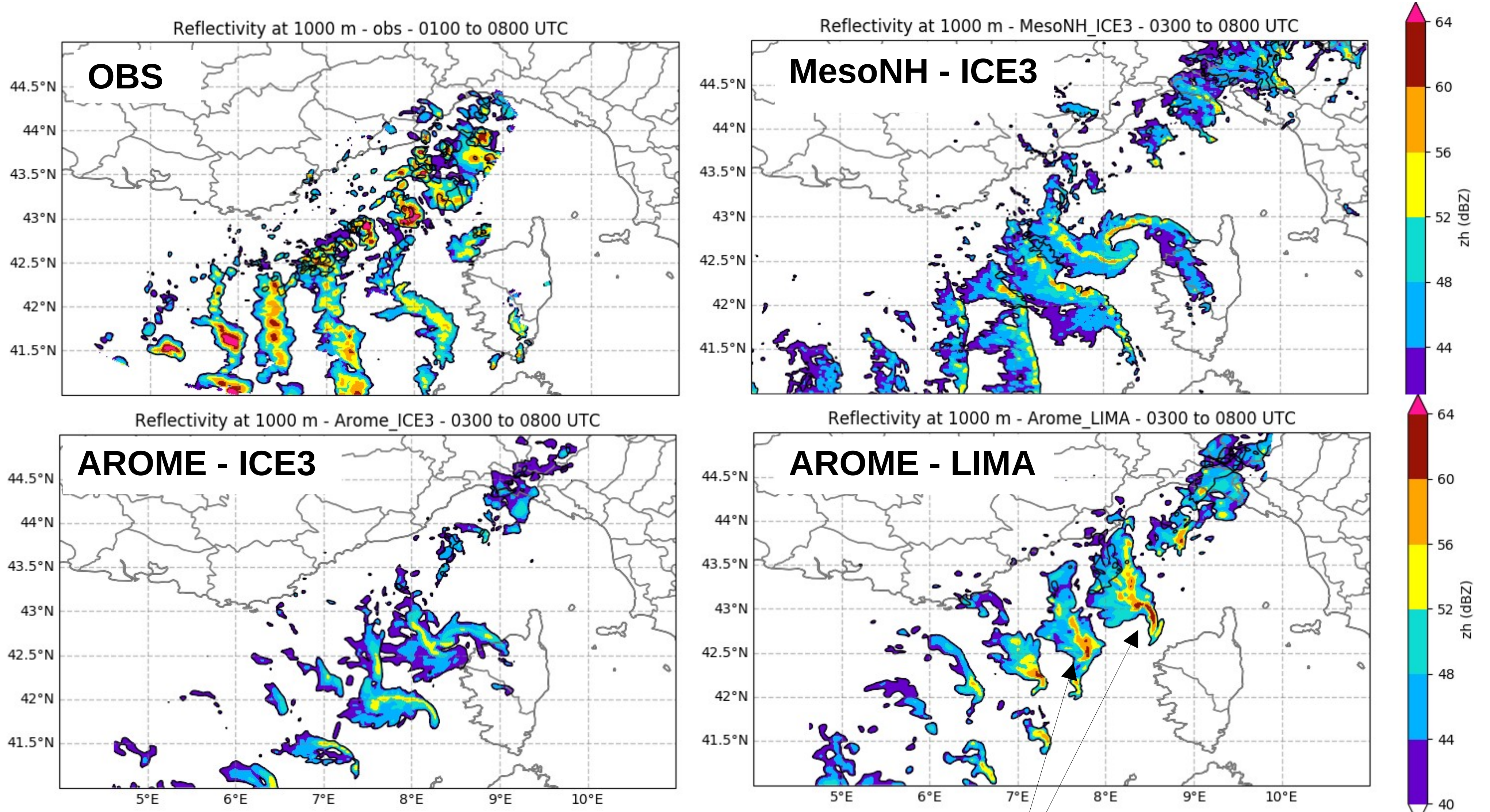
Maximum reflectivity (dBZ) - tracks (every 1h from 01 to 08 UTC)



Only **AROME-LIMA** simulates **the largest Zh** (> 60 dBZ)

