Cloud and microphysical schemes in ARPEGE and AROME models

Y. Seity, C.Lac, F. Bouyssel, Y.Bouteloup, S.Riette, V.Masson, O.Thouron, F.Beucher (CNRM)

C.Barthe (LACy), J.-P.Pinty (LA)

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Outlines

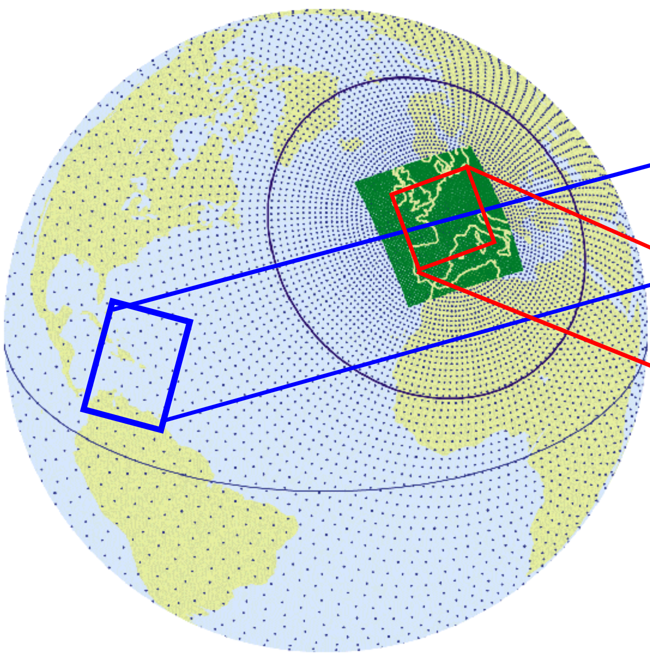
- Introduction

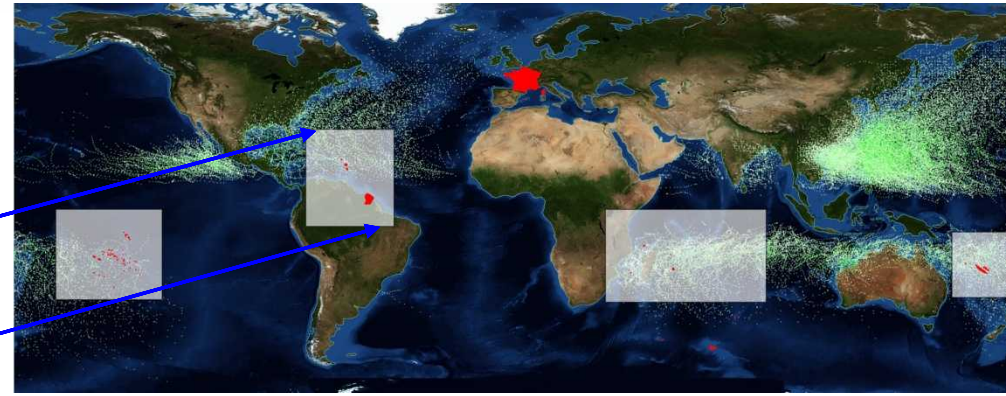
- ARPEGE and AROME-oper microphysics
- ARPEGE and AROME-oper cloud schemes
- AROME and ARPEGE-oper evaluations
- Research works

- Conclusions

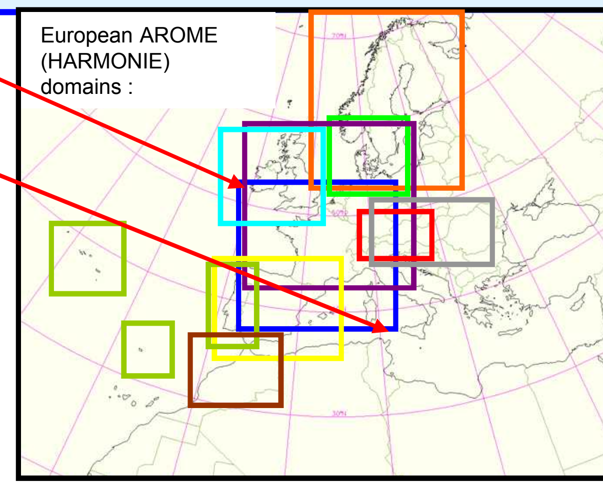
Operational Weather forecasting systems

ARPEGE/ALADIN and AROME





LAM ALADIN : ~3-days forecasts, dx~8km, 70 vertical levels, dt=450s - *3DVar Data Assimilation*



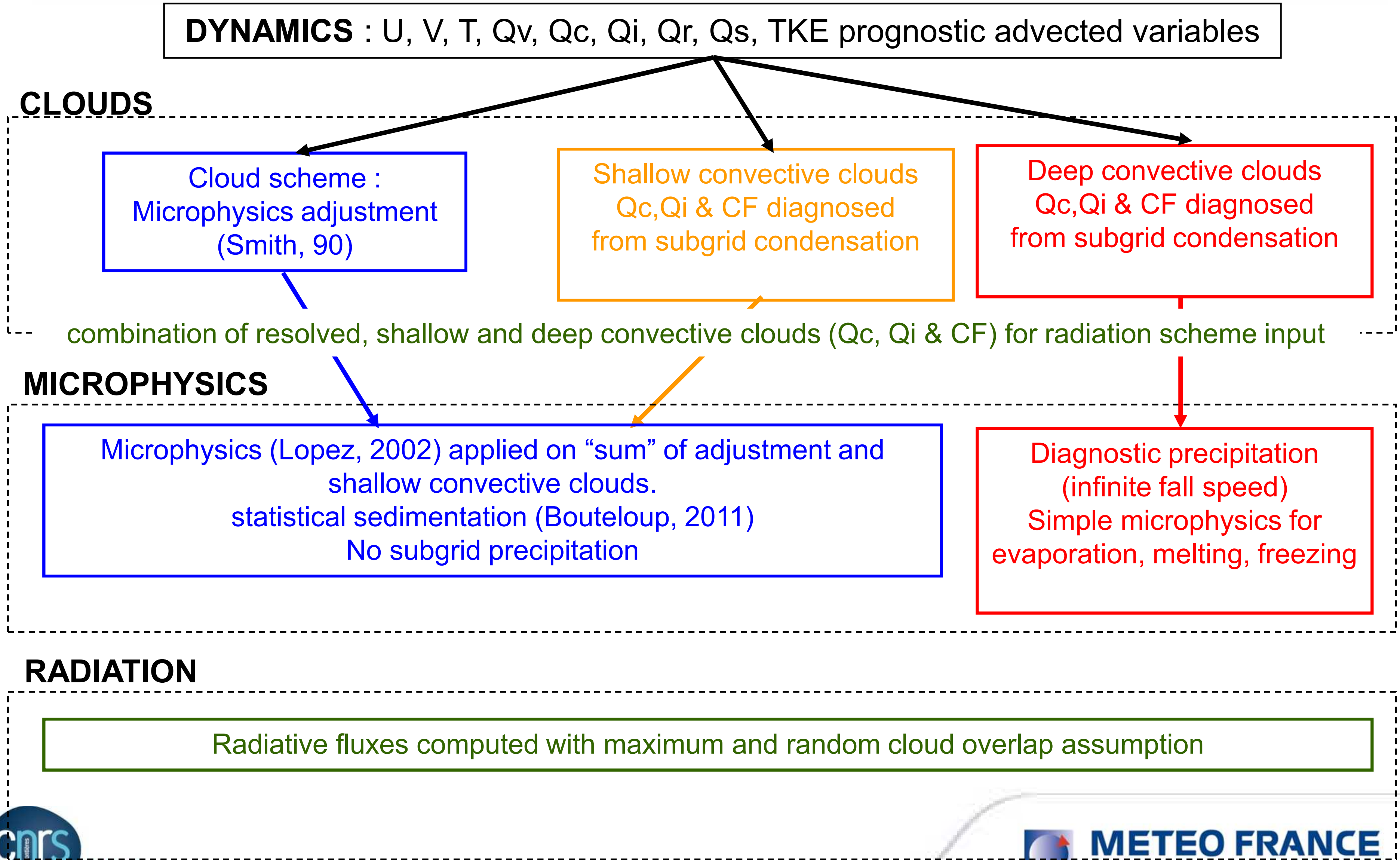
Global ARPEGE : T798c2.4L70
~4-days forecasts every 6 hours
dx~10km over France, ~60km over antipodes,
dt~9mn, 70 vertical levels
4DVar incremental Data Assimilation
Low resolutions : T107c1L70 (~180km)
and T323c1L70 (~60km)

LAM Cloud Resolving Model AROME-France
30 h forecasts every 6h, dx=2.5km, 60 vertical levels,
dt=1mn, ALADIN-NH dynamics, MesoNH physics
3DVar (RUC3h) with radar (reflectivities and winds)

ARPEGE/ALADIN and AROME atmospheric physics

	ARPEGE/ALADIN	AROME
Vertical diffusion	1.5 closure scheme with prognostic TKE (Cuxart et al., 2000) modified according (Cheng et al., 2002)	
L Mixing length	Non local mixing length (Bougeault, Lacarrere, 1989)	
Shallow convection	Moist shallow convection. Cape closure. (Bechtold et al, 2001) (available also in AROME)	Dry and moist shallow convection. Surface flux closure. (Pergaud et al, 2009) (under tests in ARPEGE)
Cloud scheme	Statistical scheme with climatological triangular PDF. (Smith, 90)	Statistical scheme with possibly mixed symmetric (Gaussian) and asymmetric (Exponential) functions. (Bougeault, 82)
Microphysics	1 moment bulk scheme with 4 prognostic variables for cloud droplets, rain, ice crystals and snow (Lopez, 2002)	1 moment bulk scheme with 5 prognostic variables for cloud droplets, rain, ice crystals, snow and graupel (Pinty and Jabouille, 1998)
Deep Convection	Mass flux scheme based on moisture convergence for closure and intensity. (Bougeault, 1985) + modifications	X
Subgrid orography	Gravity wave drag. Form drag. Anisotropy. (Catry et al., 2008)	X
Radiation	ECMWF codes : LW=RRTM (Mlawer, 97), SW=old IFS scheme (Fouquart, Morcrette) Rain and snow not used yet in radiation. Independent cloud optical properties used	

Parameterization of clouds and microphysics in ARPEGE/ALADIN



Parameterization of clouds and microphysics in AROME

DYNAMICS : U, V, T, Qv, Qc, Qi, Qr, Qs, Qg, TKE prognostic advected variables

CLOUDS

Cloud scheme :
Microphysics adjustment
(Bougeault, 82)

Shallow convective clouds
Qc, Qi & CF diagnosed
from subgrid condensation

sum of resolved and shallow clouds (Qc, Qi & CF) for radiation scheme input

MICROPHYSICS

Microphysics (ICE3, 1998) applied on “sum” of adjustment and shallow convective clouds.
Statistical sedimentation (Bouteloup, 2011)
No subgrid precipitation

