Clouds in LMDZ

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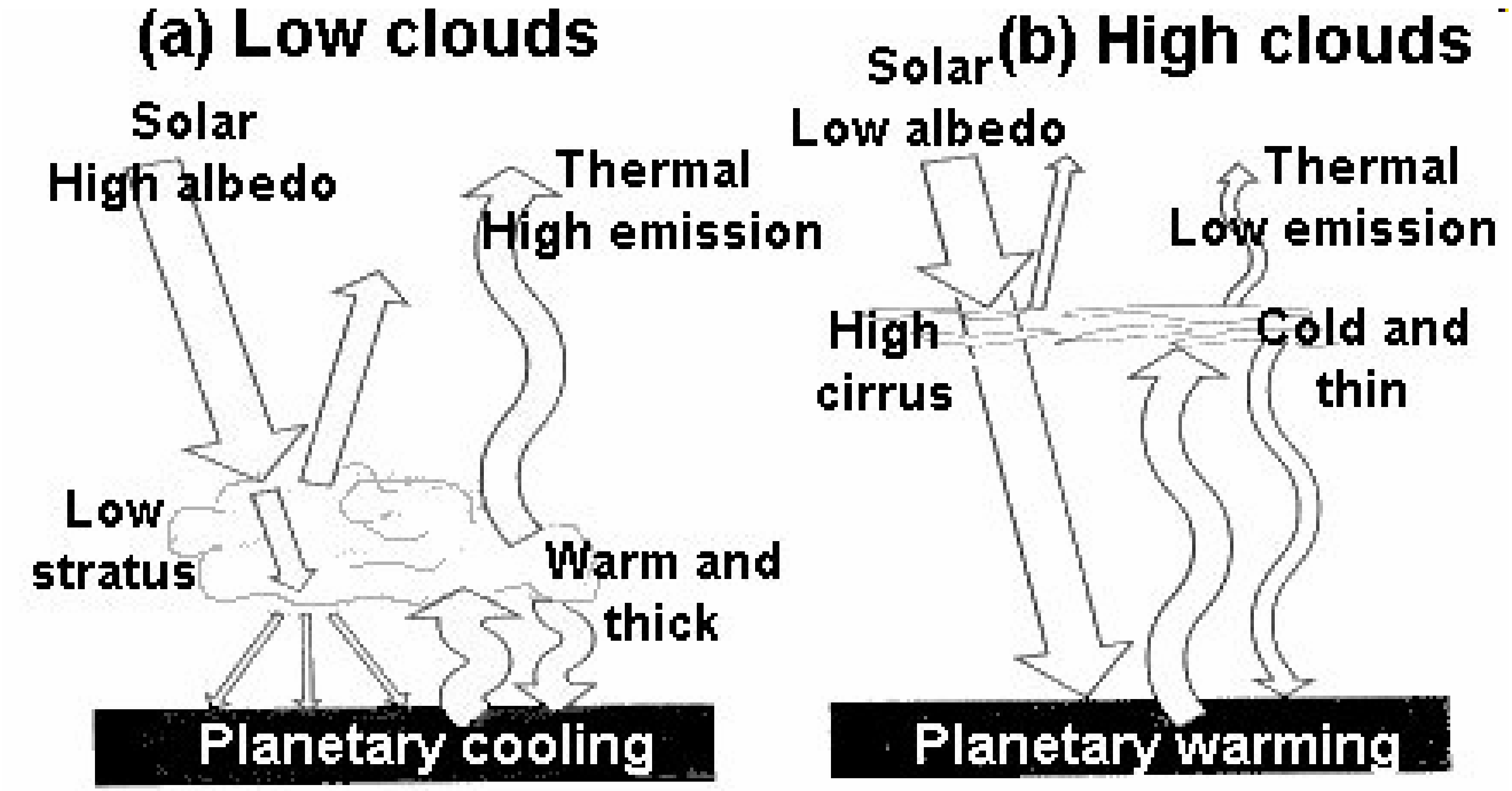
Clouds and radiation

Albedo effect: clouds reflect an important part of the incoming solar radiation
Maximum when the contrast of albedo clouds/surface is maximum: over ocean

Greenhouse effect: clouds absorb a part of the radiation emitted by the earth surface
Maximum when the contrast of temperature clouds/surface is maximum: high clouds



Low clouds:
- Strong albedo effect (reflectivity 40-50%)
- Weak greenhouse effect (warm clouds)

High clouds:
- Weak albedo effect
- Strong greenhouse effect (cold clouds)

cooling

warming

The radiative forcing of clouds

LW radiative forcing

Positive: clouds decrease the
energy reflected (clouds colder)

Annual mean: +29W/m2

SW radiative forcing

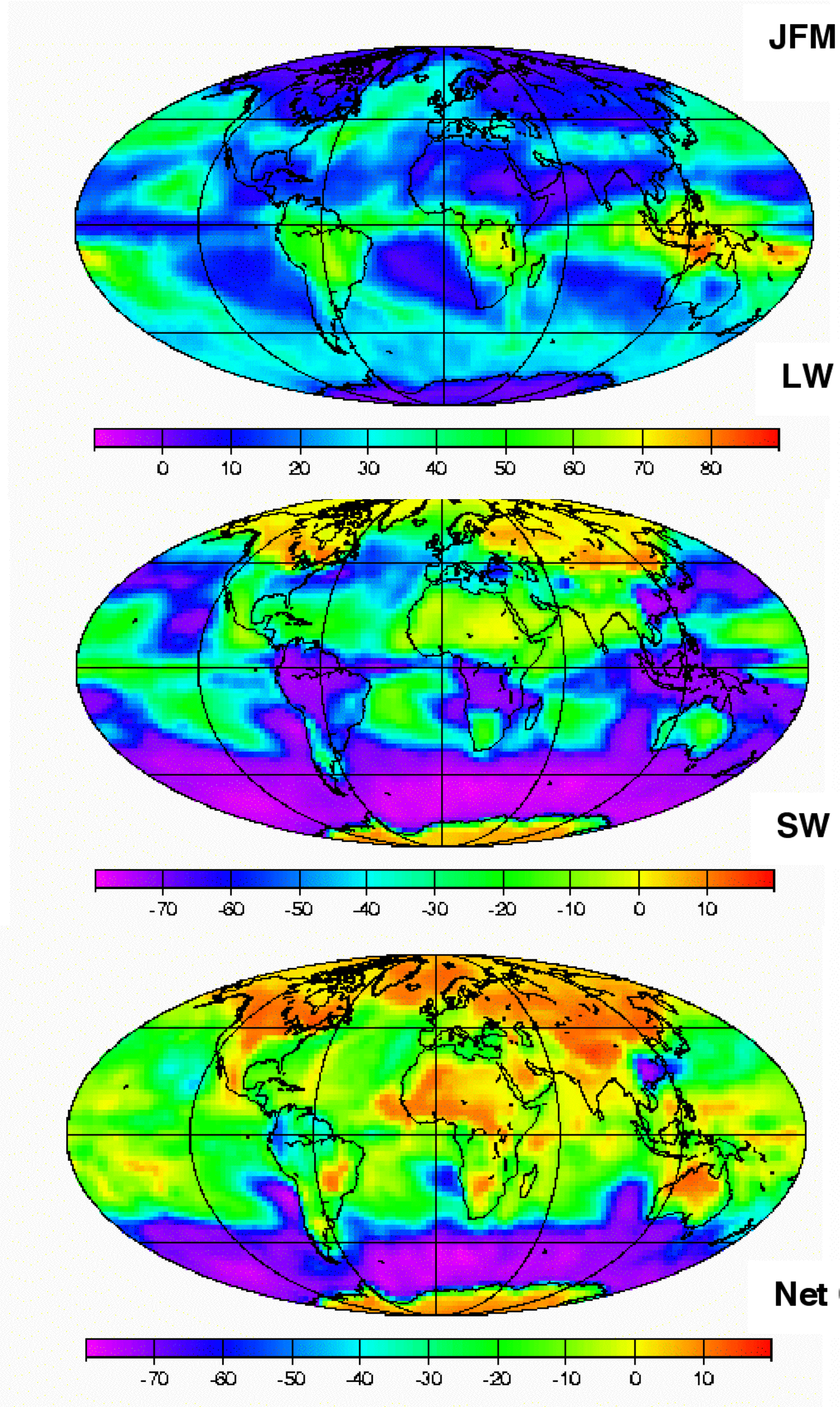
Negative: clouds decrease
the energy absorbed (clouds brighter)

