Warm microphysical schemes available in MésoNH

Jean-Pierre Pinty, Evelyne Richard
Laboratoire d’Aérologie, Toulouse

Olivier Geoffroy, Christine Lac
Météo-France, Toulouse

NorFam Meeting, Toulouse, March, 2007

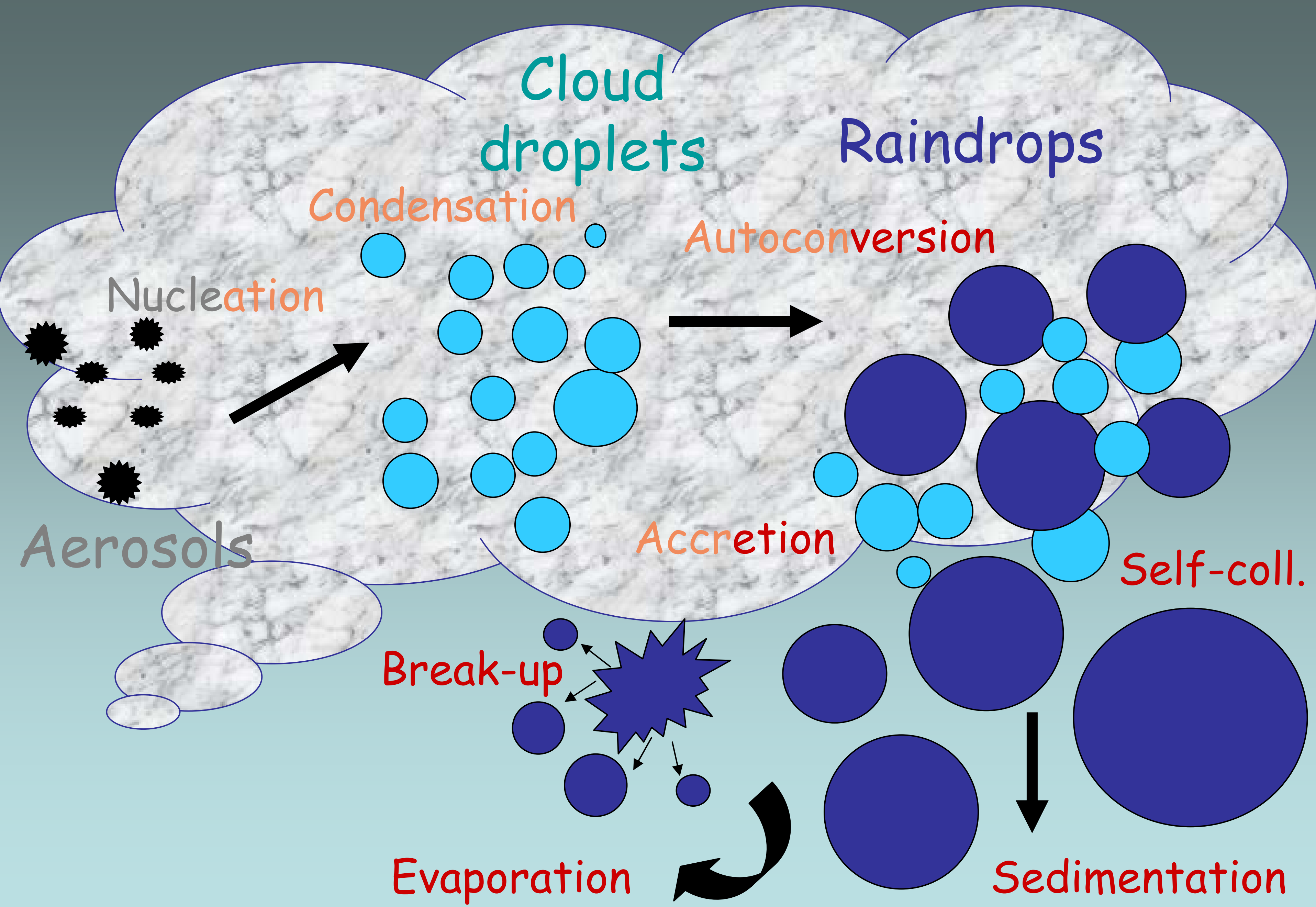
« Warm » microphysics ?

