Cumulus Parameterization in the Context of Turbulence Studies

Physical Processes & Issues
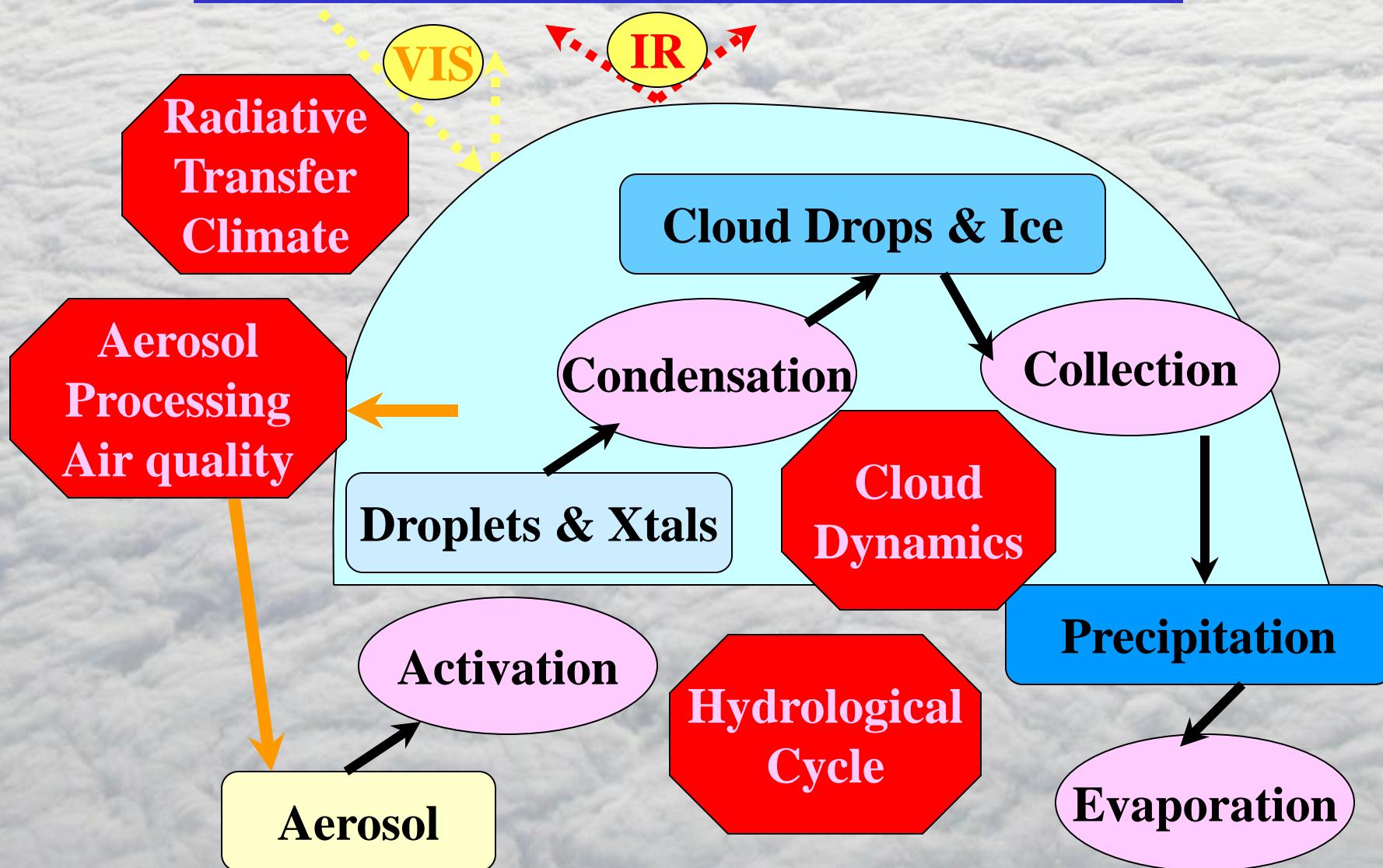
VIS IR

Radiative Transfer Climate

Aerosol Processing Air quality

Cloud Drops & Ice

Condensation

Collection

Droplets & Xtals

Cloud Dynamics

Activation

Hydrological Cycle

Precipitation

Aerosol

Evaporation

Issues

Hydrological Cycle

- Turbulence and the onset of precipitation
- Cloud Microphysics/Dynamics Feed-back
- Impact of Aerosol on Precipitation Efficiency (☹)

Issues

Hydrological Cycle

• Turbulence and the onset of precipitation

• Cloud Microphysics/Dynamics Feed-back

• Impact of Aerosol on Precipitation Efficiency (☹)

Climate Studies

• Cloud Radiative forcing (Nr_v^3, Nr_s^2)

• Aerosol 1st Indirect Effect (Aerosol Activation & Cloud/Radiation)

• Aerosol 2nd Indirect Effect (Cloud Life Time)

Issues

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Environment & Air Quality

• Gas/Aerosol Interactions

• Aerosol Processing in Clouds

Parameterization of the Microphysics

Bulk thermodynamics : $q_c = q_t - q_{vs}(T)$

+0

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Bulk microphysics :   liquid precipitating q_c , q_r **+1**

q_c , q_r , N_c **+2**

q_c , q_r , N_c , N_r **+3**

mixed phase q_c , q_r , N_c , N_r , q_i , q_s , q_g , …   **+4~10**

Parameterization of the Microphysics

Bulk thermodynamics :	$q_c = q_t - q_{vs}(T)$		**+0**
Bulk microphysics :	liquid precipitating	q_c , q_r	**+1**
		q_c , q_r , N_c	**+2**
		q_c , q_r , N_c , N_r	**+3**
	mixed phase	$q_c , q_r , N_c , N_r , q_i , q_s , q_g , \ldots$	**+4~10**
Spectral microphysics :	liquid precipitating	$f_c(r)dr , f_r(r)dr$	**+2p**
	mixed phase	$f_x(r)dr$	**+4p ~ 10p**

Parameterization of the Microphysics

Bulk thermodynamics : $q_c = q_t - q_{vs}(T)$ **+0**

Bulk microphysics :   liquid precipitating q_c , q_r **+1**

                                                                q_c , q_r , N_c **+2**

                                                                q_c , q_r , N_c , N_r **+3**

              mixed phase q_c , q_r , N_c , N_r , q_i , q_s , q_g , …   **+4~10**

Spectral microphysics :   liquid precipitating $f_c(r)dr$, $f_r(r)dr$

                            mixed phase $f_x(r)dr$

Spectral microphysics + aerosol q_c , N_c , m_a **+2**

                                                        q_c , N_c , m_a , N_a **+3**

        diverse composition q_c , N_c , $m_{a,x}$, $N_{a,x}$ **+1+2q**

        diverse mixing states q_c , N_c , $m_{a,x,y}$, $N_{a,x,y}$ **+1+2ql**

Spectral coupled aerosol/droplet $f(m_a,r_d)dm_a,dr_d$ **+pql**

Parameterization of the Microphysics

For the most complete description of cloud microphysics, we should describe each aerosol & cloud particle, its location, velocity, temperature, chemical composition, surface properties, hygroscopic and optical properties, amount of water, its shape, complete address, bank account and social security number.

