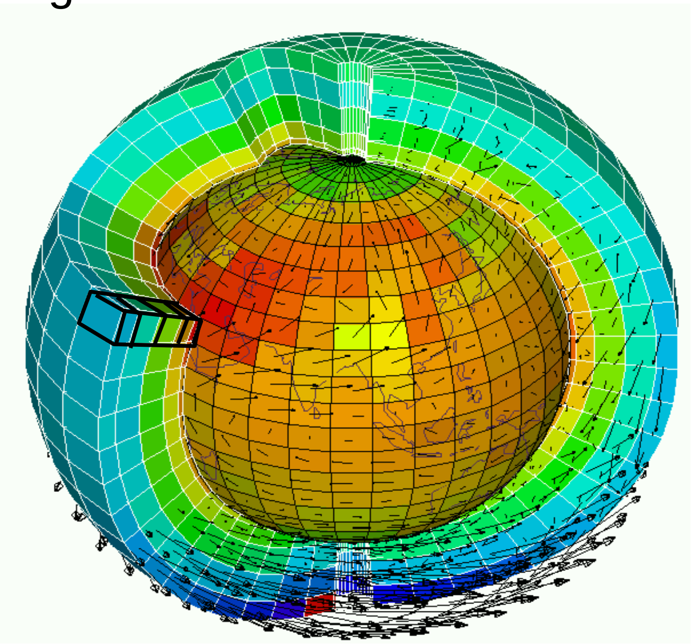
Strengths and weaknesses of the different physical packages of LMDZ

Catherine Rio
LMDZ Development Team

LMDZ training course – 7/8/9 December 2015 – LMD Jussieu

Physical parameterizations

The general circulation model LMDZ



Dynamical component:
Discretization of conservation equations on the sphere

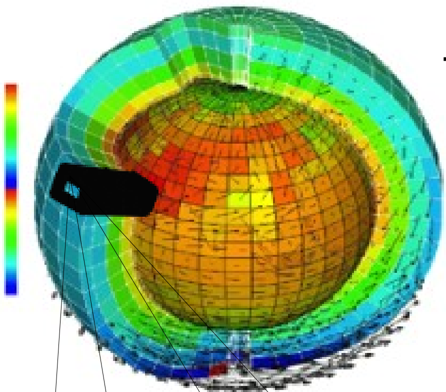
Physical component:
Represents the effects of sub-grid scale processes non resolved by the dynamical equations (source terms) in each atmospheric column

Key for the representation:
- vertical profiles of **heating rates** and the large-scale circulation
- Vertical profiles of **mass fluxes** and tracer transport
- Clouds and their **radiative impacts**
- **precipitation**

Key role in the **coupling** with the other components:
- transport of chemical species
- surface fluxes
- hydrology

Provide the variables necessary for **impact** studies:
- precipitation
- sub-grid scale variations of winds, etc...

Methodology to develop and evaluate parameterizations

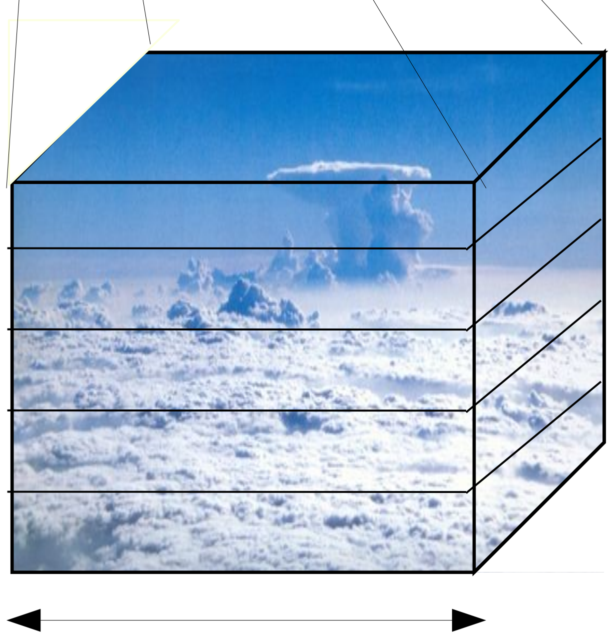


1D case studies built from field campaigns (BOMEX, TOGA-COARE, TWP-ICE, AMMA...) or routinely in-situ measurements (ARM)

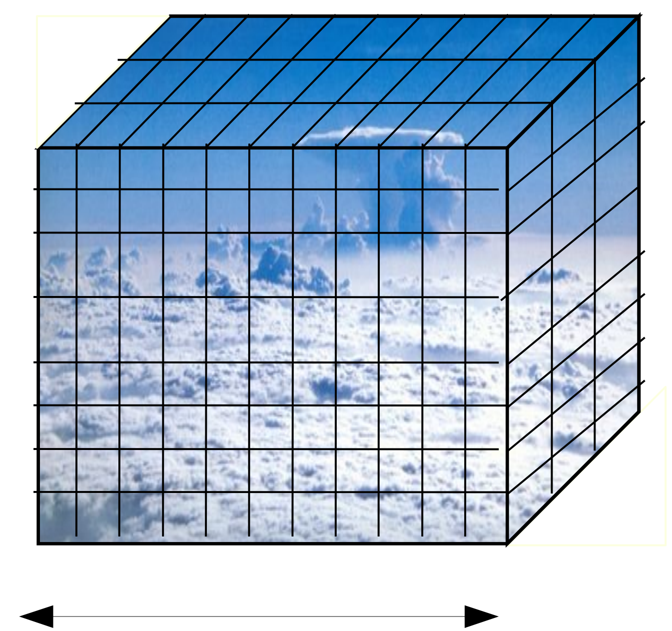
1D simulations

Explicit simulations over a domain equivalent to a GCM grid cell

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

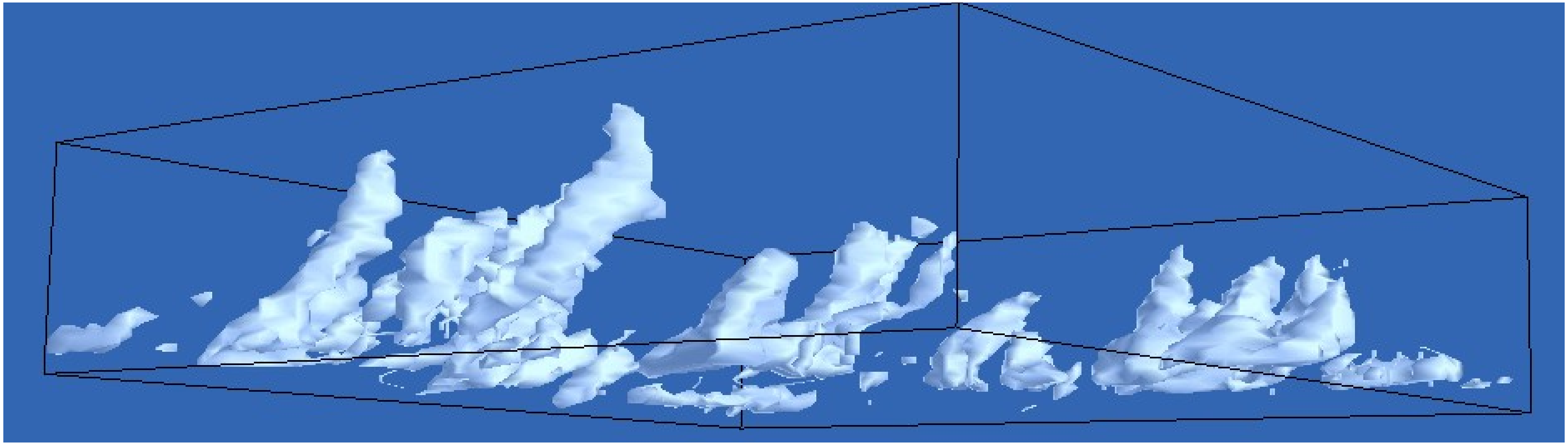


Identical forcing:
Initial profiles
Large-scale advection
Surface fluxes



Use of explicit simulations for parameterization development

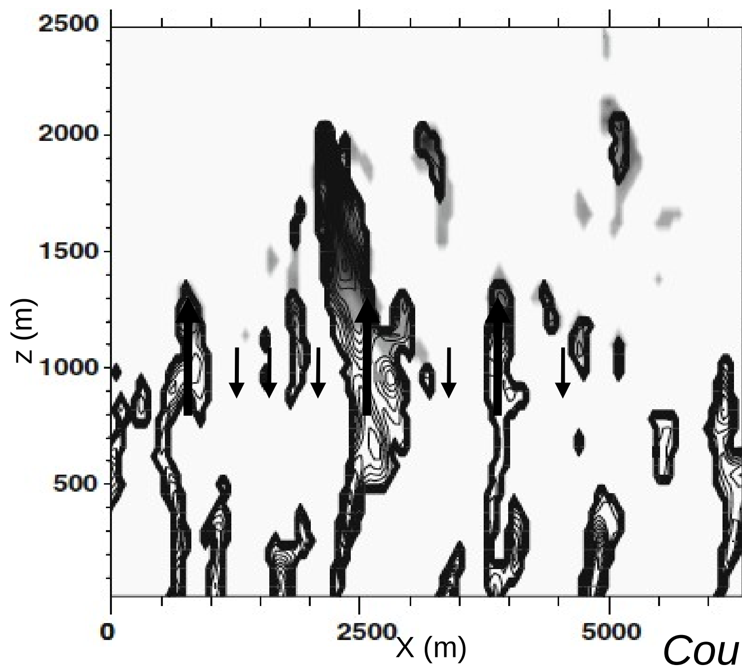
Simulated cumulus field:



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

Identification of thermals in the Large-Eddy Simulation

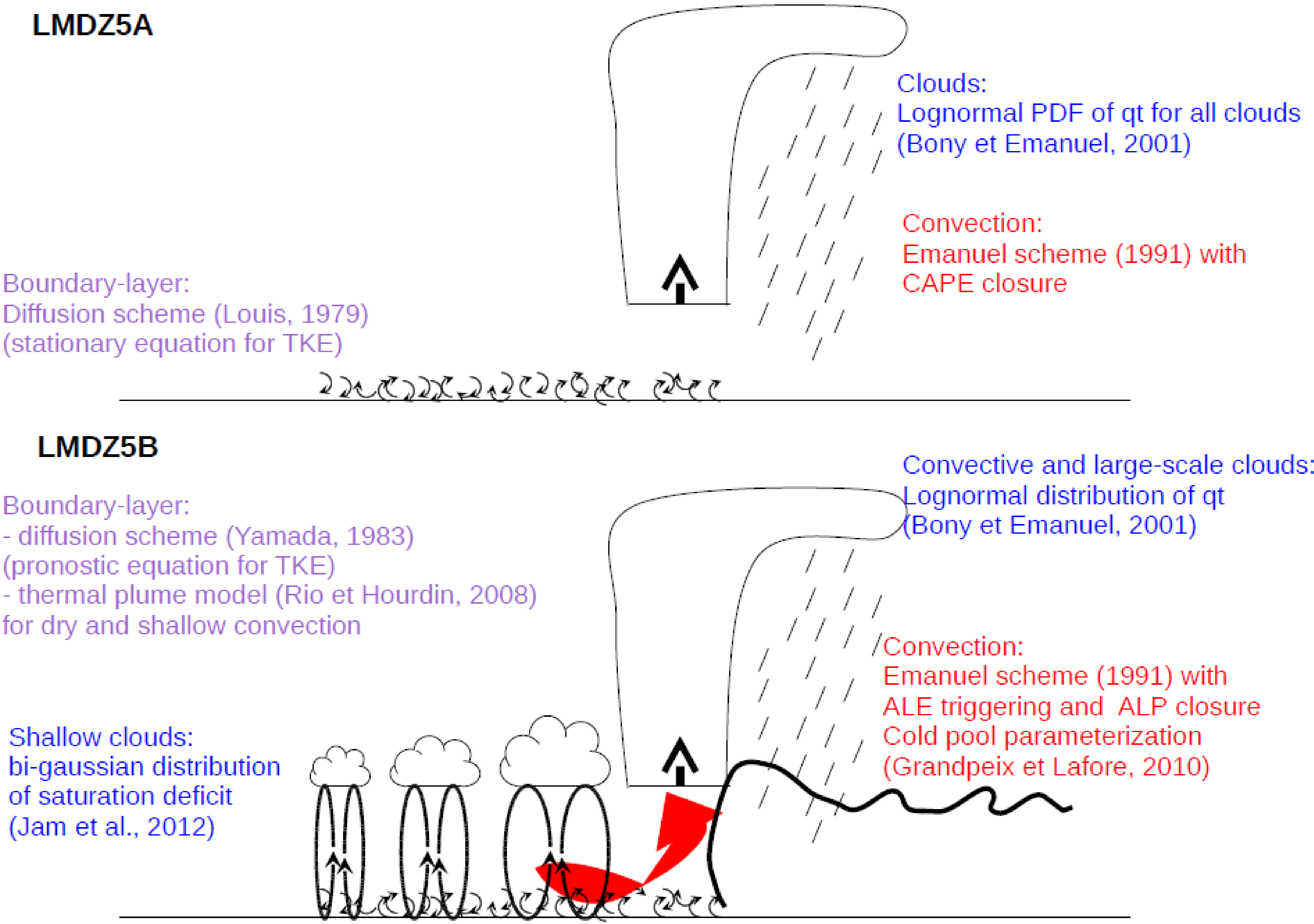
- Evolution of mean variables:
  - Ex: T, q, cloud fraction (cf)
- Statistics over the domain:
  - Ex: PDF of qt, θl
- Properties of clouds:
  - Ex: condensate