RADIATION

Radiative fluxes computed with maximum and random cloud overlap assumption

CNRS INSU Observer & comprendre

METEO FRANCE Toujours un temps d’avance

Oulines

- Introduction

- ARPEGE and AROME-oper microphysics
- ARPEGE and AROME-oper cloud schemes
- AROME and ARPEGE-oper evaluations
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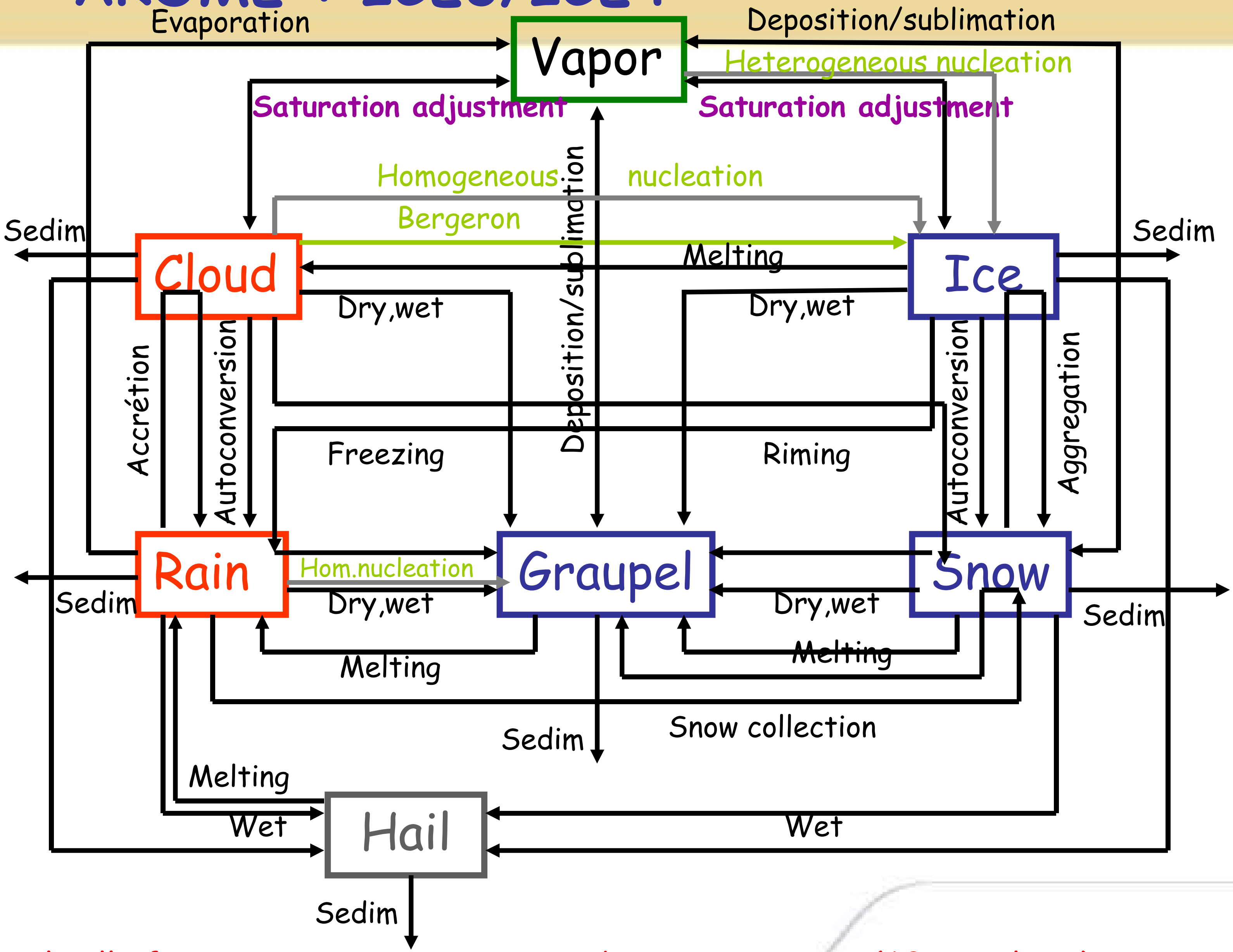
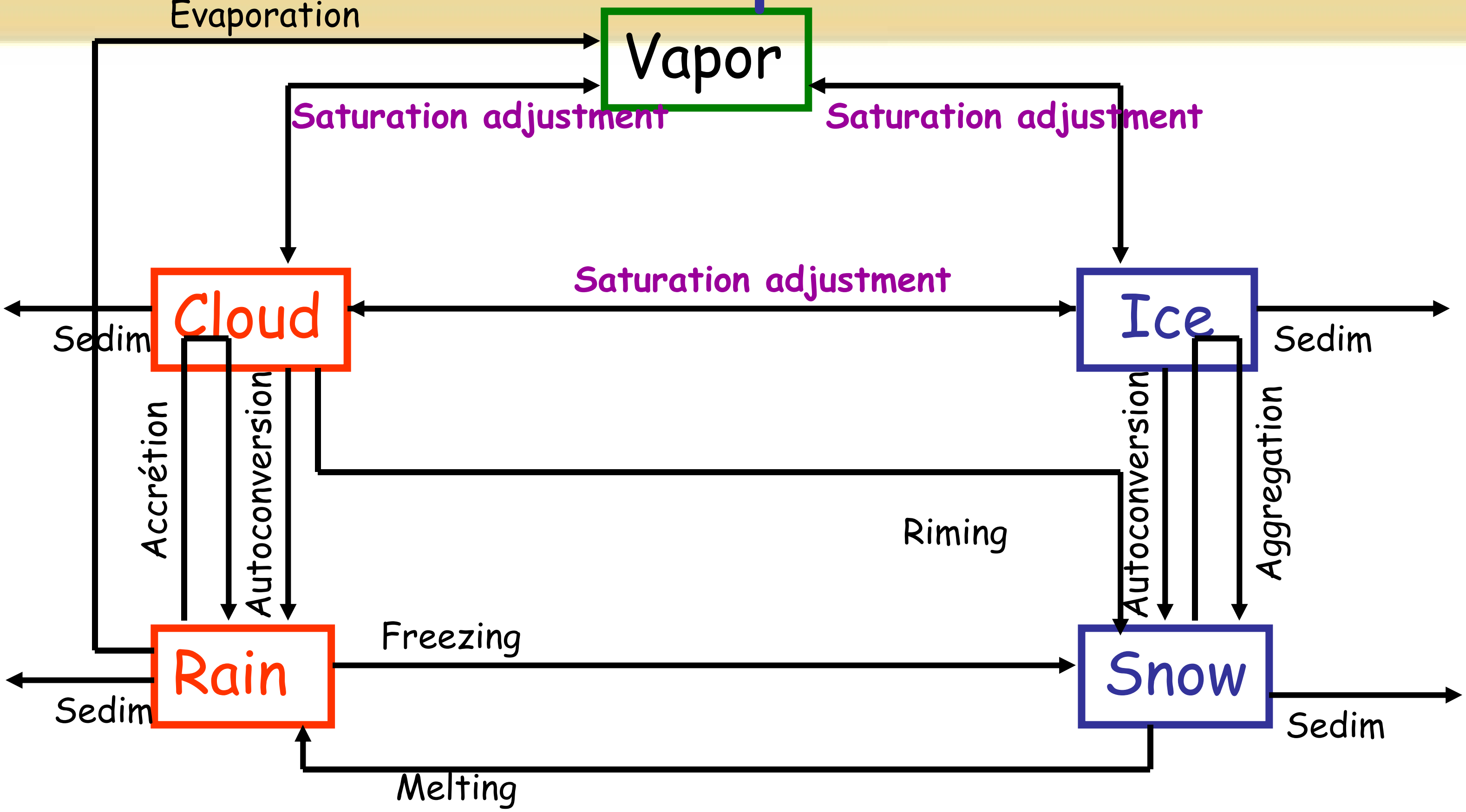
AROME : ICE3/ICE4 *(Caniaux, 1993 – Pinty and Jabouille, 1998)*



-> Sequential call of processes -> sensitive to ordering , time step (60s is a limit)

ARPEGE/ALADIN : Lopez

(Lopez, 2002 – Bouteloup et al., 2005)



- **Size distribution** **Marshall-Palmer** **only for rain & snow :**

  $n(D)dD=N.\exp(-\lambda D)dD$

  λ is the slope parameter deduced from the mixing ratio, N the total number concentration
- **Mass-Size relationship:** $m=aD^b$
- **Fall speed-Size relationship:** $v=cD^d . (\rho_{00}/\rho_a)^{0.4}$ (used only on collection processes)

AROME : Particle size distributions in ICE3/ICE4

- Size distribution (n(D)): **Generalized Gamma law**

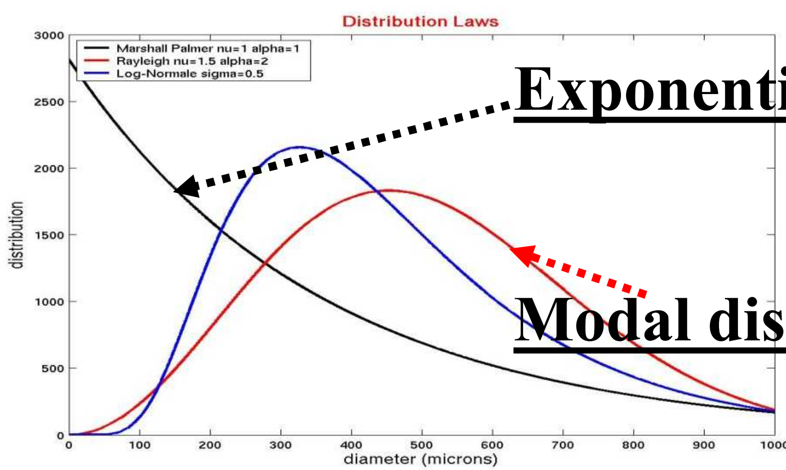
$$n(D)dD = Ng(D)dD = N\frac{\alpha}{\Gamma(\nu)}\lambda^{\alpha\nu}D^{\alpha\nu-1}\exp\left(-(\lambda D)^{\alpha}\right)dD$$

N is the total concentration (g(D) is a normalized distribution law) : $N=C\lambda^{x}$

For clouds, N imposed (Nc=300/cm3 on land, 100/cm3 on sea)

λ is the slope parameter deduced from the mixing ratio

(α, ν) are free shape parameters (Marshall-Palmer law for precipitating species : $\alpha=\nu=1$)



Exponential decay : rain, snow, graupel, hail

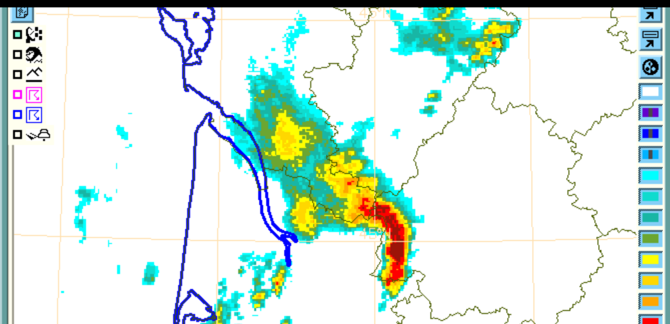
Modal distribution : droplets, cloud ice

- **Mass-Size relationship: $m=aD^{b}$**
- **Fall speed-Size relationship: $v=cD^{d}.(\rho_{00}/\rho_{d})^{0.4}$**

About Hail in AROME

OBSERVATIONS :

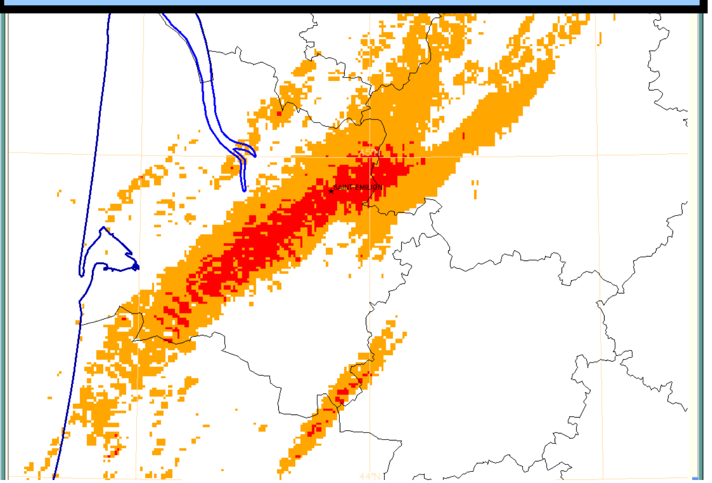
Observation (reflectivity at 2h30 UTC)



Hail risk (from radar)

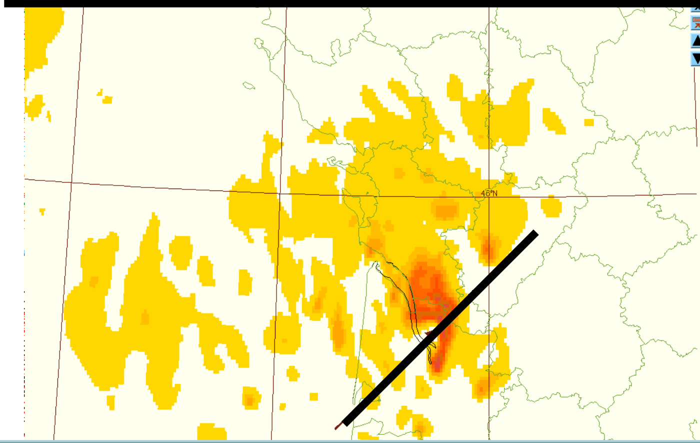
Orange : hail

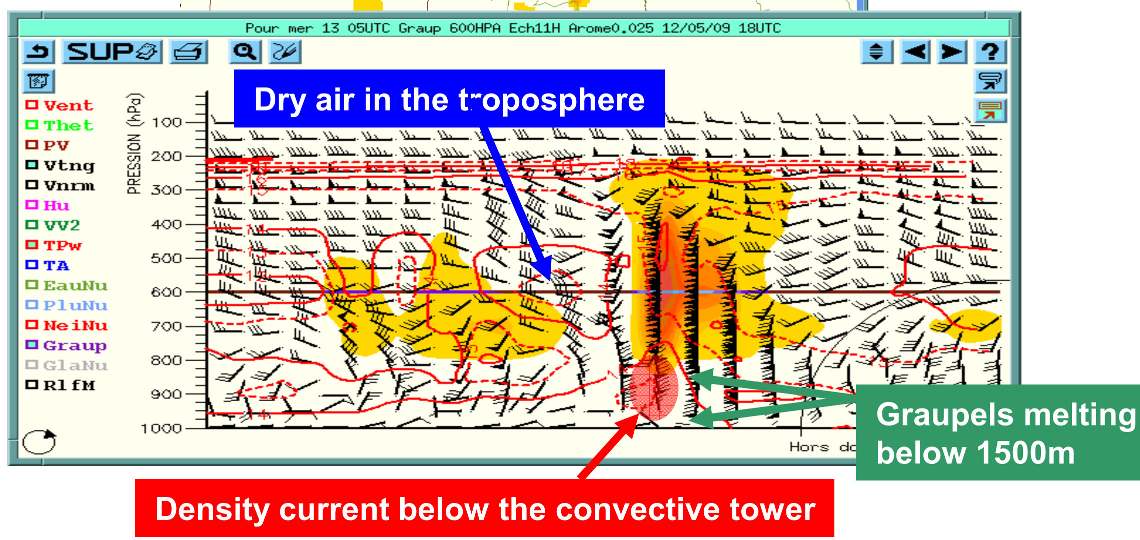
Rouge : strong hail



AROME :

