Clouds in LMDZ

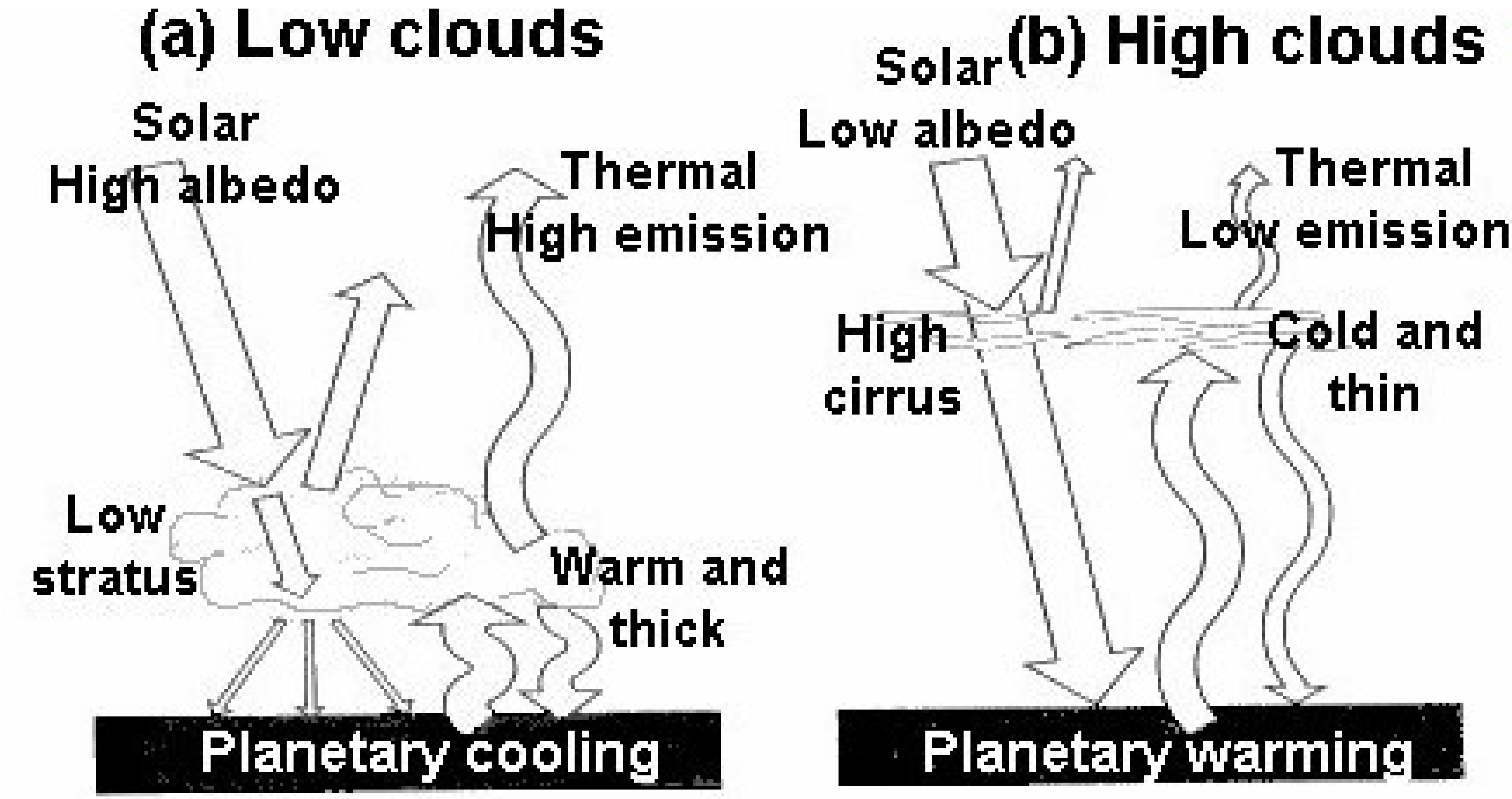
Catherine Rio
LMDZ Development Team

LMDZ training course – 9/10/11 December 2013 – LMD Jussieu

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

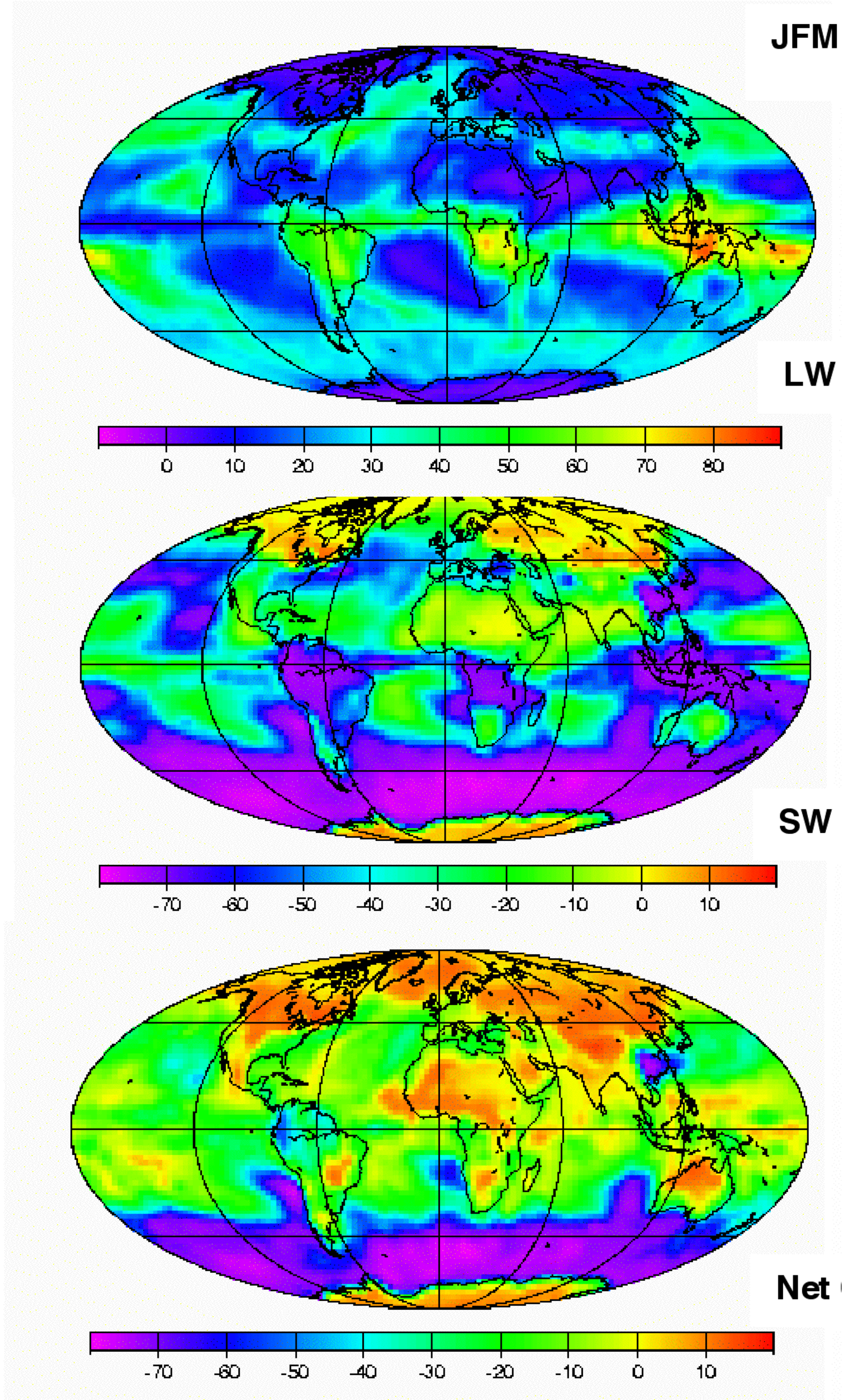
Negative: clouds decrease
the energy absorbed (clouds brighter)

Annual mean: -47W/m2

Net radiative forcing

Annual mean: -18W/m2

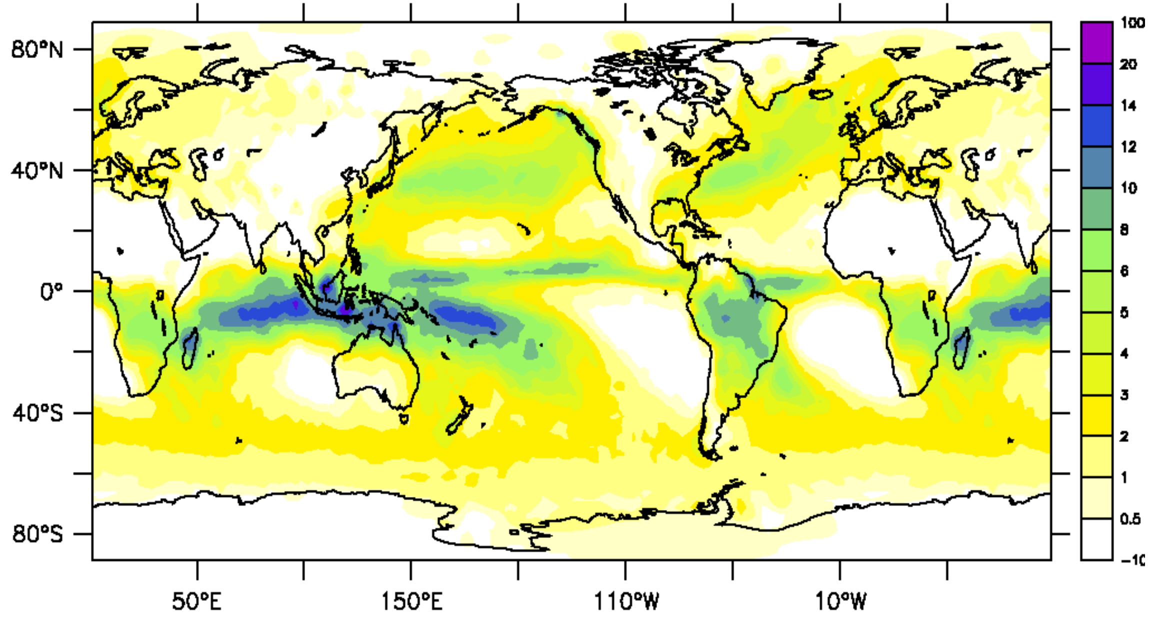
Globally, clouds cool the planet.



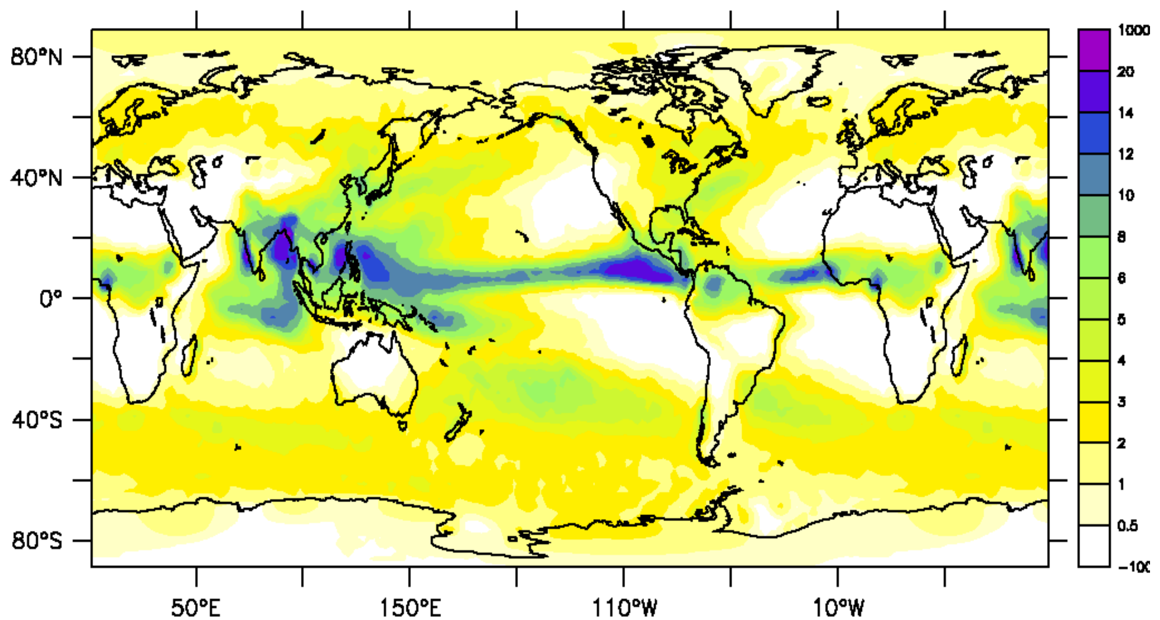
Clouds et precipitation

Precipitation (mm/day)

January

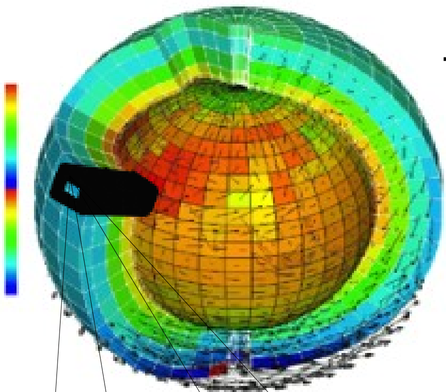


July



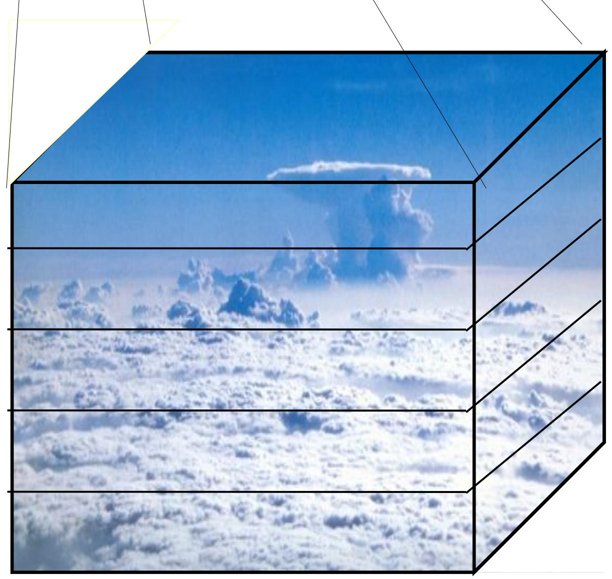
Importance of the good representation of the occurrence frequency of the different types of clouds, their seasonal variability, their diurnal cycle...