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

Couvreux et al., BLM, 2010

The physical packages used for CMIP5

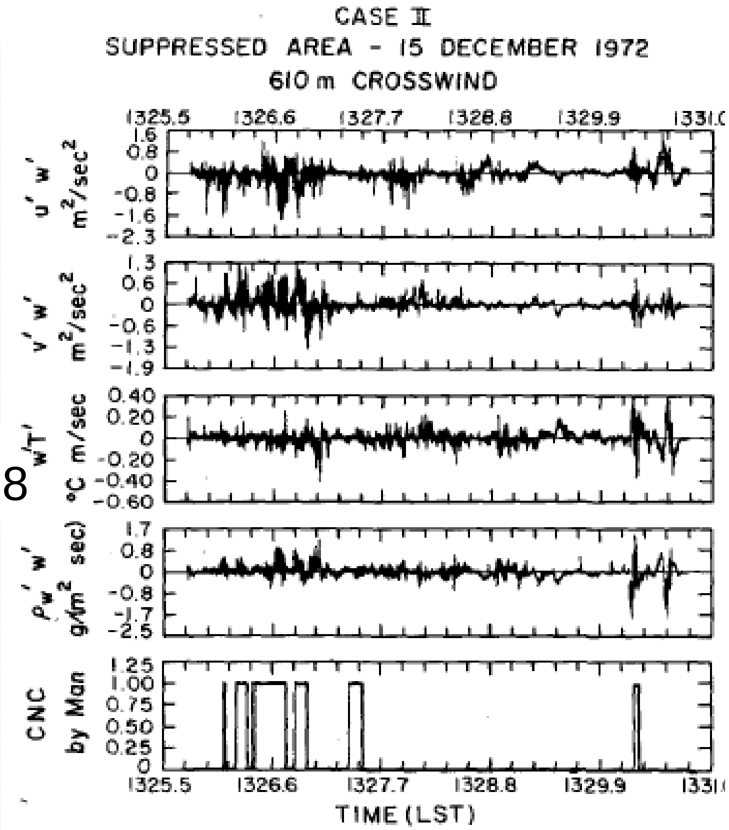


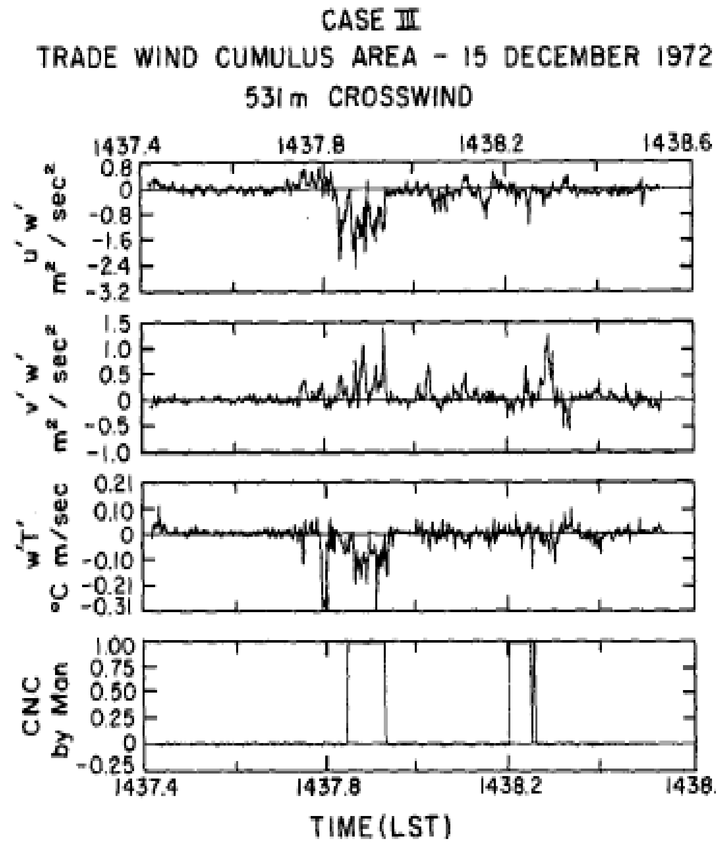

Boundary-layer convection and clouds

Cumulus and thermals

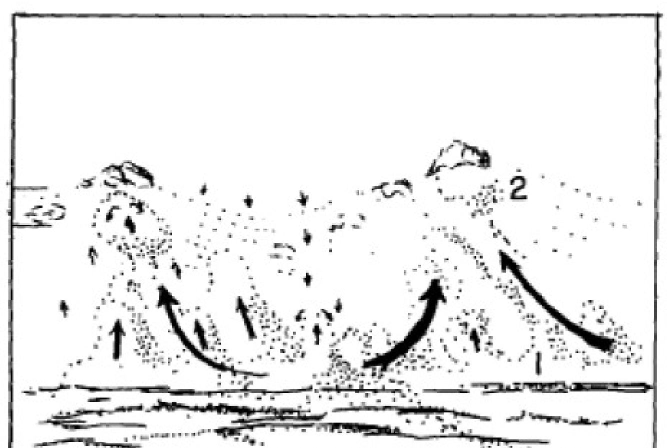
Case II: 15 dec 1972- 12h48

Case III: 15 dec 1972 - 14h18

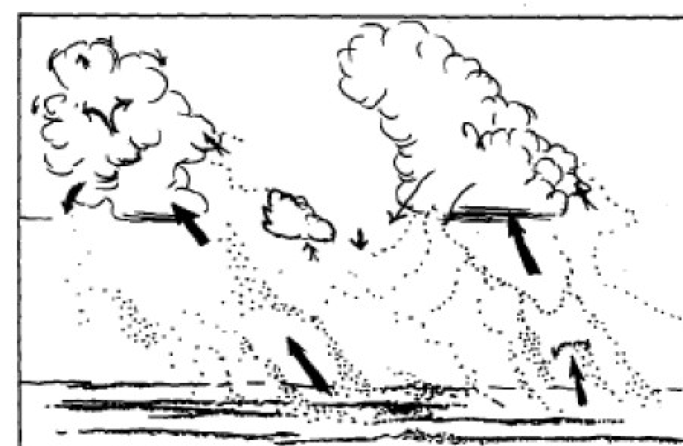




Cumulus are the saturated part of thermals initiated at the surface



(a)



(b)

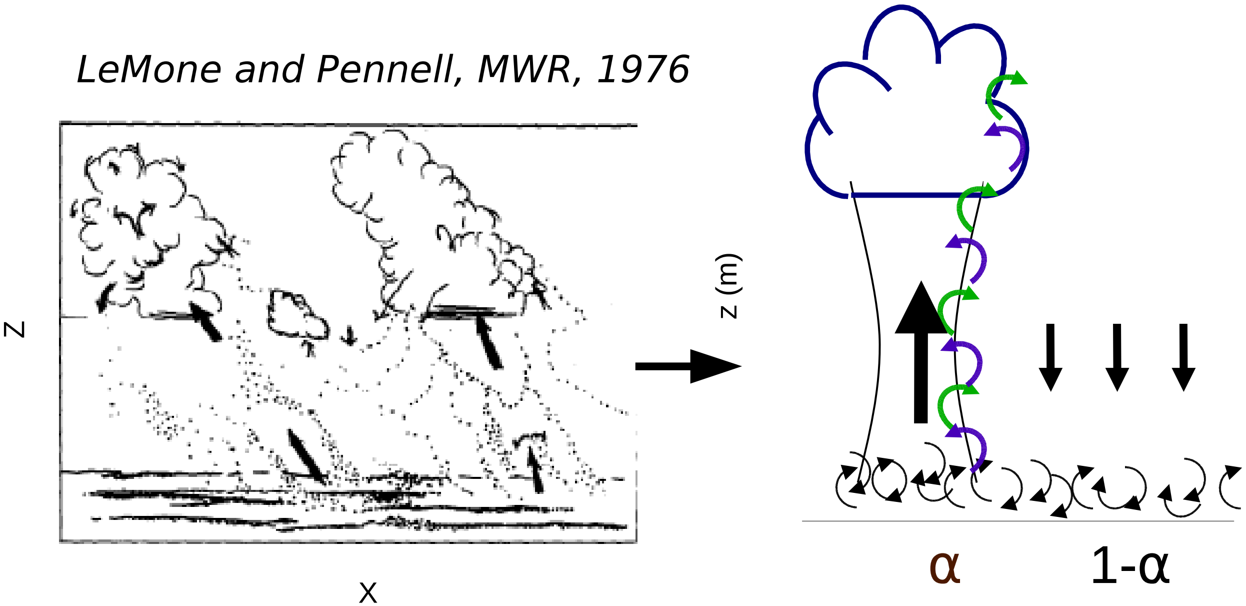
Lemone et Pennell, MWR, 1976

The thermal plume model

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

calltherm.F90

LeMone and Pennell, MWR, 1976



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

Equations

Conservation of mass:

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

Transport of θl, qt, u, v

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

Conservation of momentum:

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

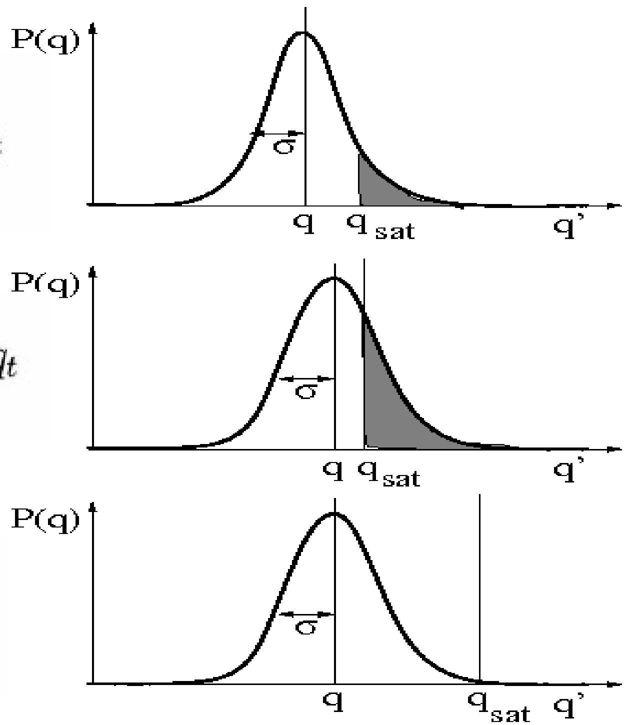
+ Specification of entrainment and detrainment rates
+ Computation of the mass-flux at the base of plumes

The boundary-layer cloud scheme
cloudth.F90

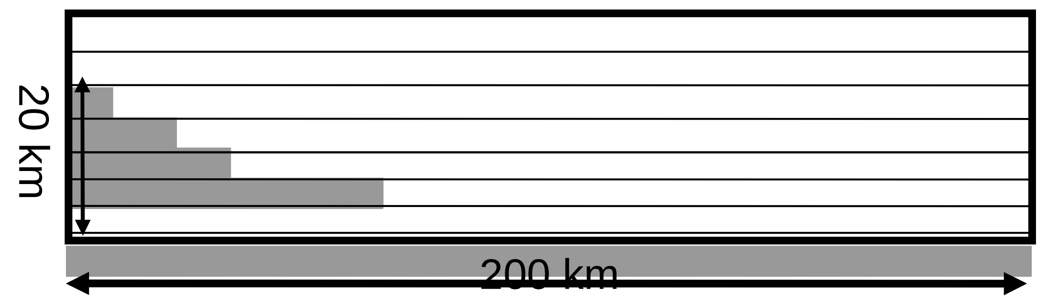
$$f = \int_{q_s}^{\infty} P(q_t)\, dq_t$$

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

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



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



Simple parameterization : Gaussian σ / *q* = 20%

Bi-Gaussian distribution
of saturation deficit s:

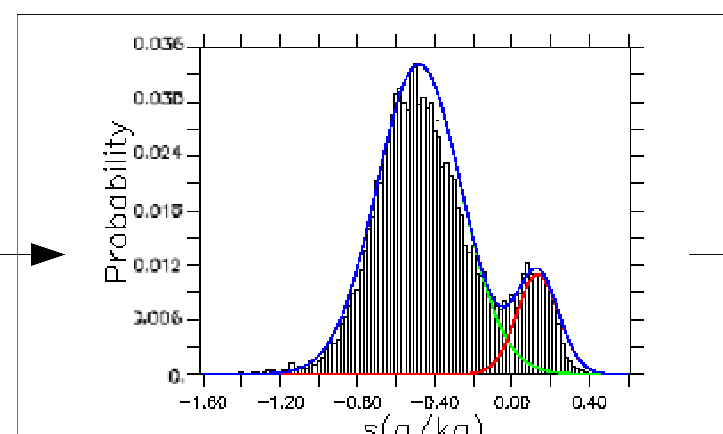
s =al (qt – qsat(Tl))