Sometimes, simplifications are welcome.

Question 1: which level of simplification ?
        Consistency with the whole model!
Question 2: is it that the physical process is not understood,
        even with the most detailed model ? or only
        a matter of simplifying the detailed model ?

Cumulus Parameterization in the Context of Turbulence Studies

Hydrological Cycle , Climate Studies , Environment

Hydrological Cycle
• Turbulence and the onset of precipitation

Small cumuli are precipitating faster than predicted !

Diffusional growth by vapour diffusion on a population of droplets randomly distributed in space is too slow for producing the few big droplets that will act as precipitation embryo !

Droplets are not randomly distributed in space (turbulent microstructure), some isolated priviledged droplets are lucky and grow more than droplets in crowded cloud suburbs !

Social science in cloud microphysics

Hydrological Cycle , Climate Studies , Environment

Droplets are not randomly distributed in space (turbulent microstructure), some isolated priviledged droplets are lucky and grow more than droplets in crowded cloud volumes !

Chaumat & Brenguier JAS 2000

Cumulus Parameterization in the Context of Turbulence Studies

Hydrological Cycle , Climate Studies , Environment
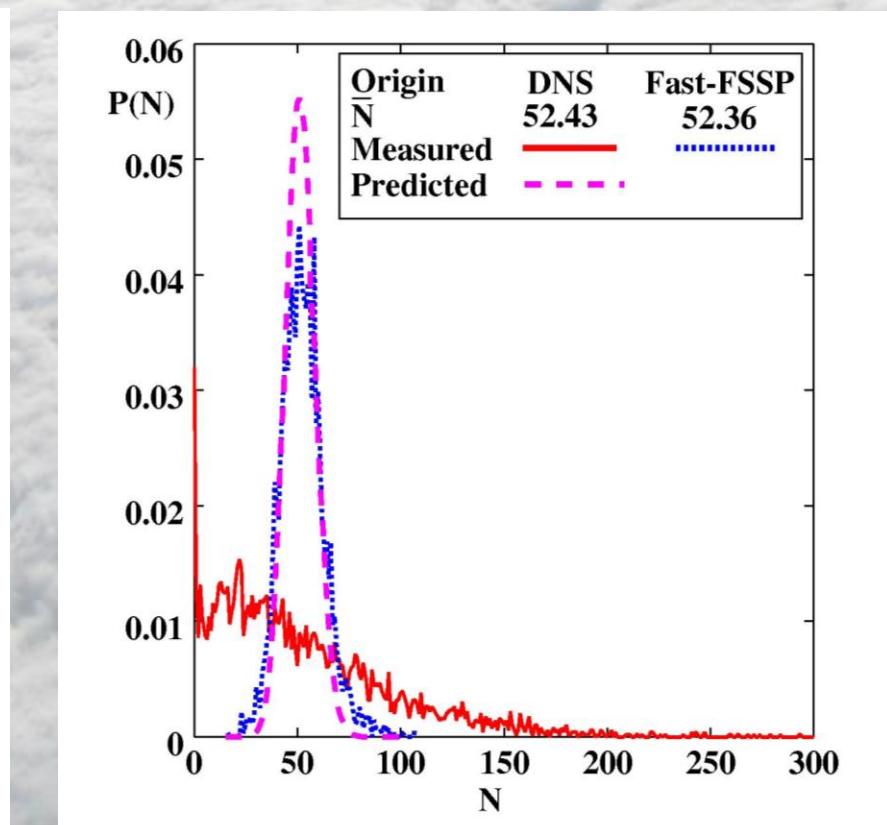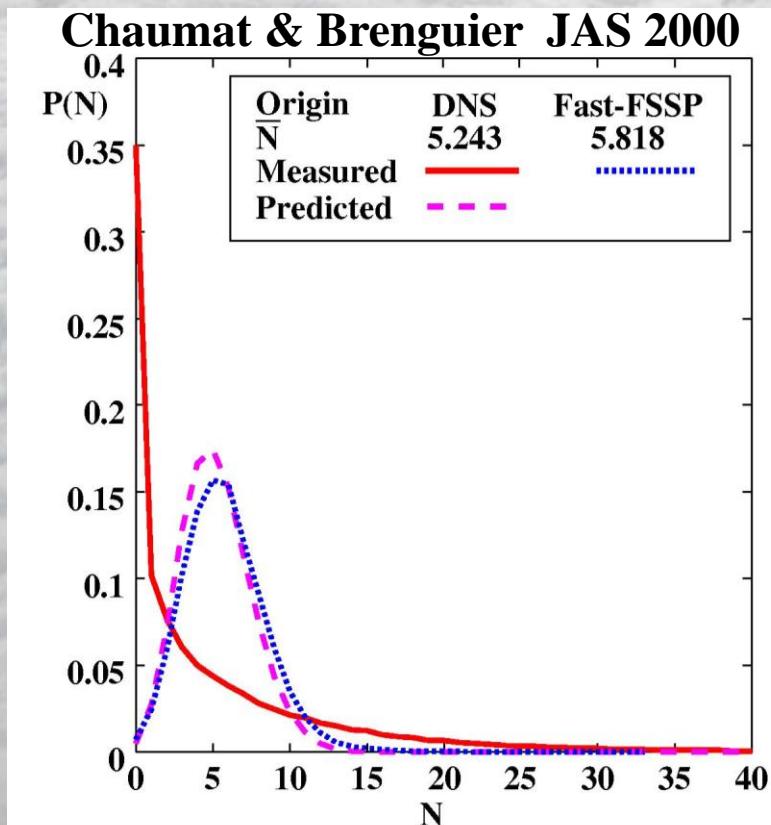
Small cumuli are precipitating faster than predicted !

Any experimental evidence of this assessment ?

Spatial heterogeneities may play a role, but not for enhancing the condensation process, possibly for the collection process !

Hydrological Cycle , Climate Studies , Environment

Hydrological Cycle
- Cloud Microphysics/Dynamics Feed-back
- Impact of Aerosol on Precipitation Efficiency (☹)

(☹) Aerosol particles impact cloud droplet and ice particle formation.
This is well known since 50 years

Does that mean that there are modifications of the precipitation efficiency ?
50 years of weather modification programmes have not been sucessful to demonstrate such an assessment, nor the sign of the change !

