Description of the MésoNH-AROME microphysical scheme and its evaluation by remote sensing tools

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Outlook

- Introduction
- Common assumptions made in microphysical schemes
- The current scheme developed and used in MésoNH
  - Warm microphysics
  - Mixed-phase microphysics
- Examples and tools to evaluate the scheme
- Conclusion and perspective

The explicit simulation of the Water Cycle is a major issue of many mesoscale studies and model applications.
Microphysical schemes are the key parametrisation to follow the evolution of the condensed phases of water at high resolution in the atmosphere.

Explicit cloud modeling

There are many cloud types to simulate !

Fogs, Extended cloud sheets, Cirrus, Cumulus clouds

Wide span of particle size: ~ 4 decades (μm → cm)

of particle habit: many ice particle types to consider

Microphysical fields describe discontinuous and sparse objects.

Clouds have sharp boundaries (→ microphysical fields are ≥0) which do not fit a regular grid system (→ cloud fraction)

Many interactions involving clouds and precipitation:

Dynamics, Radiation, Surface, Aerosols, Chemistry, Electricity

→ What is the level of complexity really needed for a microphysical scheme to cover all these applications ?

Choice of the microphysical variables

- State variables: Mixing ratios (mass of water / mass of dry air)
- Assumptions about number concentrations: parameterization or Aerosol Physics
- Number of cloud and precipitation variables

2 water variables for warm clouds:

Cloud water (droplets),
Rain water (drops)

2, 3, 4, 5 ice variables for cold clouds:

Cloud ice (pristine crystals),
Snow (large crystals), Aggregates (assemblage of crystals),
Graupel (rimed crystals), Hail (large heavily rimed crystals)

General case ➔ Mixed-phase microphysics with liquid & ice phases

Common features of many microphysical schemes

- **Limited number of water species (~ 6): 1 vap. + 2 liq. + 3 ice**

- **Size distribution:**
  Mathematical (parametric) distribution law [$0 < D < \infty$]

- **Mass-size and Fall speed-size relationships:**
  Power law → analytical integration

- **Uncertainties about the representation of some processes and about the value of some bulk coefficients:**

→ **collision-sticking efficiencies of collection kernels**
→ **autoconversion processes (onset of precipitating particles)**
→ **adjustment to saturation (pure ice-phase clouds)**

Description of the microphysical scheme of MésoNH

- **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 the normalized distribution law

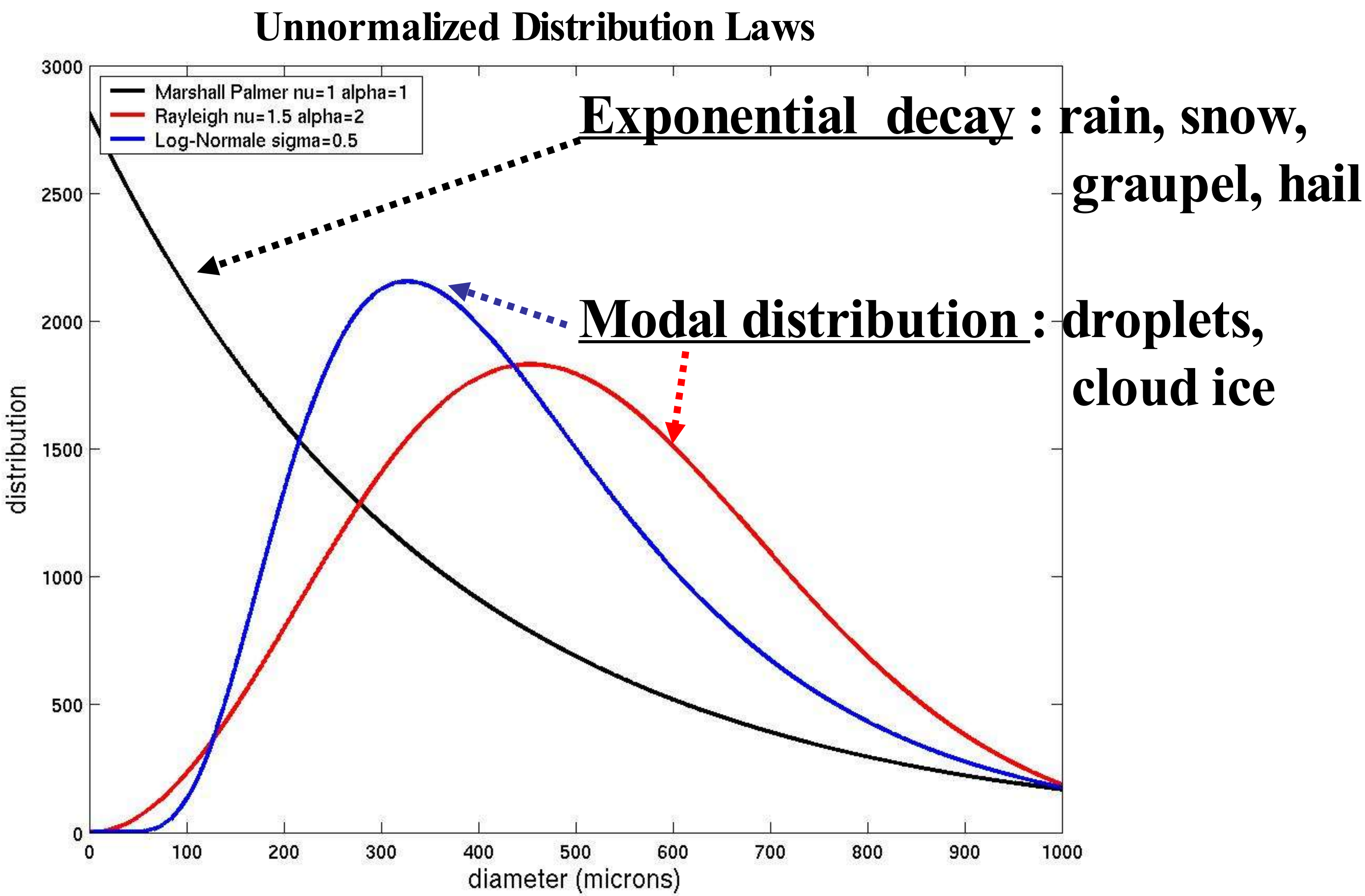
λ is deduced from the mixing ratio

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

- **Very useful p-moment formula**

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

Particle size distributions in microphysical schemes



Microphysical characteristics (1)

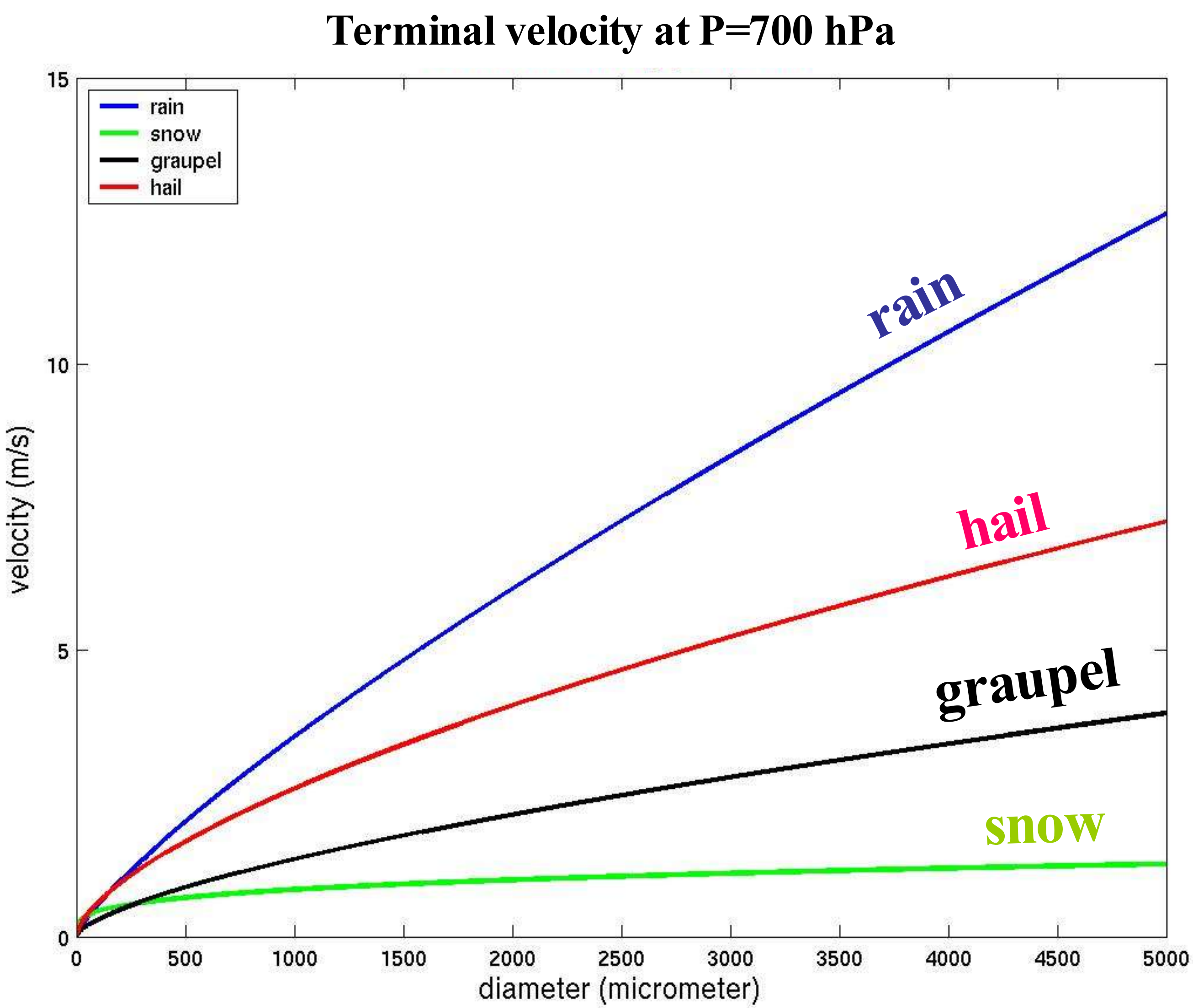
- **Mass-Size relationship: $m=aD^b$**
- **Fall speed-Size relationship: $v=cD^d \cdot (\rho_{00}/\rho_a)^{0.4}$**

Foote-DuToit correction

Category → Parameters		**Cloud water**	**Rain water**	**Cloud ice**	**Snowflake Aggregate**	**Graupel**	**Hail**
mass	a	524	524	0.82	0.02	19.6	470
	b	3	3	2.5	1.9	2.8	3.0
speed	c	3.2e7	842	800	5.1	124	207
	d	2	0.8	1.00	0.27	0.66	0.64

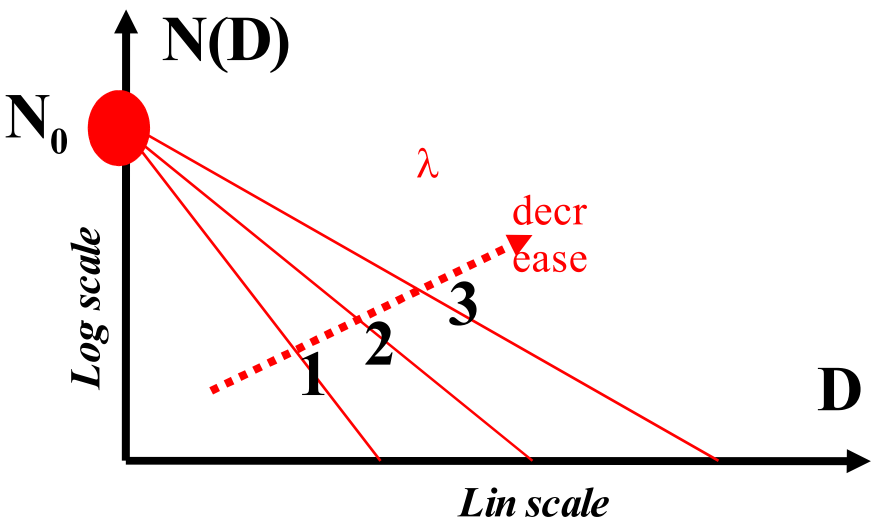
The **a, b, c** and **d** coefficients (MKS units) are adjusted from ground or *in situ* measurements

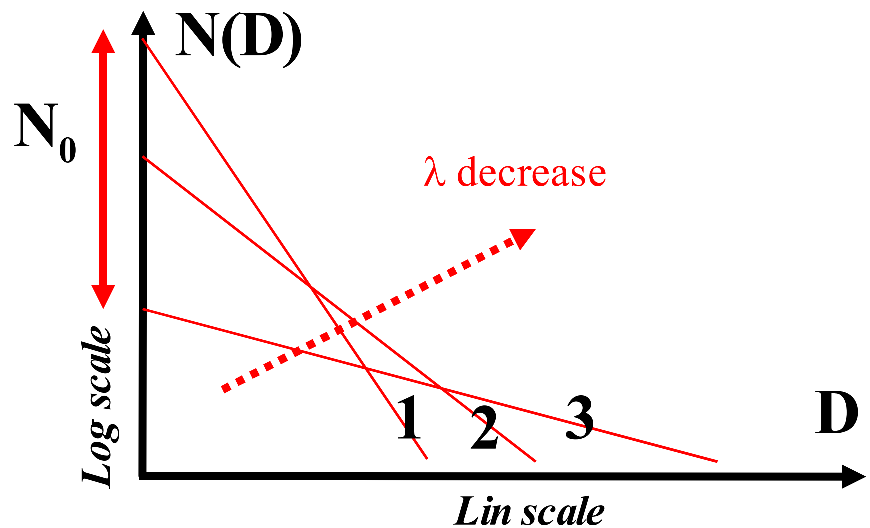
Fall speed of the hydrometeors



Microphysical characteristics (2)

The total concentration of precipitating particles: rain, snow, graupel, is given by $N=C\lambda^x$ instead of fixed N_0 value ($N_0=N.\lambda$) as it is often the case in classical Marshall-Palmer schemes





