Representation of CLOUDS in AROME

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Workshop ECMWF November 13rd-15th 2006

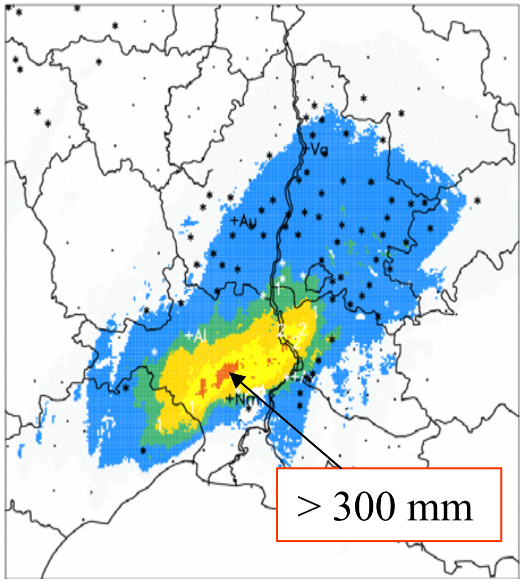
AROME = ALADIN-NH dynamics + a selection of Méso-NH physics (ECMWF radiation)

Daily runs since June 2005 over small domains (SW of France + a seasonal one)

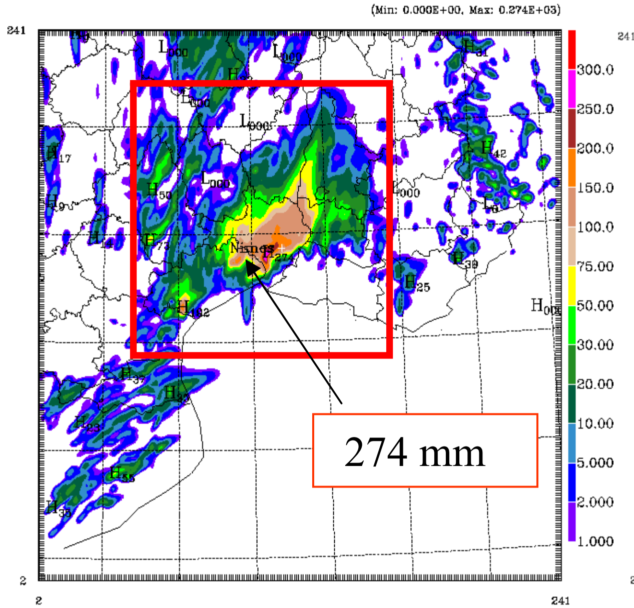
-> Robust
-> Good representation of intense convective events
-> Needs significant improvements in the representation of Cu, Sc : an improved shallow convection scheme currently tested
-> 2007 : Numerous tests for evaluation/validation
-> 2008 : Operational

« Gard » flash flood (8 Sept. 2002)

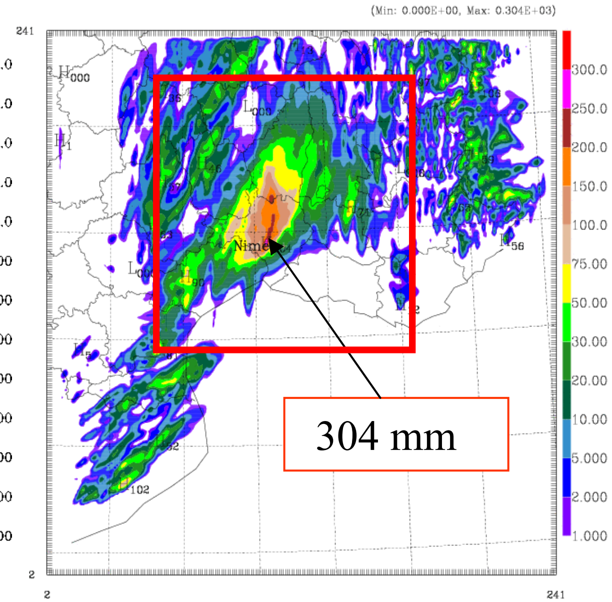
12-22 TU Nîmes radar cumulated rainfall



MésoNH 4s



Arome 60s

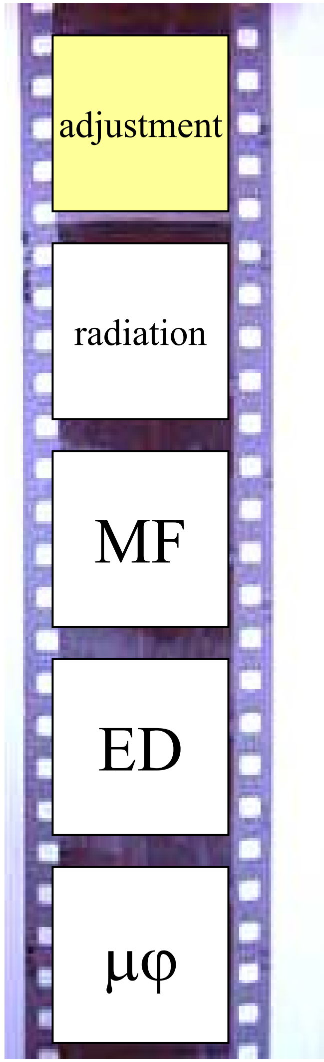


2.5 km horizontal resolution, L41 (Arpege/Aladin levels)

Initial Conditions : Mesoscale surface data reanalysis

Boundary Conditions : Aladin 3h Forecasts

Y.Seity

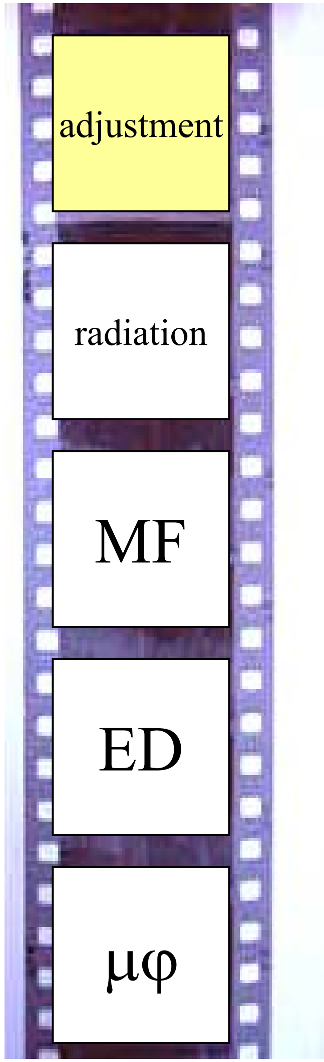


Arome/MésoNH : pronostic or diagnotic clouds?

$\bar{r}_{np}$, $\bar{T}_l$ → hypotheses → $\bar{r}_v$, $\bar{r}_c$, $\bar{r}_i$, $\bar{T}$ (but $\delta r_c = r_c\_r_c^-$)

- All or Nothing (resolved cloud scheme)
- Subgrid cloud scheme (subgrid adjustment to saturation)

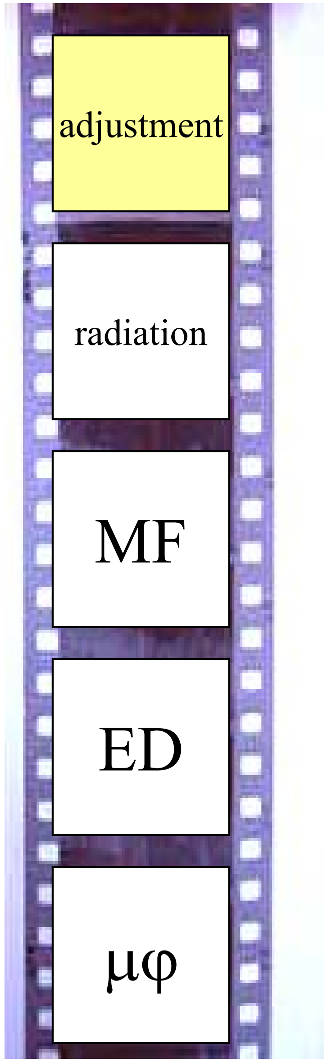
What kind of cloud in Arome?



$\overline{rc}$ and N = stratiform + convective ?
= resolved + subgrid ?
= f(resolved, subgrid) ?

- $\overline{rc}$ is diagnostic and historic : the processes to describe the all life cycle of cloud have to be present
- N is only diagnostic
- The water budget is closed at the scale of a time step

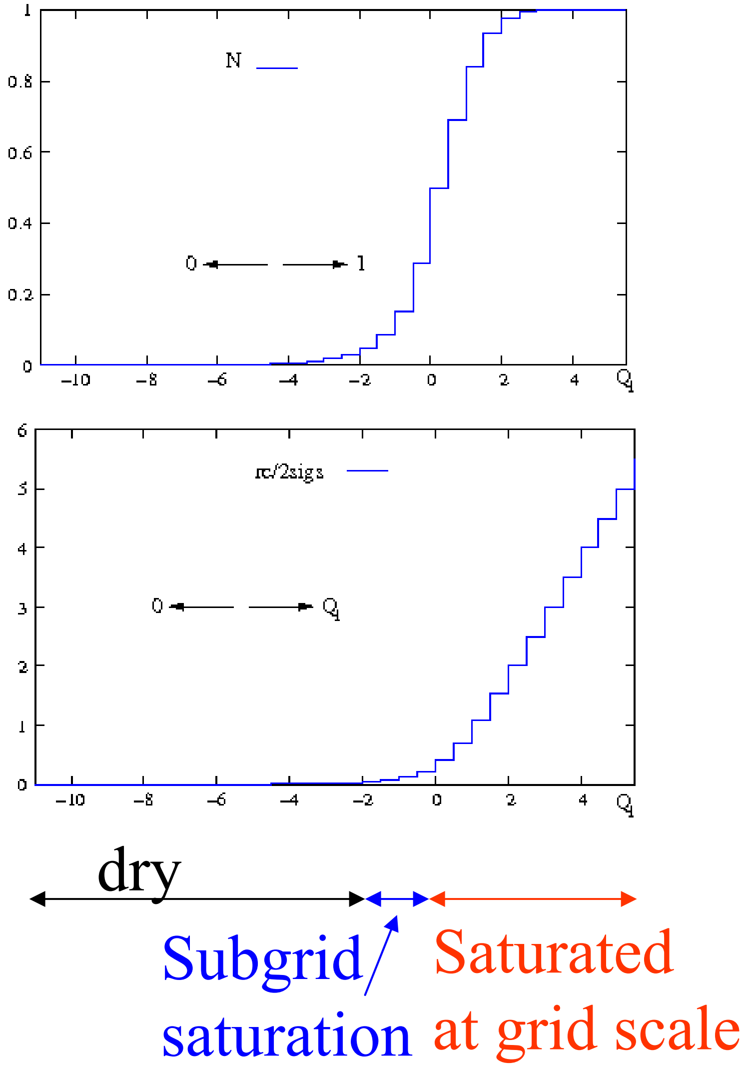
Statistical cloud scheme (Bougeault, 81, 82)

