# MICROPHYSICS in AROME

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METEO FRANCE
Toujours un temps d'avance

# Introduction

A classical bulk mixed microphysical scheme developped in Meso-NH (**http://mesonh.aero.obs-mip.fr/mesonh/**) with 3 ice categories by J.-P.Pinty based on Caniaux et al.(1993).

Analogous schemes are :
- 3 ice categories : Lin et al. (1983) : ARPS and WRF models
- Up to 5 ice categories : Walko et al. (1995) : RAMS model

Developped mainly upon tropical squall lines (Caniaux et al., after compiling various published experimental observations), largely validated on Cevenol flood events (Ducrocq et al.), MAP orographic precipitation (Asencio et al., Richard et al.) ...

Mainly adapted to β-mesoscales (<5km) : Resolved variables : grid-mean values (no account for subgrid-scale variability) and small time steps (up to 60s) due to local calculations.

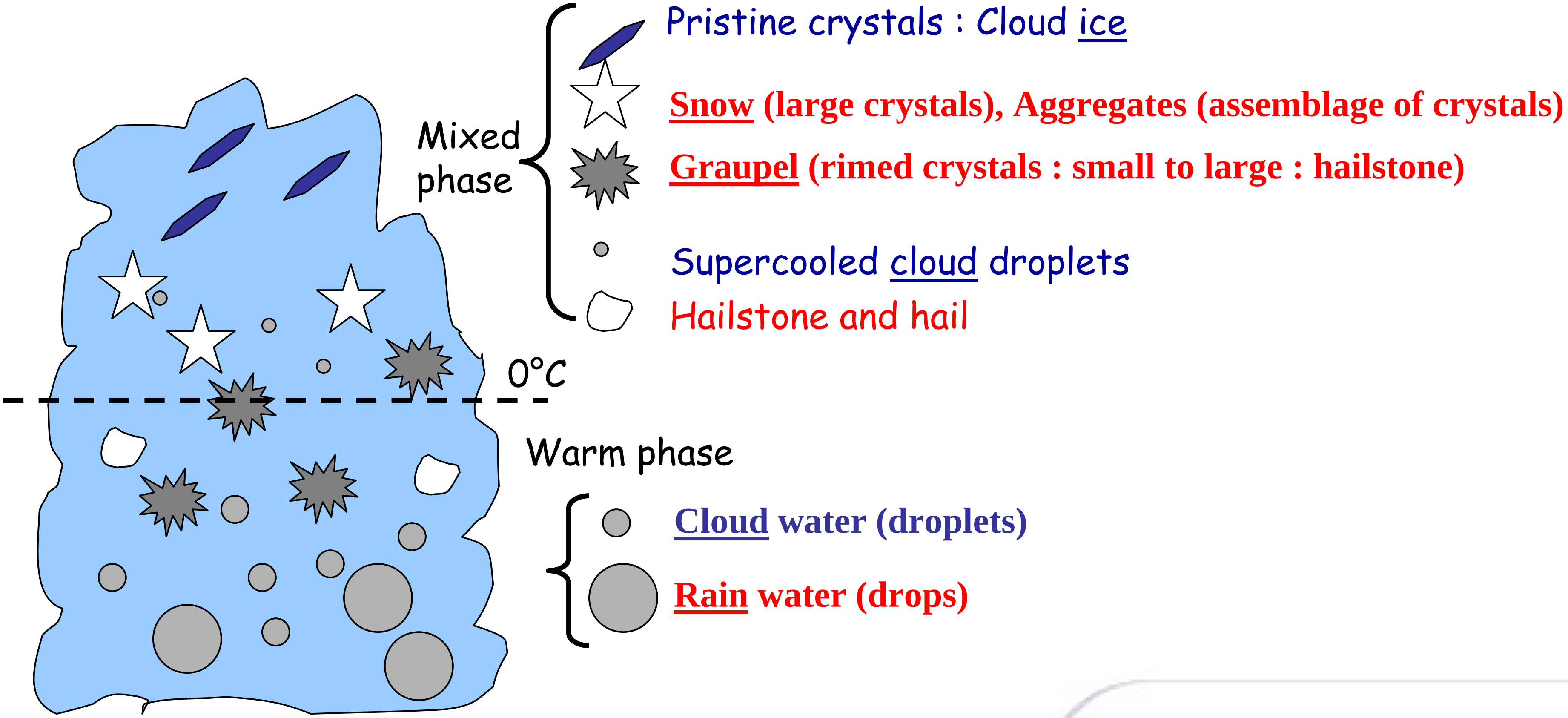
Bulk representation → Unavoidable and necessary assumptions

# Outlook

1. General characteristics of the categories
2. Generalities on the processes
3. Some details on a few processes
4. Examples

# A classical BULK mixed microphysical scheme

- Prognostic Variables: Mixing ratios (mass of water / mass of dry air) → assumptions about number concentrations (1-moment)
- Number of cloud and precipitation variables:



Mixed phase

Pristine crystals : Cloud ice

**Snow (large crystals), Aggregates (assemblage of crystals)**

**Graupel (rimed crystals : small to large : hailstone)**

Supercooled cloud droplets

Hailstone and hail

0°C

Warm phase

**Cloud water (droplets)**

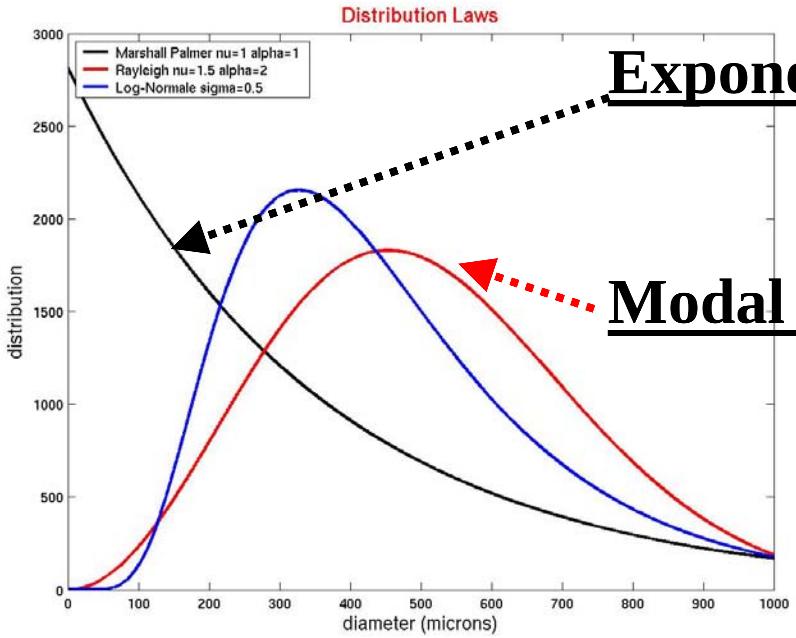
**Rain water (drops)**

# Particle size distributions

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

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

**N is the concentration (g(D) is a normalized distribution law)**
**$\lambda$ is the slope parameter deduced from the mixing ratio**
**($\alpha$, $\nu$) are free shape parameters** (Marshall-Palmer law: $\alpha=\nu=1$)



**Exponential decay : rain, snow, graupel, hail**

**Modal distribution : droplets, cloud ice**

# Microphysical characteristics

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

**Very useful p-moment formula**

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

**The content of any specy :**

$$\rho_d r=\int_0^\infty m(D)n(D)dD=aNM(b)$$

**The slope parameter depends on the content :**

$$\lambda=\left(\frac{\rho_d r}{aCG(b)}\right)^{\frac{1}{x-b}}$$

| | Cloud | Rain | Pristine ice | Aggregates and snow | Graupel and hailstone |
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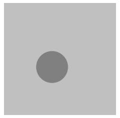
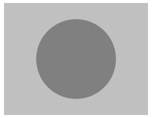
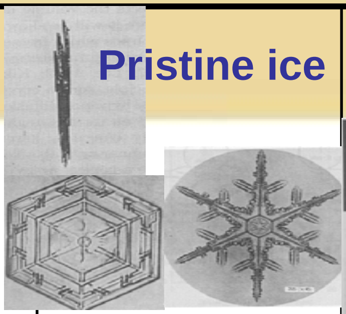
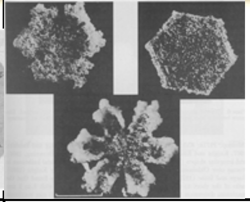
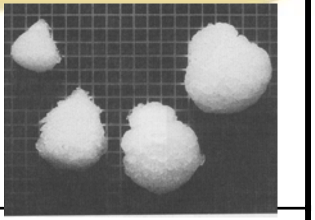
| |  |  |  |  |  |
| **Mass of a single particle (kg)**<br>$m=aD^b$ | $\frac{\pi}{6}D^3$<br>D<82μm | $\frac{\pi}{6}D^3$<br>D>82μm | $0.82D^{2.5}$<br>D~10-100μm | $0.02D^{1.9}$<br>D~1-10mm<br>$\rho_s$~100kg/m$^3$ | $19.6D^{2.8}$<br>D>7mm<br>$\rho_g$> $\rho_s$up to 900kg/m$^3$ |
| **Velocity of a single particle (m/s)**<br>$V=cD^d . (\rho_{00}/\rho_a)^{0.4}$ | $V=cD^2 . (\rho_{00}/\rho_a)^{0.4}$<br>V~a few cm/s | $V=842D^{0.8} . (\rho_{00}/\rho_a)^{0.4}$<br>V~3-10m/s | $V=800D . (\rho_{00}/\rho_a)^{0.4}$<br>V~0m/s | $V=5.1D^{0.27} . (\rho_{00}/\rho_a)^{0.4}$<br>V~0,3-1,5m/s | $V=124D^{0.66} . (\rho_{00}/\rho_a)^{0.4}$<br>V~1-5m/s up to 14-15m/s for hail |
| **Size distribution for precipitating particles**<br>$n(D) = \mathbf{C}\,\lambda^{x+1}\exp(-\lambda D)\ \textit{with}\ \lambda = \left(\frac{\rho_d r}{aCG(b)}\right)^{\frac{1}{x-b}}$ | | $8.10^6\exp(-\lambda D)$ | | $5\lambda^2\exp(-\lambda D)$ | $5.10^5\lambda^{0.5}\exp(-\lambda D)$ |

# General consideration on processes

- Resolved processes : no subgrid-scale variability. Thresholds used independtly to the grid scale or to the cloud fraction.

