Introduction

Frédéric Hourdin

LMDZ : a general circulation model

1. General Circulation Models
2. LMDZ
3. Splitting/coupling and modularity
4. Operating modes

1. General Circulation Models

The world of numerical models

appearances

theories (physics, chemistry, biologie, economy)

mathematics

numerics

computers

Mathematics constitute a common language

Modeling concerns all the layers

Always try to make links with the upper layers

At same time, you must be aware of the layer in which you are working, or at which transition between layers.

Do not forget that your goal is to explain things in the first layer.

1. General Circulation Models

The « layers » in LMDZ :

Appearances :
→ Meteorology, climate, atmospheric composition

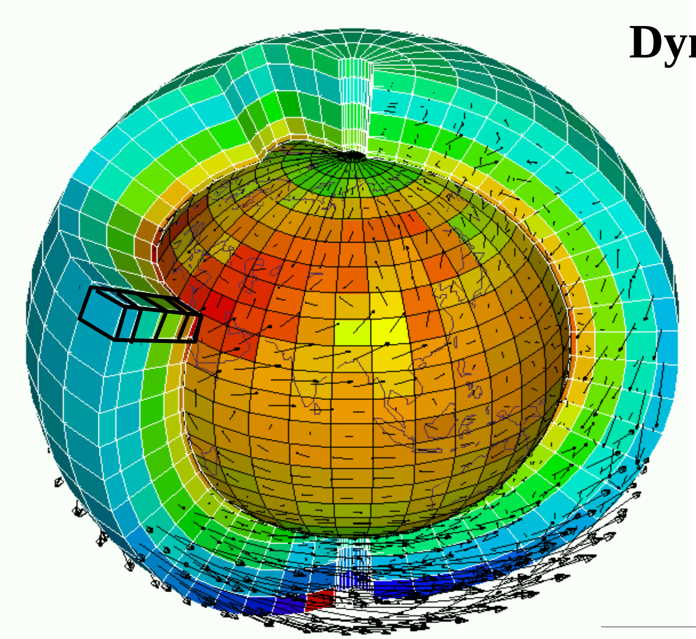
Theories :
→ Fluid mechanics
→ Gas/radiation interaction
→ Phase changes/ Thermodynamics
→ Chemistry

Mathematics
→ Navier-Stokes equations (Primitive equations)
→ Thermodynamical laws
→ Radiative transfer equations

Numerics
→ Grid point discretization
→ Finite volume and finite differences
→ Guaranty conservation of certain quantities, robustness, efficiency, rather than accuracy

Computers
→ Fortran / Linux
→ High Performance Computing
→ Modularity
→ Flexibility / Multi-configuration

1. General Circulation Models



Dynamical core : primitive equations discretized on the sphere

- Mass conservation

  $D\rho/Dt + \rho\, \mathrm{div}\underline{U} = 0$
- Potential temperature conservation

  $D\theta/Dt = 0$
- Momentum conservation

  $D\underline{U}/Dt + (1/\rho)\, \underline{\mathrm{grad}p} - \underline{g} + 2\, \underline{\Omega} \wedge \underline{U} = \underline{0}$
- Secondary components conservation

  $Dq/Dt = 0$

Primitive equations of meteorology

→ Thin layer approximation

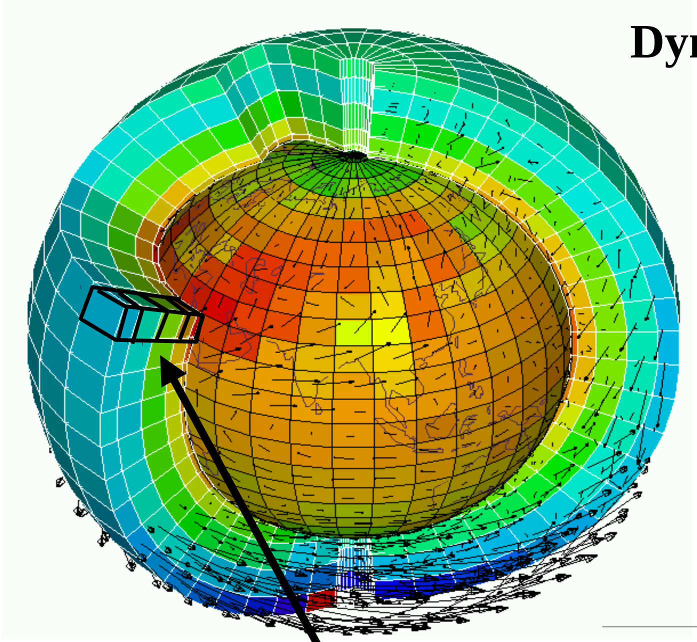
→ Hydrostatic approximation (**valid down to 10-20 km**)

From physics to numerics :

→ Finite volume and finite differences, longitude-latitude grid

→ Explicit resolution down to 30-300 km depending of the configuration

→ Numerical conservation of important quantities (mass, water, enstrophy ...).



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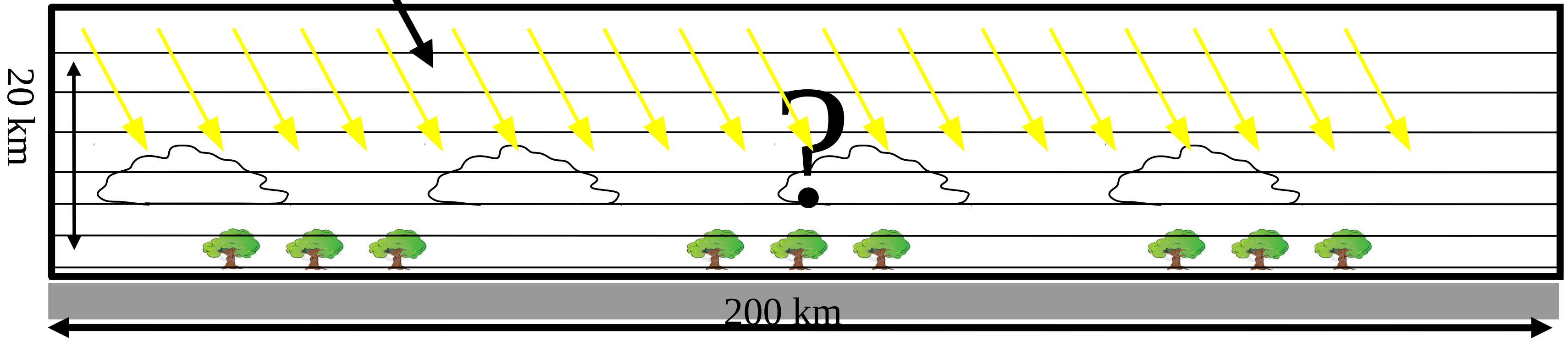
  $D\theta / Dt = Q / Cp \ (p_0/p)^{\kappa}$

- Momentum conservation

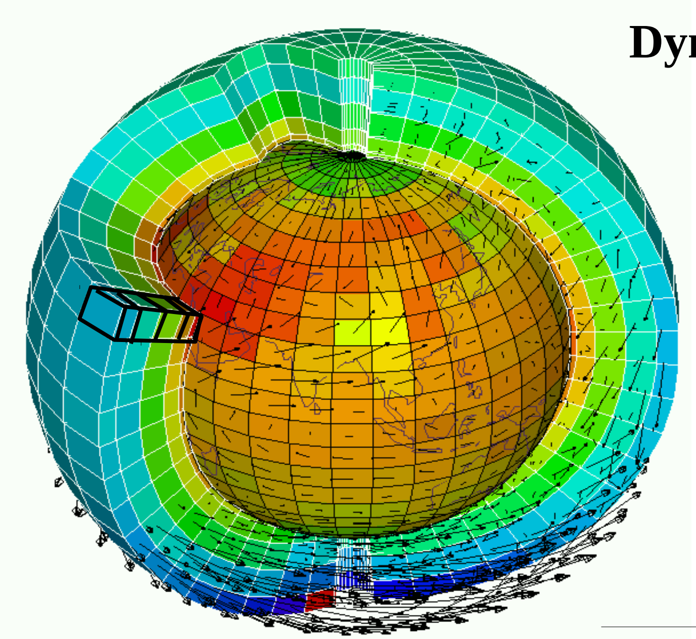
  $D\underline{U}/Dt + (1/\rho)\ \underline{\mathrm{grad}p} - \underline{g} + 2\ \underline{\Omega} \wedge \underline{U} = \underline{F}$

- Secondary components conservation

  $Dq/Dt = Sq$



1. General Circulation Models



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  $Dq/Dt = Sq$

Parameterizations purpose : account for the effect of processes non resolved by the dynamical core

→ **Traditional « source » terms in the equations**

- *Q* : Heating by radiative exchanges, thermal conduction (neglected), condensation, sublimation, **subgrid-scale motions (turbulence, clouds, convection)**
- *F* : Molecular viscosity (neglected), **subgrid-scale motions (turbulence, clouds, convection)**
- *Sq* : condensation/sublimation (q= water vapor or condensed), chemical reactions, photo-dissociation (ozone, chemical species), micro physics and scavenging (pollution aerosols, dust, ...), **subgrid-scale motions (turbulence, clouds, convection)**

Parameterizations : principles




- Compute the **average effect of unresolved processes on the global model state variables** (*U*, θ, q)

- **Based on a description of the approximate collective behavior** of processes

- Involve additional **parameterization internal variables** (cloud characteristics, standard deviation of the sub-grid scale distribution of a variable, …)

- Derive **equations** relating internal variables to the state variables

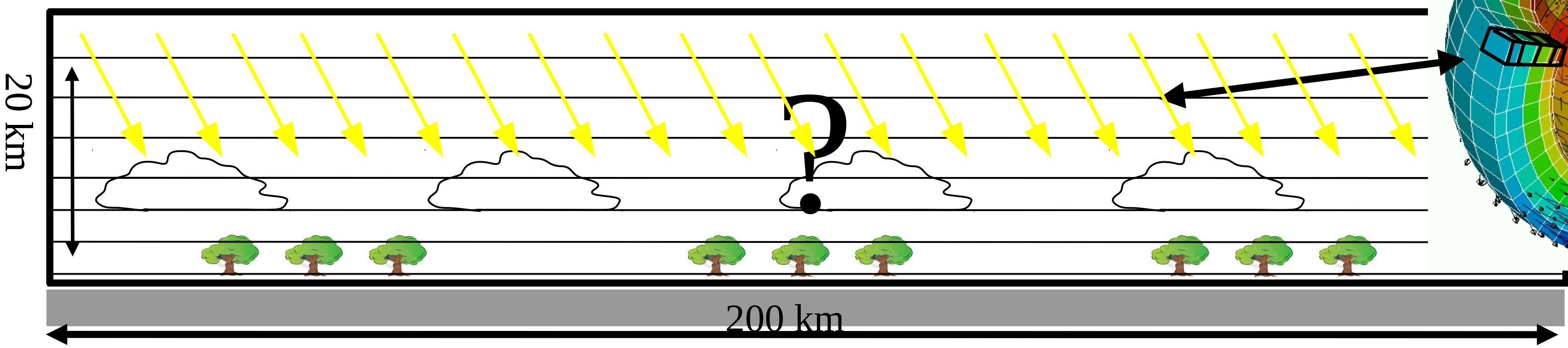
  U, θ, q at time t → **internal variables** → *F*, *Q*, *Sq* → *U*, θ, q at t+δt

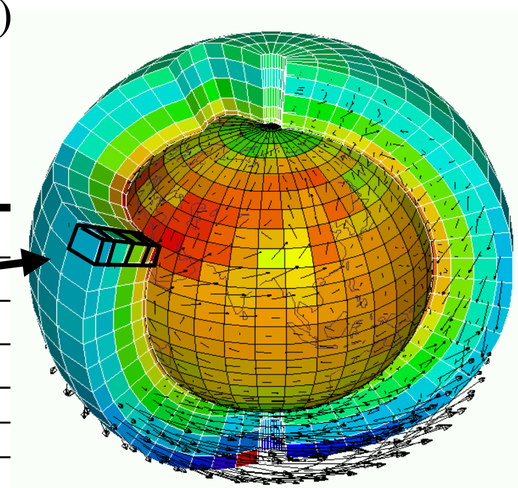
- **Homogeneity hypothesis** (statistical) on the horizontal of the targeted processes (like in the plane-parallel approximation of radiative transfer)

  → 1-dimensional equations in z (vertical exchanges only)

  → Independent atmospheric column

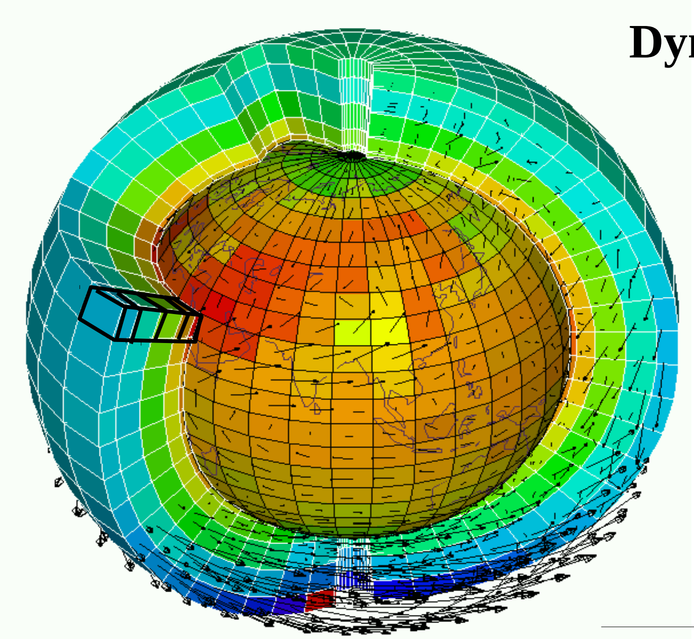
Inside an « atmospheric column » ...





I. LMDZ : a general circulation model

1. General Circulation Models
2. **LMDZ**
3. Splitting/coupling and modularity
4. Operating modes



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  $D\underline{U}/Dt + (1/\rho)\, \underline{\mathrm{grad}p} - \underline{g} + 2\, \underline{\Omega} \wedge \underline{U} = \underline{F}$
- Secondary components conservation

  $Dq/Dt = Sq$

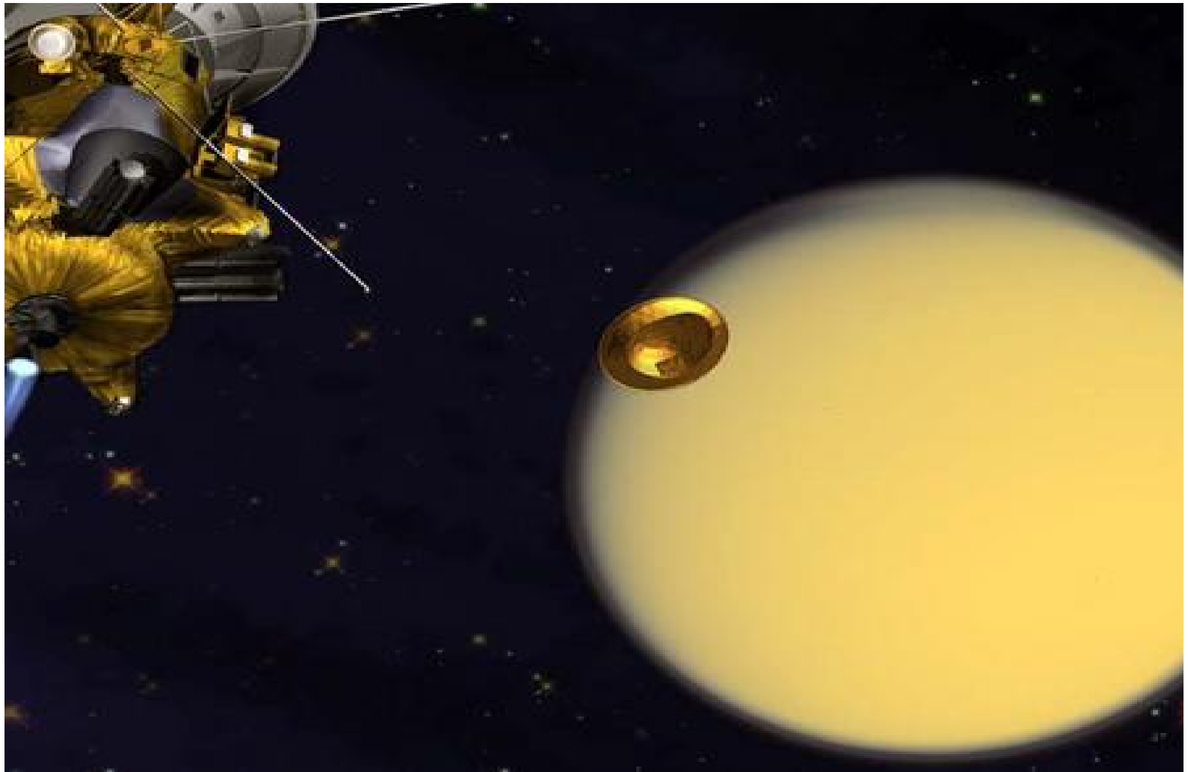
The LMDZ dynamical core :