Marshall - Palmer :

$$n(D)dD = N_0 \exp\left(-(\lambda D)\right)dD$$

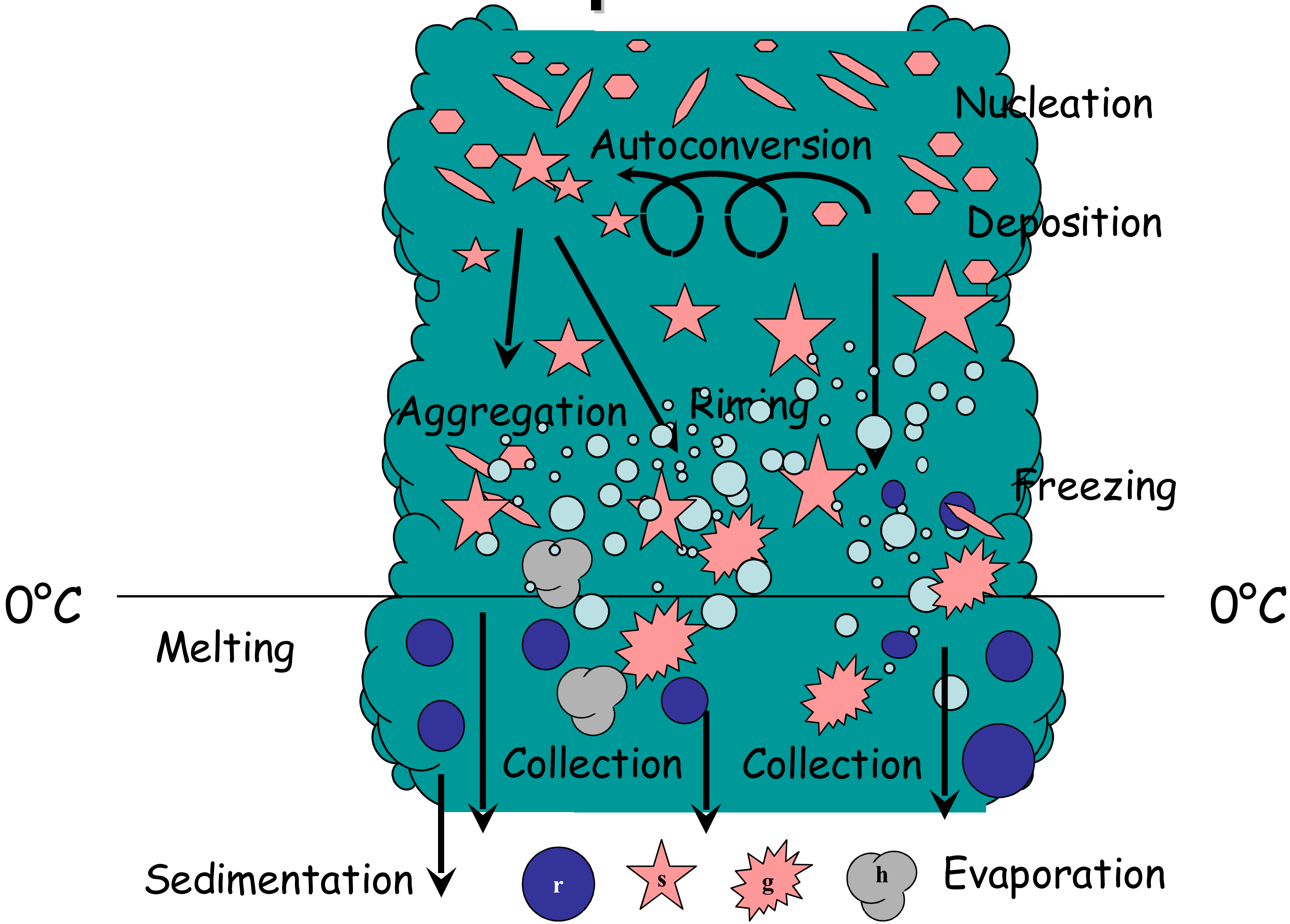
Fixed value

Gamma --> Exponential :

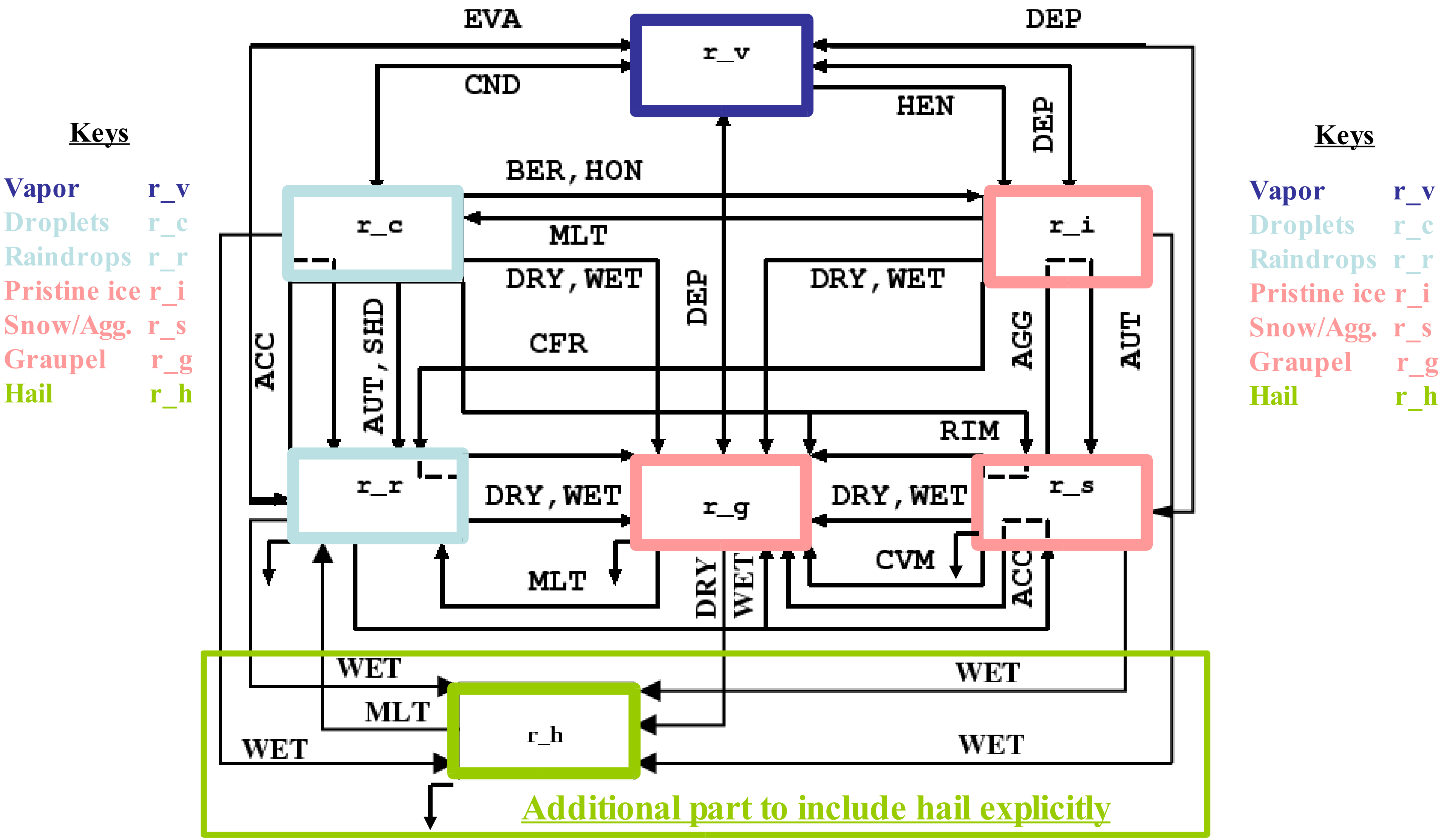
$$n(D)dD = \mathbf{N}\, \lambda \exp\left(-(\lambda D)\right)dD$$

Parameterized

Mixed-phase clouds



Microphysical Scheme diagram

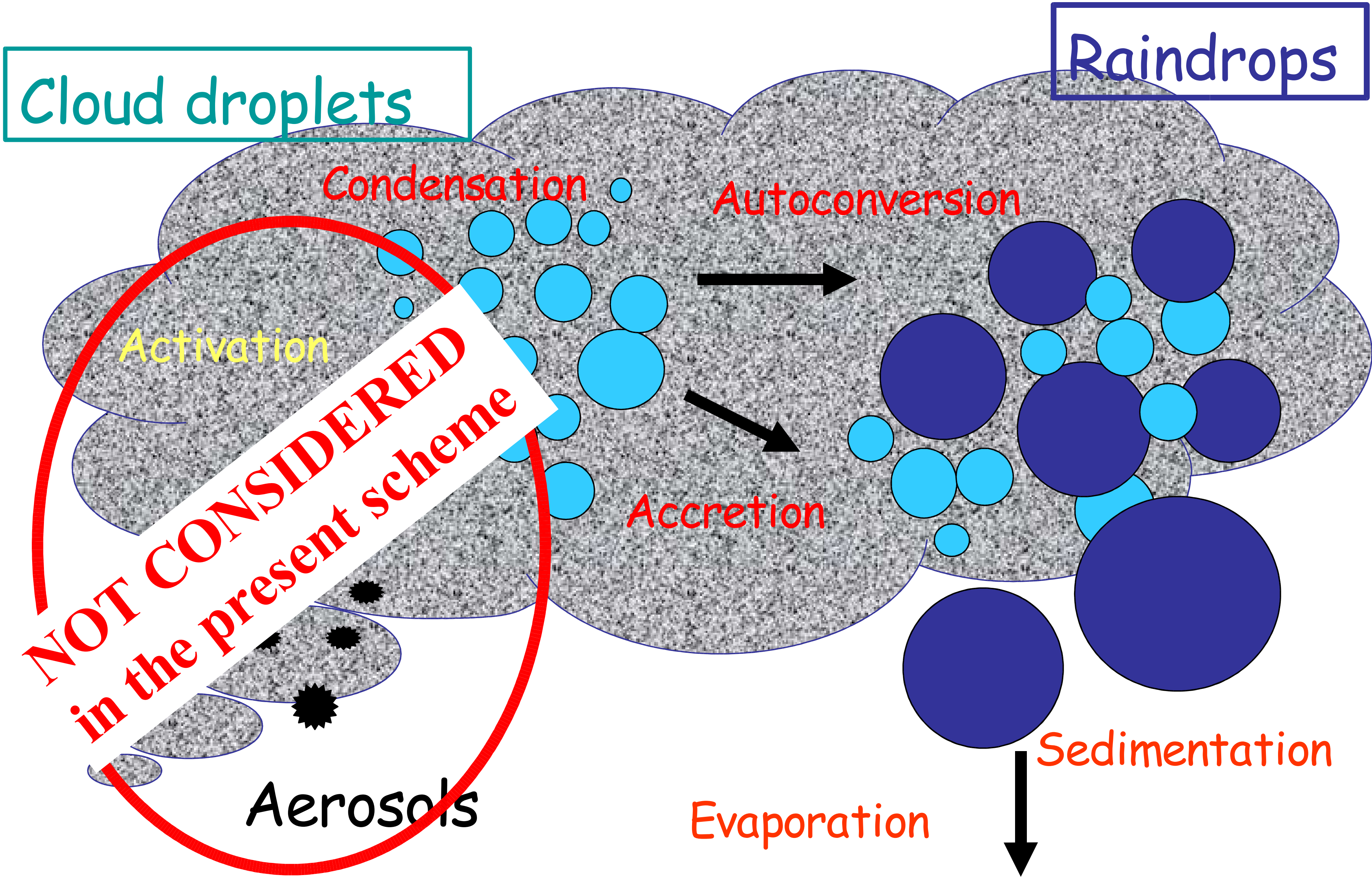


Microphysical Schemes

- **Warm clouds: no ice phase → « Kessler » scheme (1969)**
  - **To simulate the microphysical processes inside pure warm clouds (stratus decks, shallow cumuli)**
  - **To simulate the warm processes occuring in the low levels of deep convective clouds**

- **Mixed-phase clouds: additional ice phase with water-ice and ice-ice interactions → full « Méso-NH » scheme (... 1998)**
  - **To simulate ice clouds (cirrus)**
  - **To simulate heavily precipitating deep convective clouds**

Water cycle in warm clouds



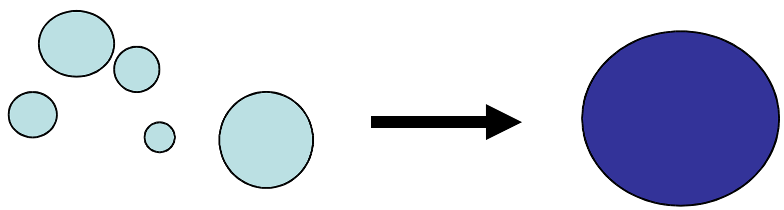
Warm microphysics: Autoconversion

Formation of rain: some cloud droplets become raindrops

➔ collection growth of a few big droplets

➔ role of the turbulence, width of the droplet size distribution

➔ subject of very active research to include N_c, D_c, σ_c, ε_{turb}



$$\left(\frac{\partial(\rho_a r_r)}{\partial t}\right)_{AUT} = -\left(\frac{\partial(\rho_a r_c)}{\partial t}\right)_{AUT} = K \times Max\left(0.0, \rho_a r_c - \rho_a r_c^{crit}\right)$$

with

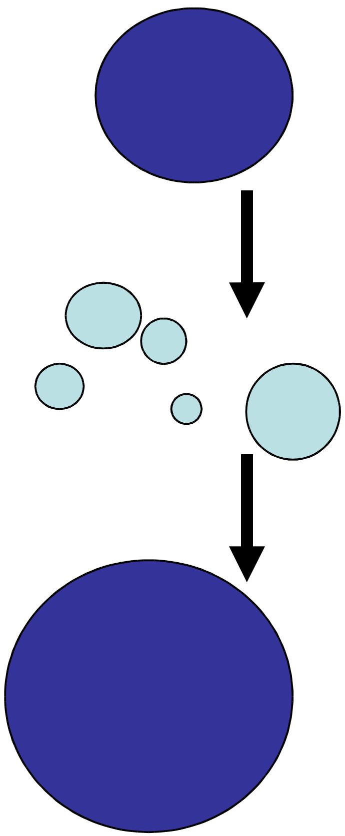
(Time scale)$^{-1}$ → $K = 10^{-3}\, s^{-1}$

Threshold → $\rho_a r_c^{crit} = 0.5 \times 10^{-3}\, kg.m^{-3}$

… a very crude but efficient parametrization

Warm microphysics: Accretion

Growth of raindrops: raindrops collect droplets during their fall



Collection kernel: geometrical sweep-out

$$K(D_c, D_r) = \frac{\pi}{4} \times (D_c^2 + D_r^2) \times |v(D_c) - v(D_r)| \times E_{coll} \times E_{stick}$$

$$\text{but } D_c << D_r \Rightarrow K(D_c, D_r) \approx \frac{\pi}{4} \times D_r^2 \times v(D_r) \times E_{acc}$$

$v(D_r)$: $cD_r^d \, (\rho_{00}/\rho_a)^{0.4}$

$$\left(\frac{\partial m(D_r)}{\partial t}\right)_{ACC} = \frac{\pi}{6} \rho_w \int_0^\infty K(D_c, D_r) \times D_c^3 \times n_c(D_c) \, d\, D_c = \frac{r_c}{\rho_a} K(D_r)$$

$$\left(\frac{\partial (\rho_a r_r)}{\partial t}\right)_{ACC} = -\left(\frac{\partial (\rho_a r_c)}{\partial t}\right)_{ACC} = \int_0^\infty \left(\frac{\partial m(D_r)}{\partial t}\right)_{ACC} n_r(D_r) \, d\, D_r = \frac{\pi}{4} r_c E_{acc} M(d_r + 2)$$

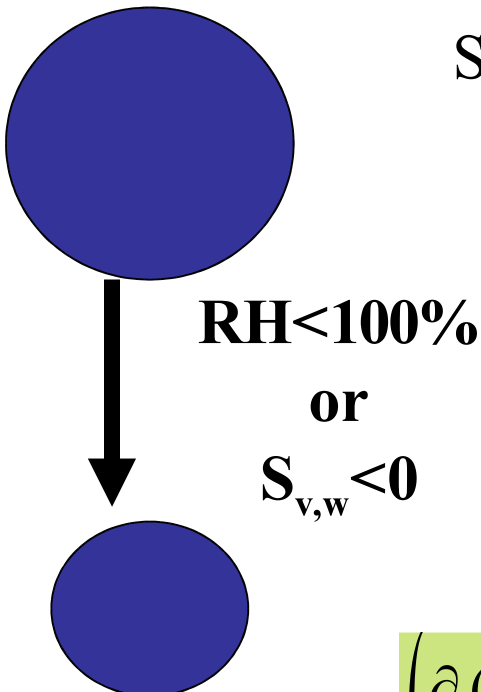
with

$$E_{acc} = 1$$

… the parametrization is based upon the collection kernel

Warm microphysics: Evaporation

Decay of raindrops: raindrops evaporate below cloud



Evaporation rate: function of the undersaturation $S_{v,w}$ and of a ventilation coefficient $\bar{f}(D)$

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

with

$$A_w(T,P) \cong \frac{L_v^2}{k_a(T) R_v T^2} + \frac{R_v T}{e_{sw}(T) D_v(T,P)}$$

$$S_{v,w} = (r_v - r_{vs})/r_{vs} \quad (\text{here} \quad S_{v,w} < 0)$$

$$\bar{f} = 1 + F \times \sqrt{Re} \quad \text{with} \quad F = 0.22, \quad Re = \frac{v(D)D}{\nu}$$