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Hydrological Cycle , **Climate Studies** , Environment

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Aerosol Activation:

Closure Experiment on the Activation Process

18-July

CDNC, cm^{-3}

Snider et al. JGR 2003
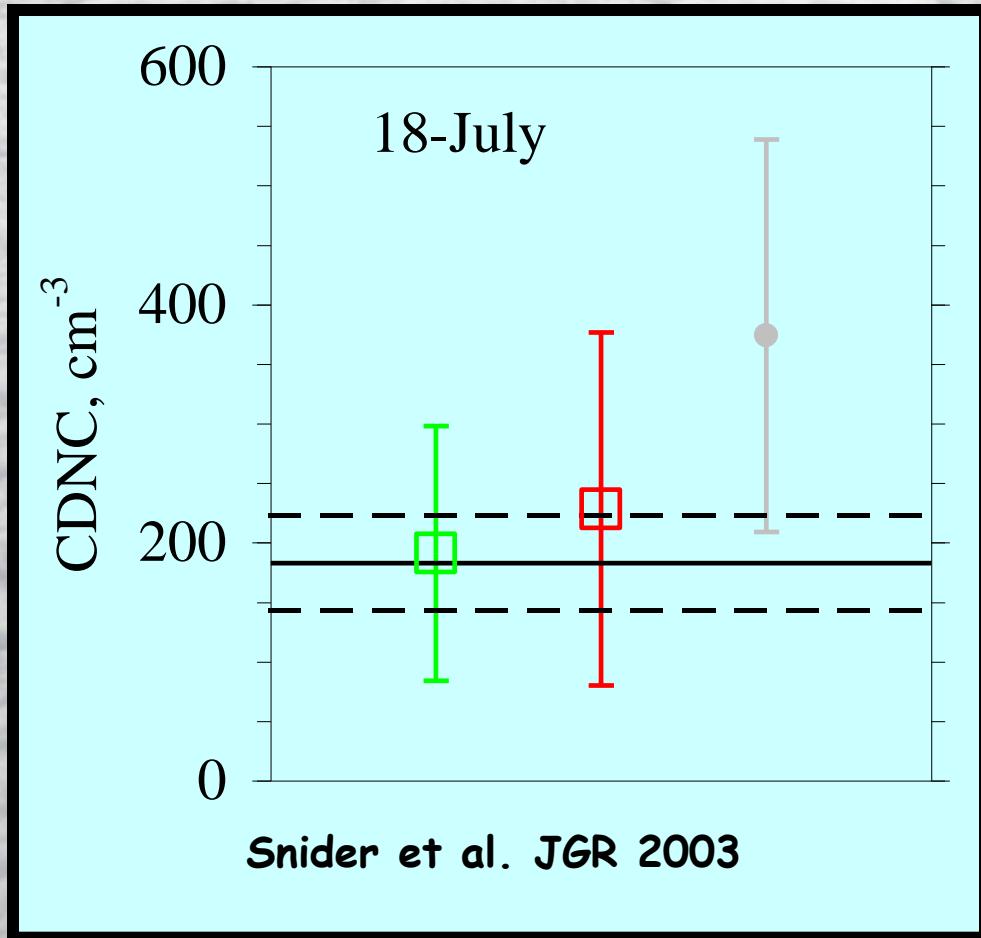
**Comparison between measured CDNC (horizontal bars)
and predictions based on
- observed aerosol properties (black)
- properties derived from measured CCN activation spectrum (red & green)**

The CDNC prediction is overestimated by a factor of up to 2

Closure Experiment on the Activation Process
Is that bias an obstacle ?

In BL clouds CDNC values in non-diluted (quasi-adiabatic) cloud cells varies from 50% to 150 % of the mean N_{act}

$q_c(h) > 0.9 \, q_{cad}(h)$

$N_{drizzle} < 2cm^{-3}$

$0.4H < h < 0.6H$
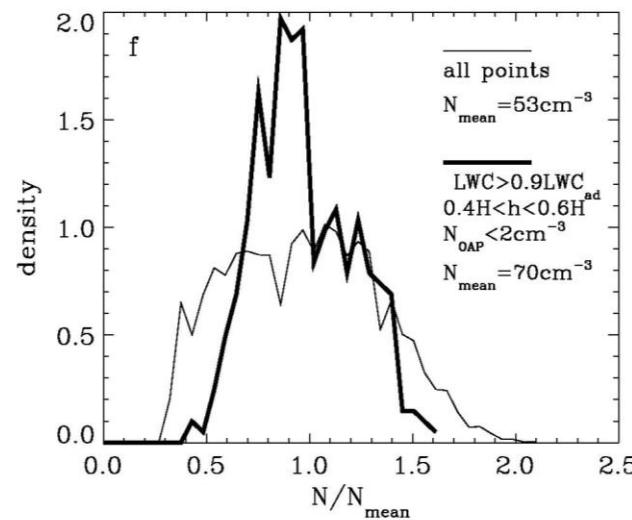
Pawlowska & Brenguier Tellus 2000

Closure Experiment on the Activation Process
Is that bias an obstacle ?

Droplet growth is well parameterized with the adiabatic model, with $N=N_{act}$

26 June 1997 — $N_{act}=55 \text{ cm}^{-3}$

9 July 1997 — $N_{act}=244 \text{ cm}^{-3}$

Pawlowska & Brenguier Tellus 2000
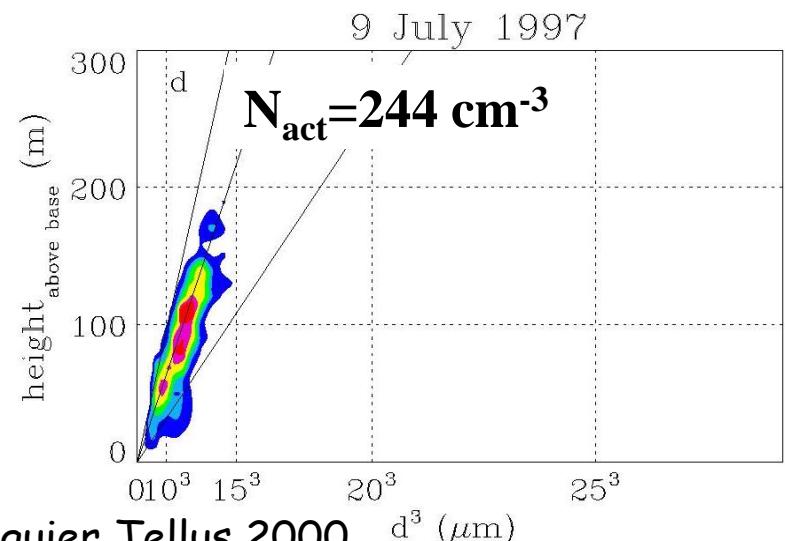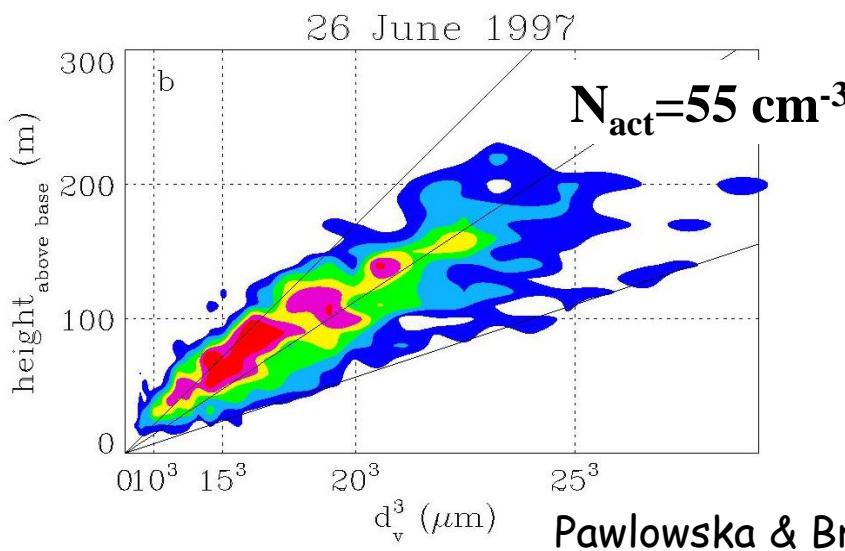
Droplet mean volume diameter versus height above cloud base
The middle line is the adiabatic prediction with $N=N_{act}$