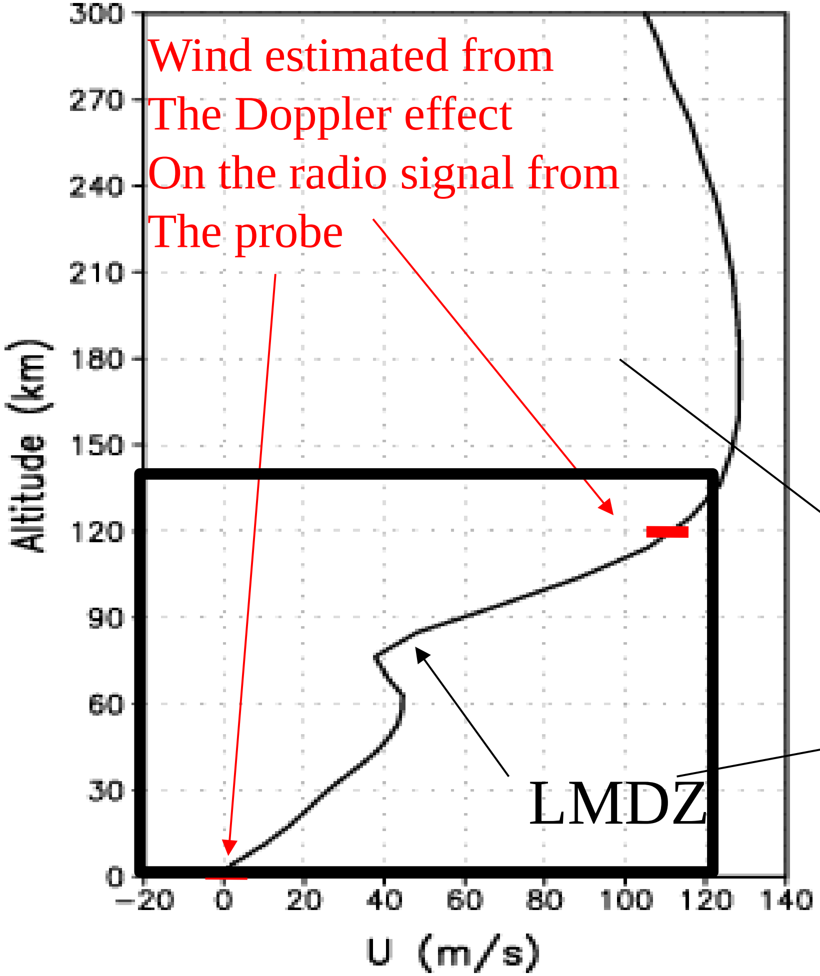
→ Global longitude-latitude grid
→ Zoom capability (« Z » of « LMDZ »)
→ Finite difference / finite volume numerical schemes
→ Conservation of air mass, enstrophy, partly angular momentum and energy
→ Positive/monotonic/conservative Van Leer schemes for tracer advection
→ Horizontal dissipation (stability + scale interaction) : iterated Laplacian
→ Sponge layer (dumping winds and wave in the upper layers)

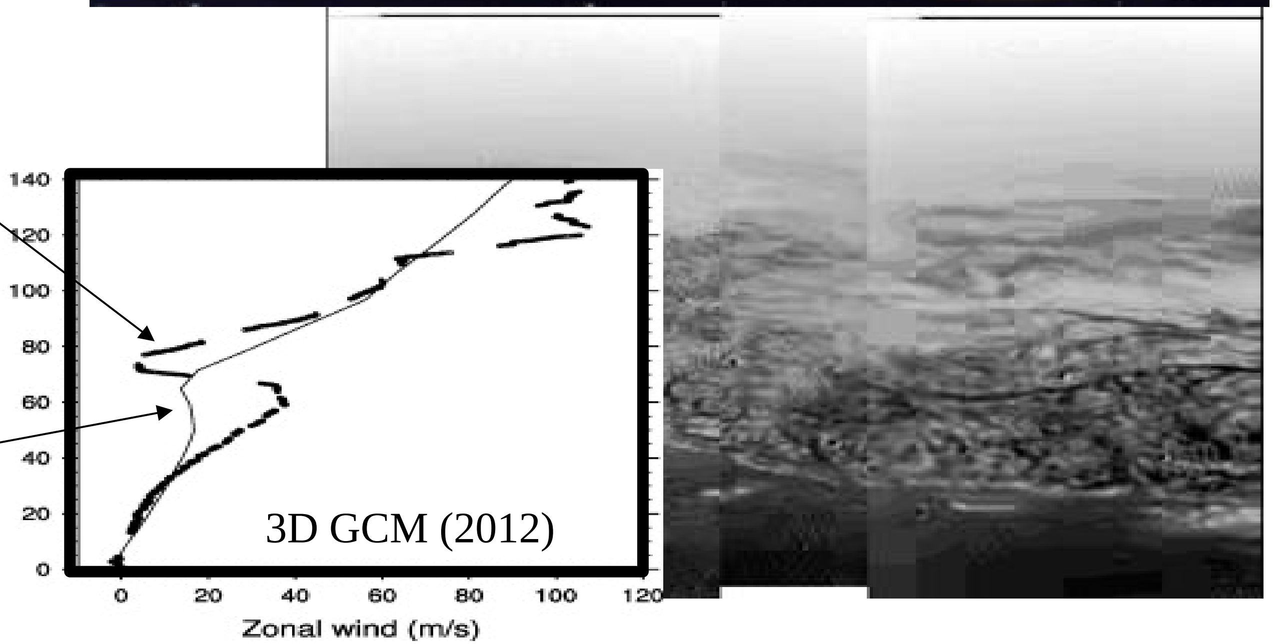
2. LMDZ

Planetary atmospheres
Mars, Titan, Venus, Triton, ...

Prediction of Titan atmospheric super-rotation
with the LMDZ Titan GCM (1995, 2005)
An a posteriori comparison with
The Huygens entry profile

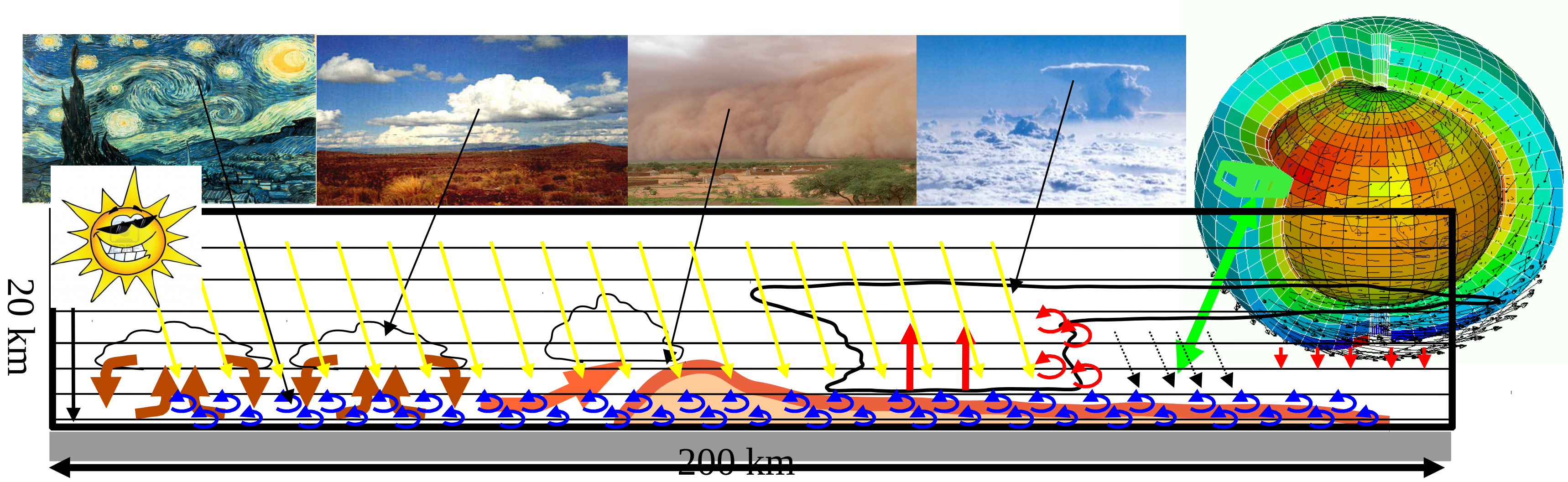






2. LMDZ

Earth : development of a **« New Physics »** version (15-year team work)
New framework for model development and evaluation
Splitting in 3 scales for vertical transport
turbulence / organized structure of the boundary layer / deep convection



→ Couvreux, F., F. Hourdin, and C. Rio, **2010**, Resolved Versus Parametrized Boundary-Layer Plumes. Part I: A Parametrization-Oriented Conditional Sampling in Large-Eddy Simulations, Boundary-layer Meteorol., 134, 441–458, 2010.
→ Grandpeix, J., and J. Lafore, **2010**, A Density Current Parameterization Coupled with Emanuel's Convection Scheme. Part I: The Models, Journal of Atmospheric Sciences, 67, 881–897, 2010.
→ Grandpeix, J. Y., V. Phillips, and R. Tailleux, 2004, Improved mixing representation in Emanuel's convection scheme, Q. J. R. Meteorol. Soc., 130, 3207–3222, **2004**.
→ Grandpeix, J., J. Lafore 2010, A Density Current Parameterization Coupled with Emanuel's Convection Scheme. Part I Journal of Atmospheric Sciences, 67, 898–922, **2010**.
→ Grandpeix, J., J. Lafore, and F. Cheruy, 2010, A Density Current Parameterization Coupled with Emanuel's Convection Scheme. Part II: 1D Simulations, Journal of Atmospheric Sciences, 67, 898–922, **2010**.
→ Hourdin, F., F. Couvreux, and L. Menut, **2002**, Parameterisation of the dry convective boundary layer based on a mass flux representation of thermals, J. Atmos. Sci., 59, 1105–1123, 2002.
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→ Hourdin, F., J.-Y. Grandpeix, C. Rio, S. Bony, A. Jam, F. Cheruy, N. Rochetin, L. Fairhead, A. Idelkadi, I. Musat, J.-L. Dufresne, A. Lahellec, M.-P. Lefebvre, and R. Roehrig, April 2012, LMDZ5B: the atmospheric component of the IPSL climate model with revisited parameterizations for clouds and convection, Clim. Dyn., 79, April **2012**.
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→ Rio, C., and F. Hourdin, 2008, A thermal plume model for the convective boundary layer : Representation of cumulus clouds, J. Atmos. Sci., 65, 407–425, **2008**.
→ Rio, C., F. Hourdin, J. Grandpeix, and J. Lafore, 2009, Shifting the diurnal cycle of parameterized deep convection over land, Geophys. Res. Lett., 36, 7809–+, **2009**.
→ Rio, C., F. Hourdin, F. Couvreux, and A. Jam, **2010**, Resolved Versus Parametrized Boundary-Layer Plumes. Part II: Continuous Formulations of Mixing Rates for Mass-Flux Schemes, Boundary-layer Meteorol., 135, 469–483, 2010.
→ Rio et al., **2012** : closure revisited

LMDZ – a brief history

Pioneers : years 60-70. Robert Sadourny and Phu Le Van (Sadourny, 1975)

The LMD5/LMD6 model : 90-95 (Laval, 1981)

1985 : Rewriting of the dynamical core : modularity and zoom (the previous version had been written over punch cards with a very small RAM memory)

1990 : versions for Mars, Titan, and a generic 20-parameter version

1992 : decision to develop the terrestrial model on the basis of this new dynamical core, by adapting the physical package of LMD5/6

1995-1999 : transport of trace species

2005 : First participation to CMIP exercise with LMDZ

2007 : rising organization around LMDZ (web, regular meetings,Svn, training, …)

2011 : “New Physics” version (result of a 10-year research) and participation to CMIP5