Methodology to develop and evaluate parameterizations



1D case studies built from field campaigns (BOMEX, TOGA-COARE, TWP-ICE, AMMA...) or routinely in-situ measurements (ARM)

1D simulations

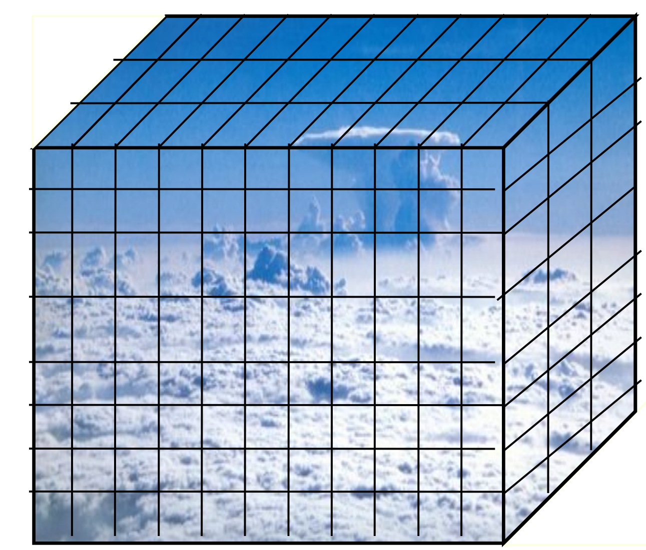


200km

Explicit simulations over a domain equivalent to a GCM grid cell

Provide quantities difficult to measure (structures properties, mixing rates etc...)

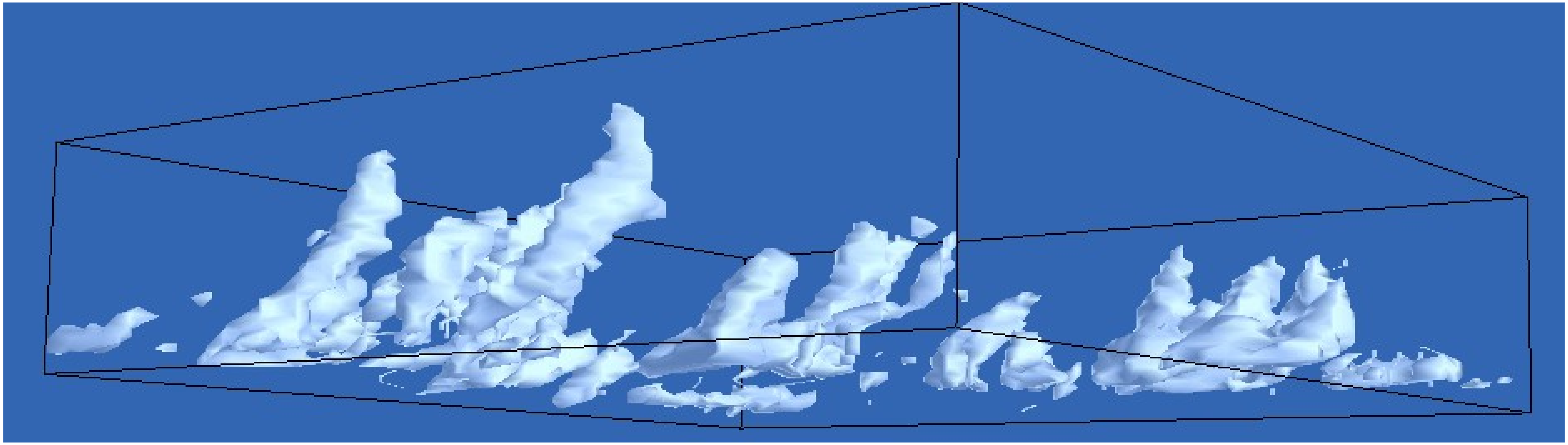
Identical forcing:
Initial profiles
Large-scale advection
Surface fluxes



200km

Use of explicit simulations for parameterization development

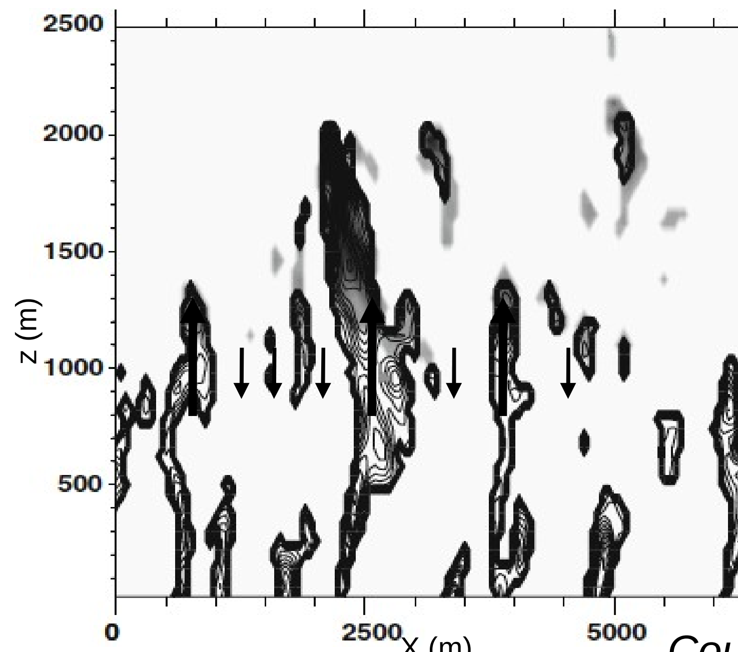
Simulated cumulus field:



http://www.knmi.nl/~siebesma/BLCWG/

- Evolution of mean variables:
  Ex: T, q, cloud fraction (cf)
- Statistics over the domain:
  Ex: PDF of qt, θl
- Properties of clouds:
  Ex: condensate

Identification of thermals in the Large-Eddy Simulation



Conditional sampling of thermals based on a tracer emitted at the surface.

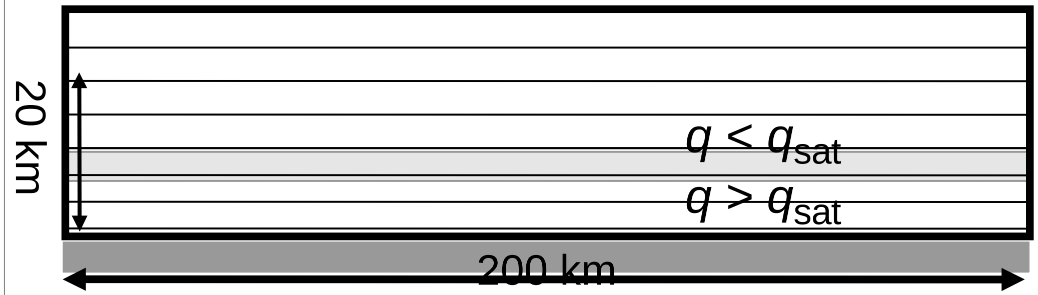
Couvreux et al., BLM, 2010

Statistical cloud schemes

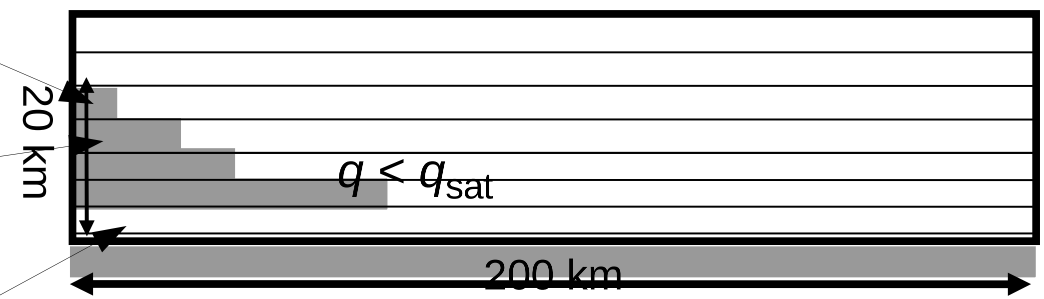
q : water vapor concentration
q_{sat} : maximum concentration at saturation
If $q > q_{sat}$:
→ water vapor condensates = clouds

We know the mean q *and* q_{sat}
→ Fraction of the grid covered by clouds ?

« all or nothing » model :
If $q > q_{sat}$ 100% cloudy, otherwise clear sky.



« statistical » model :
We assume a statistical distribution of q' around q within the grid cell

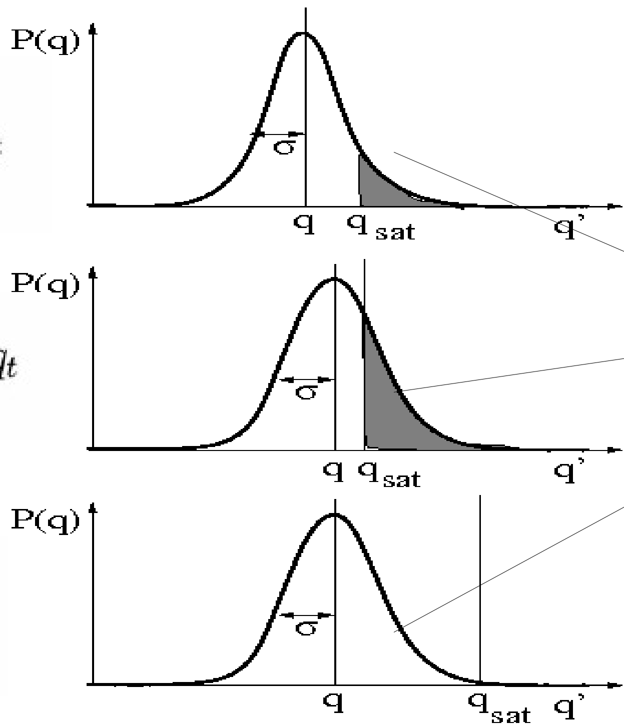


Simple parameterization : Gaussian σ / q = 20%

$$f = \int_{q_s}^{\infty} P(q_t)\, dq_t$$

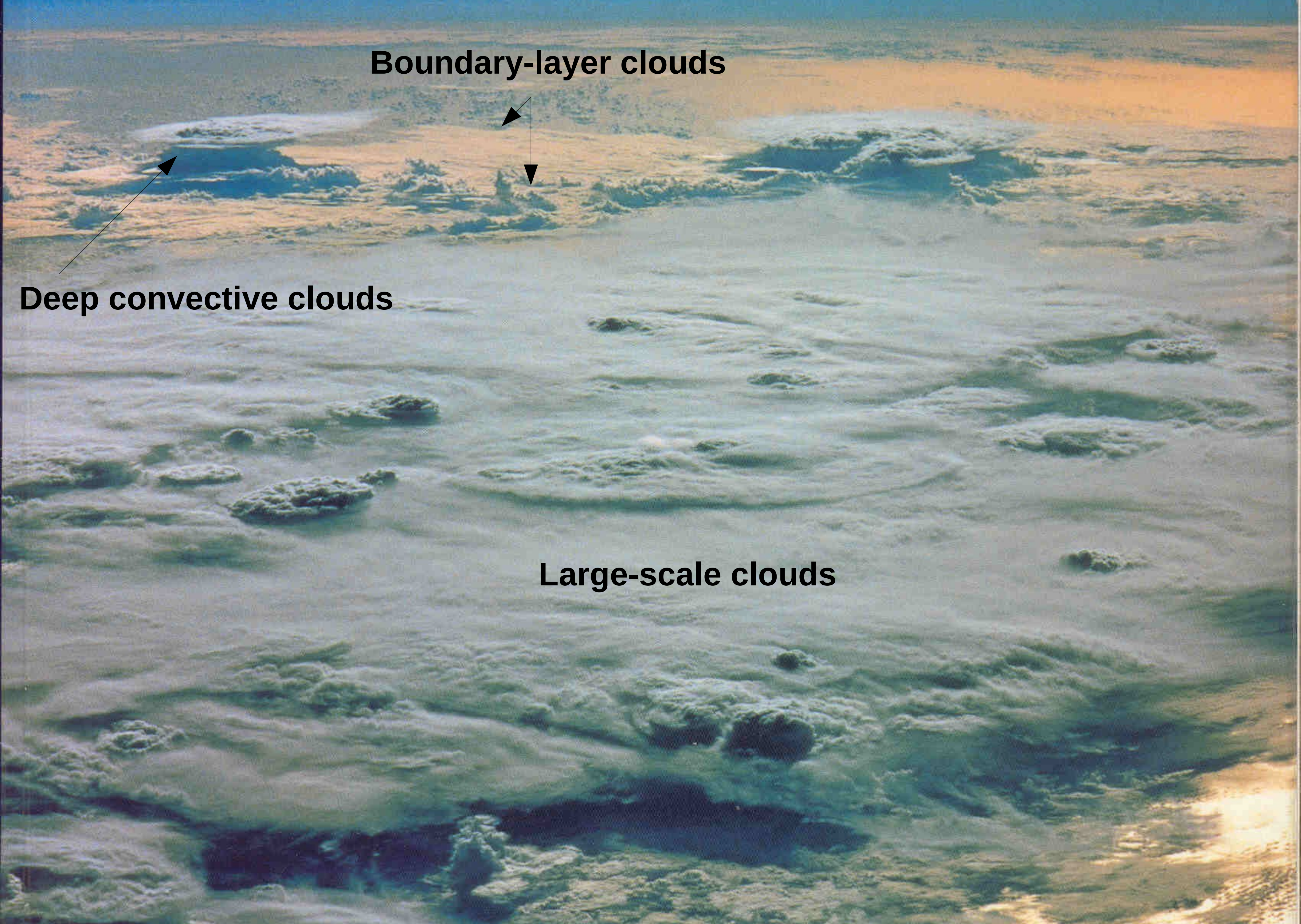
$$\overline{q_{tc}} = \int_{q_s}^{\infty} q_t P(q_t)\, dq_t$$