Annual mean: -47W/m2

Net radiative forcing

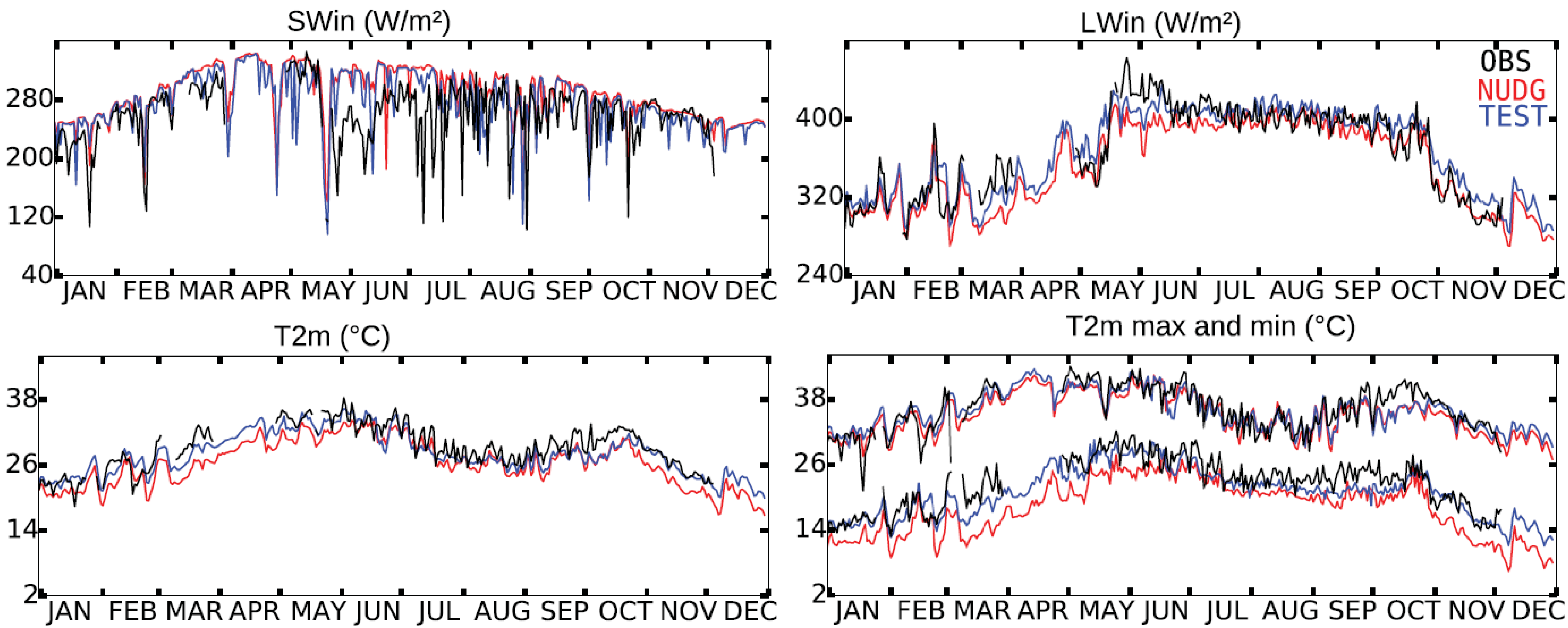
Annual mean: **-18W/m2**

Globally, clouds cool the planet.



Clouds and surface energy budget

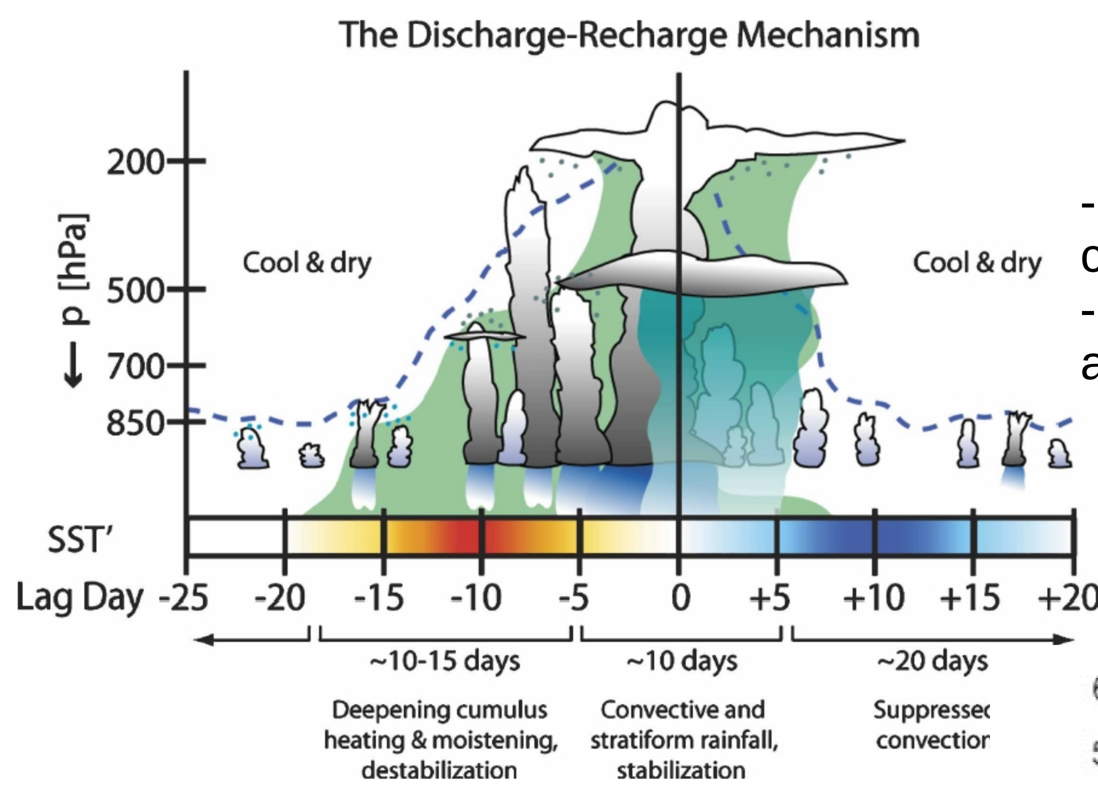
Sensitivity of surface incoming SW and LW radiation and 2m-temperature to high-cloud amount
Agoufou, 2006



Diallo et al., JAMES, 2017

→ Importance of clouds for **land/atmosphere coupling**

Clouds and variability of precipitation



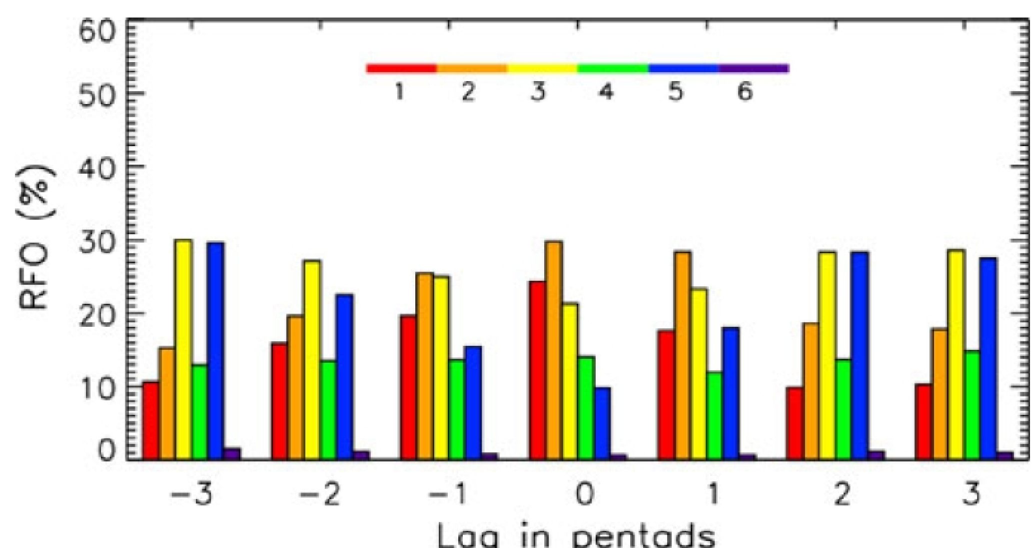
Benedict et Randall, JAS, 2007

- Moistening of the mid-troposphere by cumulus and congestus
- Drying of the mid-troposphere by precipitation and compensating subsidence

Del Genio et al., JC, 2011

Frequency of occurrence of cloud types before and after maximum of MJO event

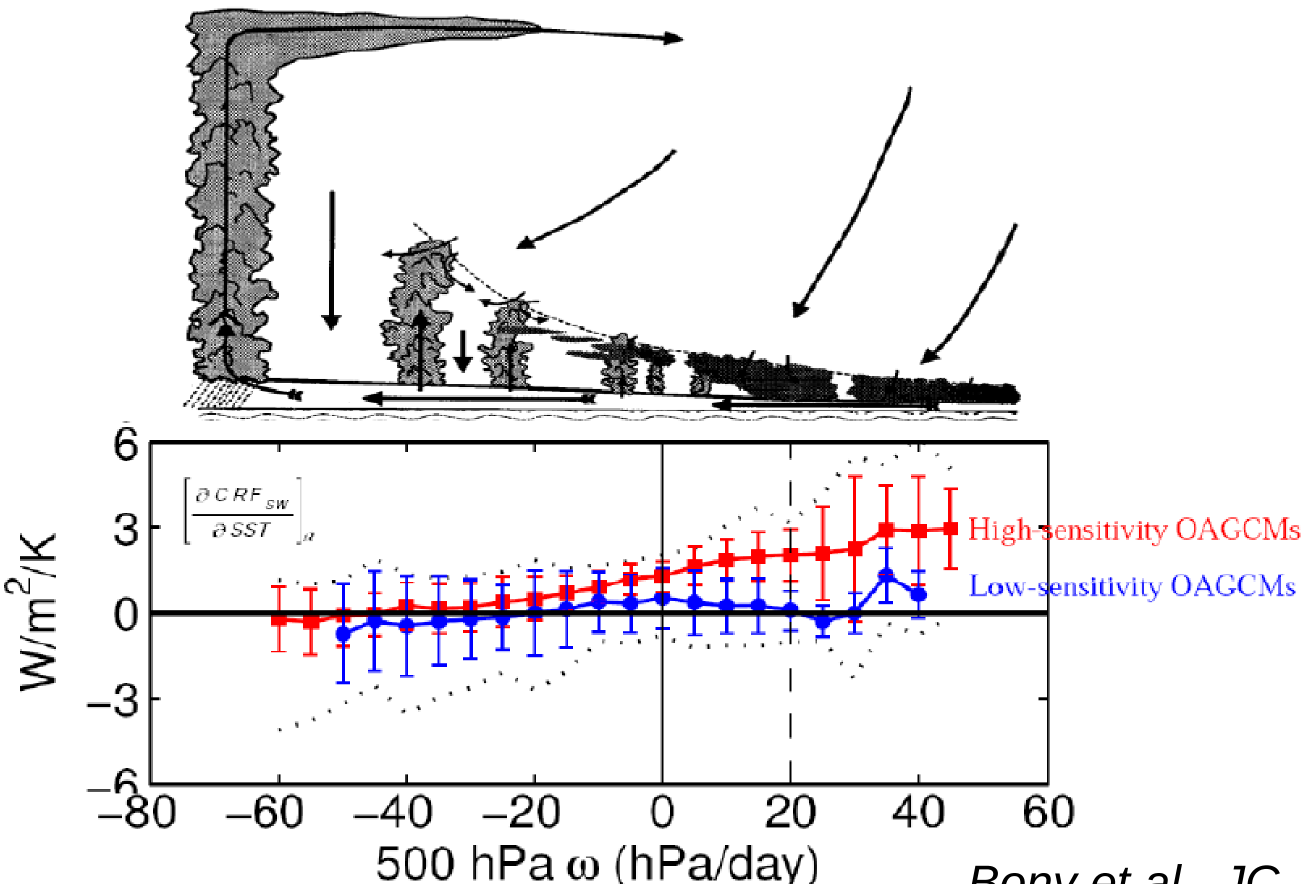
1. deep convection
2. anvil
3. congestus
4. cirrus
5. cumulus
6. stratocumulus