- **Key-processes to follow the evolution of the cloud and rain mixing ratios (kg of water/kg of dry air)**

- **2-moment schemes can also predict the cloud and the rain number concentrations (link with CCN)**

- **Bulk** *versus* **Spectral (bin) microphysics (50<bins<100)**

- **Current assumptions in the schemes:**
  - **spherical drop-droplets of size D ($m=aD^3$),**
  - **fall speed $V(D)=cD^d\,(\rho_{00}/\rho)^{0.4}$,**
  - **exponential, lognormal or gamma size-distributions n(D) (bulk schemes)**



Cloud droplets

Raindrops

Condensation

Autoconversion

Nucleation

Aerosols

Accretion

Self-coll.

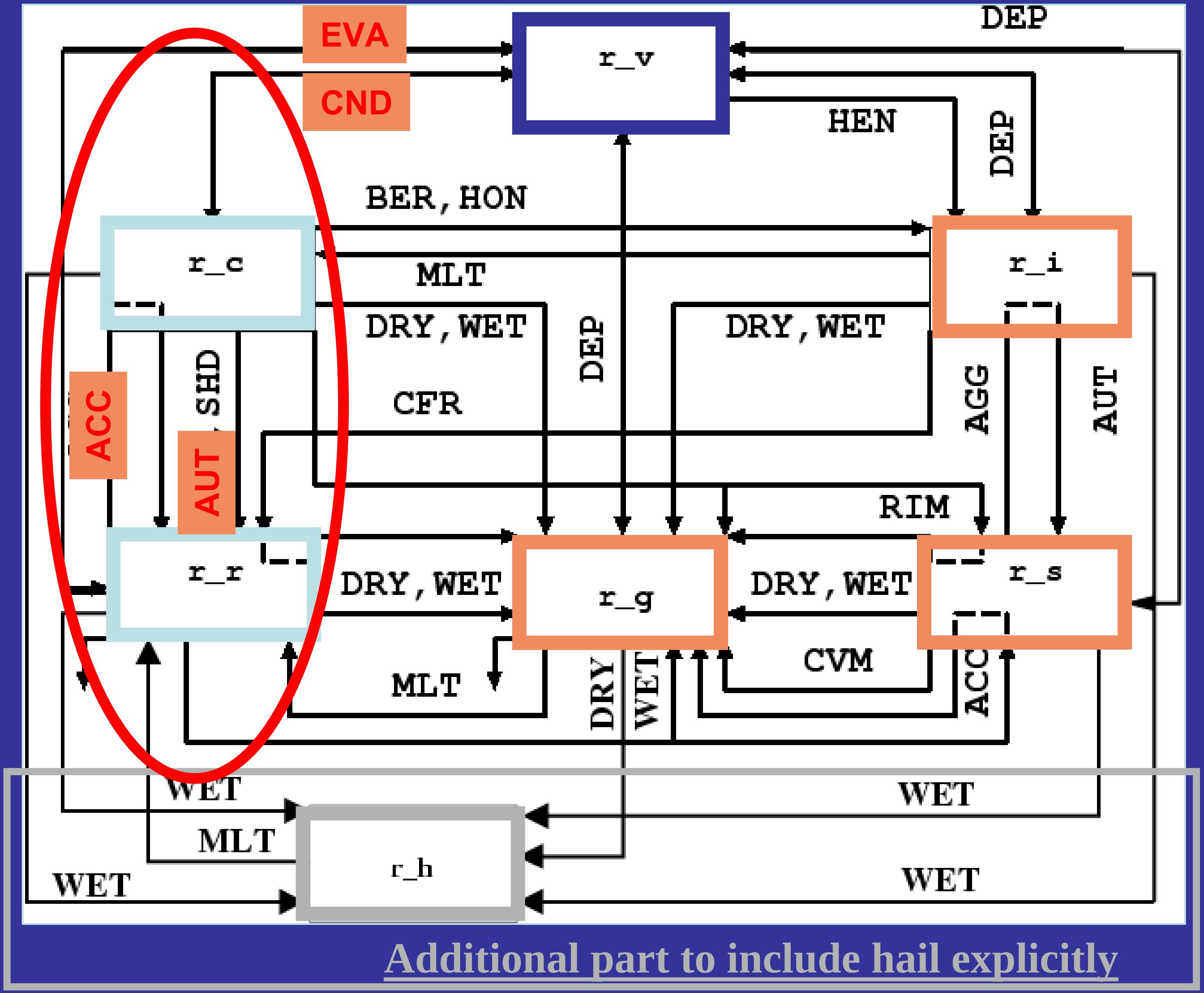
Break-up

Evaporation

Sedimentation

Microphysical Scheme diagram

Corresponds to a reduced set of a full mixed-phase microphysical scheme !



Additional part to include hail explicitly

3 bulk schemes are available

- The “**Kessler**” scheme (Kessler, 1969) is the simplest scheme used to simulate warm rain precipitation events {r_cloud, r_rain}

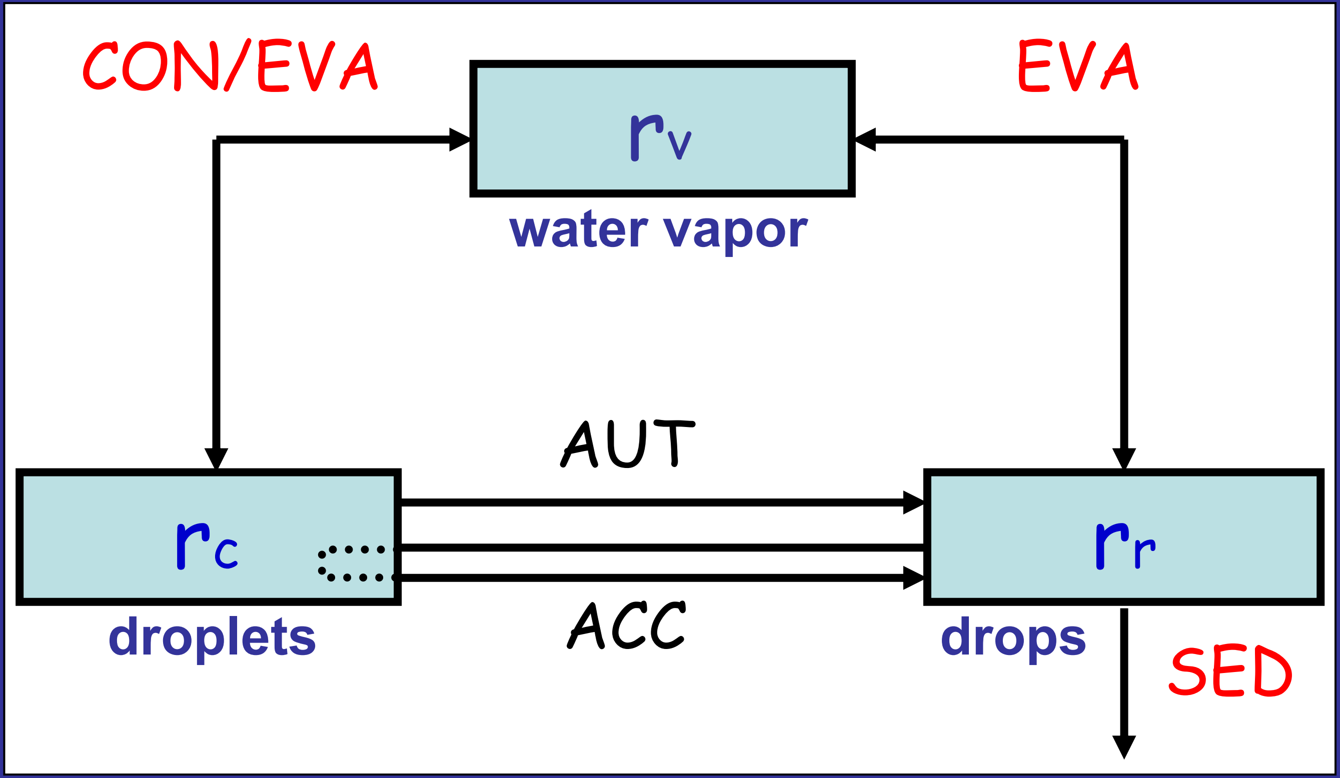
- The “**C2R2**” 2-moment scheme (Cohard & Pinty, 2000) includes the evolution of the droplet/drop concentrations {N_cloud, N_rain}