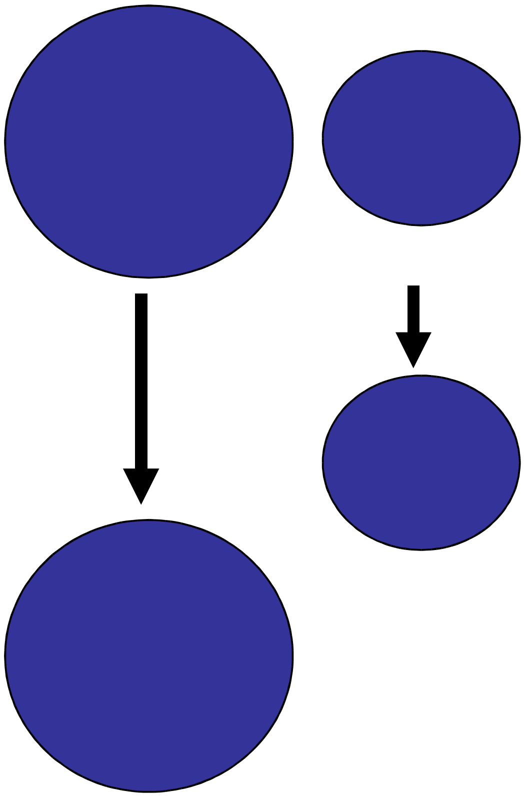
Drop **Re**ynolds number

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

… a rather accurate parametrization

Warm microphysics: Sedimentation

Fallout of raindrops: **vertical flux of raindrops relative to the air**



Sedimentation rate from sedimentation flux

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

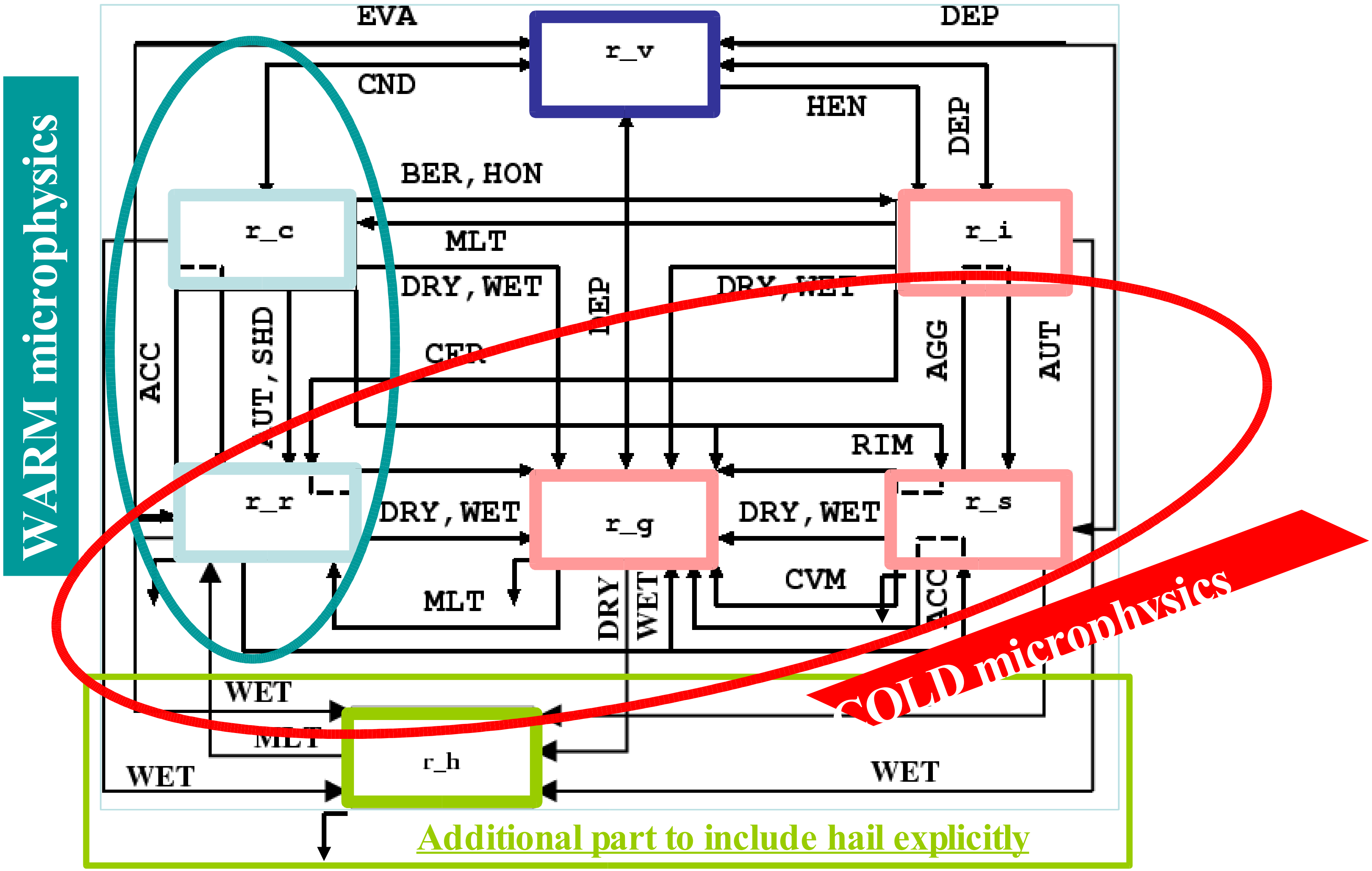
$$\mathrm{Sed\_flux} = a_r c_r (\rho_{00}/\rho_a)^{0.4} \int_0^\infty D_r^{\,b_r+d_r}\, n_r(D_r)\, dD_r$$

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

Automatic time-splitting for numerical stability

… no true size sorting effect (size shift toward large D_r)

Microphysical Scheme diagram



Ice nucleation processes

(a very simplified treatment !)

Homogeneous nucleation:
Spontaneous freezing of the cloud droplets when -35°C<T<-44°C
and
Rain➔Graupel, T<-35°C

Basics: Freezing probability P of a droplet of volume V

$$P = 1 - \exp\left(-\int_t^{t+\Delta t} J_{HOM}(\mathrm{T}) \times \mathrm{V}dt\right) \approx J_{HOM}(\mathrm{T}) \times \mathrm{V} \times \Delta t$$

Integration over the droplet size distribution

$$\left(\frac{\partial(\rho_a r_i)}{\partial t}\right)_{HON} = Min\left(\frac{\rho_a r_c}{\Delta t}, \frac{\pi}{6} J_{HOM}(T) \times (\rho_a r_c) \times \frac{\mathrm{M}(6)}{\mathrm{M}(3)}\right)$$

Heterogeneous nucleation:
Based on ice crystals growing on ice nuclei (IN)

Basics: Meyers et al. (1992) as in Ferrier (1994)

$$N_{IN} = \begin{cases} N_{NU1}, & -2°\mathrm{C} \le \mathrm{T} \le -5°\mathrm{C} \\ N_{NU2}; & \mathrm{T} \le -5°\mathrm{C} \end{cases}$$

$$\left(\frac{\partial(\rho_a r_i)}{\partial t}\right)_{HEN} = \frac{m_{NU0}}{\Delta t} \times Max\left(0, N_{IN} - N_i^{t-\Delta t}\right)$$

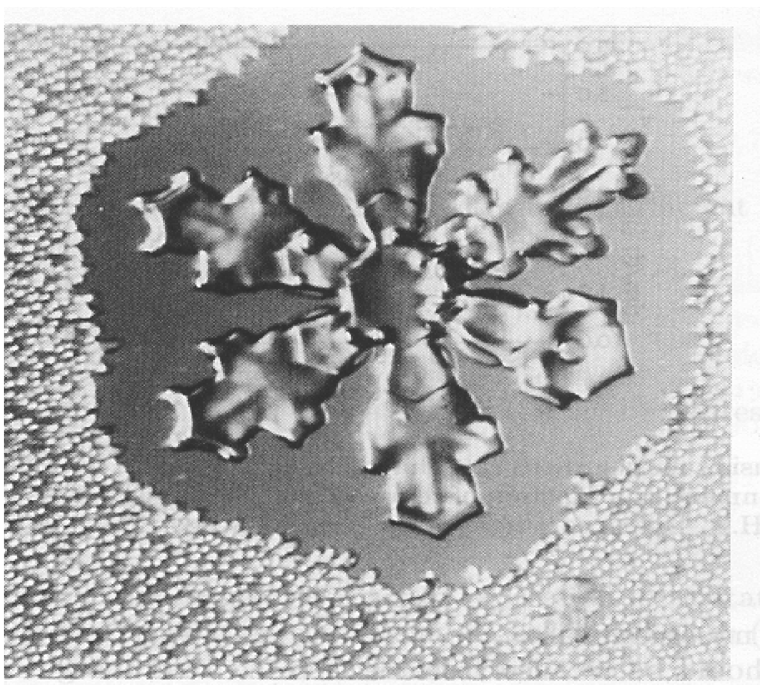
$$N_{NU1} = N_{NU10}\left[(r_v - r_{vsi}) / (r_{vsw} - r_{vsi})\right]^{\alpha_1} \exp(-\beta_1 \times \mathrm{T})$$

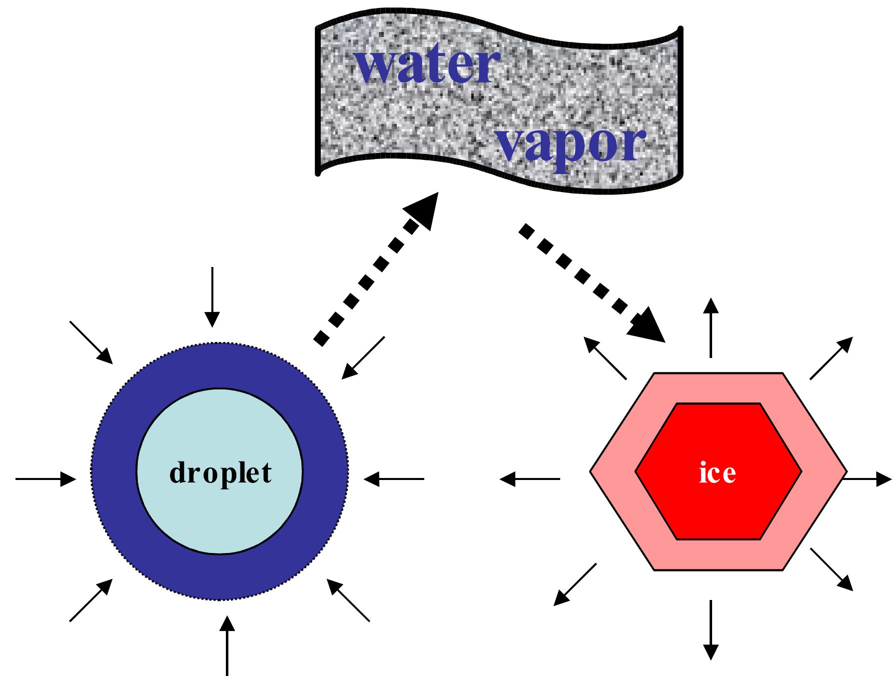
$$N_{NU2} = N_{NU20} \exp(\alpha_2 \times \mathrm{SS}_i - \beta_2).$$

… the treatment is more complex when Ni is a prognostic variable

Bergeron-Findeisen effect

$$e_{si}(T) \leq e_{sw}(T)$$ → **Growth of pristine ice crystal at the expense of cloud droplets**





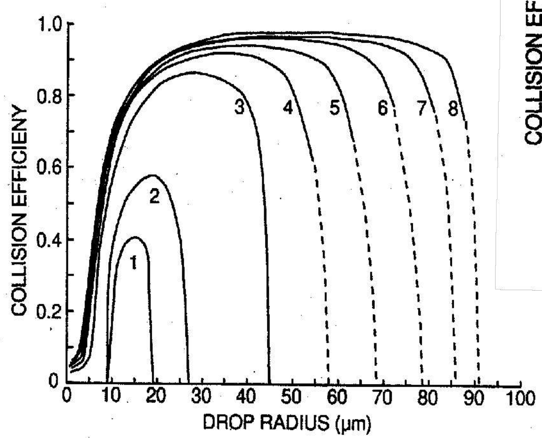
$$Evaporation\_rate = Deposition\_rate$$

… maximum effect at T=-12°C

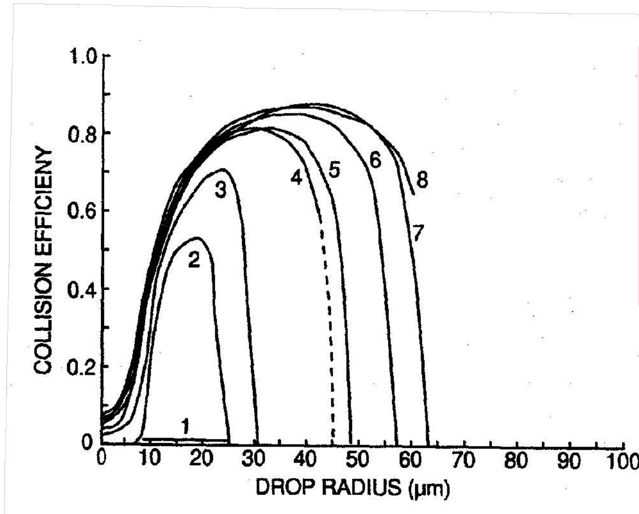
Autoconversion of pristine ice crystals

Small pristine ice crystals do not grow by collection !

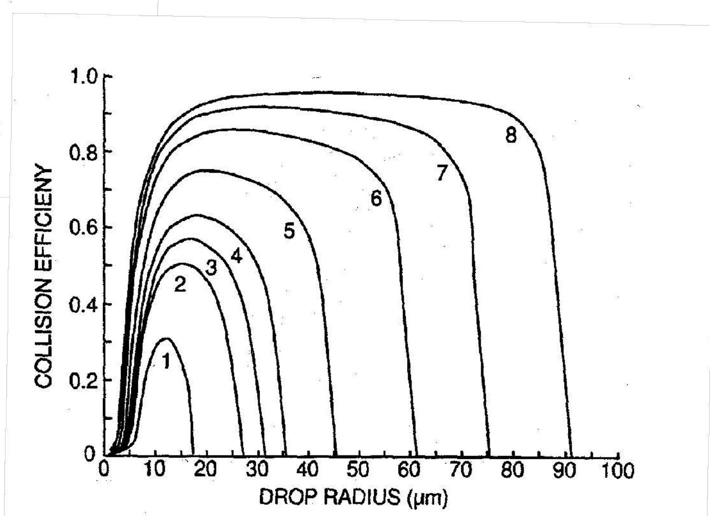
Computed drop collection efficiencies after Wang & Ji (1992)