Importance of the radiative effect of congestus clouds in the **transition from suppressed to active phase of MJO** *(Del Genio et al., JC, 2015)*

Clouds and climate sensitivity

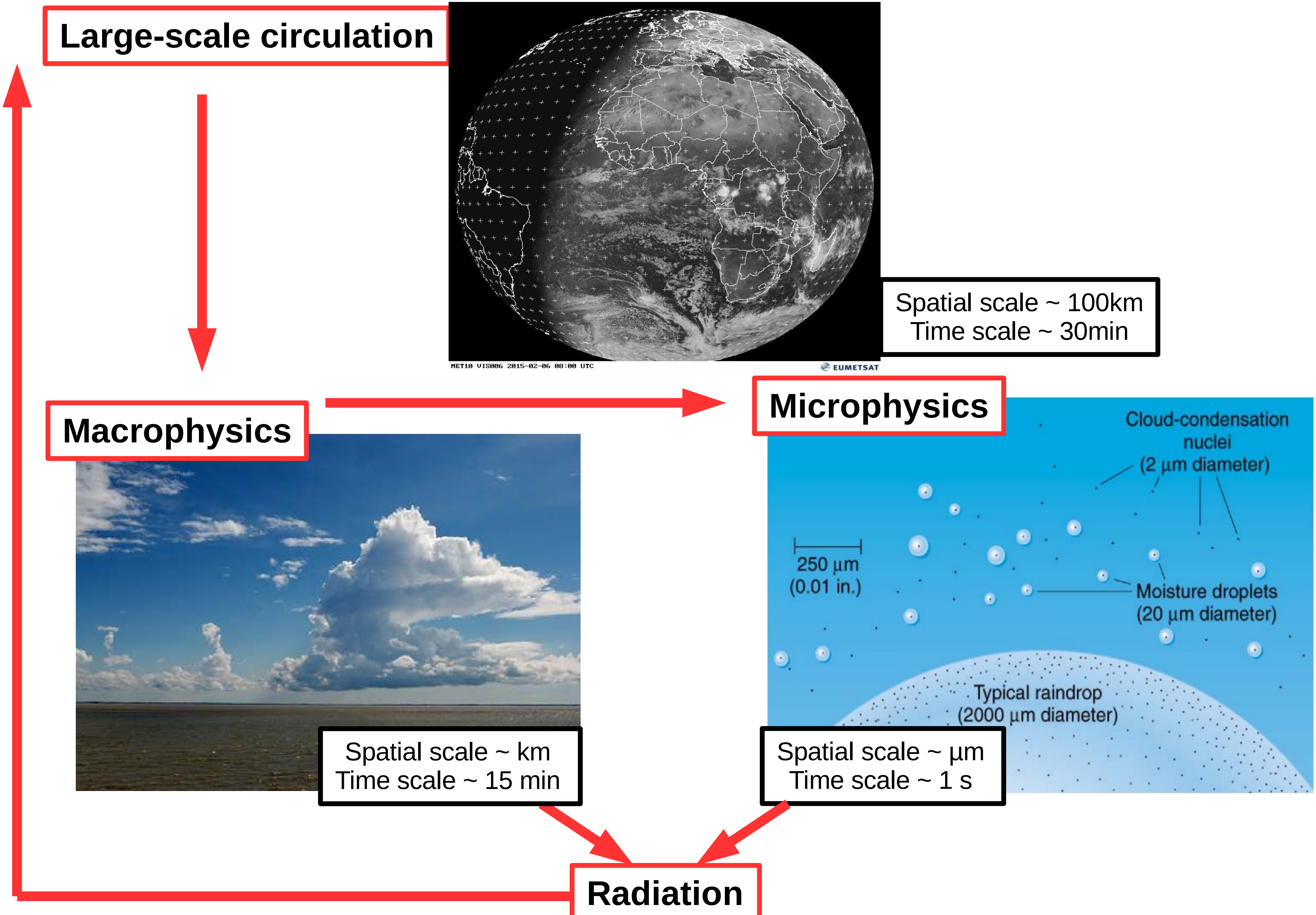
Sensitivity (in W m−2 K−1) of the SW radiative forcing of clouds in the Tropics (30°S-30°N) to the change of SST associated to an increase of CO2 of 1% per year as simulated by 15 climate models



Bony et al., JC, 2006

➔ Model dispersion is the strongest in regions of subsidence (**cumulus and stratocumulus**)

Modeling clouds in GCM : a challenge



Fundamental process

- Clausius-Clapeyron equation :

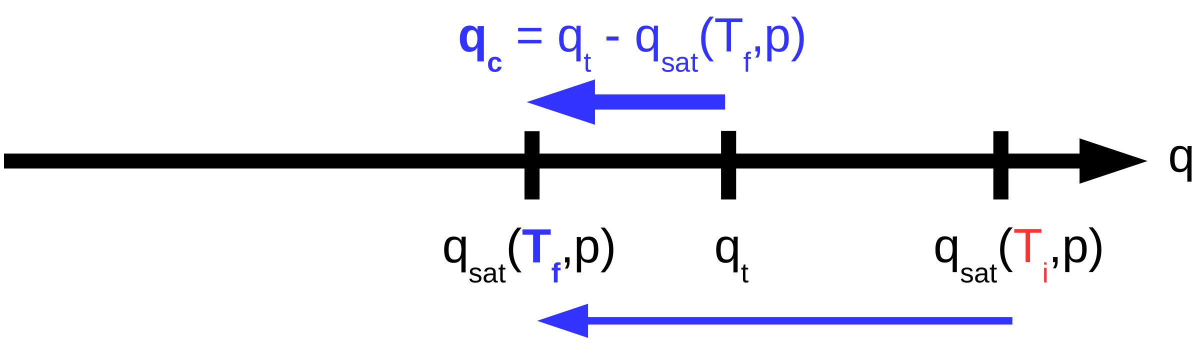
$$\frac{1}{e_{\text{sat}}}\frac{\mathrm{d}e_{\text{sat}}}{\mathrm{d}T} = \frac{L}{R_{\text{vap}}T^2}$$

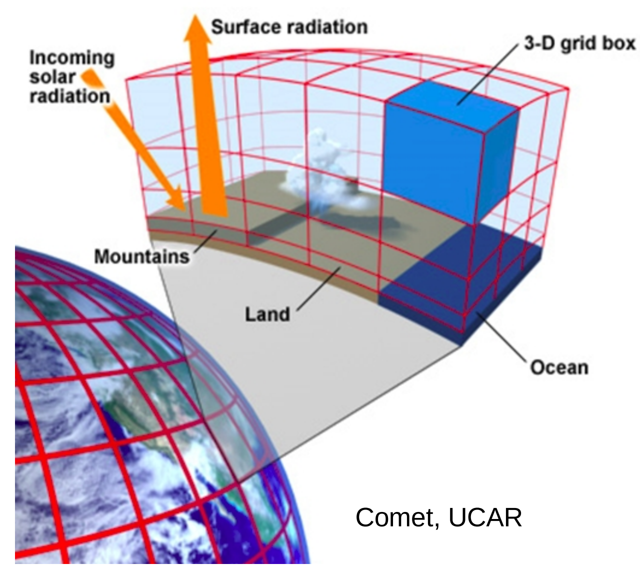
T	0°C	20°C
e_{sat}	6.1 hPa	23.4 hPa
q_{sat}	$3.7\ \text{g kg}^{-1}$	$14.4\ \text{g kg}^{-1}$

- Saturation mass mixing ratio :

$q_{sat}(T,p) \simeq 0.622\,\dfrac{e_{sat}(T)}{p}$, where $e_{sat}(T)$ grows exponentially with temperature

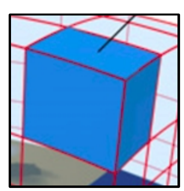
- Clouds form when an air parcel is cooled :