- All concurrent processes involving an exchange of heat and water vapor on the condensed particles are computed independently each other.

- The condensation/evaporation of cloud species (implicit adjustment of temperature, water vapor, cloud and primary ice) is performed after to introduce consistency with a strict saturation criterium. It is the key process to produce clouds.

- Calculation are done locally (eulerian budget in a grid) : Limit of the time step (60s could be considered as a limit)

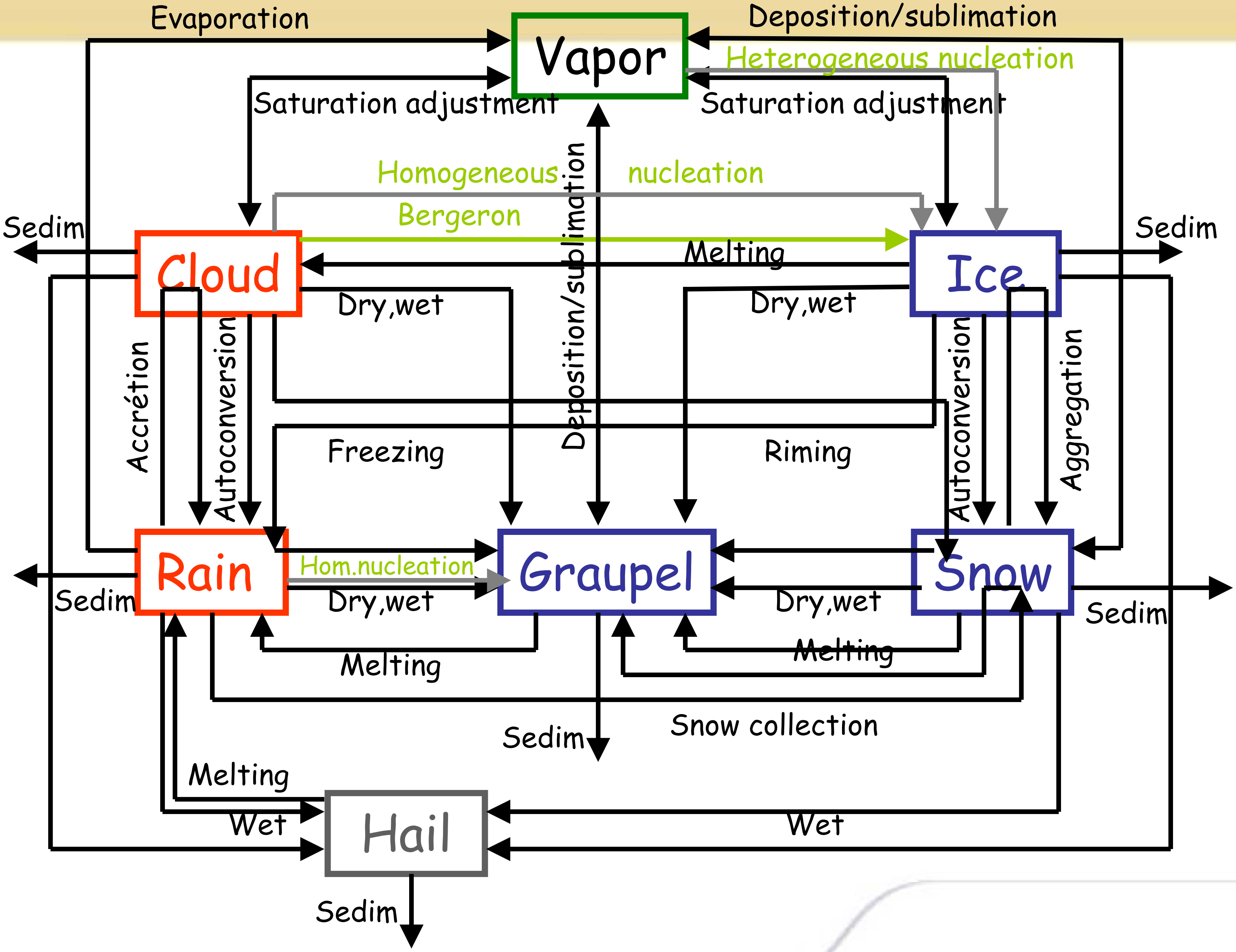
- And semi-sequentially : each process is computed with the prognostic variables defined at the current time step leading to microphysical tendencies (guess of the next instant) BUT is limited by the current state of the guess :

  *at the end of each step, guesses are checked for positivity. In some circumstances, some specy may be available or not for the next process, depending on the chosen order in the sequence of integration*

# General consideration on processes

- The saturation adjustment and the sedimentation are particular because they redistribute directly the guess.

- The sedimentation is only a « fall » process, that redistributes vertically the hydrometeor.
It computes the budget of the species in the grid (entrance – exit) due to the fall, based on the guess of the next instant. It doesn't take into account any process that could occur during the fall : the other processes are calculated locally before.



Evaporation

Vapor

Deposition/sublimation

Heterogeneous nucleation

Saturation adjustment

Saturation adjustment

Homogeneous nucleation

Deposition/sublimation

Bergeron

Sedim

Cloud

Melting

Ice

Sedim

Dry,wet

Dry,wet

Accrétion

Autoconversion

Freezing

Riming

Autoconversion

Aggregation

Rain

Hom.nucleation

Dry,wet

Graupel

Dry,wet

Snow

Sedim

Sedim

Melting

Melting

Snow collection

Sedim

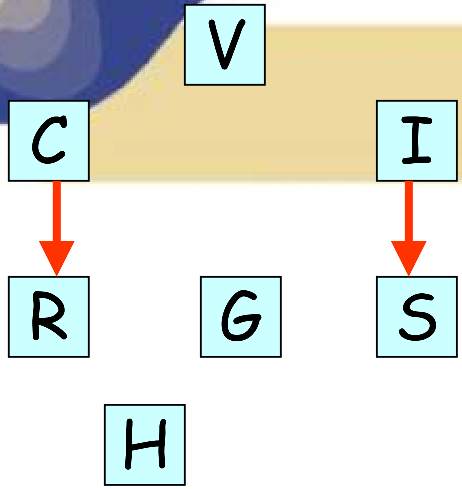
Melting

Wet

Hail

Wet

Sedim



# AUTOCONVERSION

A crude but efficient parametrization to initiate raindrops or snow aggregates.

No phase change.

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

*with*

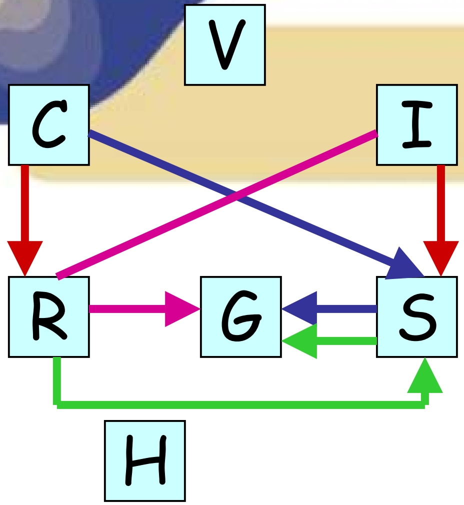
$$\text{Time scale:} \quad K = 10^{-3}\, s^{-1} \;\; \textit{for cloud}\,; \quad K = 10^{-3} \times \exp\left(0.025 \times (T - T_t)\right) s^{-1} \;\; \textit{for ice}$$

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

*Chaboureau and Pinty, 2006*

- Still subject of active research (to include $N_c$,$D_c$,$\sigma_c$,turbulence )

- Thresholds independent of the grid size. The single microphysical process that can take into account cloud fraction coming from turbulence/convection.



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

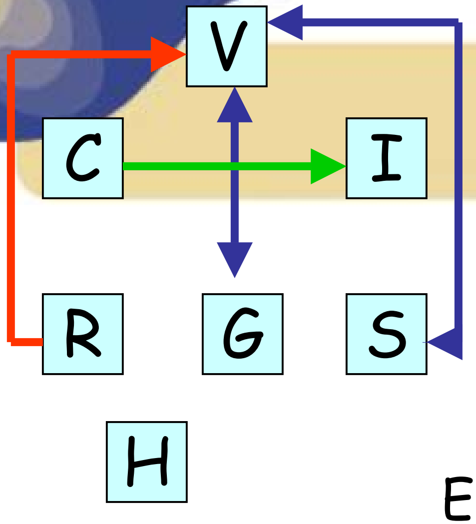
- 3 components :

  - 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 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