Hexagonal plates: (1) D=160 µm



Stellar crystals: (1) D=200 µm

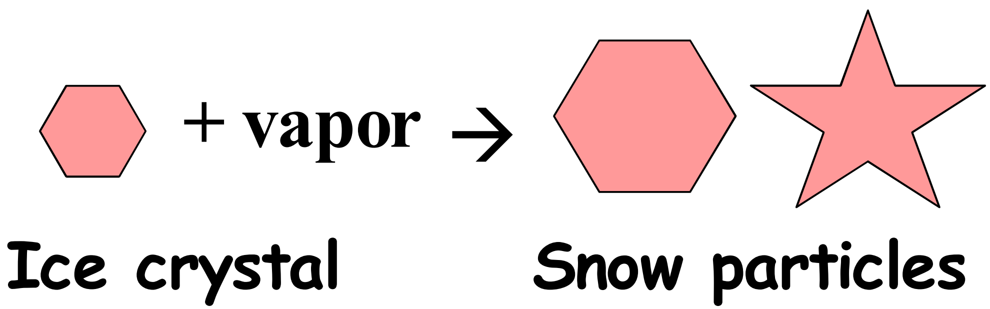


Hexagonal columns: (1) L=70 µm

… pristine crystals (D<150µm) poorly rime or grow by agregation

Autoconversion of pristine ice crystals

Formation of snow: **Some pristine ice crystals grow by deposition to get bigger than 100 ~ 200 µm**



$$\left(\frac{\partial(\rho_a r_s)}{\partial t}\right)_{AUT} = -\left(\frac{\partial(\rho_a r_i)}{\partial t}\right)_{AUT} = K \times Max\left(0.0, \rho_a r_i - \rho_a r_i^{crit}\right)$$

with

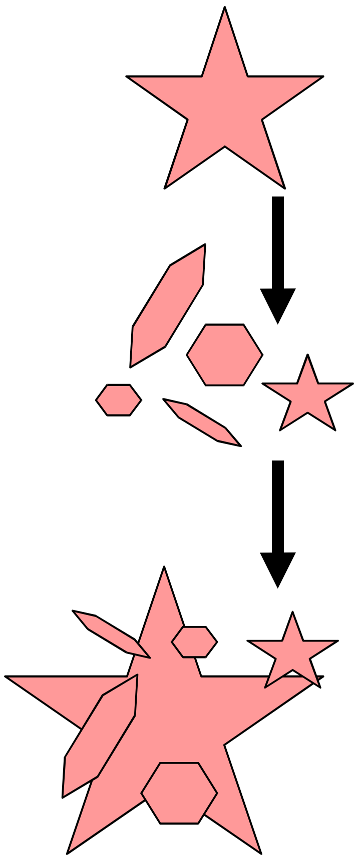
(Time scale)$^{-1}$ → $K = 10^{-3} \times \exp\left(0.025 \times (T - T_t)\right) s^{-1}$

Threshold → $\rho_a r_i^{crit} = 0.02 \times 10^{-3}\, kg.m^{-3}$

… modified threshold to enhance cirrus sheet precipitation

Aggregation of pristine ice → snow

Dry growth of snow: snowflakes collect ice crystals when falling



Collection kernel: geometrical sweep-out

$$K(D_i, D_s) = \frac{\pi}{4} \times \left(D_i^2 + D_s^2\right) \times \left| v(D_i) - v(D_s) \right| \times E_{coll} \times E_{stick}$$

$$\text{but } D_i << D_s \Rightarrow K(D_i, D_s) \approx \frac{\pi}{4} \times D_s^2 \times v(D_s) \times E_{agg}$$

$$v(D_s) = cD_s^d\,(\rho_{00}/\rho_a)^{0.4}$$

$$\left(\frac{\partial m(D_s)}{\partial t}\right)_{ACC} = \int_0^\infty K(D_i, D_s) \times \left(a_i D_i^{b_i}\right) \times n_i(D_i)\, dD_i = \frac{r_i}{\rho_a} K(D_s)$$

$$\left(\frac{\partial (\rho_a r_s)}{\partial t}\right)_{AGG} = -\left(\frac{\partial (\rho_a r_i)}{\partial t}\right)_{AGG} = \int_0^\infty \left(\frac{\partial m(D_s)}{\partial t}\right)_{AGG} n_s(D_s)\, dD_s = \frac{\pi}{4} r_i E_{agg} M(d_s + 2)$$

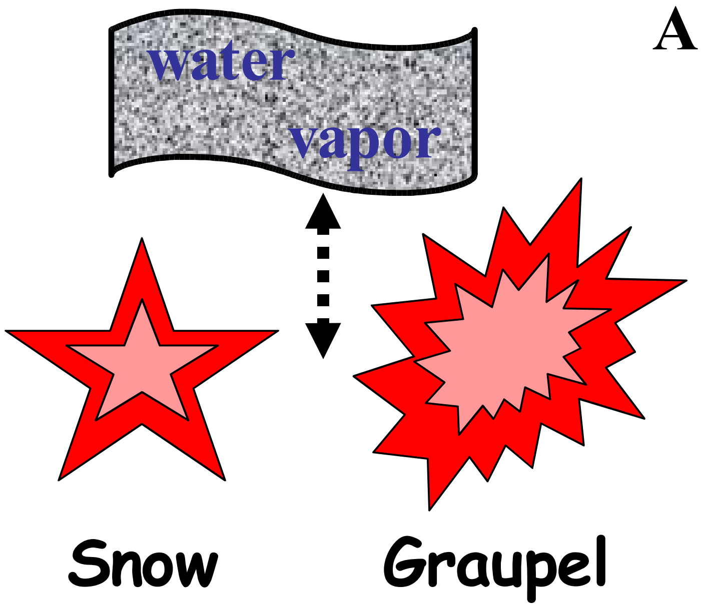
with

$$E_{agg} = 0.25 \times \exp\left(0.05 \times (T - T_t)\right)$$

… a very crude but efficient parametrization

Growth by deposition

Snow and graupel grow (inside clouds) or decay (outside clouds):



A generalization of the raindrop evaporation

$$\partial m(D)/\partial t_{DEP/SUB} = 4\pi \times S_{v,i} \times C(D) \times \bar{f}(D) / A_i(T,P)$$

with

Capacitance ↗

$$C = C_1 D$$

Ventilation ↗

$$\bar{f} = \bar{f}_0 + \bar{f}_1 \times \chi + \bar{f}_2 \times \chi^2$$

where $\chi = Sc^{1/3} Re^{1/2}$, $Sc = \dfrac{\nu}{D_v}$; $Re = \dfrac{v(D)D}{\nu}$

Schmidt & **Re**ynolds numbers

$$\left(\frac{\partial(\rho_a r_{s,g})}{\partial t}\right)_{DEP/SUB} = \int_0^\infty \left(\frac{\partial m(D_{s,g})}{\partial t}\right)_{DEP/SUB} n_{s,g}(D_{s,g})\, d D_{s,g}$$

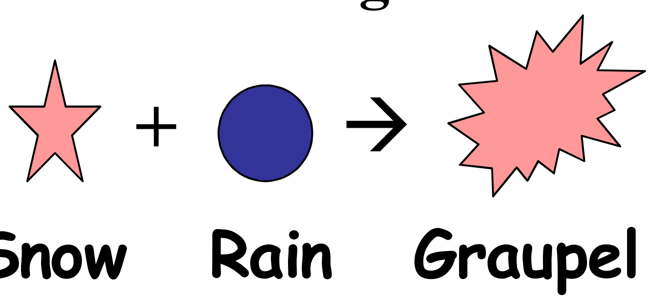
… a fully analytical parametrization

Generalities about collection processes

Collection processes: 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+Conversion of precipitating particles: tabulated integrals



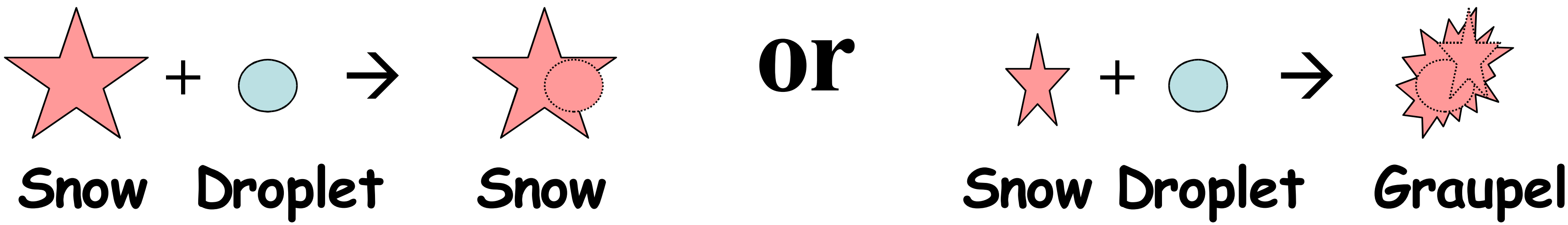
$$\left(\frac{\partial(\rho_a r_x)}{\partial t}\right)_{COLL} = -\int_0^\infty\left[\int_0^\infty K(D_x, D_y) m_y(D_y) n_y(D_y) dD_y\right] n_x(D_x) dD_x$$

$$\left(\frac{\partial(\rho_a r_y)}{\partial t}\right)_{COLL} = -\int_0^\infty\left[\int_0^\infty K(D_x, D_y) m_x(D_x) n_x(D_x) dD_x\right] n_y(D_y) dD_y$$

$$\left(\frac{\partial(\rho_a r_z)}{\partial t}\right)_{COLL} = -\left(\frac{\partial(\rho_a r_x)}{\partial t}\right)_{COLL} - \left(\frac{\partial(\rho_a r_y)}{\partial t}\right)_{COLL}$$

… but the treatment is even more complicated in the case of partial conversion (function of particle size)

Snow riming process



Conversion threshold: $D_s > D_s^{lim} = 7$ mm as in Farley et al. (1989)

➔ Splitted snow size distribution

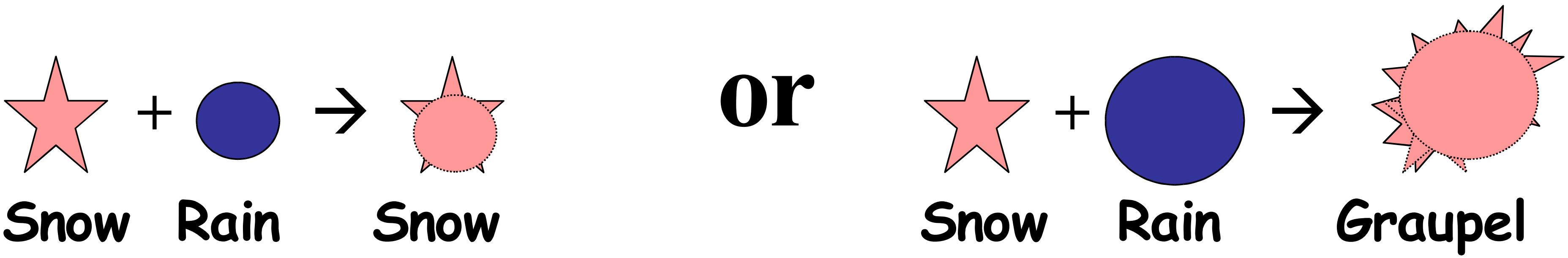
$$\left(\frac{\partial \rho_a r_s}{\partial t}\right)_{RIM} = \int_0^{D_s^{lim}} \left[\int_0^{\infty} K(D_c, D_s) m_c(D_c) n_c(D_c) dD_c\right] n_s(D_s) dD_s$$

$$\left(\frac{\partial \rho_a r_g}{\partial t}\right)_{RIM} = \int_{D_s^{lim}}^{\infty} \left[\int_0^{\infty} K(D_c, D_s) m_c(D_c) n_c(D_c) dD_c\right] n_s(D_s) dD_s$$

with $K(D_c, D_s) \approx K(D_s) \approx \frac{\pi}{4} \times D_s^2 \times v(D_s) \times E_{rim}$ and $E_{rim} = 1$

… a continuous conversion of snow by riming

Snow collection process



Conversion when $D_r > D_r^{lim}$: based on the density of a mixture of a snowflake and a raindrop $\rho_{sr} \geq 0.5 \times (\rho_g + \rho_s)$ **and leading to** $D_r^{lim} = f(D_s)$

$$\left(\frac{\partial \rho_a r_s}{\partial t}\right)_{COL} = \int_0^{\infty} \left[\int_0^{D_r^{lim}} K(D_r, D_s) m_r(D_r) n_r(D_r) dD_r \right] n_s(D_s) dD_s$$

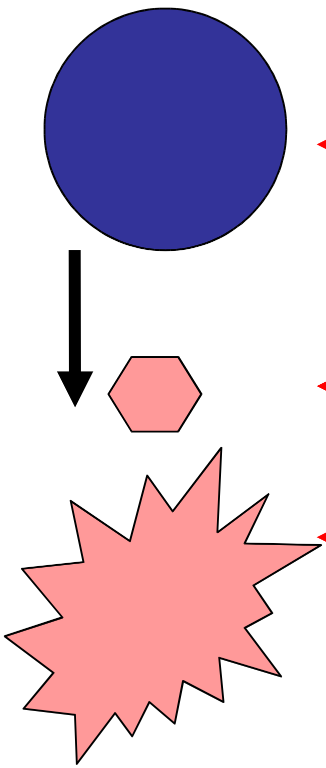
$$\left(\frac{\partial \rho_a r_g}{\partial t}\right)_{COL} = \int_0^{\infty} \left[\int_{D_r^{lim}}^{\infty} K(D_r, D_s) m_r(D_r) n_r(D_r) dD_r \right] n_s(D_s) dD_s$$

with tabulated normalized integrals as $v_s(D_s) \sim v_r(D_r)$

… large collected raindrops convert snow into graupel

Raindrop contact freezing

Raindrop freezing: **falling raindrops capture pristine ice crystals to form graupel particles**



$$\left(\frac{\partial \rho_a r_r}{\partial t}\right)_{CFR} = -\int_0^\infty \left[\int_0^\infty K(D_i, D_r)\, m_r(D_r)\, n_r(D_r)\, dD_r\right] n_i(D_i)\, dD_i$$

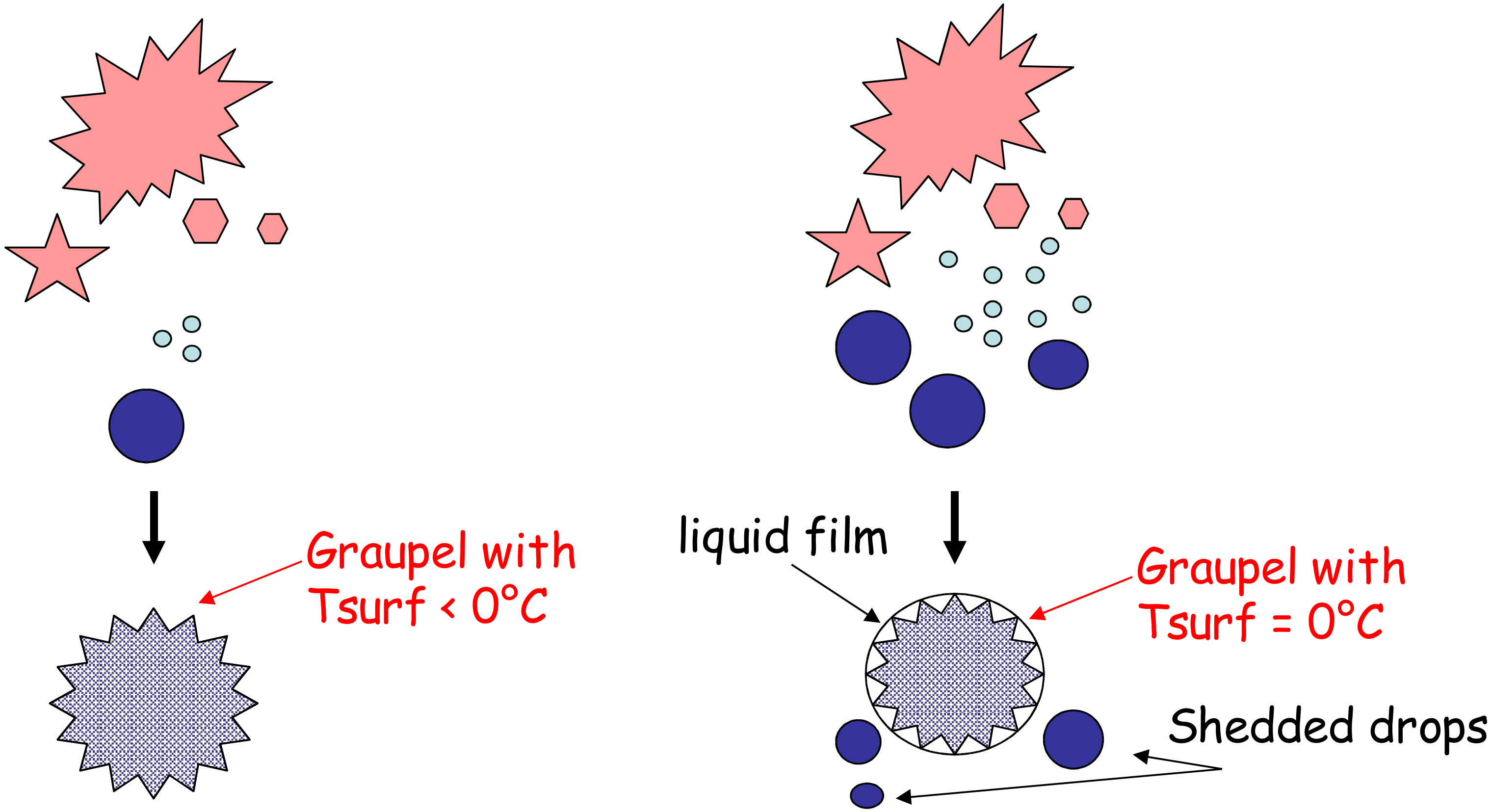
$$\left(\frac{\partial \rho_a r_i}{\partial t}\right)_{CFR} = -\int_0^\infty \left[\int_0^\infty K(D_i, D_r)\, m_i(D_i)\, n_i(D_i)\, dD_i\right] n_r(D_r)\, dD_r$$

$$\left(\frac{\partial \rho_a r_g}{\partial t}\right)_{CFR} = -\left(\frac{\partial \rho_a r_r}{\partial t}\right)_{CFR} - \left(\frac{\partial \rho_a r_i}{\partial t}\right)_{CFR}$$

with $K(D_i, D_r) \approx K(D_r) \approx \frac{\pi}{4} \times D_r^2 \times v(D_r) \times E_{cfr}$ and $E_{cfr} = 1$