$$q_c^{in} = \frac{\overline{q_{tc}}}{f} - \overline{q_s}$$



- condensate: liquid/ice partitioning (function of the temperature) → radiation
- A fraction of the condensate falls as rain (parameters controlling the maximum water content of clouds and the auto-conversion rate)
- The rain is partly evaporated in the grid below (parameter controlling the evaporation rate)

Cloud schemes depend on cloud types

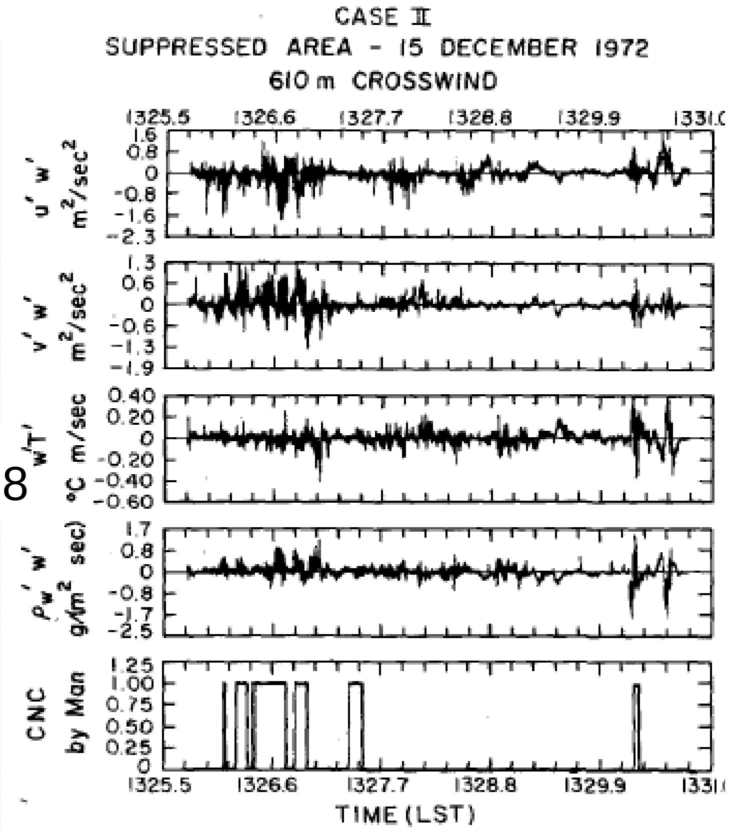


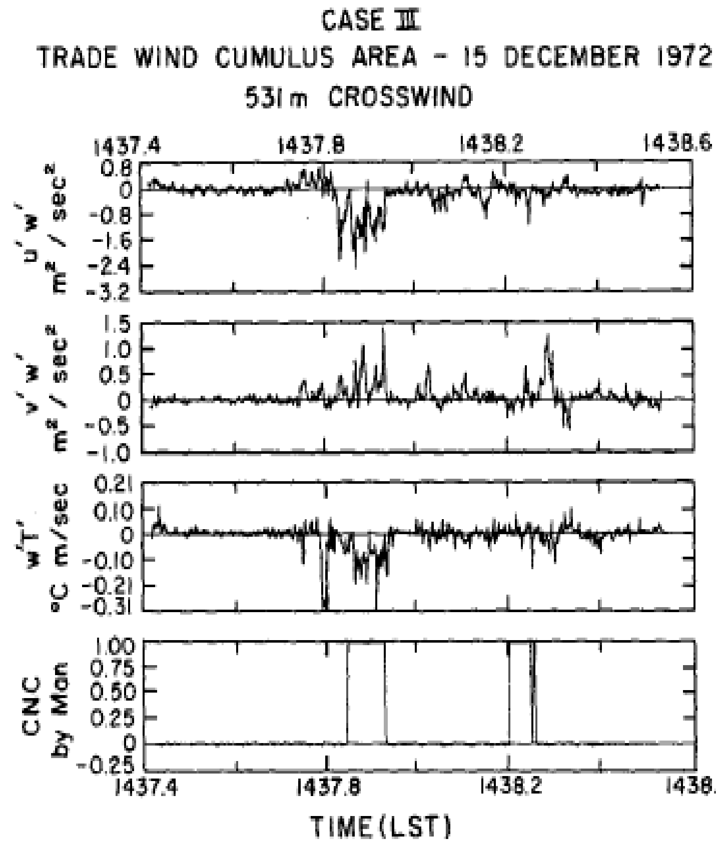

Boundary-layer clouds

Cumulus and thermals

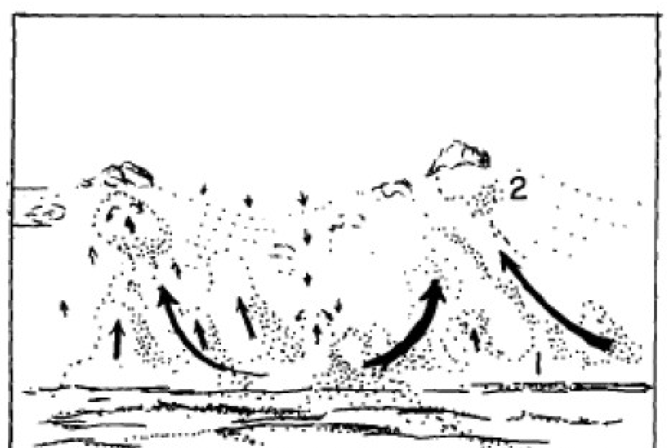
Case II: 15 dec 1972- 12h48

Case III: 15 dec 1972 - 14h18

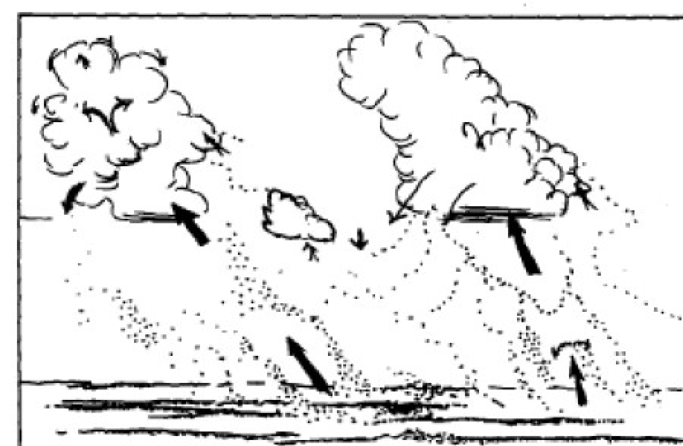




Cumulus are the saturated part of thermals initiated at the surface



(a)



(b)

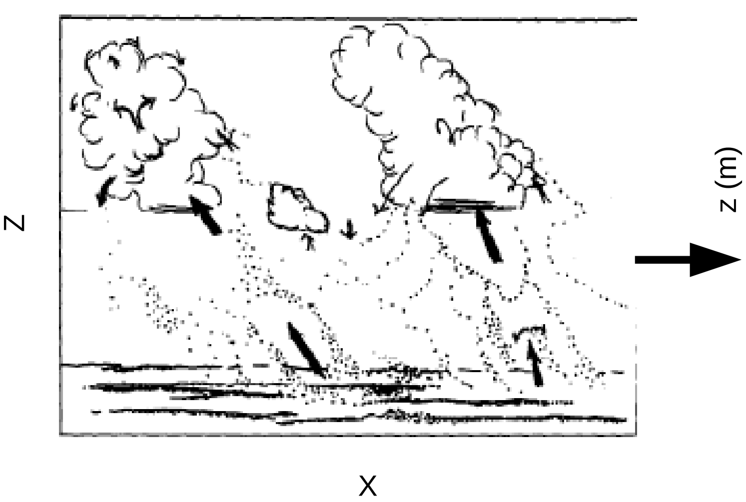
Lemone et Pennell, MWR, 1976

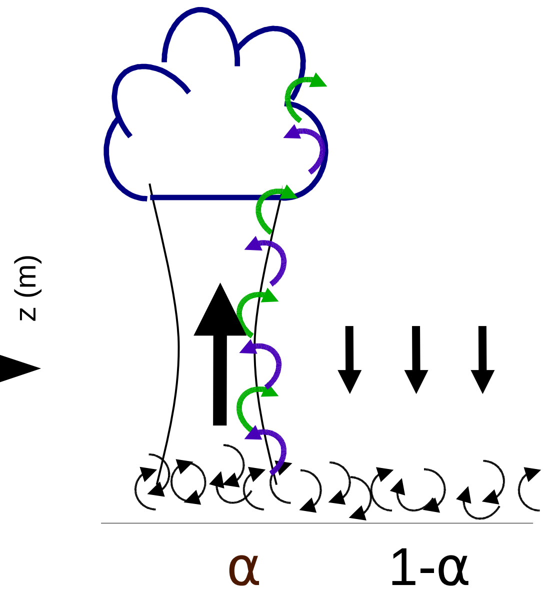
The thermal plume model

Hourdin et al., JAS, 2002; Rio et Hourdin, JAS, 2008

calltherm.F90

LeMone and Pennell, MWR, 1976





Equations

Conservation of mass:

$$\frac{\partial f}{\partial z} = e - d$$

Transport of θl, qt, u, v

$$\frac{\partial f \psi_u}{\partial z} = e\psi - d\psi_u$$

Internal variables

- w: mean vertical velocity within thermals
- α: fractional coverage of thermals
- e: entrainment rate within thermals
- d: detrainment rate from thermals
- qa: concentration of q within thermals

Conservation of momentum:

$$\frac{\partial f w_u}{\partial z} = -d w_u + \alpha g \rho \frac{\theta_{vu} - \theta_v}{\theta_v}$$

\+ Specification of entrainment and detrainment rates
\+ Computation of the mass-flux at the base of plumes

The cloud scheme
cloudth.F90

Bi-Gaussian distribution
of saturation deficit s:

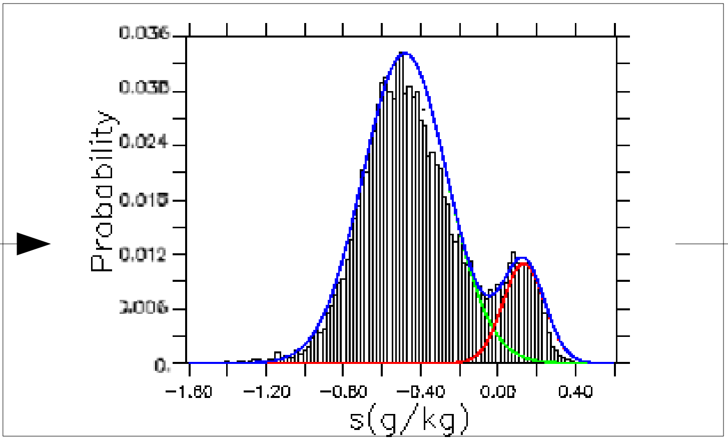
s =al (qt – qsat(Tl))

- One mode associated with thermals
sth, σth

- One mode associated with their environment:
senv, σenv

Shallow convection

senv, σenv
sth, σth,α



qc, cf

Jam & al., BLM, 2012

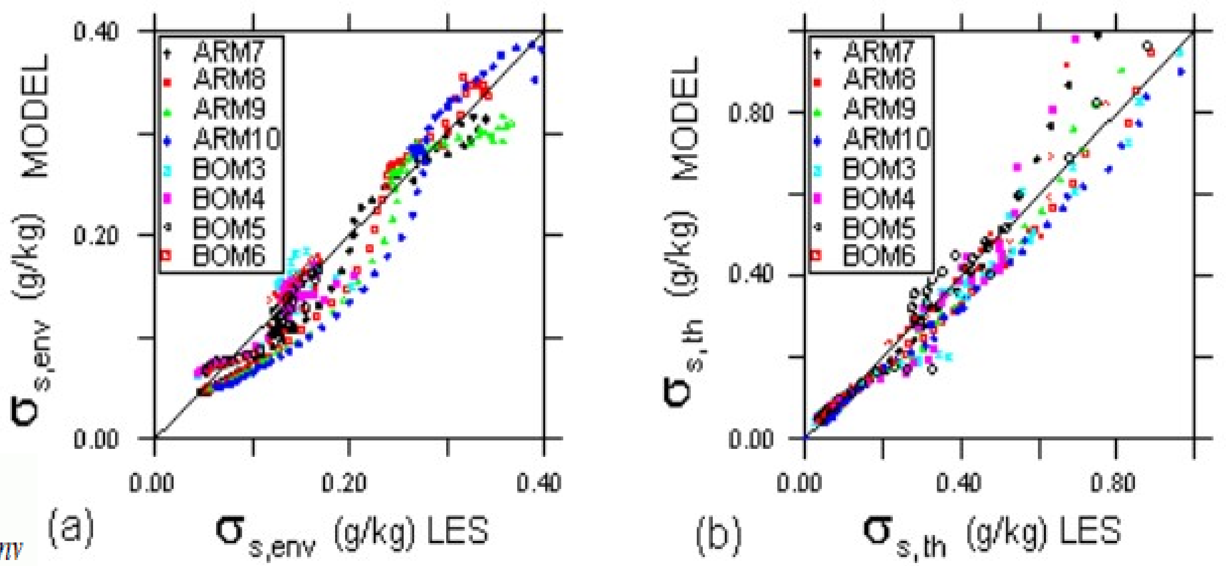
We know:
Mean state: senv
Thermal properties: sth, α

Parameterization of σenv and σth?