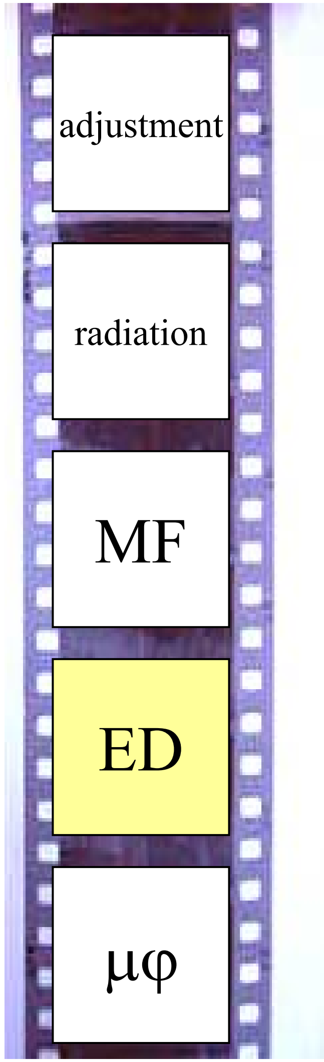


Ingredients :

$$\overline{Q_1} = \Delta \text{ sat}/(2\sigma)$$

σ^2 : variance of the distance to saturation (for each subgrid process)





ED clouds

$$\sigma_{ED} = f\left(\overline{r'_{np}{}^2}, \overline{\theta'_l{}^2}, \overline{r'_{np}\theta'_l}\right)$$

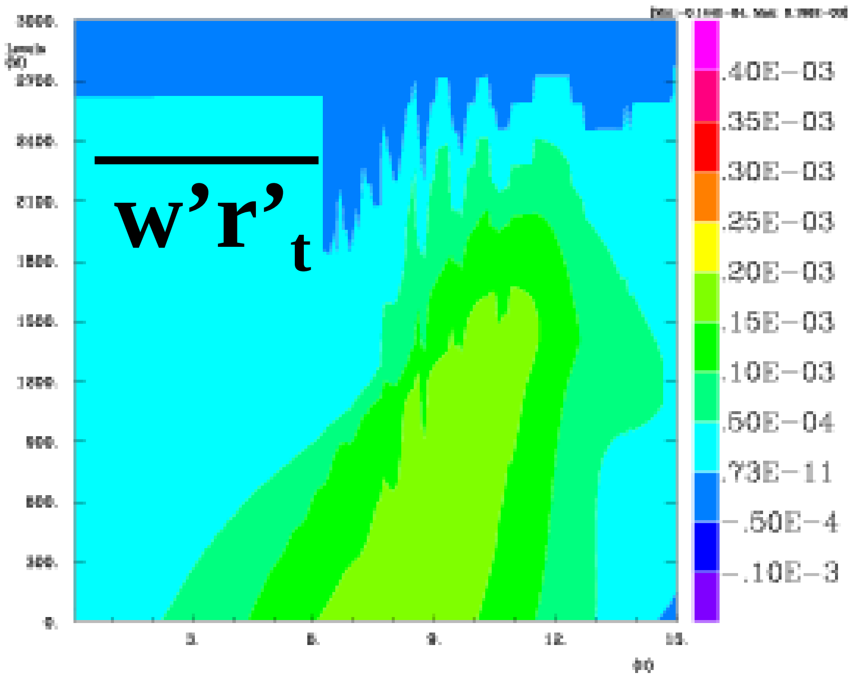
with $\overline{r'_{np}{}^2}, \overline{\theta'_l{}^2}$ and $\overline{r'_{np}\theta'_l}$ from the ED scheme

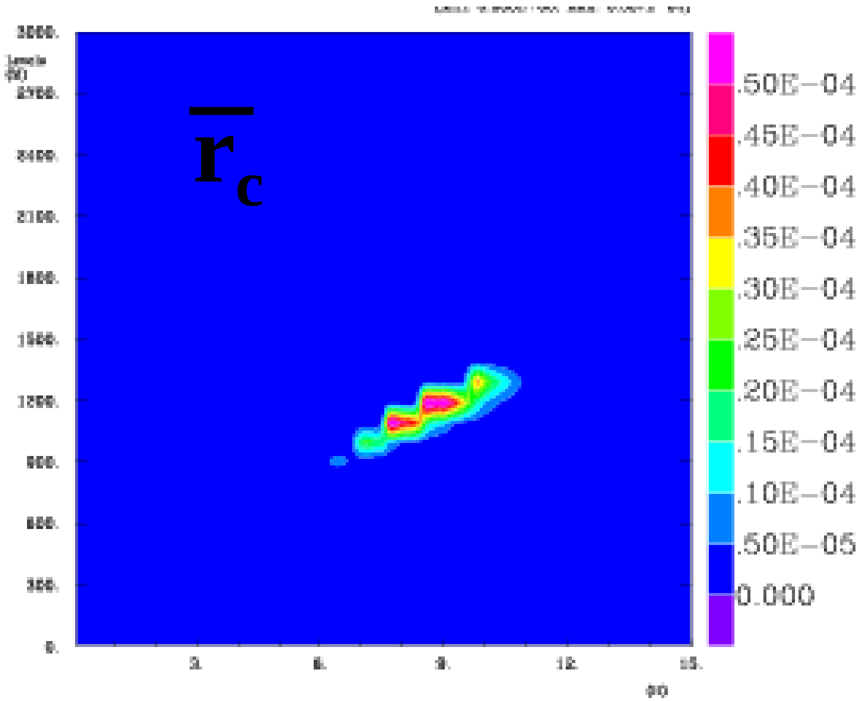
- For Q1>0 (saturation for grid scale parameters), clouds are also associated with σ_{ED}
- But ED is usually not active enough in « vertical thermics », so a complementary σ is needed for subgrid convective clouds (only shallow ones in Arome)

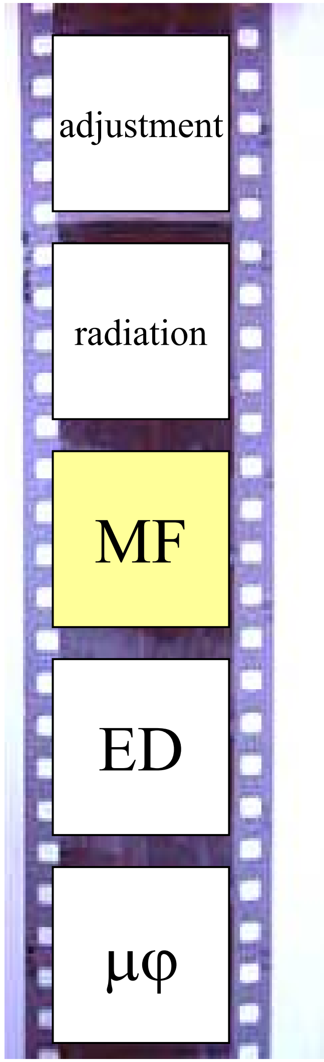
EUROCS/ARM/Cu

With KFB and σ_{ED} only

The subgrid fluxes of conservative variables are correct but we have some cloud only where the ED turbulence is active







MF clouds

From KFB, EDMF, EDKF …..