- 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

Representation of low clouds in LMDZ5A and LMDZ5B

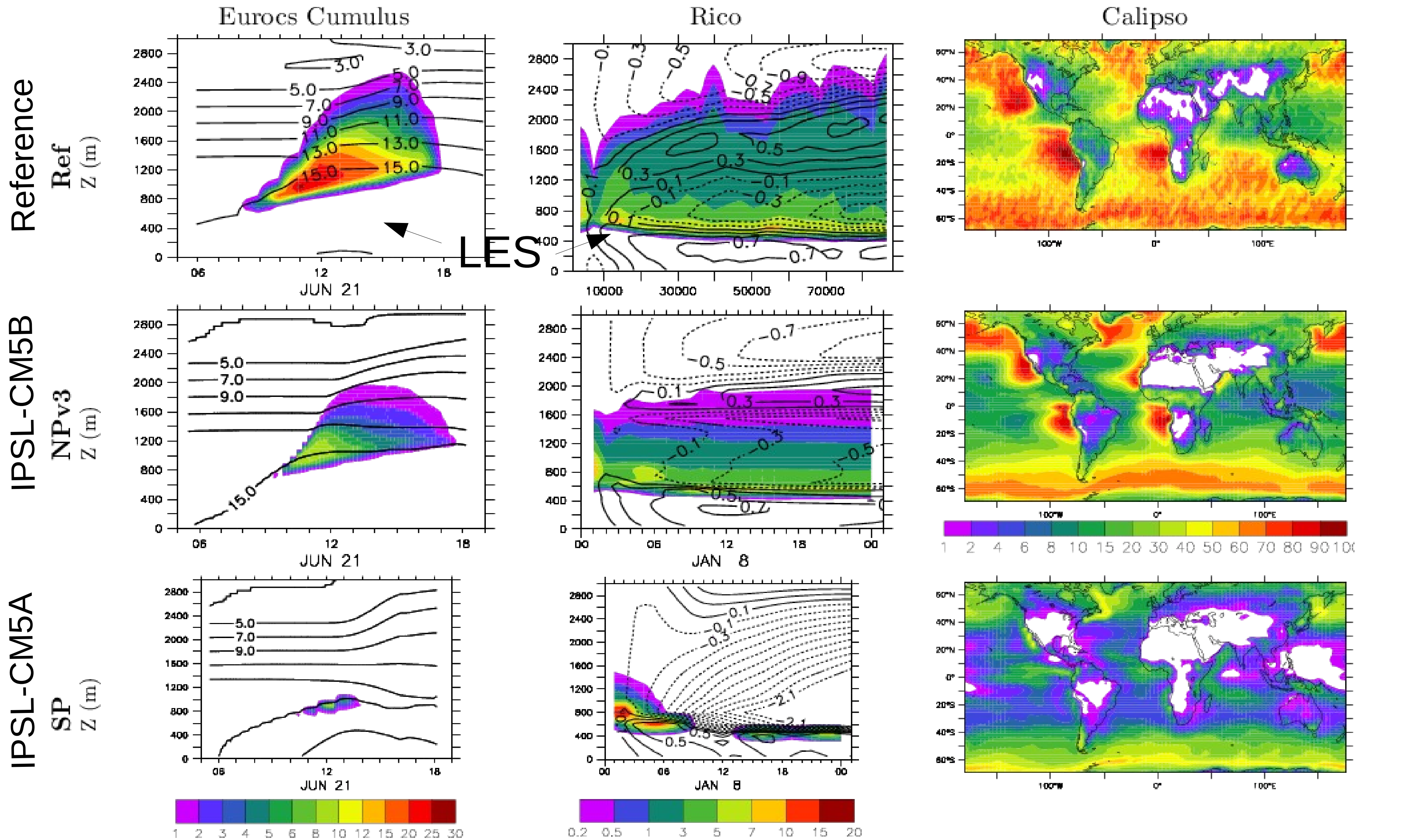
1D cases

Cloud fraction (%) and liquid water (g/kg)

3D simulations

Low cloud fraction (%)

Annual mean



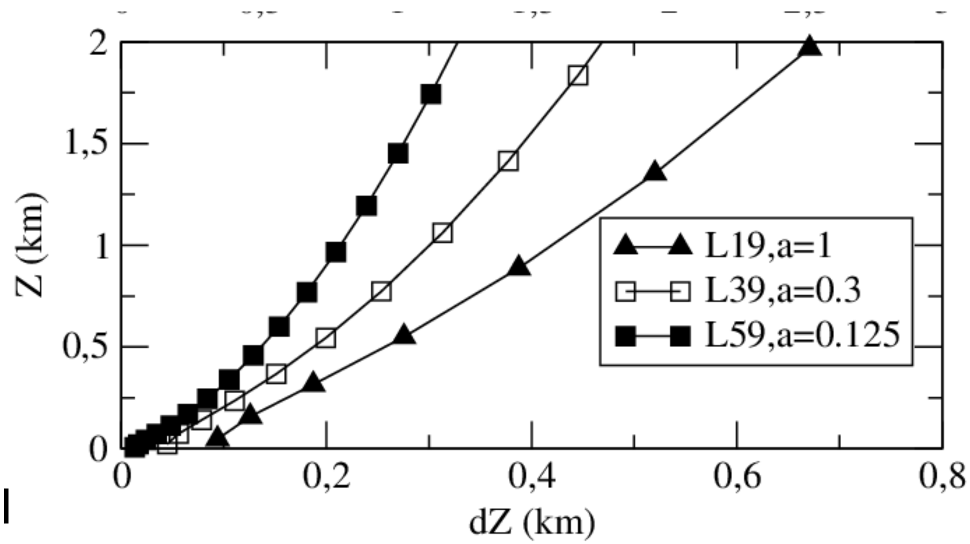
Better representation of low-level clouds in IPSL-CM5B

Hourdin et al., 2012

To come in LMDZ6

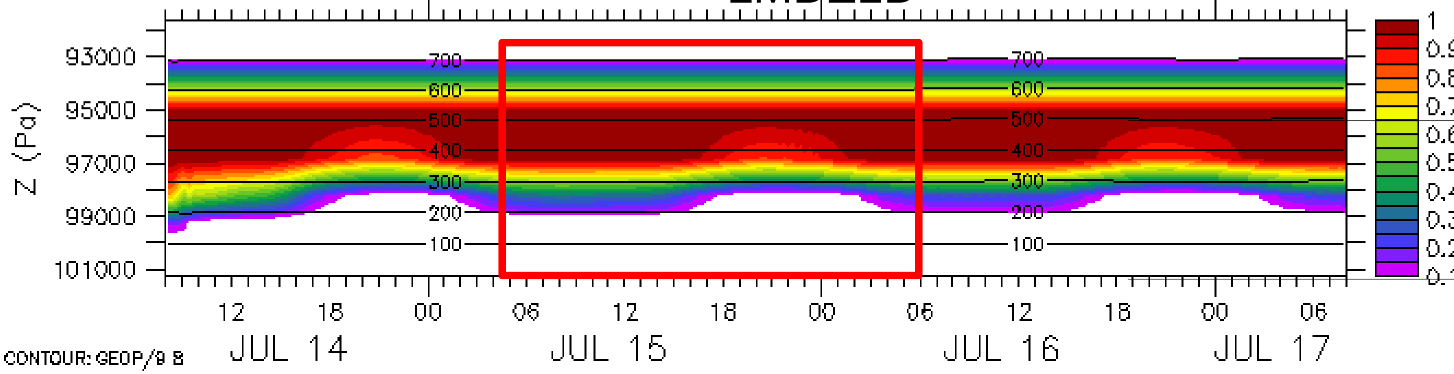
- Increase of vertical resolution with a refinement at low levels

- Activation of the thermal plume everywhere
Modification of entrainment and detrainment in the thermal plume model to account for cloud-top mixing in stratocumulus (Jam et al., in preparation)

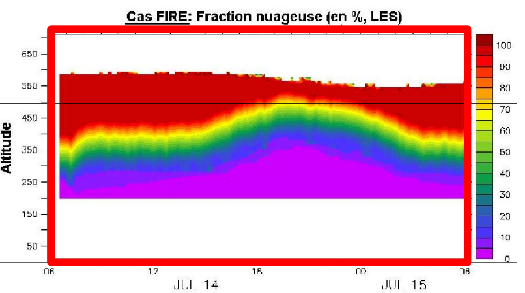


1D FIRE case with the modified thermal plume model

LMDZ1D

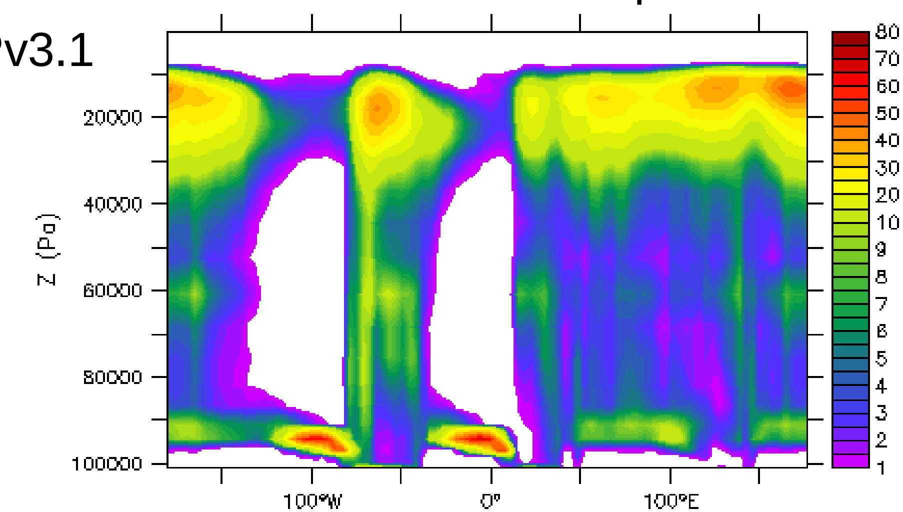


LES

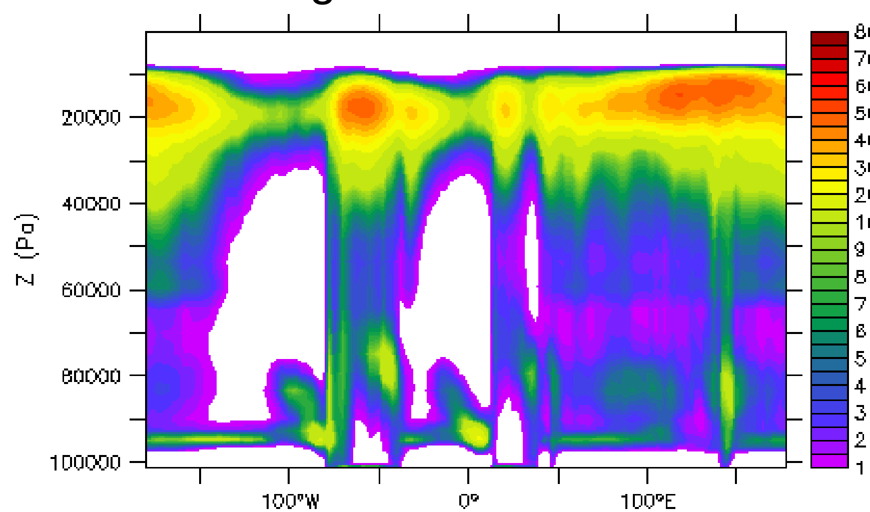


Effect in 3D simulations: Vertical profile of cloud fraction averaged between 5S and 20S