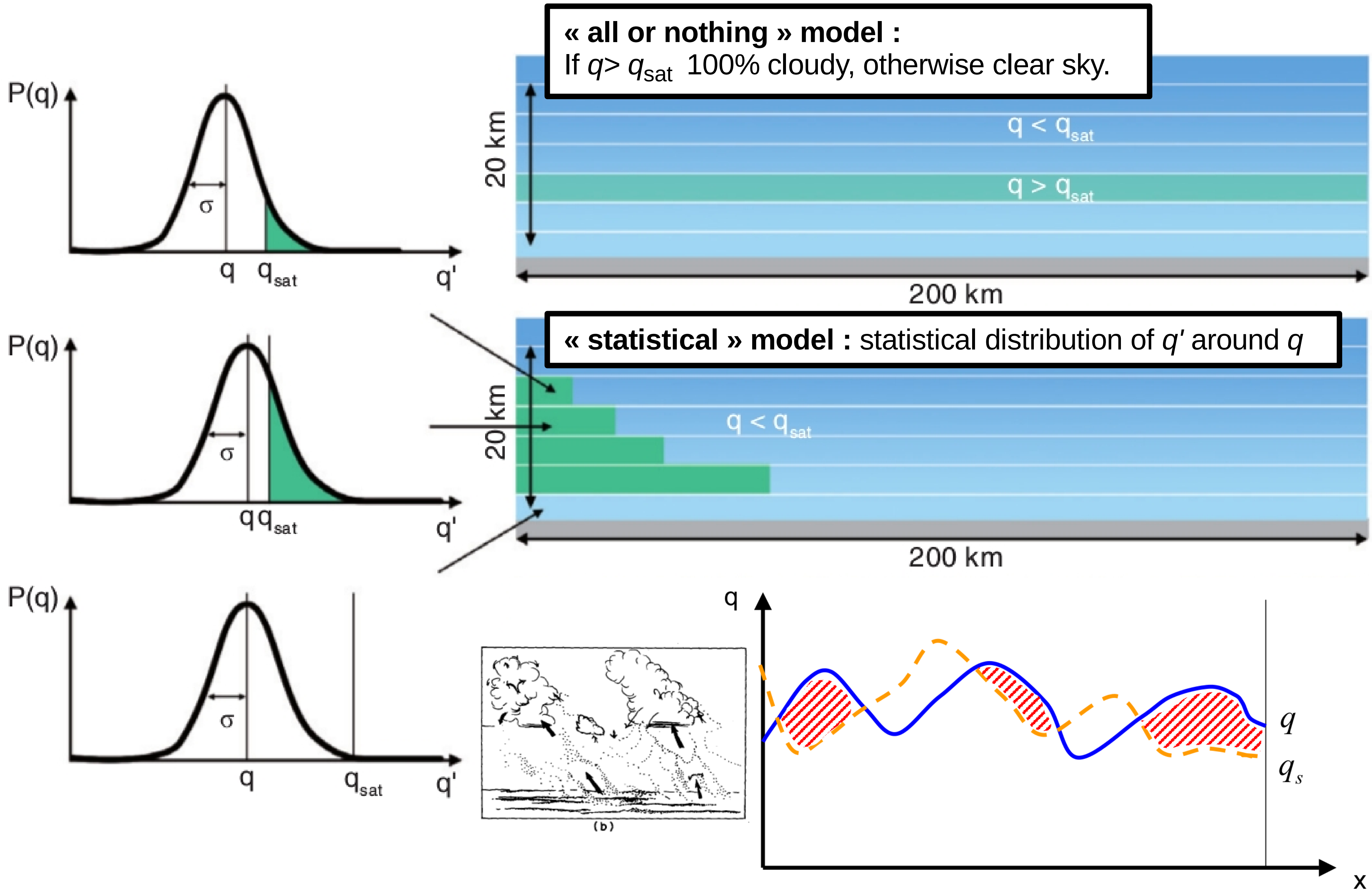


Comet, UCAR

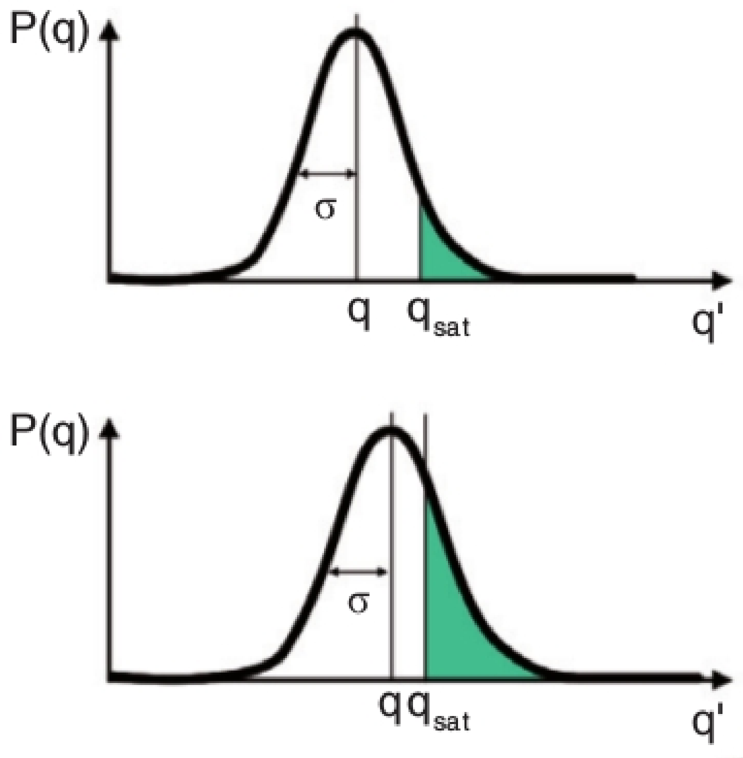
- But clouds do not look like that :



Statistical cloud scheme



Statistical cloud scheme



The goal of a cloud scheme is therefore to compute q_c^{in} and the cloud fraction based on the different physical parameterizations.

Mean total water content :

$$\bar{q} = \int_0^{\infty} q \; P(q) \; dq$$

Domain-averaged amount of condensate :

$$q_c = \int_{q_{sat}}^{\infty} (q - q_{sat}) P(q) dq$$

Cloud fraction :

$$\alpha_c = \int_{q_{sat}}^{\infty} P(q) dq$$

In-cloud condensed water content :

$$q_c^{in} = \frac{q_c}{\alpha_c}$$

LMDZ physics parameterizations

physiq_mod.F90 structure - I

Initialization (once) : *conf_phys, phyetat0, phys_output_open*

Beginning *change_srf_frac, solarlong*

Cloud water evap. *reevap*

Vertical diffusion (turbulent mixing) *pbl_surface*

Deep convection *conflx* (Tiedtke) or *concvl* (Emanuel)

Deep convection clouds *clouds_gno*

Density currents (wakes) *calwake*

Strato-cumulus *stratocu_if*

Thermal plumes *calltherm* and *ajsec* (sec = dry)

Thermal plume clouds

Large scale condensation *fisrtilp*

Diagnostic clouds for Tiedtke *diagcld1*

Aerosols *readaerosol_optic*

Cloud optical parameters *newmicro* or *nuage*

Radiative processes *radlwsw* (bis)

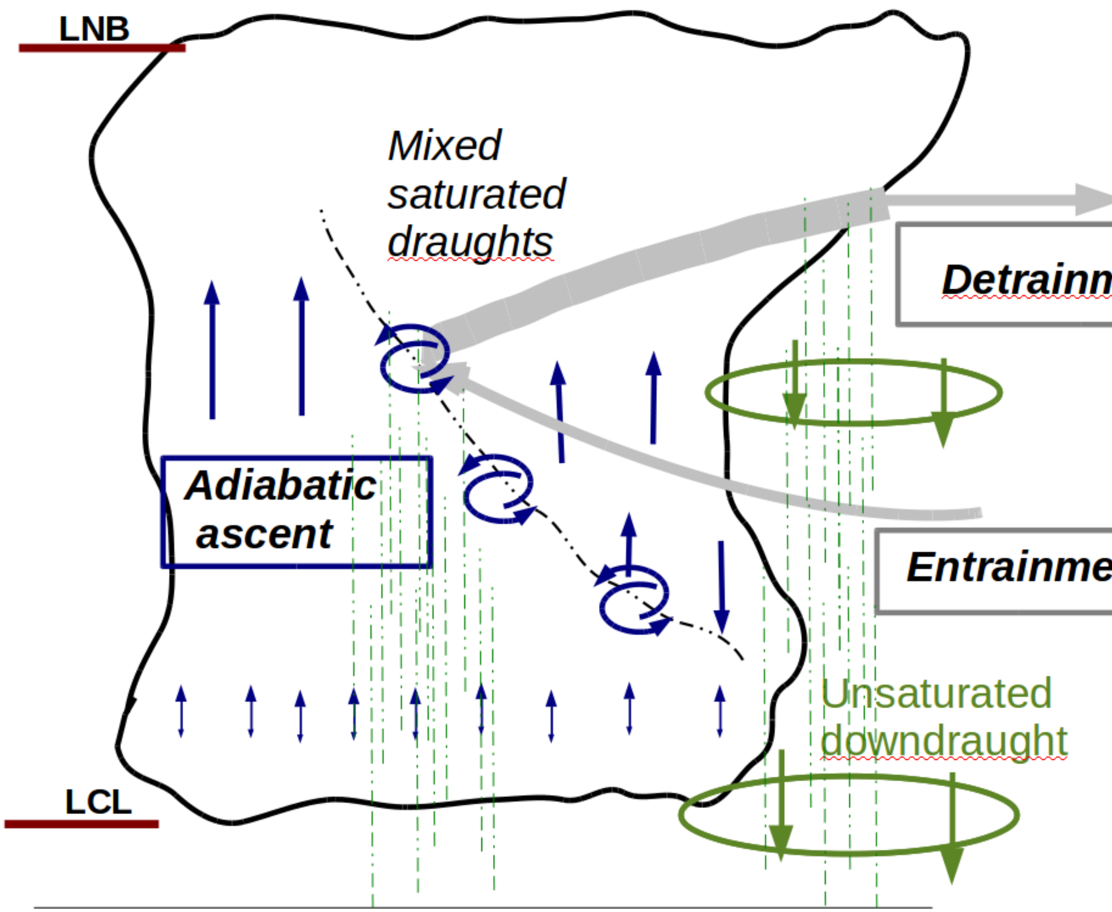
In blue : subroutines and instructions modifying state variables

CAREFUL : clouds are evaporated/sublimated at the beginning of each time step (~15 min), but vapor, droplets and crystals are prognostic variables. In other words, clouds can move but can't last for more than one timestep (meaning that for example, crystals can't grow over multiple timesteps).