- The “**KHKO**” scheme is an adaptation of (Khairoutdinov & Kogan, 2000). It is a parametric scheme to simulate the drizzle

No spectral scheme yet !

Some merits of the Kessler scheme

- **Simplicity (5 processes)**



- **CON/EVA adjustment to saturation with conservation of $h=C_pT+Lq_{vs}(T)$**
- **EVA explicit drop evaporation rate**
- **SED explicit differentiation of sedimentation fluxes**

Autoconversion in Kessler scheme

- **Autoconversion: cloud droplets → rain drops**

$$(\partial \rho_a r_r / \partial t)_{AUT} = K \, Max(0, \rho_a r_c - \rho_a \tilde{r}_c)$$

with

$$K = 10^{-3} s^{-1}$$

$$\rho_a \tilde{r}_c = 0.5 g/m^3$$

- **Many variants: Manton and Cotton (1977) or Liu and Daum (2006) could be used to relate the two adjusted parameters to the droplet spectra**

Accretion in Kessler scheme

- **Accretion: raindrop+cloud droplets → bigger raindrop**

$$(\partial \rho_a r_r / \partial t)_{ACC} = \int_0^\infty r_c \left(\frac{\pi}{4} D^2 V(D) \right) E\, n_r(D)\, dD$$

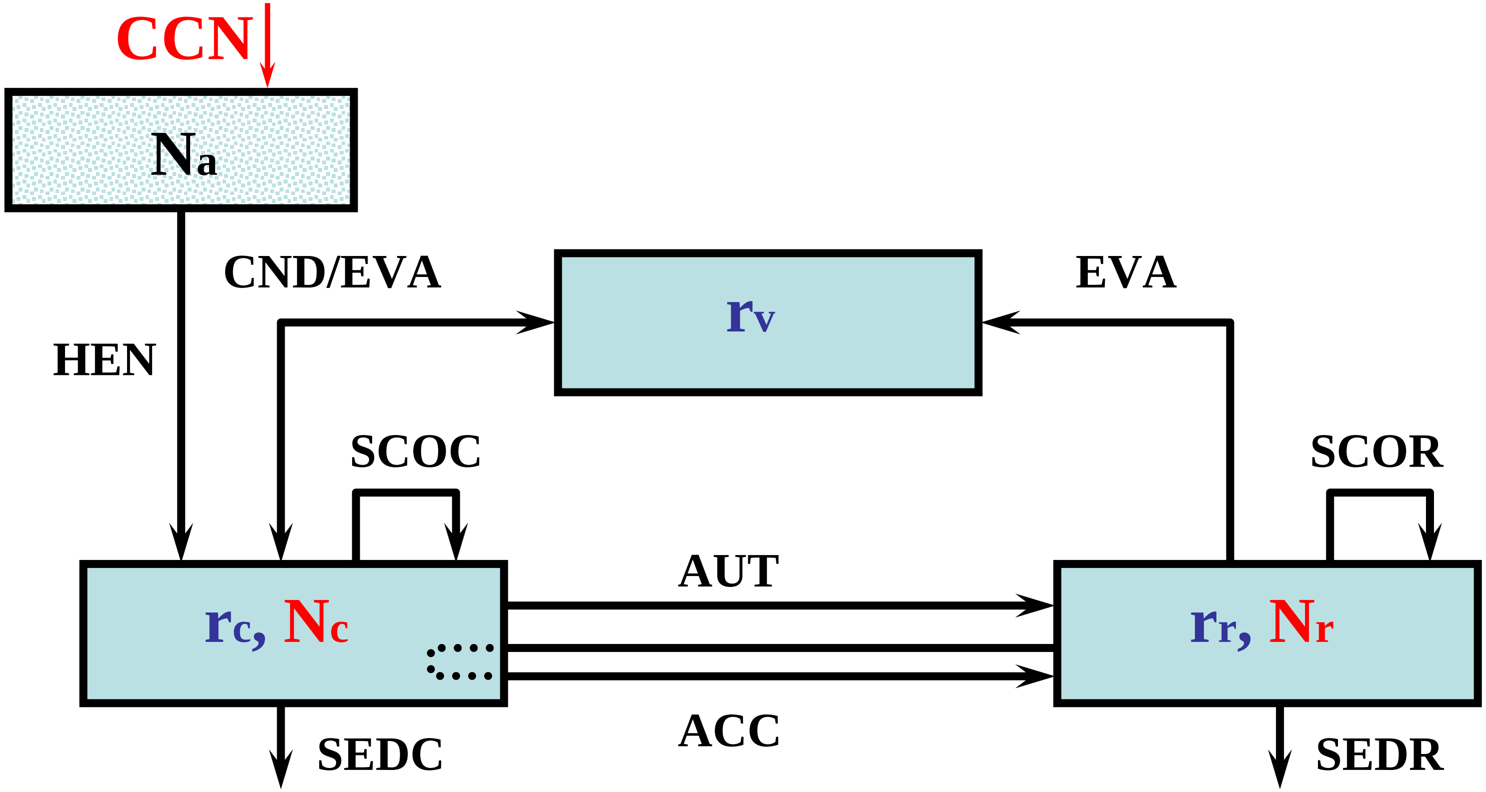
$$\text{with}$$
$$E = 1$$

- **Exact integration for a given n_r(D) size distribution but uncertainties about the value of the mean collection efficiency E**

The 2-moment C2R2 scheme

Generalized gamma size distribution law

$$\begin{cases} n(D) = N \dfrac{\alpha}{\Gamma(\nu)} \lambda^{\alpha\nu} D^{\alpha\nu-1} \exp\left(-(\lambda D)^{\alpha}\right) \\ \alpha, \nu \ \textbf{are free parameters} \end{cases}$$



Nucleation in C2R2 scheme

Theory of Twomey

- **Activation spectrum** :

$$N_{CCN}\left(s_{v,w}\right) = \int_0^{s_{v,w}} n(s)\,ds$$

- **Sursaturation** :

$$\frac{ds_{v,w}}{dt} = \psi_1(T,P)w - \psi_2(T,P)\frac{dr_c}{dt}$$

- **Diffusion growth** (Köhler) :