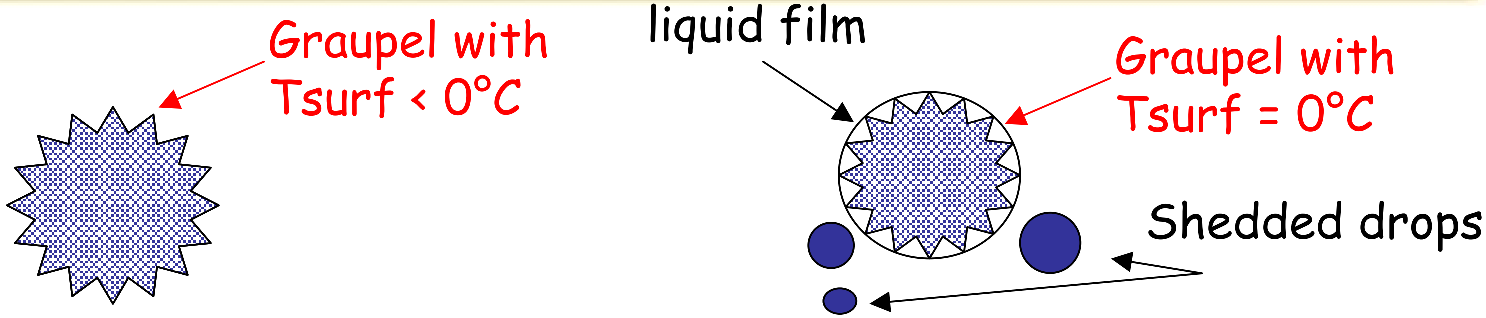
Ventilation coefficient

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



Graupel with Tsurf < 0°C

liquid film

Graupel with Tsurf = 0°C

Shedded drops

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

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

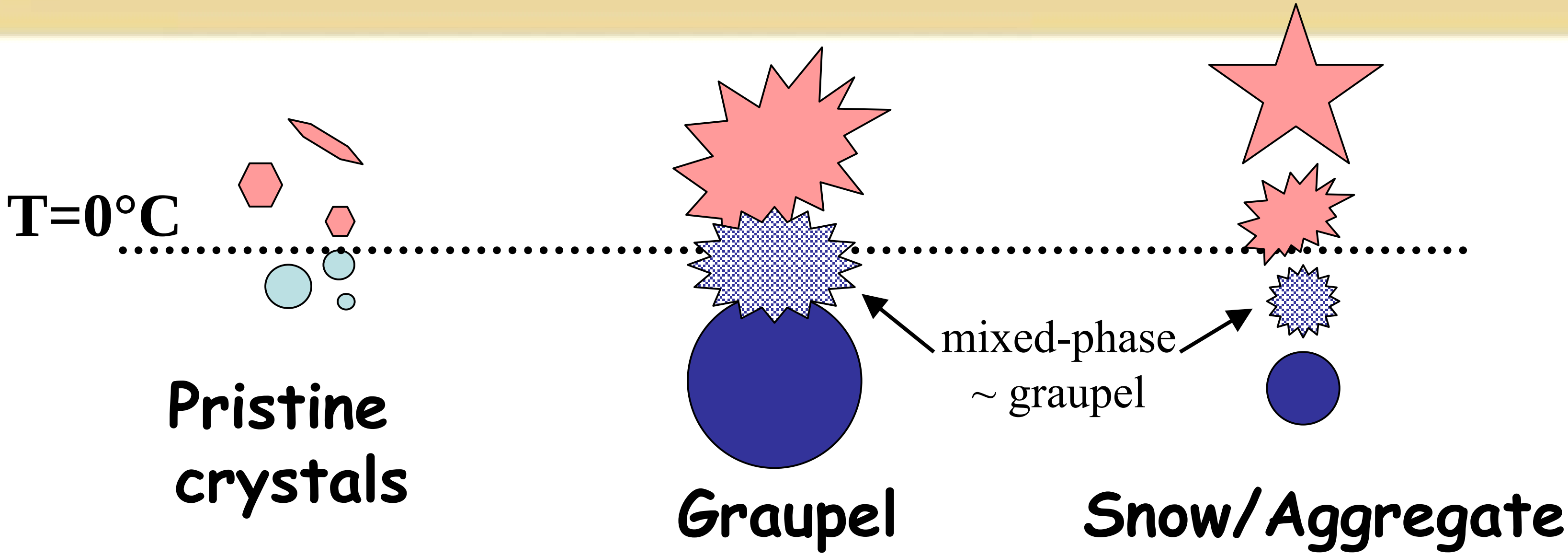
WET growth = Maximum freezing rate of the graupel.
The minimum growth rate must be taken

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

# Melting of the ice particles (T>0°C)



Pristine ice crystals: instantaneously melted into cloud droplets

Graupel particles ➔ raindrops: heat budget equation taking into account the fall and the collection capability of the particles

Snow/aggregates →graupel ➔ raindrops: heat budget equation and conversion into graupel

# Sedimentation

**Fallout of a specie:** **vertical flux of the specie relative to the air**

**Sedimentation rate from sedimentation flux :**

$$\mathrm{Sed\_flux} = \int_0^{\infty} v(D_r) \times m(D_r) \times n_r(D_r)\, d\, D_r$$

$$\mathrm{Sed\_flux} = a_r\, c_r\, (\rho_{00}/\rho_a)^{0.4} \int_0^{\infty} D_r^{\,b_r+d_r}\, n_r(D_r)\, d\, D_r$$

2 techniques available in AROME :

1. Time-splitting for numerical stability: the particle doesn't cross more than 1 vertical grid during the sub time-step (appropriate for small time steps like Meso-NH, expensive for AROME)

2. The local approach of Bouteloup and Geleyn as in ARPEGE-ALADIN : appropriate for AROME

# Sedimentation : the local approach (Bouteloup et al.)

Fall speed $$W = \frac{Sed\_Flux}{\rho_d r}$$

$P_0$ = Proportion of particles that cross 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 : Drops 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 : Drops which come from the upper level:

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

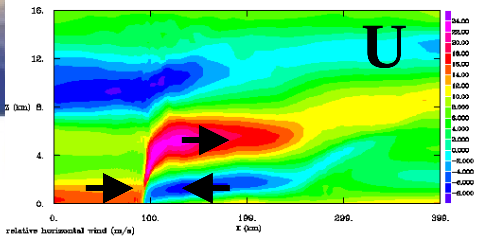
3 : Drops which are produced continuously during the time step : **For AROME included in P1**

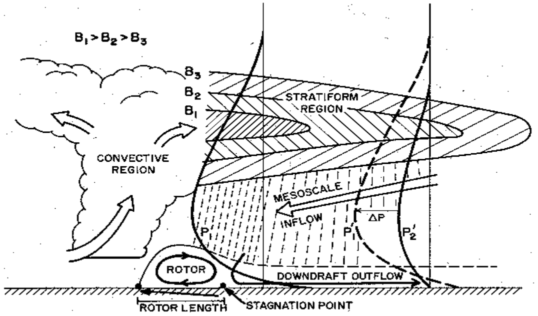
$$\boxed{Sed\_Flux(k) = P_1 \Delta z \frac{\rho_d r}{\Delta t} + P_2 Sed\_Flux(k+1)}$$

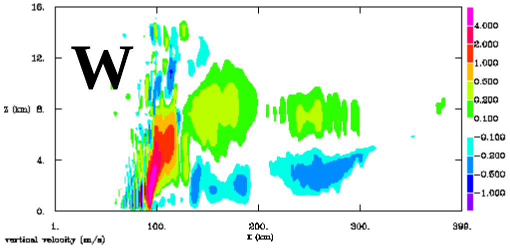
$$\left(\frac{\partial(\rho_a r_r)}{\partial t}\right)_{SED} = \frac{1}{\rho_d} \frac{\partial}{\partial z}(\mathrm{Sed\_flux})$$