Parameterization of the variances:

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

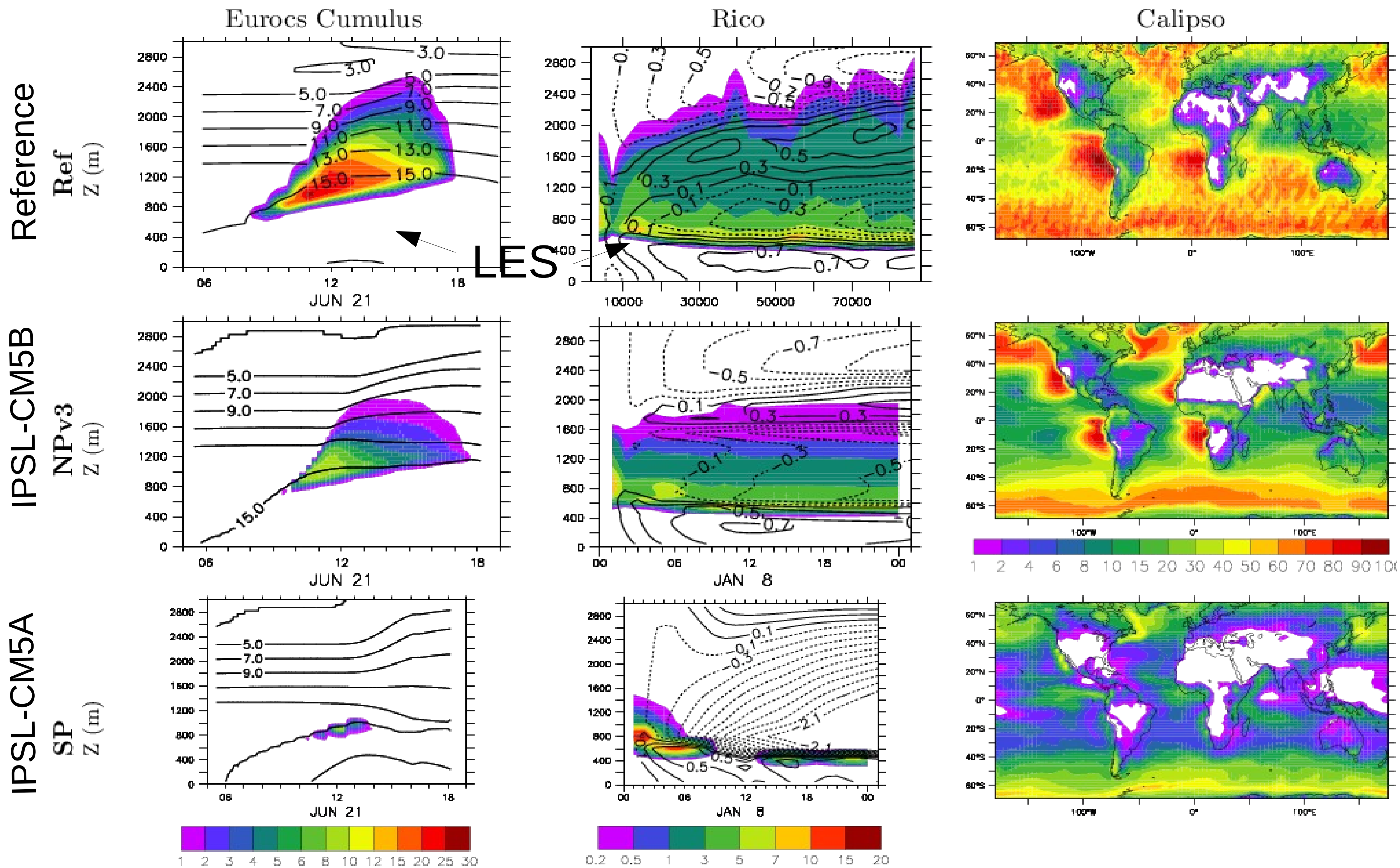
$$\sigma_{s,th} = c_{th} \times \left(\frac{\alpha}{1-\alpha}\right)^{-\frac{1}{2}} \times \left(\bar{s}_{th} - \bar{s}_{env}\right) + b \times \bar{q}_{t_{th}}$$



Representation of low clouds in LMDZ

1D cases
Cloud fraction (%) and liquid water (g/kg)

3D simulations
Low cloud fraction (%)
Annual mean



Better representation of low-level clouds in IPSL-CM5B

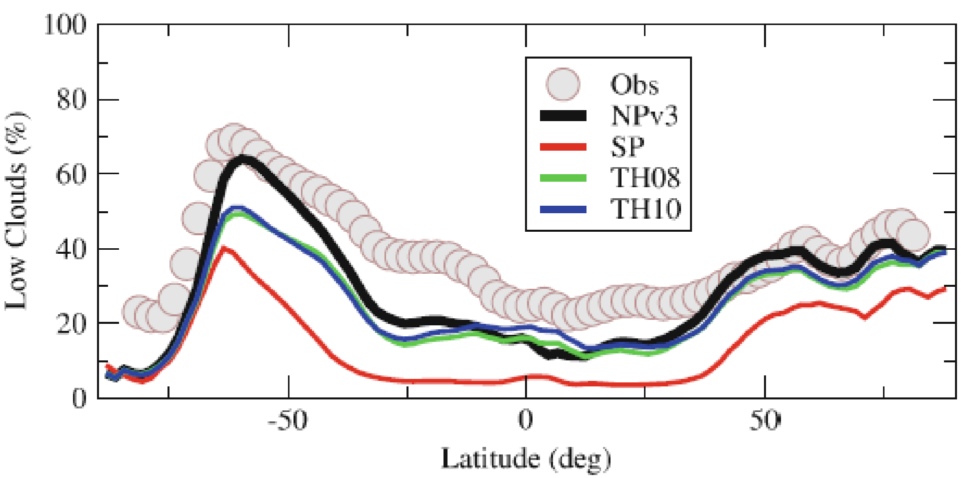
Hourdin et al., 2012

Tuning parameters

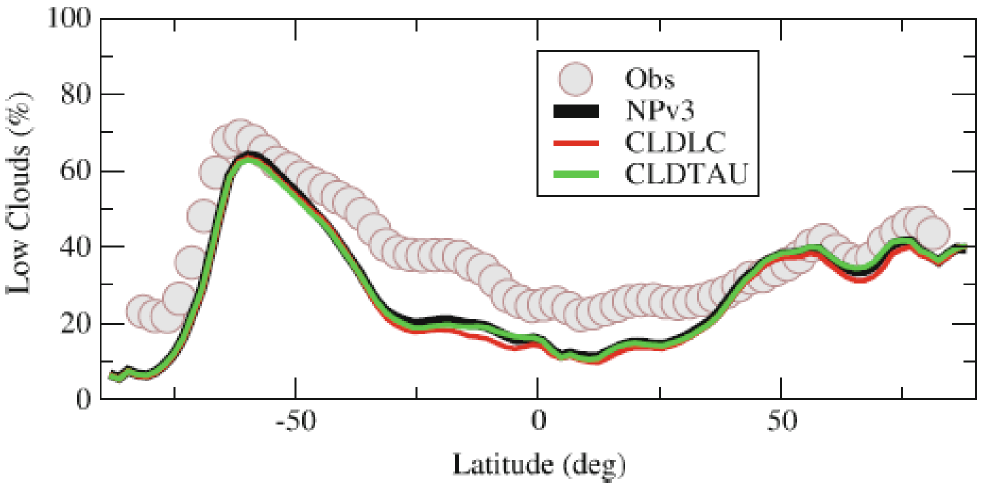
CLDLC: threshold on the maximum liquid water content of clouds *(cld_lc_lsc)*
CLDTAU: autoconversion rate *(cld_tau_lsc)*
COEF_EVA: parameter controlling the evaporation of precipitation *(coef_eva)*

Sensitivity of the low-level cloud fraction to:

A change of parameterizations



A change of parameters

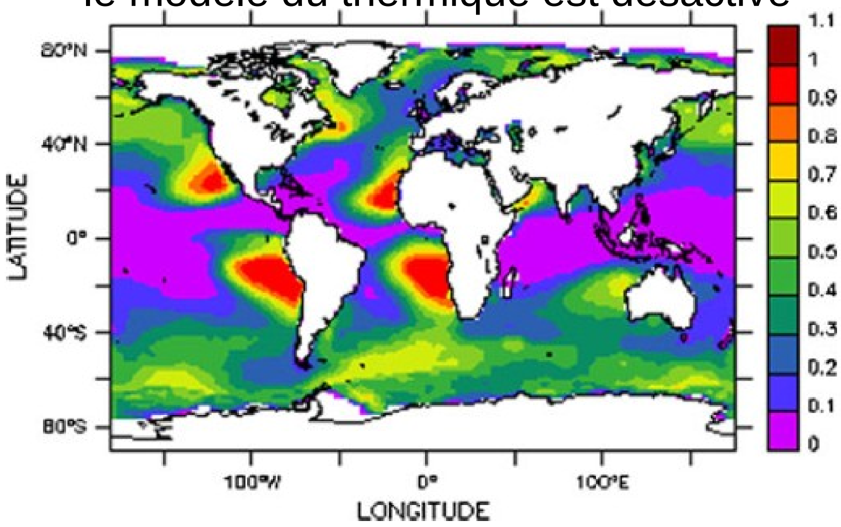


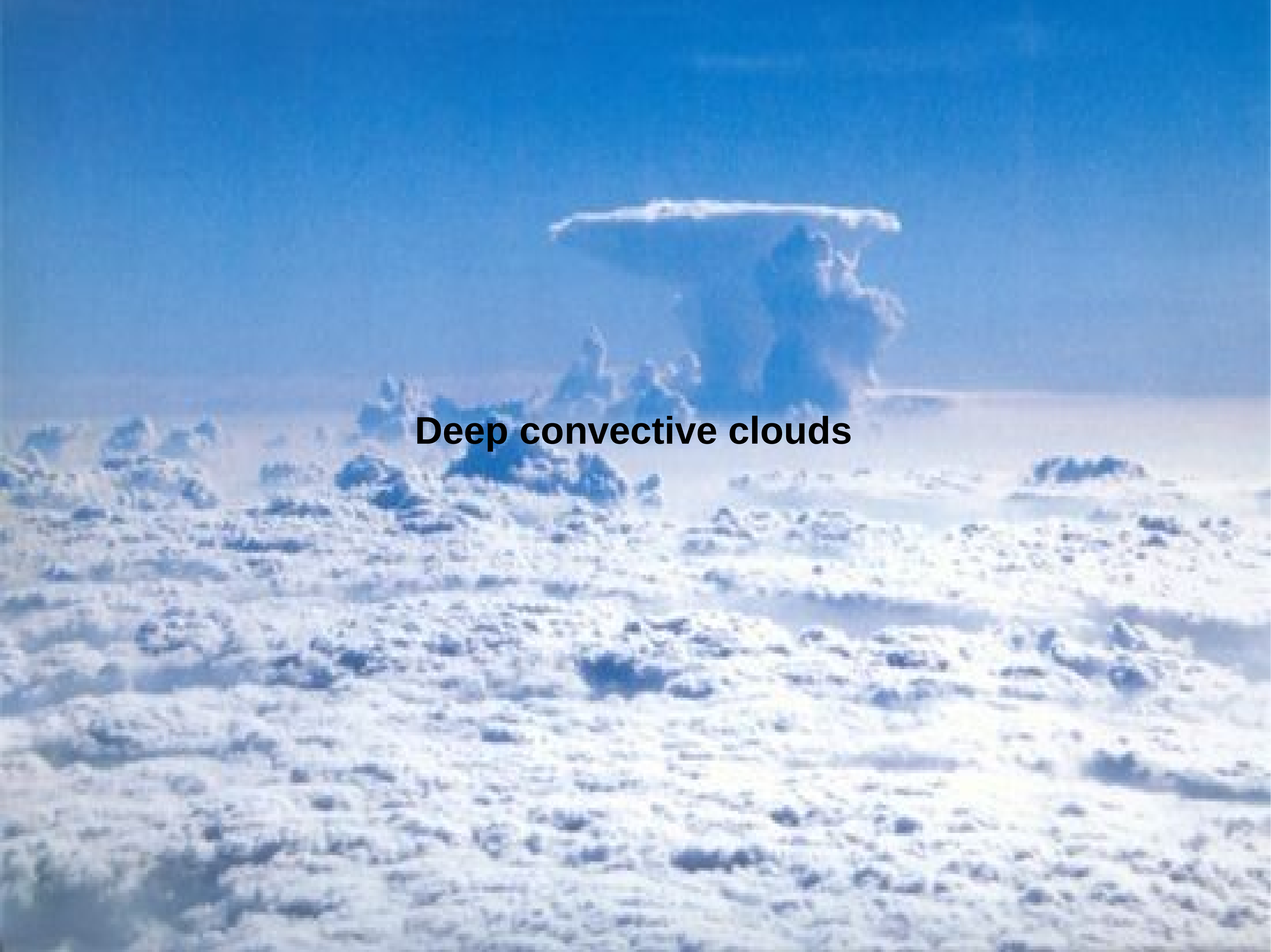
The problem of the stratocumulus

The thermal plume model is desactivated in regions of strong inversion.