Application : Corsica derecho 18/08/2022

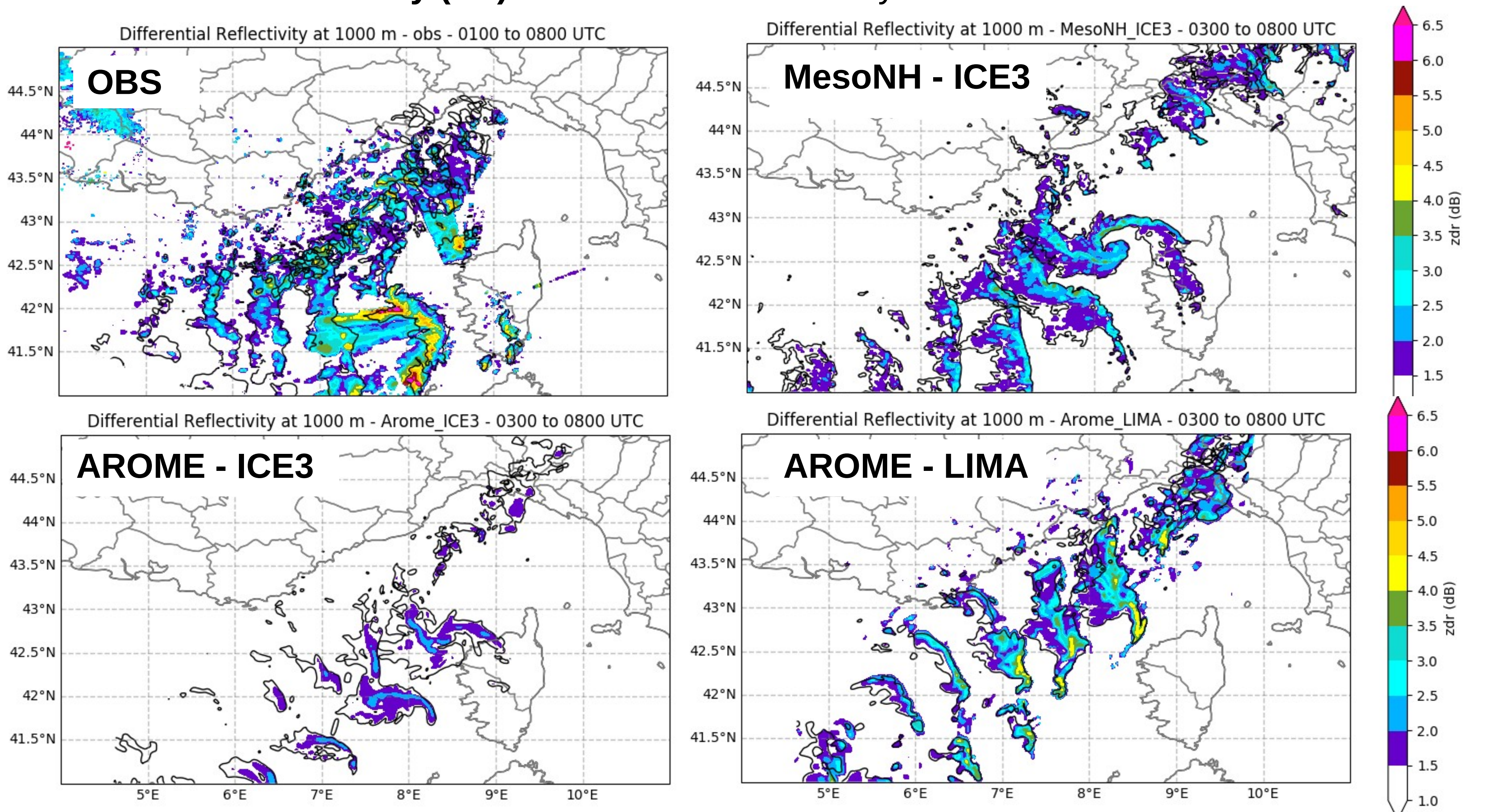
Reflectivity (dBZ) at 1000 m - tracks every 1h from 01 to 08 UTC



Only **AROME-LIMA** simulates the **largest Zh** (> 60 dBZ)
=> **in rain** (is this realistic ???)