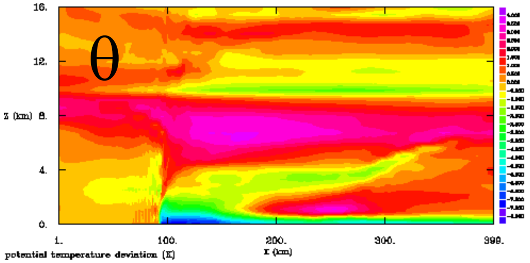
: Upstream differencing scheme

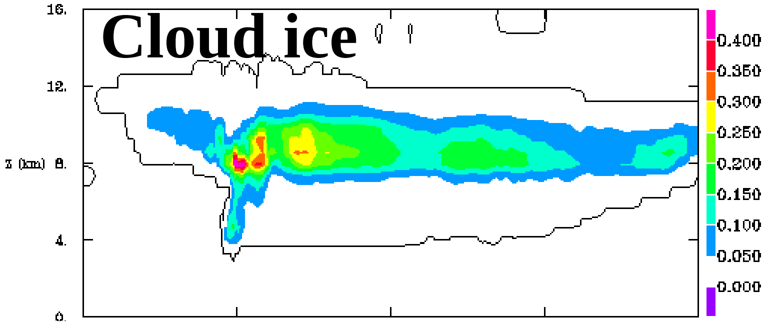
# 2D Tropical Squall Line with Meso-NH

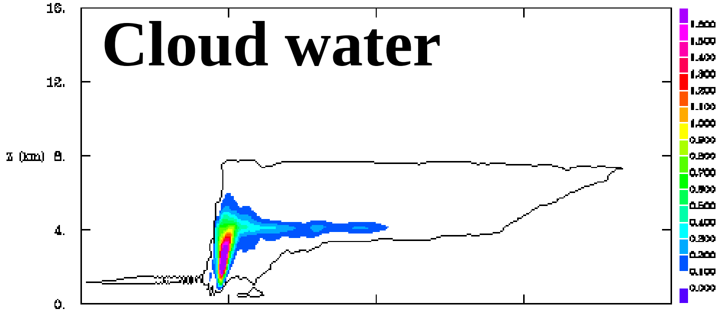


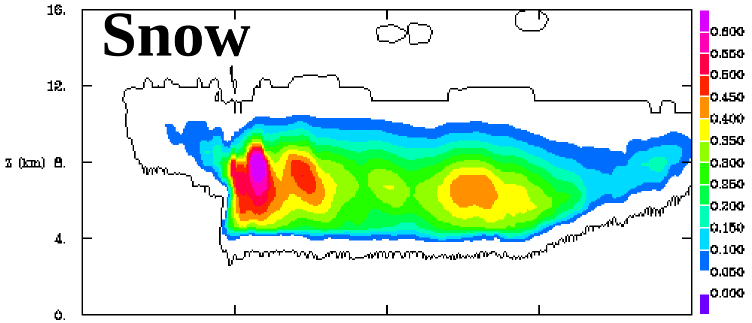


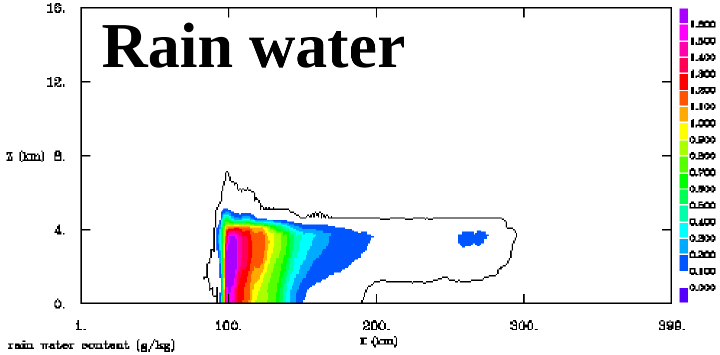


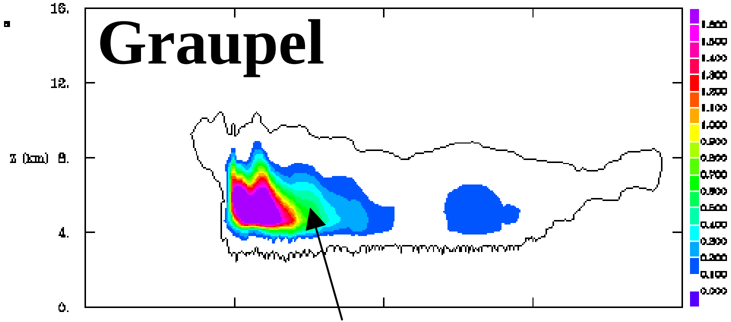




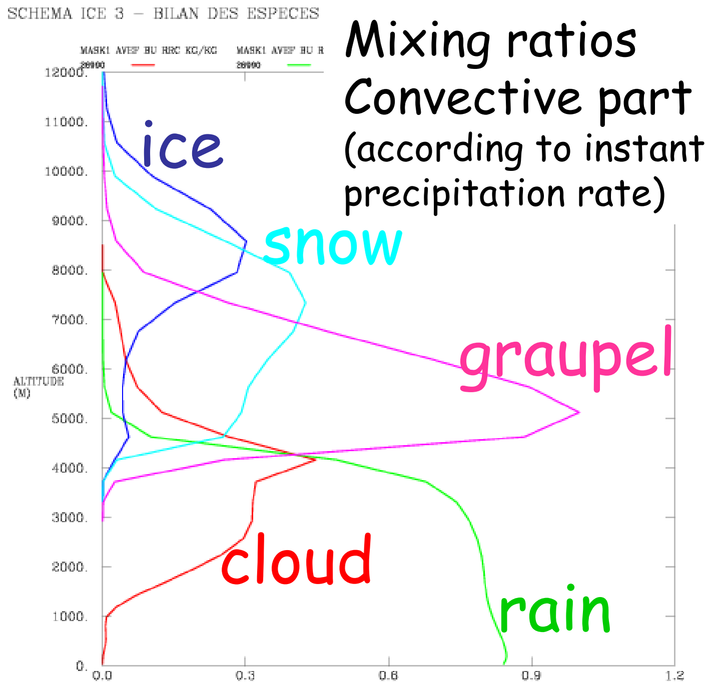




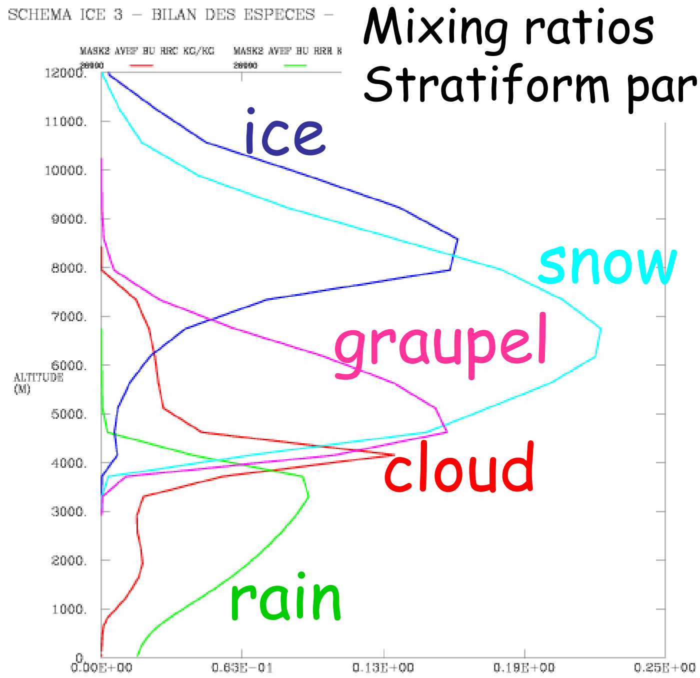




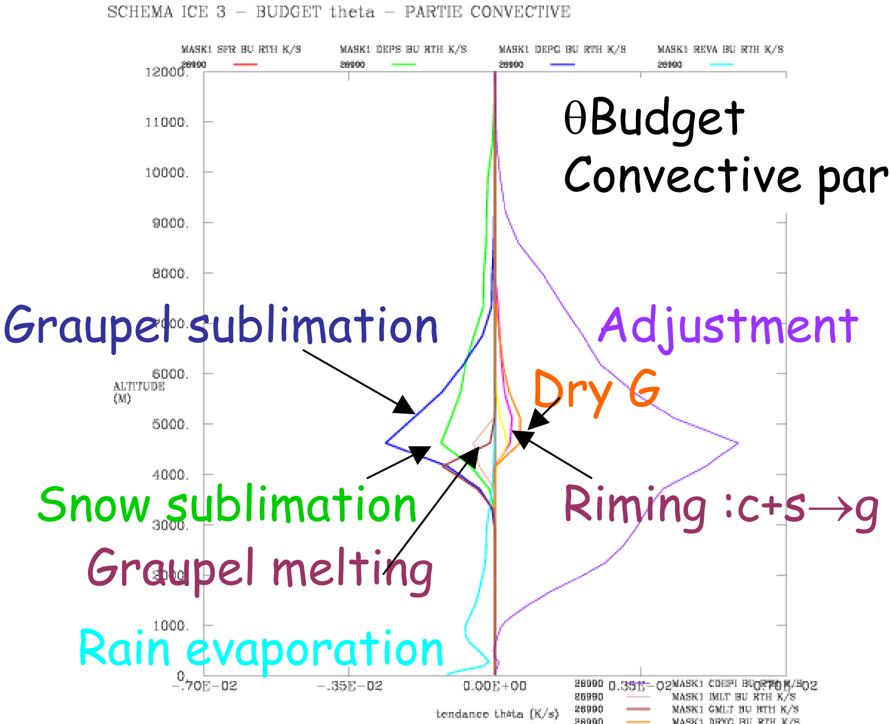
Supercooled cloud water



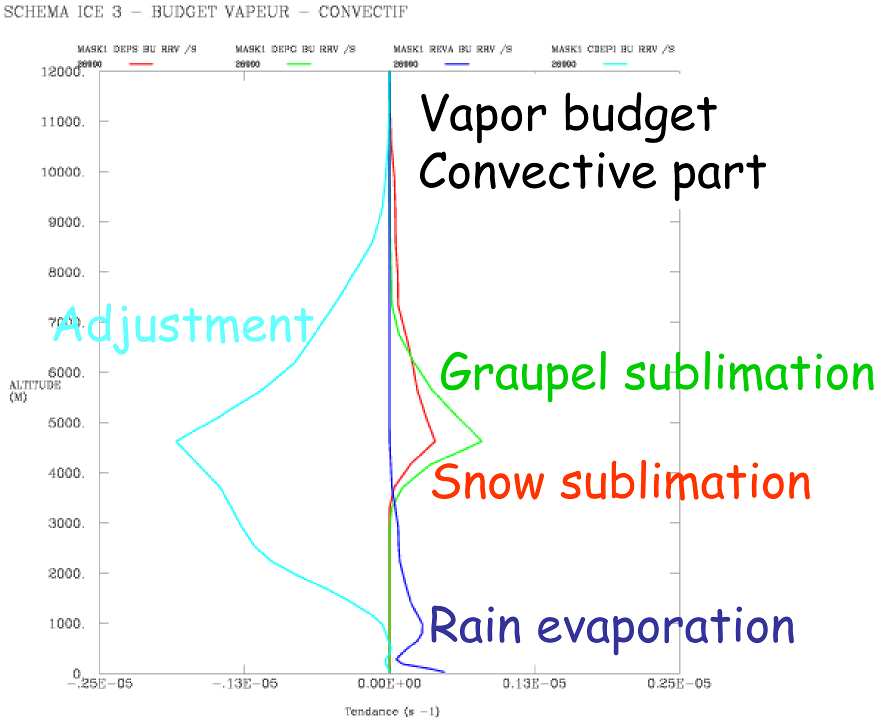
Mixing ratios
Convective part
(according to instantaneous precipitation rate)