… collection and simultaneous conversion

Graupel growth: other effects



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

Wet growth (→ Hail)
(Heat balance equation)

The minimum growth rate *must* be taken

Wet growth and water shedding of the graupels → initiation of hailstones

Heat balance equation: **Musil (1970), Nelson (1989)**

$$L_m(T_t)\left.\frac{\partial m}{\partial t}\right|_{c+r} + \left.\frac{\partial m}{\partial t}\right|_{i+s} c_{i,s}(T_t - T) = 4\,\pi\, C_g\, \bar{f}_g \left[k_a(T)(T_t - T) + \frac{L_v D_v(T,P)}{R_v T}\left(e_{vs}(T_t) - e_v\right)\right]$$

Heat due to collected water — **Heat due to collected ice** — **dissipated Heat by the graupel**

Mass budget:

$$\left.\frac{\partial m}{\partial t}\right|_{g} = \left.\frac{\partial m}{\partial t}\right|_{c+r} + \left.\frac{\partial m}{\partial t}\right|_{i+s}$$

→ *Wet growth rate of the graupel*

… water shedding rate is computed → raindrops

A simple way to initiate hail ?

(…this r_h extension is still under test)

A realistic « graupel → hail » conversion rate can be parameterized from the theoretical

→Dry growth rate of the graupel

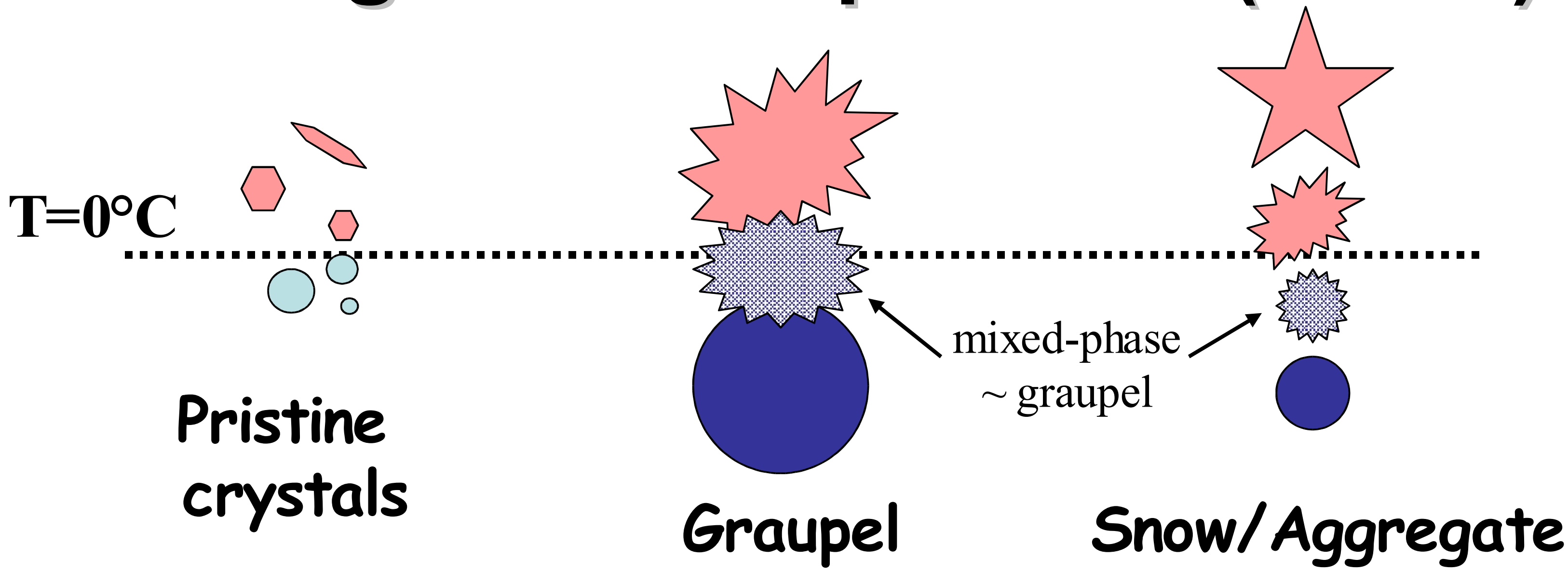
→Wet growth rate of the graupel

$$\left.\frac{\partial r_h}{\partial t}\right|_{g \to h} = \left(\frac{\partial r_g}{\partial t}\right)^* \times \left(\frac{\text{Dry}}{\text{Dry} + \text{Wet}}\right)$$

Hail rate — **Graupel tendency before conversion** — **Weighting factor with Dry/Wet rates**

… to be improved to avoid a continuous conversion into hail

Melting of the ice particles (T>0°C)



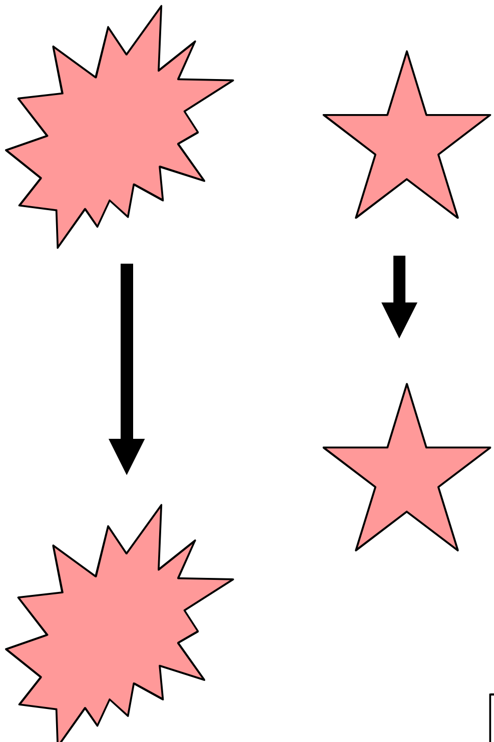
Pristine ice crystals: instantaneously melted into cloud droplets

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 of ice particles

Same as for the raindrops, the pristine ice crystals are weakly precipitating (McFarqhar & Heymsfield)

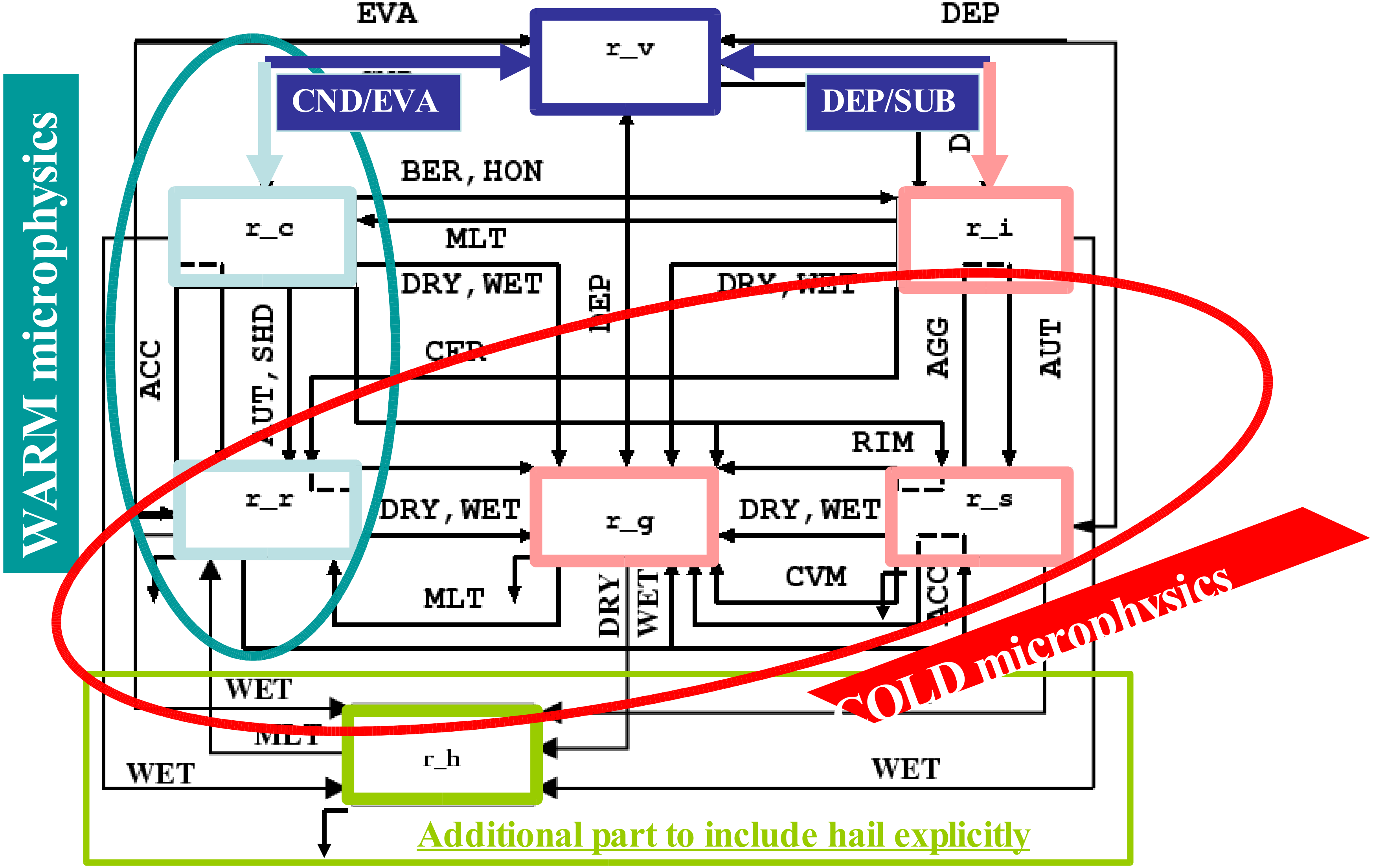


$$\mathrm{Sed\_flux} = \int_0^\infty \mathrm{v}(\mathrm{D}_{i,s,g}) \times \mathrm{m}(\mathrm{D}_{i,s,g}) \times \mathrm{n}_{i,s,g}(\mathrm{D}_{i,s,g})\, \mathrm{d}\mathrm{D}_{i,s,g}$$

$$\left(\frac{\partial(\rho_a r_{i,s,g})}{\partial t}\right)_{SED} = \frac{\partial}{\partial z}\left(\mathrm{Sed\_flux}\right)$$

Automatic time-splitting for numerical stability

Microphysical Scheme diagram

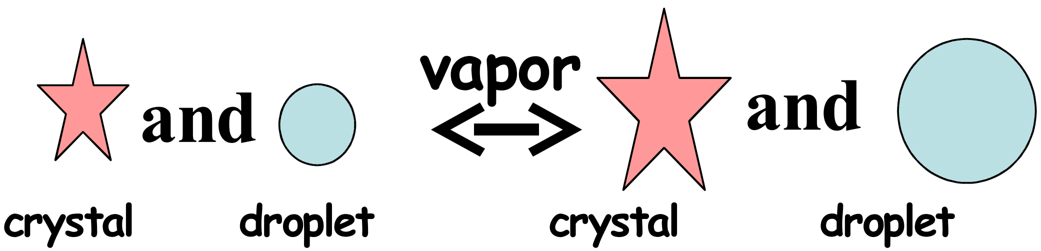


Implicit adjustment to saturation

Saturation mixing ratio:
using a barycentric formula
→ 'no' supersaturation

$$r_{v,sat}^{w+i} = \frac{r_c^* \, r_{v,sat}^{w}(T) + r_i^* \, r_{v,sat}^{i}(T)}{r_c^* + r_i^*}$$

Cond/Evap+Dep/Subl rates:
Variational adjustment



$$F(T) = C_{ph}(T - T^*) + \left[L_{vw}(T) \frac{r_c^*}{r_c^* + r_i^*} + L_{vi}(T) \frac{r_i^*}{r_c^* + r_i^*} \right] \left(r_{v,sat}^{w+i}(T) - r_v^* \right)$$

$1 - \textit{Find} \quad T \quad \textit{such} \quad \textit{as} \quad F(T) = 0$

$2 - \textit{Compute} \quad \Delta r_v = r_v^* - r_{v,sat}^{w+i}(T)$

$3 - \textit{Get} \quad \Delta r_c = \Delta r_v \frac{r_c^*}{r_c^* + r_i^*} \quad \textit{and} \quad \Delta r_i = \Delta r_v \frac{r_i^*}{r_c^* + r_i^*}$

Temporal stepping

- **Sedimentation processes**
- **Warm processes**
- **Slow mixed-phase processes (nucleation, auto-conversion, aggregation, deposition, etc.)**
- **Fast mixed-phase processes (riming, collections, melting, etc.)**

- **Saturation ajustment is the last integrated process**

Microphysical Scheme of MésoNH

Summary

- Warm processes (Kessler scheme)
- Light and Heavy riming rates of the snowflakes by the cloud droplets and by the rain drops and the conversions into graupel particles
- Wet/Dry growth modes of the graupels
- Melted particles are considered as graupels
- Possible extension to simulate a « hail » phase

- Sedimentation (1st order upstream scheme)
- Processes are integrated one-by-one after carefully checking the availability of the sinking categories
- On-line budgets

Present uncertainties …

- **Onset of precipitating drops and precipitating ice:**

➔ **Simulation of extended cloud sheets of moderate lifetime (Sc, Ci) ?**

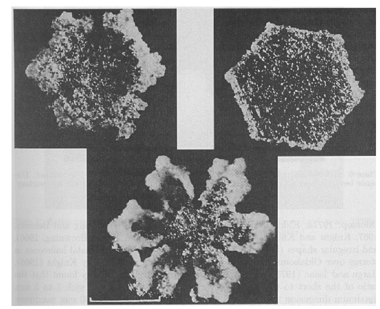
- **Physics of the ice phase:**

➔ **Collection efficiencies ?**

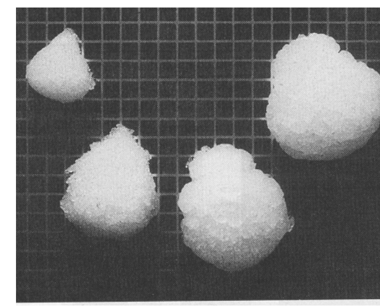
➔ **Supercooling of water ?**

➔ **Ice nucleation ?**

snow



graupel



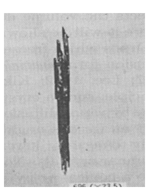
1-10 mm

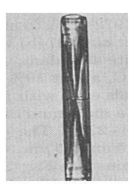
(Pruppacher and Klett, 1997)