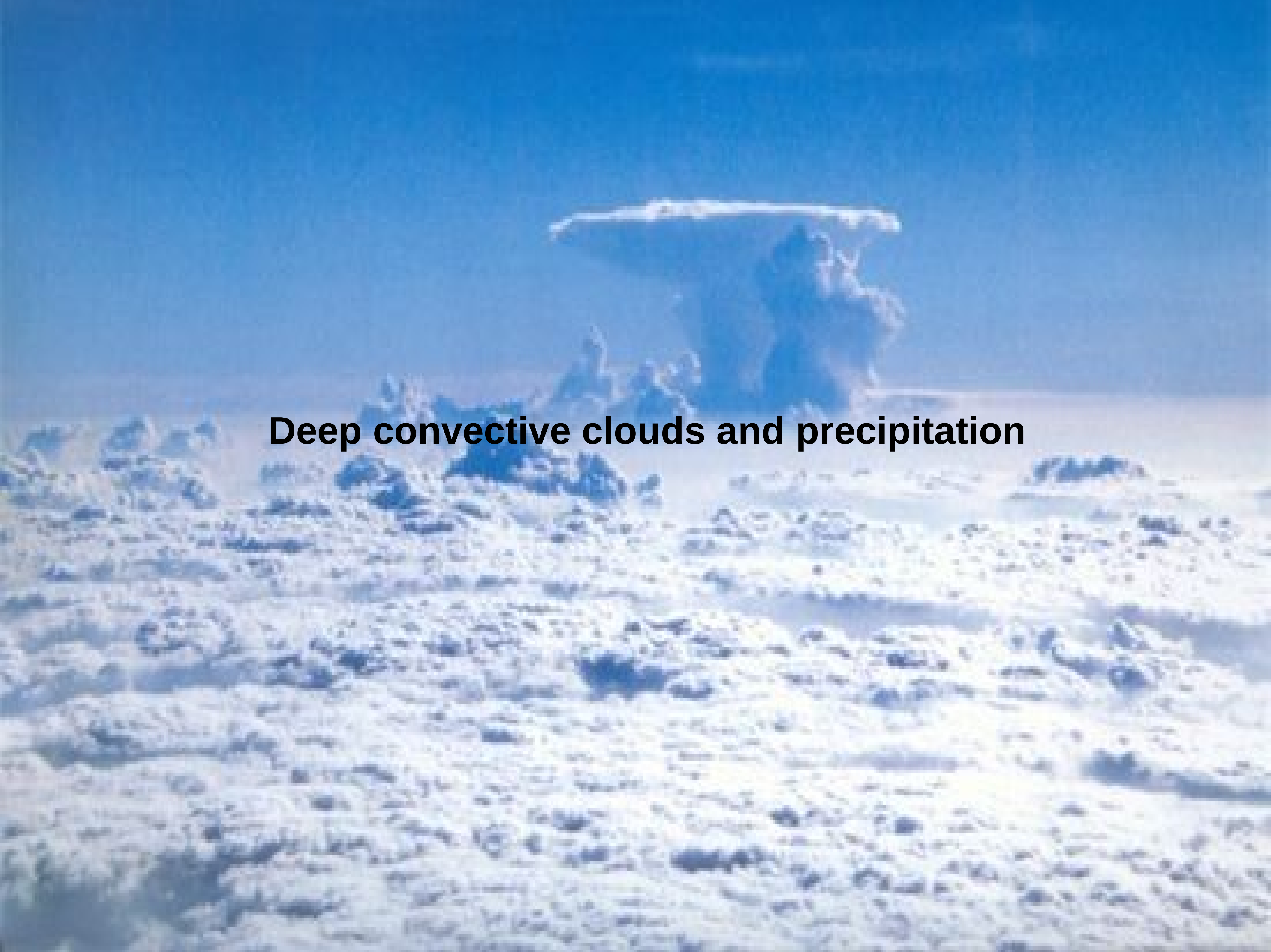
NPv3.1



NPv4.12



Deep convective clouds and precipitation



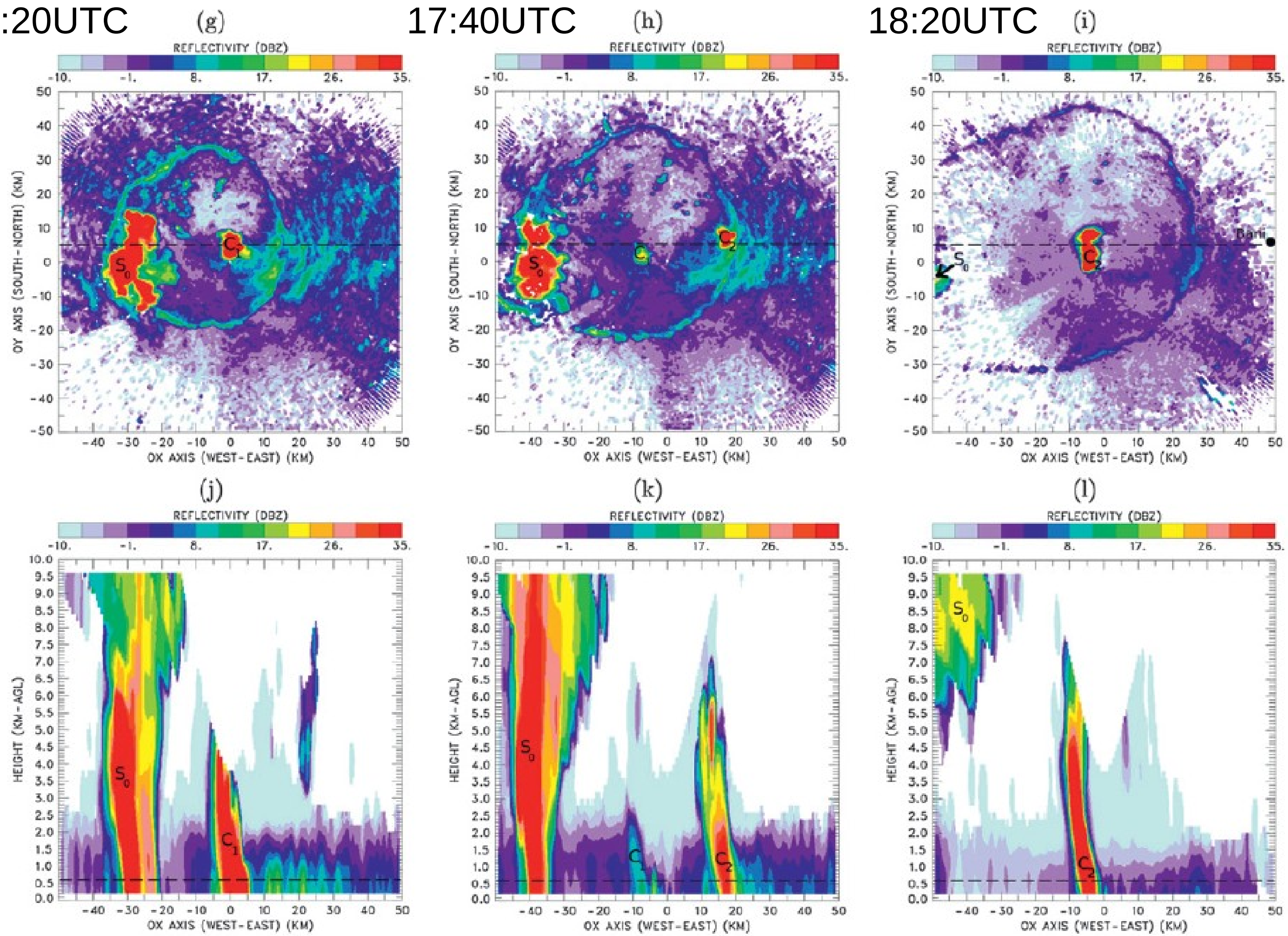
Cumulonimbus, updrafts and cold pools
Local convection in semi-arid region: The 10 of July 2006 in Niamey

Development of organized structures associated with deep convection

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

Horizontal cross-section at 600m

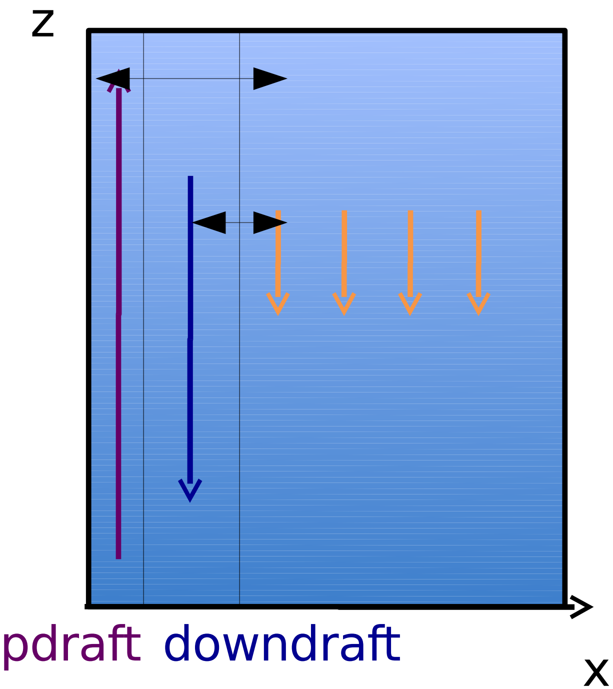
Vertical cross-section 5km north of the RADAR

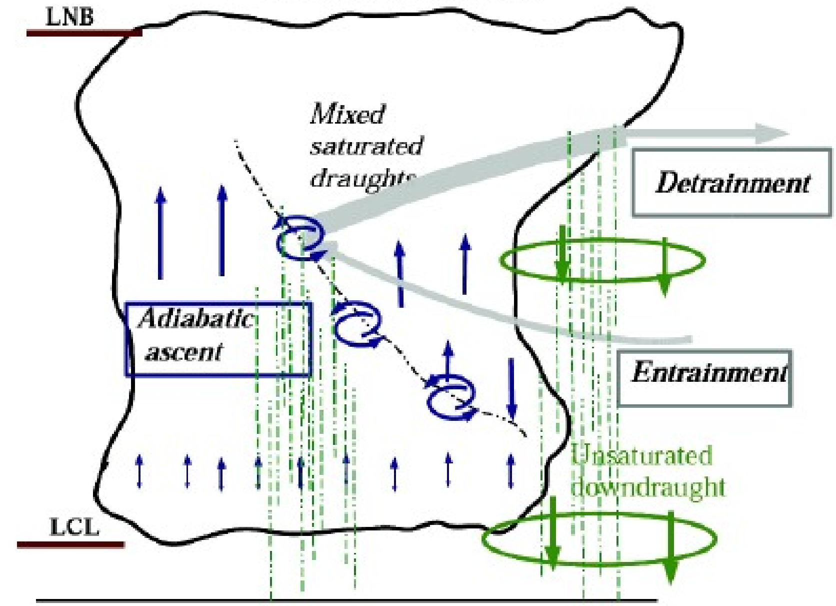


Lothon et al., MWR, 2011

The deep convection scheme

concvl.F





Emanuel, 1991

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

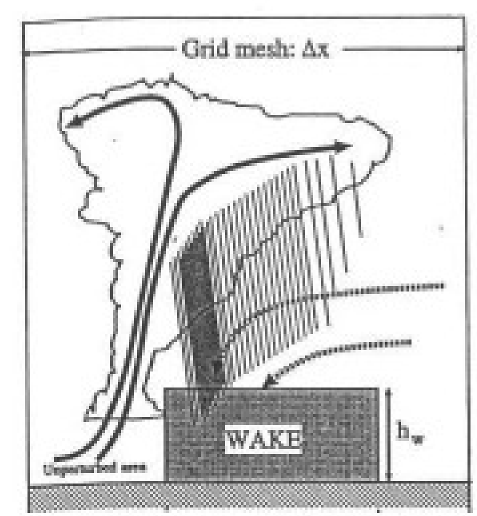
- Convection intensity ("closure"):
Convective intensity related to mean environmental properties (LMDZ5A)
Convective intensity related to sub-cloud processes (LMDZ5B)

- 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

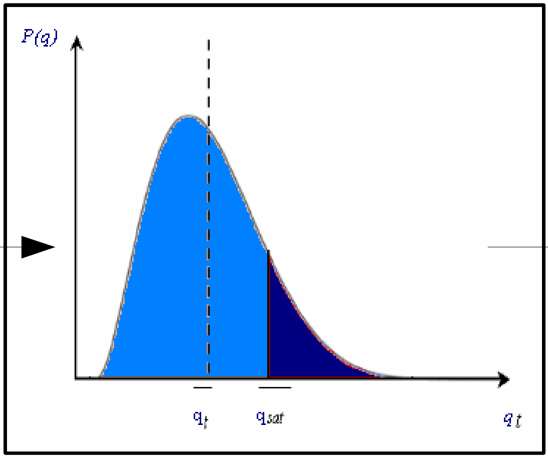
The deep convection cloud scheme
clouds_gno.F

Log-normal distribution of total water qt

Grid cell
mean state → qt, qsat

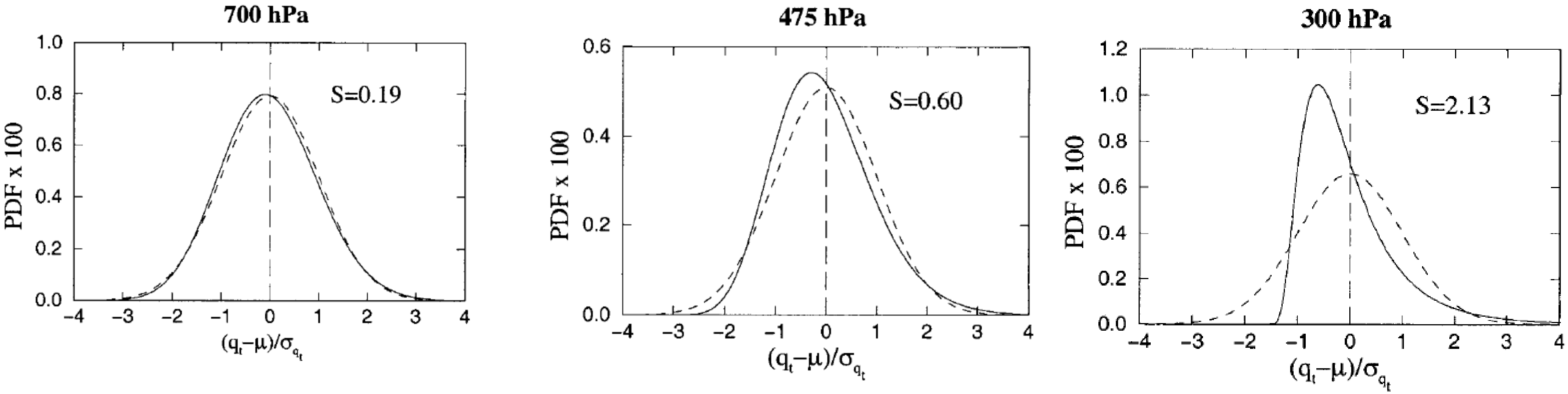
Convection scheme → qc

→



→ σ, cf

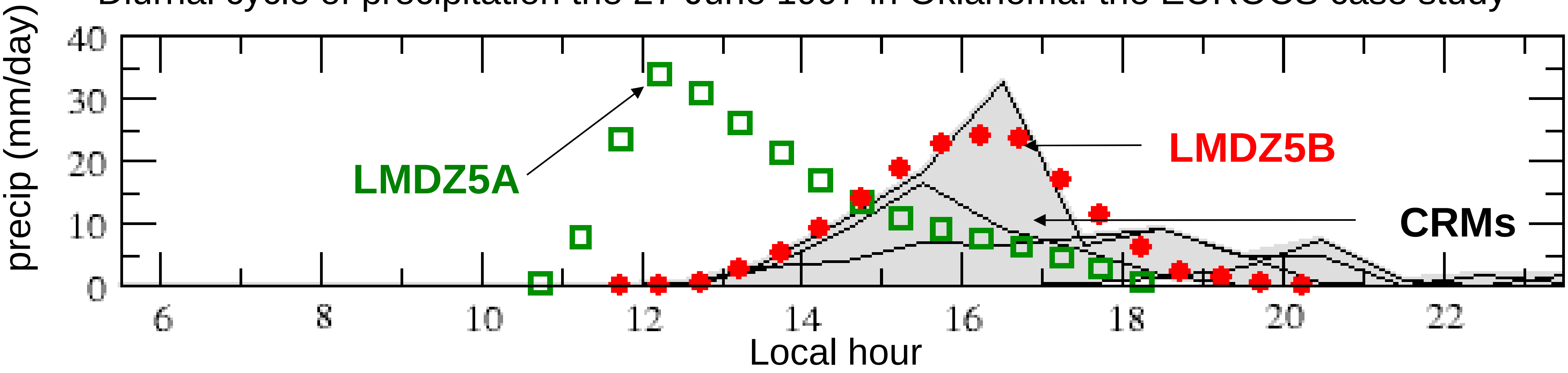
Vertical variation of the PDF on the oceanic case TOGA-COARE
20-27 December 1992