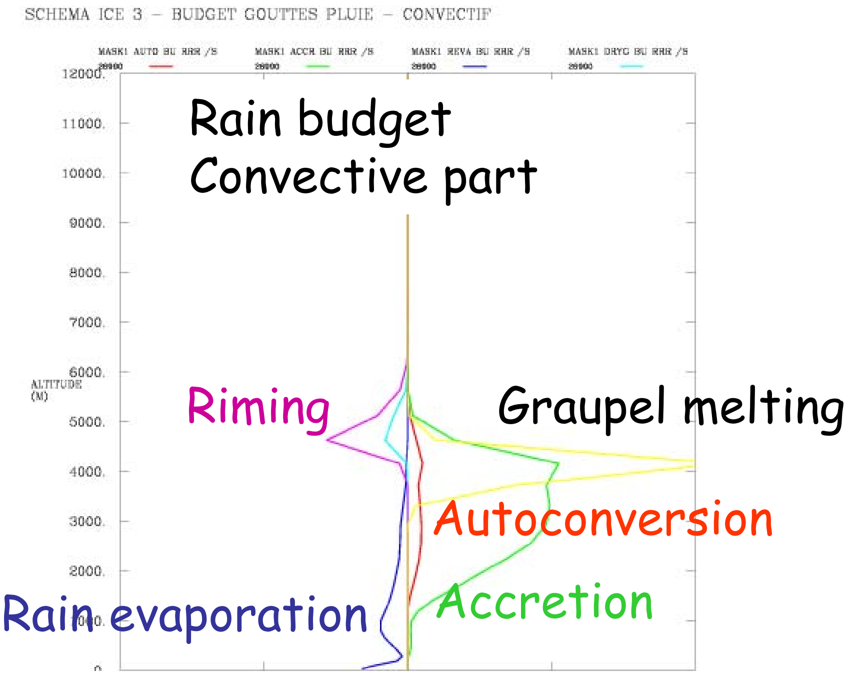
Mixing ratios
Stratiform part



θBudget
Convective part



Vapor budget
Convective part



Rain budget
Convective part

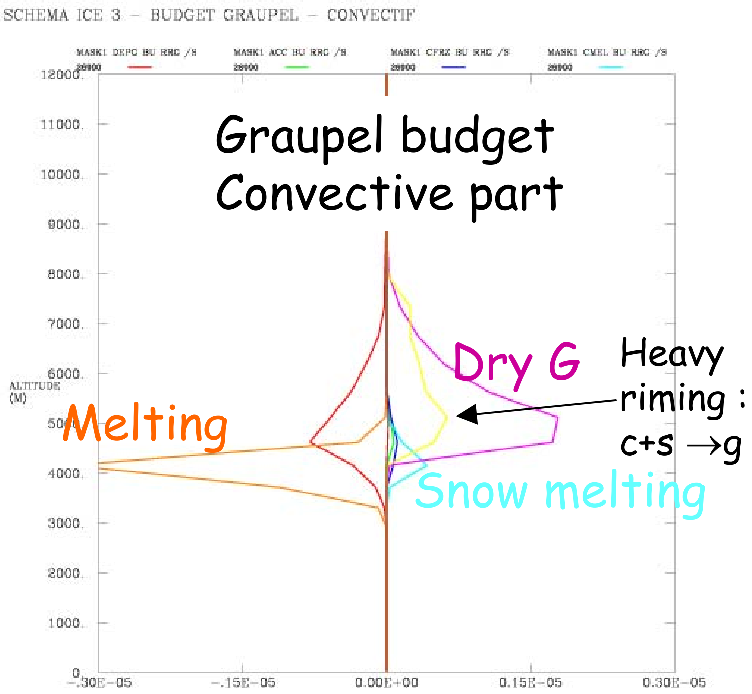
Riming

Graupel melting

Autoconversion

Accretion

Rain evaporation



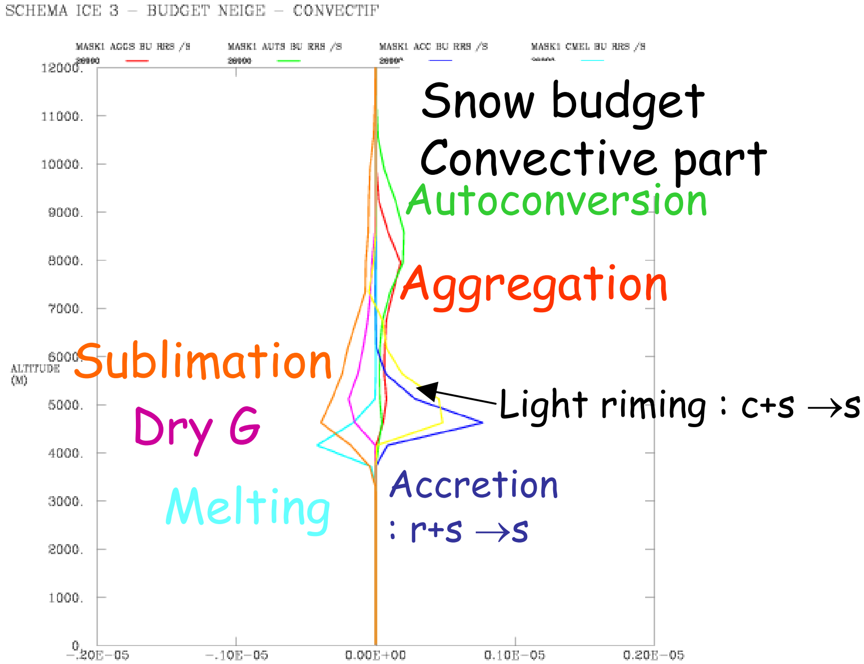
Graupel budget
Convective part

Dry G

Heavy
riming :
c+s →g

Melting

Snow melting



Snow budget
Convective part

Autoconversion

Aggregation

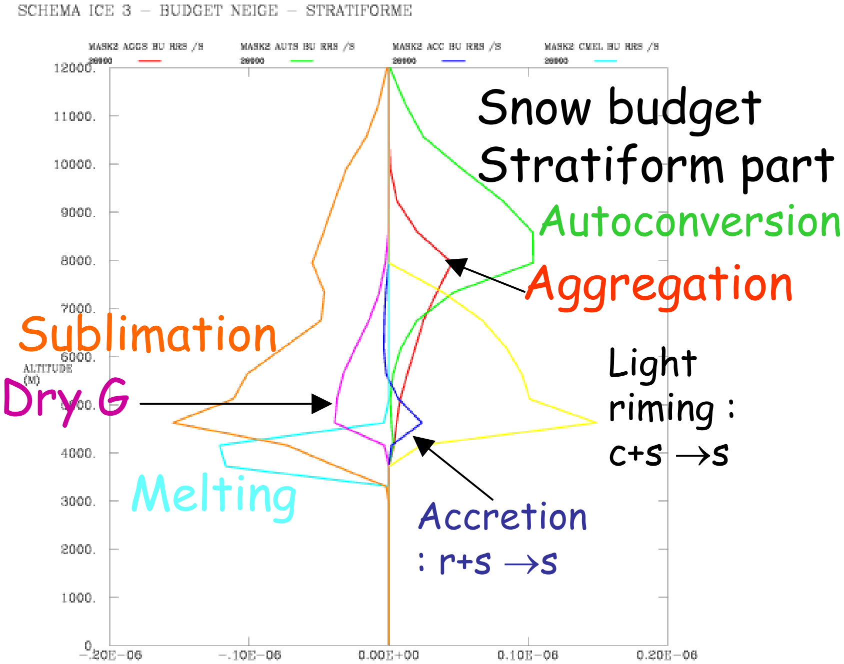
Sublimation

Dry G

Light riming : c+s →s

Melting

Accretion
: r+s →s



Snow budget
Stratiform part

Autoconversion

Aggregation

Sublimation

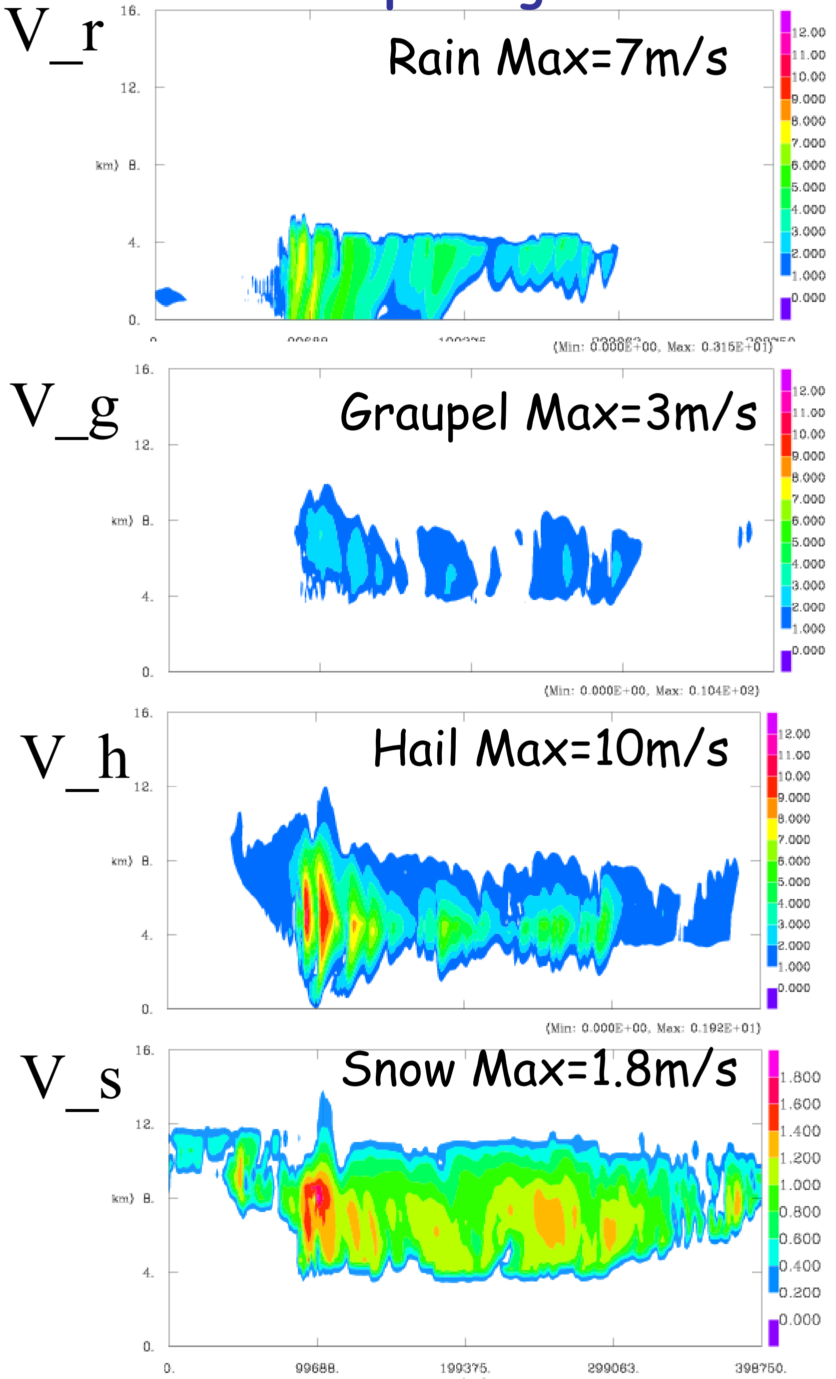
Dry G