2 possibilities :

Statistic cloud scheme

MF

↓

Convective variances
(Lenderink and Siebesma, 2000,
Soares et al, 2004 or
Bechtold and Chaboureau, 2002)

↓

σ_{MF}

↓

$$\sigma_{tot}^2 = \sigma_{ED}^2 + \sigma_{MF}^2$$

Updraft cloud scheme

r_{c_up}

↓

$\delta\overline{r}_{c\_conv} = N\, r_{c\_up}$

↓

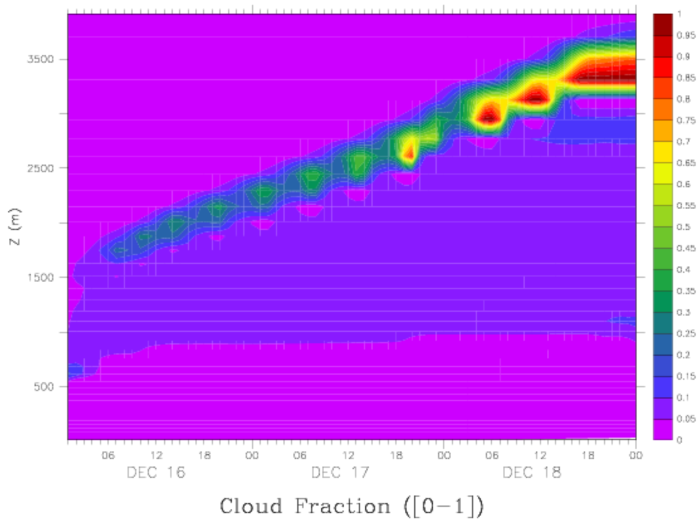
$$\overline{r}_c = f(\overline{r}_{c\_ED}, \overline{r}_{c\_conv})$$

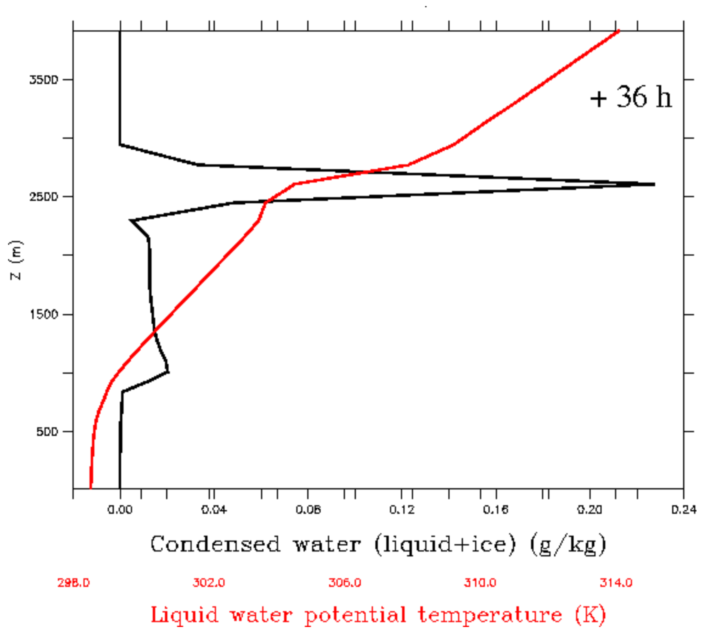
(scheme used for the Rico case)

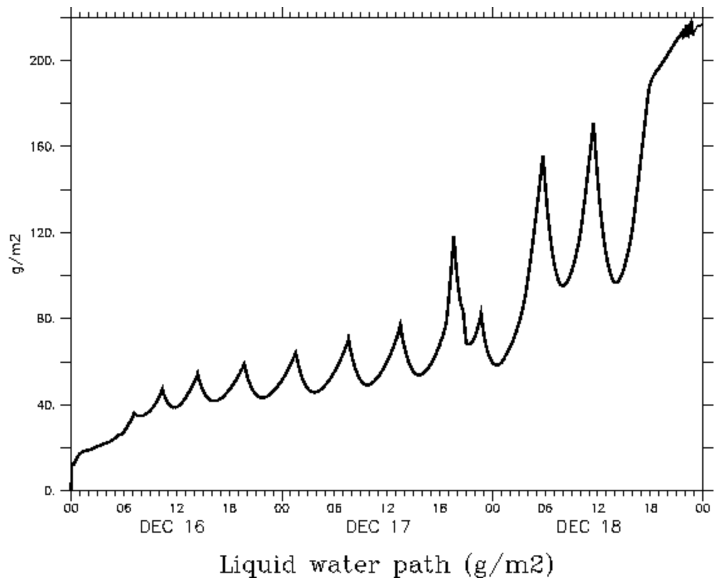
Rico : high resolution composite case

KFB shallow convection scheme
(Bechtold et al, 1993)
with statistical cloud scheme
(Chaboureau and Bechtold, 2002)

Results are identical if shallow+deep



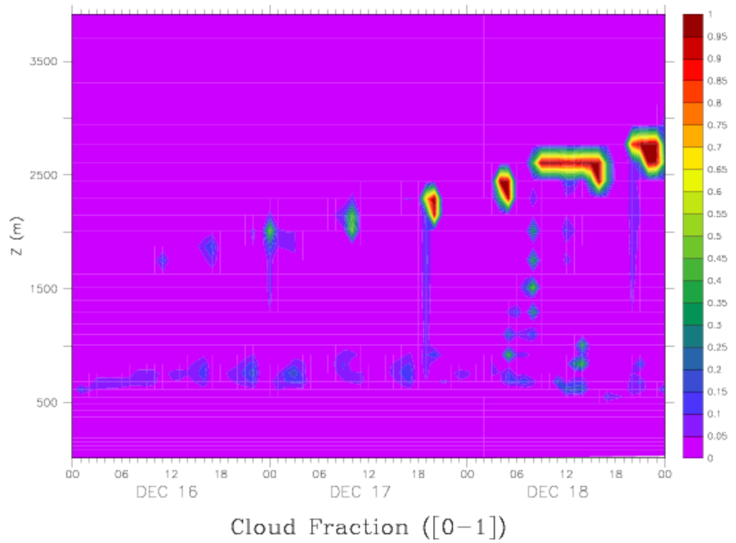


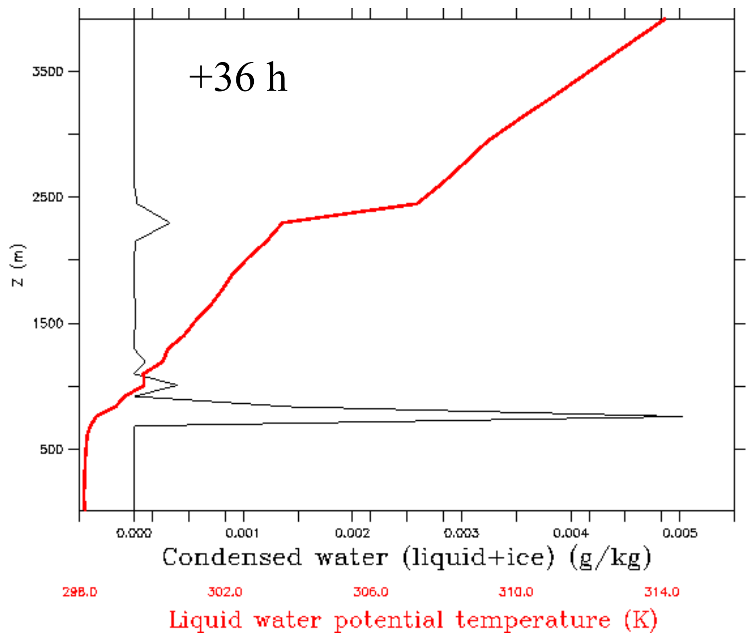


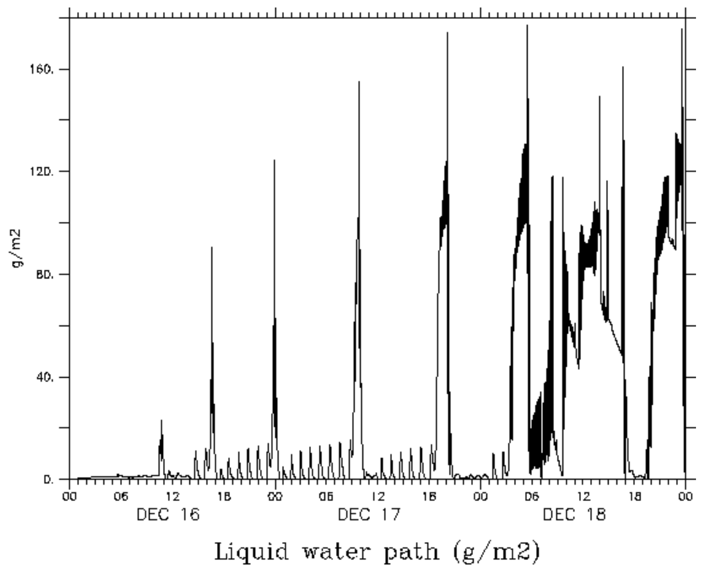
Rico : high resolution composite case

EDMF (Soares et al, 2004)

with statistical cloud scheme (Soares et al, 2004)