Application : Corsica derecho 18/08/2022

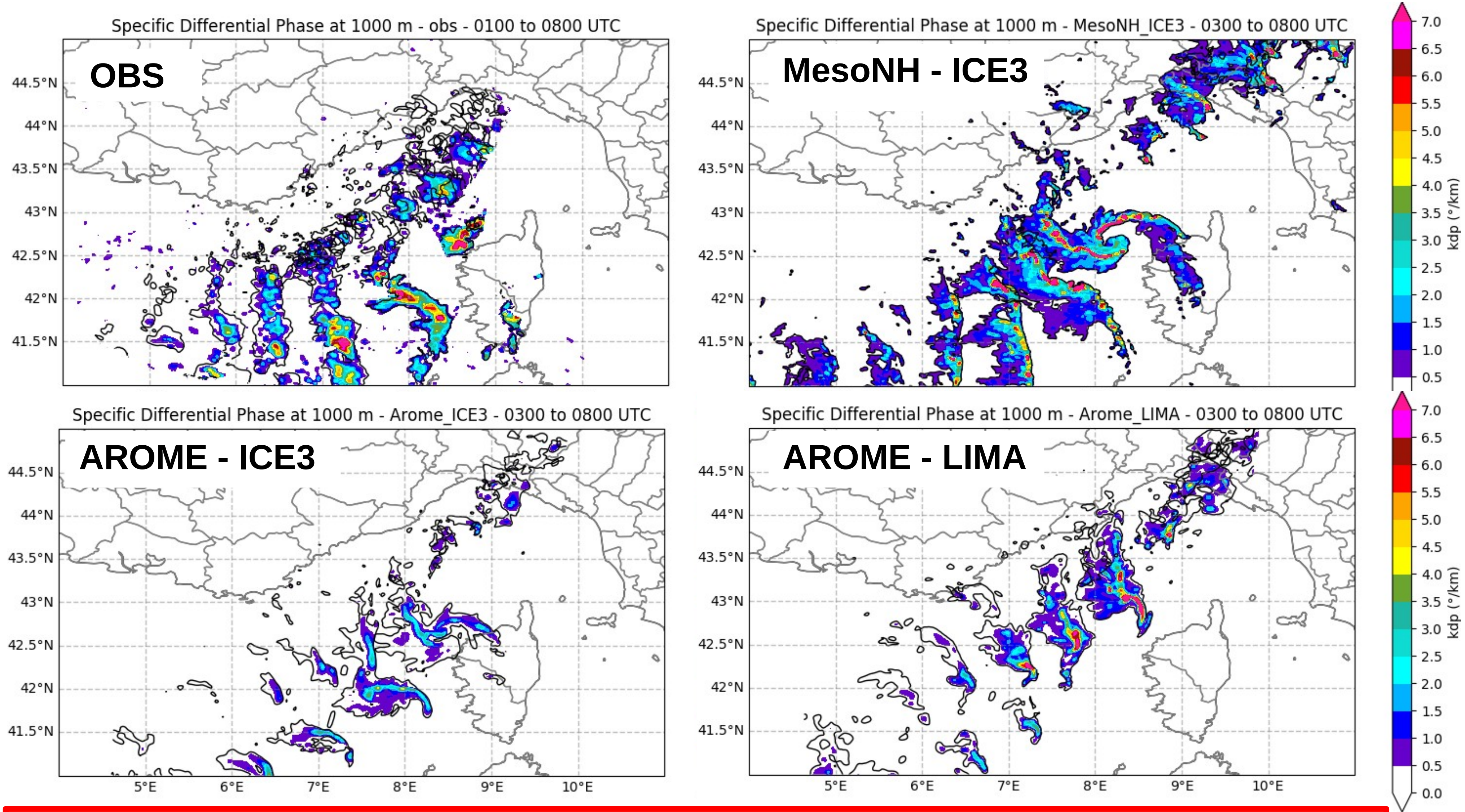
Differential reflectivity (dB) at 1000 m - tracks every 1h from 01 to 08 UTC



AROME-LIMA better simulates the largest Zdr in rain (but still too low in this case ?)
AROME-ICE3 really too low, MesoNH-ICE3 slightly better

Application : Corsica derecho 18/08/2022

Kdp (°/km) at 1000 m - tracks every 1h from 01 to 08 UTC



AROME-LIMA and **MesoNH-ICE3** are able to **simulate the largest Kdp (> 6°/km)**
AROME-ICE3 clearly too low