Light
riming :
c+s →s

Melting

Accretion
: r+s →s

## Sedimentation Splitting



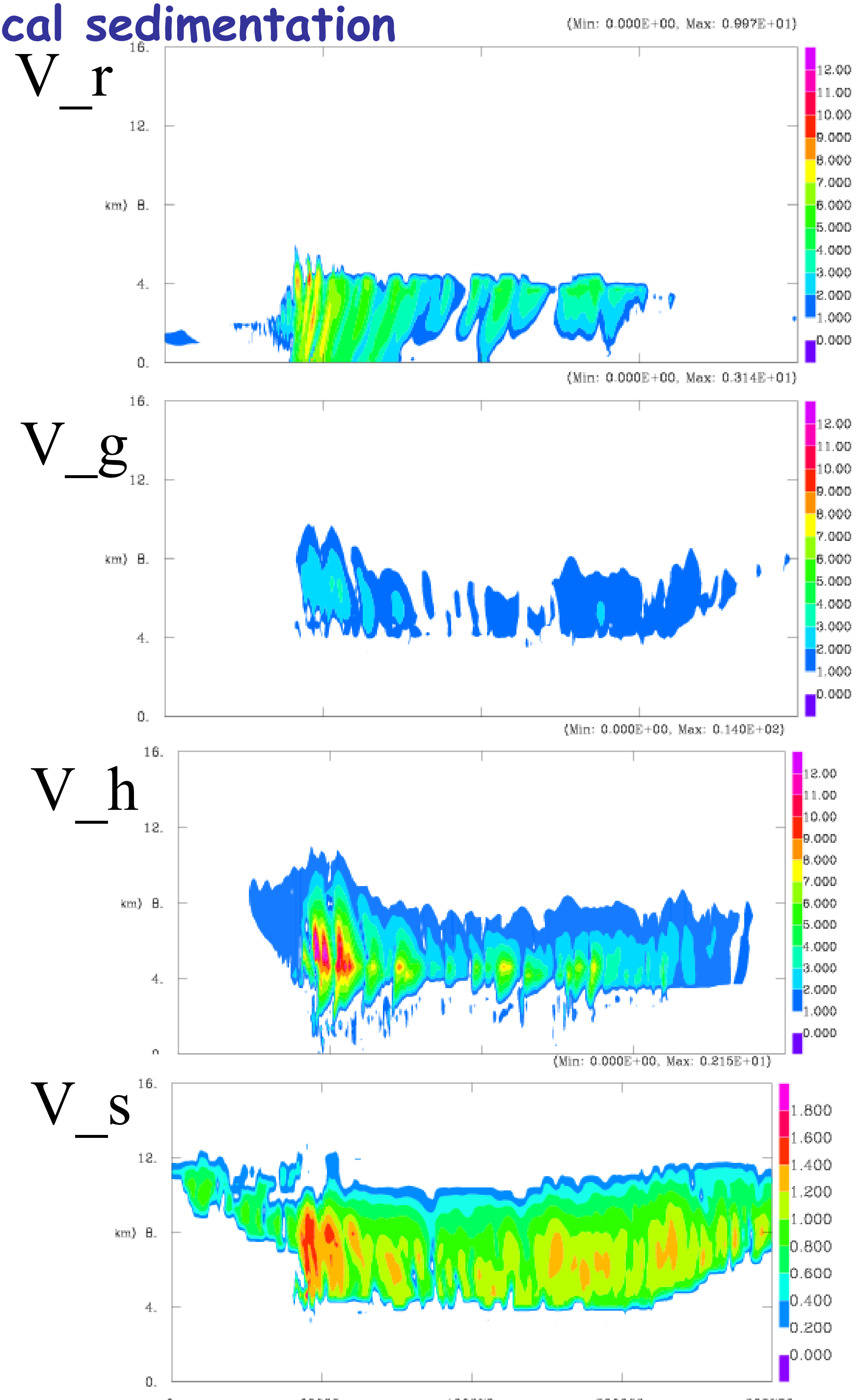
Rain Max=7m/s

Graupel Max=3m/s

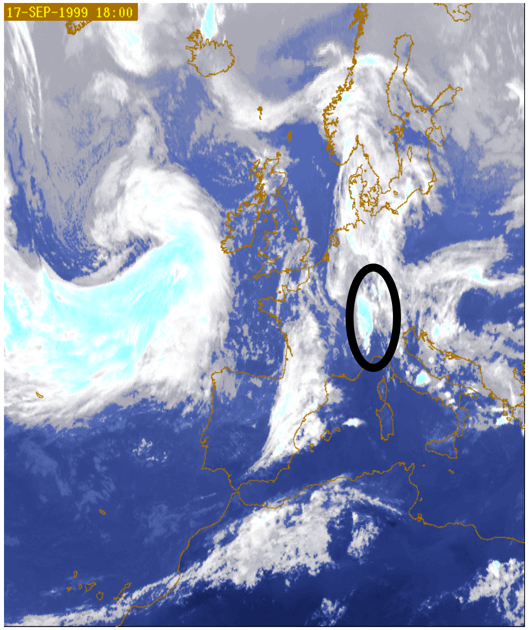
Hail Max=10m/s

Snow Max=1.8m/s

## Local sedimentation

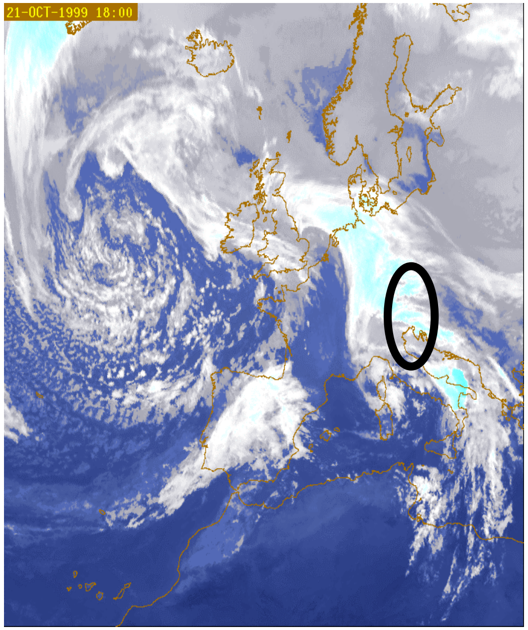


# Orographic precipitation 3D (MAP) : Meso-NH



**IOP 2A**

**Strong Convection**



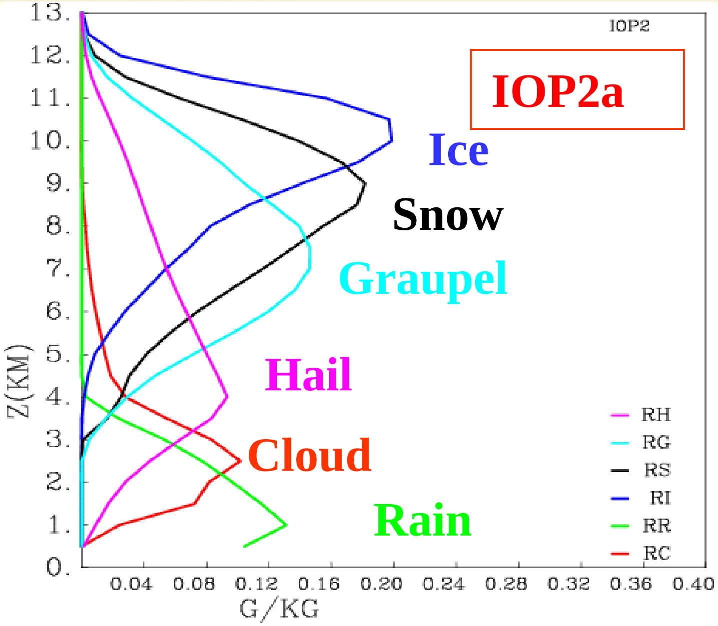
**IOP 8**

**Stratiform rain**

*F.Lascaux and E.Richard, 2005*

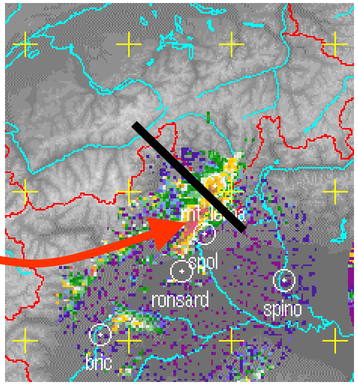
# IOP2a

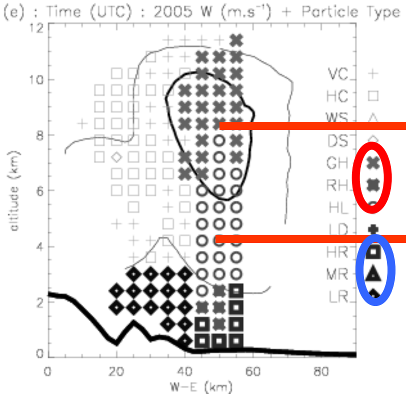
**IOP2a** ( Strong convection)
- Deep system (unblocked unstable case, high Fr)
- Large amount of hail and graupel