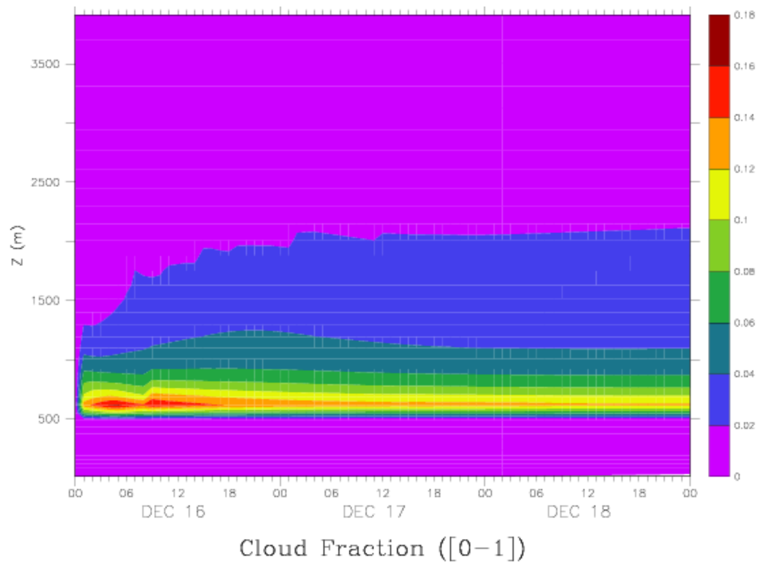


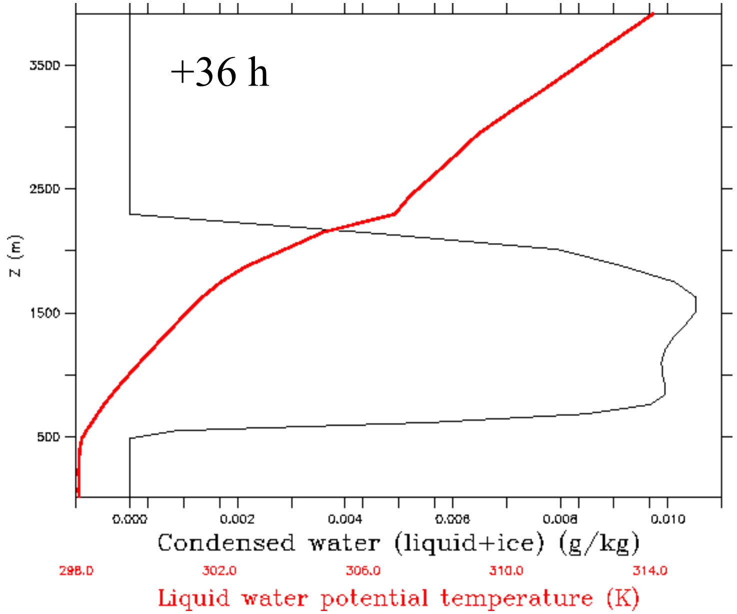


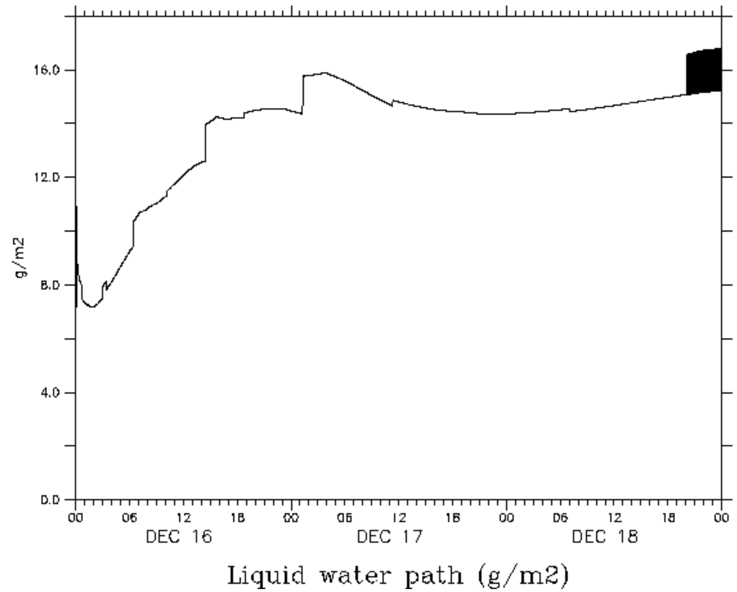


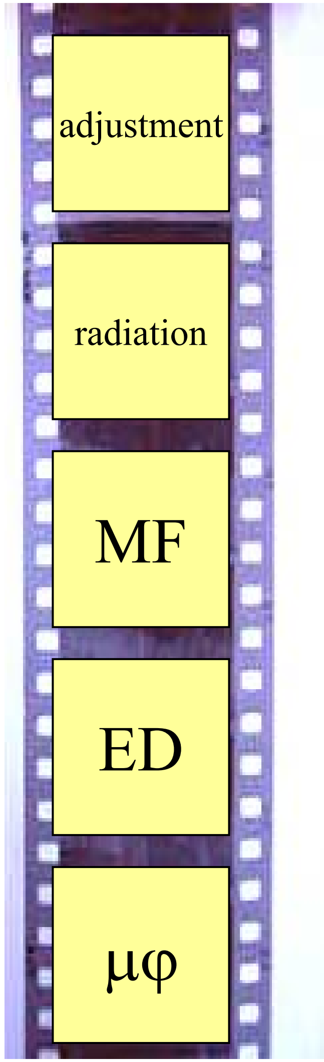
Rico : high resolution composite case

EDKF (Pergaud, Malardel, Masson)
with updraft cloud scheme









Other interactions

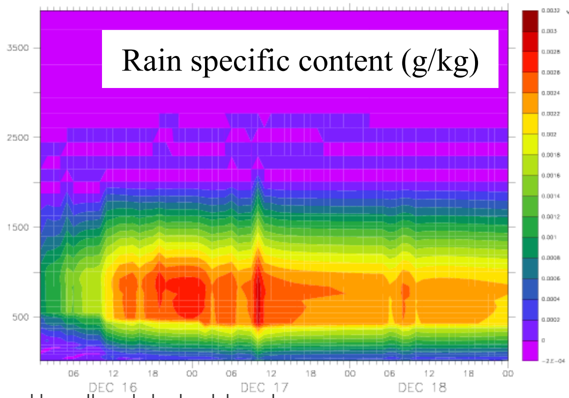
- How to design the optimal physical data flow in the physics (how many adjutments and where)?
- How to compute non conservative fluxes ($\overline{w'\theta'}_v$ in TKE production) ?
- Which clouds for radiation ?
- Which clouds for microphysics of precipitation ?

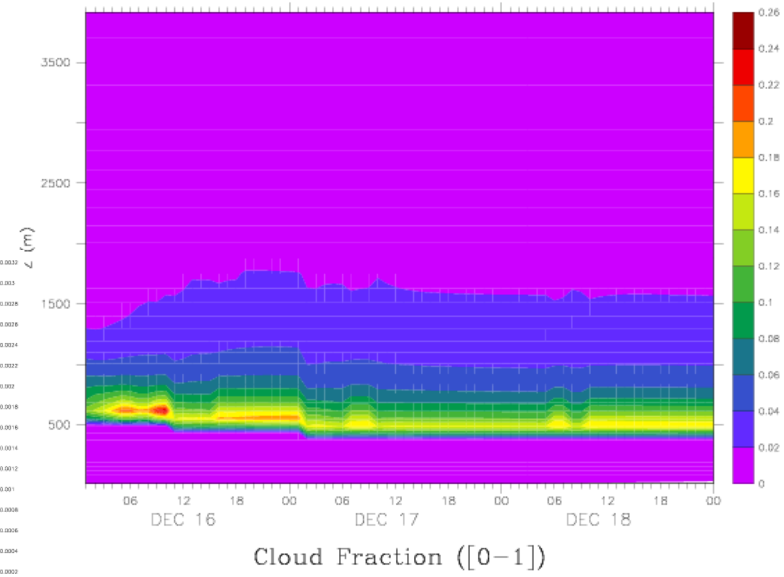
✓Help (?) : re-visit the Navier-Stokes equations

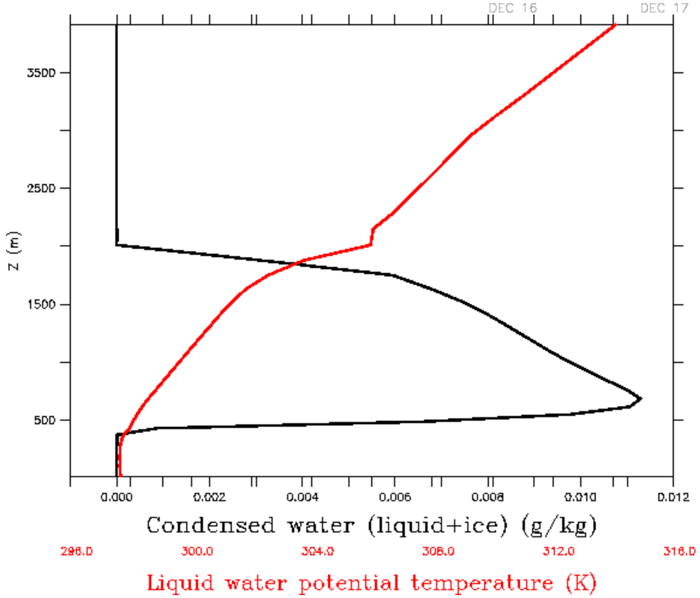
Rico : high resolution composite case

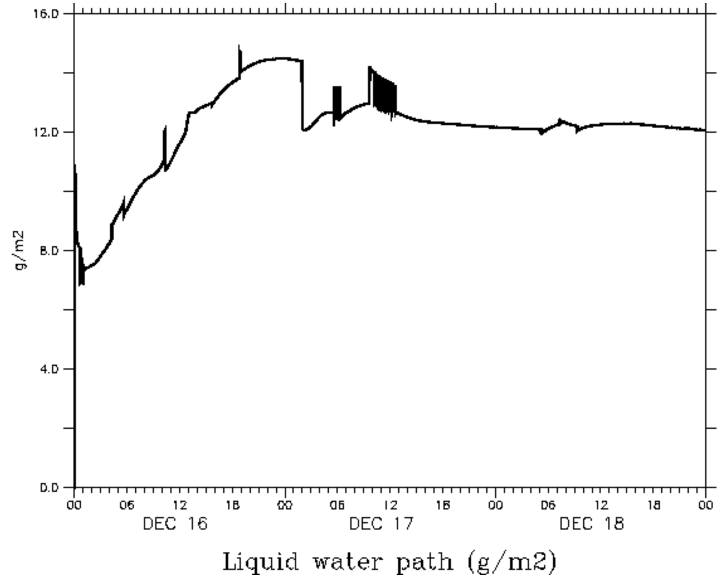
EDKF (Pergaud, Malardel, Masson)

with subgrid autoconversion









The ICE3/ICE4 MICROPHYSICS *: CHARACTERISTICS*

Pinty and Jabouille, 1998; Caniaux, 1983

Set of « slow » microphysical processes (mainly precipitating processes)
Includes Mixed-phase microphysics.

Bulk scheme with 1 moment :
Prognostic Variables: Mixing ratios (mass of water / mass of dry air)

2 water variables for warm clouds:
Cloud water (droplets) + Rain water (drops)
4 ice variables for cold clouds:
Cloud ice (pristine crystals), Snow and Aggregates (assemblage of crystals), Graupel (rimed crystals), *Hail (large heavily rimed crystals)*

→Resolved variables : grid-mean values (no account for subgrid-scale variability)

→ Limit of validity for Large Scale (>10km ?)