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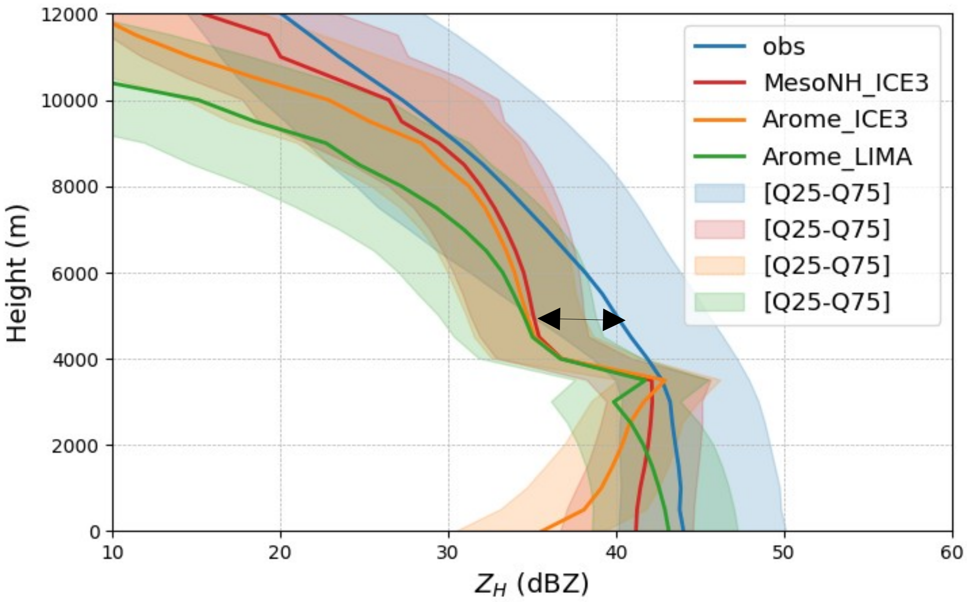
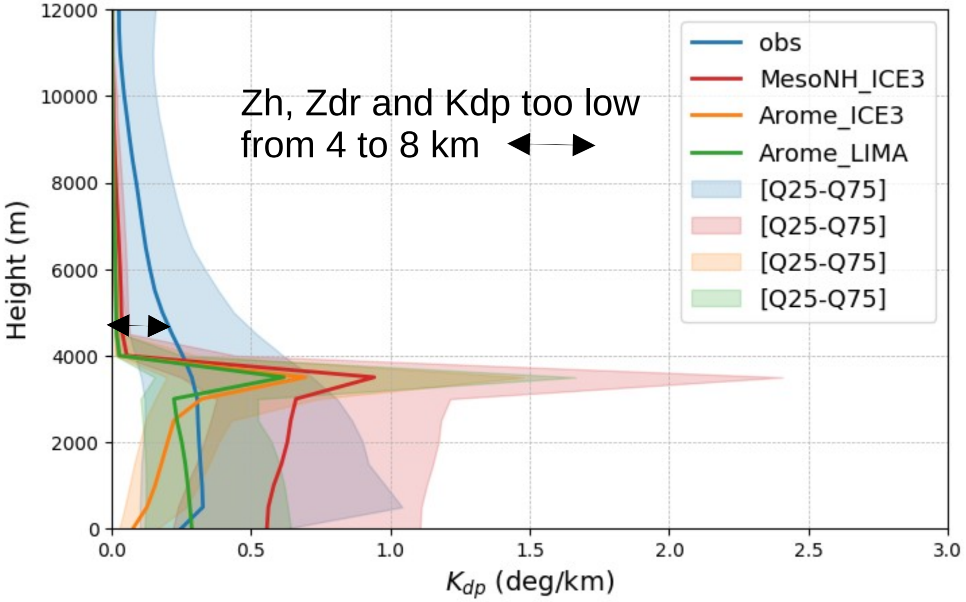
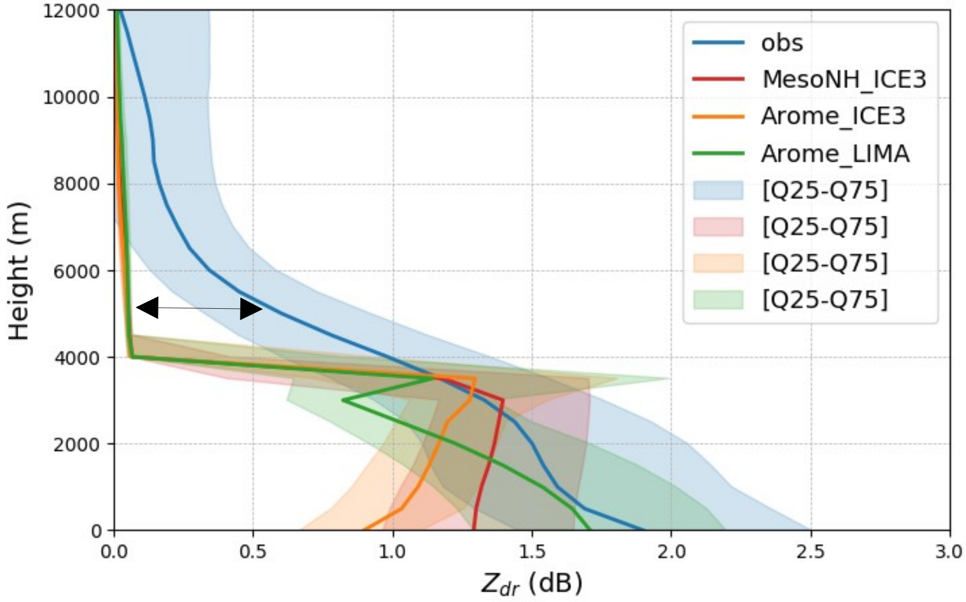
Application : Corsica derecho 18/08/2022