Stratocumulus are handled as large-scale clouds.

Fraction de l'année pour laquelle
le modèle du thermique est désactivé




Deep convective clouds

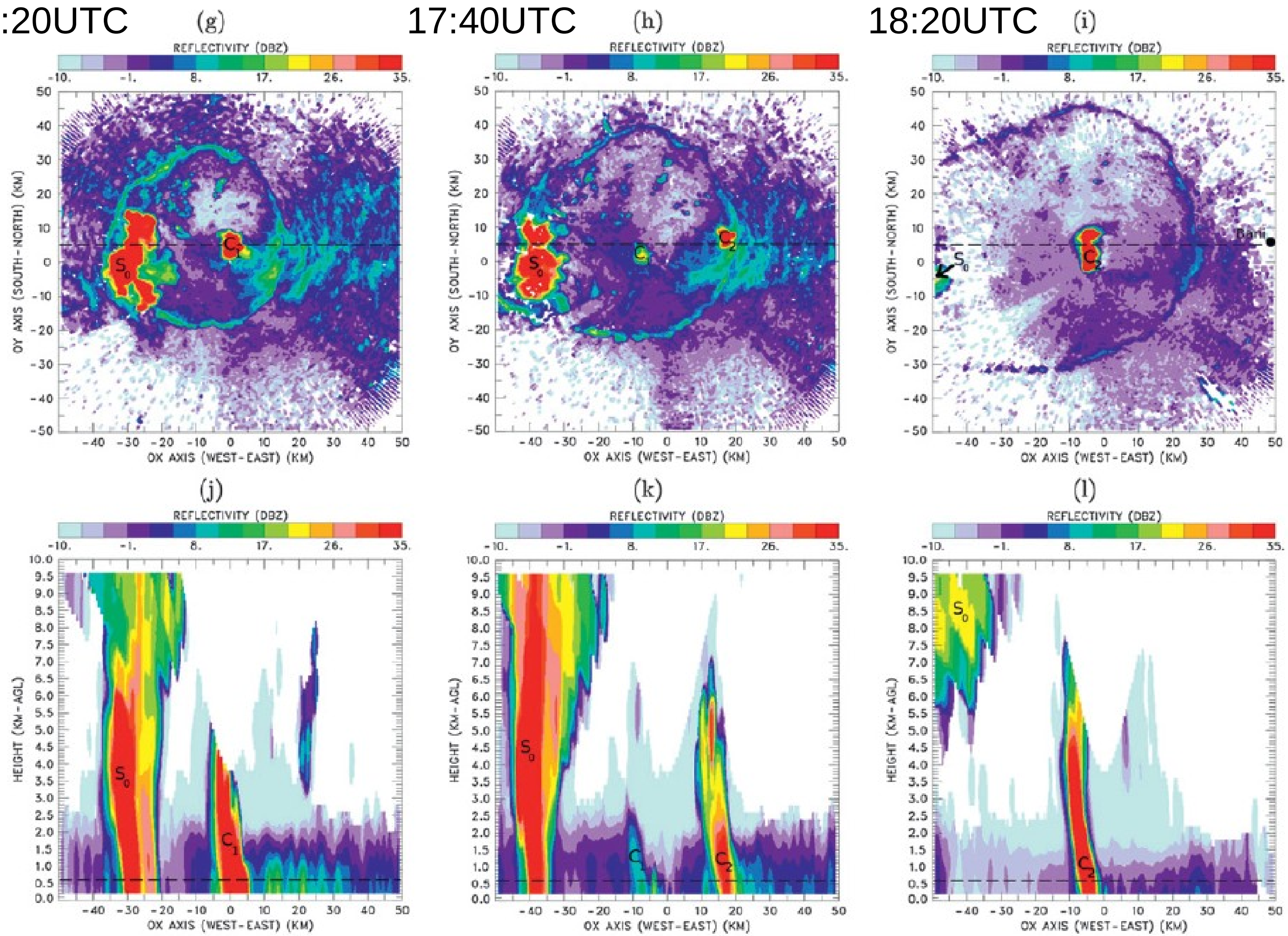
Cumulonimbus, updrafts and cold pools
Local convection in semi-arid region: The 10 of July 2006 in Niamey

Development of organized structures associated with deep convection

17:20UTC 17:40UTC 18:20UTC

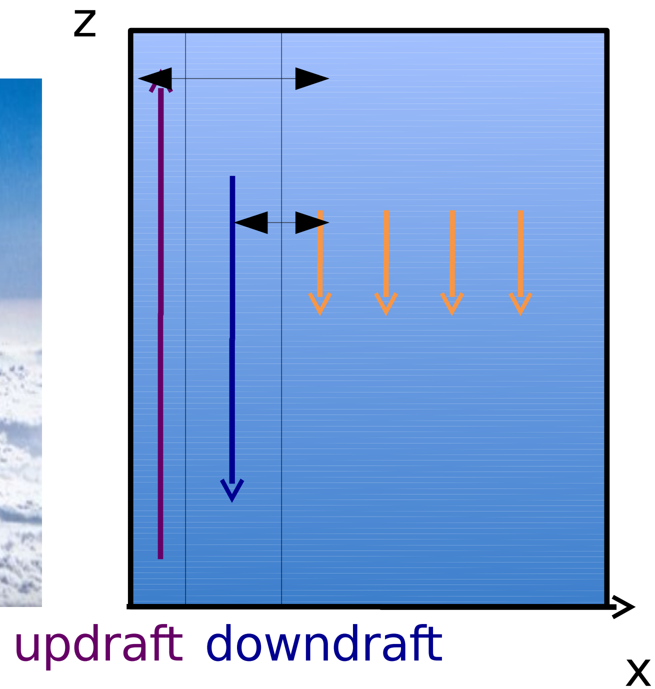
Horizontal cross-section at 600m

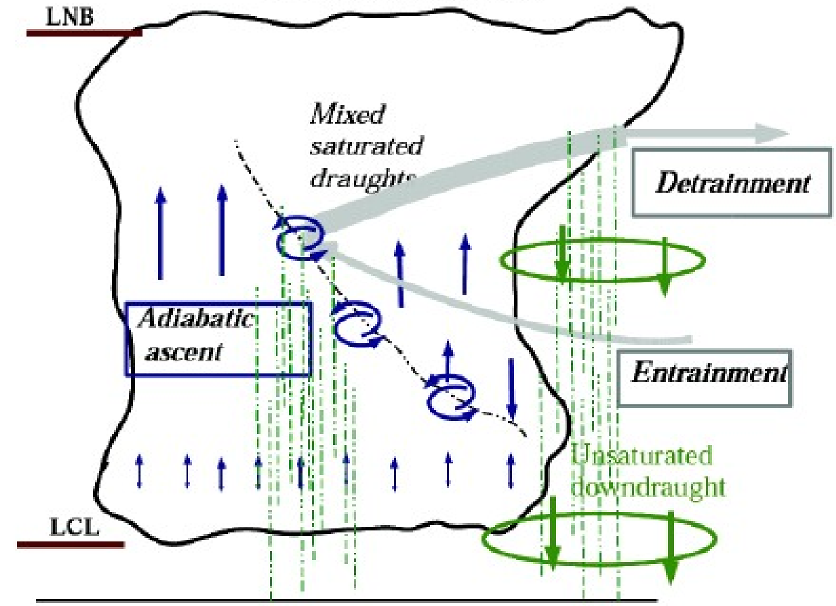
Vertical cross-section 5km north of the RADAR



Lothon et al., MWR, 2011

The deep convection scheme
concvl.F





Emanuel, 1991

- Triggering function of the deep convection scheme:
Criteria on the convective inhibition

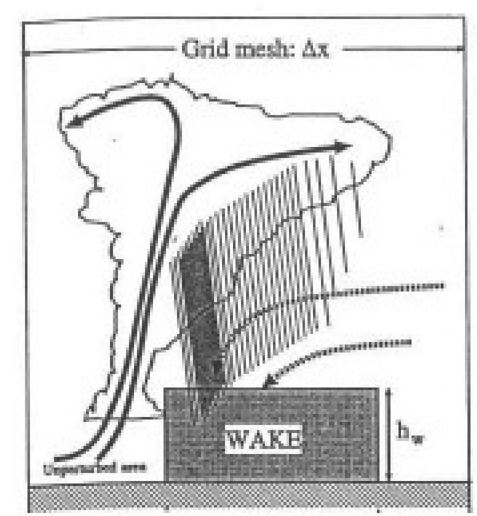
- Convection intensity ("closure"):
Convective intensity related to mean environmental properties (LMDZ5A)
Convective intensity related to sub-cloud processes (LMDZ5B)

- Precipitation efficiency: fraction of condensate that precipitates instead of being detrained

- Updrafts and downdrafts properties: vertical velocity, buoyancy and fractional coverage

- Mixing rates between clouds and environment

Parameterization of cold pools (LMDZ5B)



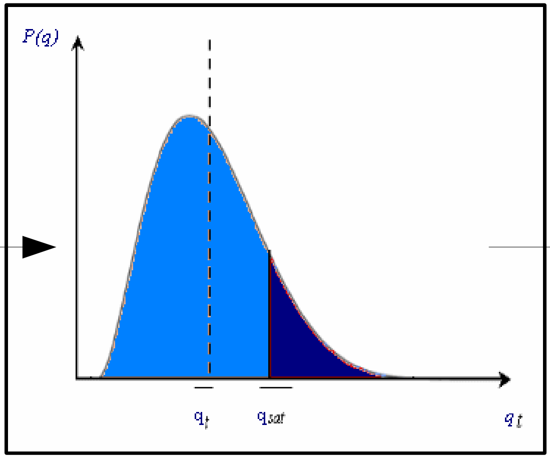
Grandpeix & Lafore, JAS, 2010

The cloud scheme
clouds_gno.F

Log-normal distribution of total water qt

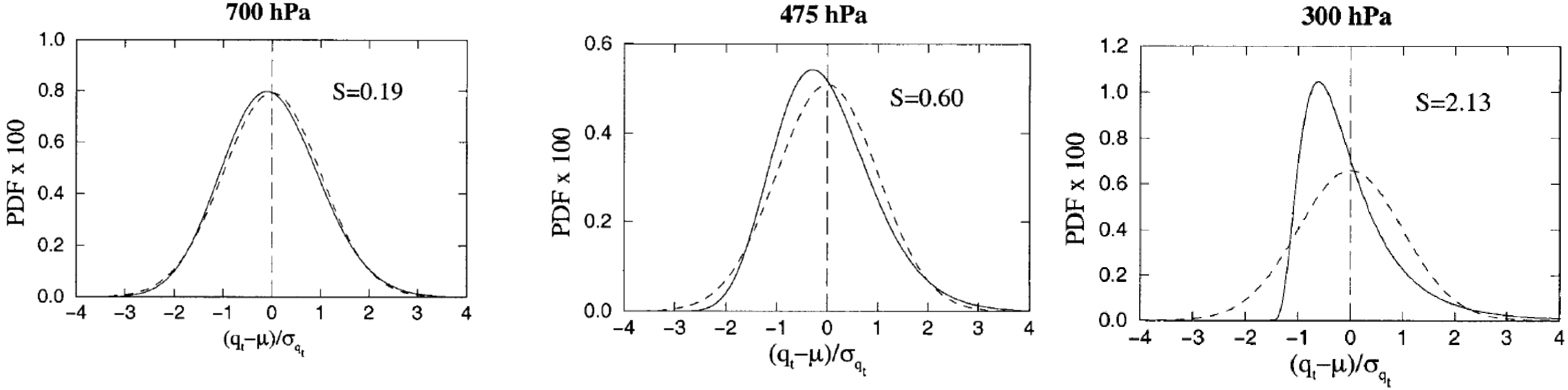
Grid cell
mean state → qt, qsat

Convection scheme → qc



→ σ, cf

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



Bony & Emanuel, JAS, 2001

Representation of middle clouds in LMDZ

Parameterization developed on the oceanic case TOGA-COARE

But over land:

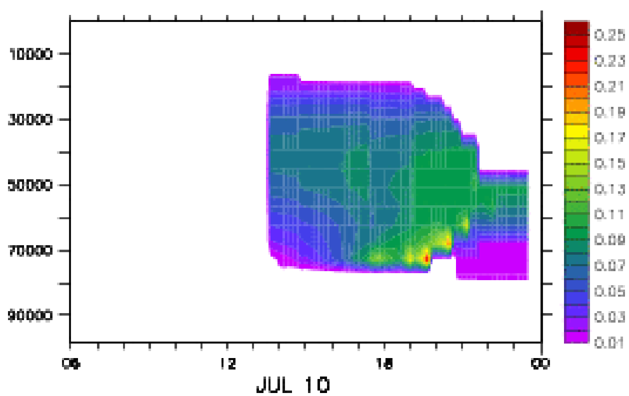
1D Cases

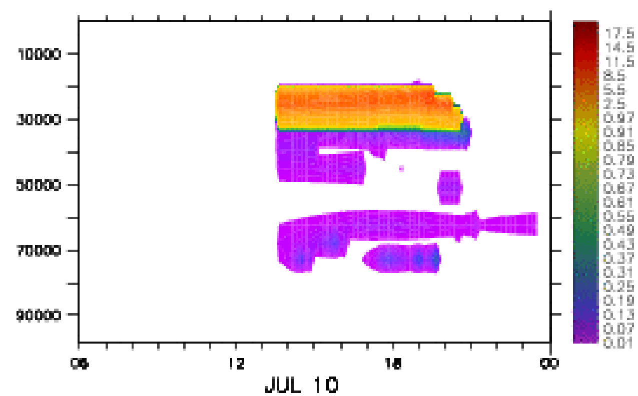
AMMA case

Cloudy water (g/kg)

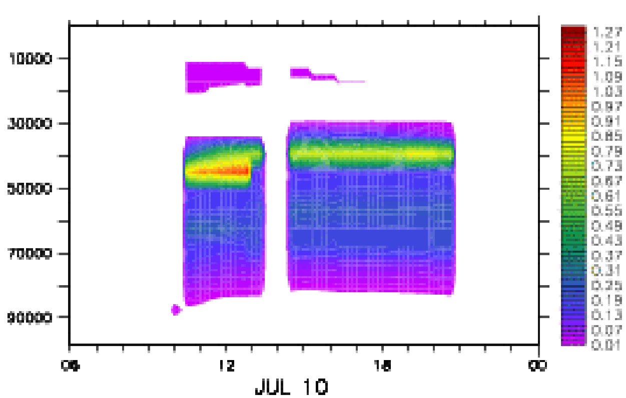
Cloud fraction (%)

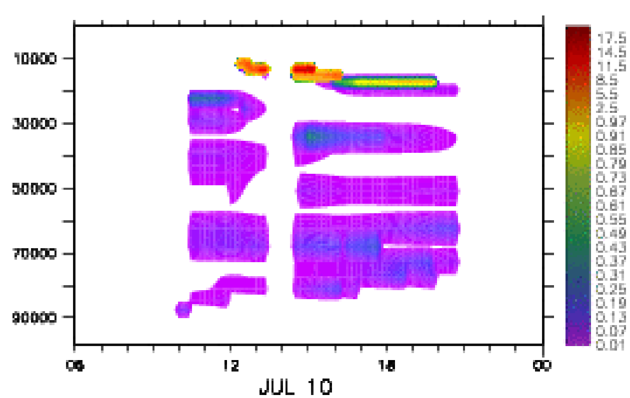
LMDZ5B





LMDZ5A

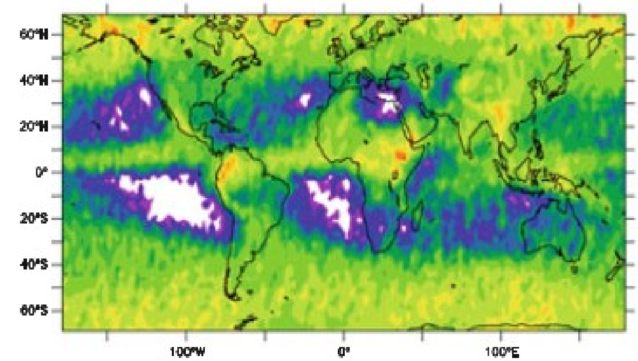


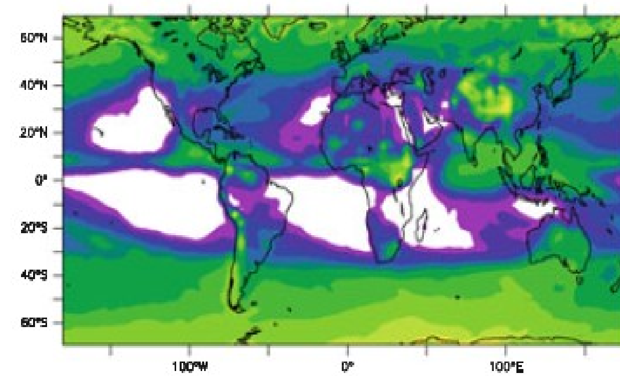


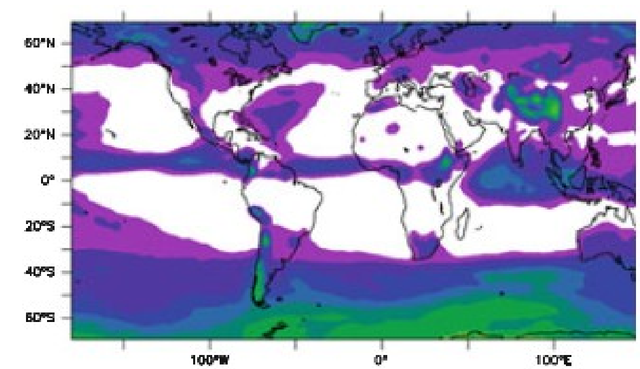
3D simulations

Middle-Cloud fraction (%)

Annual mean







Strong under estimation of middle clouds in dry environment

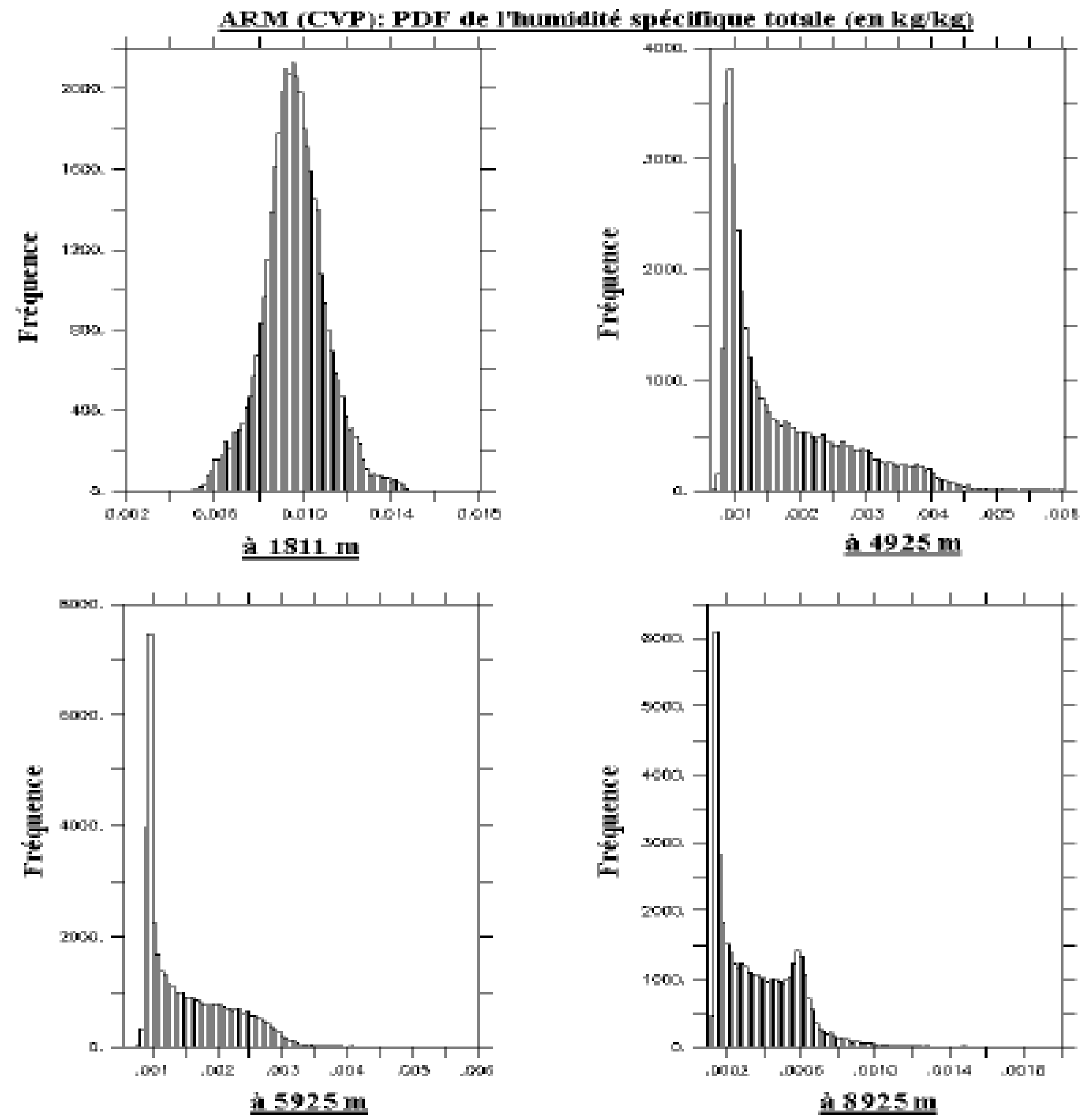
Tuning parameters

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

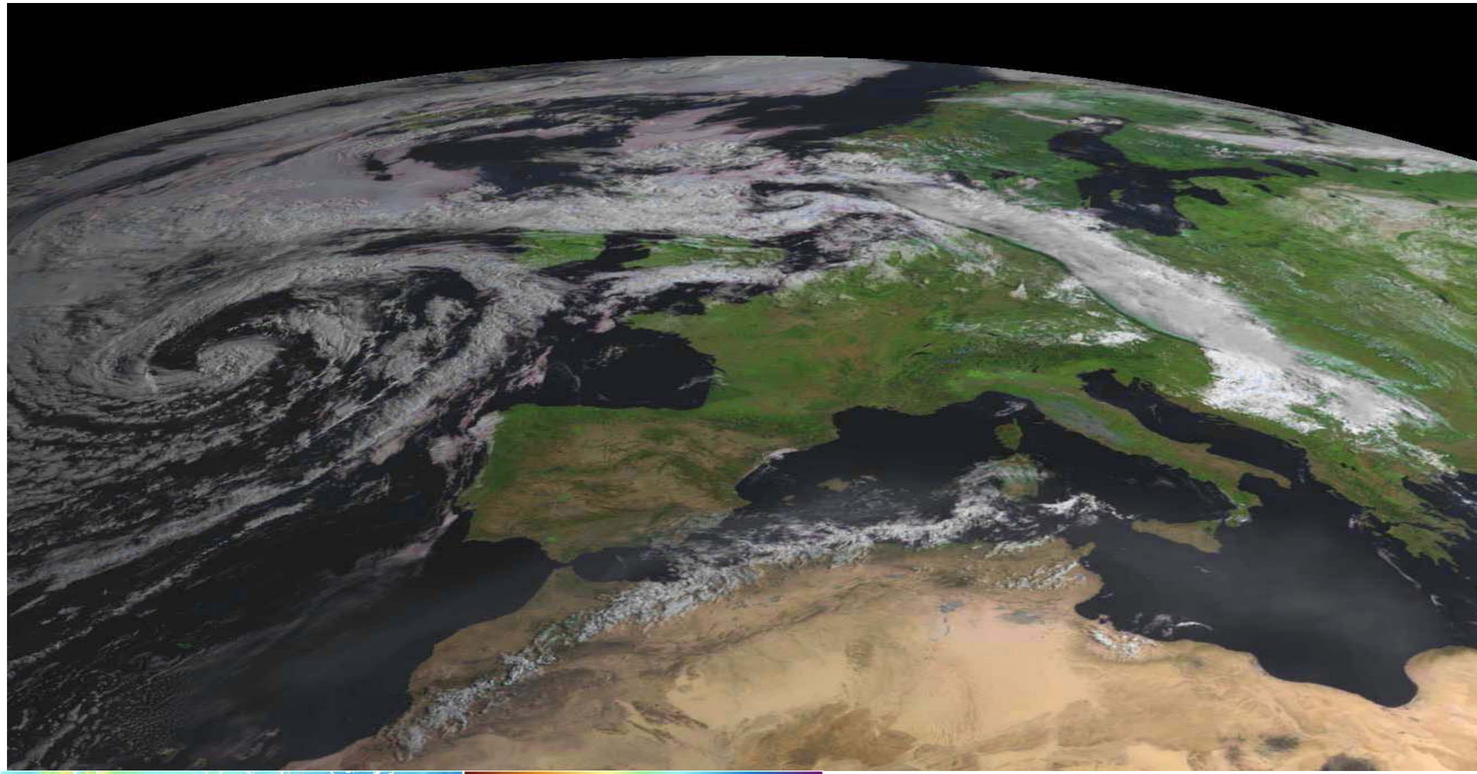
Work in progress to define a bimodal distribution from deep convection characteristics (thesis of Arnaud Jam)