➔ **Which ice crystal characteristics to choose ?**

10-100 μm

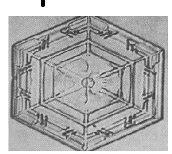
needle



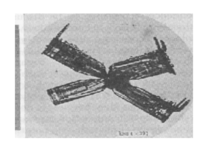


column

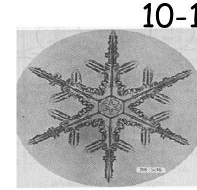
plate



bullet

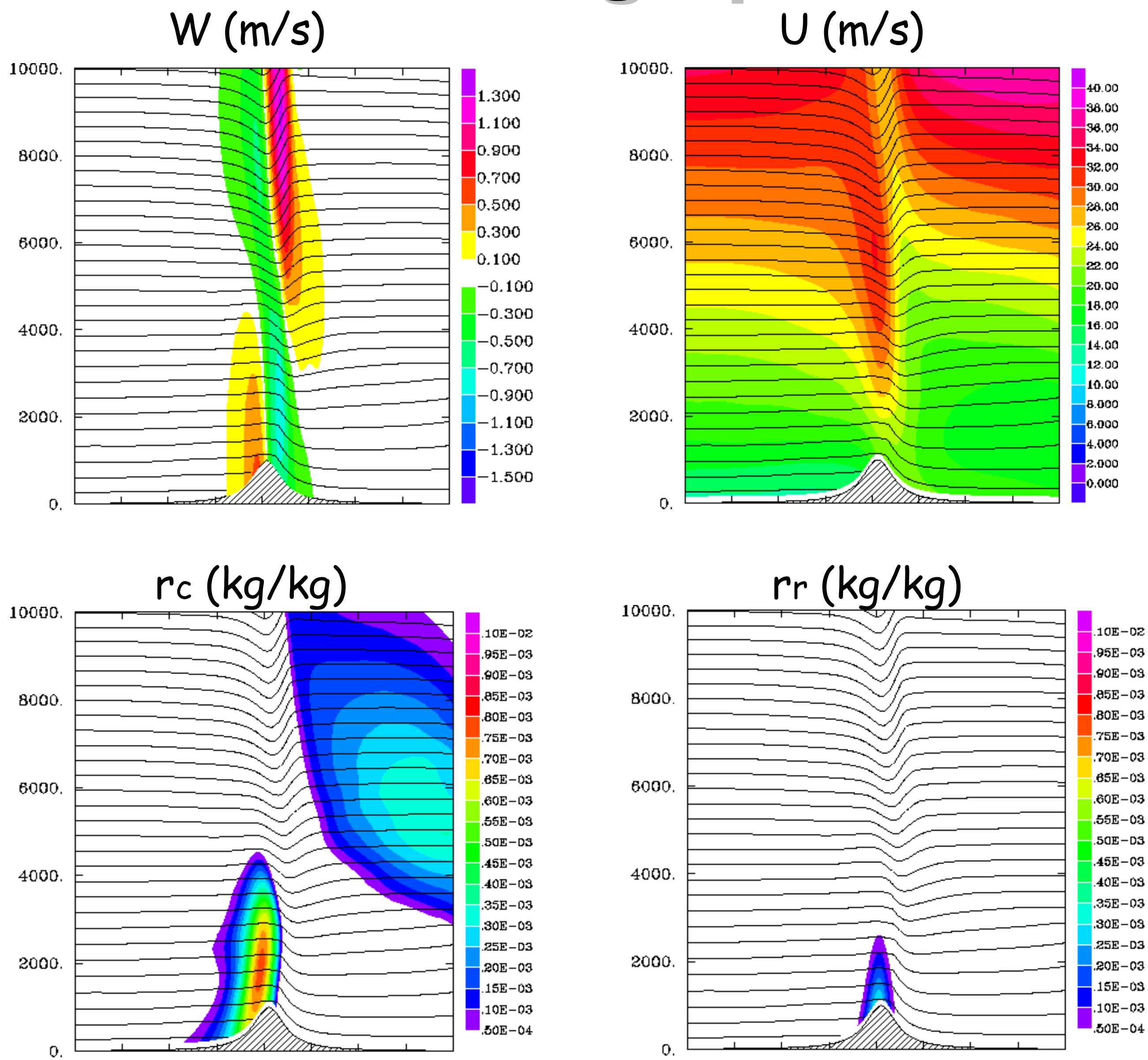


rosette

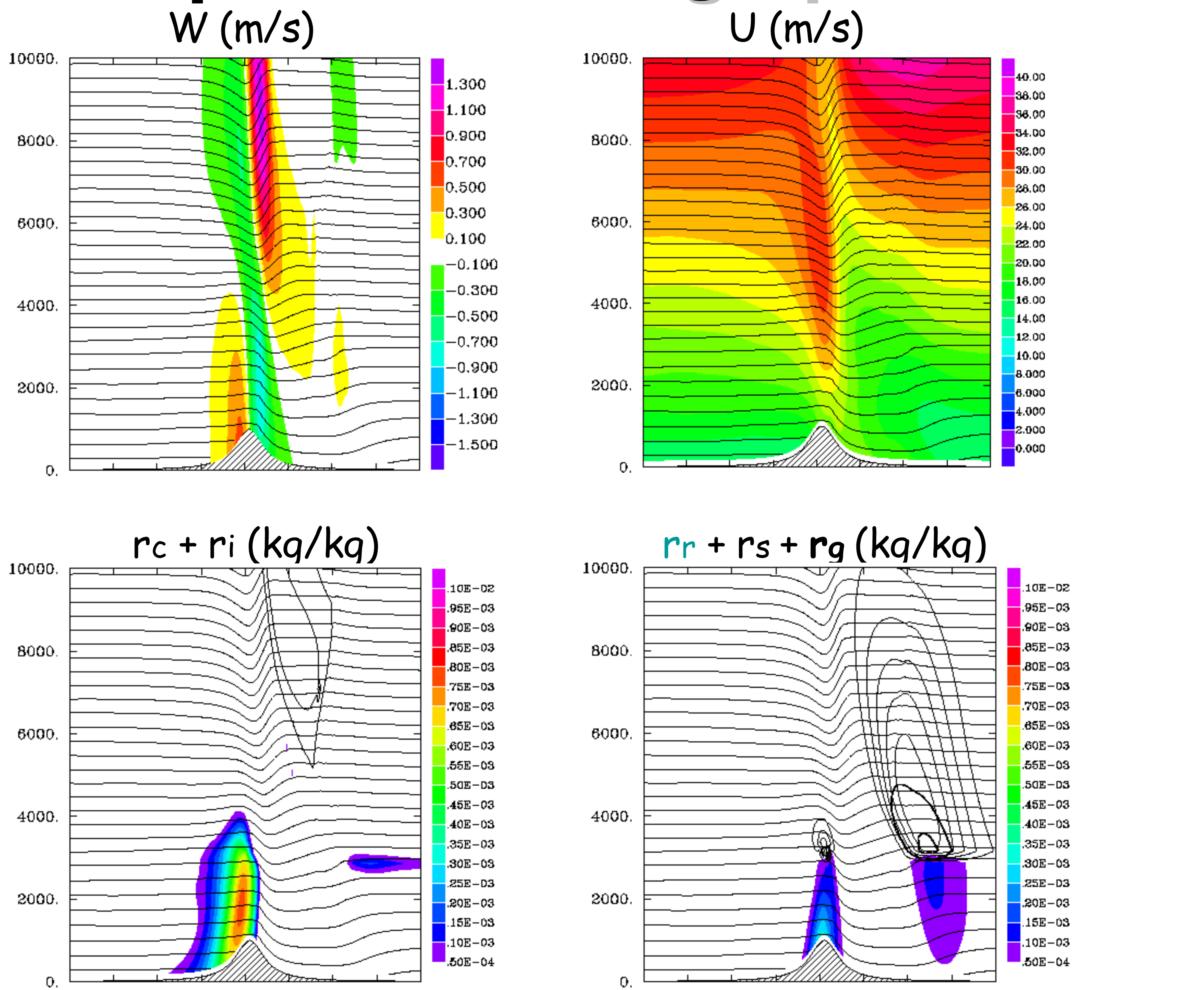


dendrite

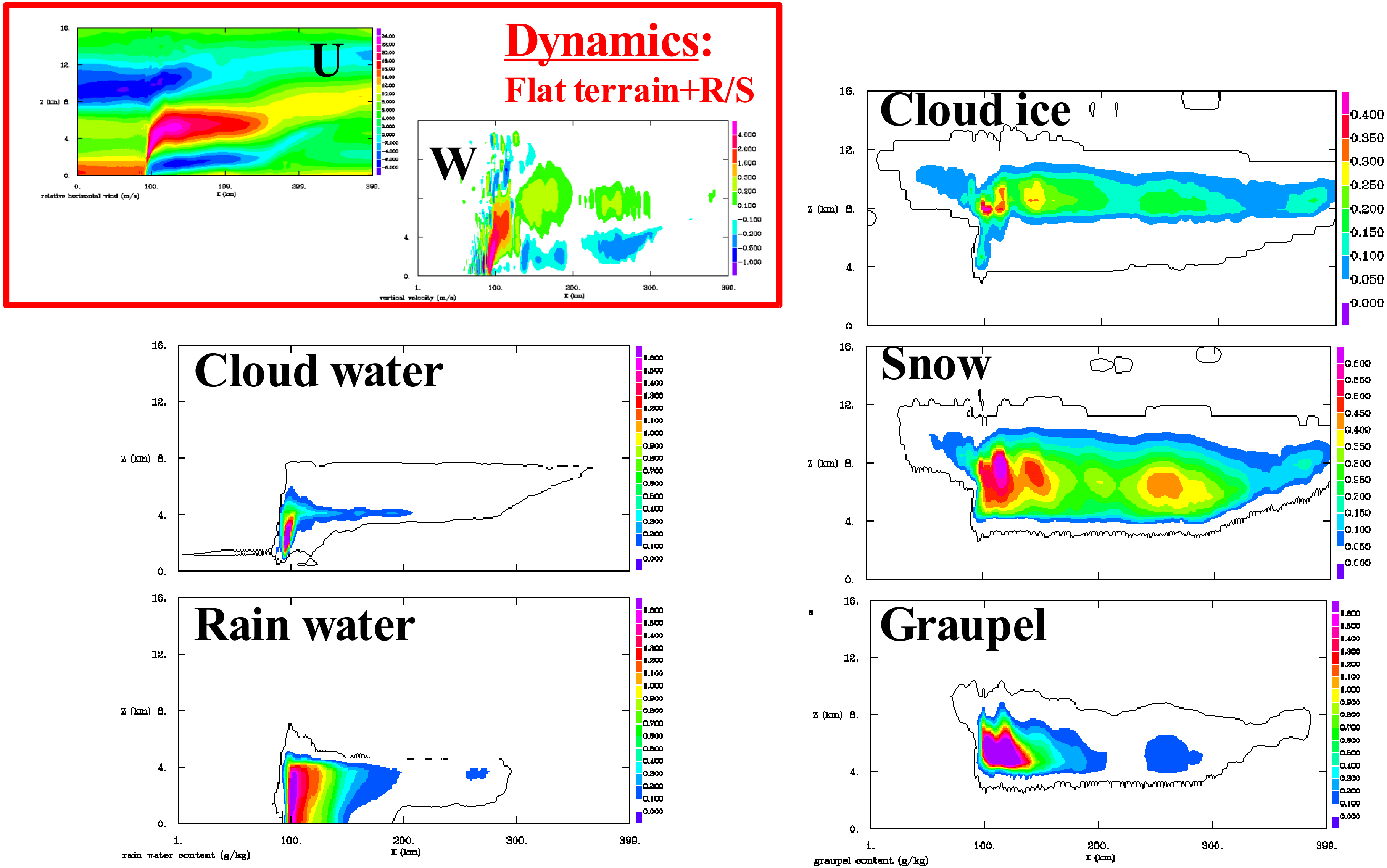
Warm 2D Orographic Cloud



Mixed-phase 2D Orographic Cloud



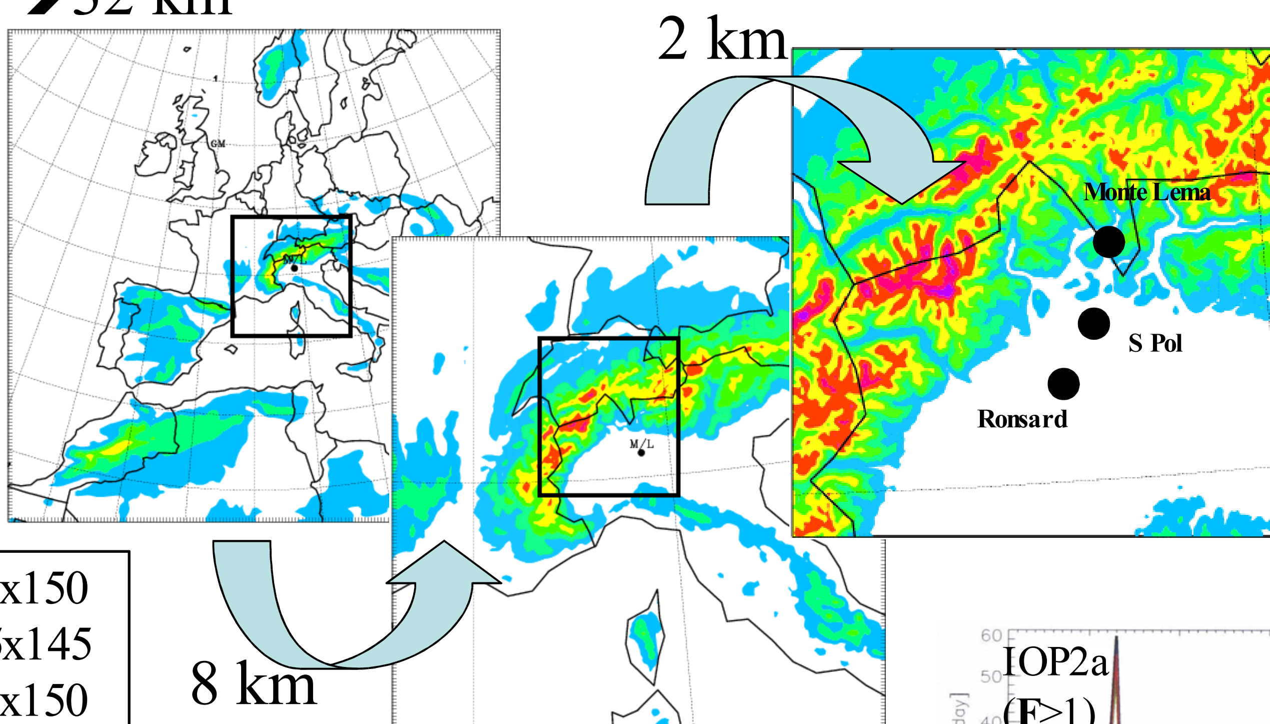
2D Tropical Squall Line



3D Orographic precipitation (MAP)

How does the flow over complex terrain modify the growth mechanisms of precipitation particles?