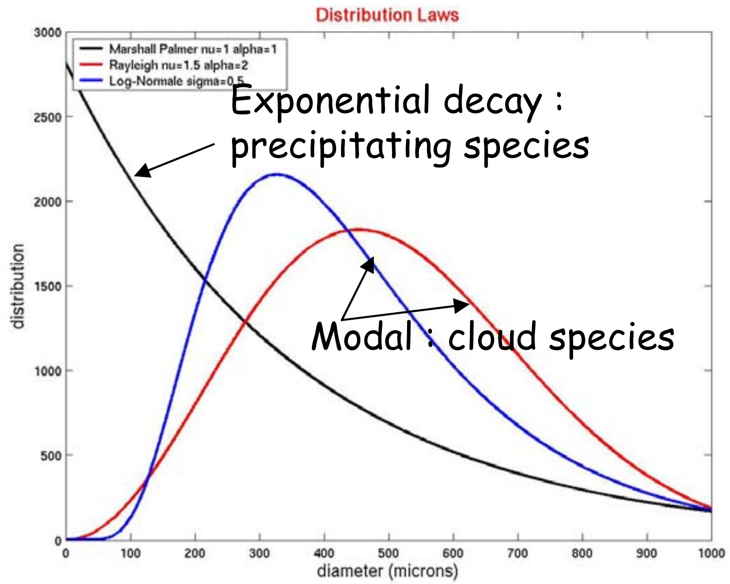
→ Most sophisticated species adapted to convective scale (graupel, hail)

Temporal integration : Processes treated explicitly (tendencies) and independently BUT the sequence gives the availability of the species

MICROPHYSICS : *HYPOTHESIS*

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

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

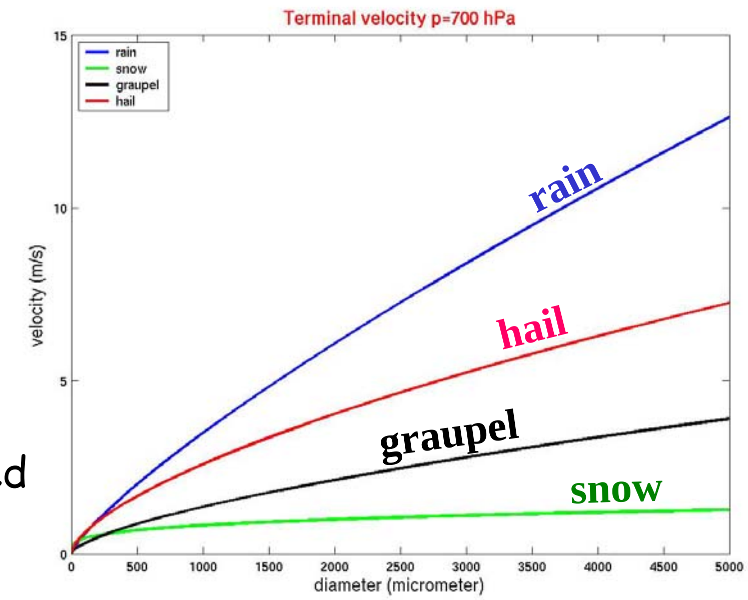


Very useful p-moment formula

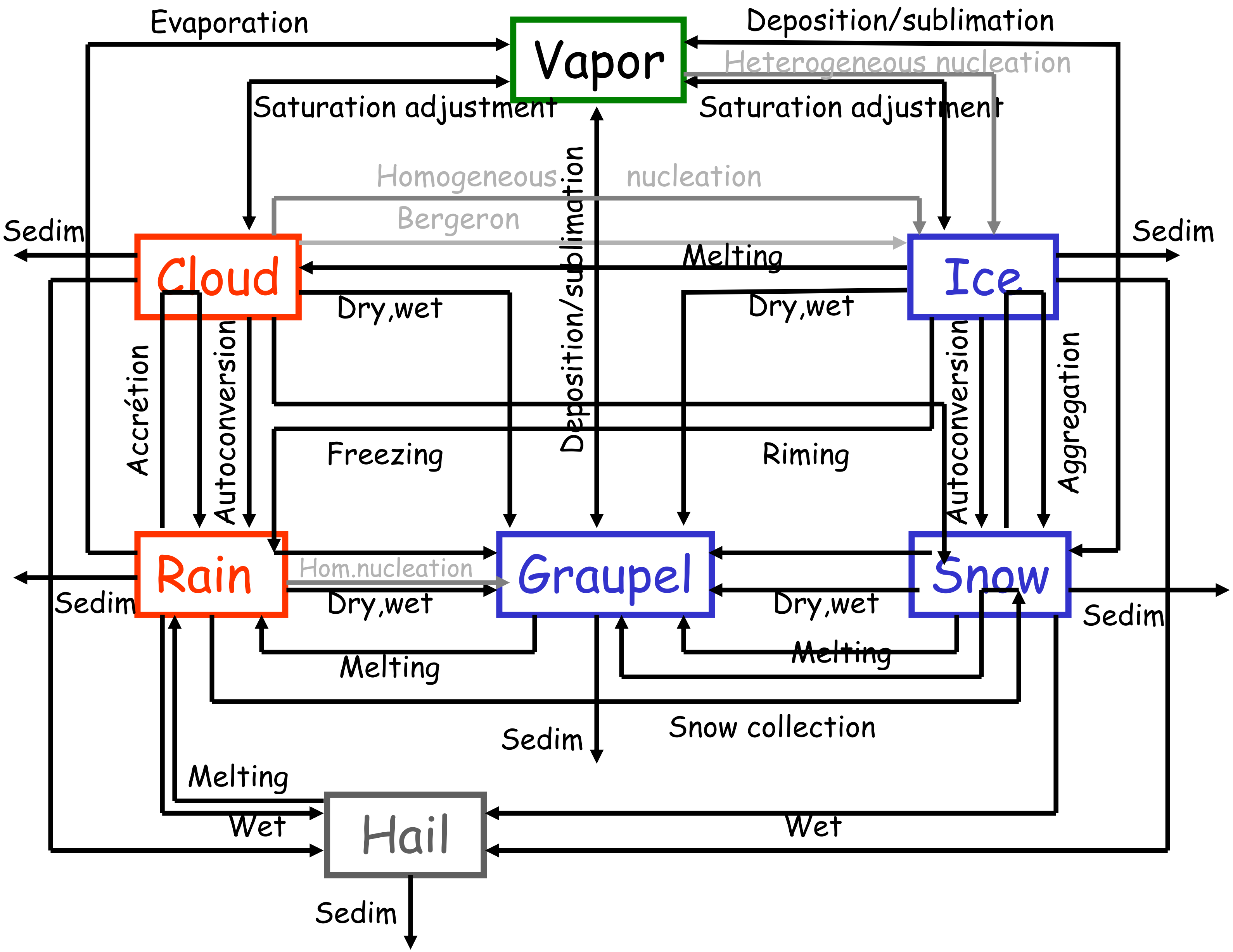
$$M(p) = \int_0^{\infty} D^p\, n(D)\, dD = N\frac{\Gamma(\nu + p/\alpha)}{\Gamma(\nu)}\frac{1}{\lambda^p}$$

- Mass-Size relationship: $m=aD^b$

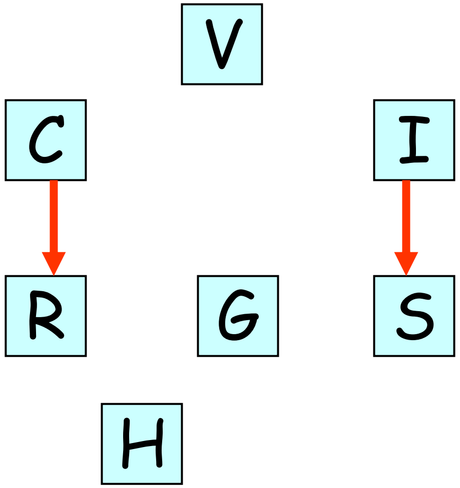
Fall speed-Size relationship:
$v=cD^d \, . \, (\rho_{00}/\rho_a)^{0.4}$



$\rho_d r_j = a_j N_j M(b_j)$: distribution of r_j, supposed homogeneous in the grid



Caniaux, 1993 – Pinty and Jabouille, 1998



AUTOCONVERSION

A crude but efficient parametrization to initiate raindrops or snow aggregates

$$\left(\frac{\partial(\rho_d r_k)}{\partial t}\right)_{AUT} = -\left(\frac{\partial(\rho_d r_j)}{\partial t}\right)_{AUT} = K \times Max\left(0.0, \rho_d r_j - \rho_d r_j^{crit}\right)$$

with

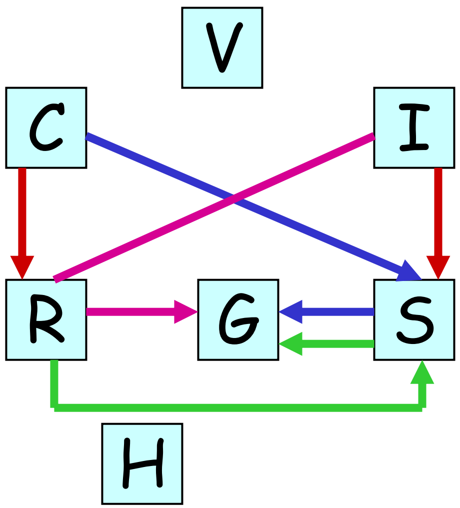
Time scale : $K = 10^{-3} s^{-1}$ *for cloud* ; $K = 10^{-3} \times \exp\left(0.025 \times (T - T_t)\right) s^{-1}$ *for ice*

Threshold : $\rho_d r_c^{crit} = 0.5 g.m^{-3}$ *for cloud* ; $\rho_d r_i^{crit} = 0.02 g.m^{-3}$ *for ice*

Chaboureau and Pinty, 2006

- Controversial process : Subject of active research (to include N_c,D_c,σ_c,turbulence)

- Account of horizontal partial cloudiness improves RICO cumulus. Needs to be more evaluated. Vertical partial cloudiness for Sc ?