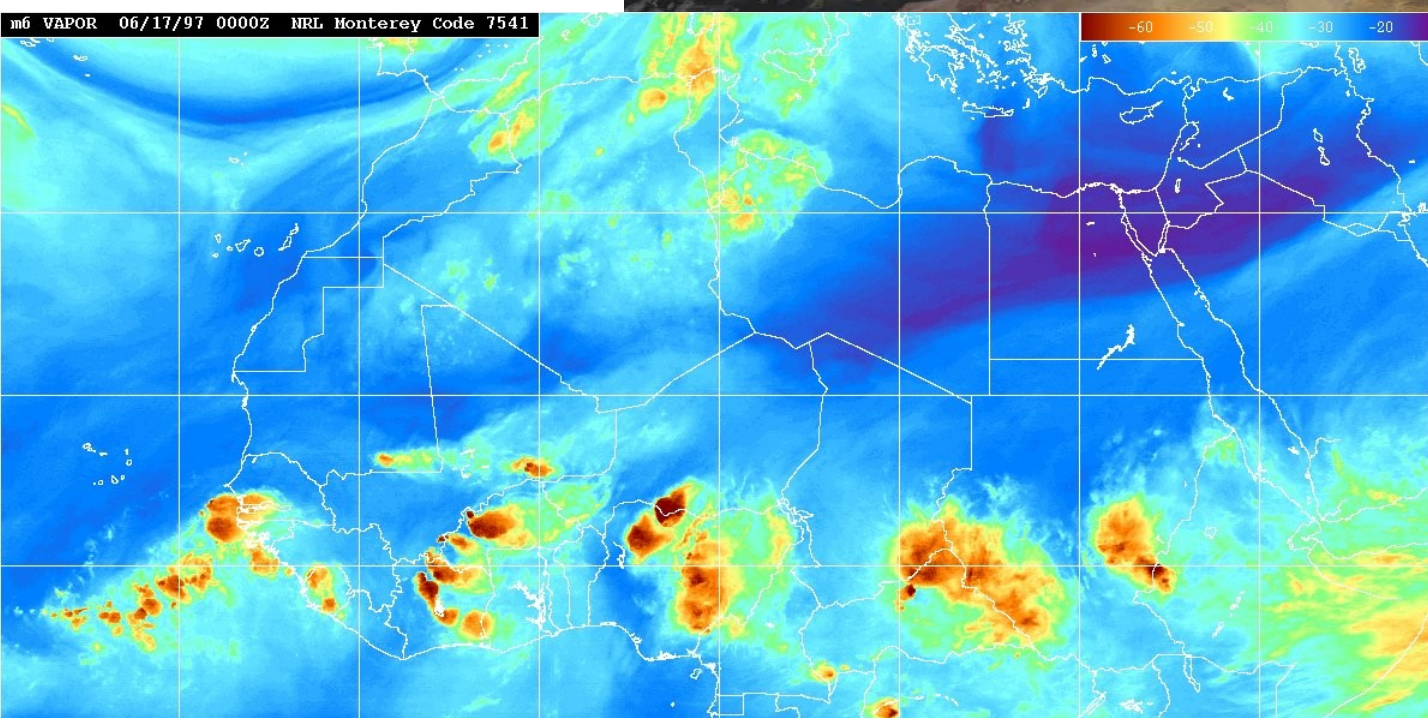



Large-scale clouds

Large-scale condensation

Mid-latitude cyclones





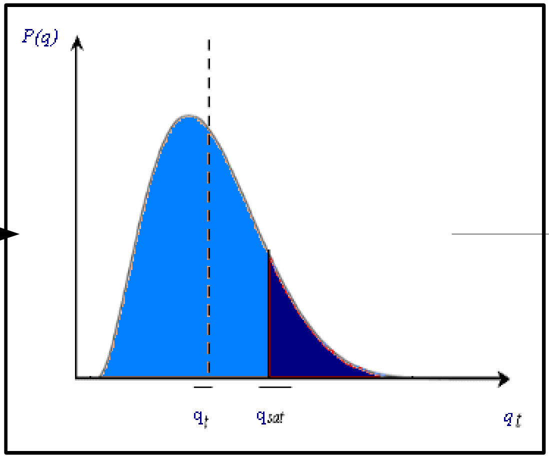
Convection organized in squall lines in Africa

The cloud scheme
fisrtilp.F90

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

Grid-cell mean state → q, qsat

σ/q imposed



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

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

The profile of σ/qt is defined by:

iflag_ratqs=0: increases linearly from ratqsbas to ratqshaut between the surface and 300hPa.
= ratqshaut above 300hPa.

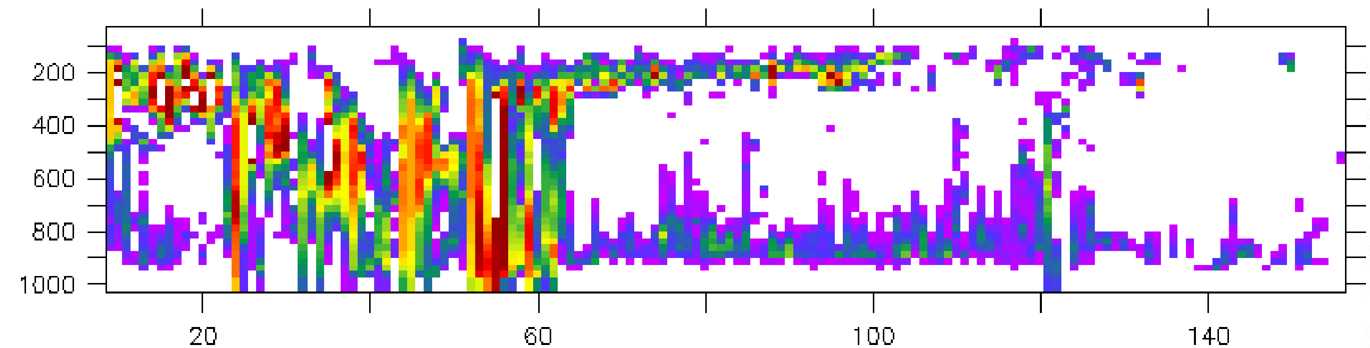
iflag_ratqs=2: increases linearly from 0 to ratqsbas between the surface and 600hPa.
increases linearly from ratqsbas to ratqshaut between 600 and 300hPa.
= ratqshaut above 300hPa.

ratqsbas and ratqshaut are defined in physiq.def.

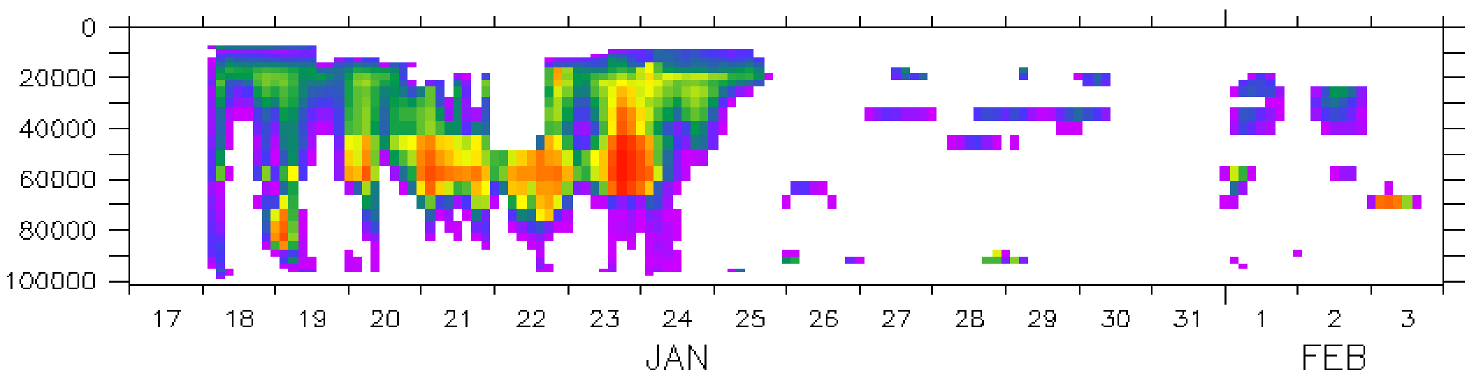
Representation of high clouds in LMDZ

1D case of oceanic convection (TWP-ICE)

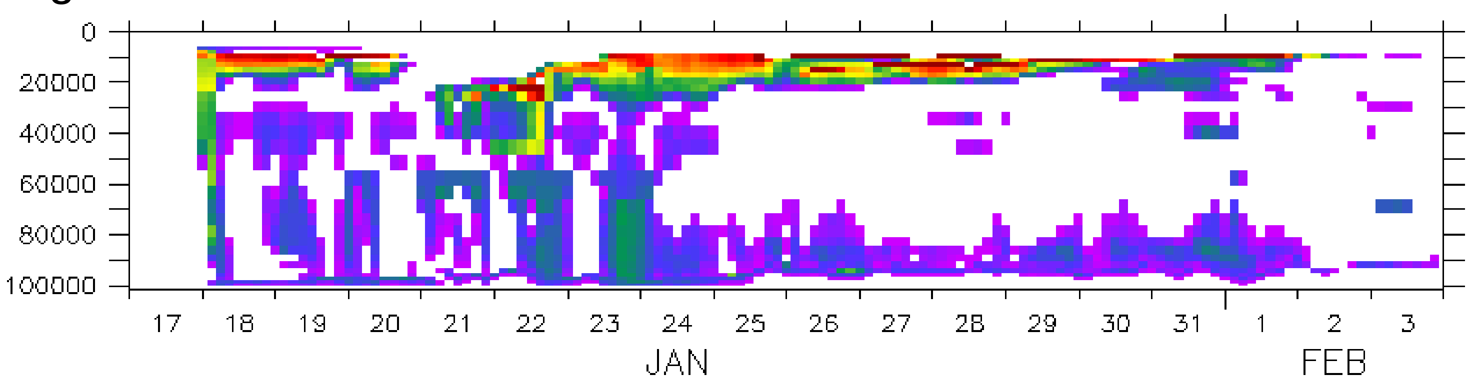
Observed cloud fraction



Cloud fraction associated with deep convection



Cloud fraction associated with boundary-layer turbulence and large-scale condensation

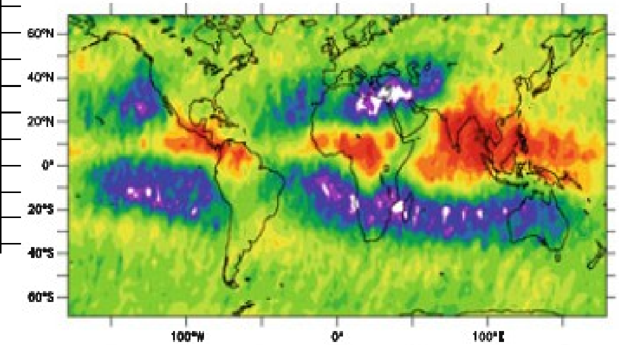


3D simulations

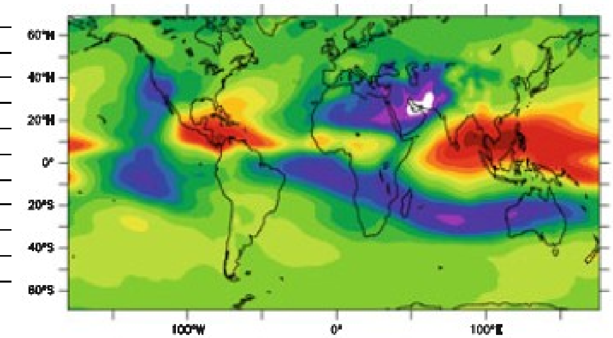
High cloud fraction (%)

Annual mean

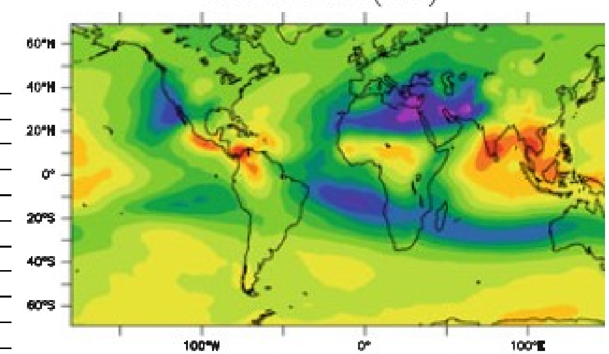
GOCCP



LMDZ5B (NPv3)



LMDZ5A (SP)