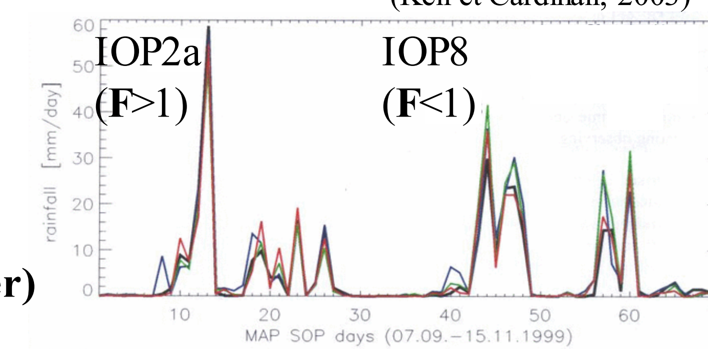
ECMWF→32 km



3 Doppler radars (●)

32km : 150x150
8km : 145x145
2km : 150x150
over 51 levels

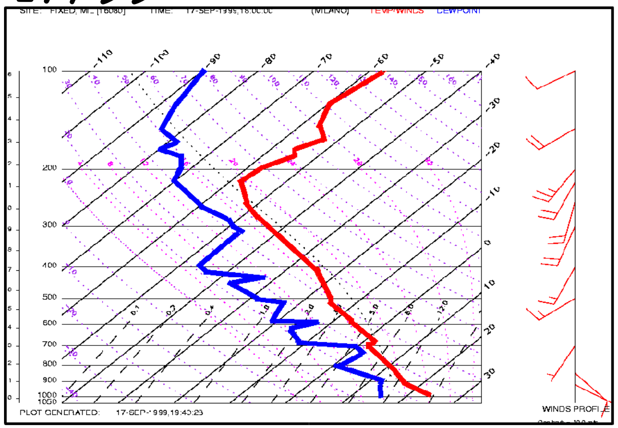
(Keil et Cardinali, 2003)



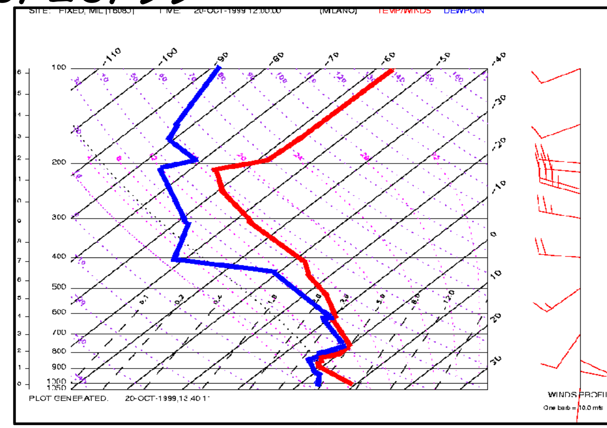
(F: Froude number)

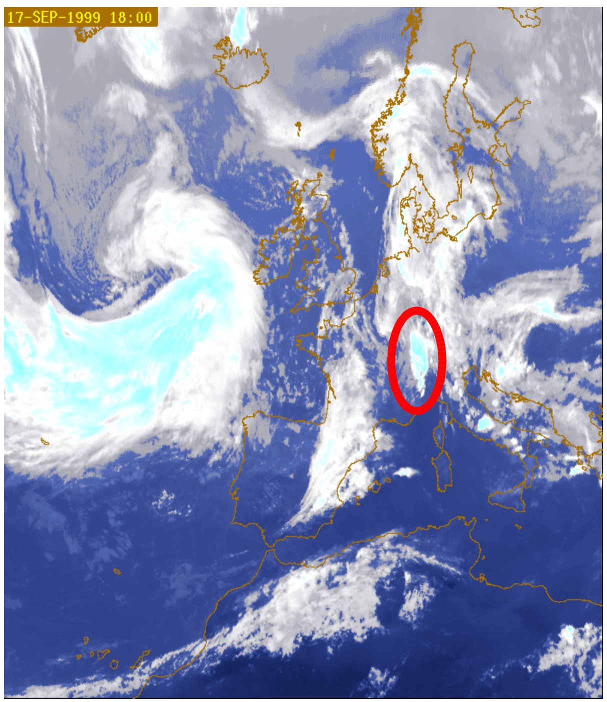
3D Orographic precipitation (MAP)

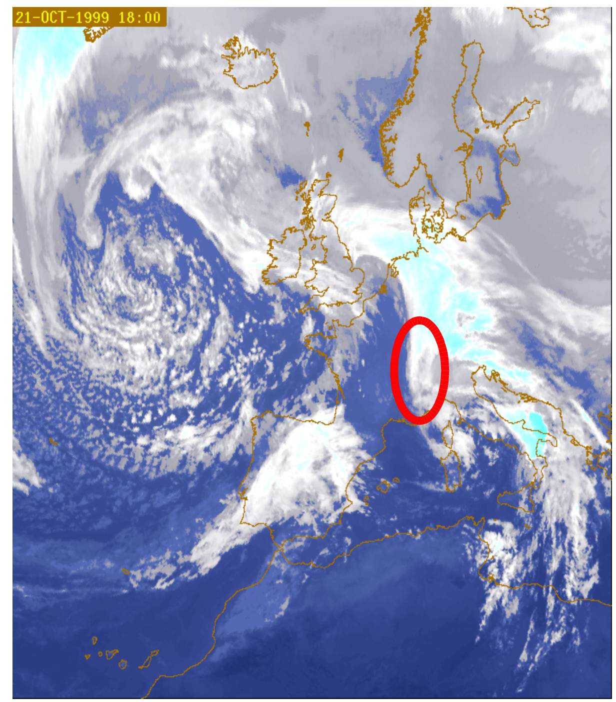
IOP2a: 09/17/99
18 UTC
Unstable
Flow
over



IOP8: 10/20/99
12 UTC
Stable
Blocked
flow

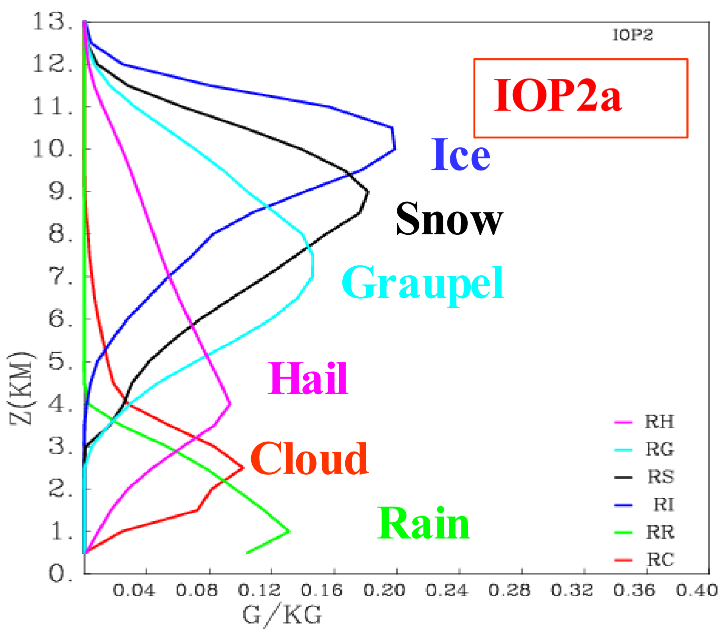


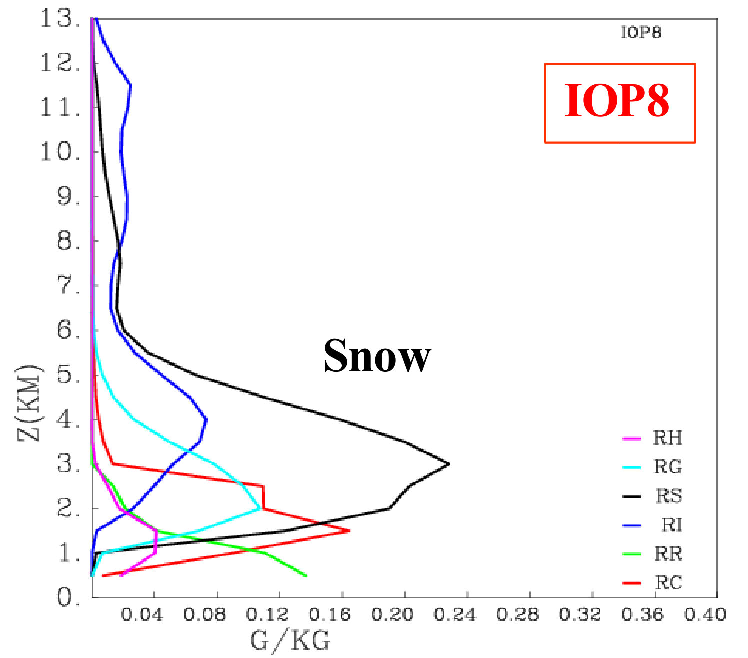




3D Orographic precipitation (MAP)

Mean vertical distribution of the hydrometeors





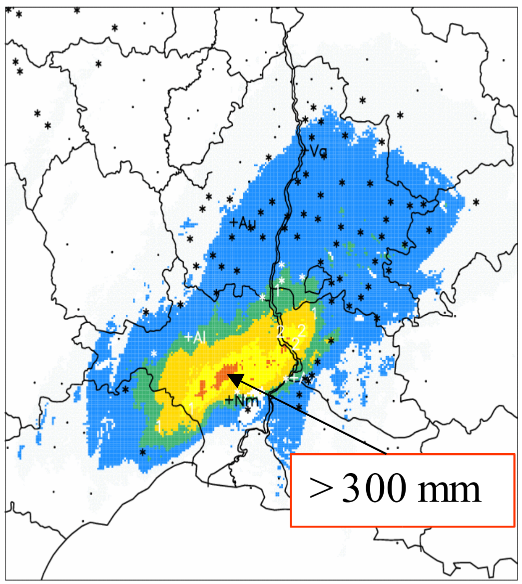
IOP2a (Strong convection)
- Deep system
- Large amount of hail and graupel

IOP8 (Stratiform event)
- Shallow system
- Large amount of snow

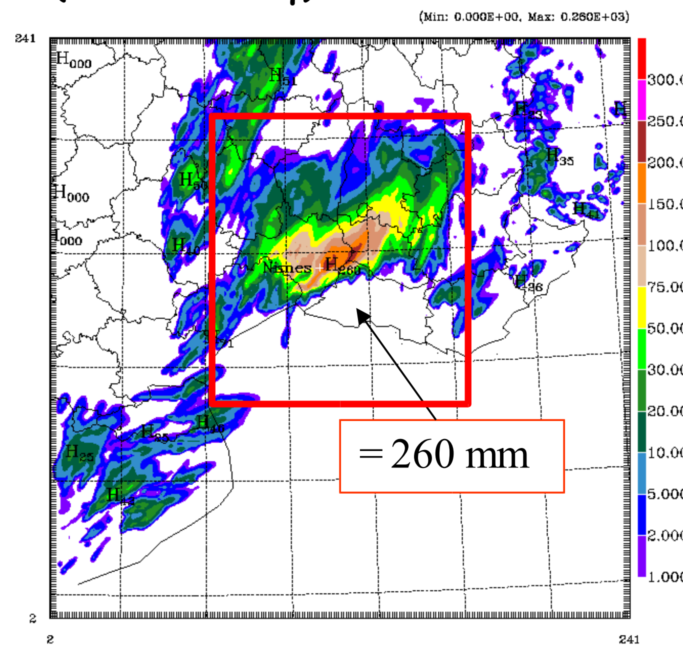
Explained by analysing the dominant microphysical processes

« Gard » flash flood (8 Sept. 2002)

12-22 TU Nîmes radar cumulated rainfall



MesoNH with grid_nesting (V. Ducrocq)



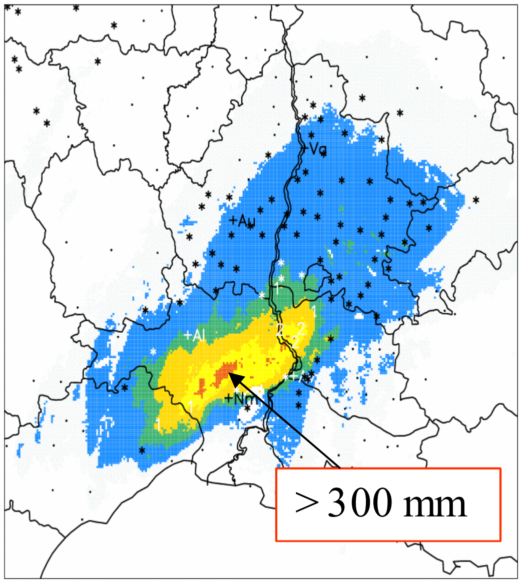
Arpège-> MésoNH 10km -> MésoNH 2.5km

IC : Mesoscale surface data reanalysis

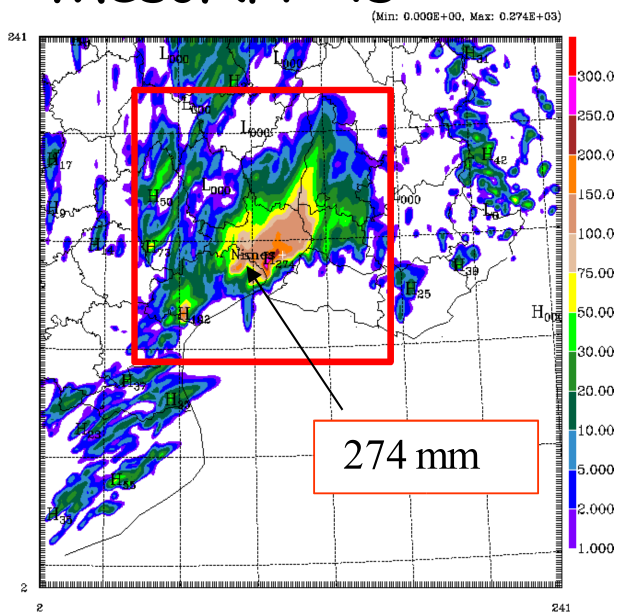
BC : Aladin 3h Forecasts

« Gard » flash flood (8 Sept. 2002)