COLLECTION

Based on continuous collection kernels (geometrical swept-out concept)

$$K(D_x, D_y) = \frac{\pi}{4}\left(D_x + D_y\right)^2 \left|v_x(D_x) - v_y(D_y)\right| E_{xy}$$

Collection efficiency (poorly known !)

- 2 components : *Accretion, Aggregation*

$$\left(\frac{\partial(\rho_d r_r)}{\partial t}\right)_{ACC} = -\left(\frac{\partial(\rho_d r_c)}{\partial t}\right)_{ACC} = \frac{\pi}{4} r_c N_r c_r E_{acc} M(d_r + 2) E_{acc}$$

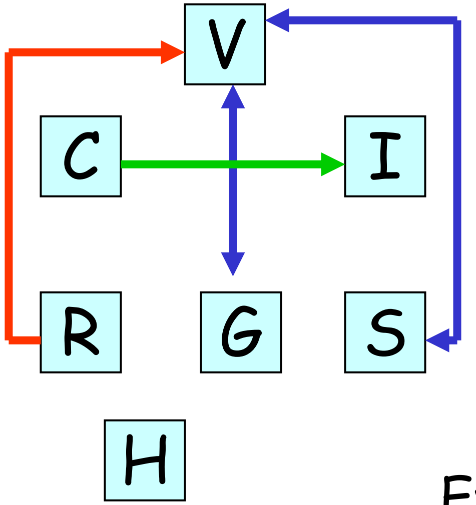
- 3 components :

  - Raindrop contact freezing : falling raindrops capture ice to form graupeln (V_i negligible)

  - Snow riming with cloud droplets, giving snow or graupel (D_s^{lim}>7mm)

  - Snow collection with raindrops, giving snow or graupel (D^{lim}based on a mixture of snowflake and raindrop)

Collection : the most difficult and controversial task (uncertainties on collection efficiencies)



EVAPORATION-DEPOSITION/SUBLIMATION-BERGERON

Evaporation derived from heat balance equation

$$\partial m(D)/\partial t_{EVA/SUB} = 4\pi \times S_{v,w/i} \times D \times \bar{f}(D) \Big/ A_{w/i}(T,P)$$

Supersaturation for deposition
Sub-saturation for evaporation/sublimation

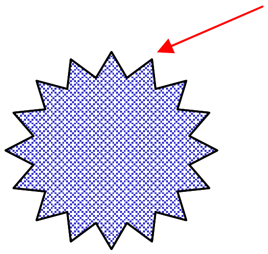
Ventilation coefficient

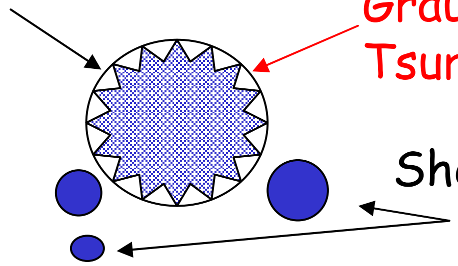
Thermodynamical function

$$\left(\frac{\partial(\rho_d r_r)}{\partial t}\right)_{EVA} = \int_0^\infty \left(\frac{\partial m(D_r)}{\partial t}\right)_{EVA} n_r(D_r)\, d D_r$$

EVAPORATION : a fully analytical and accurate parameterization
No account of partly saturated grids

WET/DRY GROWTH OF GRAUPEL





DRY growth (→ Graupel)
(Sum of collection rates)

WET growth (→ Hail)
(Heat balance equation, Musil,1970)

WET growth = Maximum freezing rate of the graupel.
The minimum growth rate must be taken

Wet growth regime leads to conversion to hail

$$\left(\frac{\partial \rho_d r_h}{\partial t}\right)_{WET} = \left(\frac{\partial \rho_d r_g}{\partial t}\right)^{*} \times \frac{DRY}{DRY + WET}$$

And any excess of liquid water at the surface of the graupel is shedded and converted into raindrops

SEDIMENTATION

For all species : 1st order upstream flux scheme with time-splitting for positivity
: Very diffusive and Too expensive for AROME

→ A way of improvement : a new method developed by Y.Bouteloup and F.Bouyssel for a modified version of LOPEZ microphysical scheme of ARPEGE/ALADIN

<u>Reference</u> : Semi-lagrangian advection scheme developed by Lopez (2002) modified by Bouteloup et al.(2005) : avoids time-splitting

<u>A new approach (Bouteloup and Bouyssel, 2006)</u> :
Sedimentation needs to compute the fraction of a given specy which leaves a model level during Δt
(Idea suggested first by Jean-François Geleyn)

SEDIMENTATION : a local approach (Y.Bouteloup, F.Bouyssel)

P_0 = Proportion of particles which traverses the distance z during a time t (w=fall speed)

$$P_0(z,t) = \begin{cases} 0 & if \ \frac{wt}{z} < 1 \\ 1 & if \ \frac{wt}{z} \geq 1 \end{cases}$$

1 : Droplets which are in the level at the begining of the time step:

$$P_1 = \frac{1}{\Delta z} \int_0^{\Delta z} P_0(z, \Delta t) dz = Min\left(1, \frac{w\Delta t}{\Delta x}\right)$$

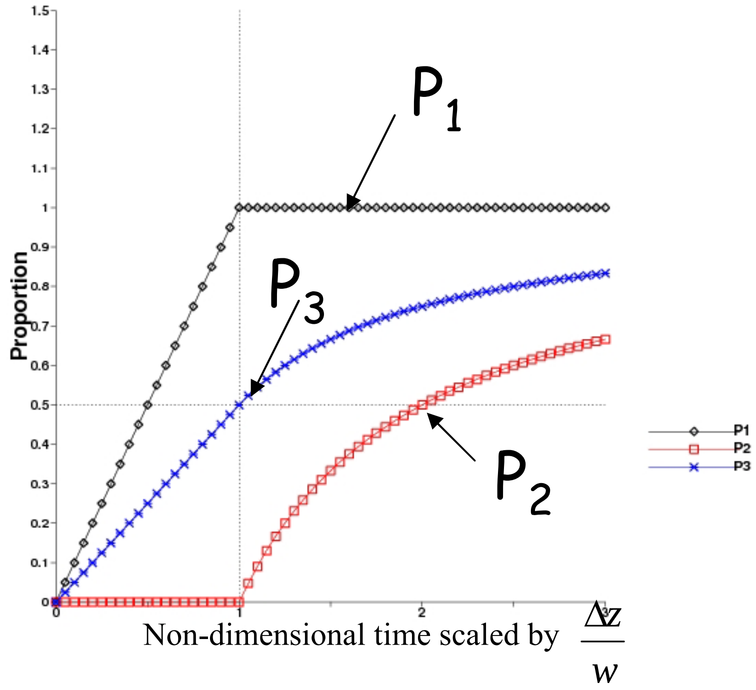
2 : Droplets which come from the upper level (incoming flux supposed continuous during Δt):

$$P_2 = \frac{1}{\Delta t} \int_0^{\Delta t} P_0(\Delta z, t) dt = Max\left(0, 1 - \frac{\Delta z}{w\Delta t}\right)$$

3 : Droplets which are produced continously during the time step (autoconv. and collection):

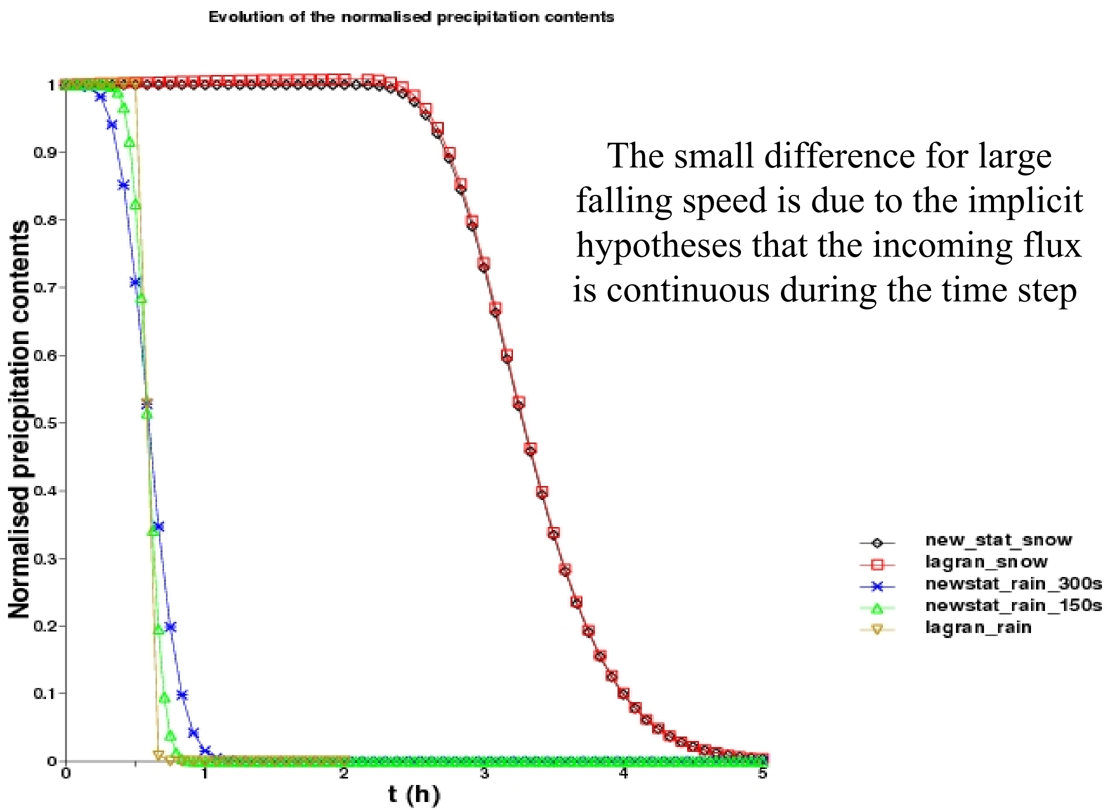
$$P_3 = \frac{1}{\Delta z \Delta t} \int_0^{\Delta t} \int_0^{\Delta z} P_0(z,t) dz dt = \frac{1}{\Delta z} \int_0^{\Delta z} P_2(z, \Delta t) dz = \frac{1}{\Delta t} \int_0^{\Delta t} P_1(\Delta z, t) dt$$

$$= \begin{cases} \frac{w\Delta t}{2\Delta z} & if \quad \Delta t \leq \frac{\Delta z}{w} \\ \frac{2w\Delta t - \Delta z}{2w\Delta t} & if \quad \Delta t \geq \frac{\Delta z}{w} \end{cases}$$