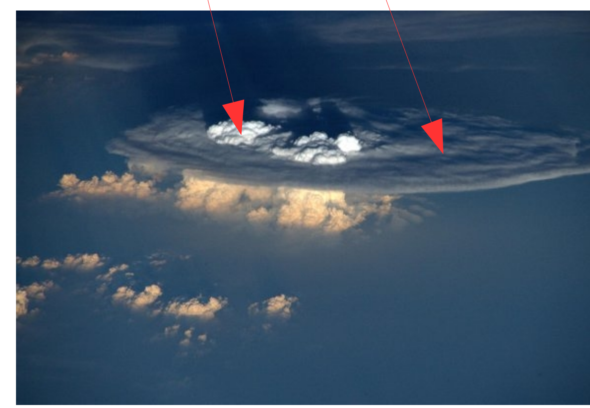

Deep convective clouds

Deep convection

Emanuel scheme



$$q_c^{in} = \frac{\sigma_a \; q_{ca} + \sigma_m \; q_{cm}}{\sigma_a + \sigma_m}$$



$$q_c^{in} = \frac{\dfrac{M_a}{\rho \; w_a} \; q_{ca} + \dfrac{\tau \; M_t \; g}{\delta p} \; q_{cm}}{\dfrac{M_a}{\rho \; w_a} + \dfrac{\tau \; M_t \; g}{\delta p}}$$

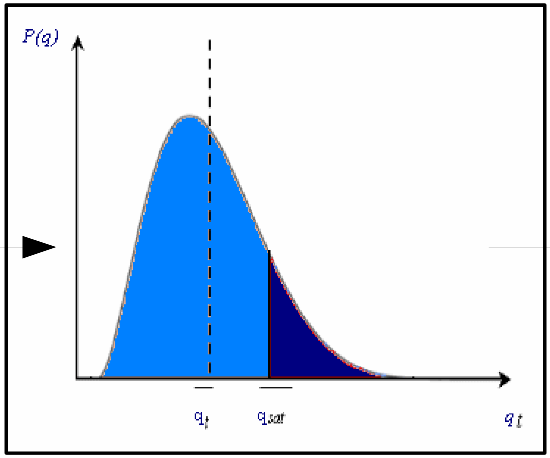
q_c^{in} is computed by the deep convection scheme and $\bar{q}$ is known → cloud fraction is found

The deep convection cloud scheme
clouds_gno.F90

Log-normal distribution of total water qt

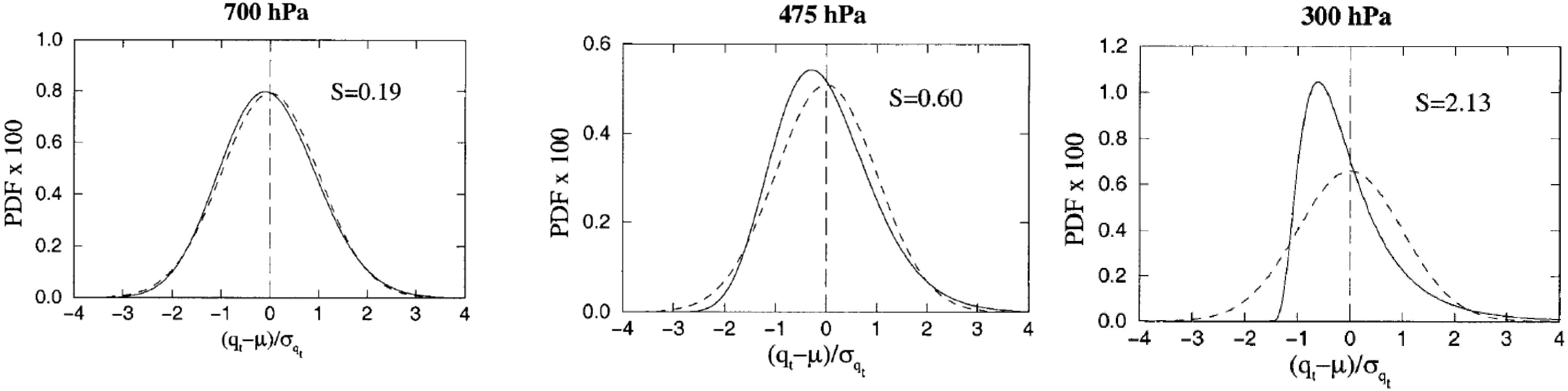
Grid cell
mean state → qt, qsat

Convection scheme → qc



→ σ, cf

Vertical variation of the PDF on the oceanic case TOGA-COARE
20-27 December 1992



Bony & Emanuel, JAS, 2001

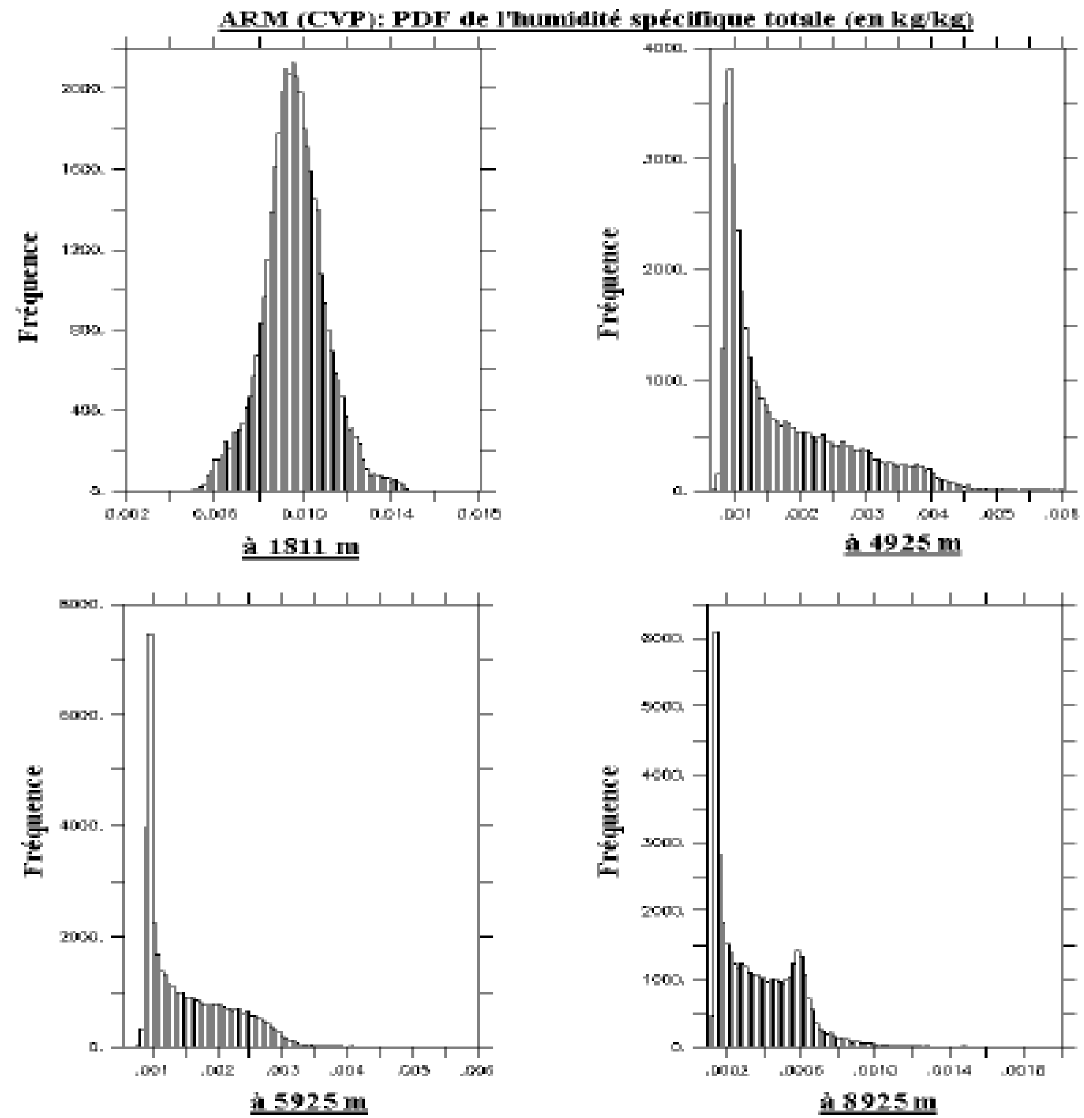
Deep convective cloud tuning parameters

CLDLC: threshold on maximum condensate *(cld_lc_con)*
CLDTAU: auto-conversion rate *(cld_tau_con)*
COEF_EVA: parameter controlling the evaporation of precipitation *(coef_eva)*
EPMAX: maximum efficiency of precipitation *(epmax)*
FALLV: factor on the fall speed of ice crystals *(ffallv_con)*