$$D\frac{dD}{dt} = 4G(D,T,P)\left(s_{v,w} - y(D,T)\right)$$

After combination → $s_{v,wMAX}$

$$\psi_1(T,P)w \approx \psi_2(T,P)\frac{dr_c}{dt}$$ **and**

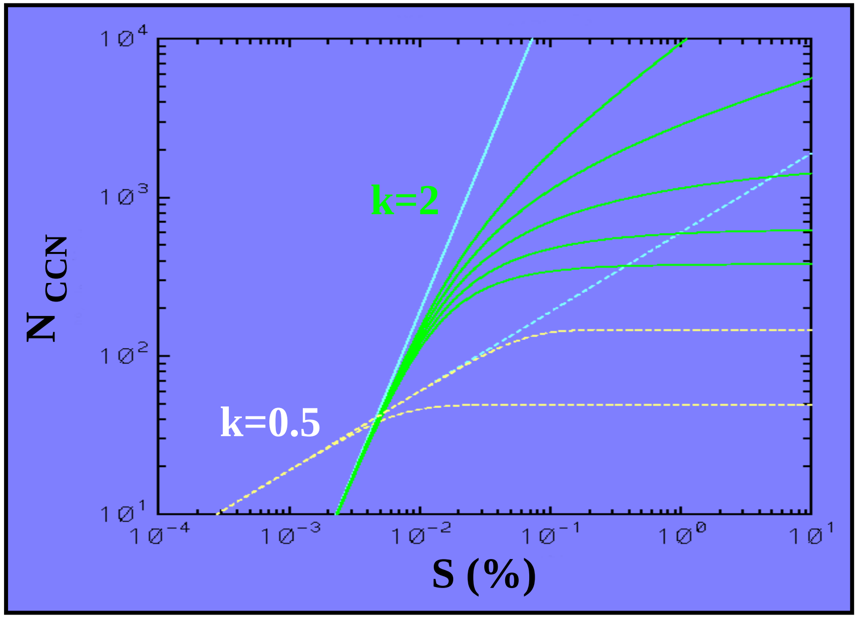
$$\frac{dr_c}{dt} \approx \psi_3(D,T,P)\int_0^{s_{v,wMAX}} n(s')\left(s^2_{v,wMAX} - s'^2\right)^{1/2} ds'$$

→ Number of activated CCN

Twomey (1959) : $N_{CCN} = Cs^k_{v,wMAX}$

Cohard *et al.* (1998) :

$$N_{CCN} = Cs^k_{v,wMAX}\, F\left(\mu, \frac{k}{2}, \frac{k}{2}+1, -\beta s^2_{v,wMAX}\right)$$



… calibration of N_{CCN} from aerosols

Autoconversion in C2R2 scheme

- **Initiation regime**: w/o raindrops

  Berry and Reinhardt (1974) parameterization
  recently reviewed by Gilmore and al. (2007)

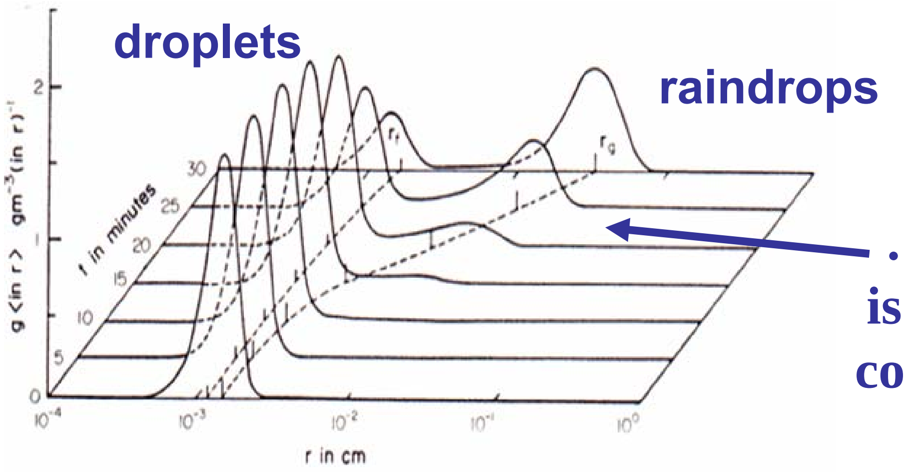
$$\begin{cases} \left(\frac{\partial r_r}{\partial t}\right)_{AUT} = -\left(\frac{\partial r_c}{\partial t}\right)_{AUT} = \frac{L}{\rho_a \tau} \\ \left(\frac{\partial N_r}{\partial t}\right)_{AUT} = -3.5\times10^9 \frac{\rho_a L}{\tau} \end{cases}$$