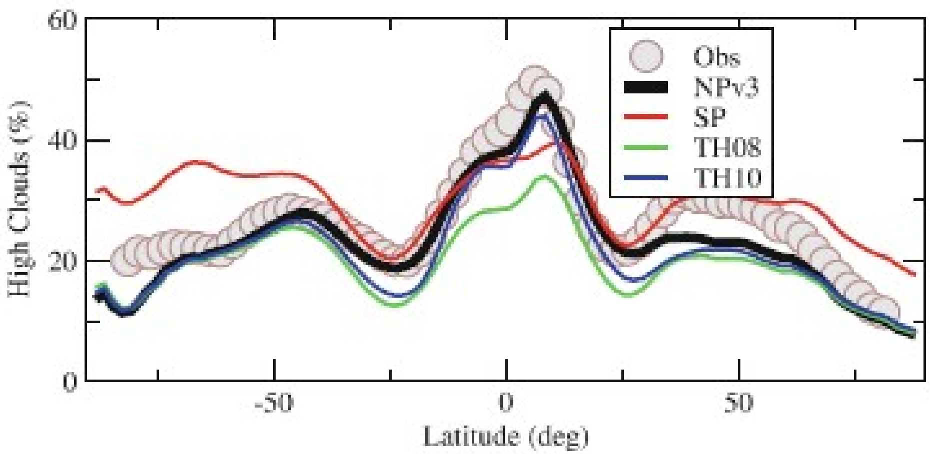


The tuning parameters

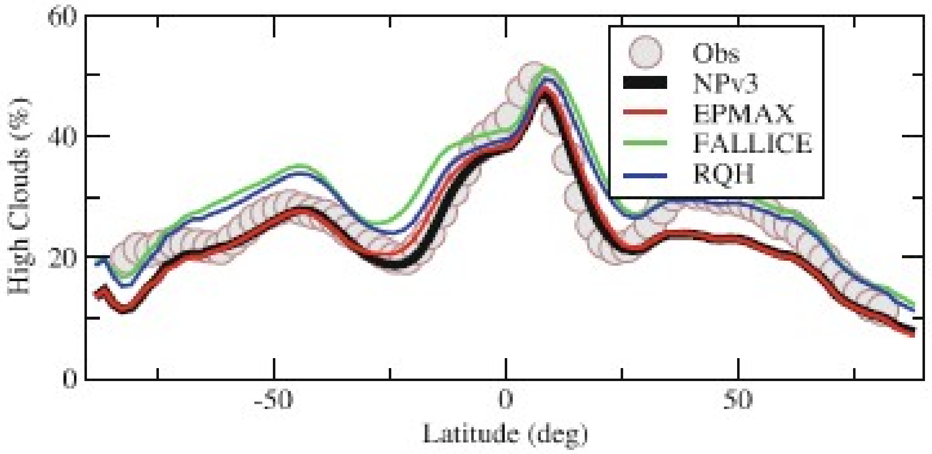
Parameters controlling large-scale clouds and precipitation (physiq.def):
CLDLC: threshold on maximum of condensate *(cld_lc_lsc)*
CLDTAU: auto-conversion rate *(cld_lc_tau)*
FALLICE: factor on the fall speed of ice crystals *(ffallv_lsc)*
COEFEVA: parameter controlling the evaporation of precipitation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

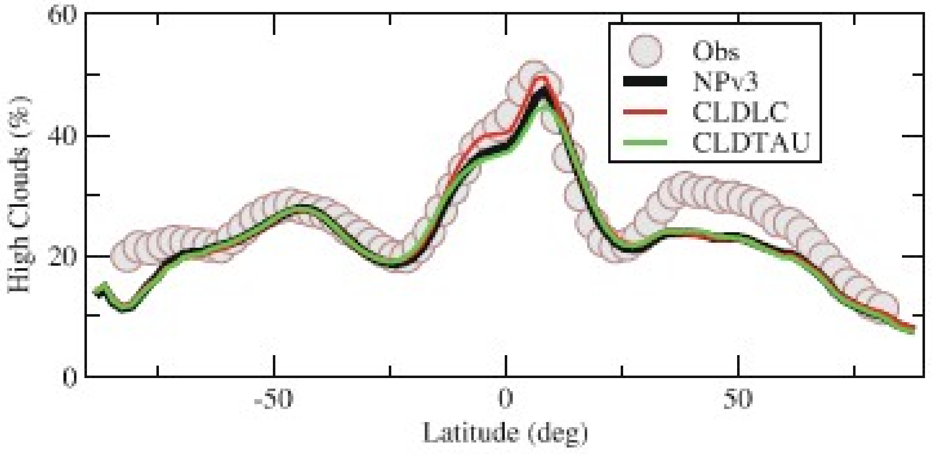
Sensitivity of the high cloud fraction to:

A change of parameterizations



A change of parameters





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

Total cloud fraction and cloud water content:

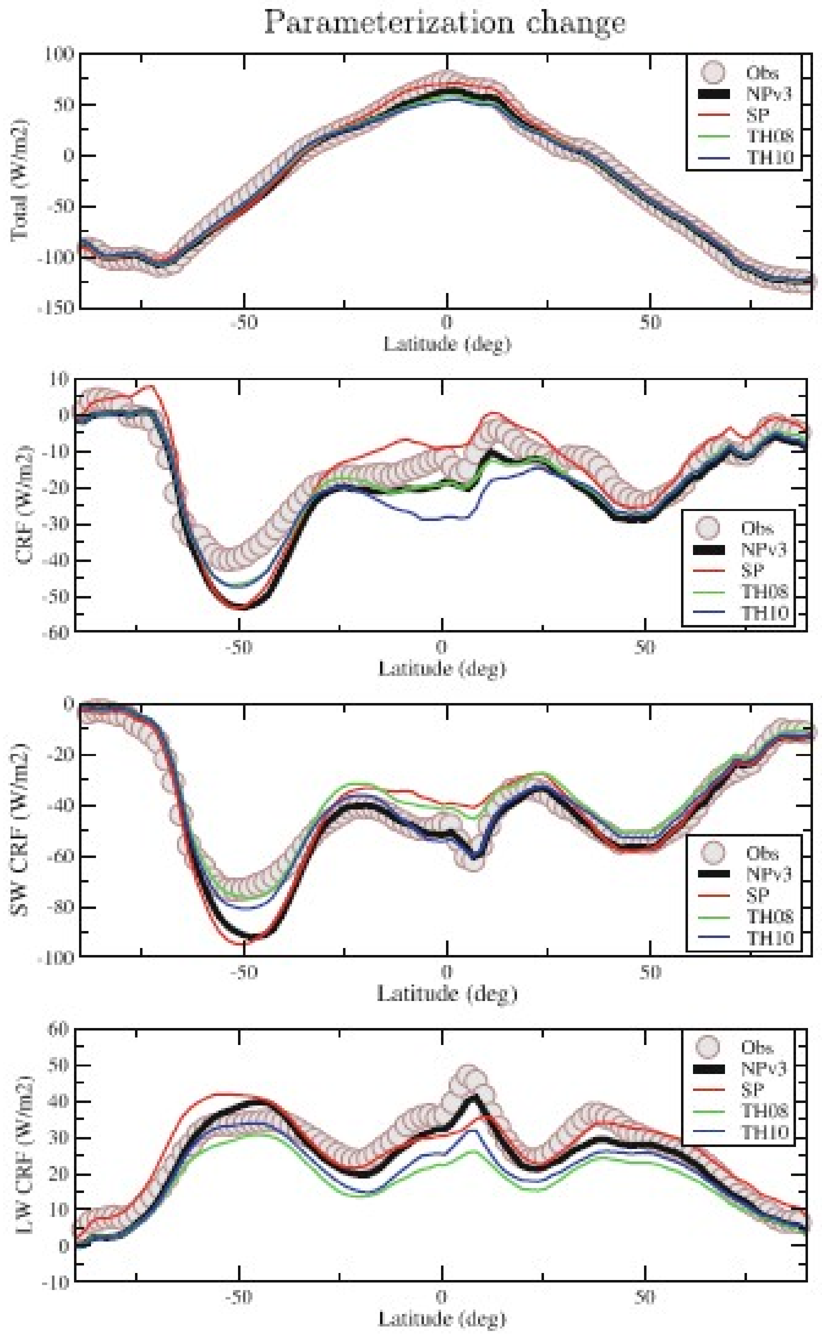
cldfra = min(cf(thermals) + cf (convection) + cf (large-scale), 1.)

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

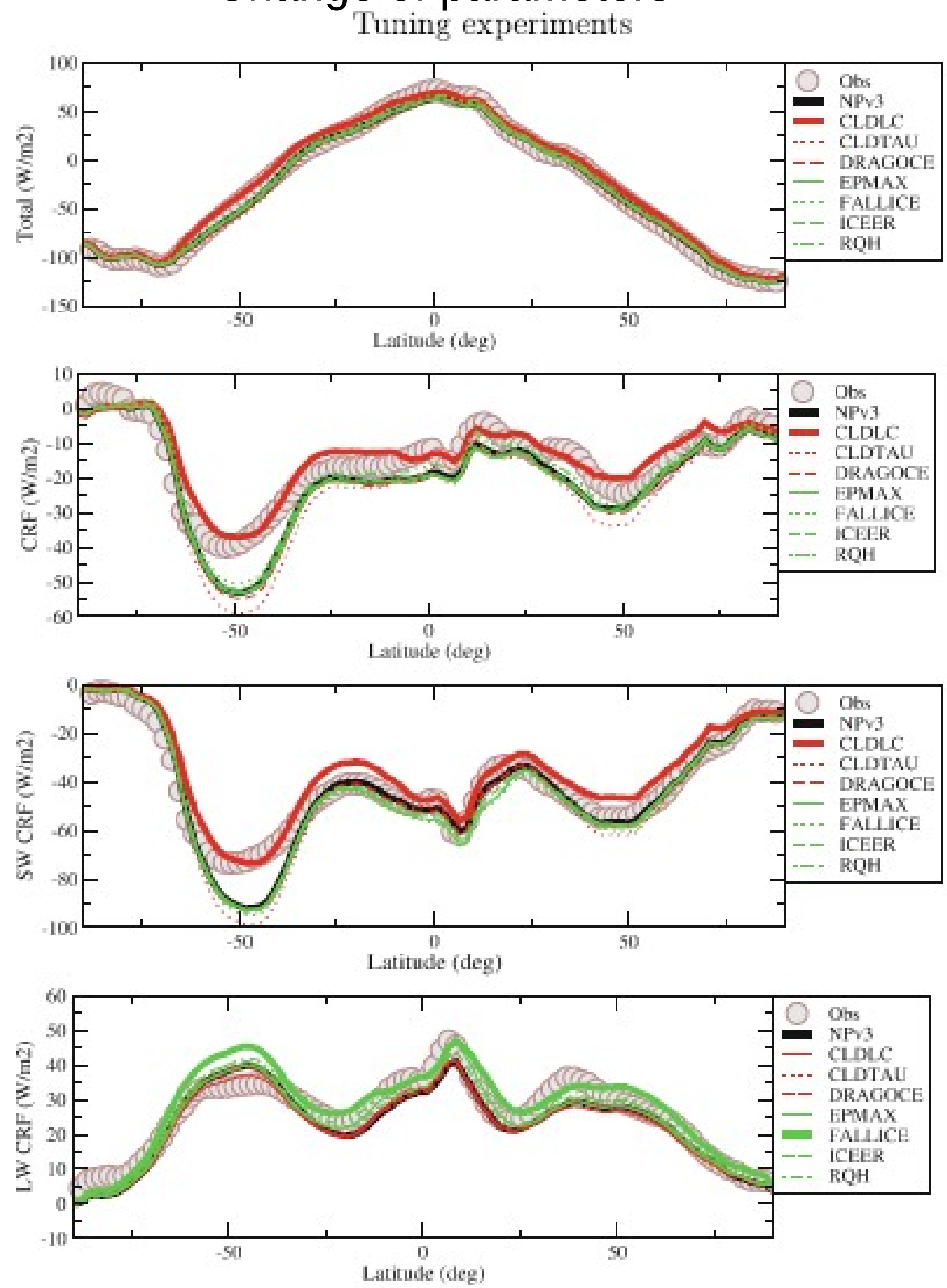
The tuning phase of the model

Sensitivity of radiative fluxes at the top of the atmosphere

Change of parameterizations



Change of parameters



LMDZ5A (AR4_physiq.def)		LMDZ5B (NPv3.1_physiq.def)
	Boundary-layer	
iflag_pbl=1	Diffusion	iflag_pbl=8
iflag_thermals=0	Thermals	iflag_thermals=15
iflag_thermals_ed=0	Mixing rates in thermals	iflag_thermals_ed=10
iflag_coupl=0	Coupling with deep convection	iflag_coupl=5
	Convection	
iflag_con=30	Emanuel old/new	iflag_con=3
iflag_clos=1	Closure CAPE/ALP	iflag_clos=2
iflag_wake=0	Cold pools	iflag_wake=1
qqa1=0 qqa2=1	PDF for mixing	qqa1=1 qqa2=0
iflag_clw=1	Computation of condensate	iflag_clw=0
epmax=0.999	Efficiency of precipitation	epmax=0.997
	Clouds	
iflag_cldcon=3	Cloud scheme	iflag_cldcon=6
iflag_ratqs=0	Profile of σ/qt	iflag_ratqs=2
ratqsbas=0.005	σ/qt min	ratqsbas=0.002
ratyqshaut=0.33	σ/qt max	ratqs_haut=0.25
cld_lc_lsc=4.16e-4	Threshold cloudy water LS	cld_lc_lsc=6e-4
cld_lc_con=4.16e-4	Threshold cloudy water CV	cld_lc_con=6e-4
ffallv_lsc=0.5	Ice crystals fall speed LS	ffallv_lsc=1.35
ffallv_con=0.5	Ice crystals fall speed CV	ffallv_con=1.35
coef_eva=2e-5	Coefficient of evaporation	coef_eva=1e-4