But tuning is not sufficient

Lognormal distribution is not the best-suited:
The distribution should also be bi-modal

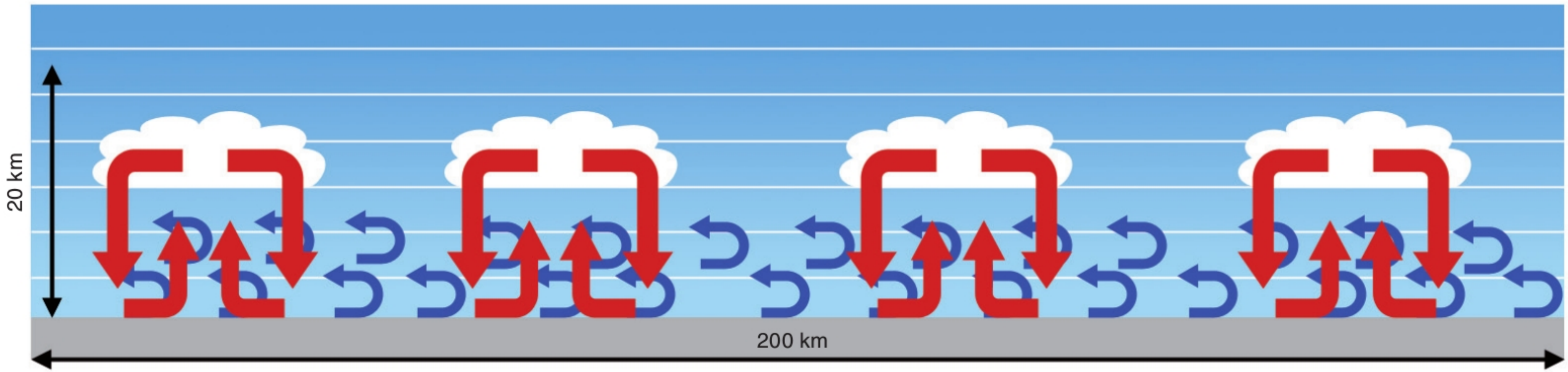
Work in progress to define a bimodal distribution from deep convection characteristics (Arnaud Jam)

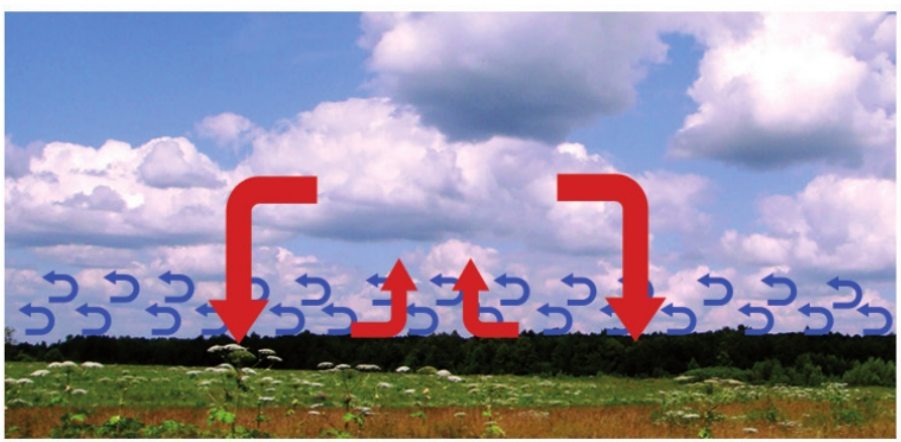


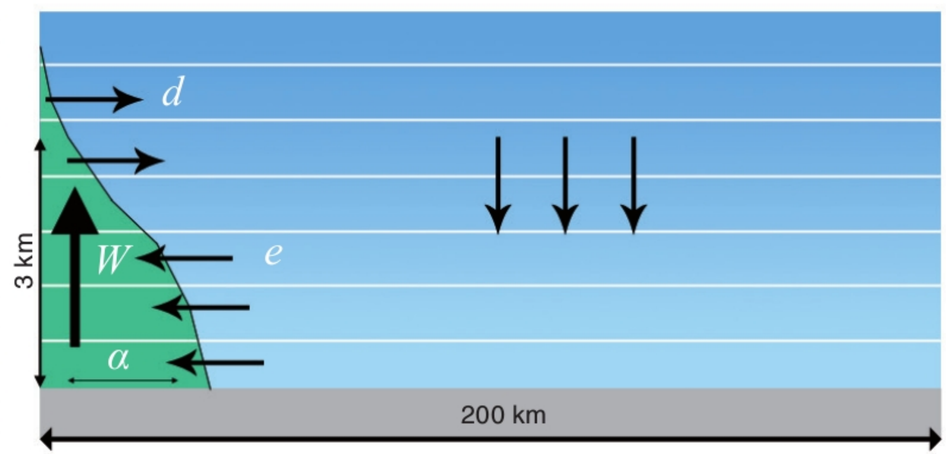

Boundary-layer clouds

Boundary-layer thermals

Cumulus are the saturated part of thermals initiated at the surface







The thermal plume model computes:
- Thermodynamical properties of thermals: θ_th, qt_th, ql_th
- The fractional coverage of thermals: α

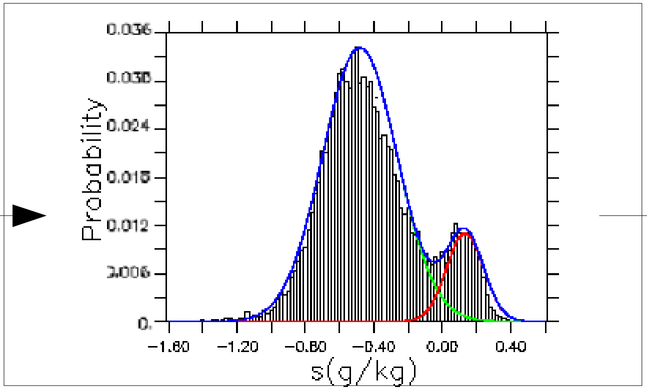
Boundary-layer cloud scheme
cloudth.F90

Bi-Gaussian distribution of saturation deficit s:

$S = a_l \, (q_t - q_{sat}(T))$

- One mode associated with thermals sth, σth
- One mode associated with their environment: senv, σenv

s_{env}, σ_{env}
$s_{th}, \sigma_{th}, \alpha$ →



→ q_c, cf

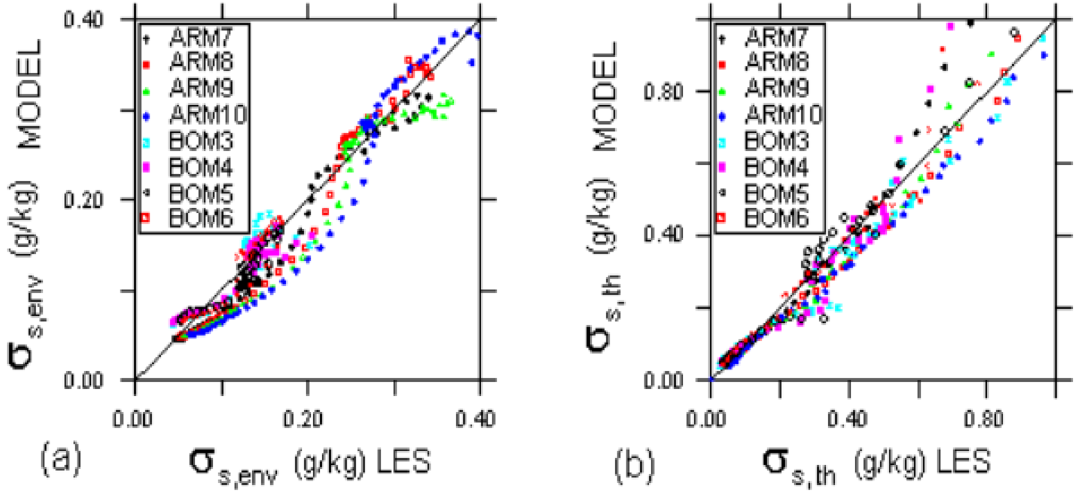
Jam & al., BLM, 2013

We know:
Mean state: s_{env}
Thermal properties: s_{th}, α

Parameterization of the variances:

$$\sigma_{s,env} = c_{env} \times \left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{2}} \times (\bar{s}_{th} - \bar{s}_{env}) + b \times \bar{q}_{t_{env}}$$

$$\sigma_{s,th} = c_{th} \times \left(\frac{\alpha}{1-\alpha}\right)^{-\frac{1}{2}} \times (\bar{s}_{th} - \bar{s}_{env}) + b \times \bar{q}_{t_{th}}$$