20H

Z > 60 dBz



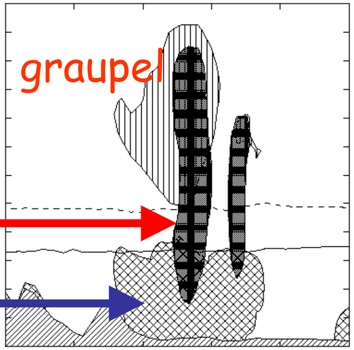


100 km

(x) hail + graupel

(o) hail

(□ ) rain

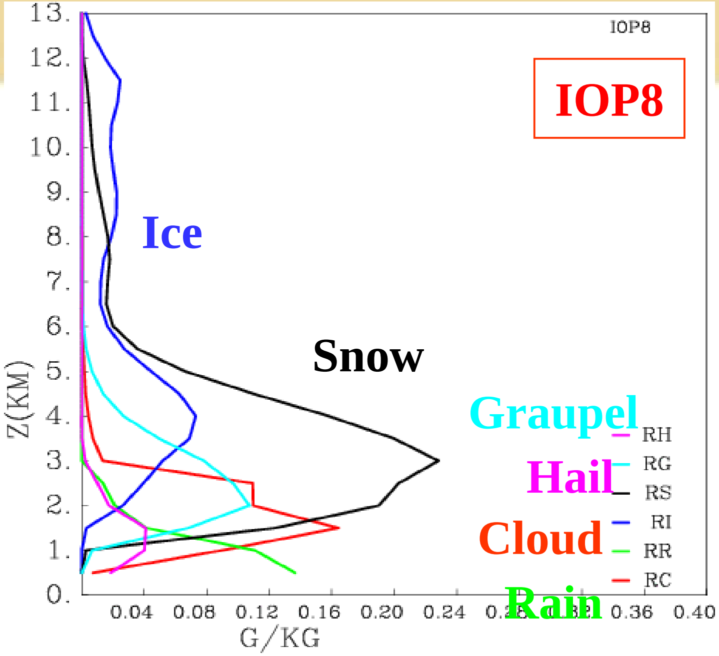


*Lascaux et Richard, 2005*

*Tabary, 2002*

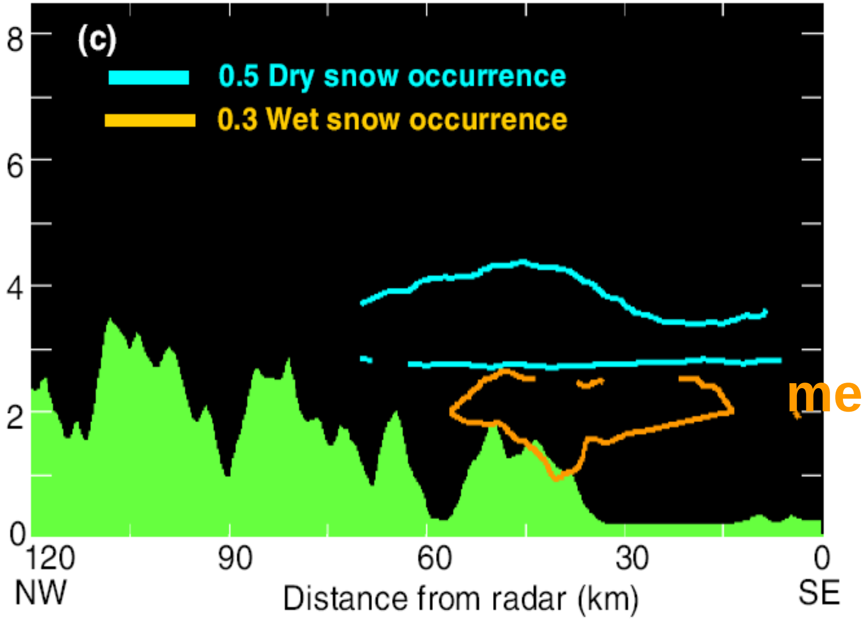
# IOP8

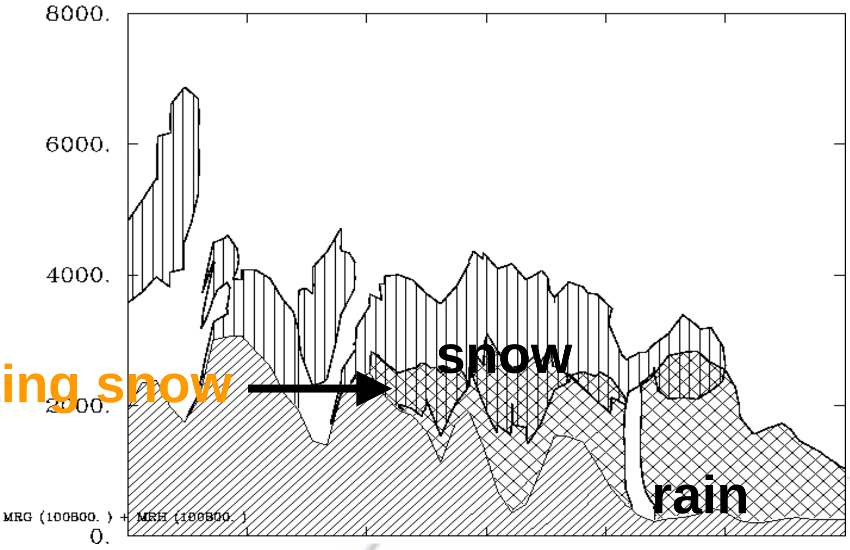
**IOP8** ( Stratiform event)
- Shallow system (blocked case, low Fr)
- Large amount of snow



