Hydrological Cycle
• Turbulence and the onset of precipitation
• Cloud Microphysics/Dynamics Feed-back
• Impact of Aerosol on Precipitation Efficiency (😢)
Cumulus Parameterization in the Context of Turbulence Studies

Issues

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

Climate Studies
• Cloud Radiative forcing ($N_r^3$, $N_r^2$)
• Aerosol 1st Indirect Effect (Aerosol Activation & Cloud/Radiation)
• Aerosol 2nd Indirect Effect (Cloud Life Time)
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Environment & Air Quality
- Gas/Aerosol Interactions
- Aerosol Processing in Clouds
Bulk thermodynamics: $q_c = q_t - q_{vs}(T)$

Parameterization of the Microphysics
### Parameterization of the Microphysics

<table>
<thead>
<tr>
<th>Bulk thermodynamics</th>
<th>$q_c = q_t - q_{vs}(T)$</th>
<th>+0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk microphysics: liquid precipitating</td>
<td>$q_c, q_r$</td>
<td>+1</td>
</tr>
<tr>
<td></td>
<td>$q_c, q_r, N_c$</td>
<td>+2</td>
</tr>
<tr>
<td></td>
<td>$q_c, q_r, N_c, N_r$</td>
<td>+3</td>
</tr>
<tr>
<td>mixed phase</td>
<td>$q_c, q_r, N_c, N_r, q_i, q_s, q_g, ...$</td>
<td>+4~10</td>
</tr>
</tbody>
</table>
Cumulus Parameterization in the Context of Turbulence Studies

Parameterization of the Microphysics

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

Bulk microphysics:
- Liquid precipitating: \( q_c, q_r \) (1)
- Liquid precipitating: \( q_c, q_r, N_c \) (2)
- Liquid precipitating: \( q_c, q_r, N_c, N_r \) (3)
- Mixed phase: \( q_c, q_r, N_c, N_r, q_i, q_s, q_g, ... \) (4-10)

Spectral microphysics:
- Liquid precipitating: \( f_c(r)dr, f_r(r)dr \) (2p)
- Mixed phase: \( f_x(r)dr \) (4p - 10p)
Cumulus Parameterization in the Context of Turbulence Studies

Parameterization of the Microphysics

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

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  \( q_c, q_r, N_c, N_r, q_i, q_s, q_g, \ldots \)  \(+4\text{~to~}10\)

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  \( f(m_a, r_d)dm_a, dr_d \)  \(+pql\)
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?
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 privileged droplets are lucky and grow more than droplets in crowded cloud suburbs!

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

Chaumat & Brenguier  JAS 2000

<table>
<thead>
<tr>
<th>Origin</th>
<th>DNS</th>
<th>Fast-FSSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{N}$</td>
<td>5.243</td>
<td>5.818</td>
</tr>
</tbody>
</table>

- Measured
- Predicted
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

- 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 successful to demonstrate such an assessment, nor the sign of the change!
Cumulus Parameterization in the Context of Turbulence Studies

Hydrological Cycle, Climate Studies, Environment

- Cloud Radiative forcing ($N_r^3$, $N_r^2$)
- Aerosol 1st Indirect Effect (Aerosol Activation & Cloud/Radiation)
- Aerosol 2nd Indirect Effect (Cloud Life Time)

Aerosol Activation:
Closure Experiment on the Activation Process

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

Snider et al. JGR 2003
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 $N_{act}$

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

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

$0.4H < h < 0.6H$

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 $N = N_{\text{act}}$

Droplet mean volume diameter versus height above cloud base

The middle line is the adiabatic prediction with $N = N_{\text{act}}$

Pawlowska & Brenguier Tellus 2000
Cumulus Parameterization in the Context of Turbulence Studies

Hydrological Cycle, Climate Studies, Environment

- Cloud Radiative forcing ($N_r^3$, $N_r^2$)
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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 %
• Cloud Radiative forcing ($N r_v^3$, $N r_s^2$)
• Aerosol 1\textsuperscript{st} Indirect Effect (Aerosol Activation & Cloud/Radiation)
• Aerosol 2\textsuperscript{nd} Indirect Effect (Cloud Life Time)

**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 Isolines

N retrieval versus Nact
Schüller et al. JGR 2003
Cumulus Parameterization in the Context of Turbulence Studies

Hydrological Cycle, **Climate Studies**, Environment

• Cloud Radiative forcing ($N_r^3$, $N_r^2$)
• Aerosol 1\textsuperscript{st} Indirect Effect (Aerosol Activation & Cloud/Radiation)
• Aerosol 2\textsuperscript{nd} Indirect Effect (Cloud Life Time)

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

- Cloud Radiative forcing \((N_{r_v}^3, N_{r_s}^2)\)
- Aerosol 1\(^{st}\) Indirect Effect (Aerosol Activation & Cloud/Radiation)
- Aerosol 2\(^{nd}\) Indirect Effect (Cloud Life Time)

Aerosol Activation:

Cloud radiative properties:

Cloud Life Cycle:
Cumulus Parameterization in the Context of Turbulence Studies

Entrainment-Mixing

\[ r_i = 0.2 \text{ g kg}^{-1} \]

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

Radiative Transfer

Microphysics

CCN Activation

Turbulent Fluxes

Onset of Précipitation

Precipitation Evaporation <1mm /day

A=0.50

A=0.05

1\text{st} and 2\text{nd}

Aerosol Indirect Effect

23-25 February 2004 - Jean-Louis Brenguier - Météo-France
Cumulus Parameterization in the Context of Turbulence Studies

State of the art in GCM simulation of AIE

Menon et al. JGR 2004
Cumulus Parameterization in the Context of Turbulence Studies

State of the art in GCM simulation of AIE

Menon et al. JGR 2004
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

Reduction rate of cloud water by precipitation as a power law of H and $N_{act}$
Cumulus Parameterization in the Context of Turbulence Studies

Hydrological Cycle, Climate Studies, Environment

- Cloud Radiative forcing \((N_r^3, N_r^2)\)
- Aerosol 1\textsuperscript{st} Indirect Effect (Aerosol Activation & Cloud/Radiation)
- Aerosol 2\textsuperscript{nd} Indirect Effect (Cloud Life Time)

**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
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 ??
Cumulus Parameterization in the Context of Turbulence Studies

Distribution dimensionnelle des aérosols secs
Courbes de Köhler (8 noyaux de sulfate d'ammonium)

Diamètres secs :
- 0.043 μm
- 0.061 μm
- 0.079 μm
- 0.102 μm
- 0.121 μm
- 0.144 μm
- 0.171 μm
- 0.203 μm

Diamètre des gouttelettes de solution

Sursaturation de la parcelle source puit

S = S_{max} = -0.05\%

w = 0.4 m/s

Dry Diameter :
- 0.102 μm
- 0.121 μm
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

Bulk microphysics model $N_{r_s}^2$ is derived from $q_c = N_r v^3$ by assuming either
pure homogeneous (cst N) or
pure heterogeneous (cst $r_v$).
Back to basics: Model & Parameterizations Consistency
droplet formation and growth

**Homogeneous**
\[ N \lessgtr \text{ dilution only} \]
\[ \Phi v \lessgtr \text{ evaporation} \]

**Heterogeneous**
\[ N \lessgtr \text{ dilution and total evaporation of some droplets} \]
\[ \Phi v \text{ constant} \]
Cumulus Parameterization in the Context of Turbulence Studies

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

Example: Radiative transfer in BL clouds

The relative difference between hetero/homogeneous mixing schemes (~ 30 %) is equivalent to the impact of a CDNC increase by a factor of 2

<τ>=2.3
<τ>=1.7