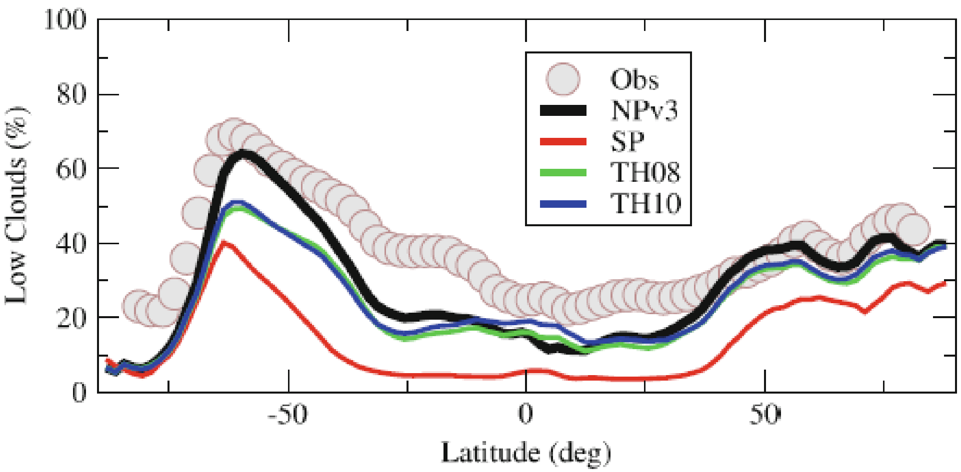
q_c^{in} and cf are deduced from the mean water content of the environment and thermals and the parameterized spreads of the two gaussian distributions

Boundary-layer cloud tuning parameters

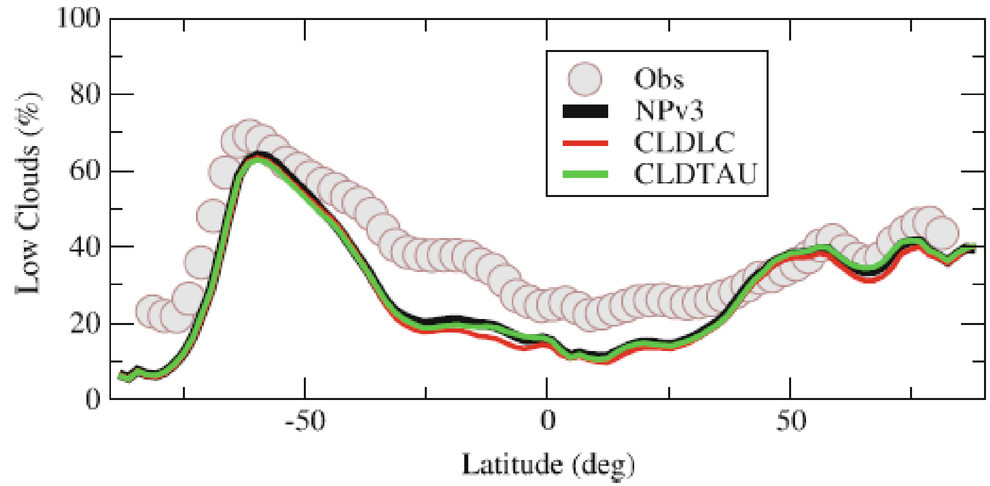
CLDLC: threshold on the maximum liquid water content of clouds *(cld_lc_lsc)*
CLDTAU: autoconversion rate *(cld_tau_lsc)*
COEF_EVA: parameter controlling the evaporation of precipitation *(coef_eva)*

Sensitivity of the low-level cloud fraction to:

A change of parameterizations



A change of parameters

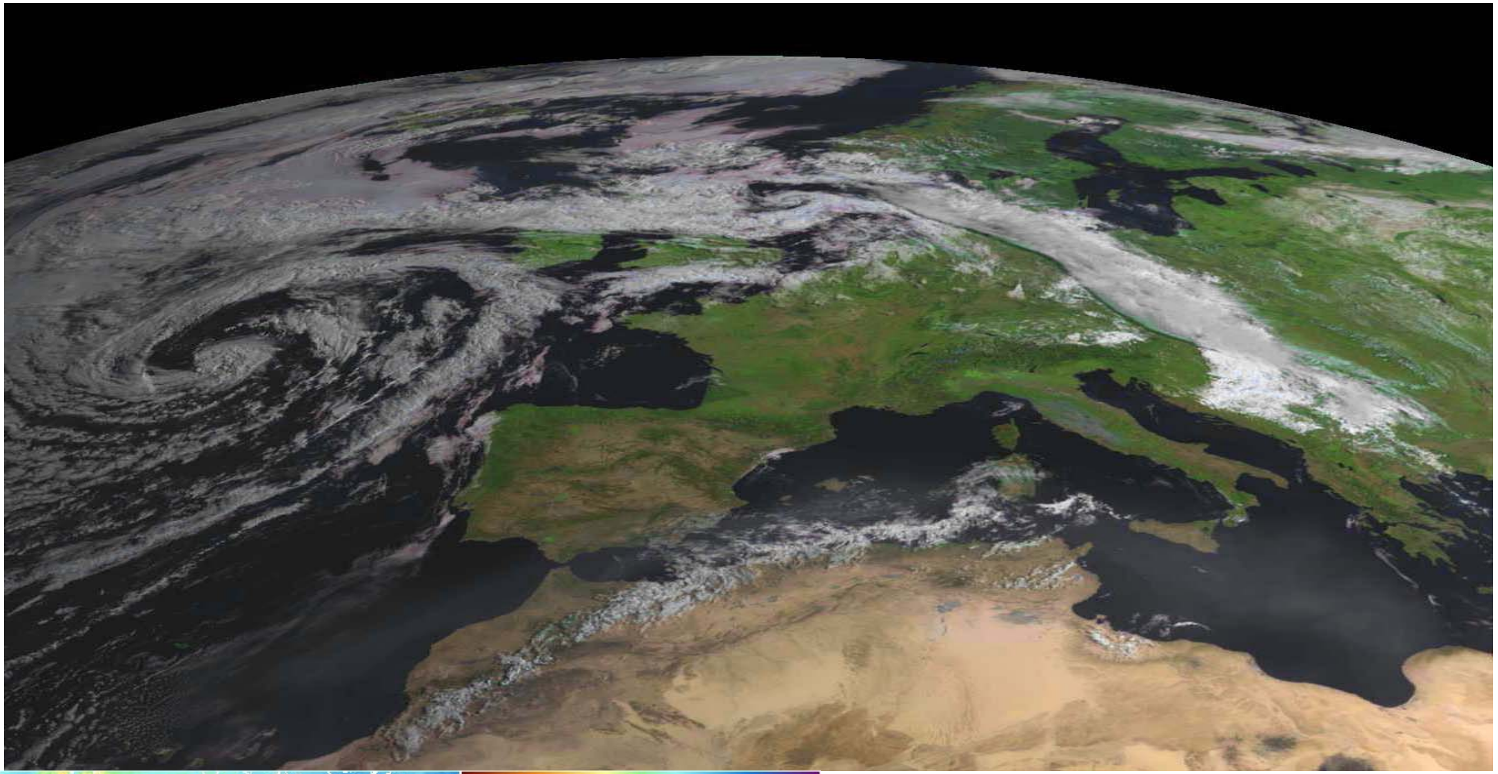


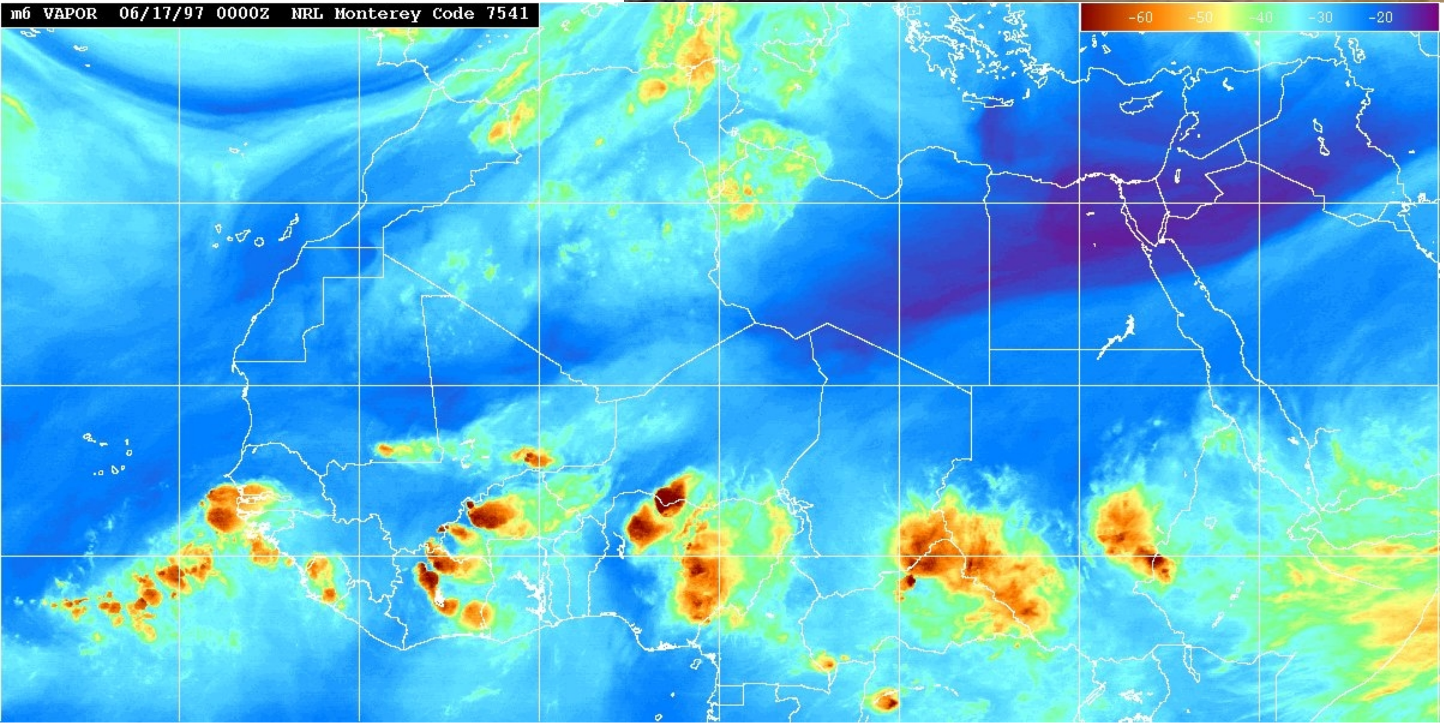
The low-level cloud cover is more sensitive to parameterization changes than tuning parameter changes.
However, tuning parameters can still impact cloud microphysical properties and thus their radiative impact.
Work is ongoing to better constrain tuning parameters using observations (COSP simulator).