Bony & Emanuel, JAS, 2001

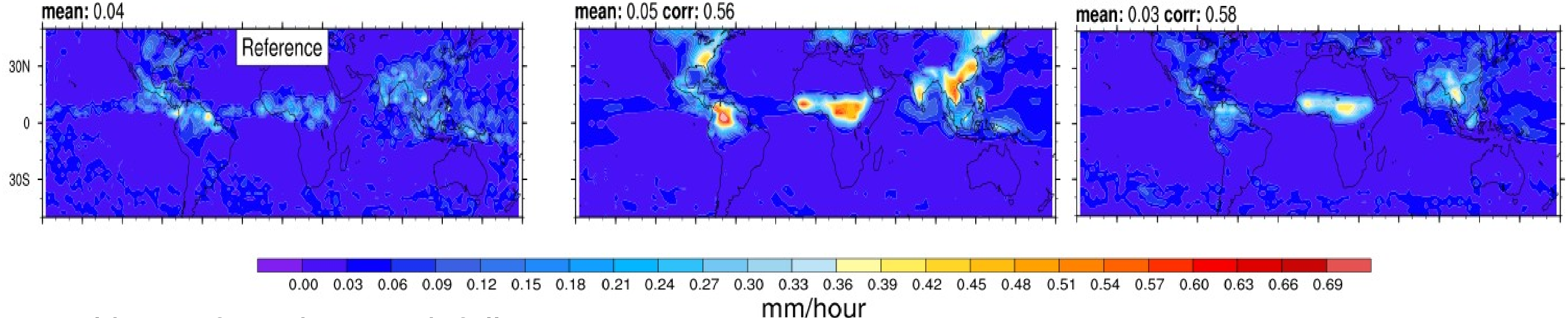
Representation of the diurnal cycle of precipitation over land

Diurnal cycle of precipitation the 27 June 1997 in Oklahoma: the EUROCS case study

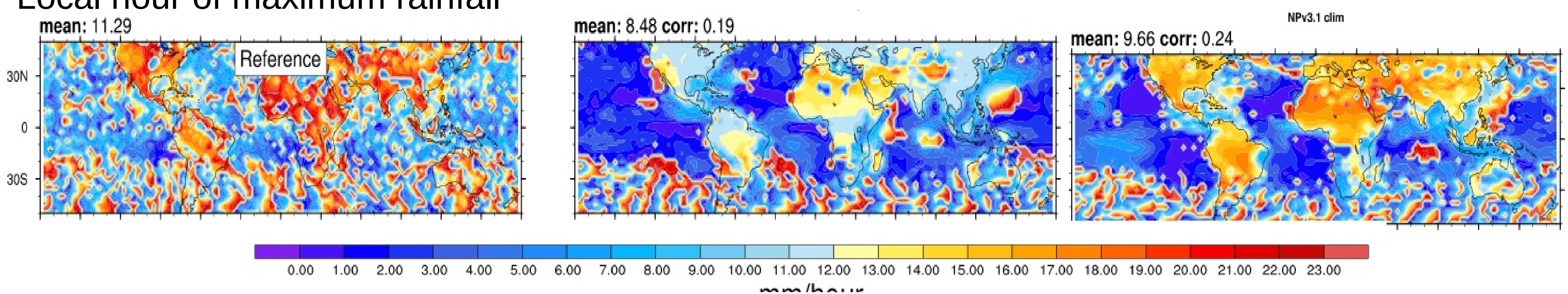


TRMM-3B42 LMDZ5A LMDZ5B

Amplitude of maximum rainfall



Local hour of maximum rainfall



To come in LMDZ6

Modification of the **triggering criteria** of the deep convection scheme
(Rochetin et al., JAS, 2014)

- Deterministic approach of deep convection triggering:
ALE> |CIN|

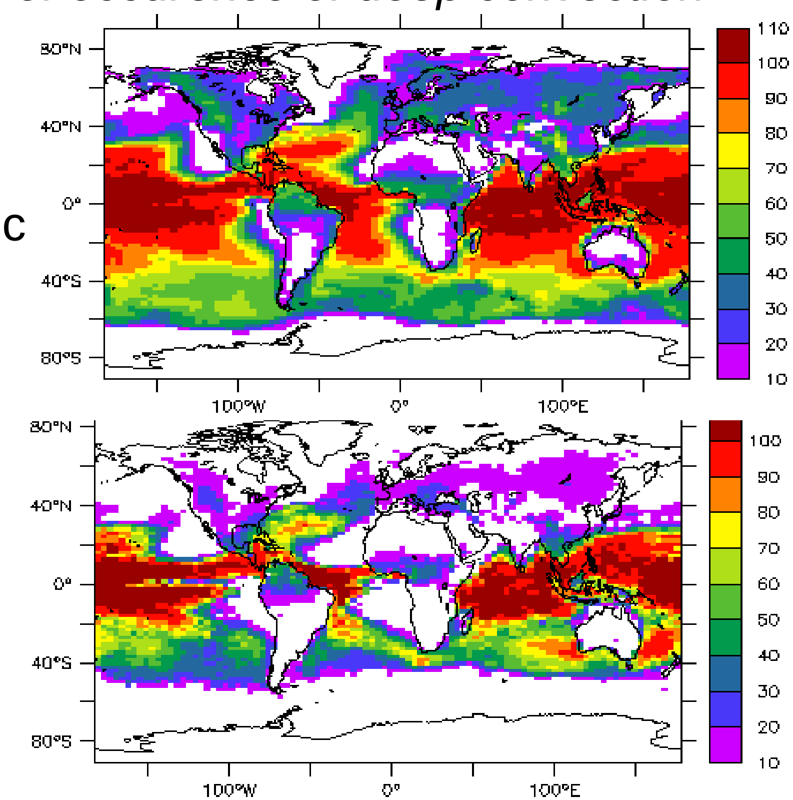
- Probabilistic approach:
What is the probability the grid-cell contains one thermal sufficiently large to trigger convection?

- **Stochastic approach:**
Random number between 0 and 1 to be compared with the triggering probability