2016 : CMIP6 version

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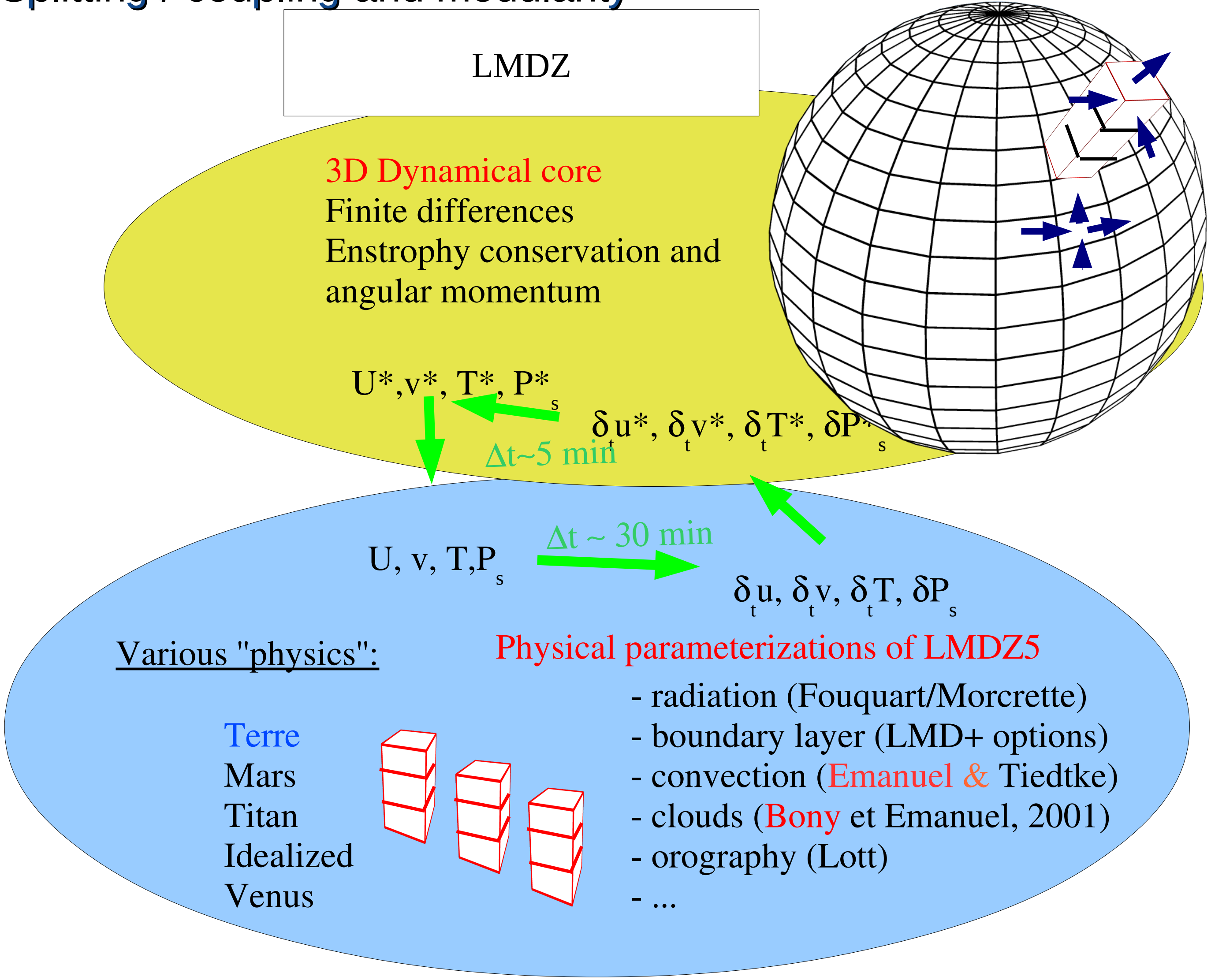
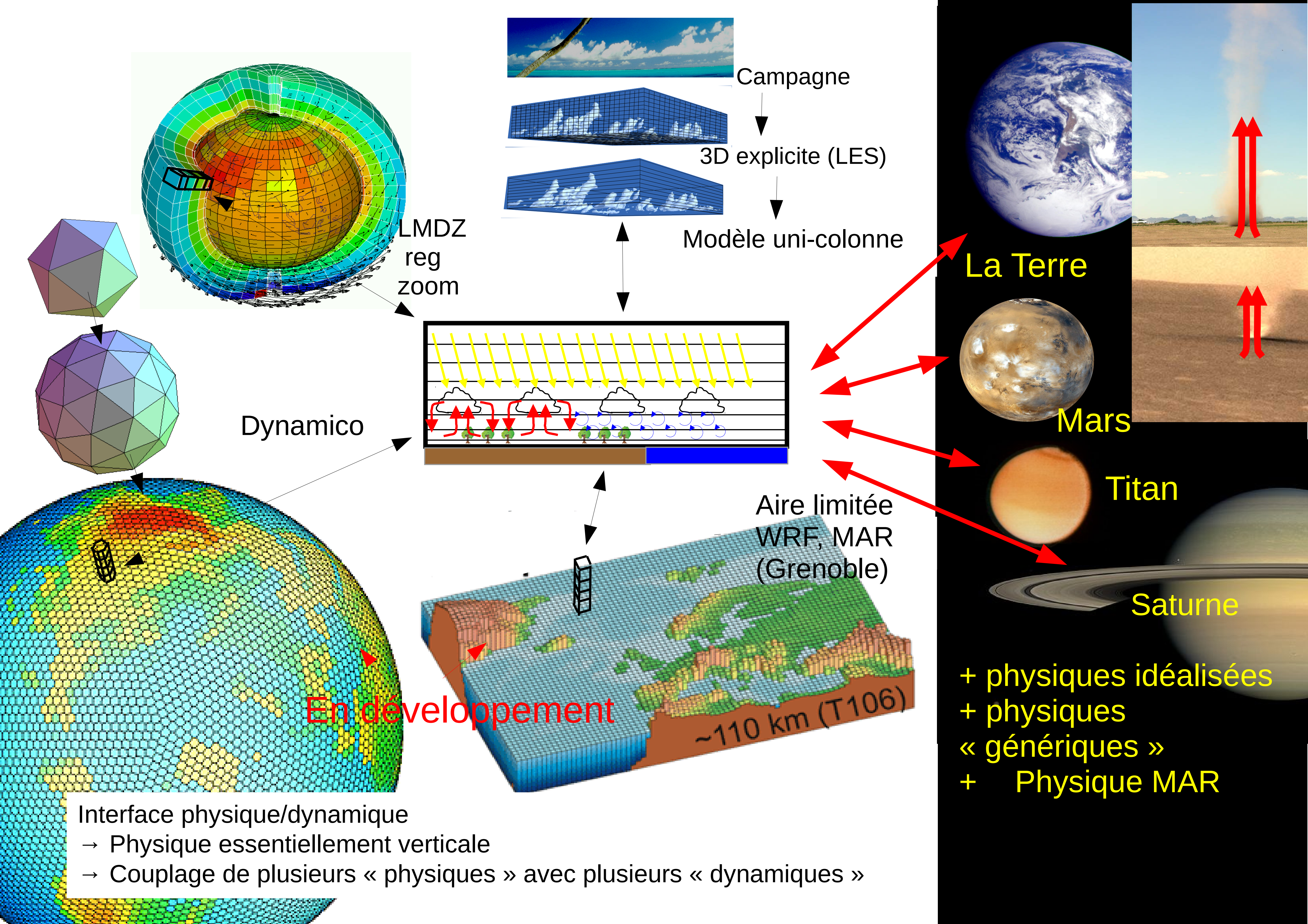
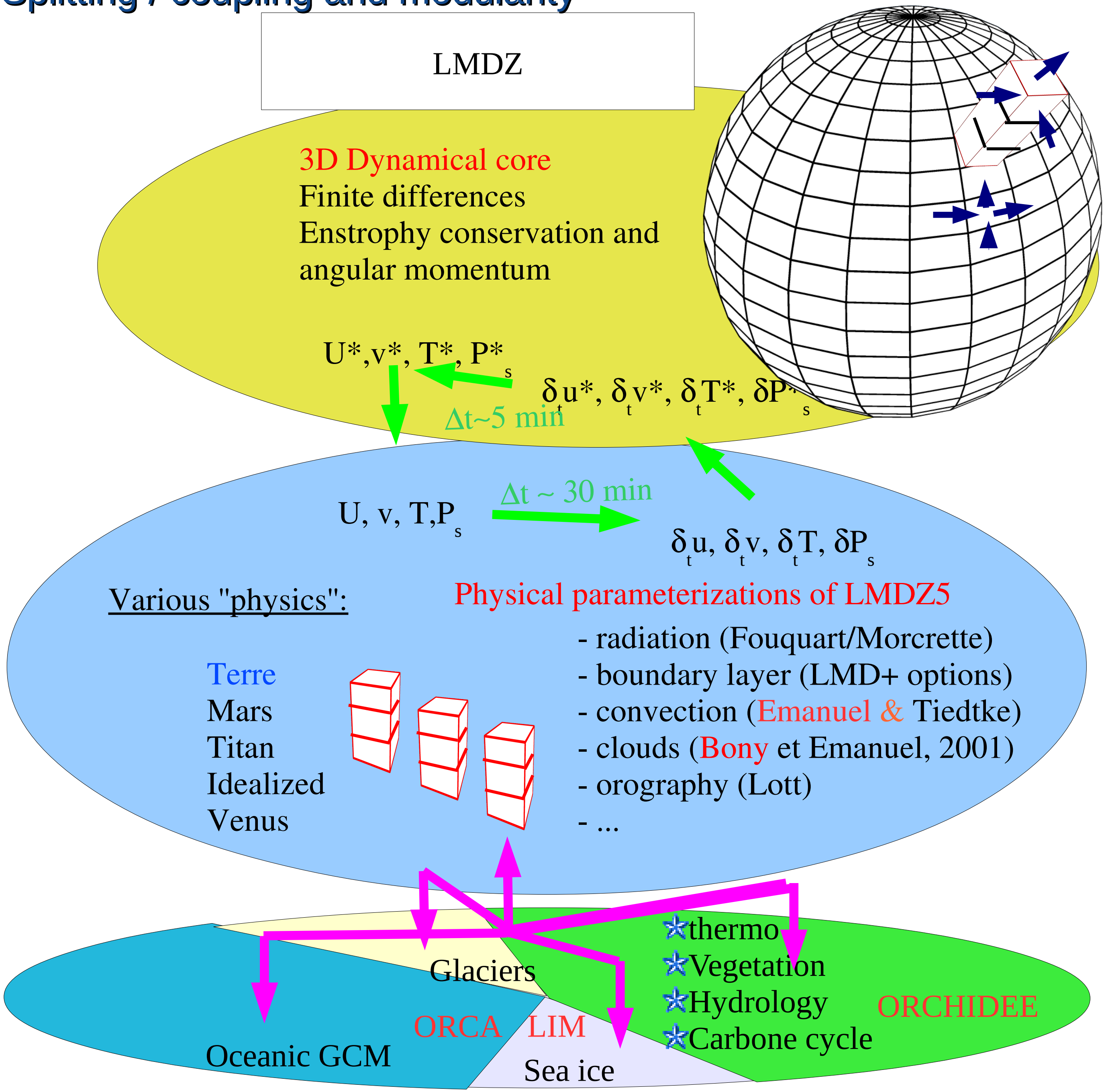
   4. Operating modes

3. Splitting / coupling and modularity




Campagne
3D explicite (LES)
Modèle uni-colonne
LMDZ
reg
zoom
Dynamico
Aire limitée
WRF, MAR
(Grenoble)
~110 km (T106)
En développement
La Terre
Mars
Titan
Saturne
+ physiques idéalisées
+ physiques
« génériques »
+ Physique MAR
Interface physique/dynamique
→ Physique essentiellement verticale
→ Couplage de plusieurs « physiques » avec plusieurs « dynamiques »

3. Splitting / coupling and modularity



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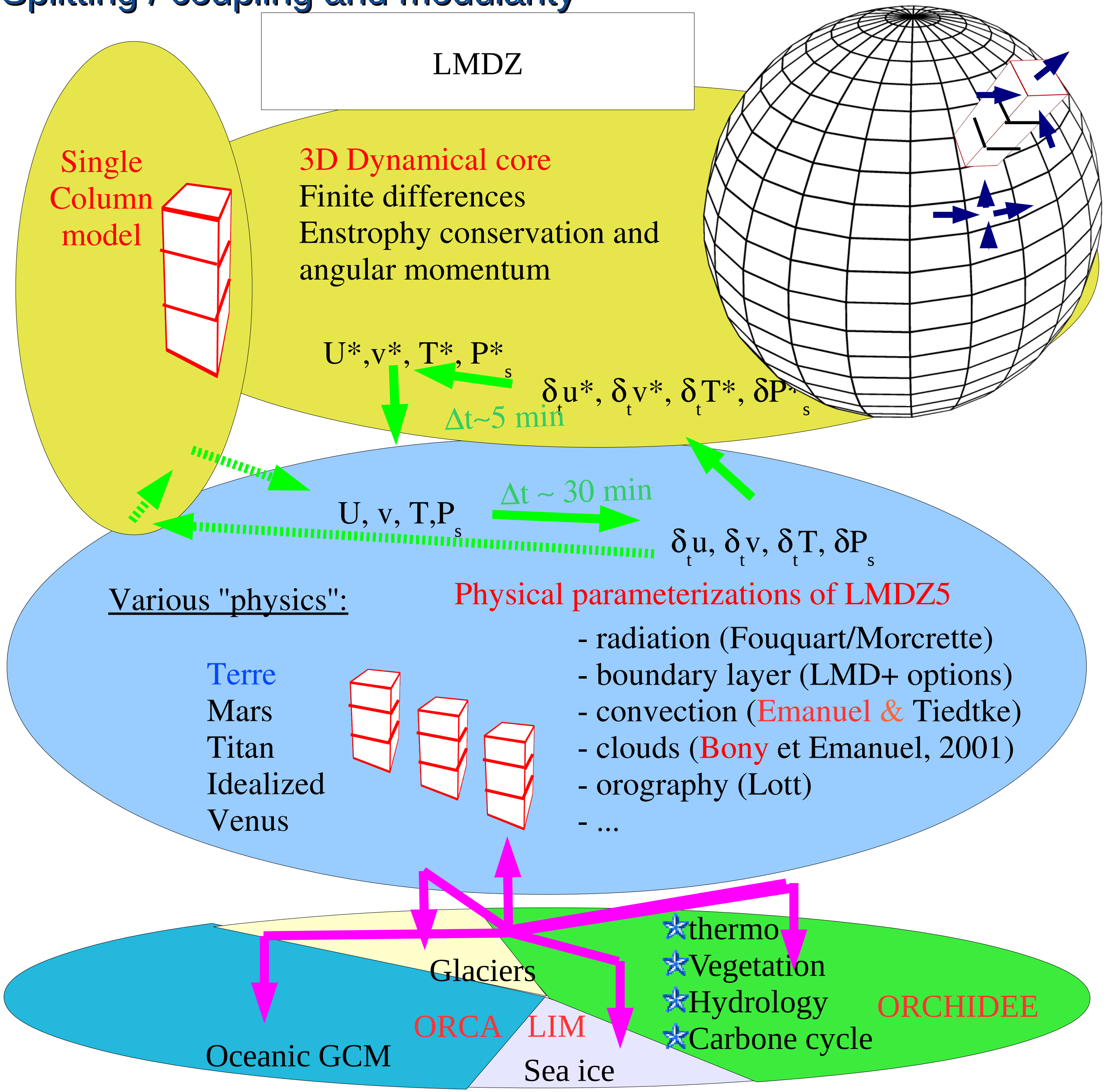

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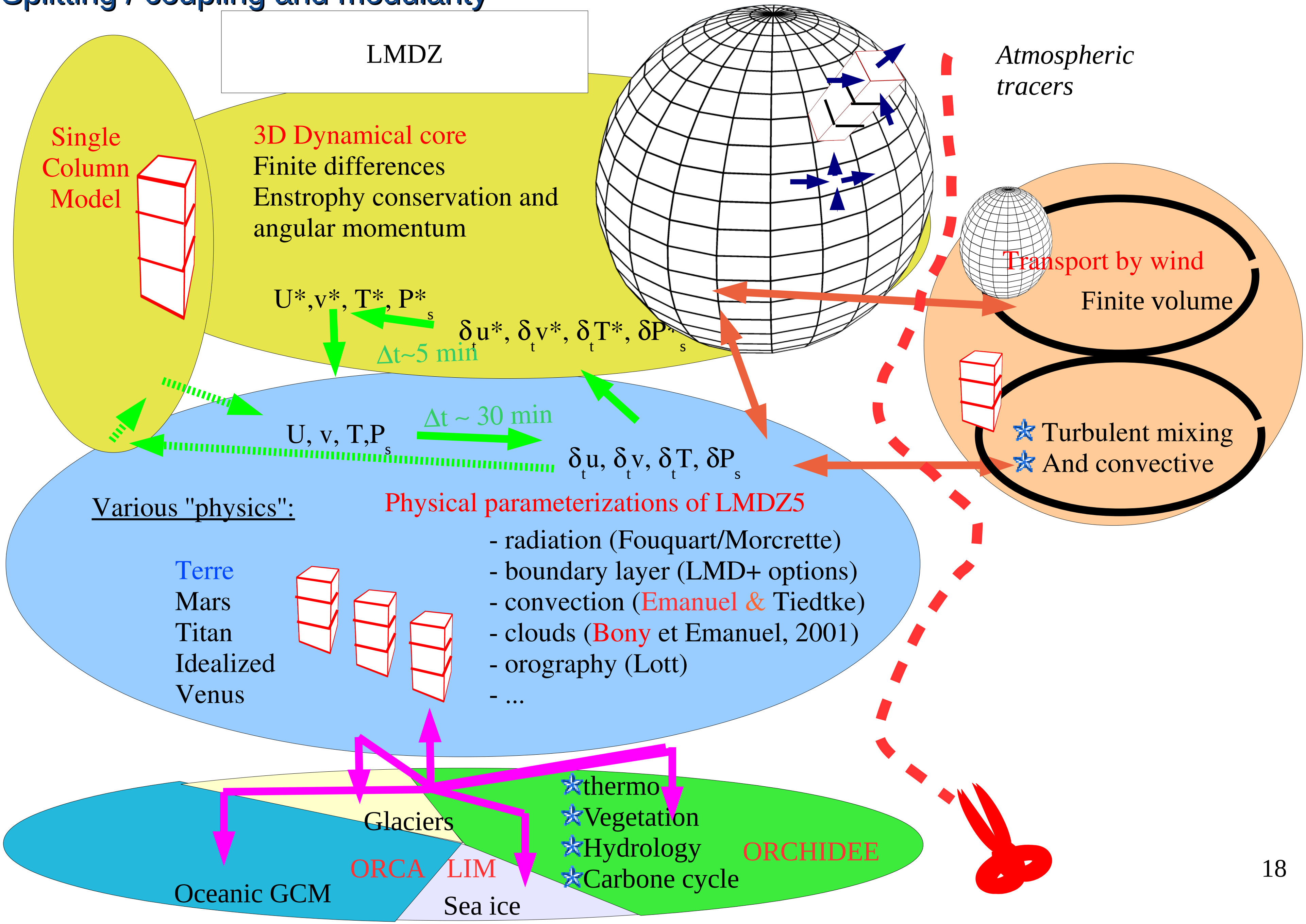