Graupels at 600hPa at 5UTC (r18)





In ICE3 microphysics scheme, hail is part of 'graupel', but graupel never reach the soil *(except in winter or/and over montains)* -> Forecasters need something else to forecast hail with AROME

Hail diagnostic

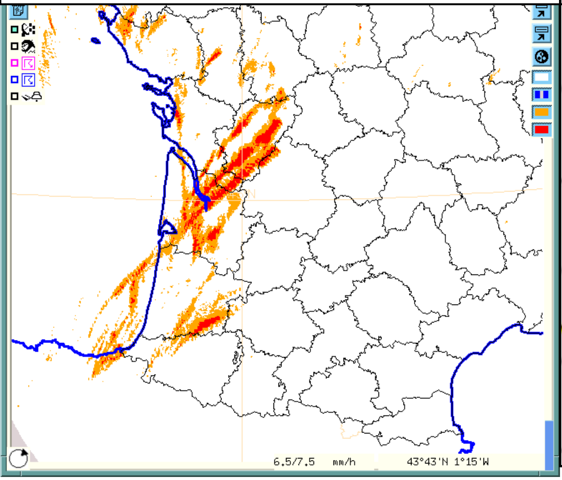
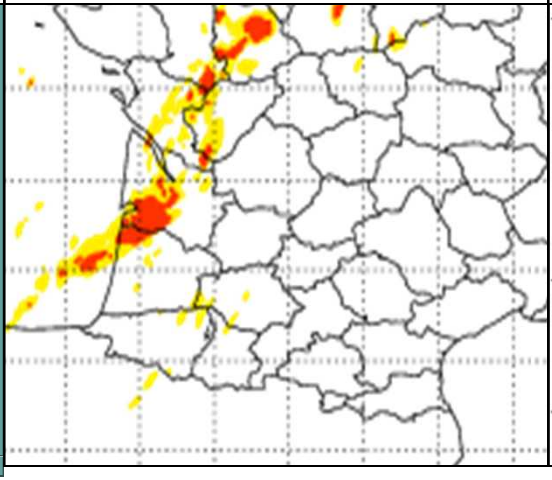
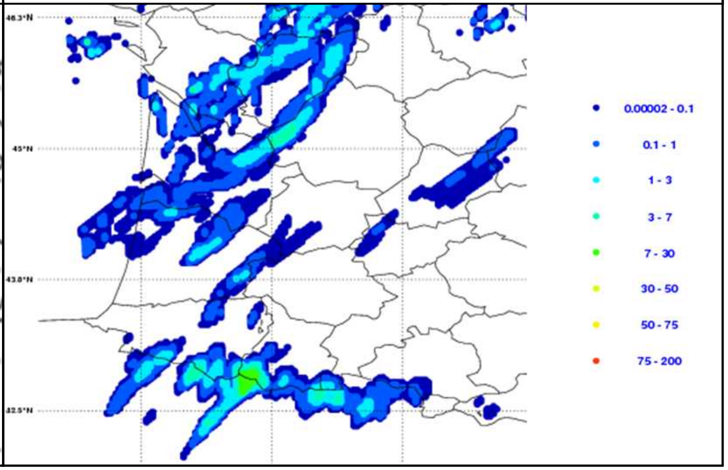
- ICE4 tests : disappointing results : very sensitive to the time step, and too active (small amount of hail but everywhere there is graupel in altitude)

- Despite a lot of sensitivity tests, we did not manage to tune the scheme correctly

=> not ready for operational use

=> We tried to diagnose hail in the model with ICE3 :

1. Compute each time step, vertically integrated graupel content
2. write in output files the maximal value since last file

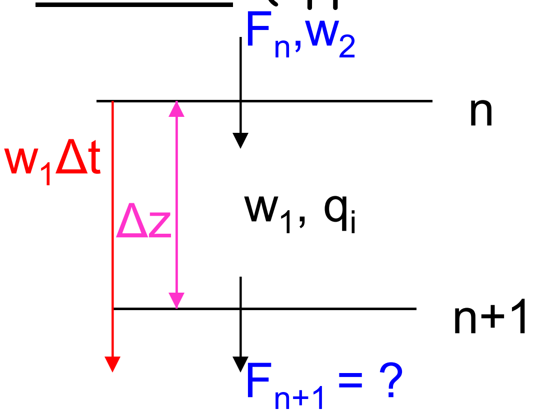
Radar hail diagnostic	AROME hail diagnotic	AROME prognostic hail (ICE4)
		

(Example of 11 May 2009, diag available for forecasters since September 2011)

Positively evaluated from 2009 year

Statistical sedimentation scheme

AROME : (applied on cloud dropplets, snow, rain and graupel)



$$P_1 = \min\left(1, \frac{w_1 \Delta t}{\Delta z}\right)$$ (Proportion of layer n leaving the layer in dt)

$$P_2 = \max\left(0, 1 - \frac{\Delta z}{w_2 \Delta t}\right)$$ (Proportion of F_n crossing the layer in dt)

$$w_2 = F_n . \frac{\Delta t}{\rho\, \Delta z}$$

$$F_{n+1} = \frac{P_1 . \rho . q_i . \Delta z}{\Delta t} + P_2 . F_n$$

ARPEGE : longer time steps -> need to take into account microphysics process during sedimentation (applied on rain and snow)

$$F_{n+1} = \left(1 - \frac{S^i_n}{q_i + (\Delta t / \rho . \Delta z) F_n + S^o_n}\right) \times \left(\frac{P_1 . \rho . q_i . \Delta z}{\Delta t} + P_2 . F_n + \frac{P_3\, \rho . \Delta z . S^o_n}{\Delta t}\right)$$

$P_3 = (P_1 + P_2)/2$ (Proportion of q_i produced in layer n during dt which leaves the layer during dt)

S^i_n = sinks of q_i (evaporation for rain, evaporation + melting for snow)

S^o_n = sources of q_i (autoconv., collection and melting for rain, autoconv. + collection for snow)

(Bouteloup et al., 2010)

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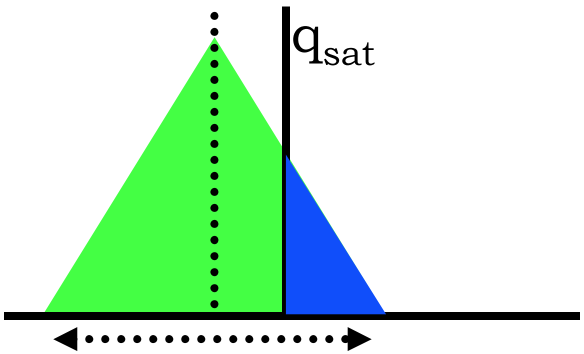
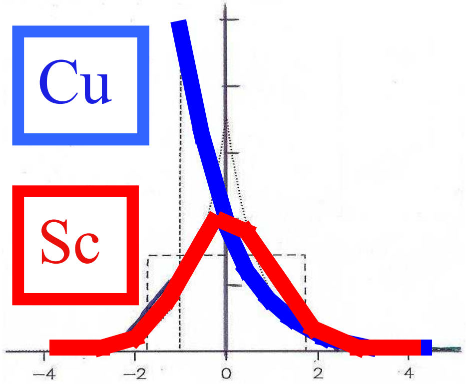
PDF used in statistical cloud schemes

ARPEGE



Climatological triangular distribution function (Smith, 90)
Width depending on horizontal resolution and height

AROME



Combination of Gaussian (stratocumulus) and exponential (cumulus) distribution functions depending on turbulent fluxes.
(Bougeault, 82) / (Bechtold, 95)

⇒ Underestimation of fractional cloudiness Arpege when using Arome PDF in Arpege, particularly for high level clouds but also for low level clouds.

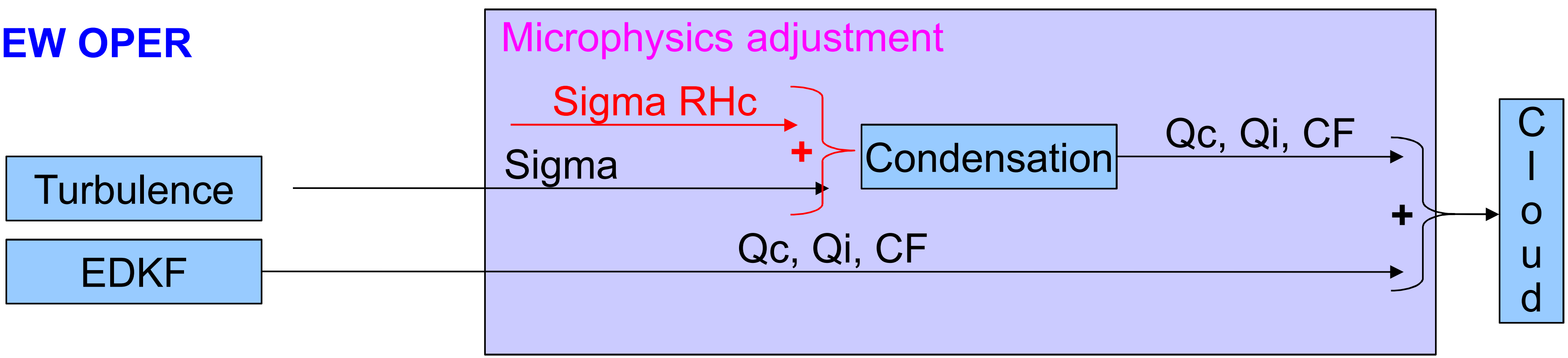
Modifications for subgrid clouds

- AROME statistical cloud scheme uses $Q = \frac{q_t - q_{sat}}{\sigma_s}$ (=normalized distance to saturation)

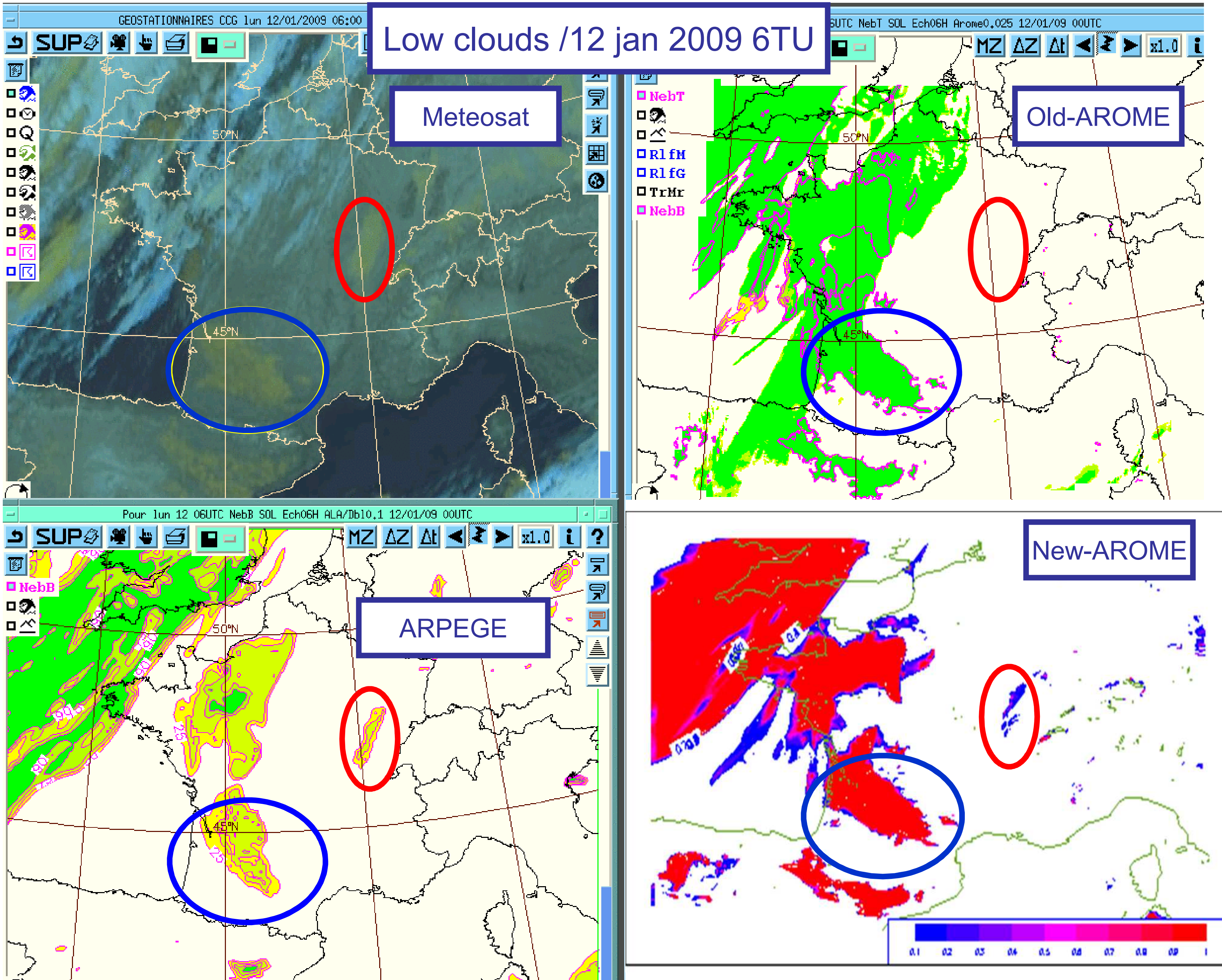
  In the previous version, σ_s comes from turbulence, but in stable situation, this term is too weak and AROME did not produce clouds