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Aerosol Activation:

State-of-the-Art: Predictions are overestimated, most likely because the hygroscopic properties of the aerosol are not correctly accounted for in the process models. However simplified parameterizations exist that accurately replicate the detailed process models.

Objective: better description of aerosol properties to reach an accuracy of **± 50 %**

Cumulus Parameterization in the Context of Turbulence Studies

Hydrological Cycle , **Climate Studies** , Environment

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Aerosol Activation:

Cloud radiative properties:

Closure Experiment on the Activation Process
Is that bias an obstacle ?

Radiative transfer retrievals are consistent with in situ observed CDNC
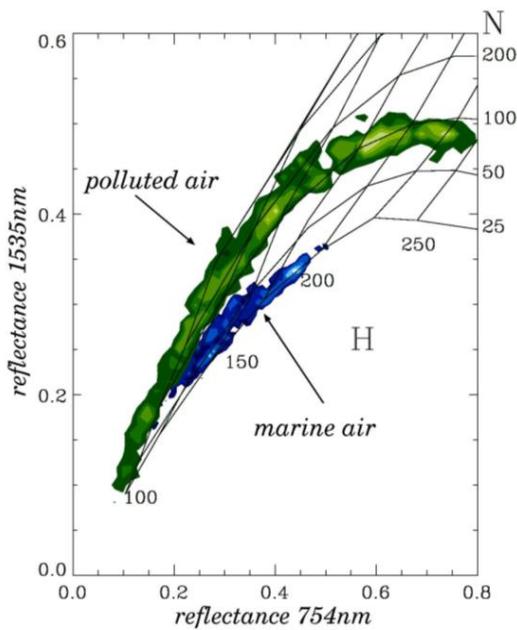
Reflectances VIS & NIR
Predicted H-N Isolignes
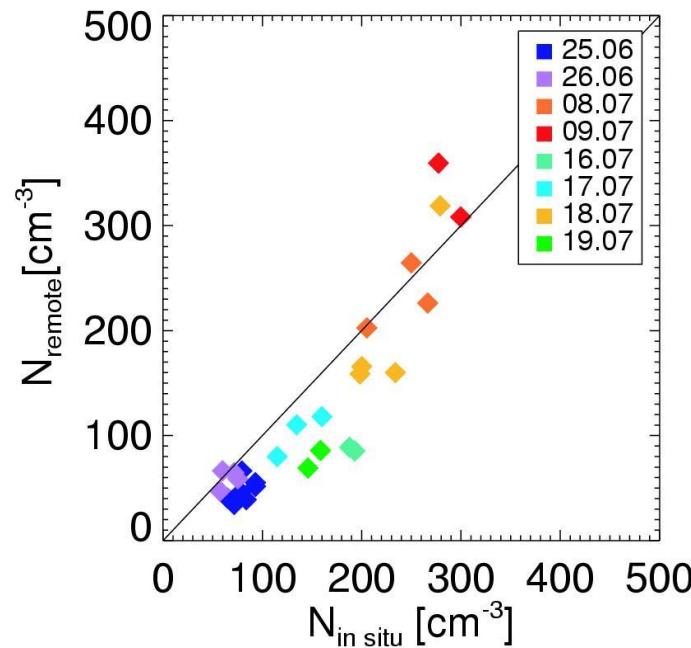
N retrieval versus Nact

Schüller et al. JGR 2003

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Aerosol Activation:

Cloud radiative properties:

State-of-the-Art: Very accurate process models and parameterizations. Still minor biases most likely due to poor description of the cloud heterogeneity and of the aerosol absorbing properties

Objective: better description of aerosol absorption and impact of cloud heterogeneity to reach an accuracy of **± 5 %**

Cumulus Parameterization in the Context of Turbulence Studies

Hydrological Cycle , **Climate Studies** , Environment

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Aerosol Activation:

Cloud radiative properties:

Cloud Life Cycle:

# Cumulus Parameterization in the Context of Turbulence Studies

A=0.50

1st **and** **2nd**
Aerosol Indirect Effect

Entrainment-Mixing

$r_l=0.2 \text{ g kg}^{-1}$

$r_v=20 \text{ g kg}^{-1}$

Radiative Transfer

Microphysics

CCN Activation

Onset of Précipitation

Turbulent Fluxes

Precipitation Evaporation <1mm /day

r_v T

A=0.05
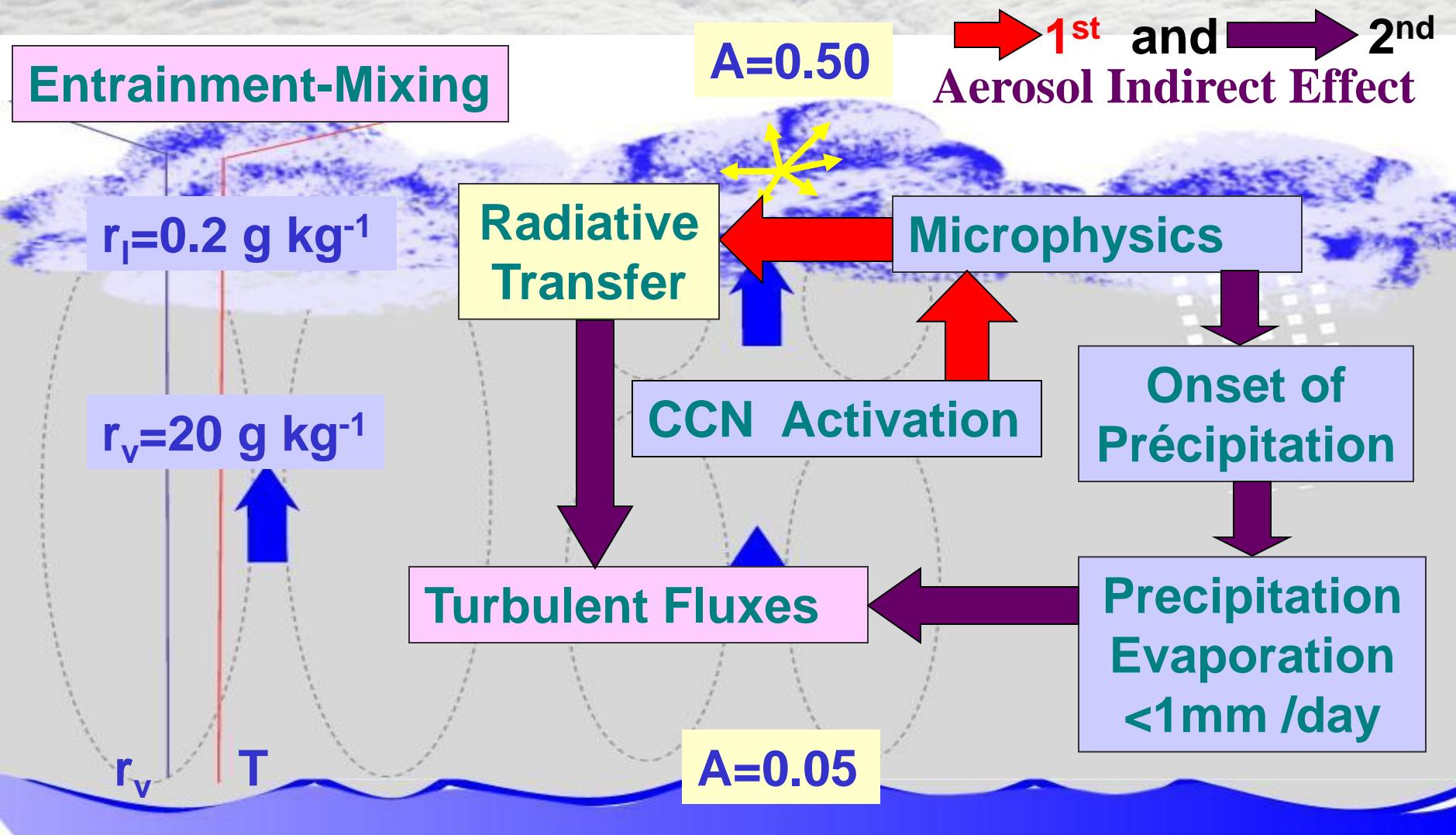
State of the art in GCM simulation of AIE
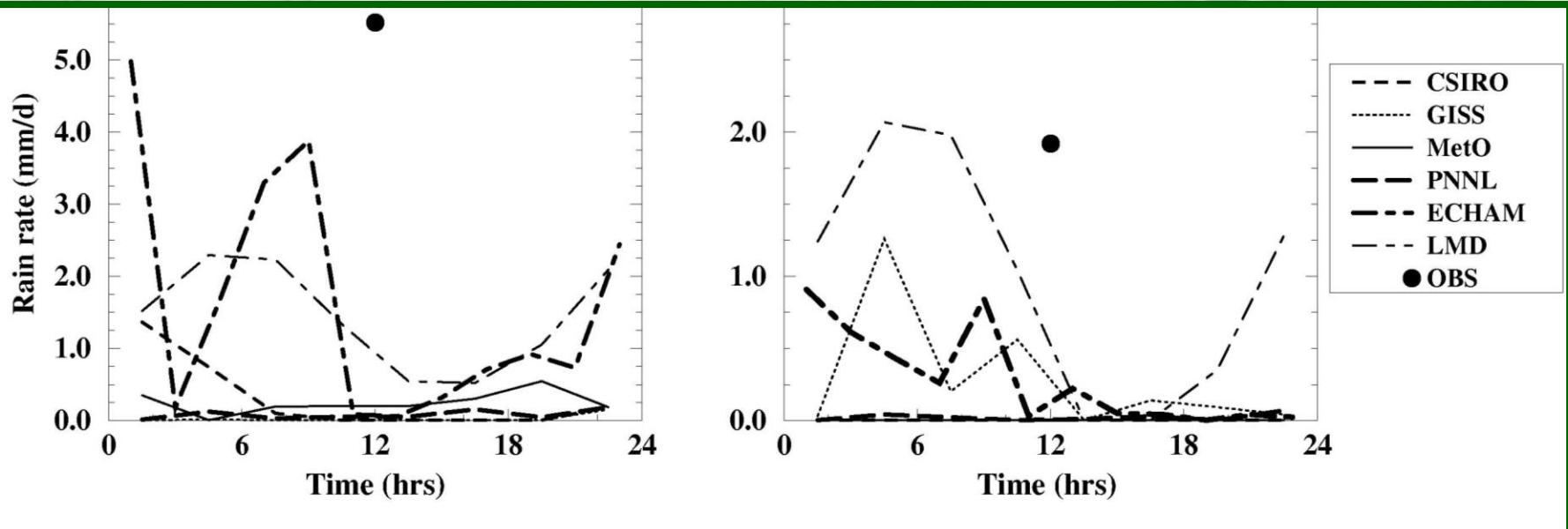
Menon et al. JGR 2004