Frequency of occurence of deep convection

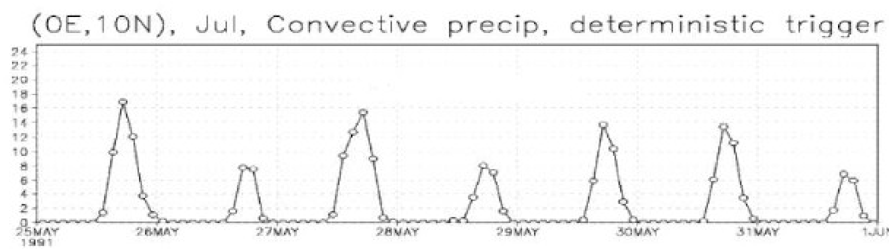
deterministic

stochastic

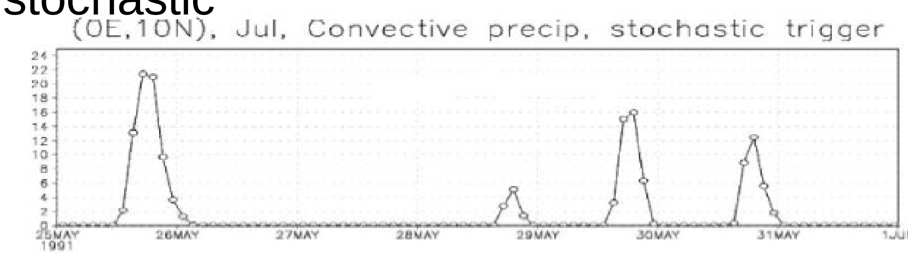


Day-to day variability of precipitation

deterministic



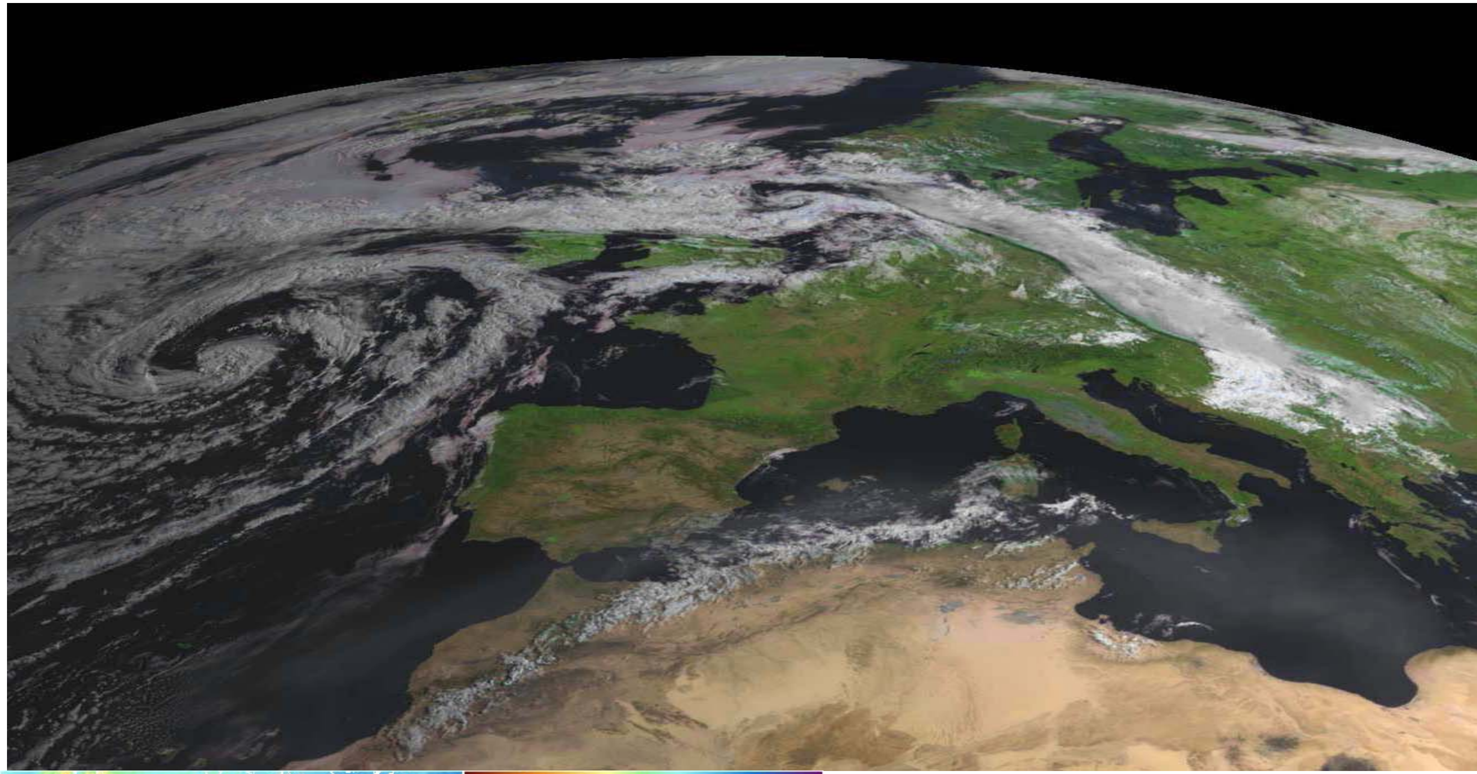
stochastic

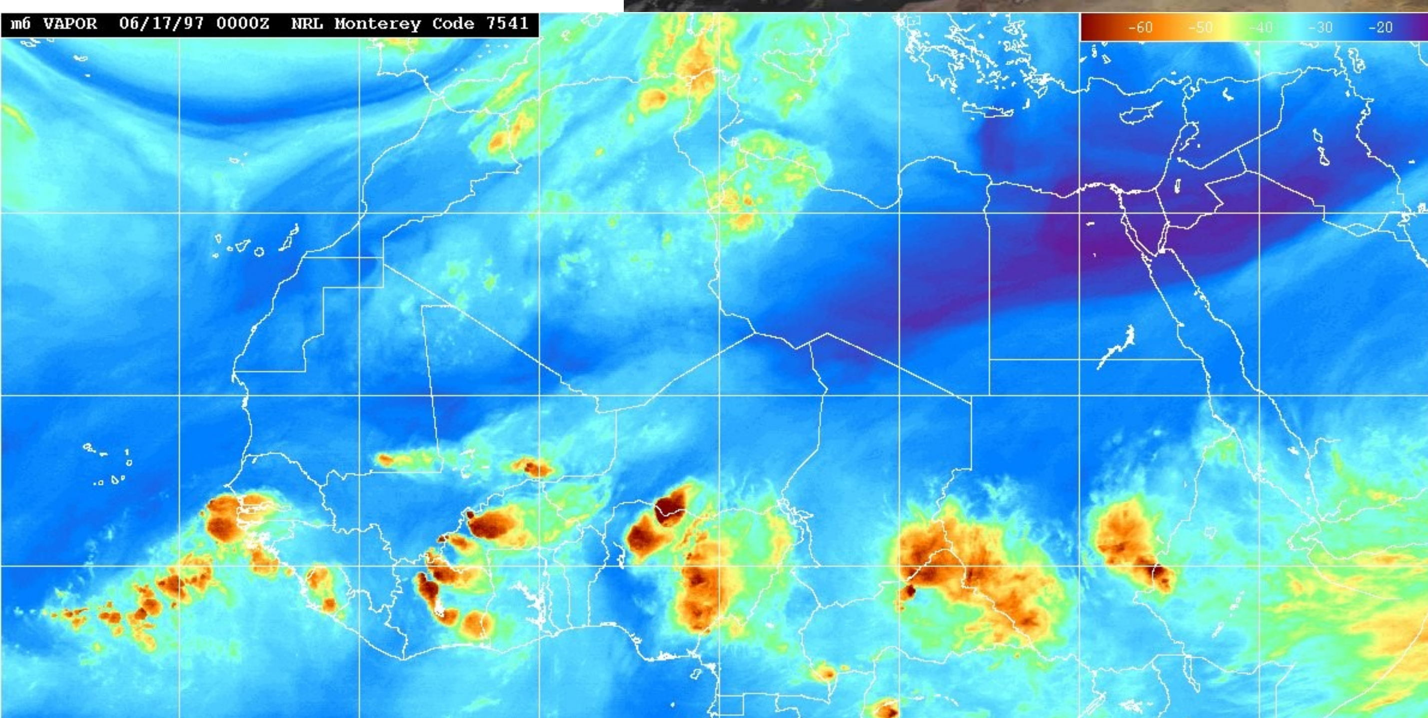


Large-scale clouds and precipitation

Large-scale condensation

Mid-latitude cyclones





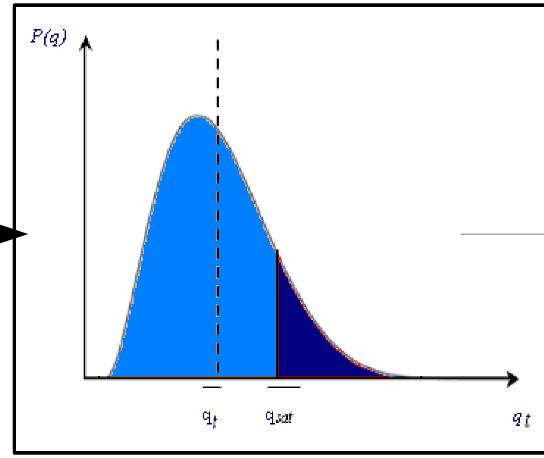
Convection organized in squall lines in Africa

The cloud scheme
fisrtilp.F90

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

Grid-cell mean state → q, qsat

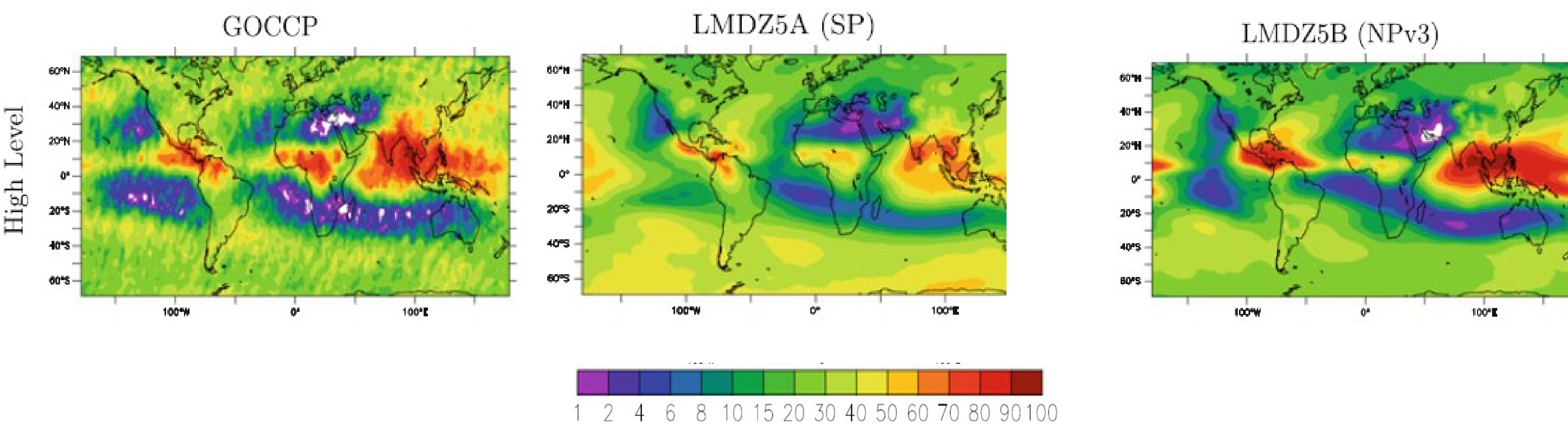
σ/q imposed



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

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

3D simulations
High cloud fraction (%)
Annual mean



Representation of precipitation mean and variability

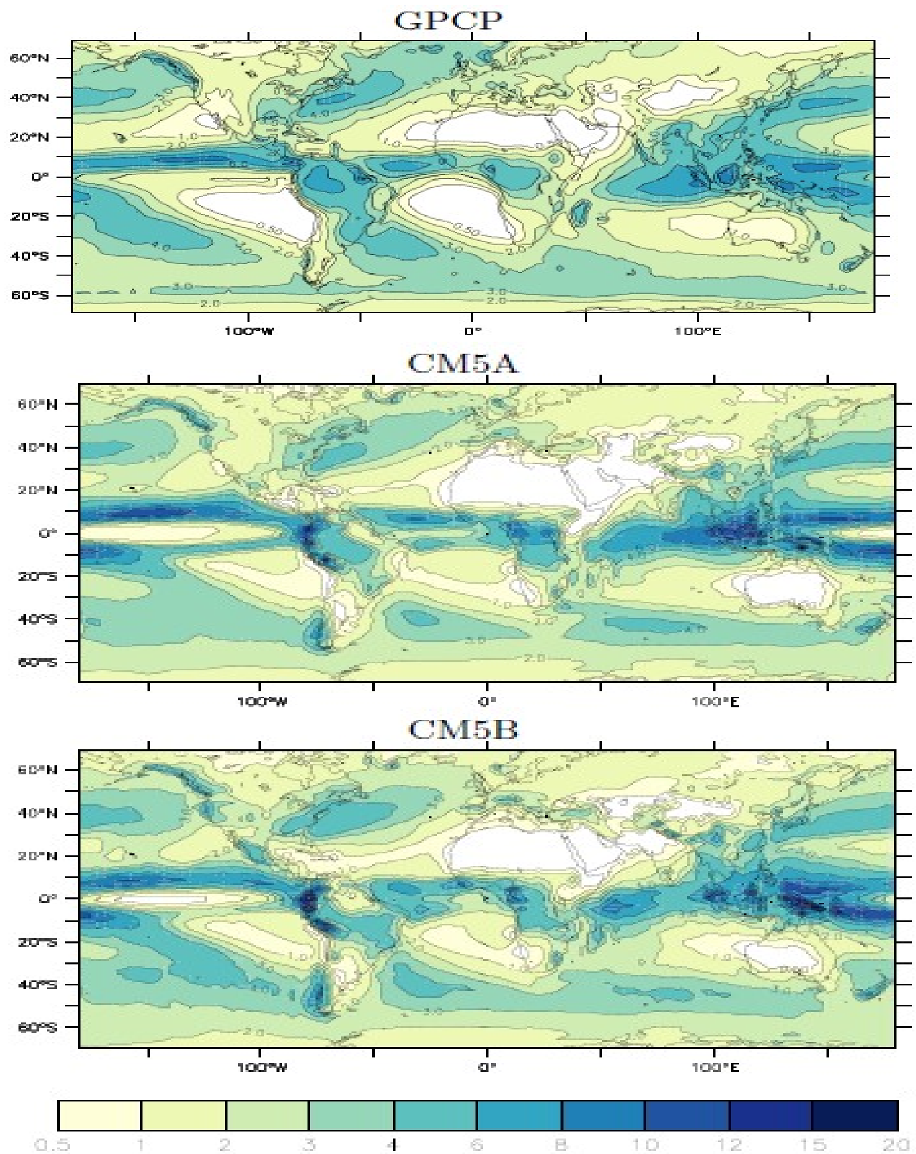
Hourdin et al., 2012

Annual precipitation (mm/day)

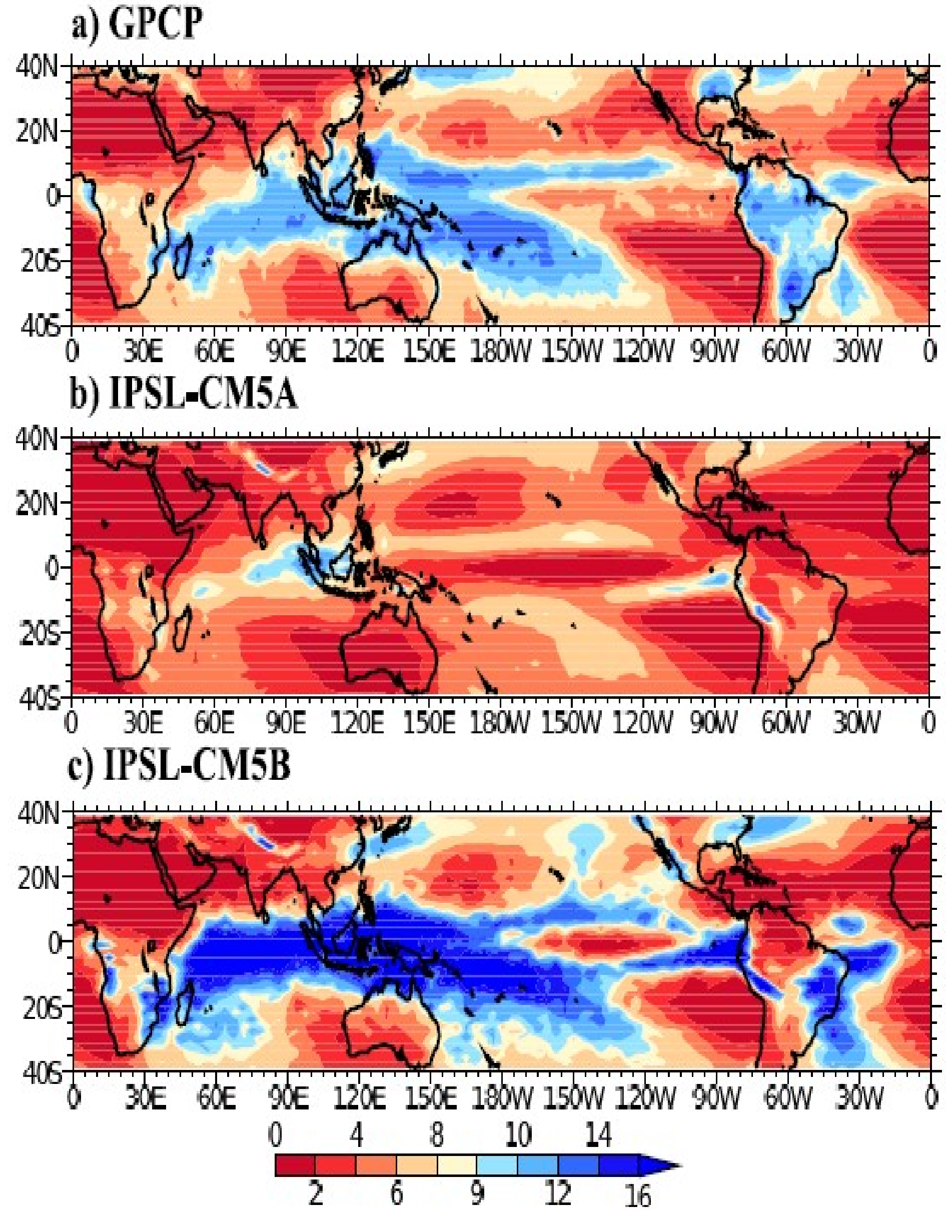
GPCP

IPSL-CM5A

IPSL-CM5B



Intraseasonal variability of precipitation (mm/day)