Following Wim de Roy ideas, we add σ_{RH_c} and $\sigma_s = \sqrt{\sigma^2_{turb} + \sigma^2_{RH_c}}$ $\left(\begin{array}{l} \alpha = 0{,}02 \\ \sigma_{RH_c} = \alpha \times q_{sat} \end{array} \right)$

NEW OPER



Low clouds /12 jan 2009 6TU



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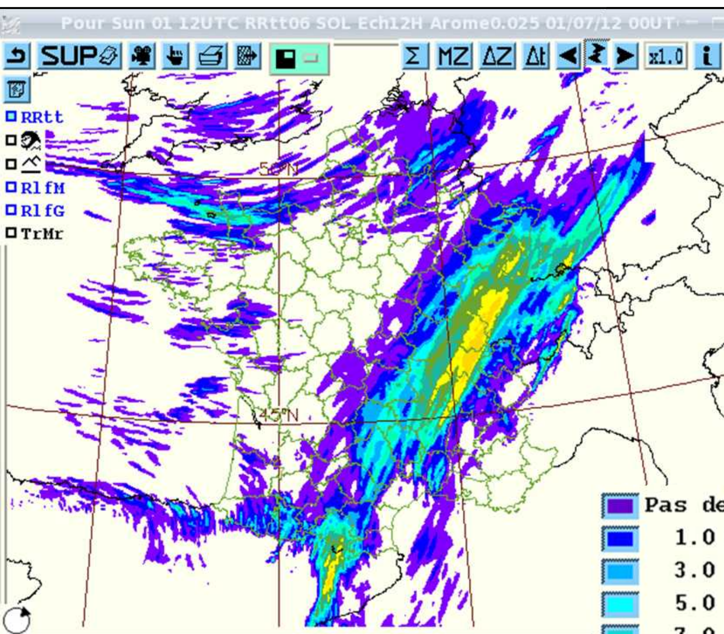
Example of 1st July 2012 :

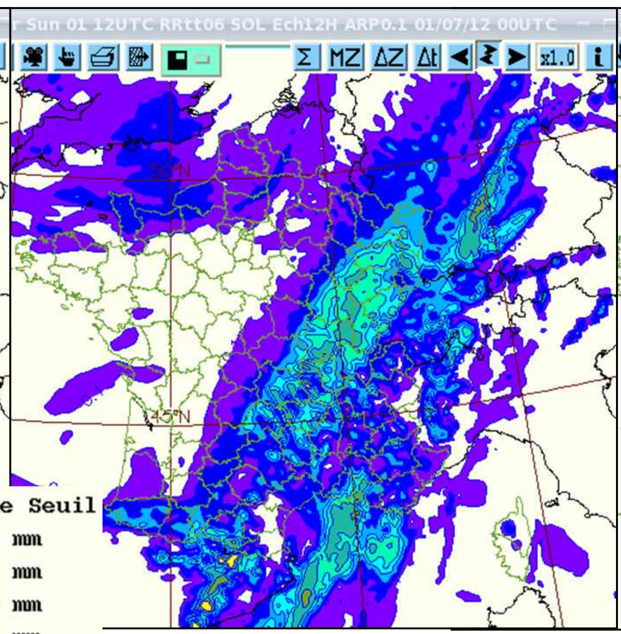
A summer convective event

24h cumulative rainfalls :

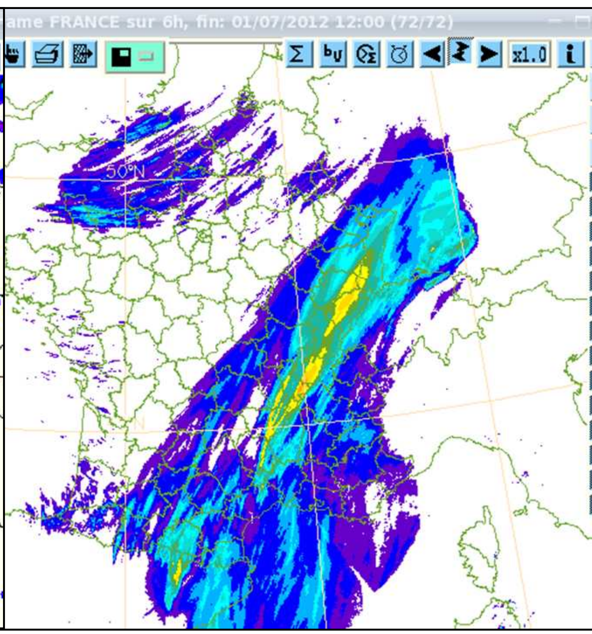
AROME :

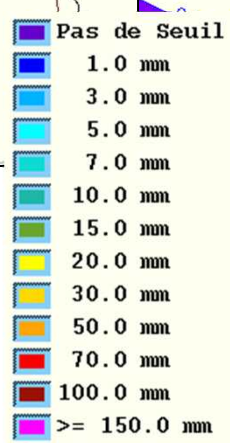


ARPEGE :



RADAR :





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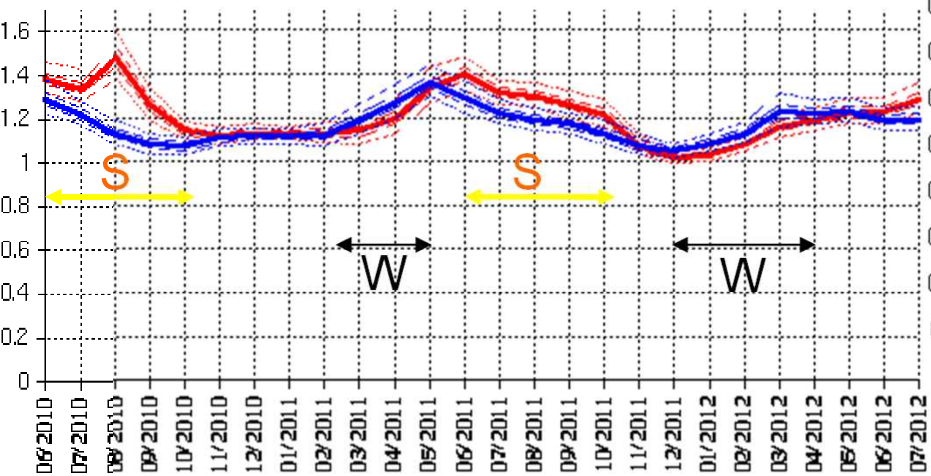
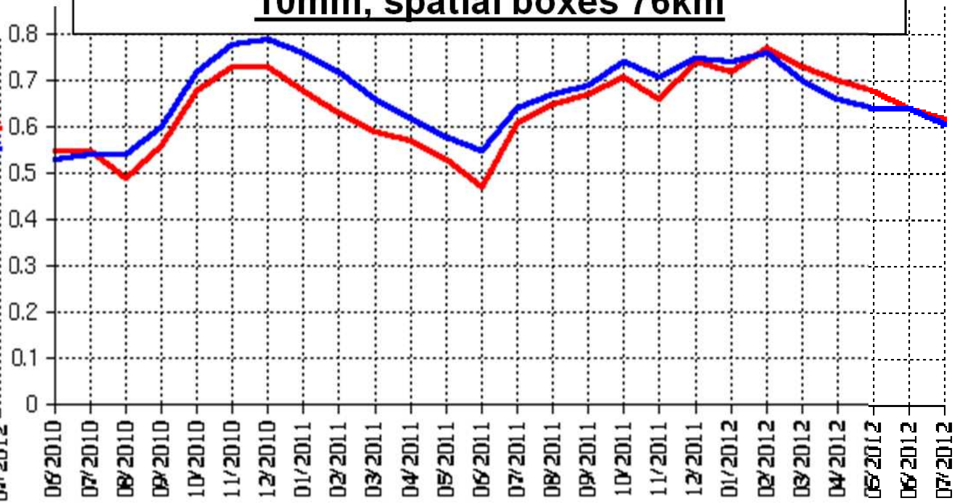
Toujours un temps d'avance

Evaluation of ARPEGE/AROME RR24

Monthly averaged bias for RR24 > 2 mm



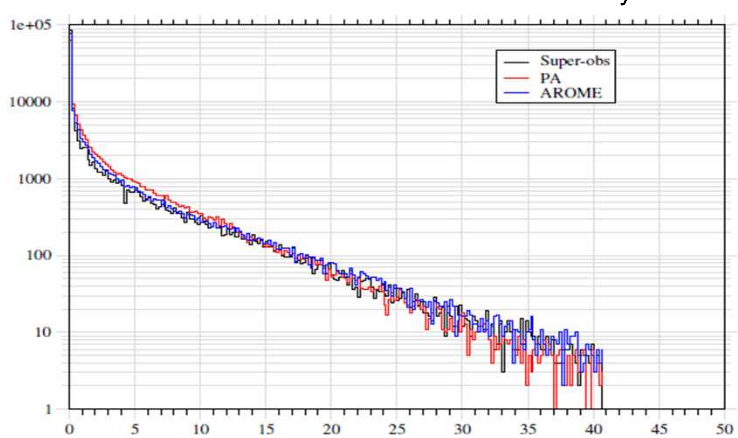
Monthly averaged BSS-NO for RR24 > 10mm, spatial boxes 76km

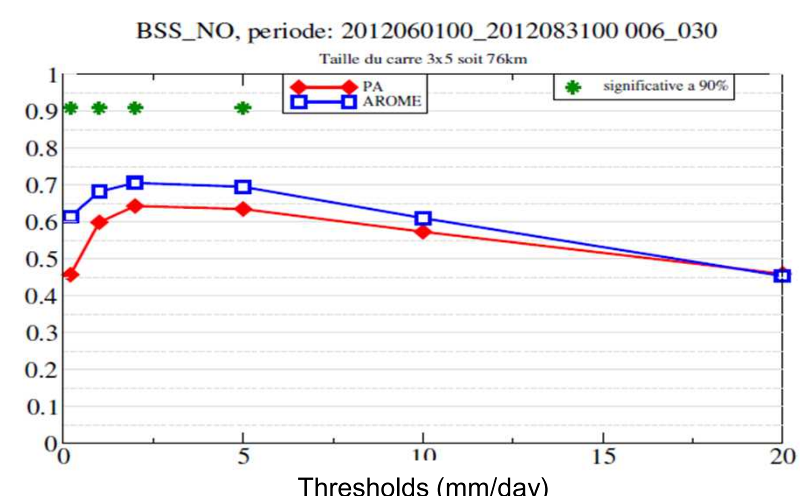


AROME performs better than ARPEGE mostly in summer.