CFAD within convective cores (max Zh > 40 dBZ)



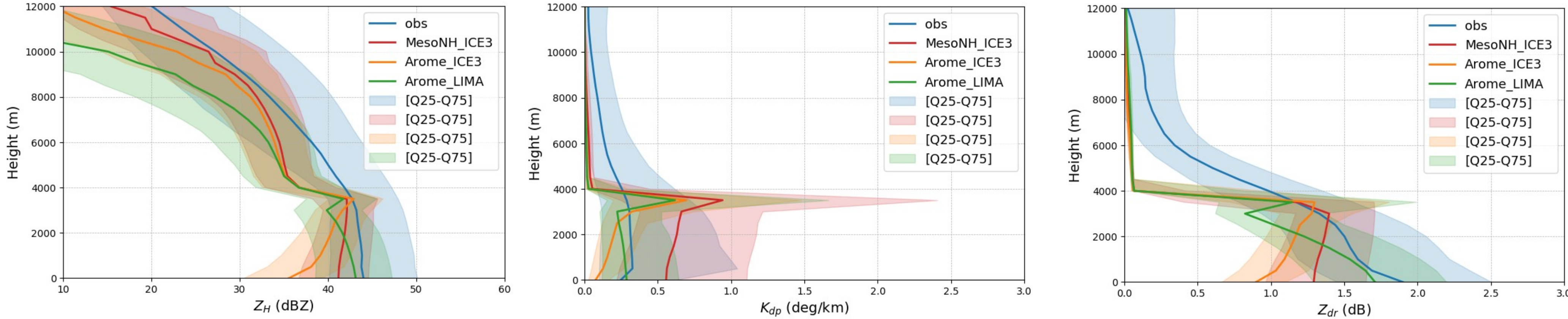
- **AROME-LIMA** closer to **observations** in rain for **Zh**, **Zdr** and **Kdp**
- **AROME-ICE3 : Kdp, Zh and Zdr** clearly too low in rain
- **MesoNH-ICE3** : Kdp too strong but Zdr and Zh too low in rain
- **Peak effects** around bright band (only in simulations) => because of beam averaging + interpolation in observation ?
- **Strong underestimation of Zh above 8 km** with **AROME-LIMA**