*Medina et Houze, 2003*

## S-Pol retrieval



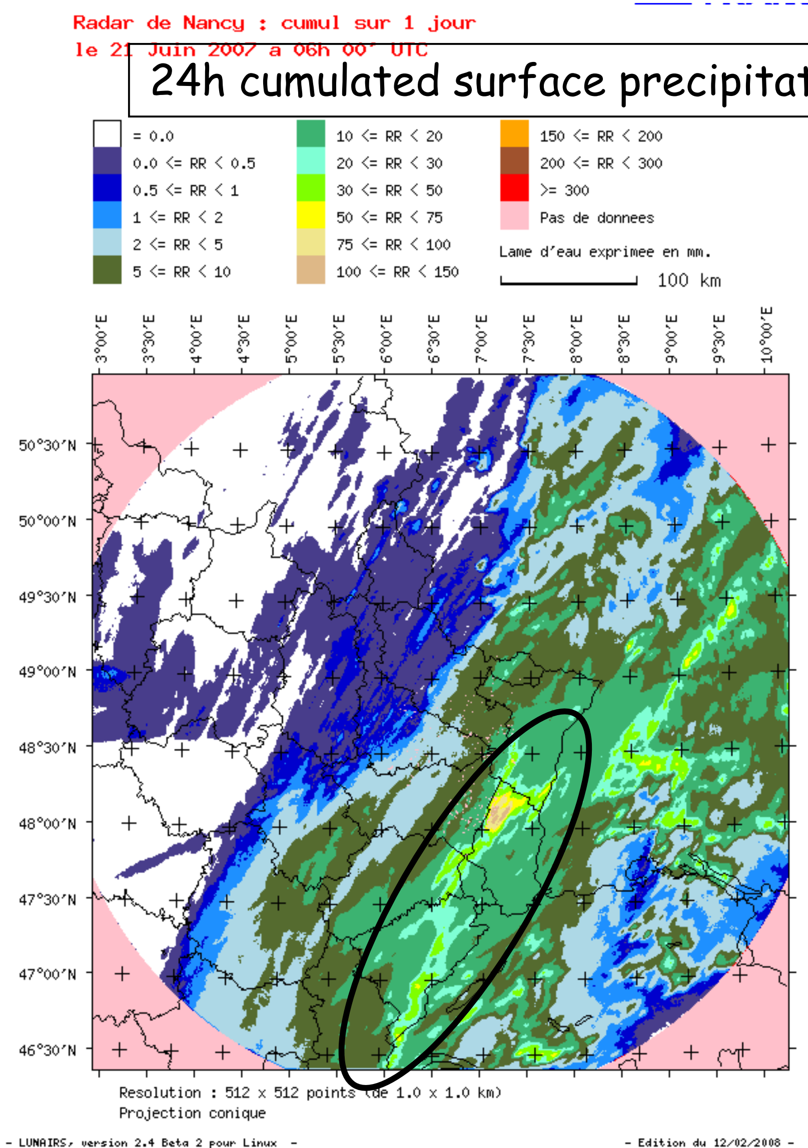


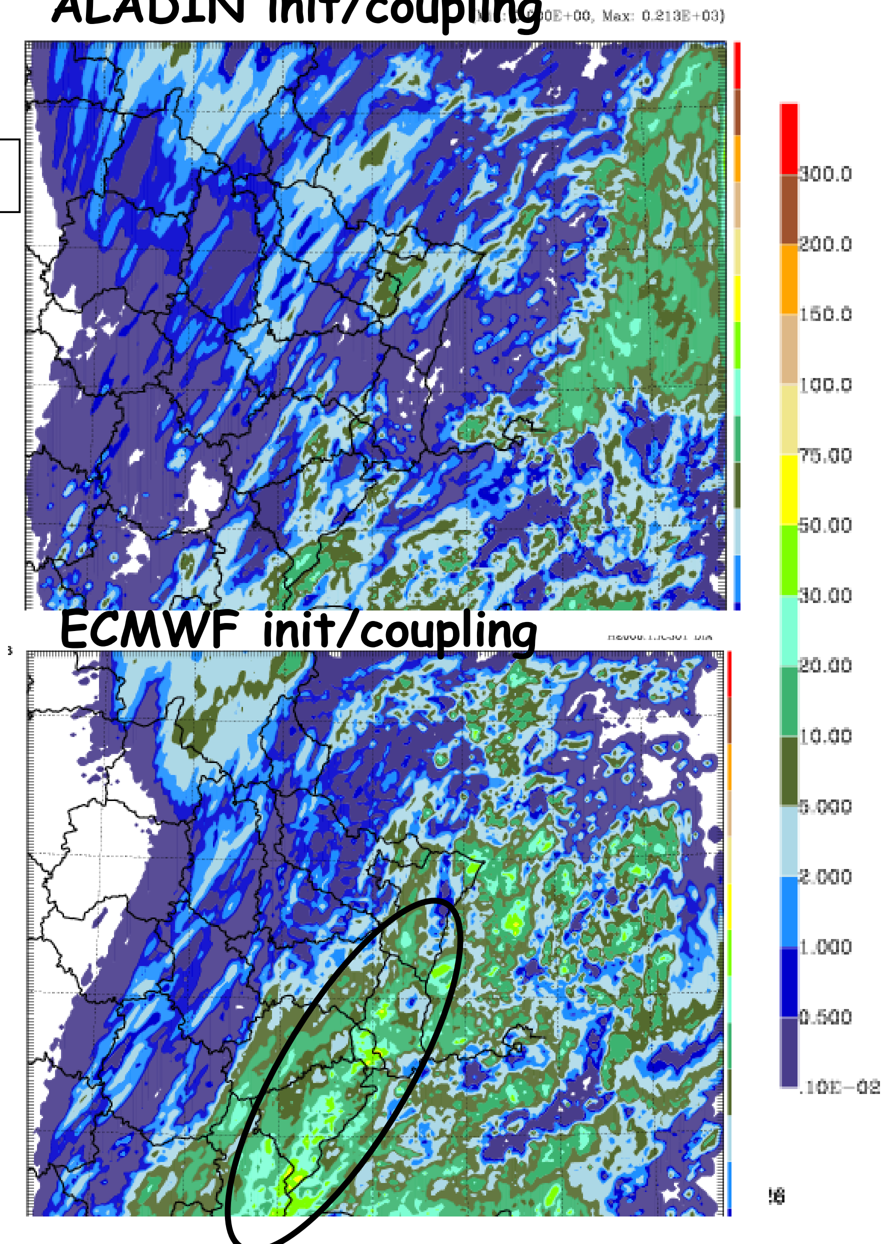
*Lascaux et Richard, 2005*

# Meso-NH : Comparison initialization/coupling ALADIN/ECMWF

20th of June 2007 : Convective cells on NE producing hail on Haut-Rhin

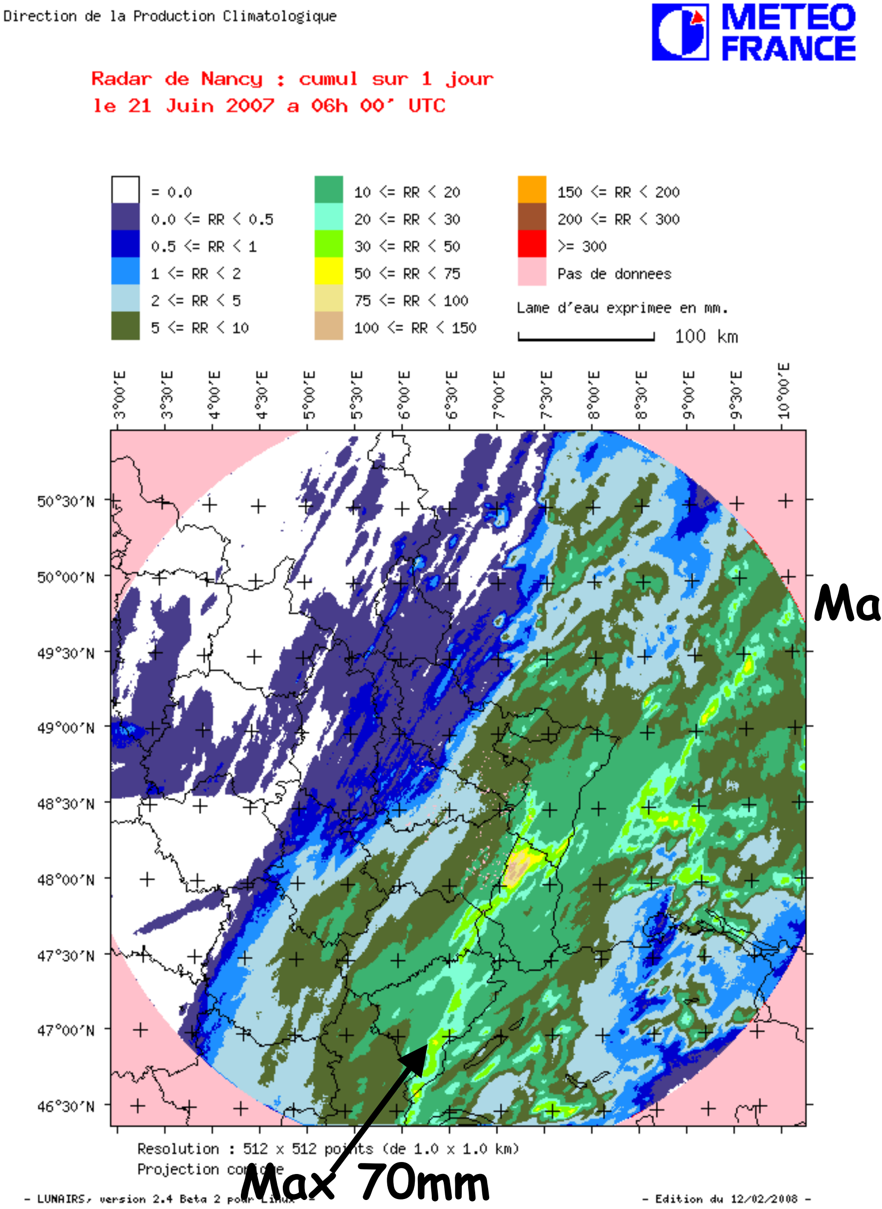
24h cumulated surface precipitation




ALADIN init/coupling

ECMWF init/coupling

# Comparison Meso-NH/AROME : Aladin initialization/coupling



Direction de la Production Climatologique

Radar de Nancy : cumul sur 1 jour
le 21 Juin 2007 a 06h 00' UTC

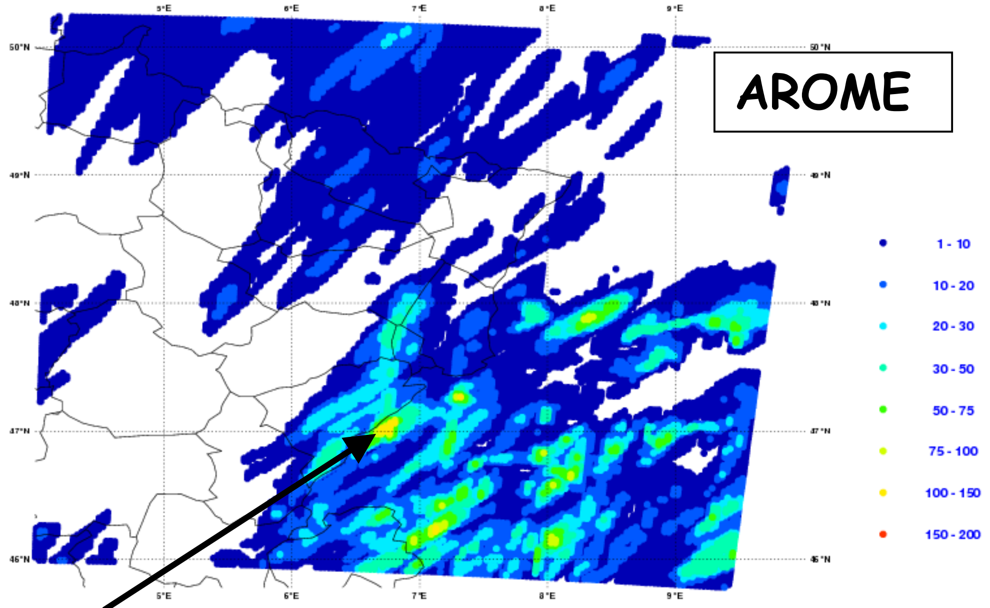
Resolution : 512 x 512 points (de 1.0 x 1.0 km)
Projection conique

- LUNAIRS, version 2.4 Beta 2 pour Linux -

- Edition du 12/02/2008 -

Max 70mm

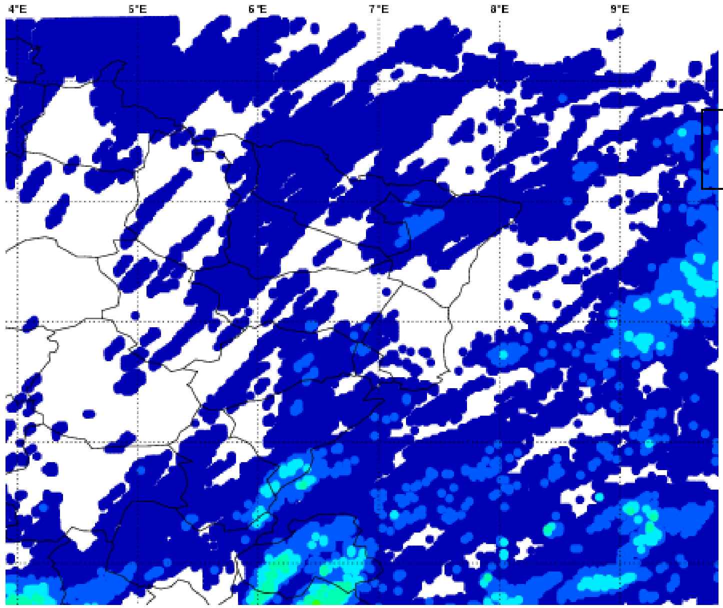
61ER_ACPRT24
ACPRT AROME ICE3
min=0 max=147.982 moy=5.26013943927 ect=9999



**AROME**

Max>100mm

ACPRT MNH ICE3
min=0 max=212.998978 moy=3.10342073535 ect=9999



**Meso-NH**