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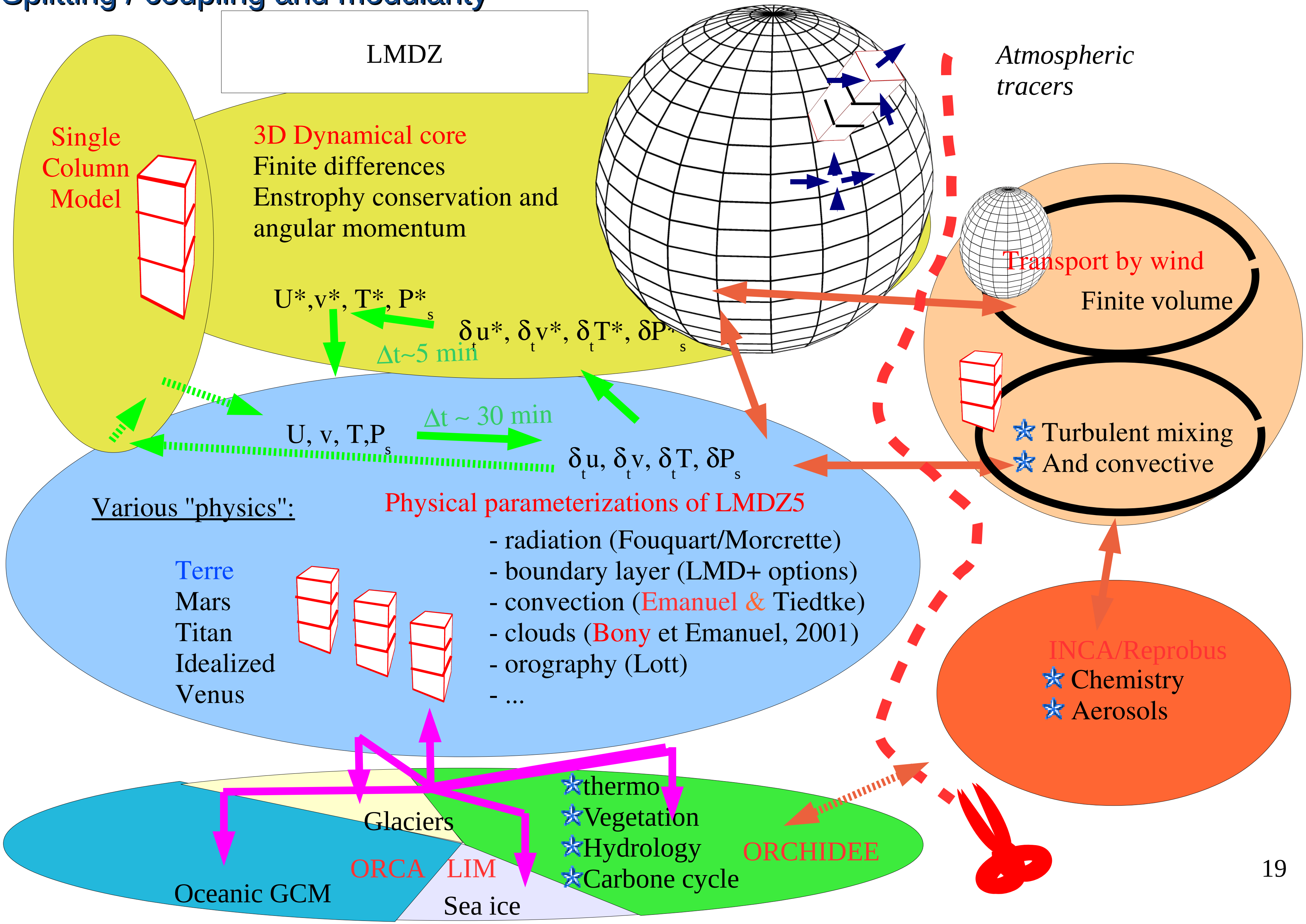
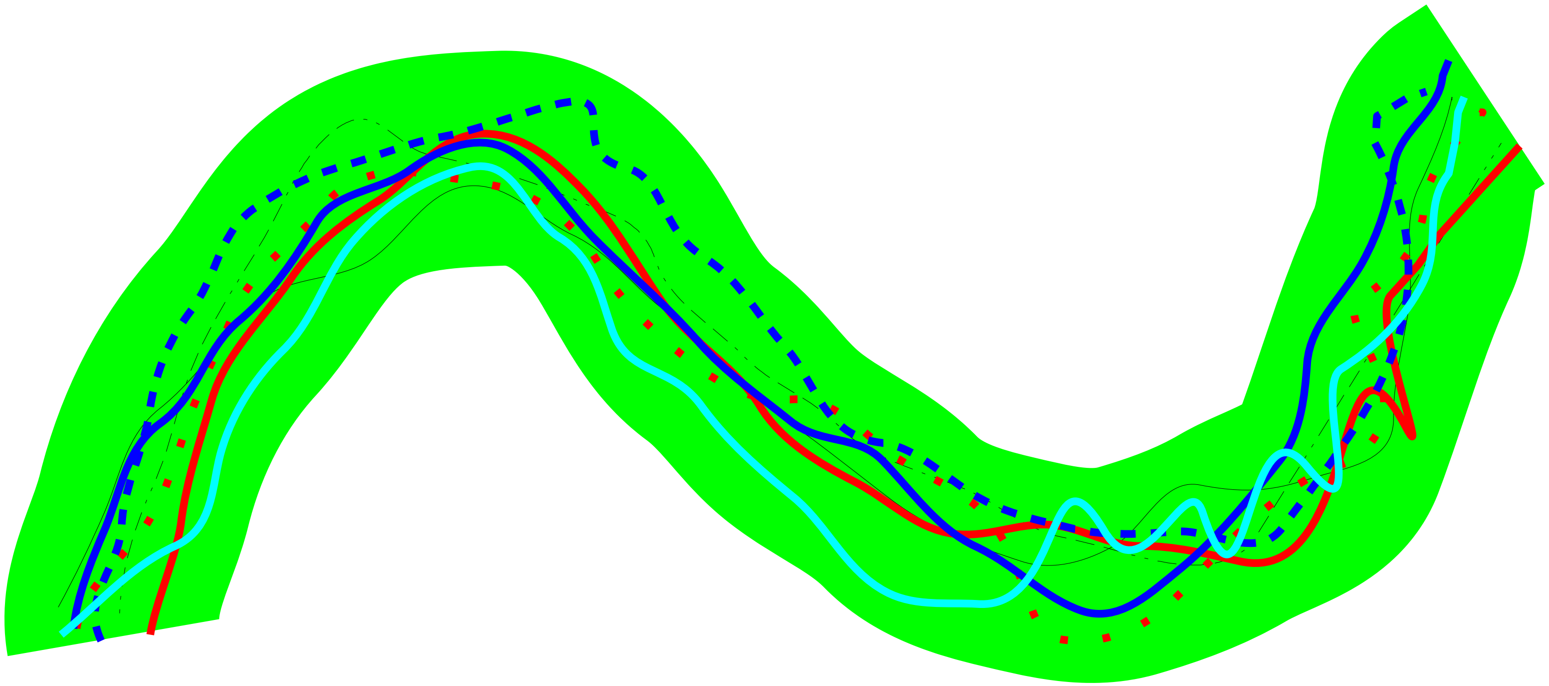
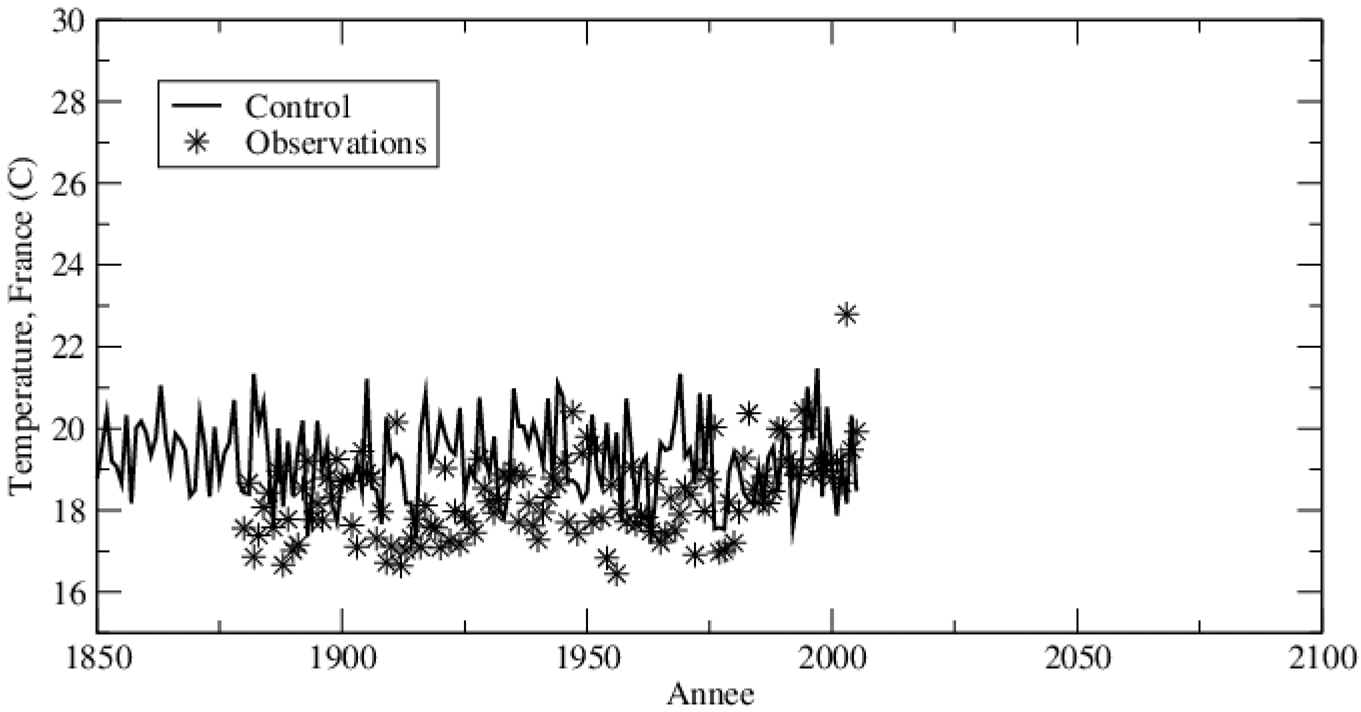


Climate modeling / numerical weather forecast

- **Models** : identical.
- **Duration** : several decades or centuries / 15 days (seasonal forecast in between)
- **Initial state** : any (existence of an attractor : the climate) / “analysis” obtained through an assimilation procedure of observations into the model.
- **Forecast** : statistical (ex : inter-annual variability, intensity of storms ...) / deterministic (the weather of tomorrow).



Climate change projections



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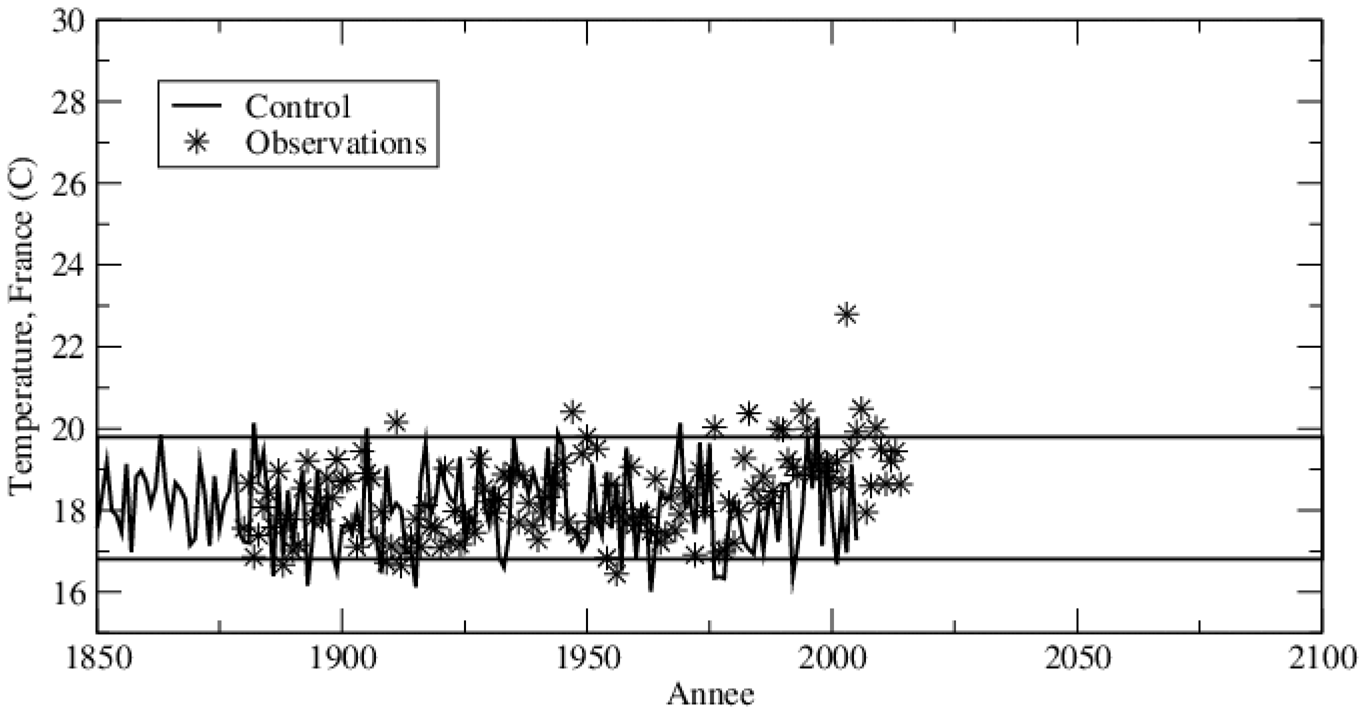

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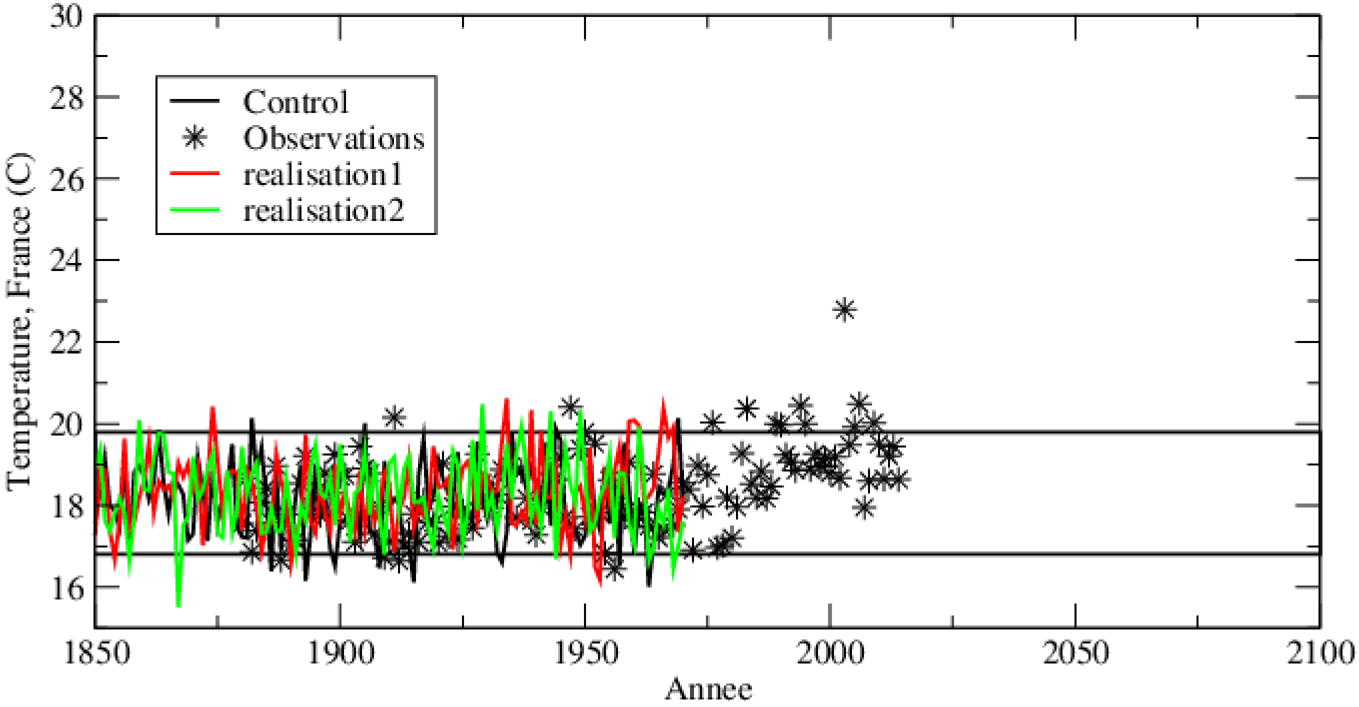