State of the art in GCM simulation of AIE

Menon et al. JGR 2004

Cumulus Parameterization in the Context of Turbulence Studies
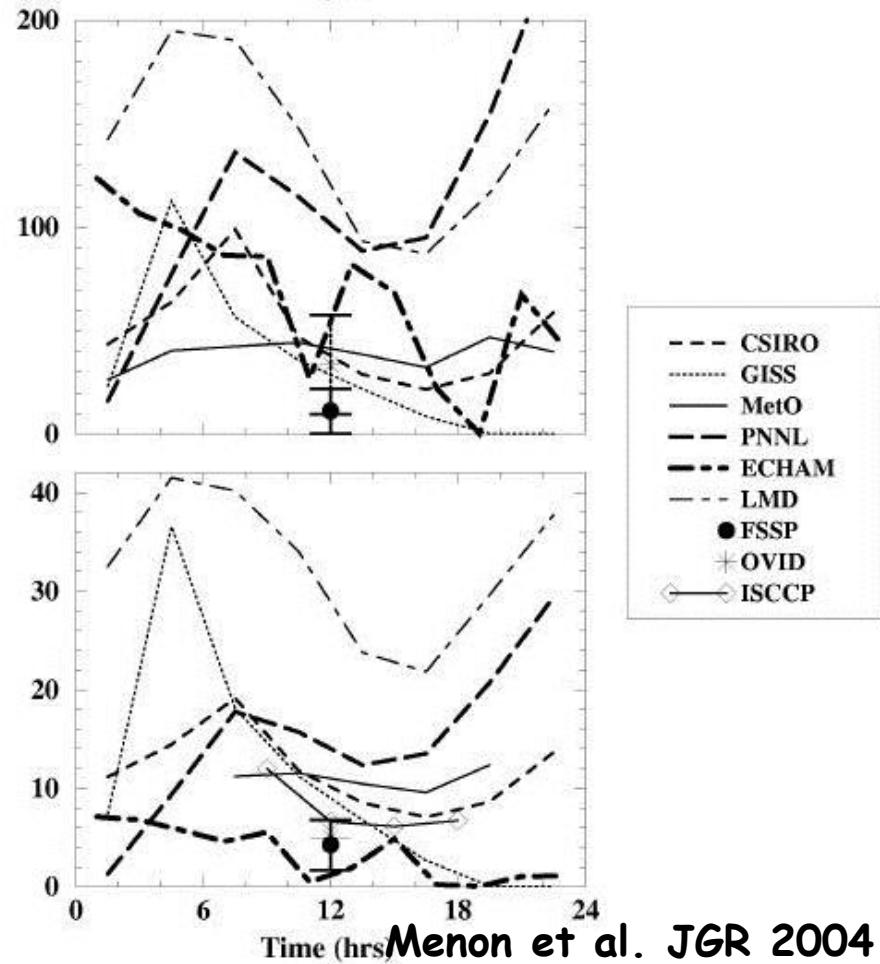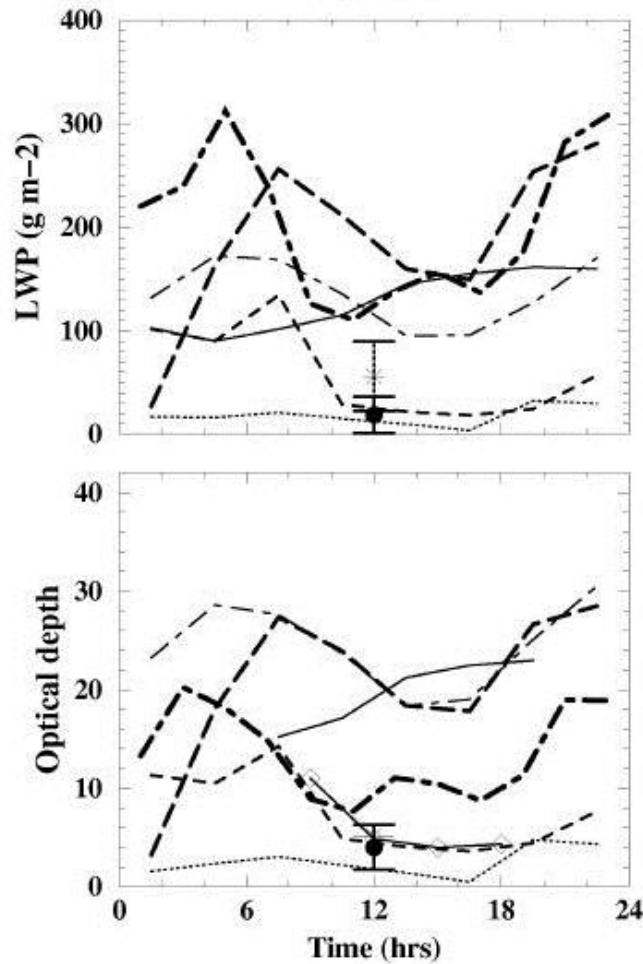
Parameterization of precipitation in GCM

Detailed microphysics 1 to 3-D (50 to 200 variables)

3-D CRM Runs (diverse conditions)
Tripoli-Cotton, Beheng, Khairoutdinov-Kogan

Bulk microphysics for CRM (3 variables: N, q_c, q_r)
Auto-conversion (N, q_c) and Accretion (N, q_c, q_r)

3-D bulk CRM Runs (meso-scale)

Bulk microphysics for GCM (2 variables : N, H)
Average precipitation rate from multi-cells in stationary state

Precipitation for an ensemble of cloud cells:
Super-bulk parameterizations of precipitation
in BL clouds, using only N and H

Pawlowska & Brenguier JGR 2003
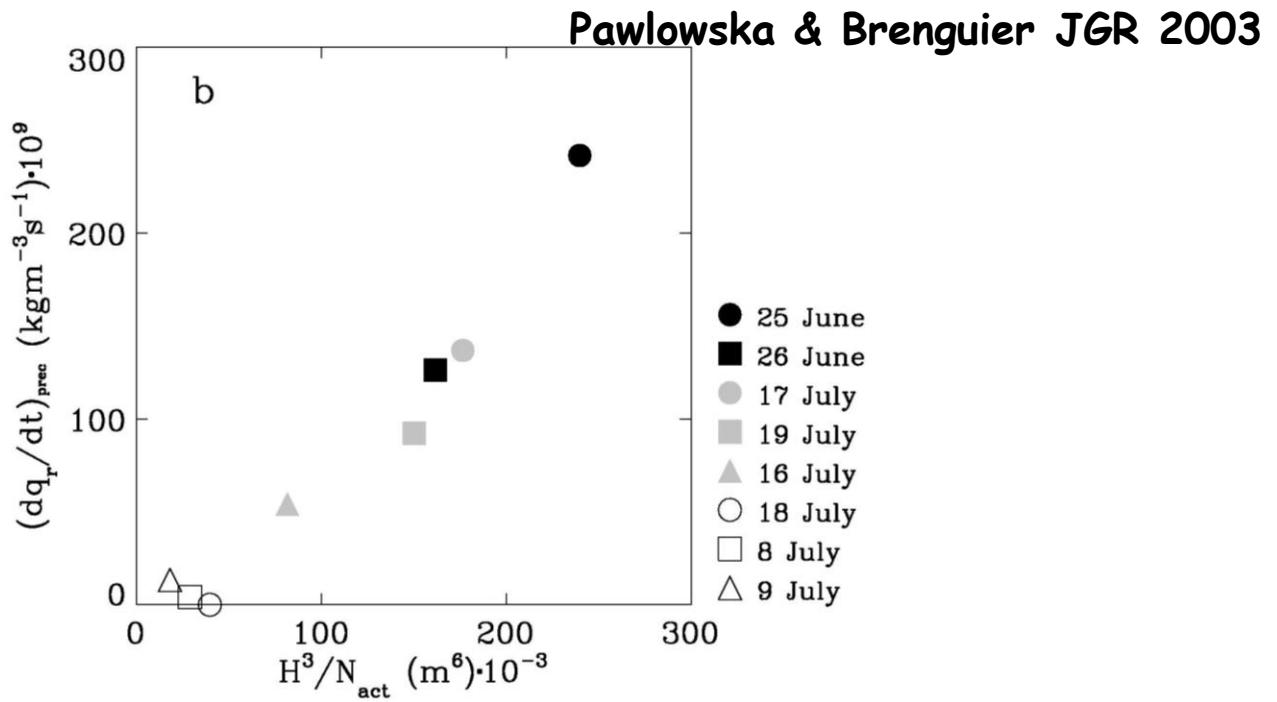
Reduction rate of cloud water by precipitation
as a power law of H and N_{act}

Hydrological Cycle , **Climate Studies** , Environment

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Aerosol Activation:

Cloud radiative properties:

Cloud Life Cycle:

State-of-the-Art: Very poor description of thin BL clouds in large scale models. Use of inadequate parameterizations that are only valid when local values of condensed water mixing ratios are prognosed.