τ : time needed to initiate the rain spectrum $\tau = \frac{1}{\rho_a r_c}(0.5\times10^6\sigma_c - 7.5)^{-1}$

L : rainwater content at τ $L = 2.7\times10^{-2}\rho_a r_c (1/16\times10^{20}\sigma_c^3 D_c - 0.4)$

- **Feeding regime**: with raindrops

$$\left(\frac{\partial N_r}{\partial t}\right)_{AUT} = \frac{N_r}{r_r}\left(\frac{\partial r_r}{\partial t}\right)_{AUT}$$



… autoconversion is mixed with other collection processes !

Collection in C2R2 scheme

Analytical solution of the Stochastic Coalescence Equation (SCE)

$$\frac{dn(x,t)}{dt} = 0.5\int_0^x K(y,x-y)n(y,t)n(x-y,t)dy - n(x,t)\int_0^\infty K(y,x)n(y,t)dy$$

with $n(x) = n_c(x) + n_r(x)$ and $K(x,y)$: polynomial kernels of Long

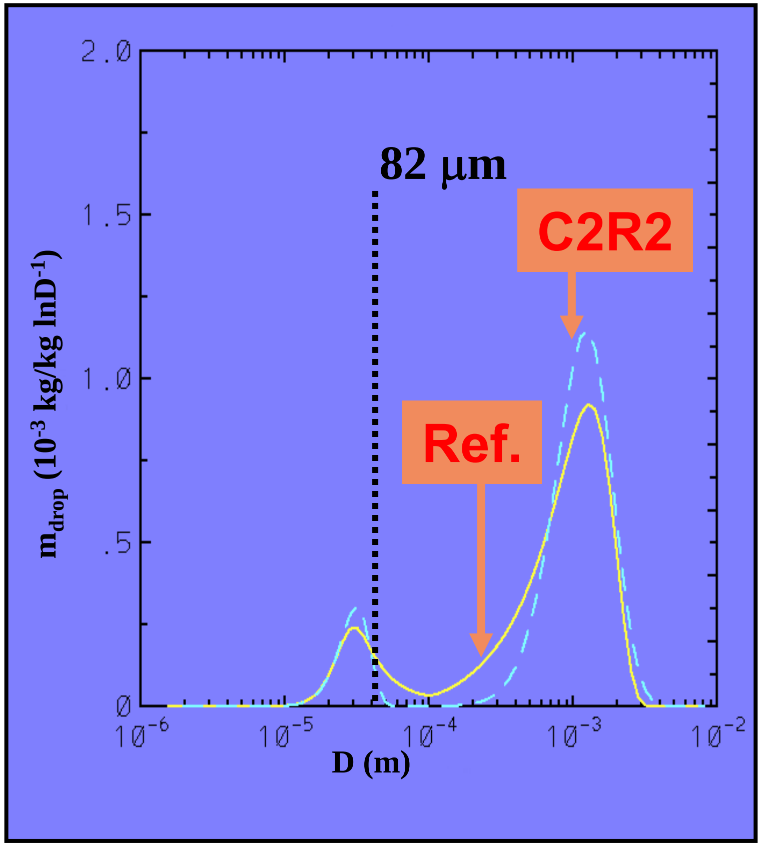
$$\frac{dn(x,t)}{dt} = SCE(n_c) + SCE(n_r) + \int_0^x K(y,x-y)n_c(y,t)n_r(x-y,t)dy$$

$$-n_r(x,t)\int_0^\infty K(y,x)n_c(y,t)dy - n_c(x,t)\int_0^\infty K(y,x)n_r(y,t)dy$$