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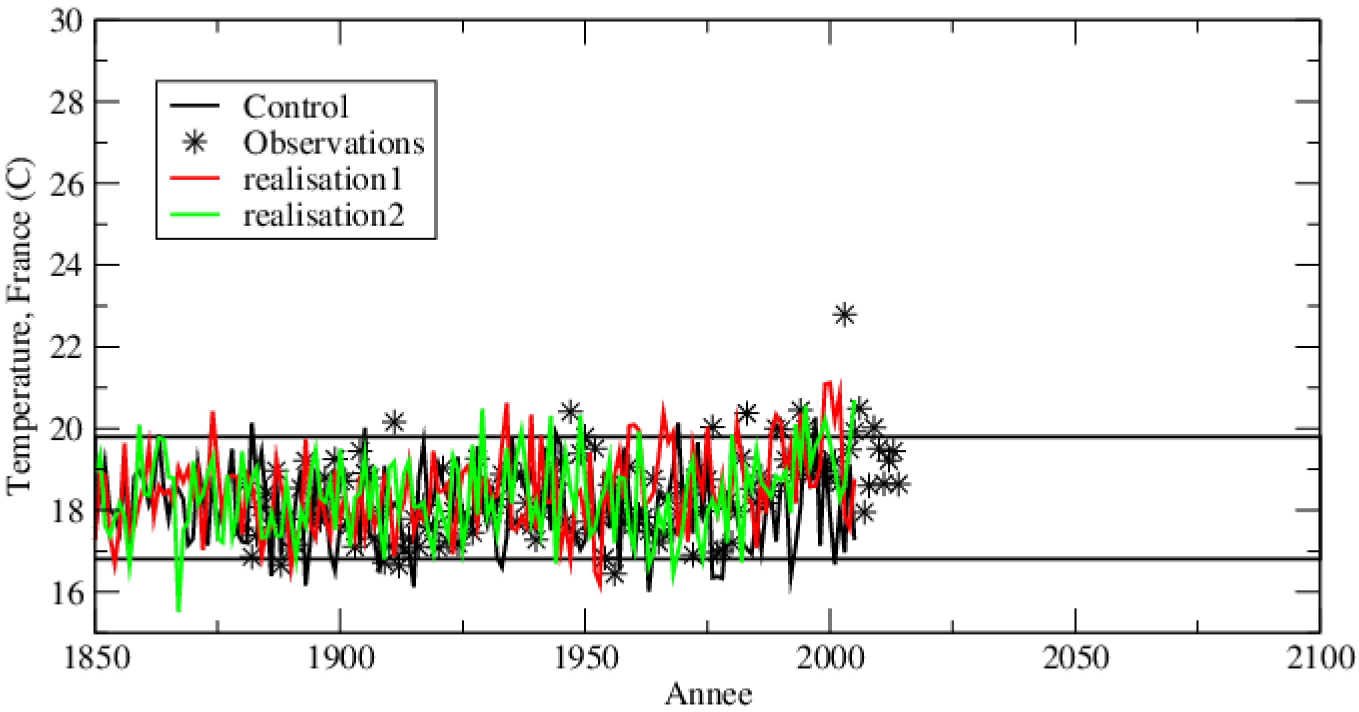

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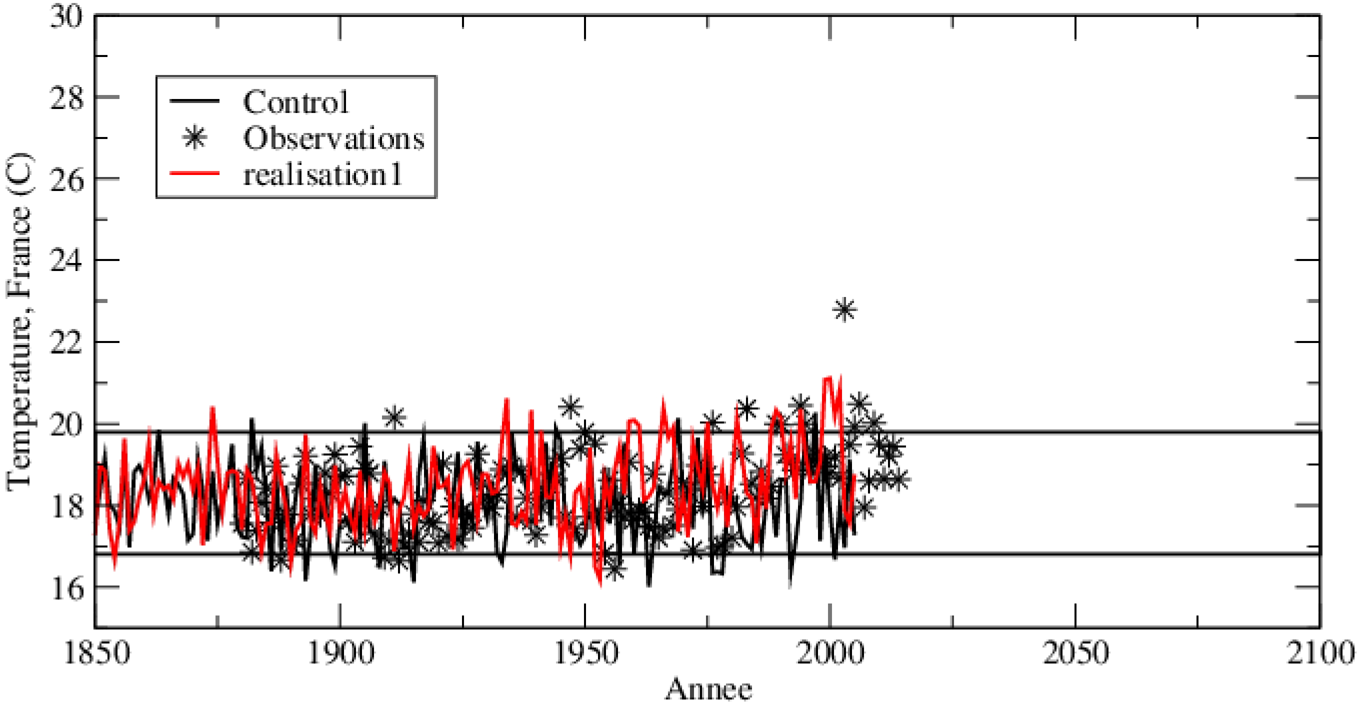

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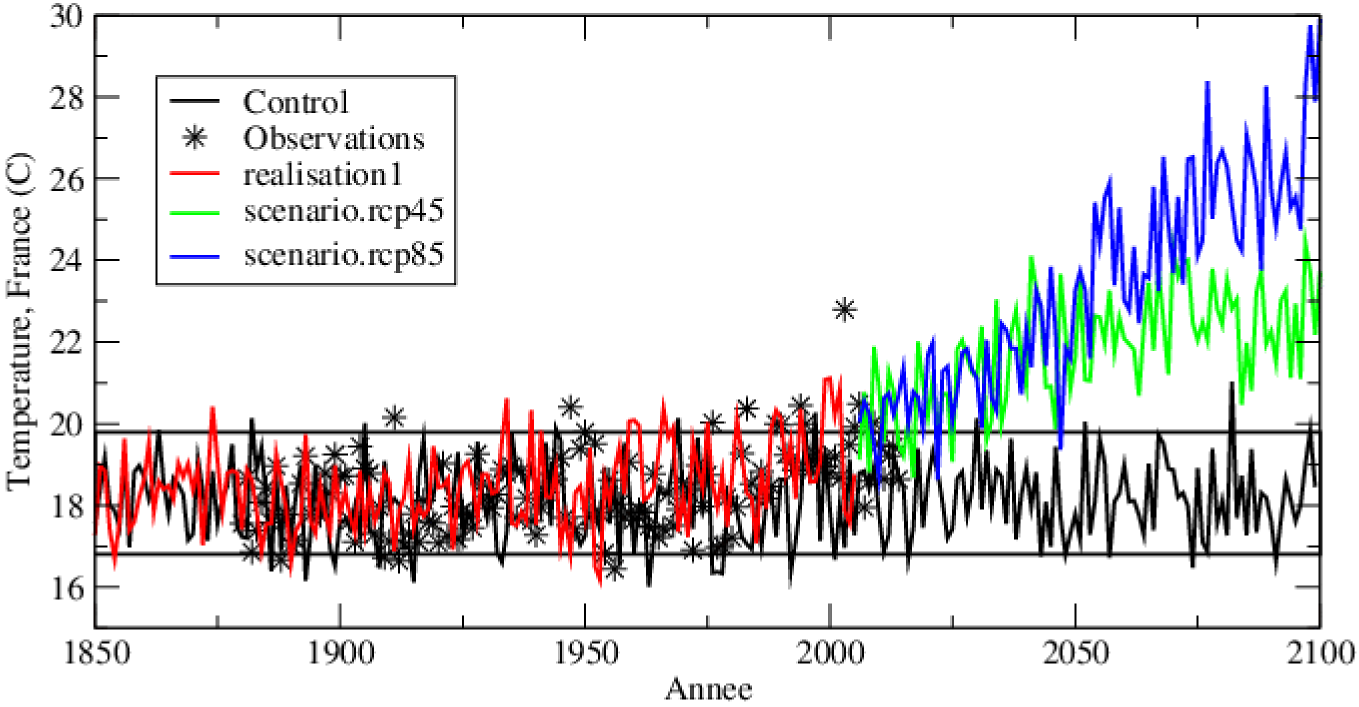
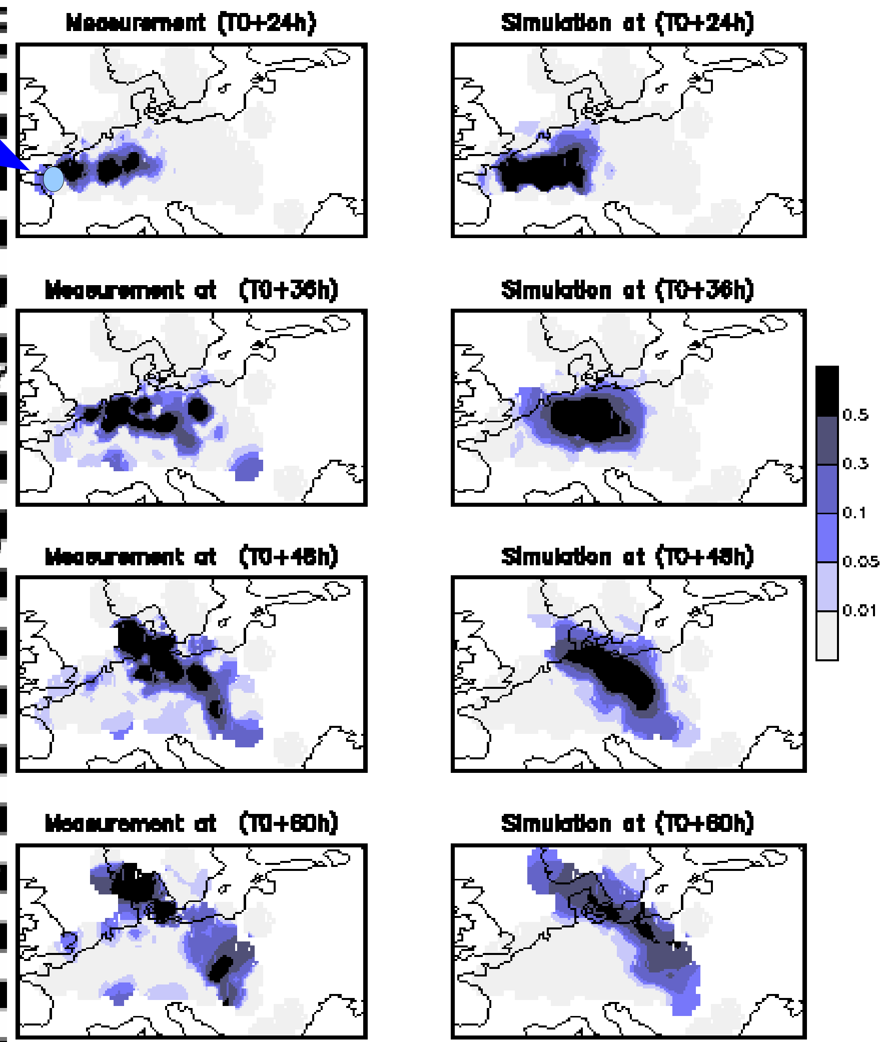


Numerical simulation with LMDZ
Chemical tracer (PMCH) emitted in French Britany (ETEX)



Nudging capability

$$\frac{\partial u}{\partial t} = \frac{\partial u}{\partial t}_{GCM} + \frac{u_{analysis} - u}{\tau}$$

$$\frac{\partial v}{\partial t} = \frac{\partial v}{\partial t}_{GCM} + \frac{v_{analysis} - v}{\tau}$$

τ Time constant for the relaxation of the model wind toward analyses

$u_{analysis}$ $v_{analysis}$

LMDZ

1. Flexible tool

2. Made of 2 well distinct parts :
   A/ dynamical core, 3D.
   B/ physical parameterizations

3. Coupling with ocean and continental surfaces at in the physics

4. Coupled to chemistry through large scale transport (dynamics) and physical parameterizations (physics)

5. Configurations :
   1D
   3D with nudging
   3D with zoom
   Off line for tracers (not maintained in current versions), direct & backward

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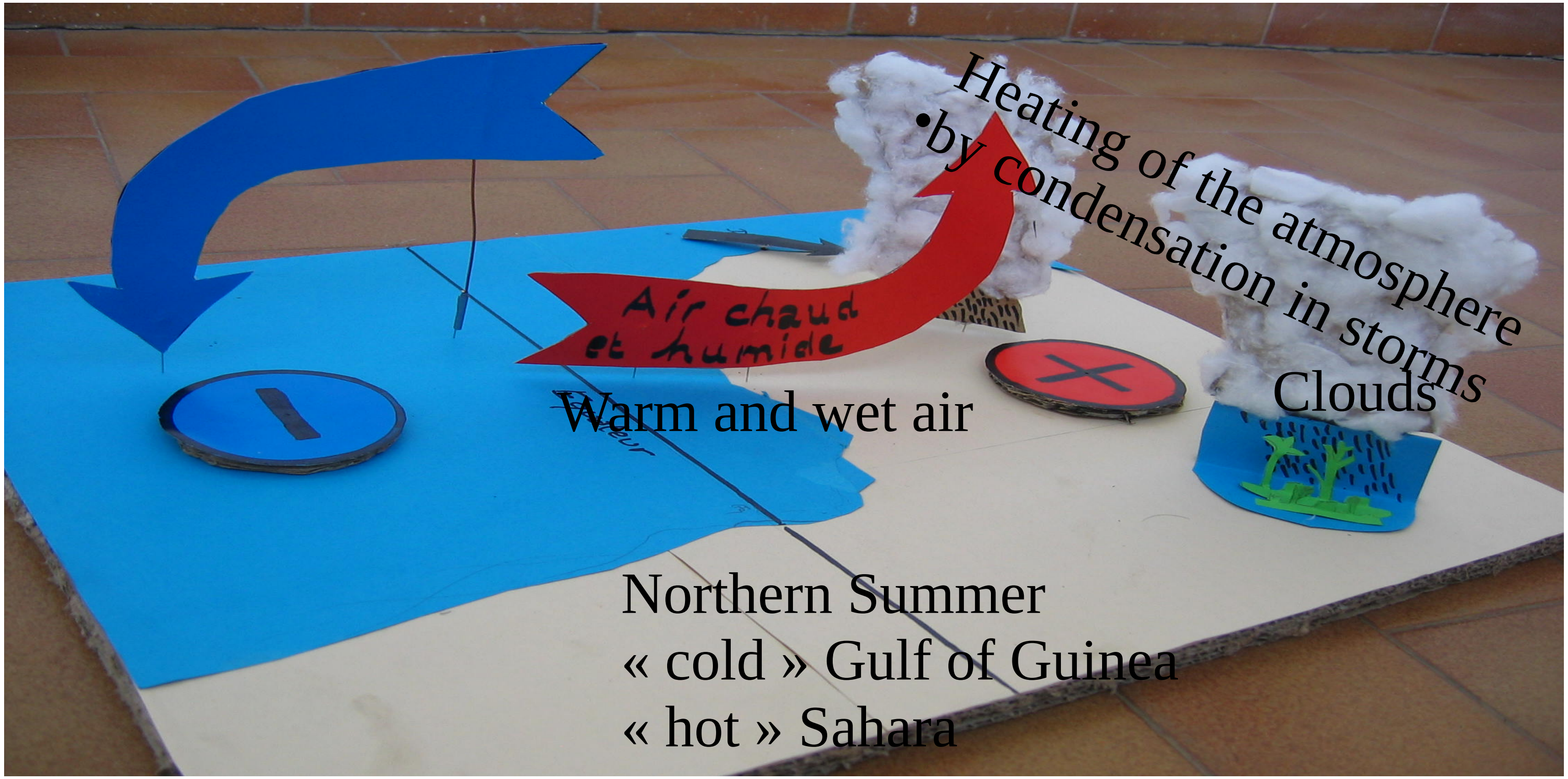
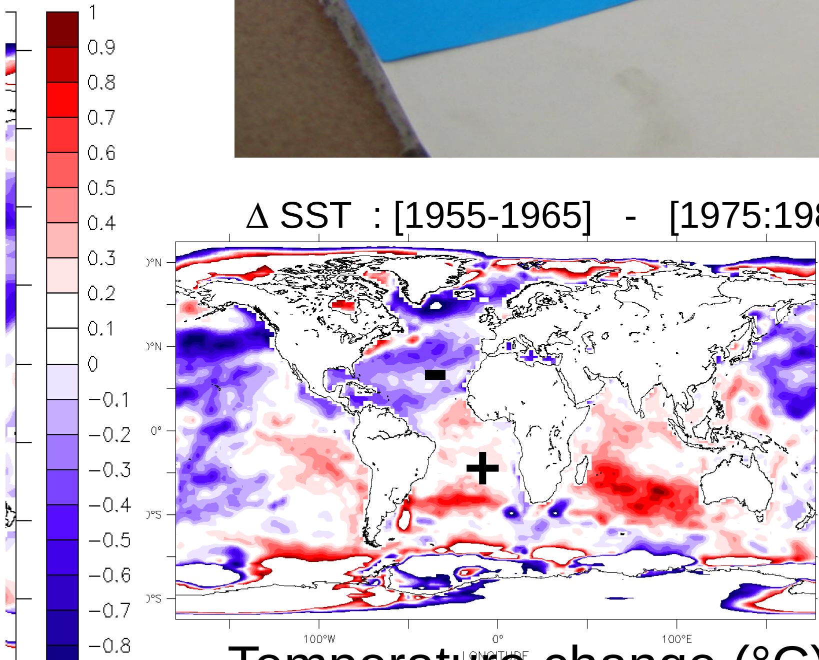
4. **Operating modes**
    - **a) Free climatic mode**
    - **b) Zooming or/and nudging for climate**
    - **c) Nudging and off-line for tracer transport**
    - **d) Nudging for parameterization evaluation**
5. Intercomparison exercises and reference versions
    - a) CMIP exercises
    - b) The IPSL model and LMDZ reference versions
    - c) Biases and skill of LMDZ
6. Model development and tuning
    - a) Choice of a new configuration : content and resolution
    - b) Importance of tuning
    - c) Methodology