**Objective**: better description of thin clouds & new super bulk parameterizations of precipitation

Back to basics: Model & Parameterizations Consistency
droplet formation and growth

How to translate the accuracy of a sophisticated 0D activation models into a multi-dimensionnal cloud model, without prognostic of supersaturation, and with a vertical resolution smaller than the height necessary for the activation process to be completed ??
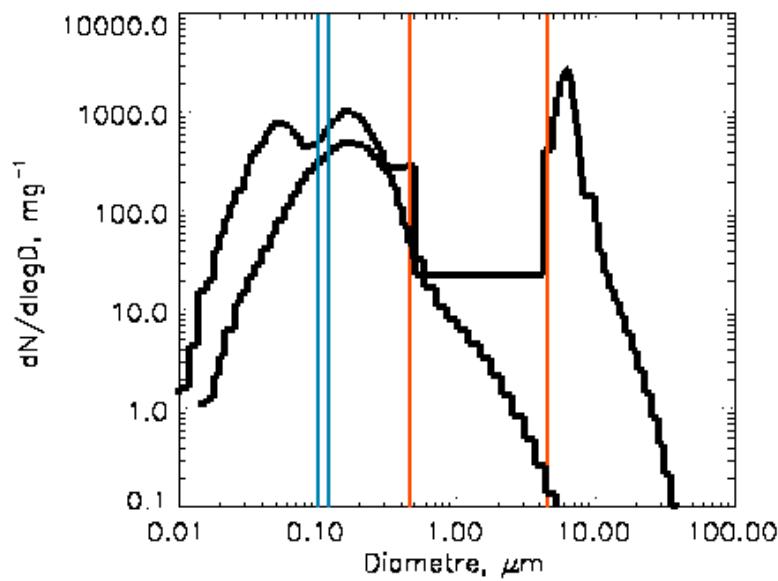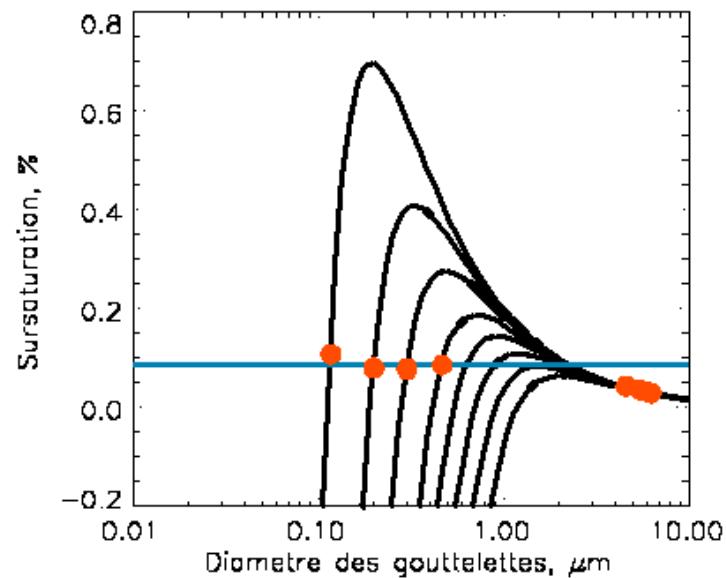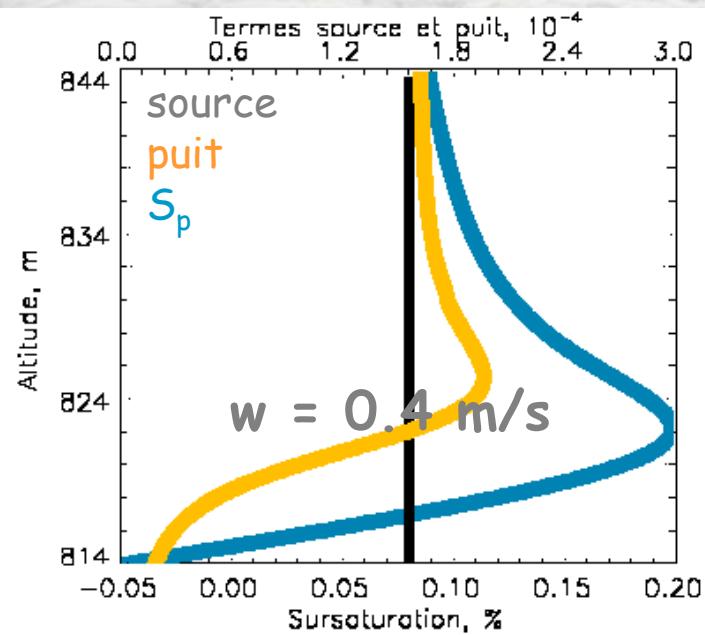
Back to basics: Model & Parameterizations Consistency
droplet formation and growth

How to translate the accuracy of a sophisticated 0D spectral microphysical model into a 3-D cloud model, without prognostic of supersaturation, and with a horizontal resolution greater than the typical scale of the mixing processes??

Back to basics: Model & Parameterizations Consistency droplet formation and growth

Example: Radiative transfer in BL clouds

Fre65nopen t=3 heures
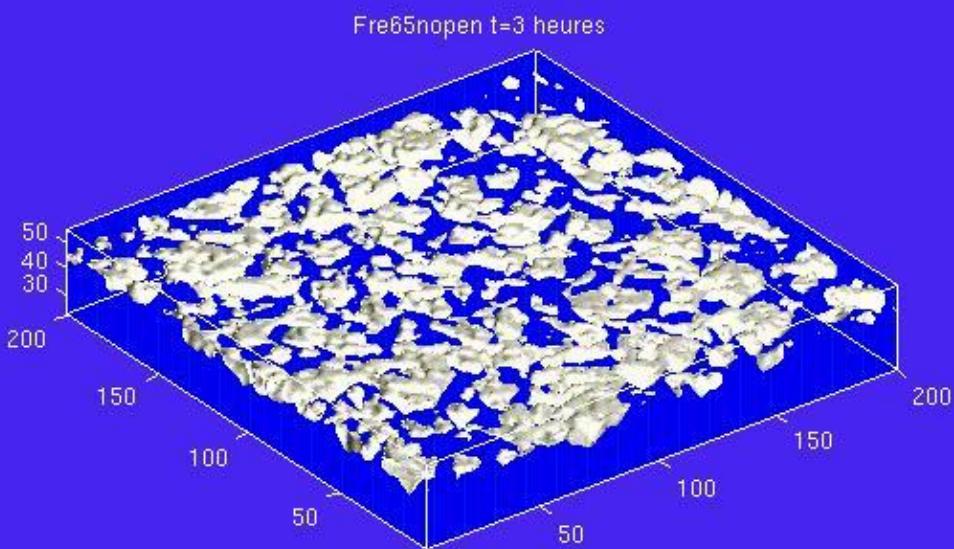
Bulk microphysics model
Nr_s^2 is derived from $q_c = Nr_v^3$
by assuming either
pure homogeneous (cst N)
pure heterogeneous (cst r_v)