Reduction of the double-ITCZ problem in IPSL-CM5B

Reinforcement of the intra-seasonal variability of precipitation over ocean in IPSL-CM5B

To come in LMDZ6: The thermodynamical effect of ice

http://www.cnrm-game.fr/

In the deep convection scheme

- Latent heat release associated with freezing in updrafts

Hyp: transformation of liquid to ice between -10 and -40°C

- Absorption of latent heat associated with melting in unsaturated downdrafts

- Introduction of 2 precipitation fluxes: Liquid and ice

- Different latent heat for evaporation and sublimation

Hyp: Ice melts linearly between 0 and 15°C

Parameter: precipitation efficiency

In the large-scale condensation scheme

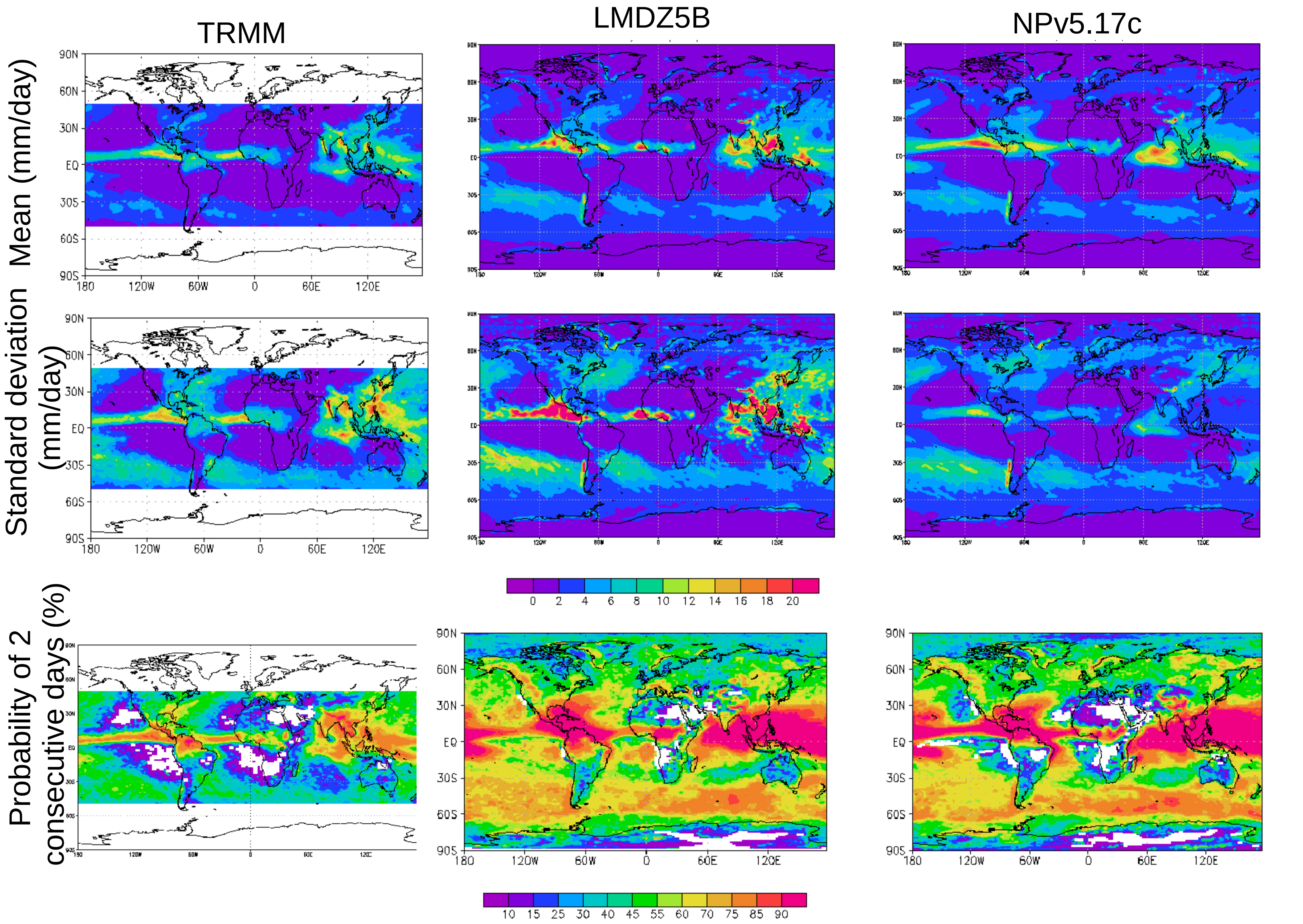
- Co-existence of liquid and ice between 0 and -40°C.
- Introduction of 2 precipitation fluxes: Liquid and ice
- Different latent heat for evaporation and sublimation

Hyp: Ice melts linearly between 0 and 2°C

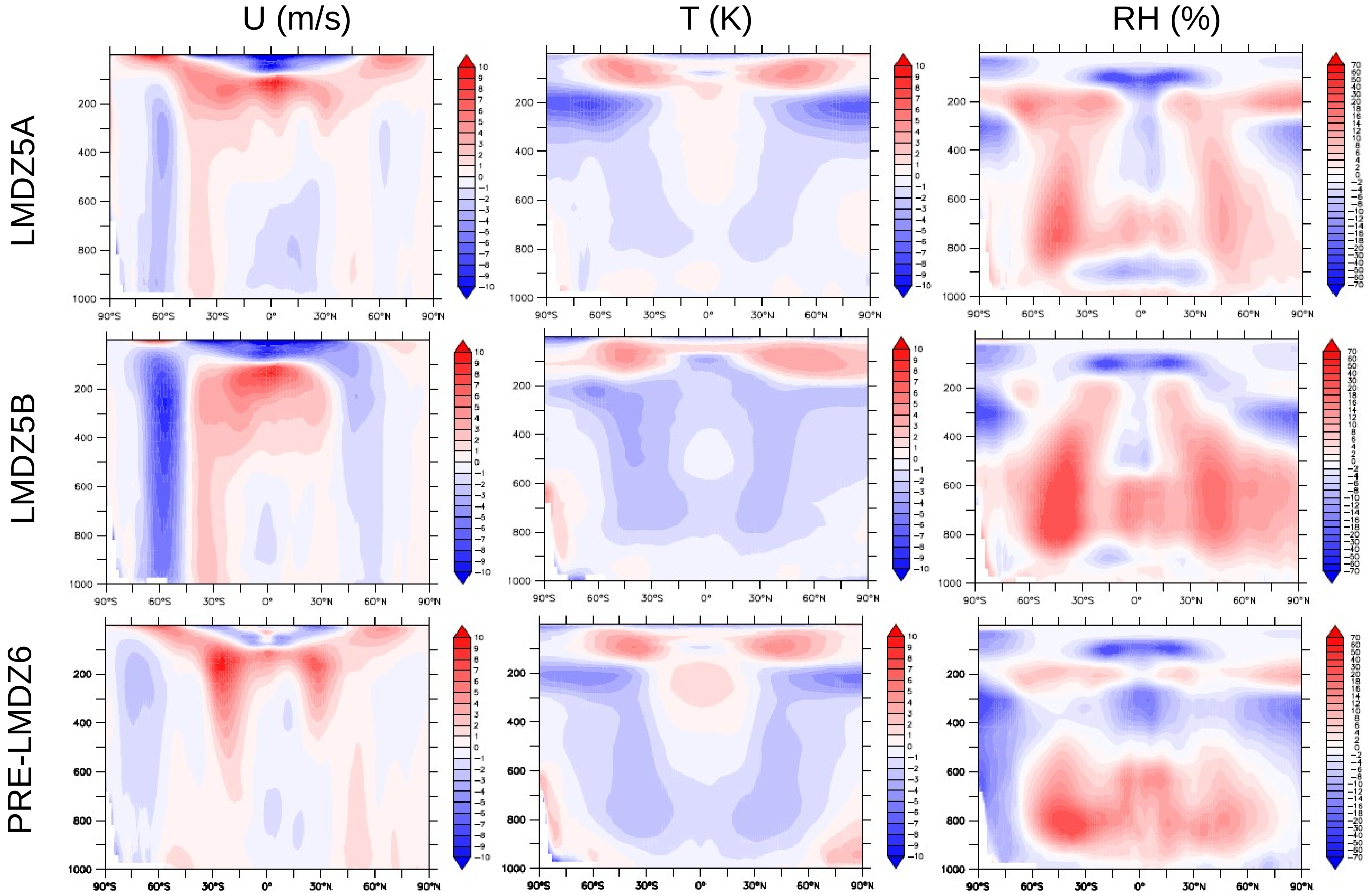
Parameters: maximum water content of clouds, autoconversion rate

+ coefficient of evaporation, scaling factor on the falling speed of ice crystals, effective radius of droplets and ice crystals

To come in LMDZ6



What about mean biases?



Mean biases amplified in LMDZ5B compared to LMDZ5A
Diminution of mean biases in PRE-LMDZ6

What about mean biases?

Results from atmospheric simulations forced by climatic sea surface temperature

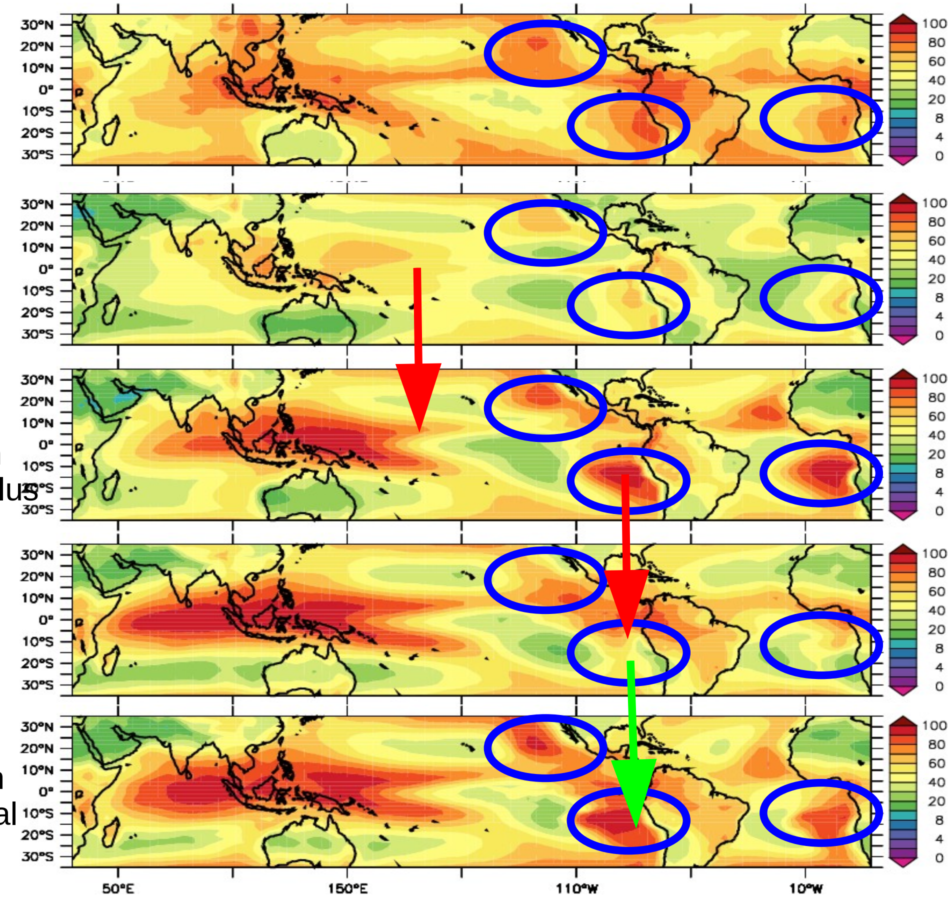
Impact of the thermal plume model on the near surface humidity bias