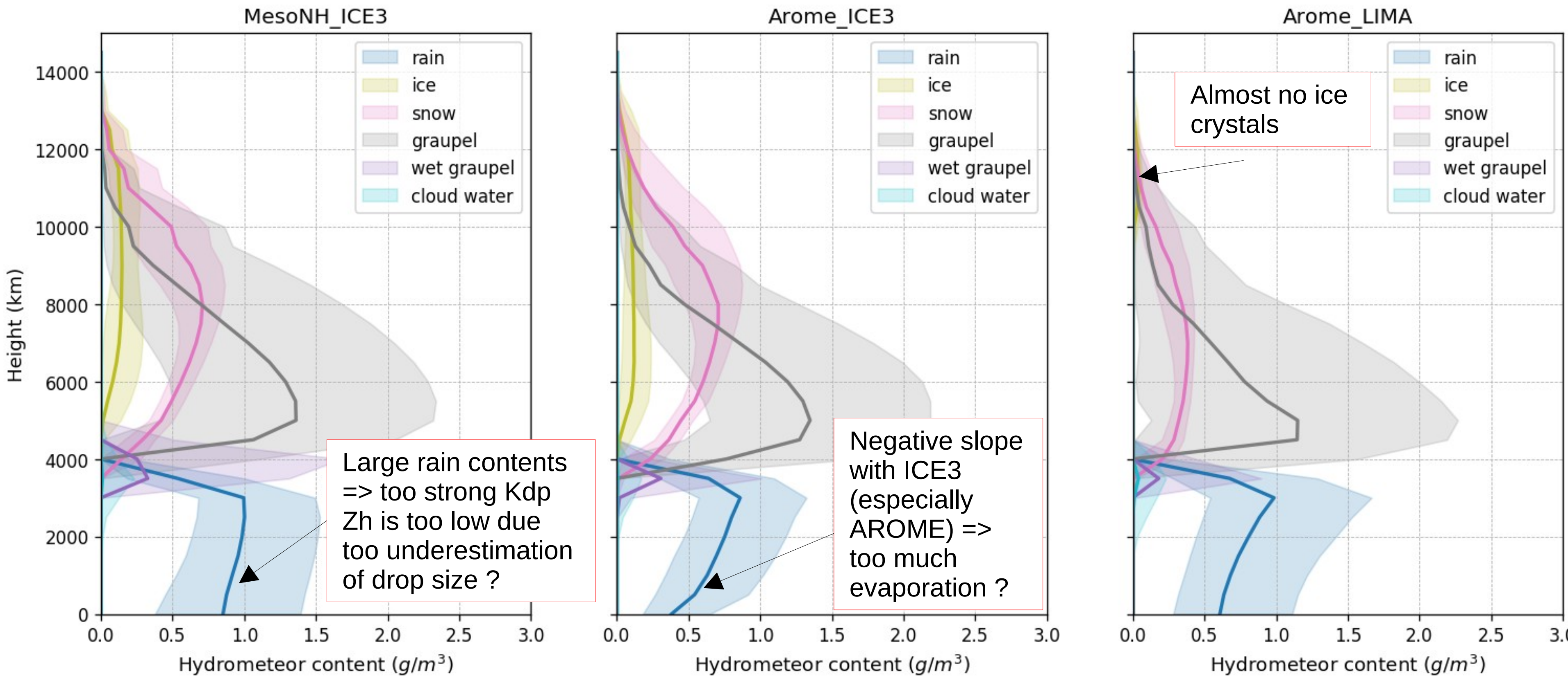




Application : Corsica derecho 18/08/2022

Hydrometeor contents CFAD within convective cores (max Zh > 40 dBZ)





Conclusions and perspectives

- First application of the **common MesoNH-AROME operadar**
- **AROME-LIMA** seems to be the best option in this case (thanks to 2-moment in rain!)
- **Comprehensive evaluation** with 30 convective cases (see Cloe's presentation !
- But :
  - For LIMA : correction of snow processes is needed (new version to be tested soon!)
  - Mixed phase parametrization needs too be improved (underestimation of Zh, Zdr and Kdp between 4 and 8 km)
  - DDA need for more realistic Zdr and Kdp ?
  - **Realistic Zh, Zdr and Kdp simulations are needed for direct assimilation in AROME with 3D-4D EnVar !**
- Perspectives :
  - Consolidate Corsica case evaluation (option with hail, option with 250 m resolution)
  - Try to implement the 2-spheres T-matrix code ? (hydroscatt Jordi Figueras)
  - Try reading of DDA tables for snow ?
  - Addition of ICON reading option to intercompare with EMVORADO ?

Thanks a lot for inviting us !

If you are interested in collaboration about **radar forward operator** and **assimilation**, please join the PROM-Meteo France discussion this afternoon !

References

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