4. Operating modes : a) free climatic mode

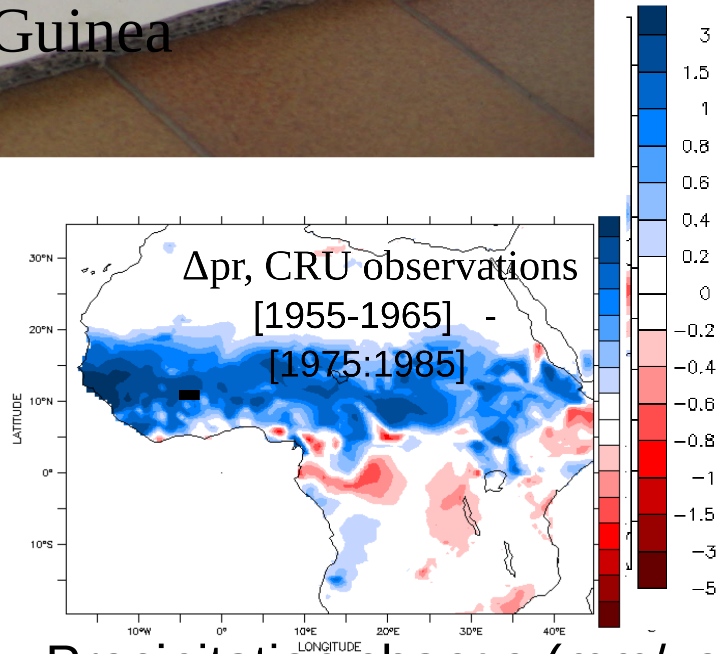


Δ SST : [1955-1965] - [1975:1985]



Temperature change (°C)

1975-1985 :
Warm SSTs in the south
- Drought over Sahel
- A large scale patern
- Linked to sea surface
- Temperature changes.

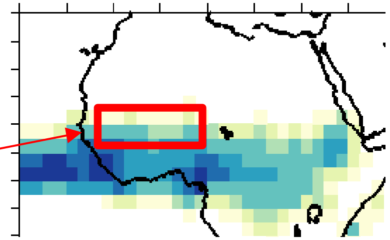


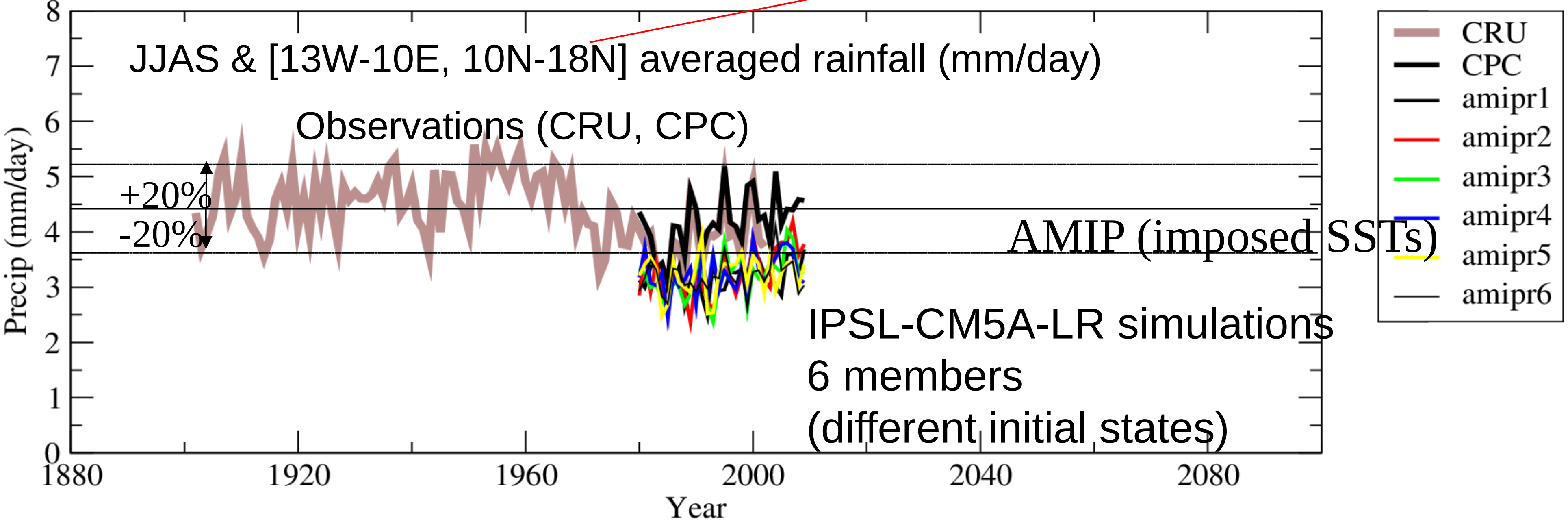
Precipitation change (mm/year)

Example 2 : the Sahelian drought

Are the model able to represent the climate variability of the past decades ?

In particular the drought of the 70s-80s.





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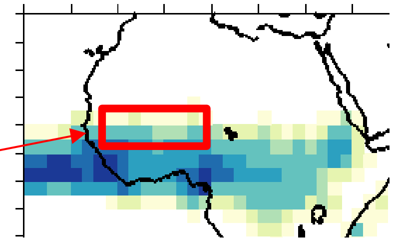
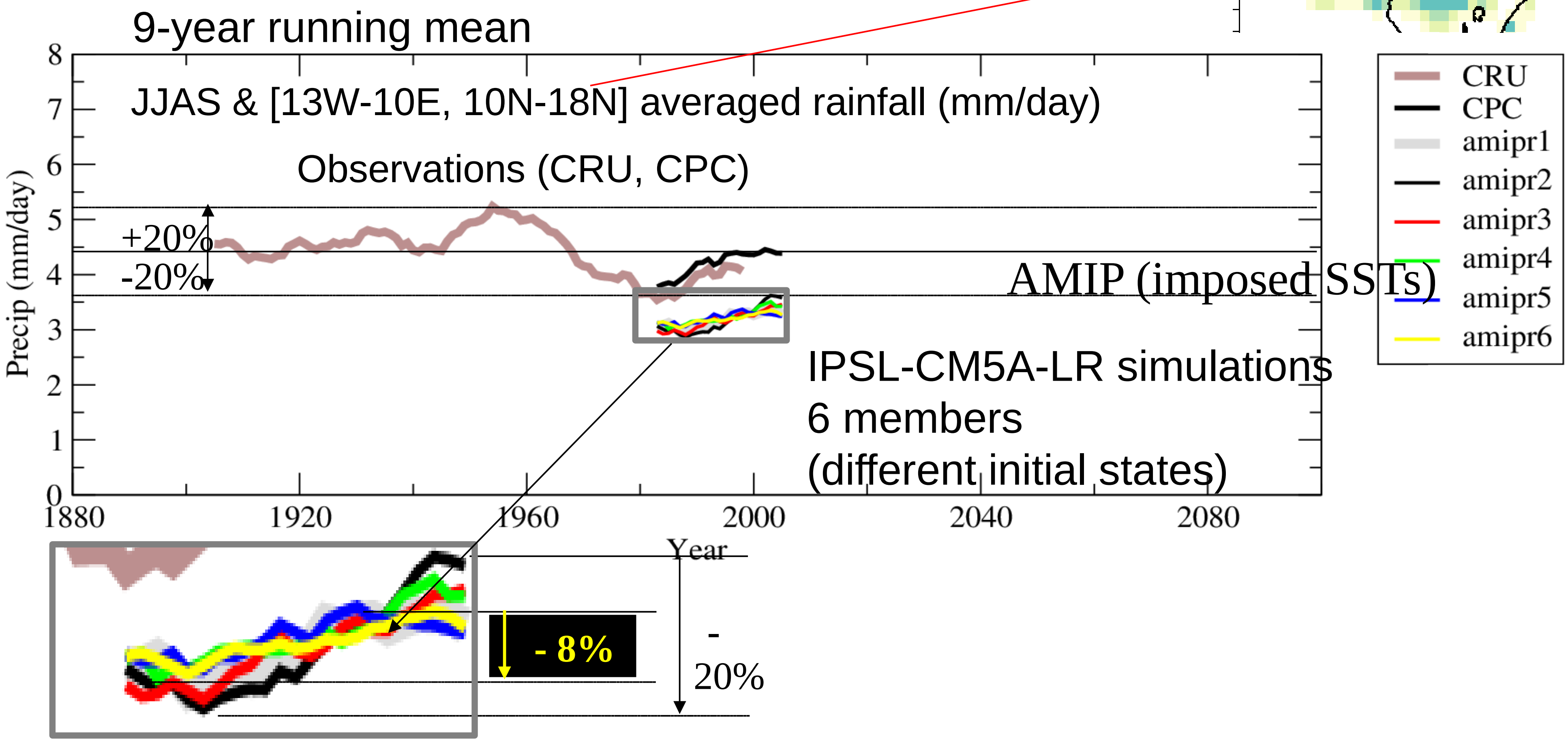
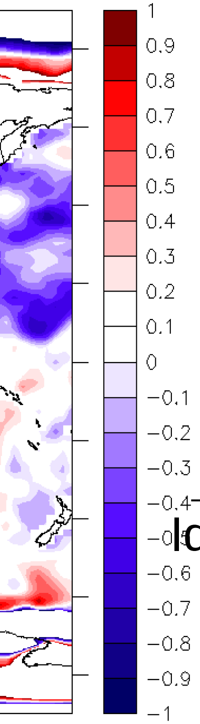
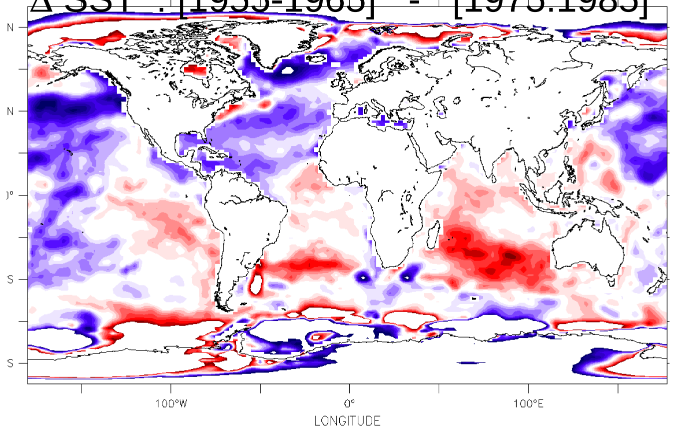




Simulations have a skill to reproduce decadal variations of monsoon rainfall in response to sea surface temperature changes
But strong internal variability (the observation is one possible experience)





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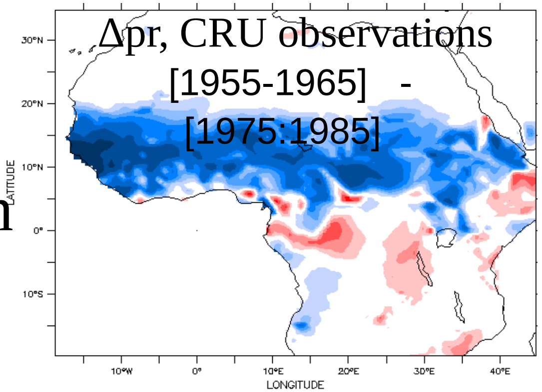
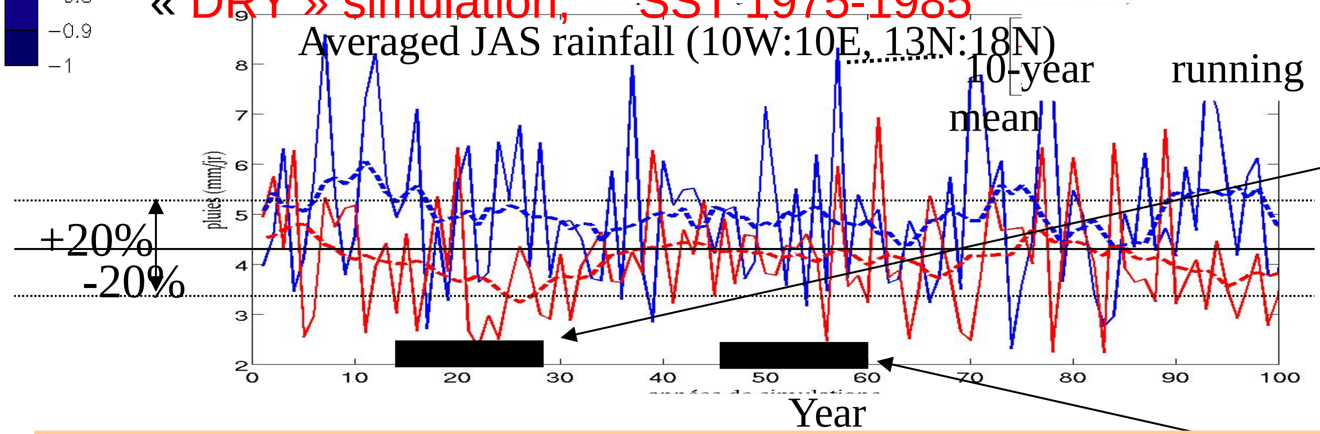
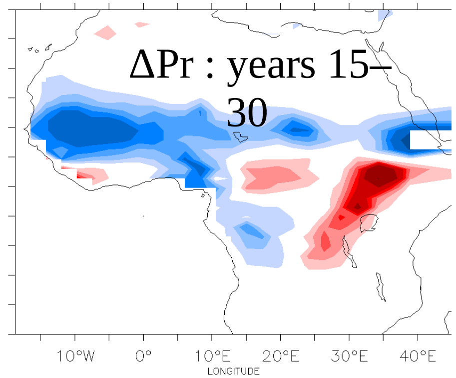


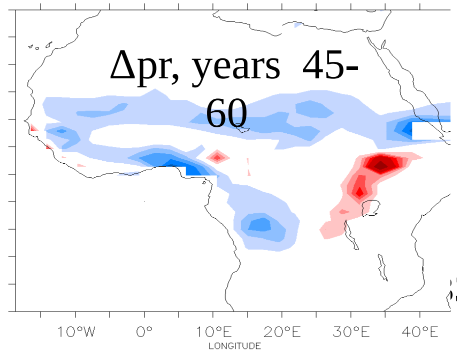
Idealized experiments with IPSL-CM5A-MR, Imposed SSTs, mean seasonal cycle