SEDIMENTATION : a local approach *(Y.Bouteloup, F.Bouyssel)*

Comparison with the operational lagrangian algorithm of ARPEGE/ALADIN :



The small difference for large falling speed is due to the implicit hypotheses that the incoming flux is continuous during the time step

In the 3D model the impact is negligible.
But the whole of the model is 1.7% less expensive (with 46 levels)
The scheme is clearer and simpler
It is planned to use this scheme in the next ARPEGE/ALADIN e-suite
Examination of implentation in AROME ?

Radiative transfer in Meso-NH/AROME

- Coupled with the ECMWF radiative transfer
  - Shortwave: SW ↦Fouquart and Bonnel (1980) (6 spectral bands)
  - Longwave :
    - LW ↦ Morcrette and Fouquart (1985) (6 spectral bands)
    - RRTM ↦ Morcrette at al.(16 spectral bands): best representation of atmospheric absorption windows
- ECMWF code Problems
  - High dependences of SW and LW scheme with vertical resolution:
    - LW: corrected by Raisanen 1998 (but not integrated)
    - SW: corrected (O.Thouron) ↦ affects the TOA albedo and flux at ground level
  - Dependence of overlap assumption with vertical resolution
    - Hogan and Illingsworth (2000) and Baker et al (2003)

AROME : SW corrected+RRTM with maximum random overlap

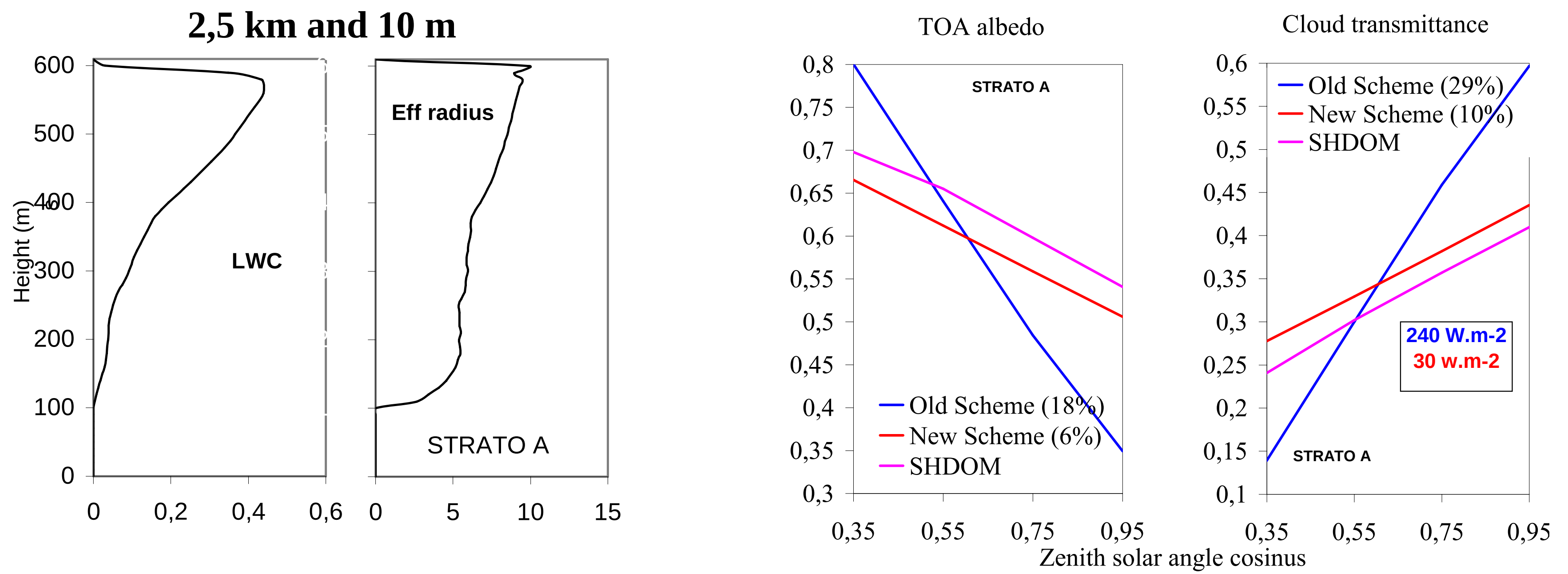
- Interface AROME/ECMWF radiation : Would need a review on new parameterizations

Ex : SW : Effective radius for liquid water content : Martin et al. (1994) based on Sc measurements : Reff<16μm

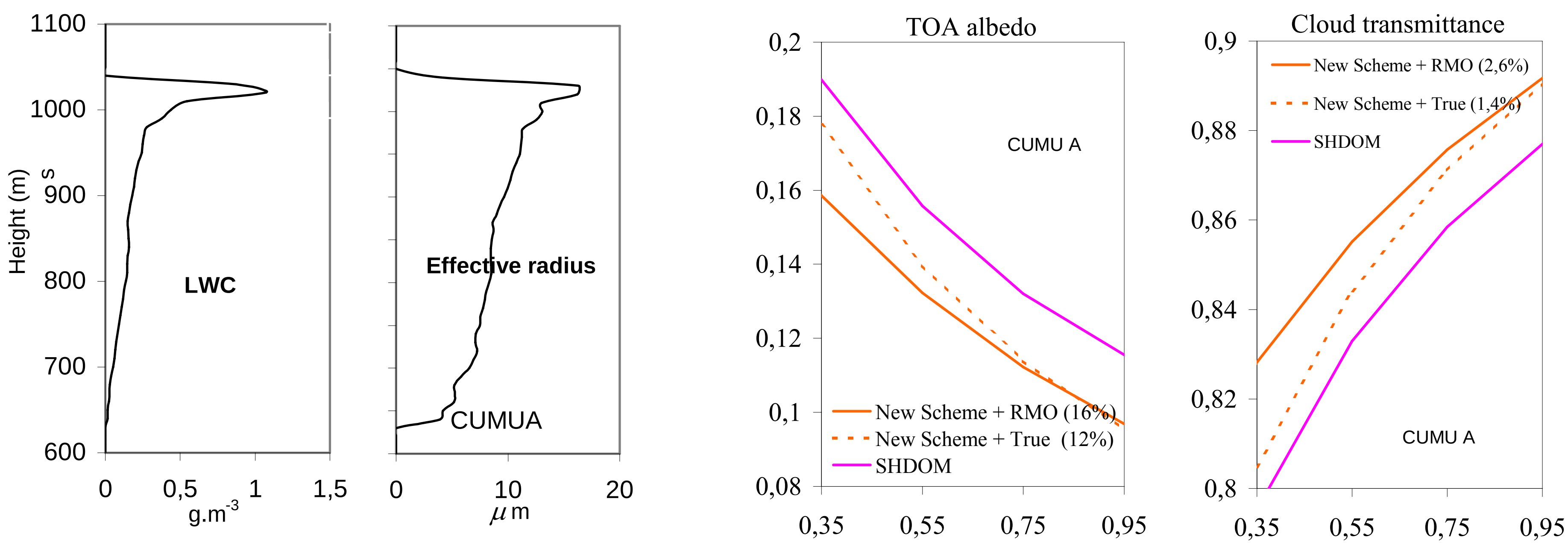
O. Thouron

SW corrected: EZA independent on the cloud overlap

O. Thouron



Dependence of overlap assumption with vertical resolution



Mesoscale Alpine Program

Lascaux, Richard and Pinty, 2006

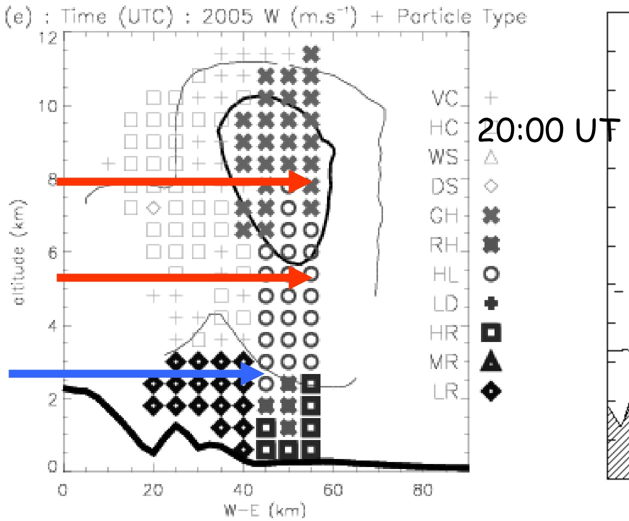
IOP2a

Restitution radar (S-Pol)