Back to basics: Model & Parameterizations Consistency droplet formation and growth
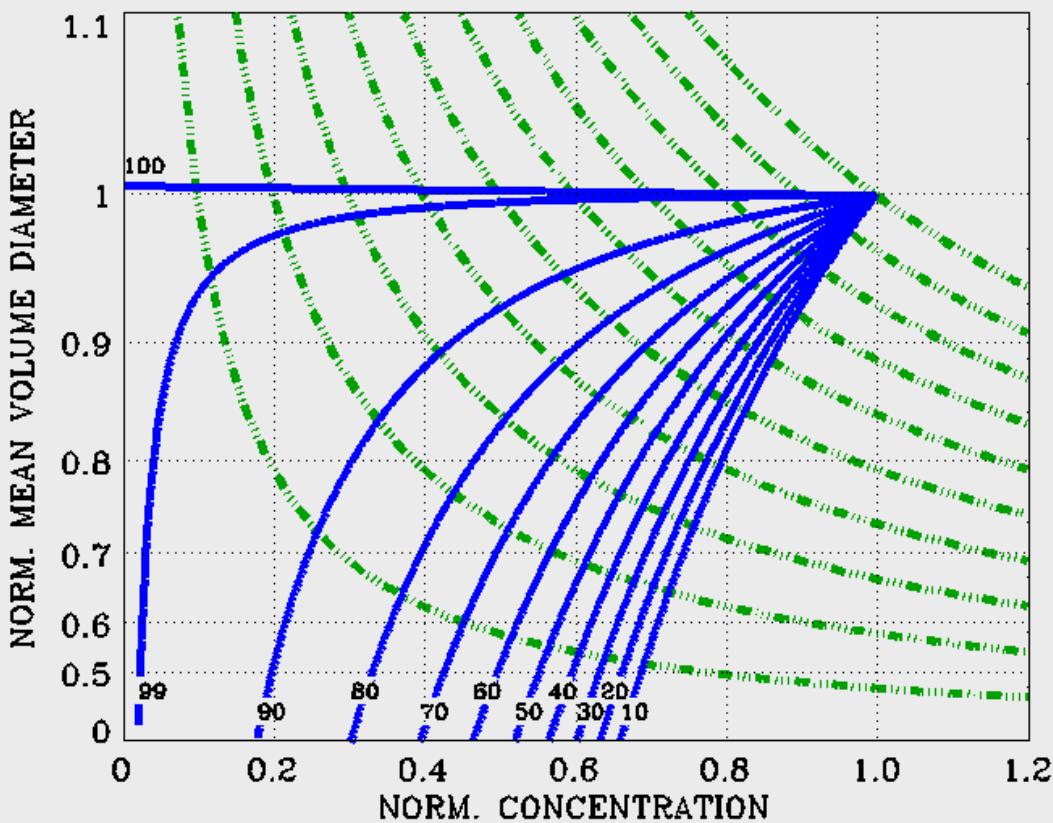
Homogeneous
N ↘ dilution only
Φv ↘ evaporation

Heterogeneous
N ↘ dilution and total evaporation of some droplets

Φv constant

Back to basics: Model & Parameterizations Consistency droplet formation and growth

Example: Radiative transfer in BL clouds

$<\tau>=2.3$ $<\tau>=1.7$
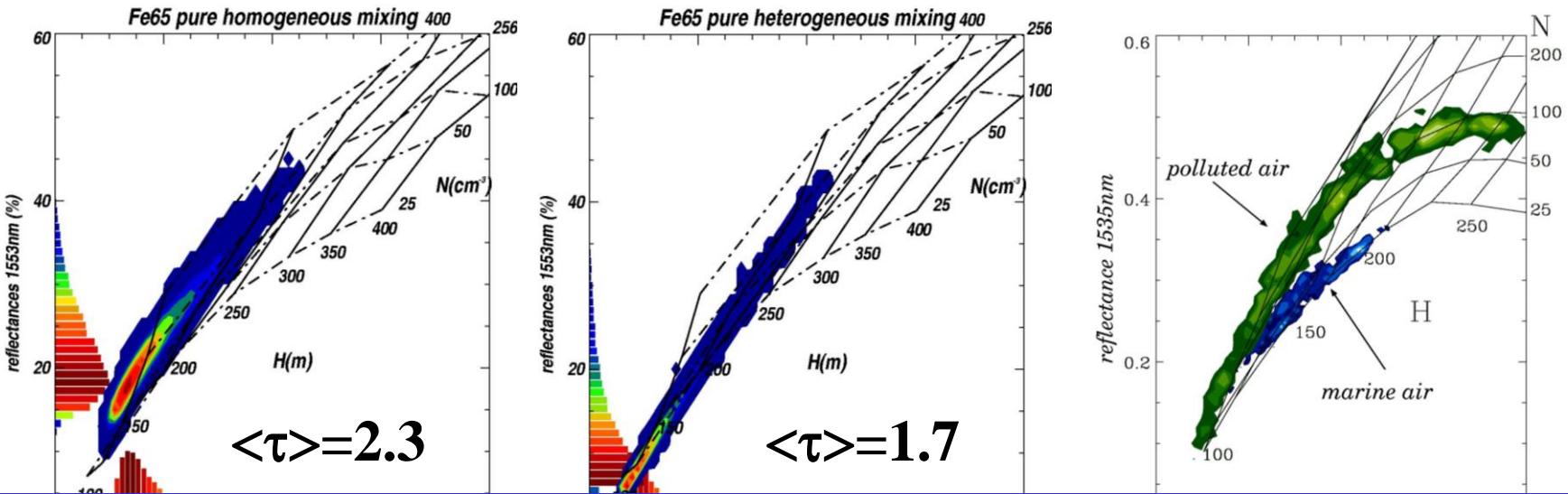
The relative difference between hetero/homogeneous mixing schemes (~ 30 %) is equivalent to the impact of a CDNC increase by a factor of 2