Zoom over last summer : Distribution (JJA 2012) BSS against persistence

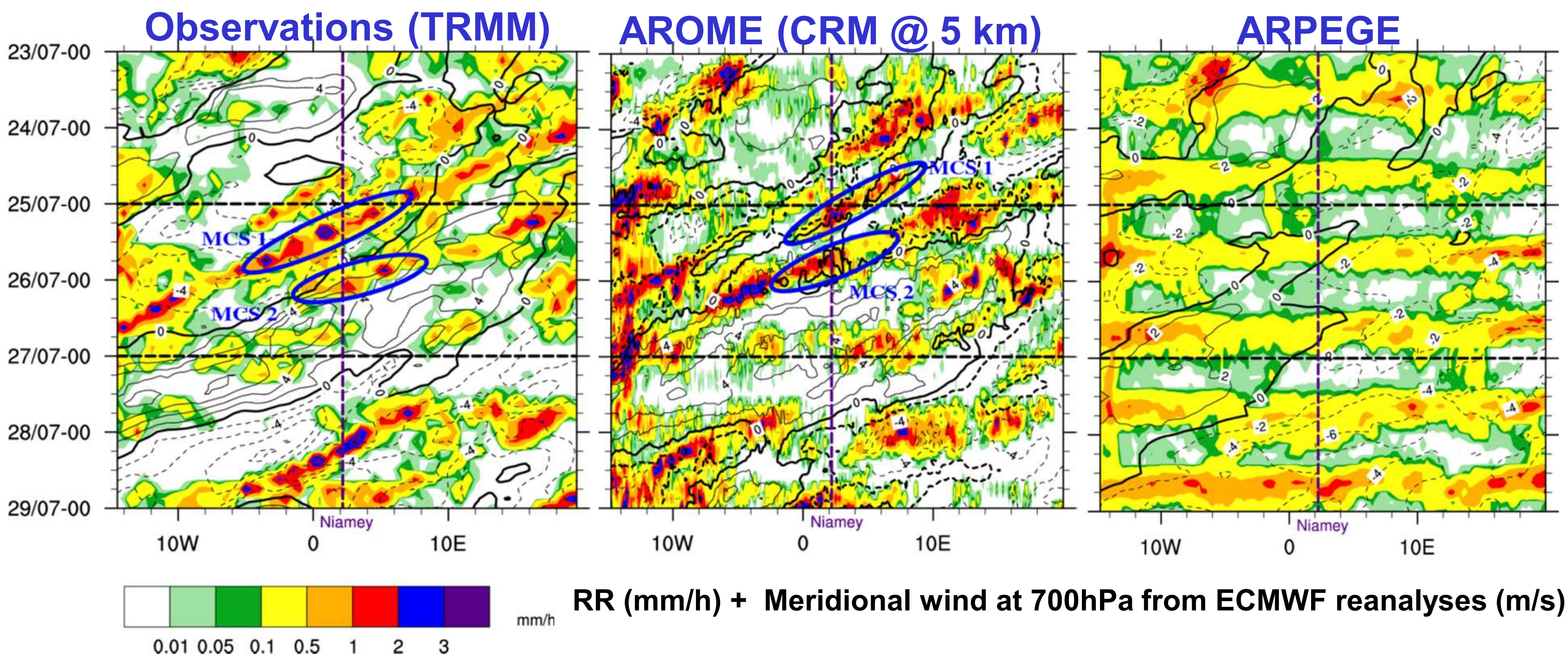
Histograms of observed and forecasted precipitation
Width of the rain classes = 0.2 mm/day





AROME-AMMA

- **AMMA well-documented case 23-29 July 2006** *Barthe et al., 2010*
  - **Intense Monsoon surge over Sahel propagating westward with AEW : Convective events**



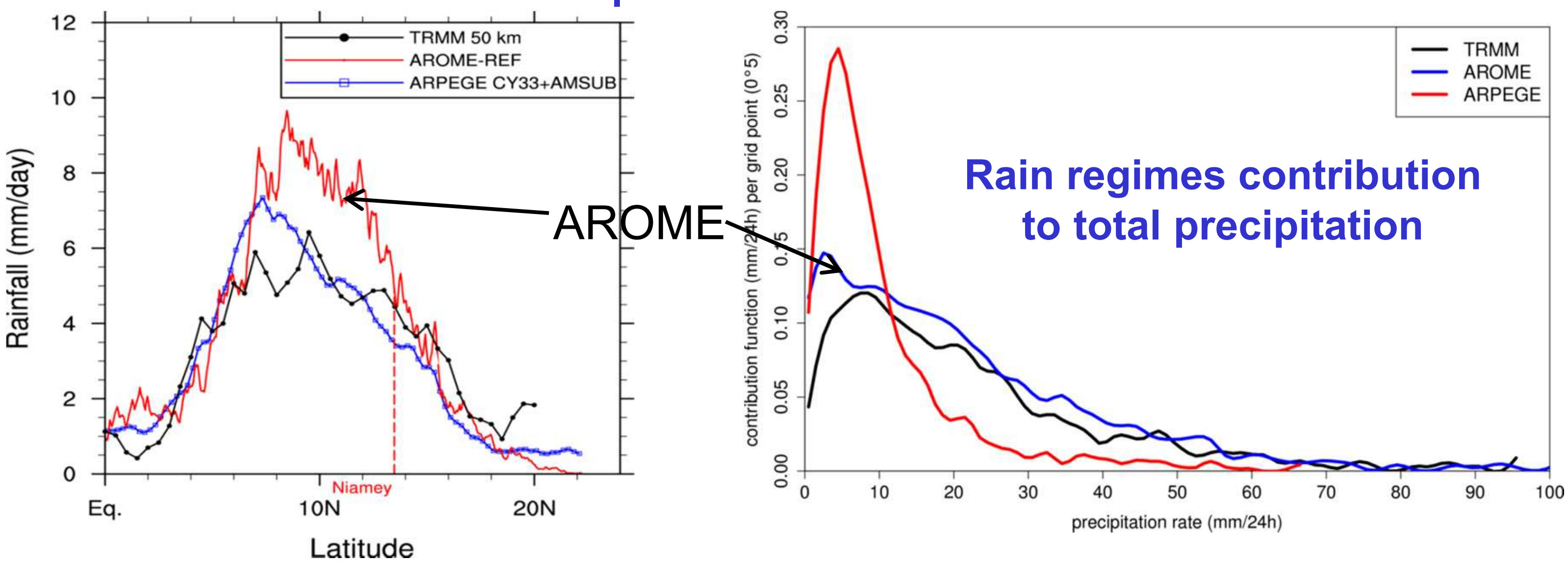
RR (mm/h) + Meridional wind at 700hPa from ECMWF reanalyses (m/s)

• NWP at low resolution: fails to reproduce AEW and the coupling with convection
• High-resolution (CRM): Better representation of the AEW-convection link. Small overestimation of the strong precipitation

Beucher et al., to be submitted

AROME-AMMA

Meridional distribution of Precipitation



Different distributions of precipitation

- ***Meridional distribution***
- ***Rain regimes:***
  - ***ARPEGE: weak events are too frequent***
    intense events are rare
  - ***CRM: distribution of events in better agreement with TRMM***

Beucher et al., to be submitted

Outlines

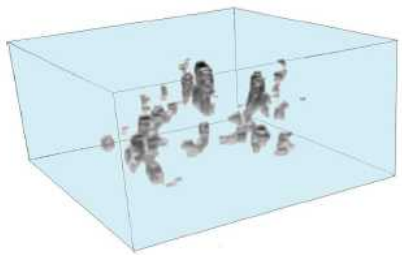
- ARPEGE-oper specificities
- AROME-oper specificities
- Common parts
- Research works :
  - Subgrid clouds
  - Subgrid rains
  - 2-moment microphysical schemes

Meso-NH for LES simulations (3D turbulence, 2-moment microphysical schemes)
→ Statistical distributions → building new parameterization in 1D
→Objective evaluation in 3D with AROME on a significant period

AROME and Meso-NH complementarity for the development/evaluation of a parameterization

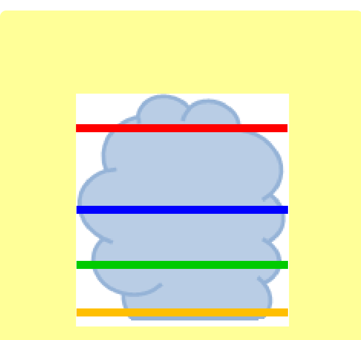
Improvement of the cloud scheme

Perraud et al, BLM, 2011



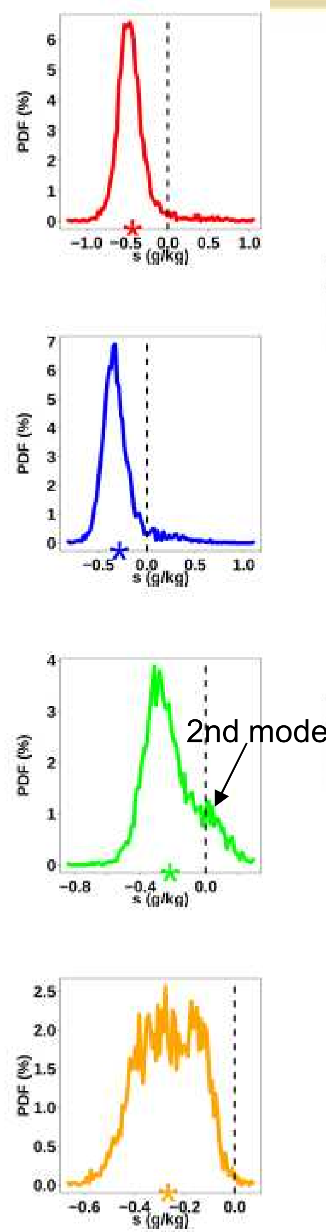
(a) ARM case - 9h

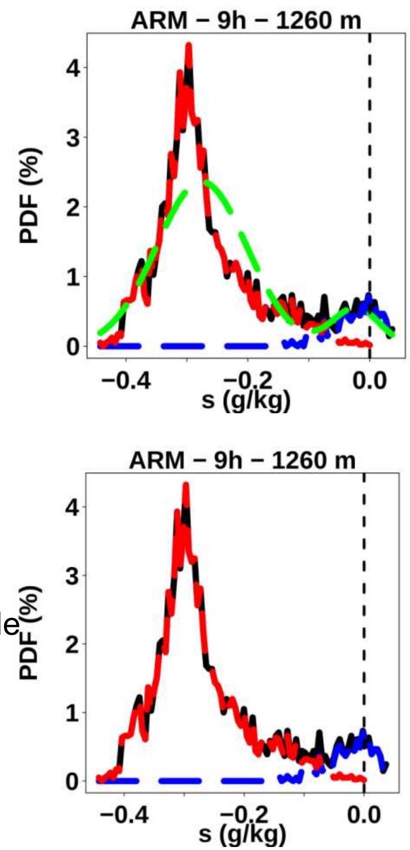
Statistical analysis of BL clouds to characterize the distribution of horizontal subgrid cloud variability



Non symetric bell shaped curves

Saturation deficit distribution





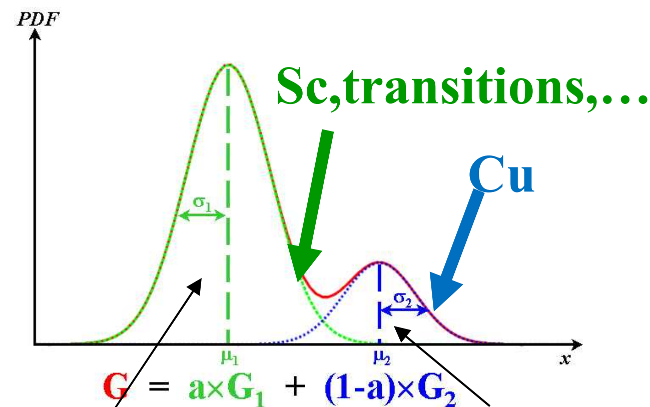
Conditional sampling (Couvreux et al., 2010)

- Whole domain
- Thermals
- Environment (clear sky)

Larson et al (2001), Golaz et al (2002)

Double gaussian

(linear combination of two simple Gaussian distributions)



Turbulence scheme

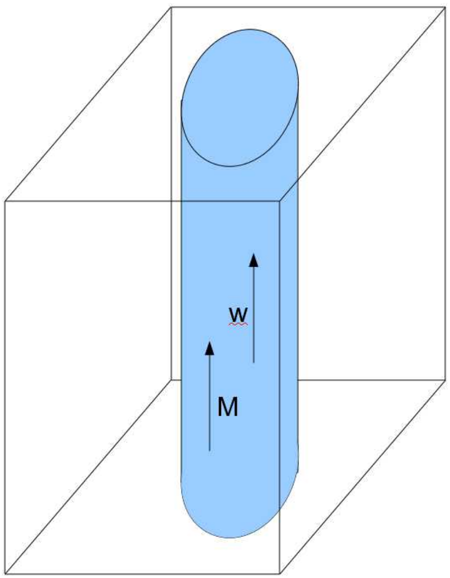
Shallow convection scheme (Pergaud et al., 2009)

Improvement of the cloud scheme

3 options in test in AROME

« DIRECT » (oper)

CF and Rc/Ri are diagnosed directly from updraft variables. (Pergaud et al, 2009)