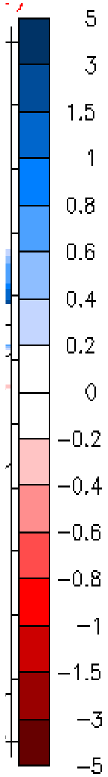
« MOIST » simulation, SST 1955-1965

« DRY » simulation, SST 1975-1985





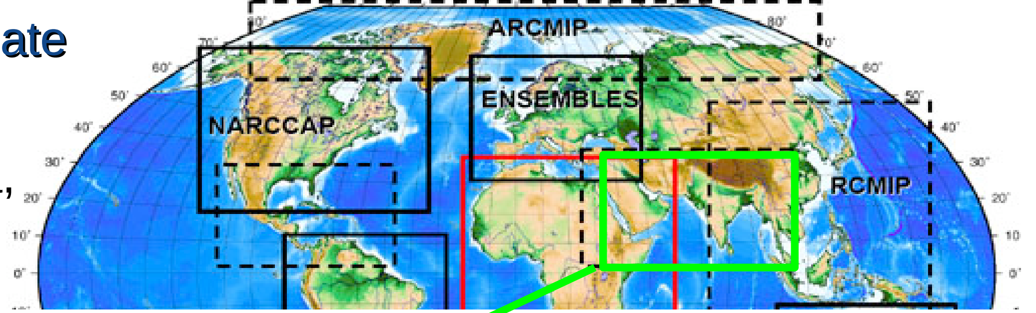


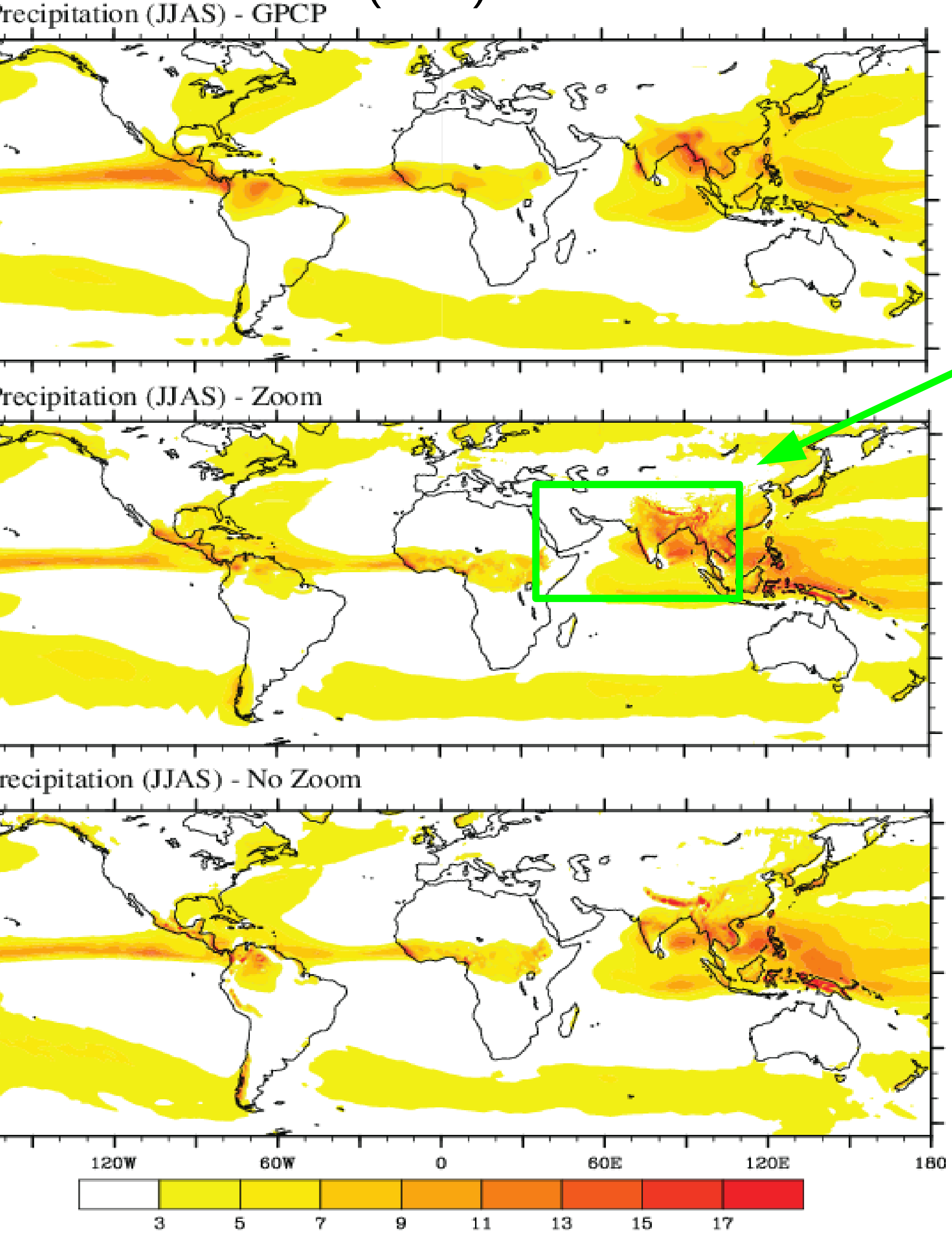


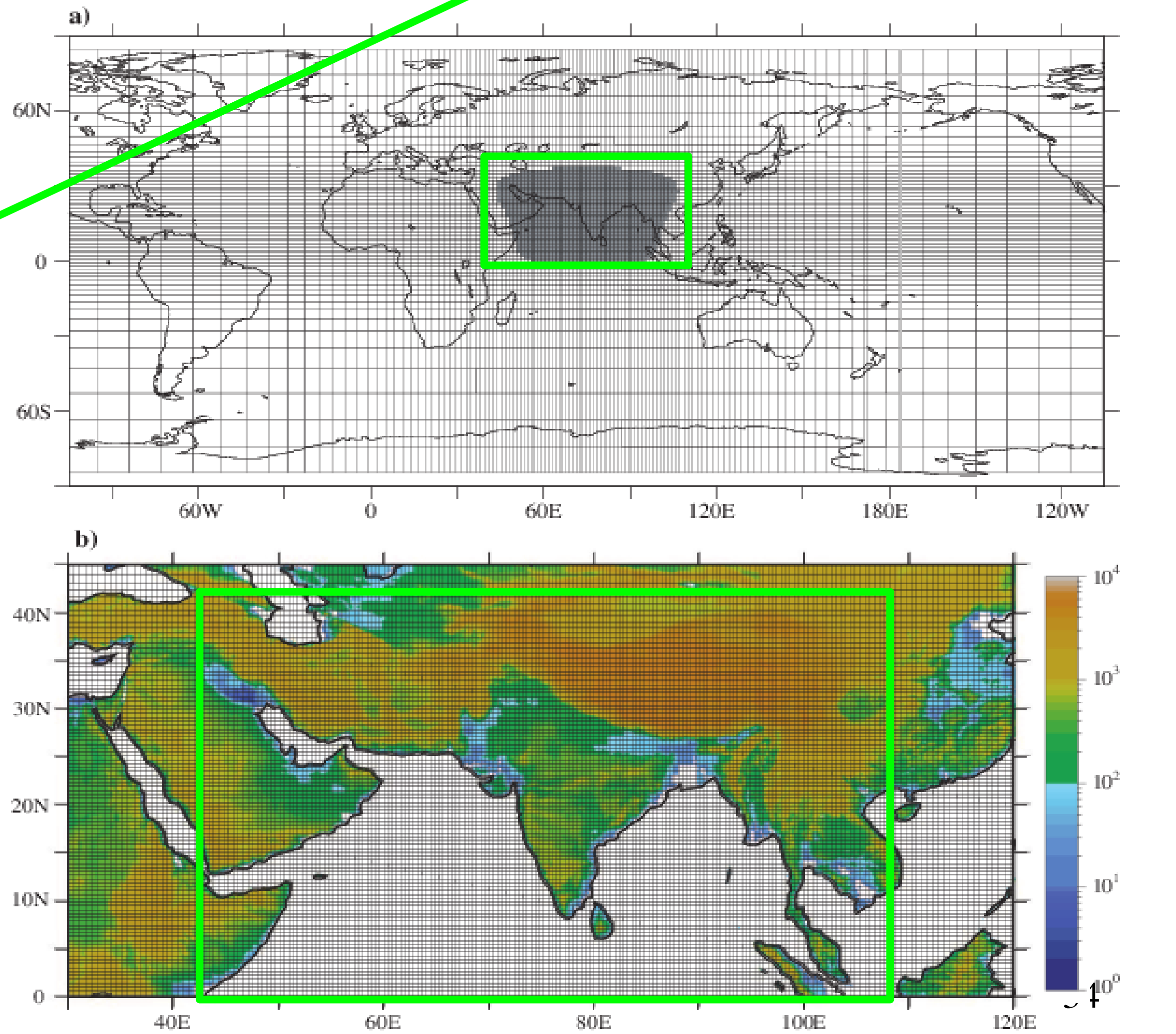
- Confirms the role of SSTs on decadal rainfall (Gianini et al., Cook et al., Zeng et al., ...)
- Strong year-to-year variability (obs and models)
- Strong signature at decadal scale (20%)
- Historical records to short to assess decadal rainfall amplitude to less than a factor 2

4. Operating modes : b) zoom and/or nudging for climate

Free climate simulation with zoom
Zoomed free climate simulation for Cordex South Asia,
Krishnan et al (IITM)



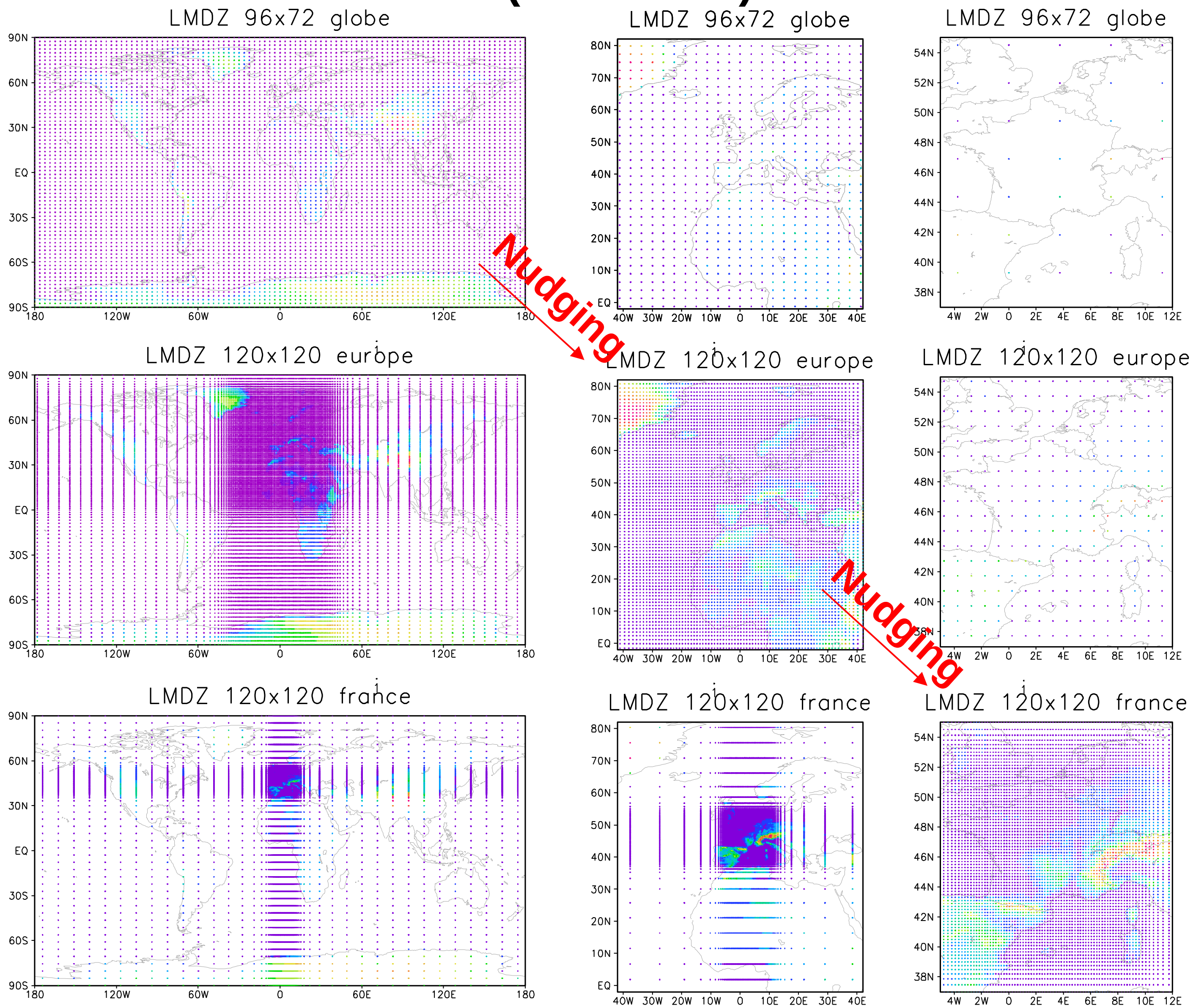




4. Operating modes : b) zoom and/or nudging for climate

Use for climate downscaling

LMDZ - Grid Cascade - (Laurent Li)



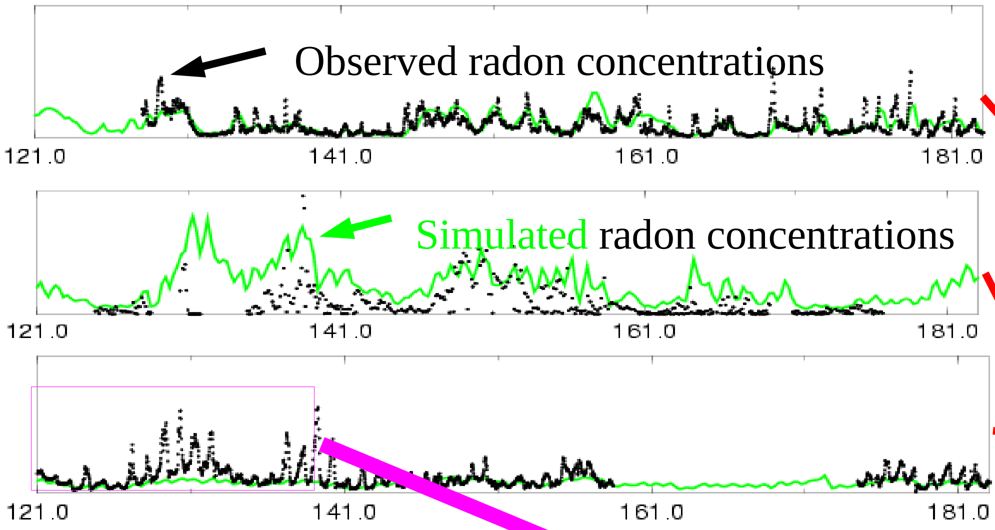
LMDZ Globe
(300 km)

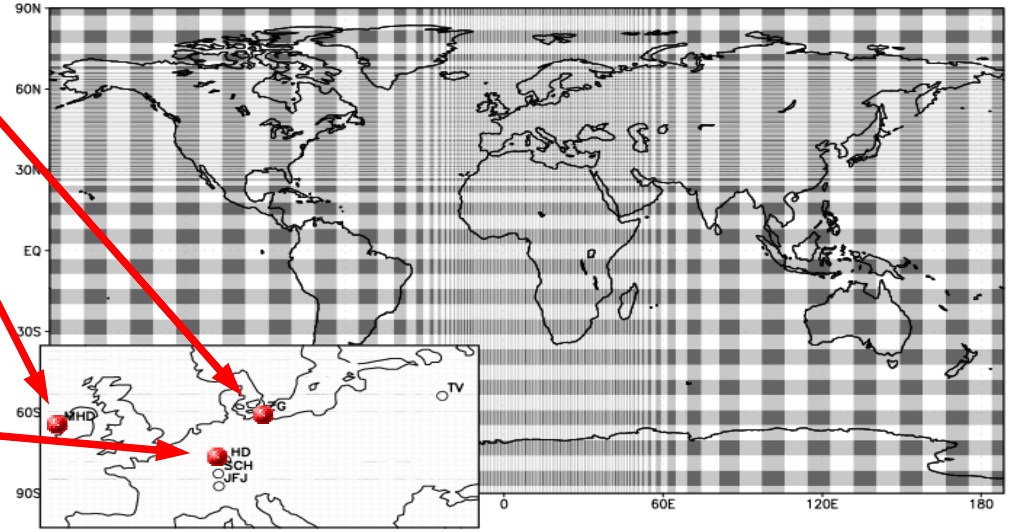
LMDZ Europe
(100 km)