Large-scale clouds

Large-scale condensation

Mid-latitude
cyclones





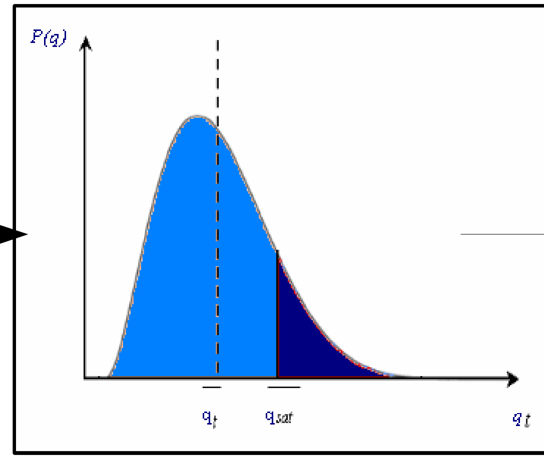
Convection organized
in squall lines
in Africa

The large-scale cloud scheme
fisrtilp.F90

Log-normal distribution of total water q_t (Bony & Emanuel, JAS, 2001)

Grid-cell mean state → q, qsat

σ/q imposed

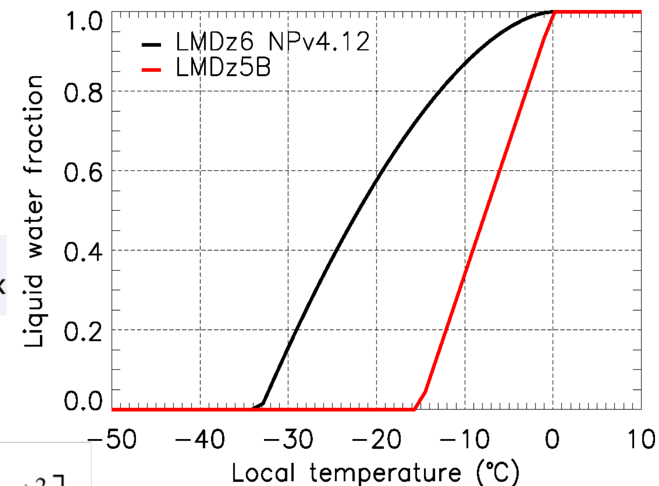


$$\alpha_c = \int_{q_{sat}}^{\infty} P(q)dq$$

$$q_c = \int_{q_{sat}}^{\infty} (q - q_{sat})P(q)dq$$

- condensate: liquid/ice partitioning (function of the temperature) :

$$^{a}\text{Cloud liquid fraction} = \left(\frac{T - T_{\min}}{T_{\max} - T_{\min}}\right)^{n}, \text{ for } T_{\min} \leq T \leq T_{\max}$$



- A fraction of the condensate falls as rain (parameters controlling the maximum water content of clouds and the auto-conversion rate) :

$$\frac{dq_{lw}}{dt} = -\frac{q_{lw}}{\tau_{convers}}\left[1 - e^{-(q_{lw}/clw)^2}\right]$$

$$\frac{dq_{iw}}{dt} = \frac{1}{\rho}\frac{\partial}{\partial z}(\rho w_{iw} q_{iw})$$

$$w_{iw} = \gamma_{iw} w_0$$

$$w_0 = 3.29(\rho q_{iw})^{0.16}$$

- The rain is partly evaporated in the grid below (parameter controlling the evaporation rate) :

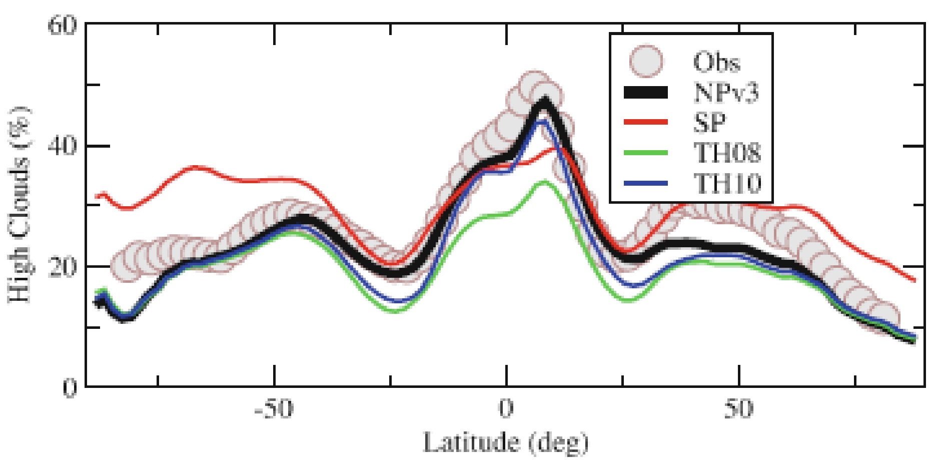
$$\frac{\partial P}{\partial z} = \beta[1 - q/q_{sat}]\sqrt{P}$$

The large-scale cloud tuning parameters

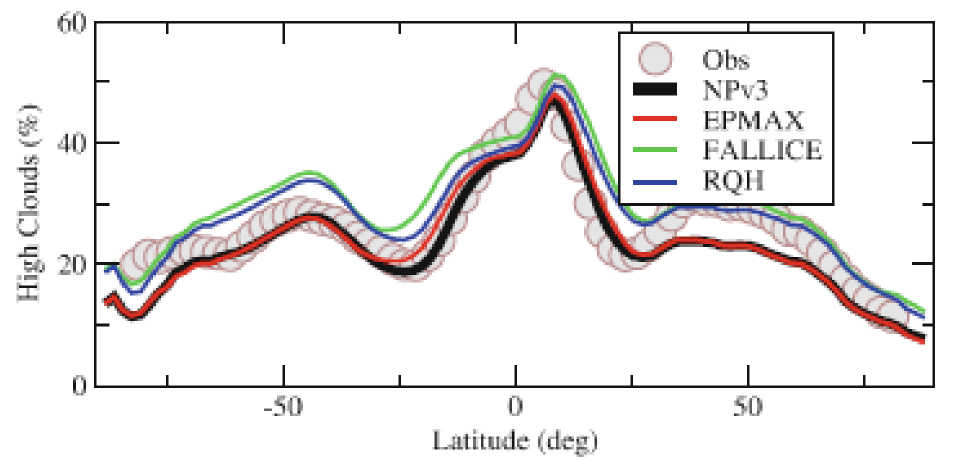
Parameters controlling large-scale clouds and precipitation (physiq.def):
CLDLC: threshold on maximum of condensate *(cld_lc_lsc)*
CLDTAU: auto-conversion rate *(cld_lc_tau)*
FALLICE: factor on the fall speed of ice crystals *(ffallv_lsc)*
COEFEVA: parameter controlling the evaporation of precipitation *(coef_eva)*

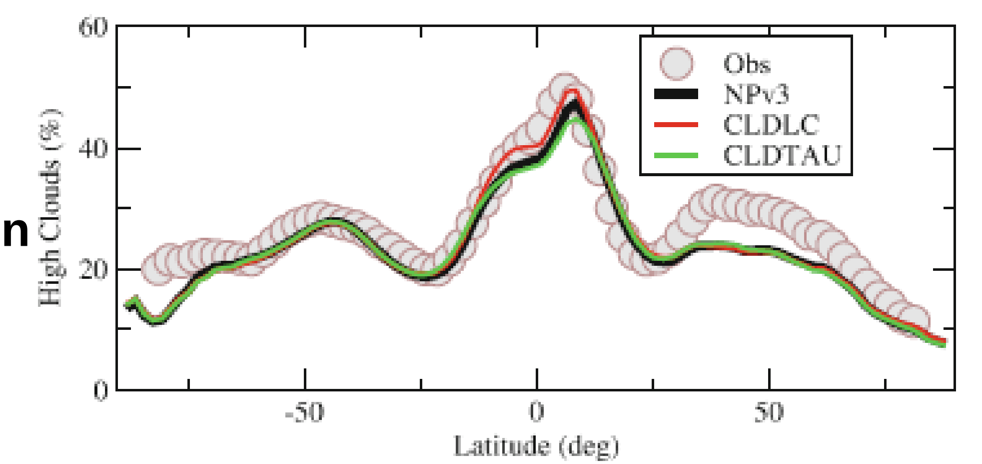
Sensitivity of the high cloud fraction to:

A change of parameterizations



A change of parameters





Strong sensitivity to tuning parameters,
in particular to the width of the distribution

→ **Need to connect the large-scale condensation to the deep convection scheme**

Total cloud fraction and cloud water content:

cldfra = min(cf(thermals) + cf (convection) + cf (large-scale), 1.)

cldliq = qc(thermals) x cf(thermals)
+ qc (convection) x cf(convection)
+ ql (large-scale)

Coupling with radiation

- Hypothesis on cloud overlap (maximum random)
- Imposed values of diameters of cloud droplets and ice crystals
- Indirect effect of aerosols