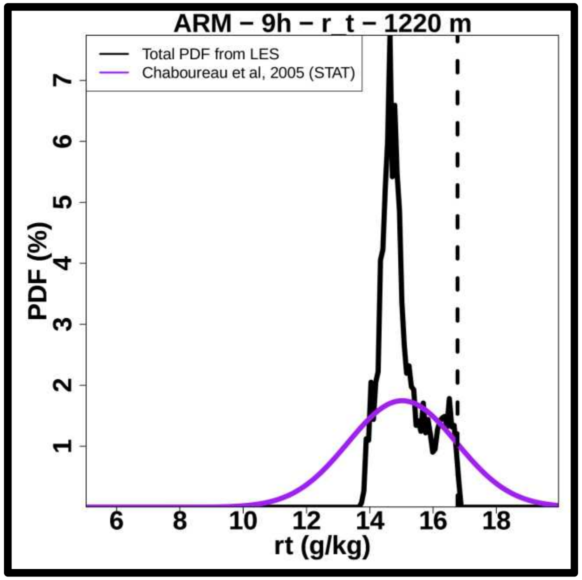


$$CF = \alpha \times \frac{M}{\rho w}$$

Riette et al., to be submitted

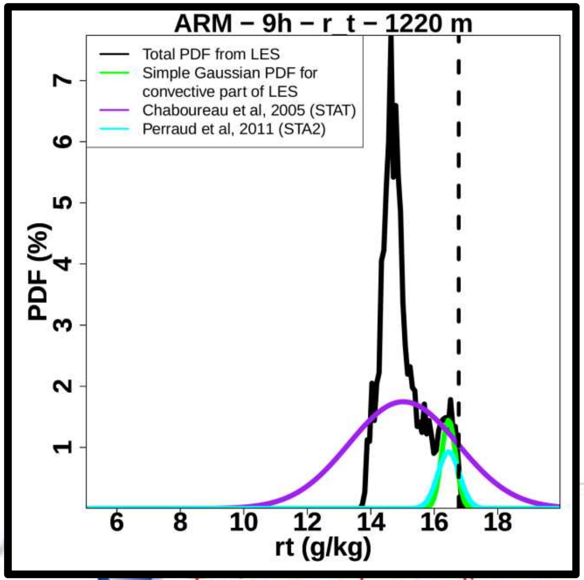
« STAT »

A variance is diagnosed from updraft variables, added to the turbulence one and applied to an uni-modal PDF (Chaboureau et al, 2005)



« BI-GAUSSIAN »

A variance is diagnosed from updraft variables applied to a double-Gaussian PDF with one mode for the environment (turbulence) and one for shallow convection (Perraud et al, 2011)

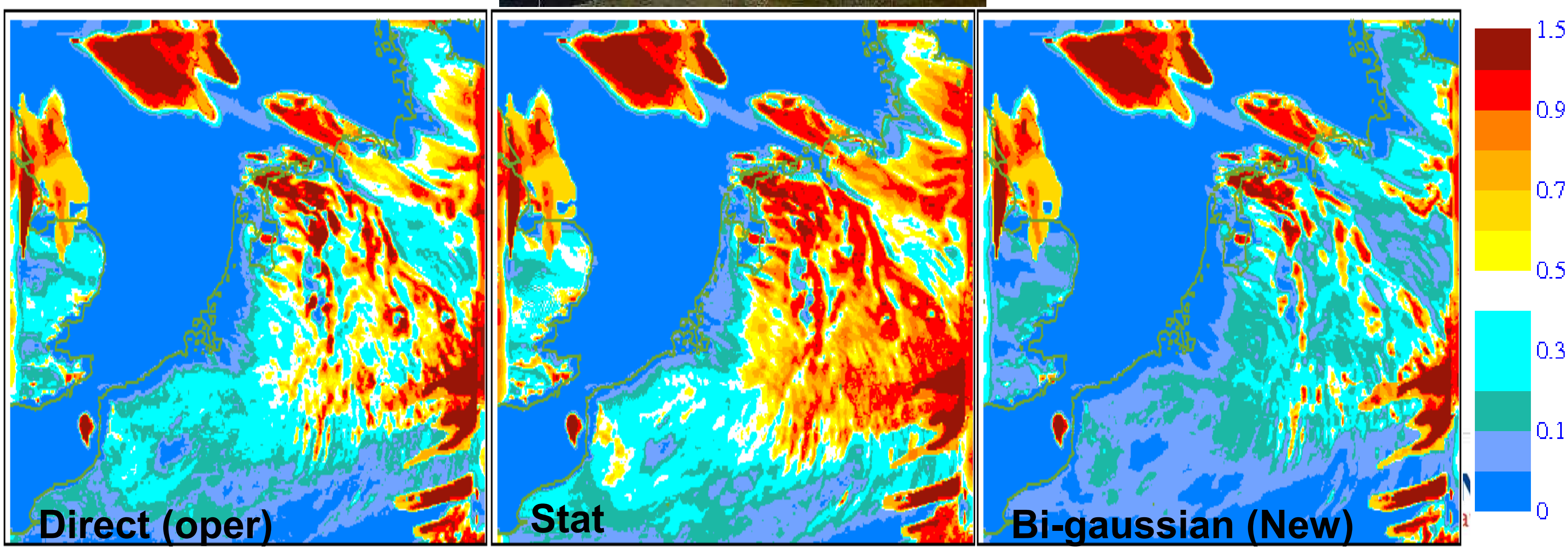


Improvement of the cloud scheme

(9 April 2010 at 12h)

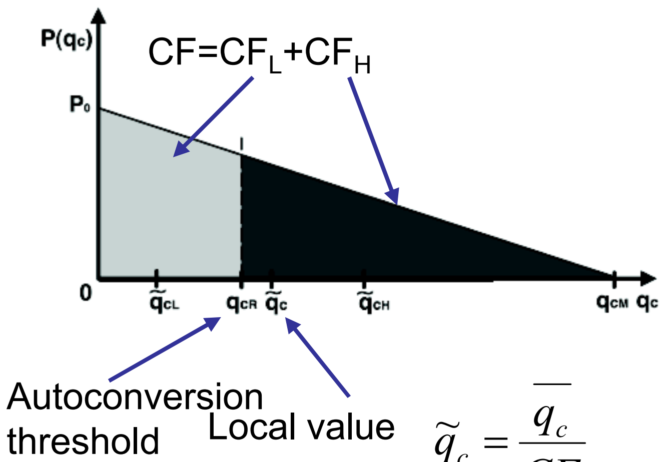
Riette et al., to be submitted

On-going evaluation with soundings and satellite products



Meso-NH : Subgrid rain *Turner et al, GMD, 2012*

To represent the gradual transition from non precipitating to fully precipitating grids

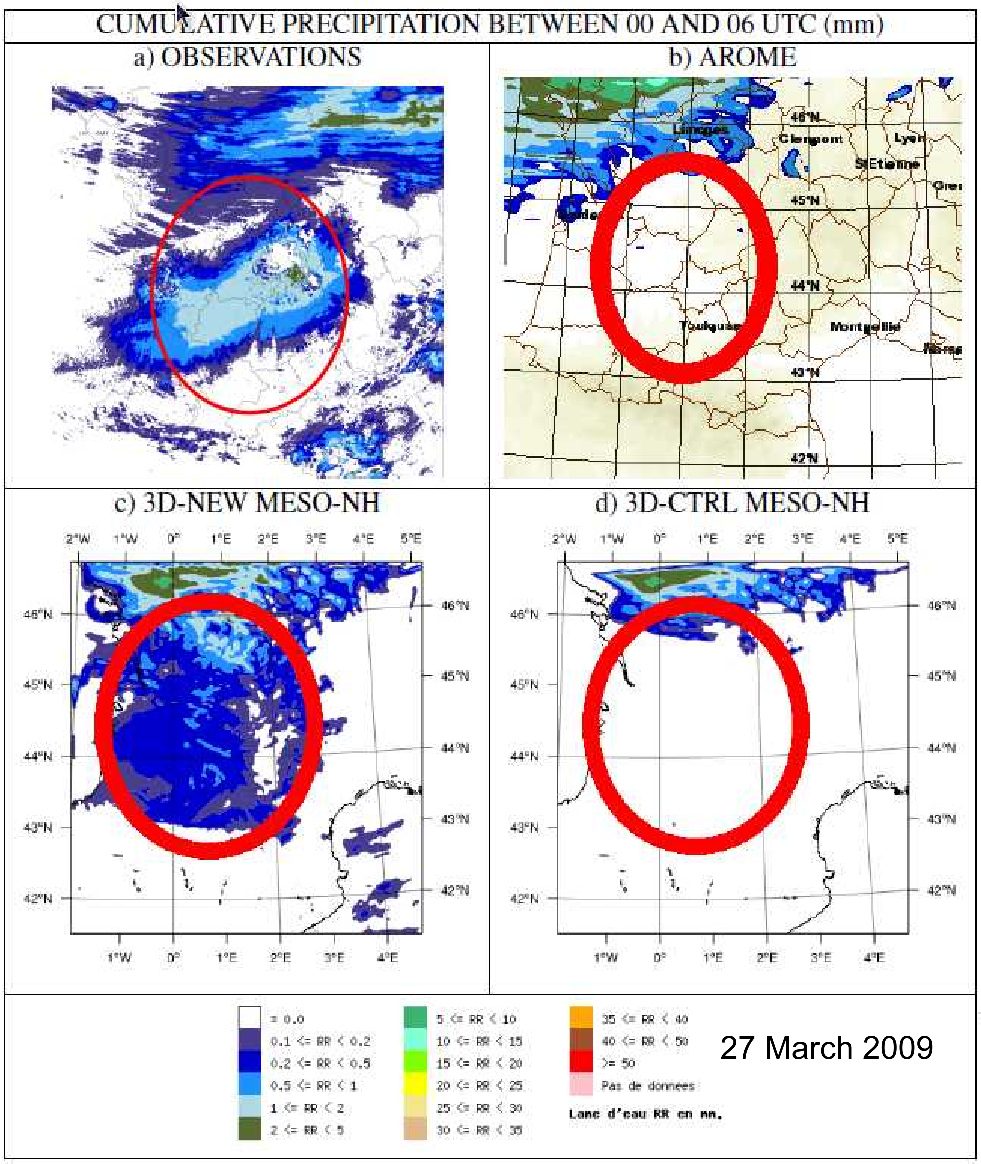


$$\tilde{q}_c = \frac{\overline{q_c}}{CF}$$

Rain fraction : $\tilde{q}_R = \frac{\overline{q_R}}{RF}$ without adding a prognostic variable