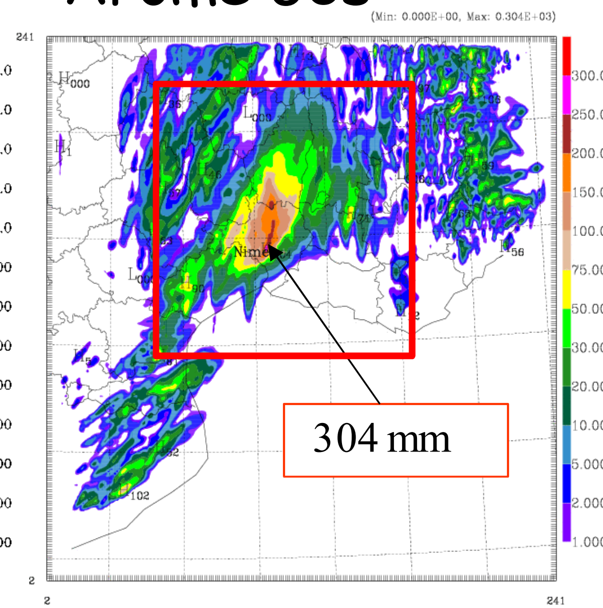
12-22 TU Nîmes radar cumulated rainfall



MésoNH 4s



Arome 60s



Single model 2.5Km

IC : Mesoscale surface data reanalysis

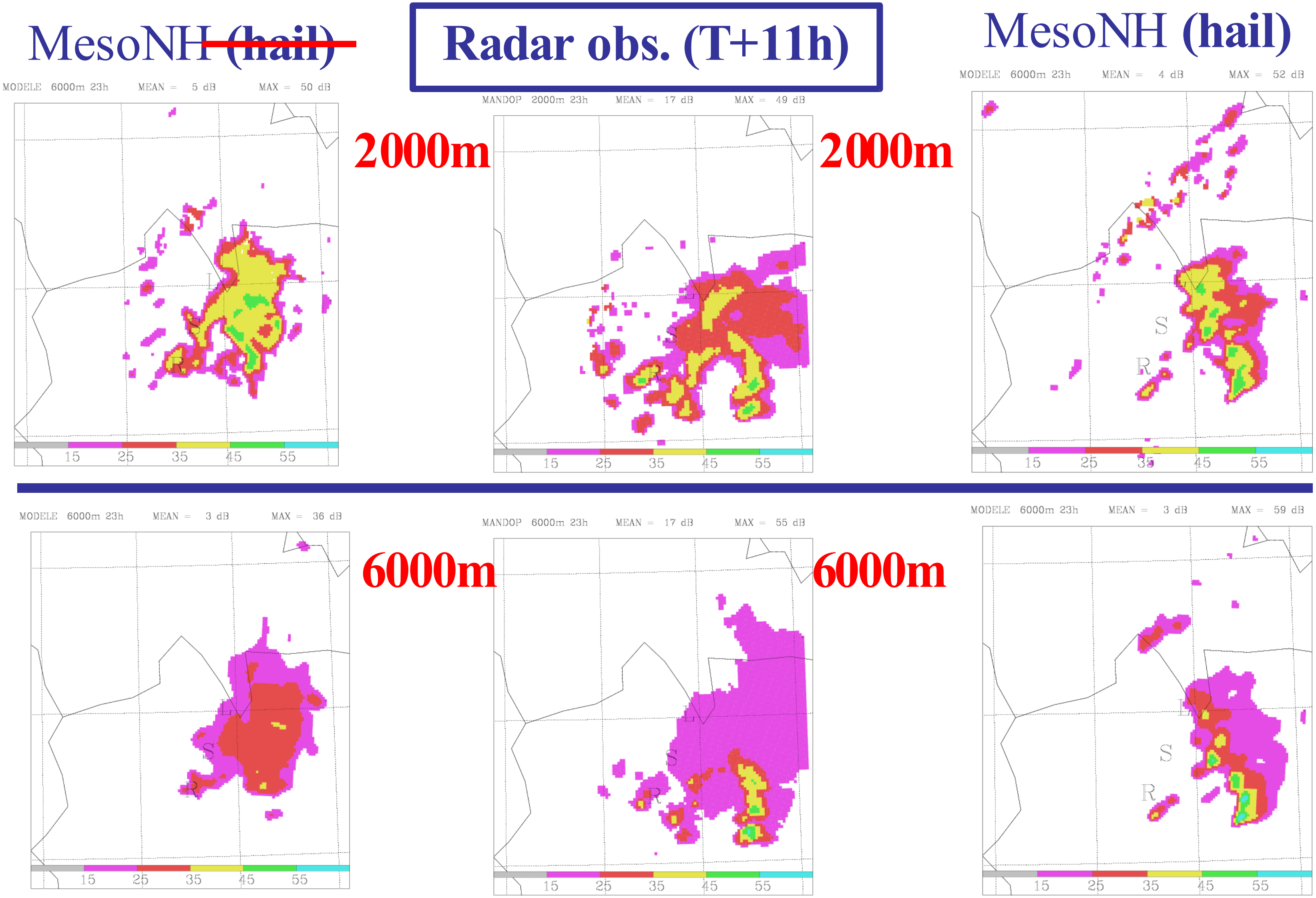
BC : Aladin 3h Forecasts

MésoNH verifying toolbox

- **Simulation of radar observations (Z_e, V_{Dop}, ZDR, …): based on the Rayleigh diffusion approximation $Z \sim ND_e^6$**

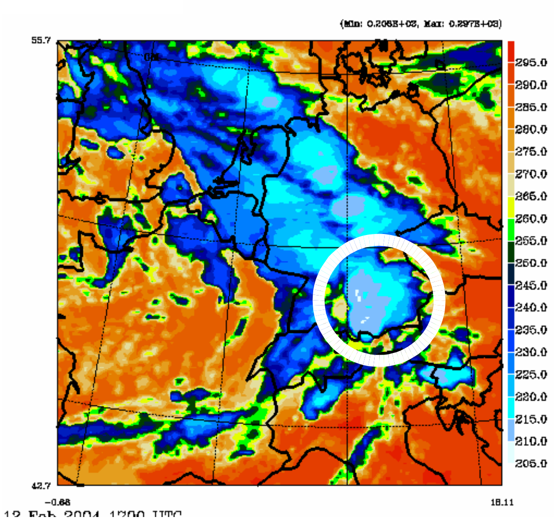
- **Simulation of satellite radiances and BTs (VIS, IR, MW): based on highly accurate radiative transfer scheme coupled to Mie/T-matrix diffusion codes or using a fast algorithm such as RTTOV**

Radar reflectivities (MAP IOP2a 2 km)

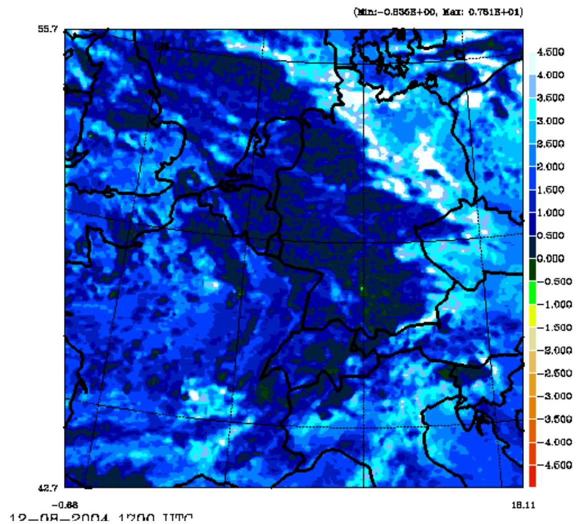


Satellite analysis of storms over Germany

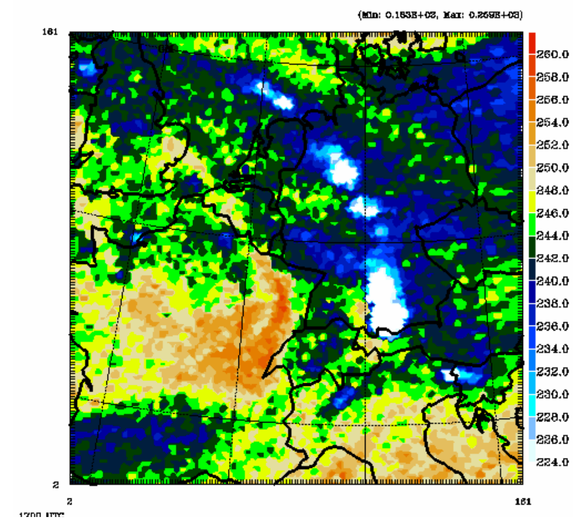
SEVIRI **10.8 µm** BT (MSG)



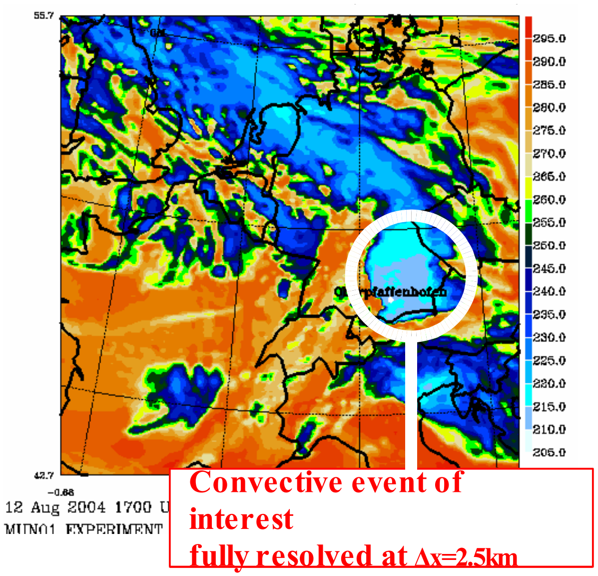
SEVIRI **10.8-12 µm** BT (MSG)

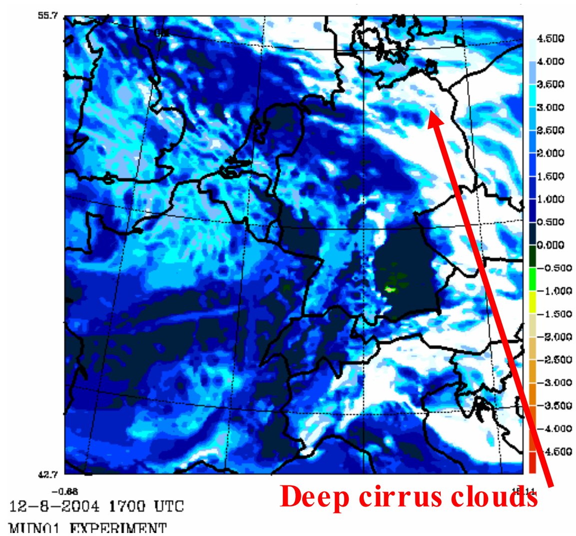


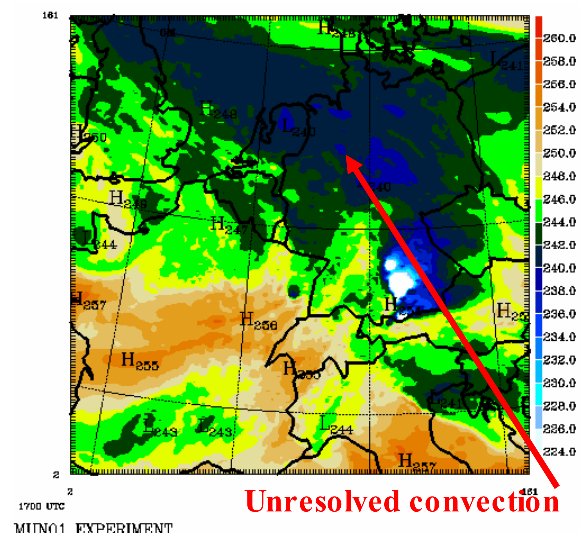
AMSUB **183+/- 1 GHz** (NOAA15)



MesoNH simulation (Δx=10km) with RTTOV results after 17 hours

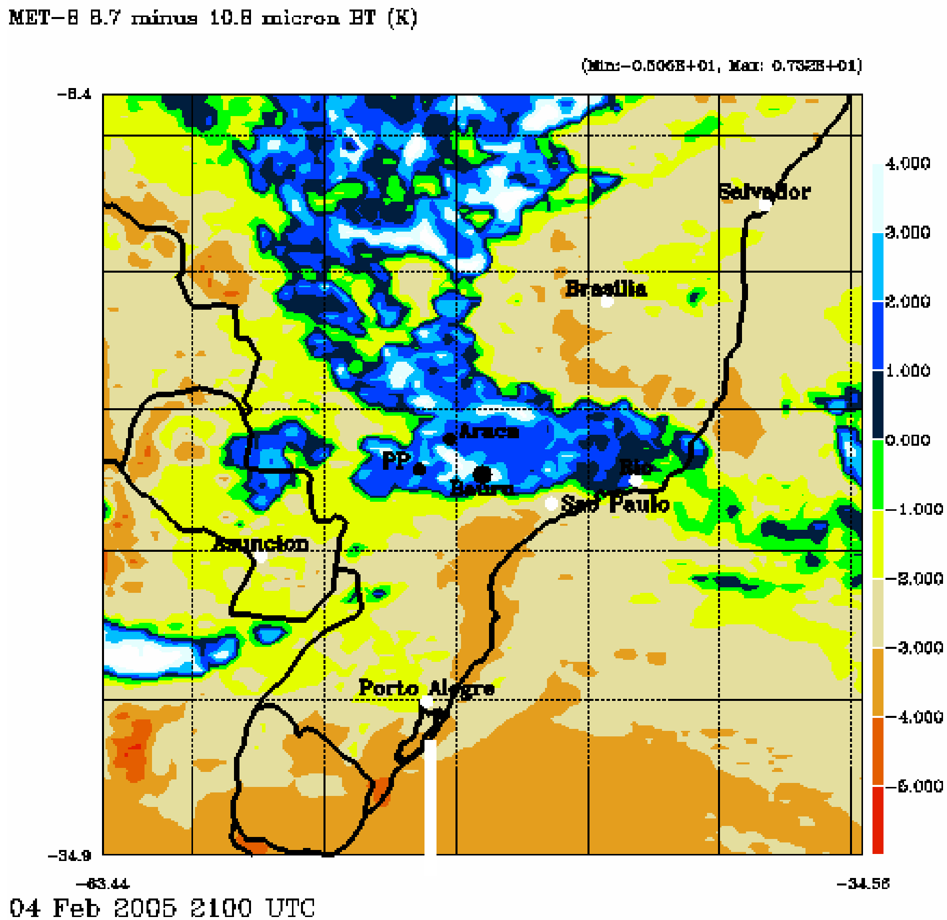




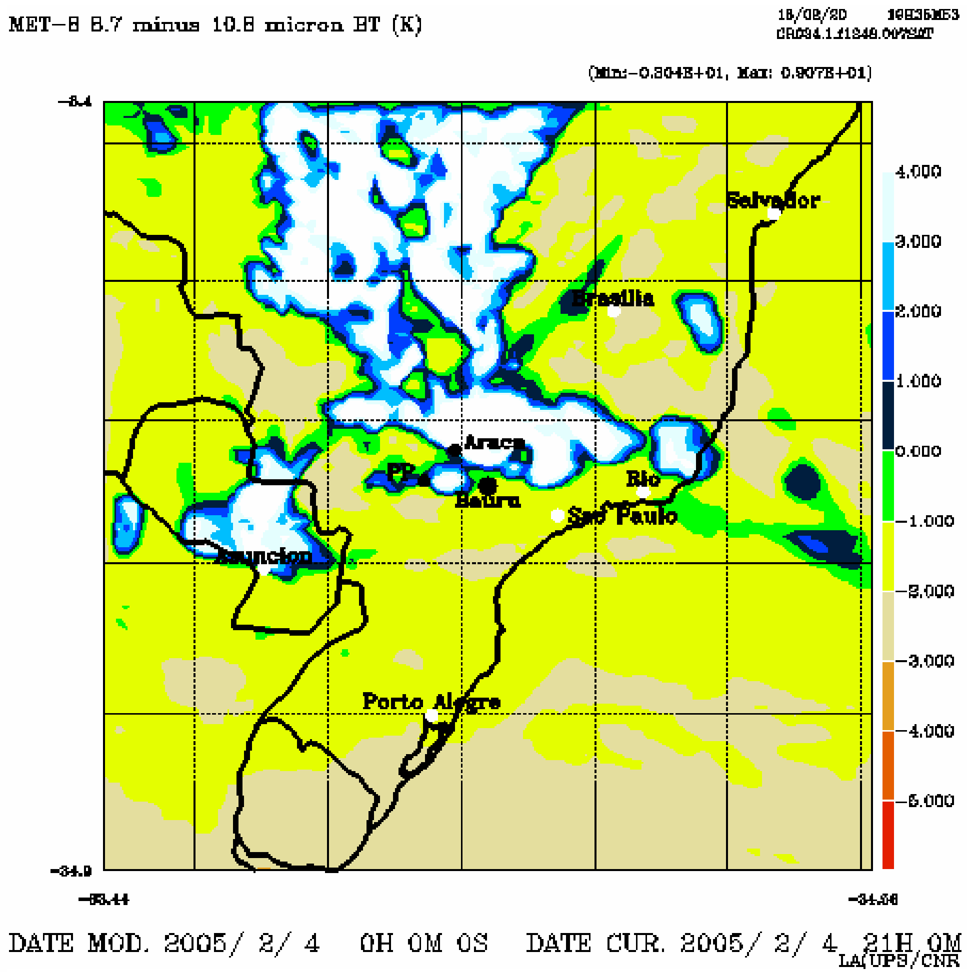


Satellite analysis of cirrus produced by deep convection over Brazil

SEVIRI 8.7-10.8 µm BTD (MSG)



MesoNH simulation (Δx=30 km) with RTTOV results after 21 hours



Conclusion

- The simulation of cloud cover and precipitation fields seems promising at high resolution even without a sophisticated initialization procedure.
- The same scheme has also potential applications in chemistry and atmospheric electricity (not shown here).
- Cloud schemes still need to be improved and tuned for the purpose of operational applications (this should be a new concern of the cloud modeling community!)
- There is a great interest in using routine radar & satellite data to assess the quality of cloud schemes.

Perspectives

- **Fractional cloud cover and subgrid scale precipitation.**
- **Interactions between convection schemes (implicit clouds) and microphysical schemes (explicit clouds) to simulate the lifetime of tropical anvil outflow.**
- **Scale dependence of microphysical schemes.**
- **Computation of various ground radar and satellite products for a multispectral and active/passive evaluation of the microphysical scheme.**