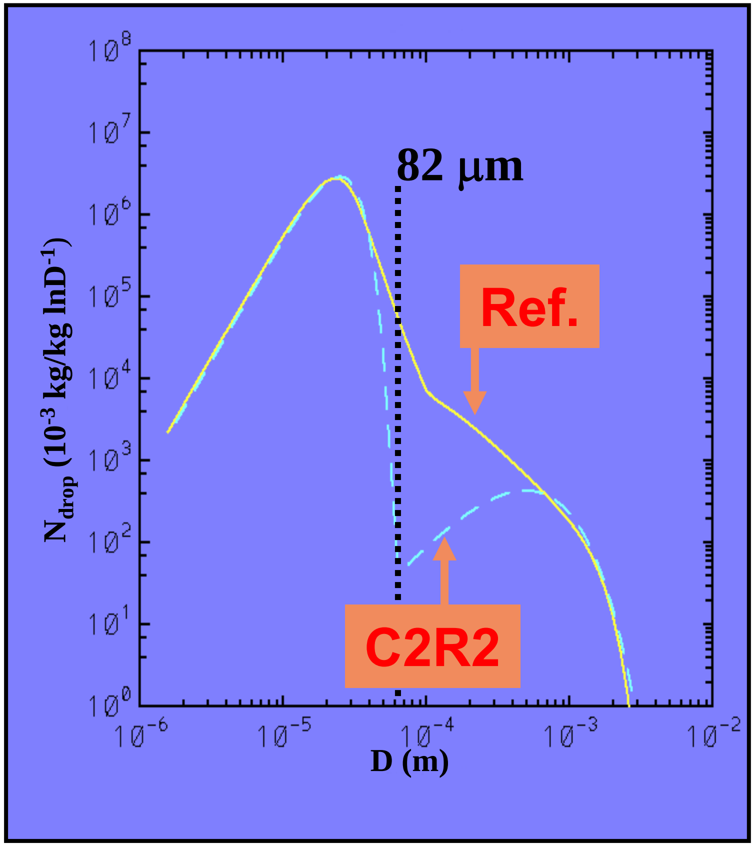
$$= \underbrace{SCOC(n_c) + SCOR(n_r)}_{\textbf{Self-Collection}} + \underbrace{ACC(n_r) + ACC(n_c)}_{\textbf{Accretion}}$$

C2R2 versus spectral scheme

Mass size-distributions



Number size-distributions



… an acceptable agreement !

The parametric KHKO-like scheme

Similar to C2R2 scheme but adapted to the drizzle

Autoconversion

$$\left(\frac{\partial r_r}{\partial t}\right)_{AUT} = 1350\, r_c^{\boxed{2,47}} N_c^{\boxed{-1,79}}$$

$$\left(\frac{\partial N_r}{\partial t}\right)_{AUT} = \left(\frac{\partial r_r}{\partial t}\right)_{AUT} \Big/ \frac{4\pi\rho_w}{3\rho_a} r_0^3$$

$$with \quad r_0 = 25 \quad \mu m$$

Ajustment from LES and spectral microphysics

No threshold of the mixing ratio =/= Kessler and C2R2 schemes !!!

The parametric KHKO-like scheme

Similar to C2R2 scheme but adapted to the drizzle

Accretion

$$(\frac{\partial r_r}{\partial t})_{ACC} = 67(r_c r_r)^{1,15}$$

$$(\frac{\partial N_r}{\partial t})_{ACC} = \frac{N_c}{r_c}\left((\frac{\partial r_r}{\partial t})_{ACC} + (\frac{\partial r_r}{\partial t})_{AUT} \right)$$

Ajustment from LES and spectral microphysics

Sedimentation

Fallspeeds of r_r *and* N_r *are ajusted*

In conclusion …

- **Bulk microphysical schemes can be used to simulate rainfall and drizzle but C2R2 and KHKO schemes are more suitable for BL clouds**

- **Autoconversion is a key-process to initiate a rain spectrum from cloud droplets (particularly important for BL clouds)**

- **Microphysics needs a detailed description of BL cloud spectra (mixing ratio AND number concentration) ➔ importance of CCN nucleation treatment to simulate the CCN spectra variability**

- **Strong impact on radiative transfer (SW and LW)**