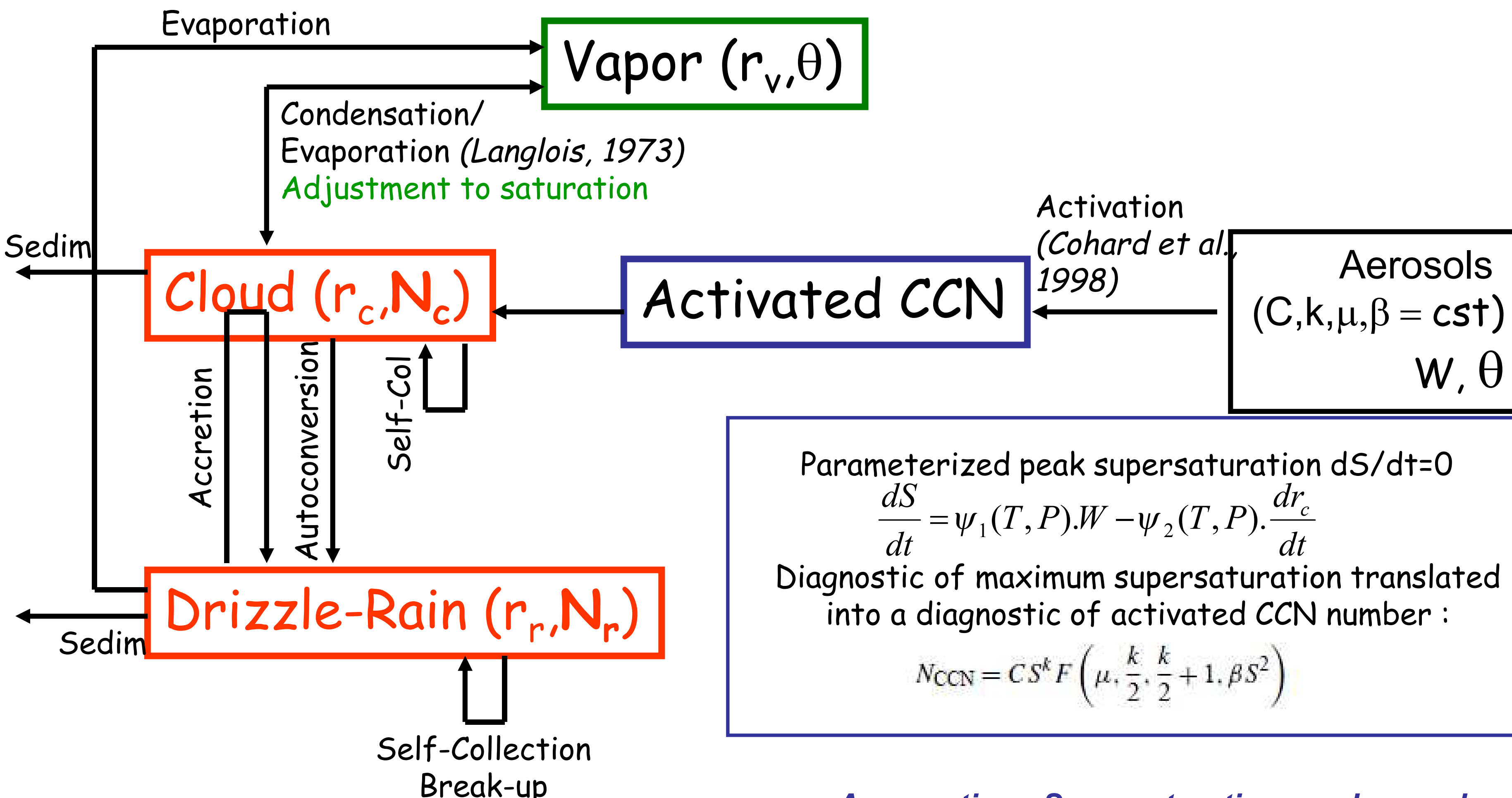
Maximum overlap assumption for RF

Will be evaluated in AROME in 2013



Meso-NH : Warm 2-moment microphysical schemes

Cohard and Pinty, 1998 for Cu ; Geoffroy et al., 2008 for Sc-St



Parameterized peak supersaturation dS/dt=0

$$\frac{dS}{dt} = \psi_1(T,P).W - \psi_2(T,P).\frac{dr_c}{dt}$$

Diagnostic of maximum supersaturation translated into a diagnostic of activated CCN number :

$$N_{CCN} = CS^k F\left(\mu, \frac{k}{2}, \frac{k}{2}+1, \beta S^2\right)$$

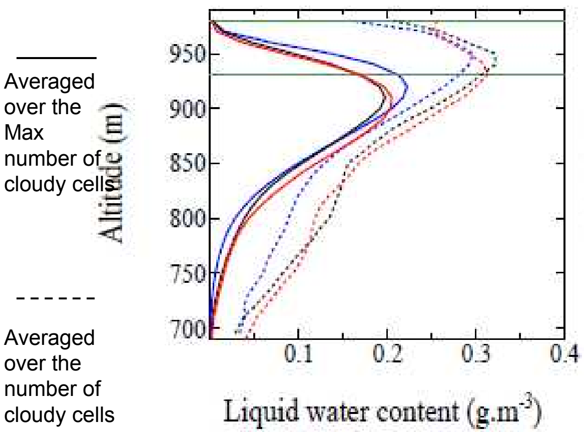
Assumption : Supersaturation reaches and passes its maximum within a time step

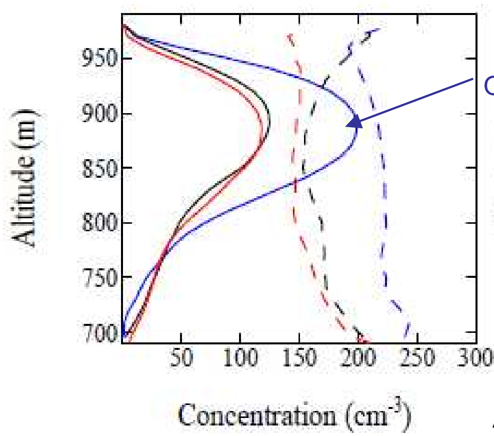
Meso-NH : Warm 2-moment microphysical schemes : Improvement for very fine resolution

Thouron et al., GMD, 2012

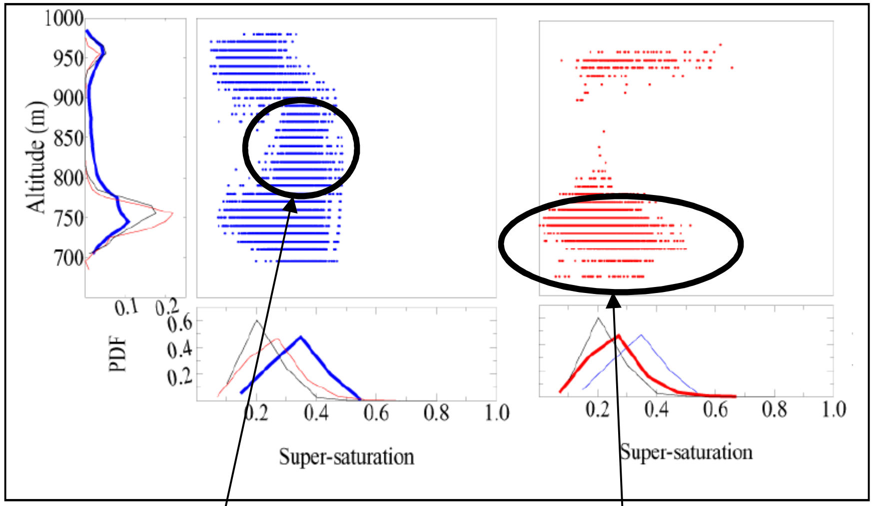
Adjustment to saturation adapted to Δz~100m and Δt>30s but not at finer resolution (Δz<10m and Δt<10s) : too thin and too short for assuming that supersaturation reaches and passes its maximum within a Δt
Also adapted for grids with no initial liquid water content, while pre-existing condensed water reduces the supersaturation peak

- **Adjustment to saturation with parameterized peak supersaturation**
- Diagnostic of supersaturation
- **Pseudo-prognostic of supersaturation** ← More realistic for LES





Overestimation



CCN activation only accounts for vertical velocity : no sink due to existing LWC

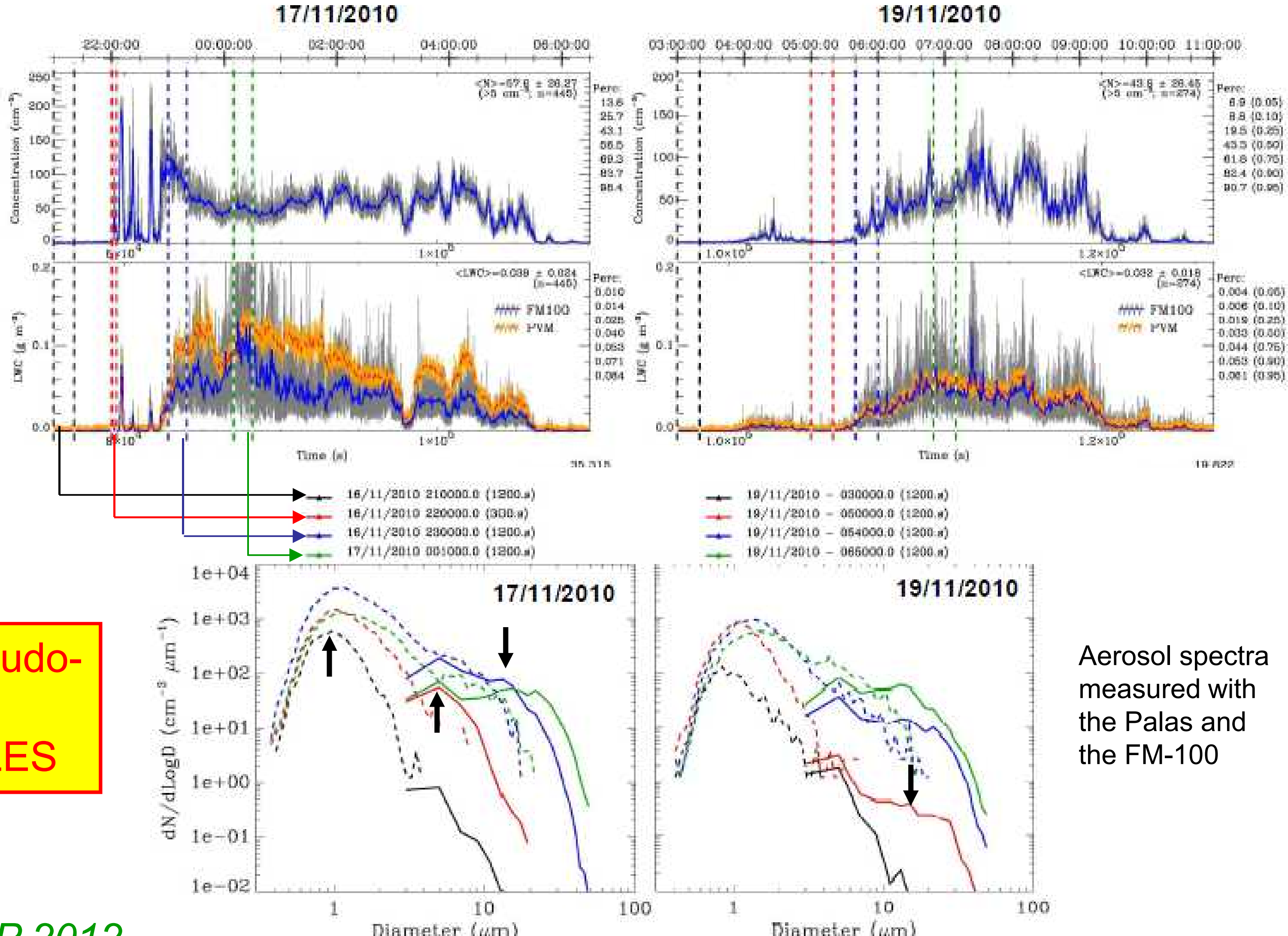
ACE-2 case (dry)

Greater S at cloud base

Meso-NH : Warm 2-moment microphysical schemes : Improvement for very fine resolution

FOG : Evaluation on **PreViBOSS campaign (2010-2013, SIRTA, Palaiseau)**

MEASUREMENTS



To test the pseudo-prognostic saturation in LES

Aerosol spectra measured with the Palas and the FM-100

Burnet et al., ICCP 2012

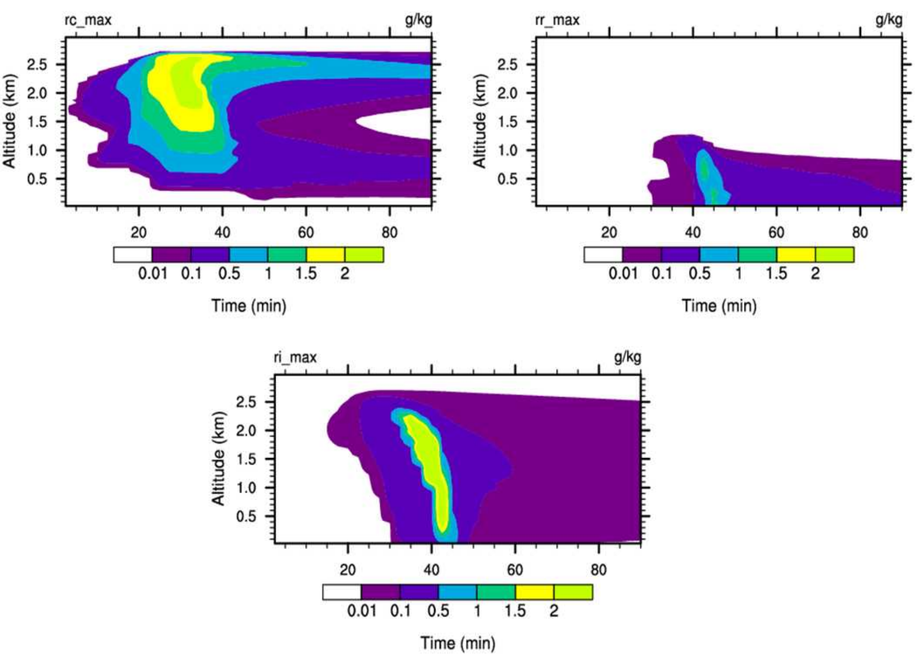
2-moment mixed microphysical scheme in Meso-NH : Implementation of Morrison and Grabowski (2008) scheme