: activating thermal plumes
: ETO region
: Detrainement modifié

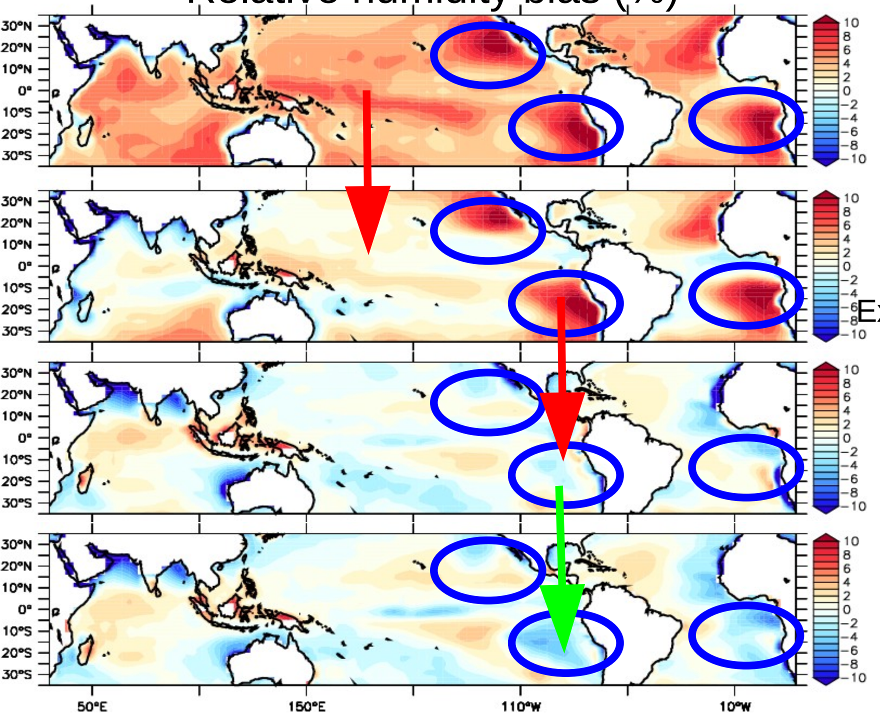
Observations Calipso GOCCP

Da Silva

Total cloud cover (%)



Relative humidity bias (%)



LMDZ5A
No thermals

LMDZ5B
Thermals activation
Except for strato-cumilus

LMDZ6.0
Thermals activation
everywhere

LMDZ6.1
Thermals activation
Everywhere + special
Treatment for strato
Cuulus clouds

To come in LMDZ6

Reduction of the relative humidity bias in the Eastern part of Tropical Ocean

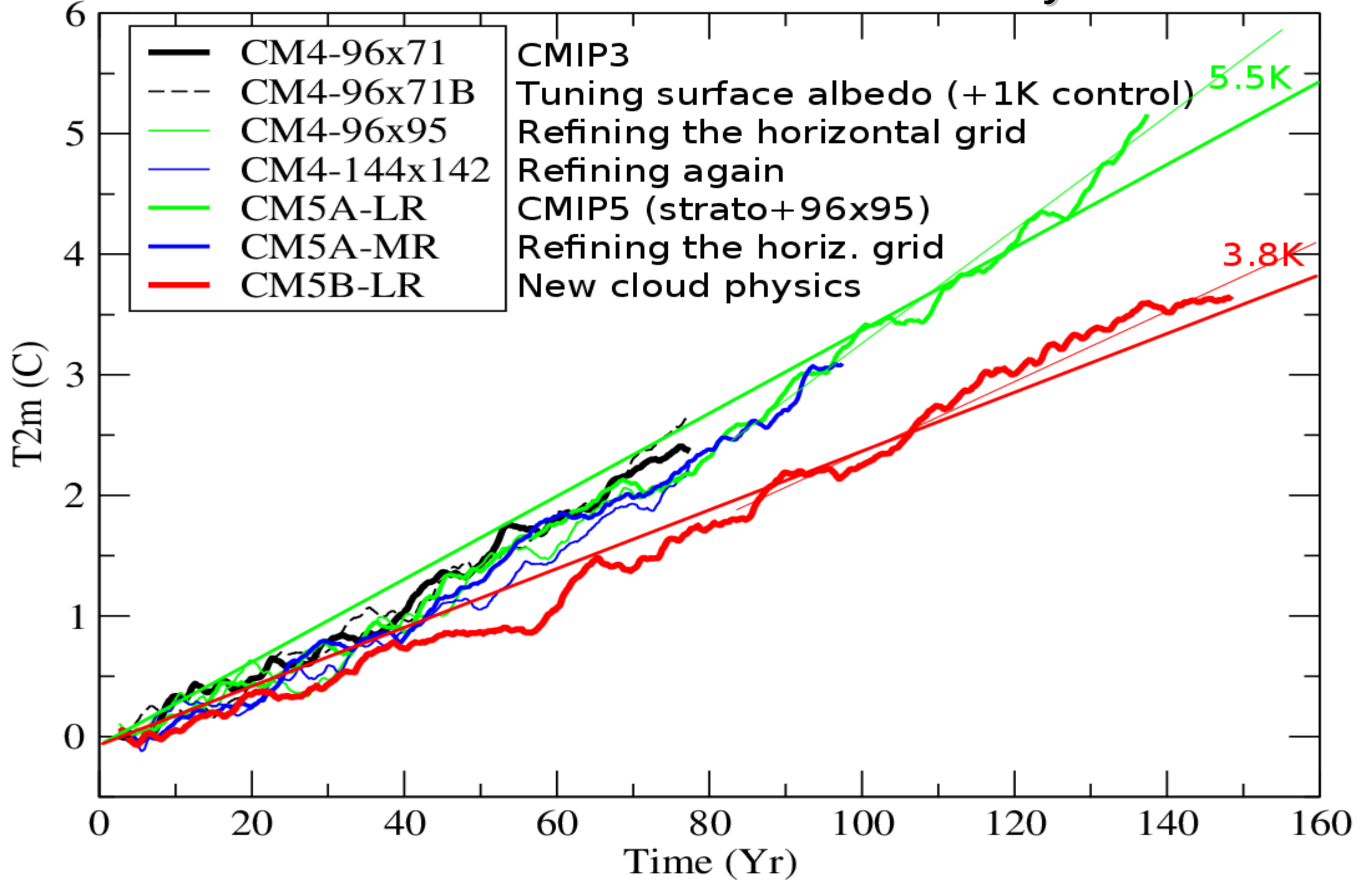
Reduction of corresponding latent heat flux bias in forced mode and SST bias in coupled mode

What about thermohaline circulation and climate sensitivity?

- Dramatic drop of the thermohaline circulation in IPSL-CM5B
- Lower sensitivity in IPSL-CM5B than in IPSL-CM5A

Sensitivity to resolution and physical package

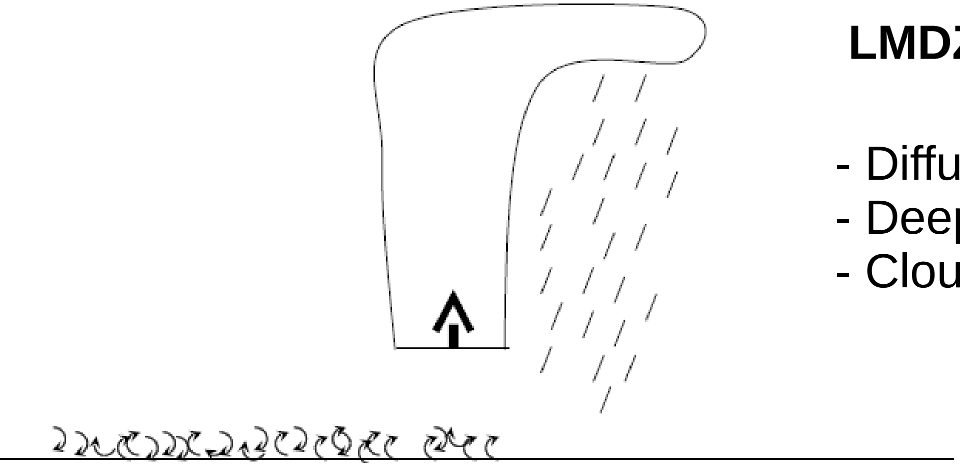
Evolution of mean T2m
Increase of CO_2 concentration of 1% / year



Hourdin et al., 2012

To come in LMDZ6?

The different physical packages of LMDZ

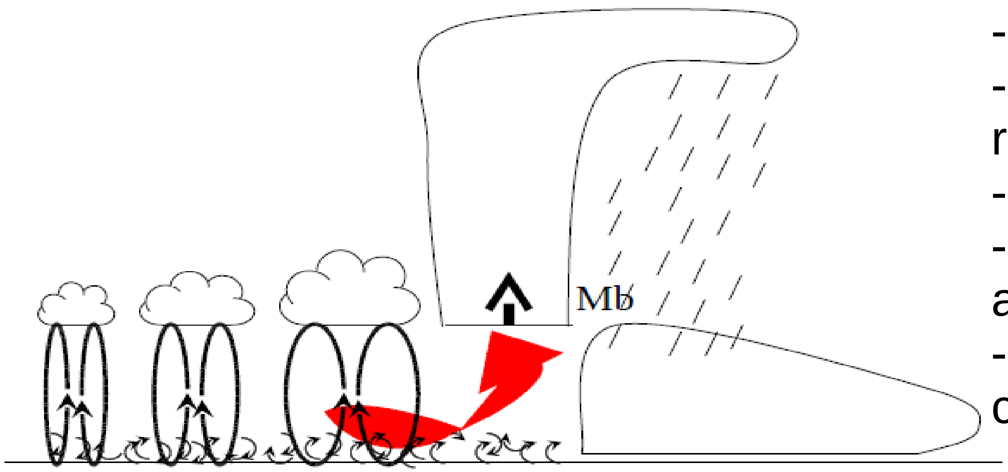


LMDZ5A

- Diffusion scheme (Louis, 1979)
- Deep convection (Emanuel, 1991)
- Cloud scheme (Bony et Emanuel, 2001)

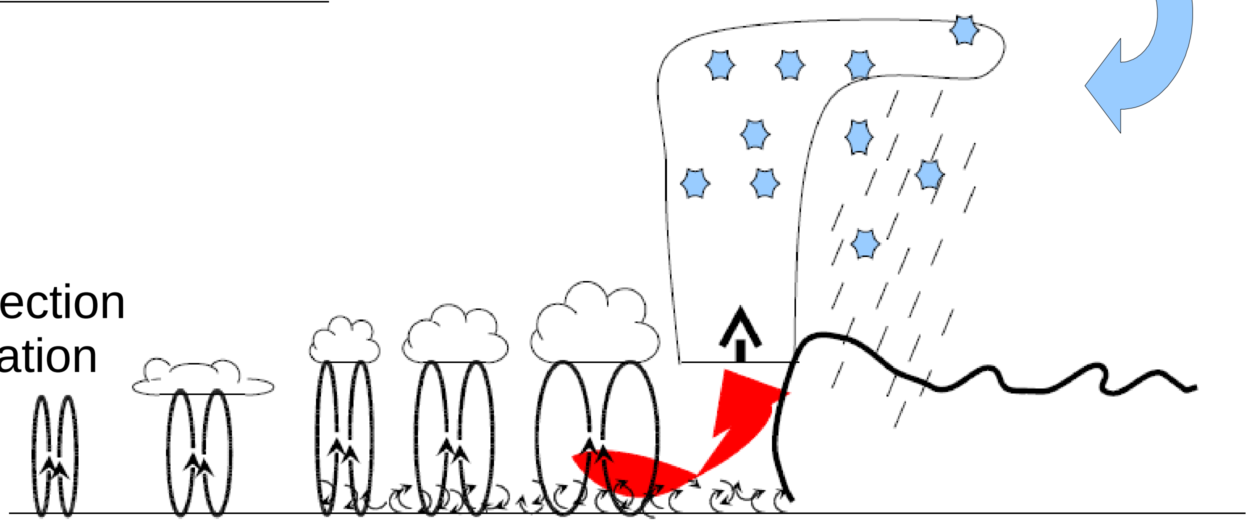
LMDZ5B

- Diffusion scheme (Yamada, 1983)
- Thermal plume model in shallow cumulus regions (Rio et al., 2010)
- Cold pool (Grandpeix et Lafore, 2010)
- Deep convection controlled by thermals and wakes (Rio et al., 2012)
- Bi-gaussian cloud scheme for shallow convection (Jam et al., 2013)



PRE-LMDZ6

LMDZ5B
+ Thermal plume model everywhere
+ Stochastic triggering of deep convection
+ Different convective mixing formulation
+ Thermodynamical effect of ice



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
iflag_mix=0	PDF for mixing	iflag_mix=1
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

LMDZ5A (AR4_physiq.def)		LMDZ5B (Npv3.1_physiq.def) (NPv5.17h_physiq.def) UNDER DEVELOPMENT!!
	Boundary-layer	
iflag_pbl=1	Diffusion	iflag_pbl=8 (11)
iflag_thermals=0	Thermals	iflag_thermals=15 (18)
iflag_thermals_ed=0	Mixing rates in thermals	iflag_thermals_ed=10 (8)
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
		iflag_trig_bl=1
iflag_mix=0	PDF for mixing	iflag_mix=1 (0)
iflag_clw=1	Computation of condensate	iflag_clw=0
epmax=0.999	Efficiency of precipitation	Epmax=0.997 (0.998)
	Clouds	
iflag_cldcon=3	Cloud scheme	iflag_cldcon=6
iflag_ratqs=0	Profile of σ/qt	iflag_ratqs=2 (4)
ratqsbas=0.005	σ/qt min	ratqsbas=0.002
ratyqshaut=0.33	σ/qt max	ratqs_haut=0.25 (0.312)
		iflag_t_glace=1
		iflag_ice_thermo=1
cld_lc_lsc=4.16e-4	Threshold cloudy water LS	cld_lc_lsc=6e-4 (3e-4)
cld_lc_con=4.16e-4	Threshold cloudy water CV	cld_lc_con=6e-4(3e-4)
ffallv_lsc=0.5	Ice crystals fall speed LS	ffallv_lsc=1.35 (0.665)
ffallv_con=0.5	Ice crystals fall speed CV	ffallv_con=1.35 (0.665)
coef_eva=2e-5	Coefficient of evaporation	coef_eva=1e-4 (2e-5)