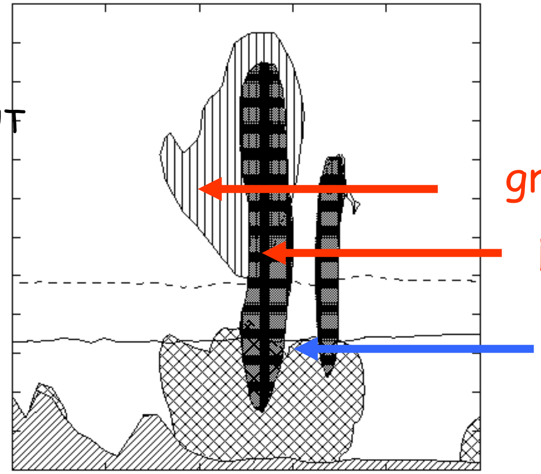
hail + graupel

hail

rain



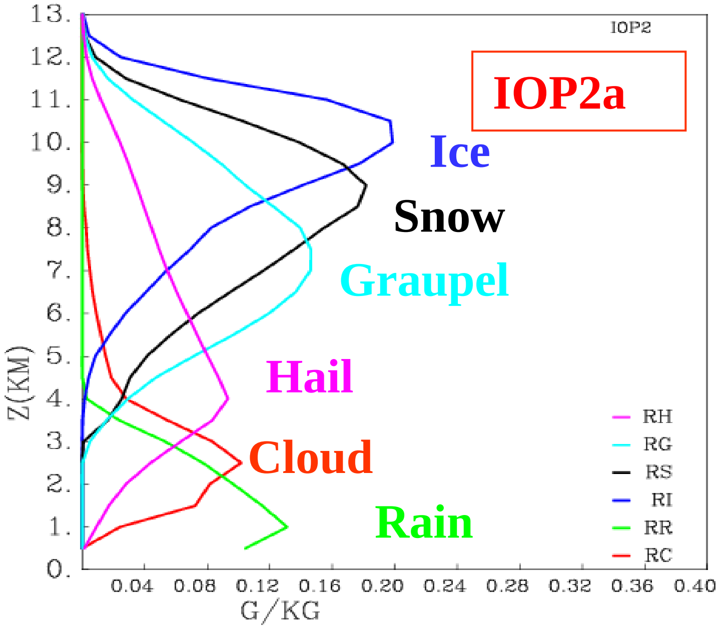
Meso-NH



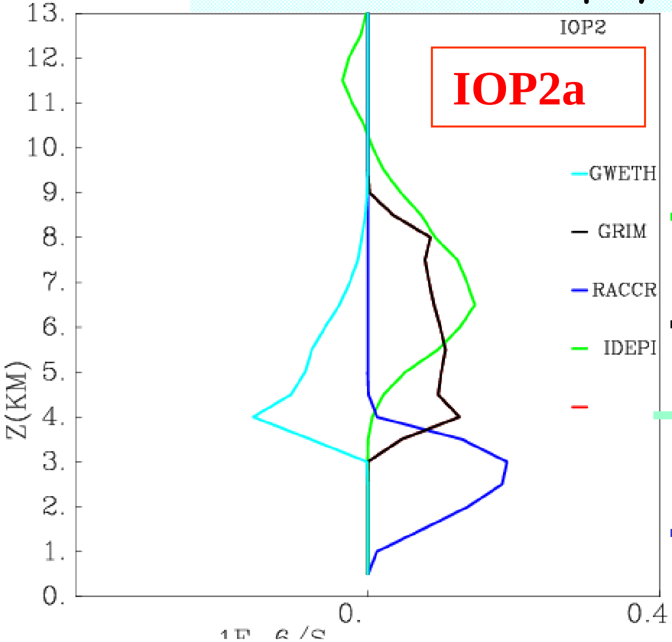
graupel

hail

rain



Dominant microphysical processes



DEPOSITION on ice (and sublimation)

Growth of graupel by RIMING

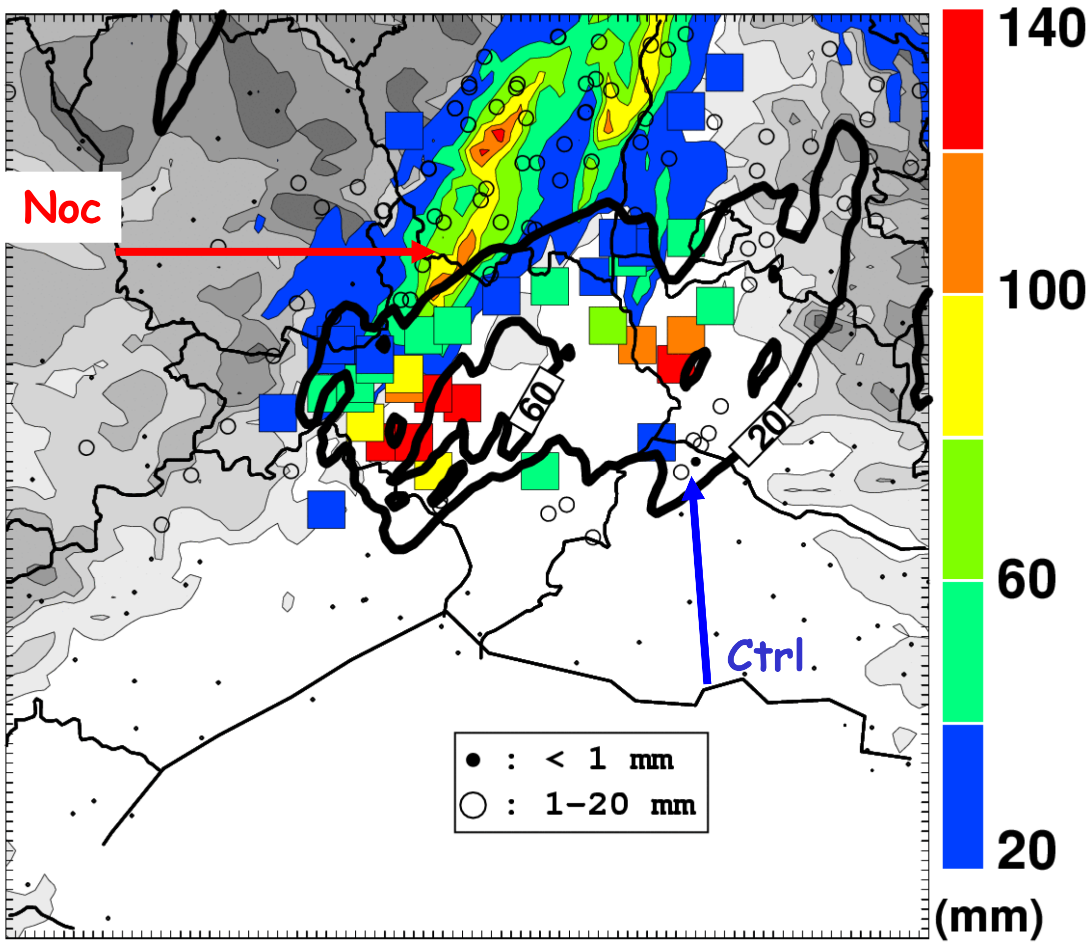
Depletion of graupel by WET GROWTH of hail

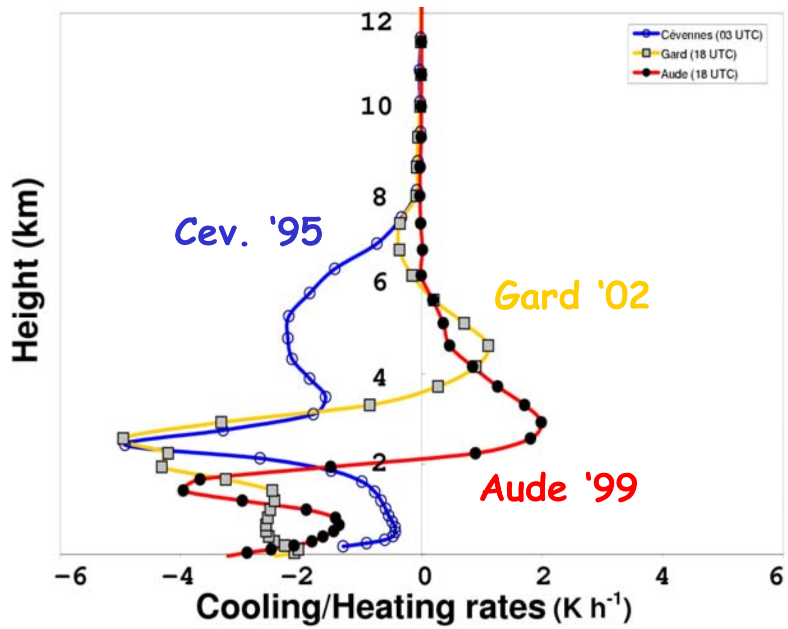
ACCRETION of cloud droplets by raindrops

Flash flood on South-East

Impact of evaporative cooling on the stationnarity of the system

4h-accumulated rainfall 18-22 UTC on 8 Sept. 2002





1D- θ budget over the MCS (convective + stratiform).

Ctrl = with evaporative cooling

Noc = without evaparative cooling

Nuissier et Ducrocq, 2006

Evaluation of CLOUDS in AROME

Ci : Not already evaluated

Cb - MCS : Subjective evaluation shows encouraging results (no excessive W).
→ Impact of hail ?

Sc : Evaluation in the near future
→ Impact of vertical resolution? Necessity of vertical partial cloudiness, subgrid entrainment ?

Cu : Currently evaluated with modified EDMF scheme

Fog : Preliminary tests on the impact of droplet sedimentation and vertical resolution