C.Barthe, LACy, La Reunion

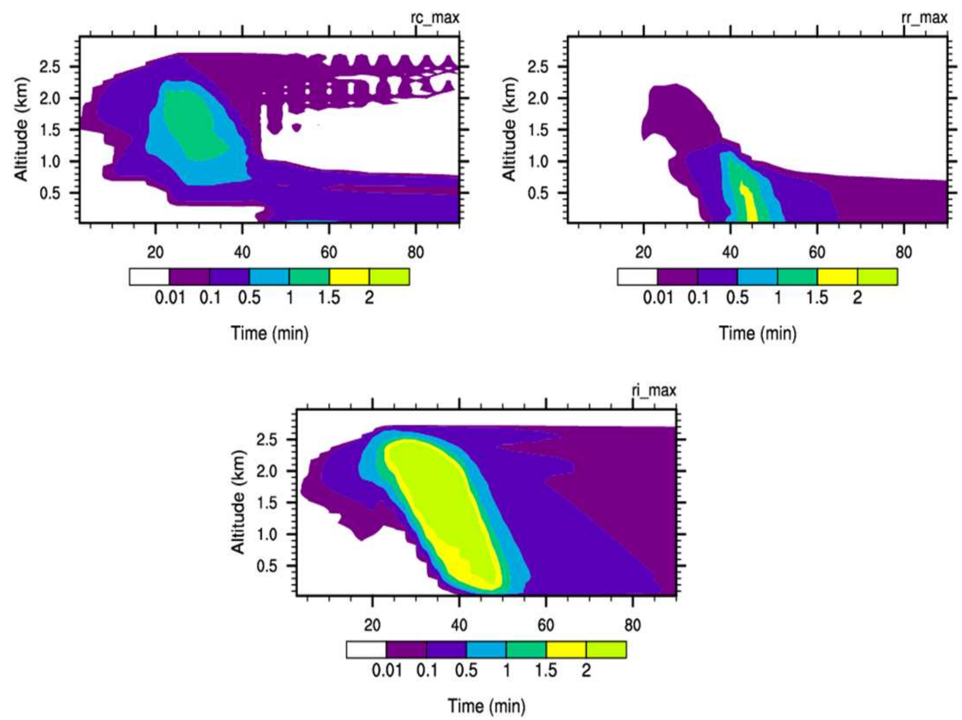
→1st step: implementation and test on the 2D HaRP case

Idealized shallow convective plume (Szumowski et al., 1998) with colder initial temperature profile to simulate mixed-phase conditions

Morrison and Grabowski (2008) scheme



Pinty and Jabouille (1998) scheme

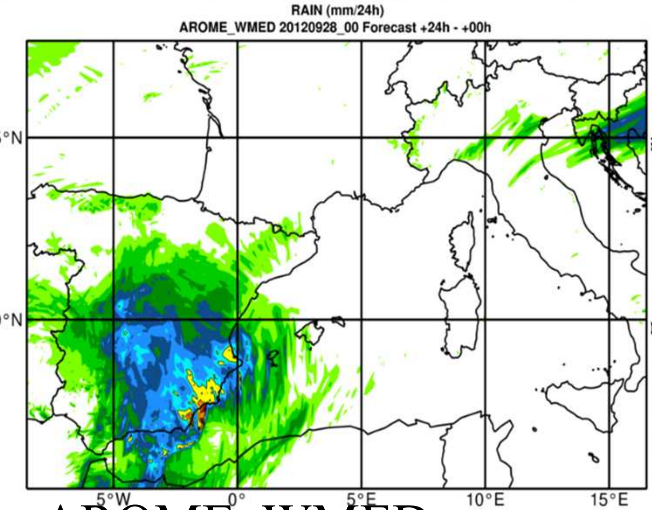


Time evolution of horizontal maxima of r_c, r_r and r_i

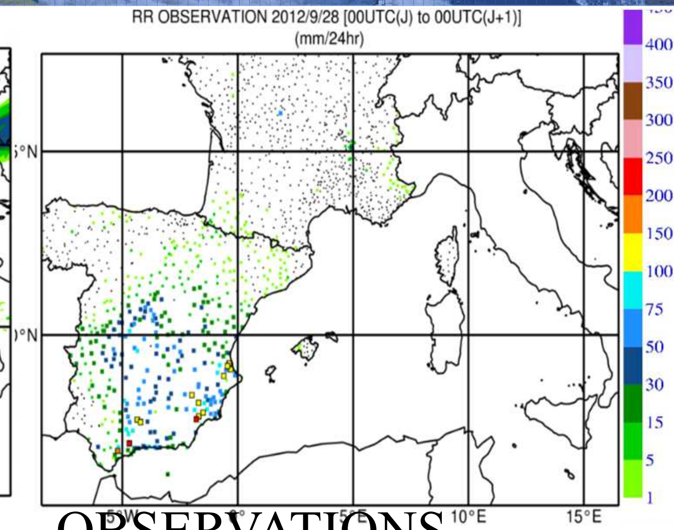
→2nd step : Evaluation on High Precipitation events (Hymex, tropical disturbance…)

METEO FRANCE
Toujours un temps d'avance

HyMeX IOP8 – September 28th



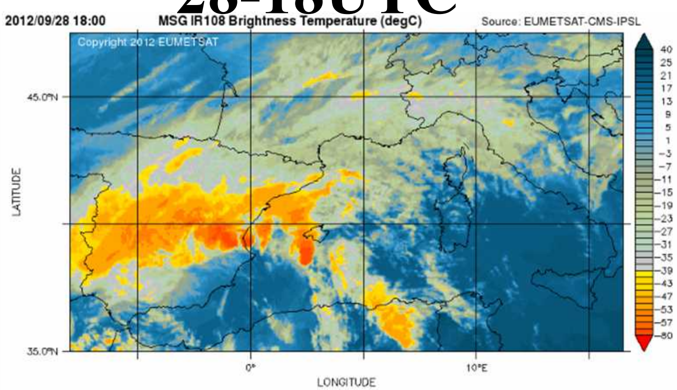
AROME_WMED

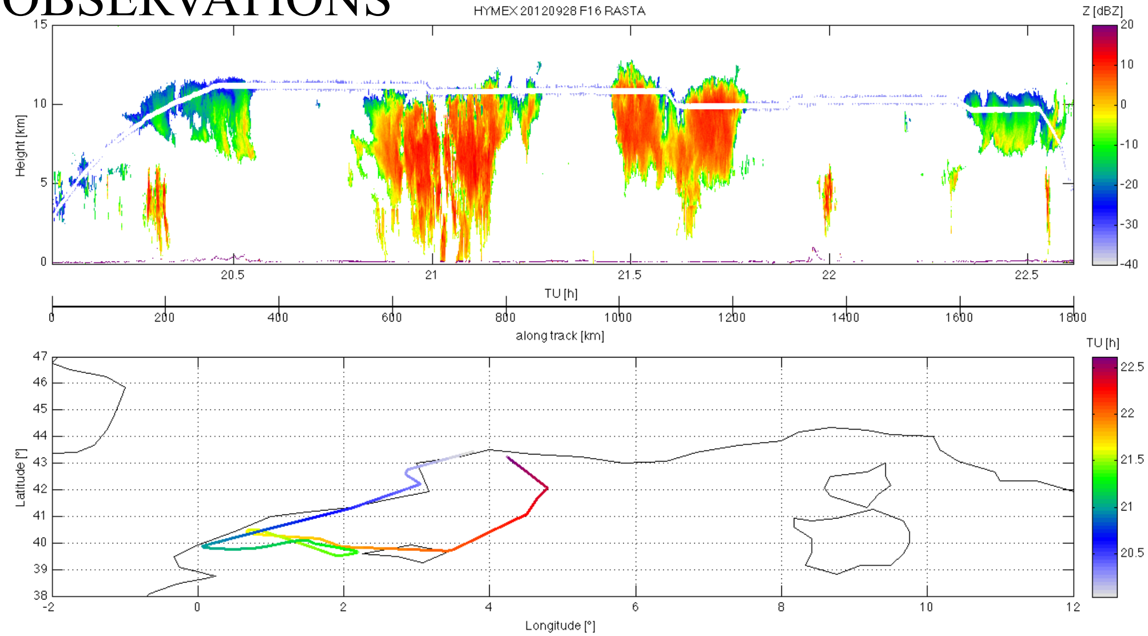


OBSERVATIONS

Bridge destruction

28-18UTC





Radar RASTA reflectivity along the Flight track on **28/09** from 20h to 23h UTC

Conclusion

✓Operational : ARPEGE and AROME : Physics tend to be closer but microphysics and cloud scheme remain different for the moment

✓ Evaluation : ARPEGE tends to overestimate small precipitation and to underestimate strong precipitation.

AROME tends to slightly overestimate moderate to strong precipitation

✓ In evaluation and to become operational in 2013 for AROME : subgrid cloud scheme improvement + subgrid rain.

✓ AROME 1.3km, ~90 lev. planned to be operational in 2014

✓ Research works on 2-moment microphysical schemes :

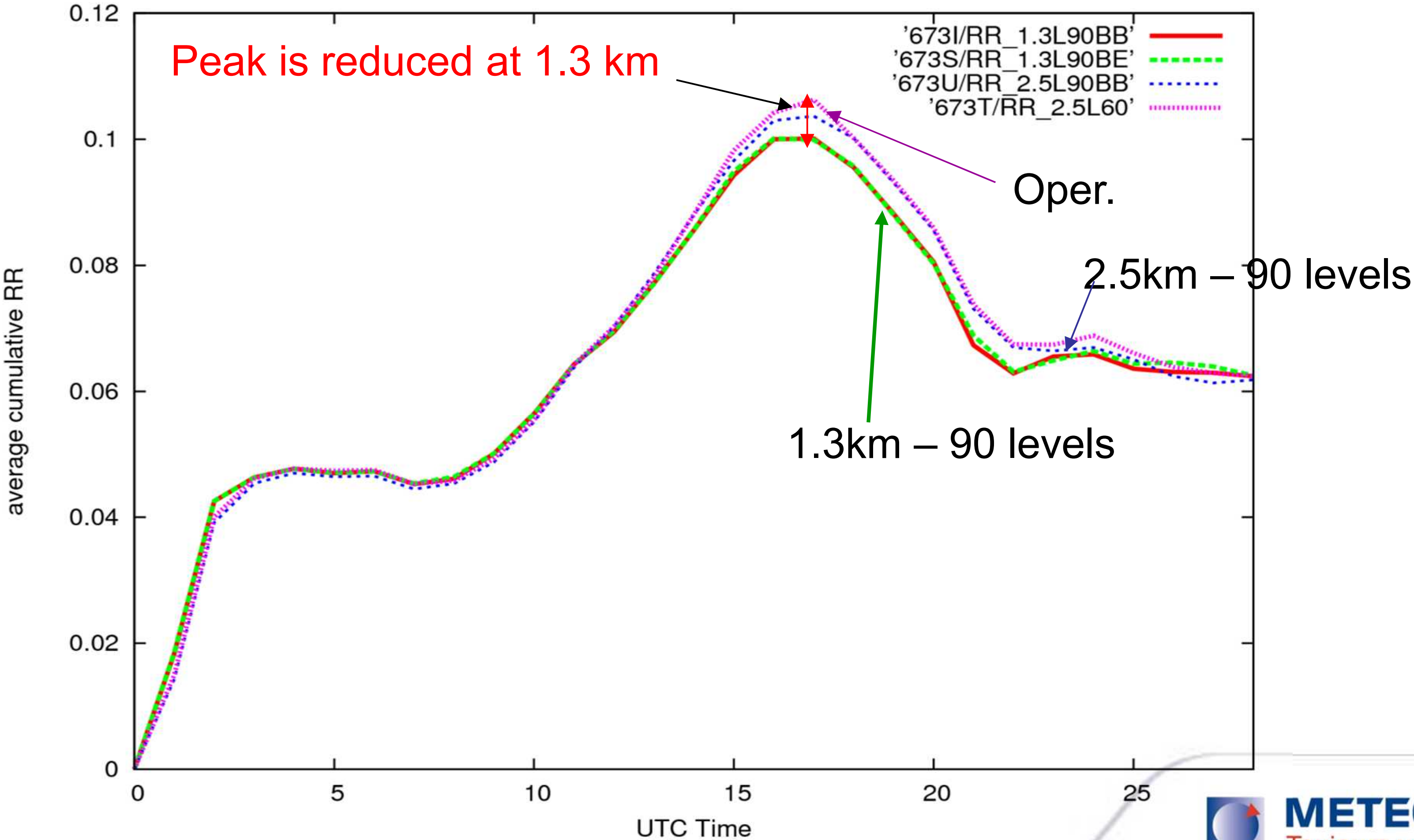
- Warm : Pseudo-prognostic of supersaturation for LES – Evaluation on fogs driven by radiative cooling

- Mixed : Morrison-Grabowski (2008) scheme evaluation

Firsts results from AROME 1.3km

Planned to be oper in 2014

Evolution of mean hourly cumulated rainfalls over France (JJA 2012)



Cloud and microphysical schemes in ARPEGE and AROME models

Y. Seity, C.Lac, F. Bouyssel, Y.Bouteloup, S.Riette, O.Thouron, F.Beucher, F.Burnet (CNRM)
C.Barthe (LACy), J.-P.Pinty (LA)

cnrs INSU Observer & comprendre

Ecclouds November 2012

METEO FRANCE
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