LMDZ France
(20 km)

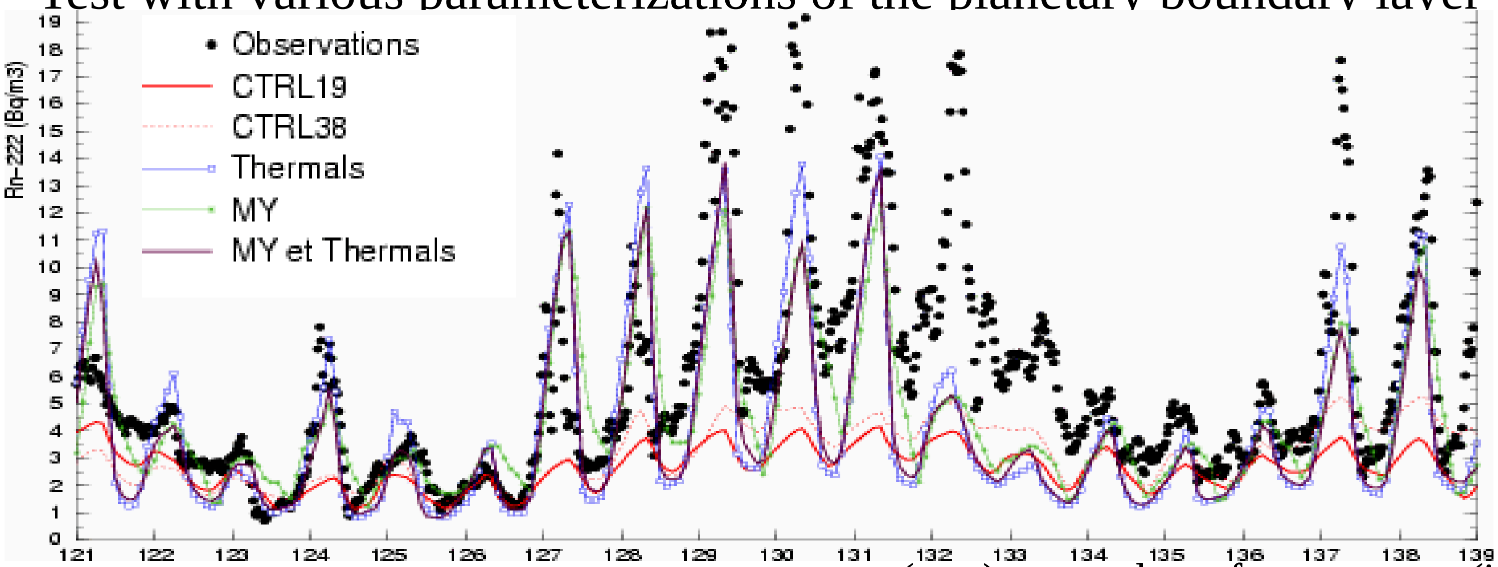
Similar to what is done with limited area models (like WRF)
Cheaper than the previous approach
Loosing the feedback from the zoomed region to the global scale : consistency issues

Simulation of the surface concentration of radon* with LMDZ, nudged by ECMWF winds, with a refined grid over Europe (40x40 km2)





Test with various parameterizations of the planetary boundary layer



(may) days of year (june)

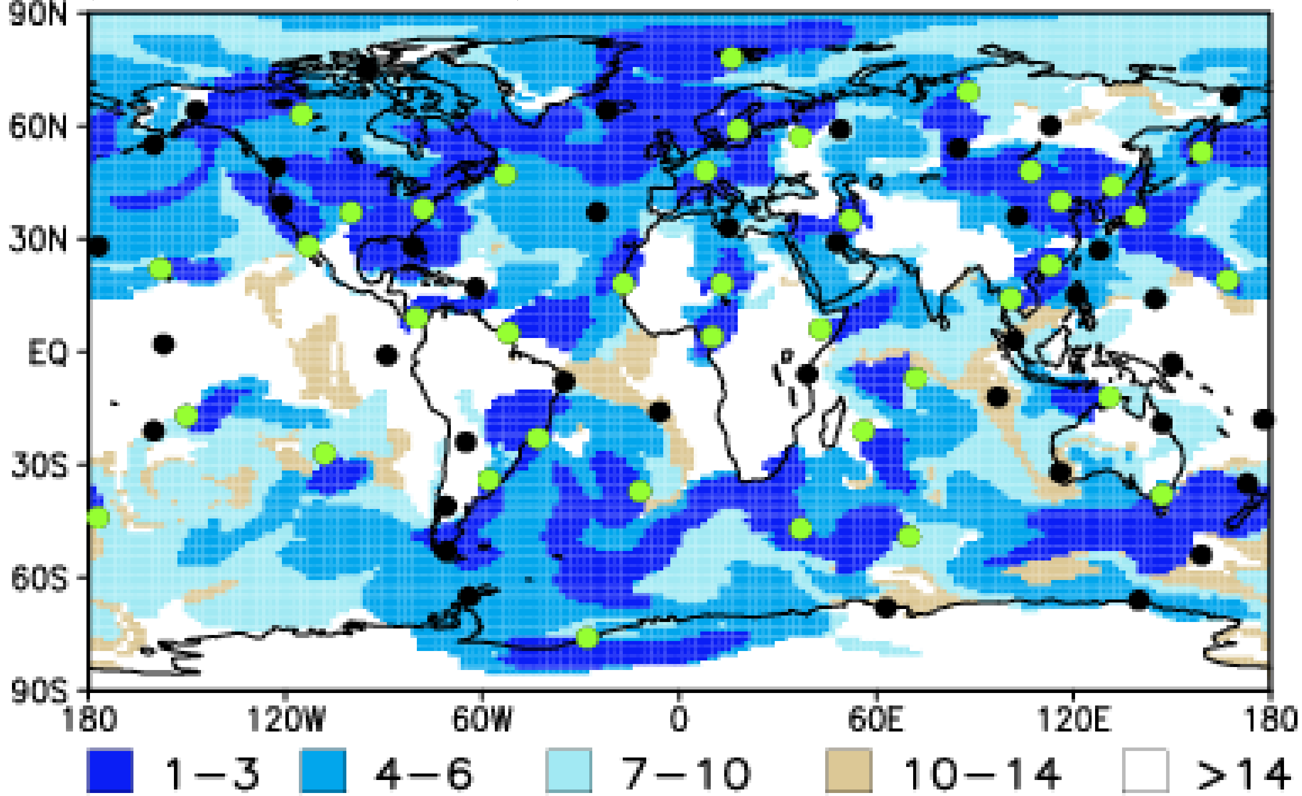
* Radon is a tracer of continental air masses, emitted almost uniformly by continents only. Life time of about 4 days.

4. Operating modes : b) nudged and off-line simulations for tracers

Use in off-line transport model, direct and inverse
→ First simulations with full meteorology computation
→ Storing the explicit mass fluxes, turbulent coefficient, sub-scale mass fluxes
→ Run transport of tracers only, in direct or backward mode (↔ adjoint model)

Example of back-tracking simulation
Off-line model used in reverse mode

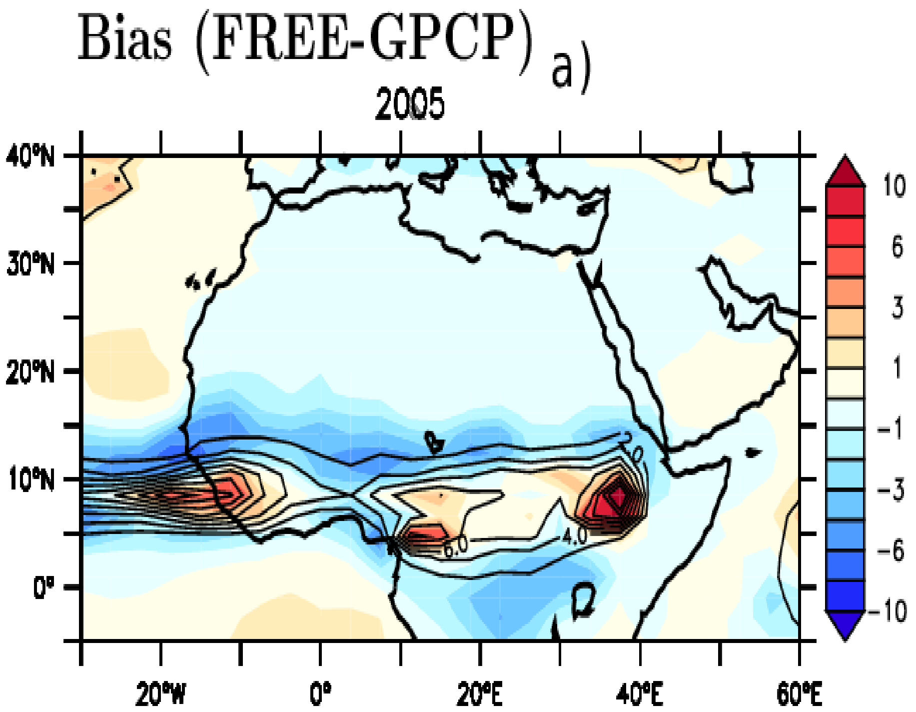
14-day Visibility of the Xenon detection network
(Hourdin et issartel, 2000)



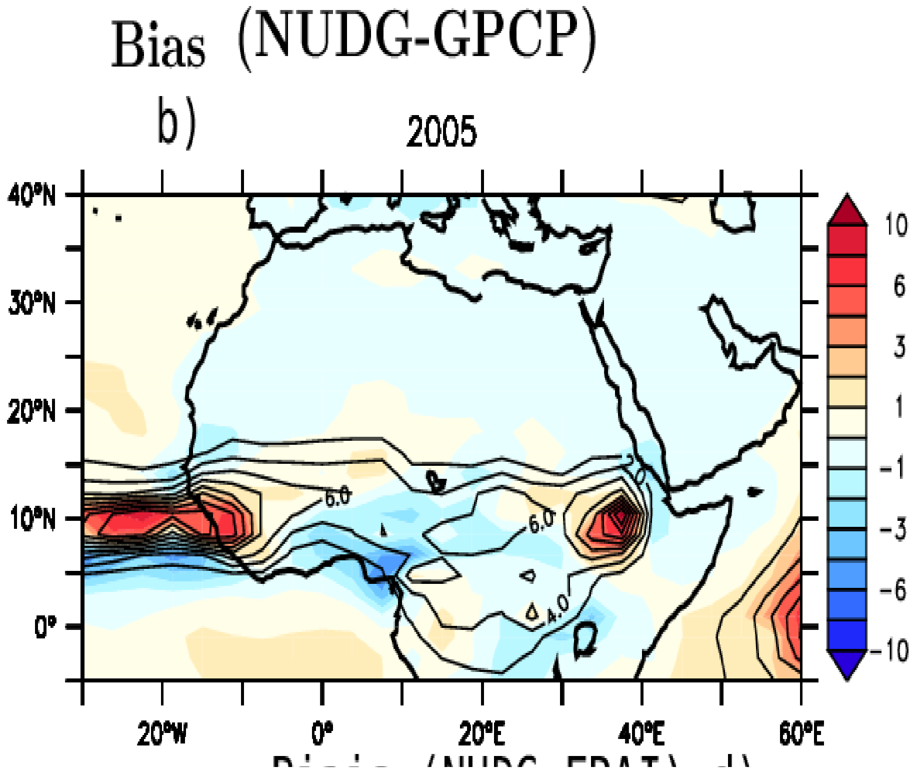
Retro-transport : transport is computed injecting a tracer at the detection stations (green) reversing the time to come back to the possible origins.
Equivalent to an adjoint computation
Used also for estimation of CO_2 and CH_4 inversions.

July-August-September mean rainfall

Free



Nudging by ERAI

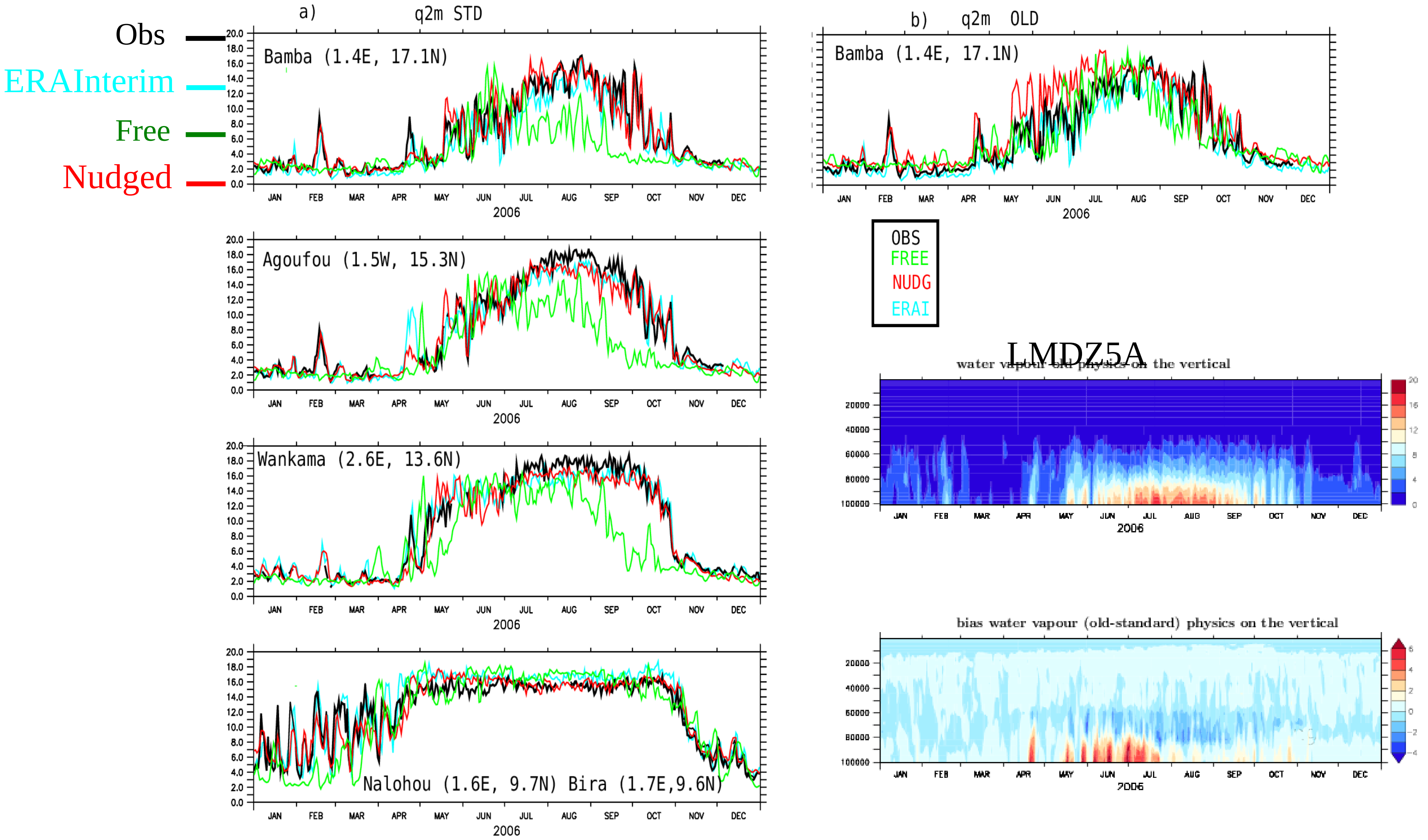


GPCP observations

Nudging helps Monsoon rainfall to progress Nortward, in better agreement with observations

4. Operating modes : b) nudged simulation for physics improvement

2m specific humidiy, Bamba (1.5W, 15.3N), year 2006



Summary of 3D operating modes

	Global regular	Zoomed
Free	**« Earth system » modeling** Forced by SST climate Idealized experiments (aquaplanets, ...) **Analyzes/evaluation in terms of statistics** **Need for ensemble and/or long simulations** **Strongly depends on model parameters tuning**	
Nudged	Chemistry-Transport model (coupled to Inca or Reprobus) Source inversion Evaluation of physical parameterizations with imposed dynamics	Analysis of field campaign experiments and site observations **Climate downscaling**

Analyses/evaluation on day-by-day baises
Can be used in quasi real-time / forecast mode

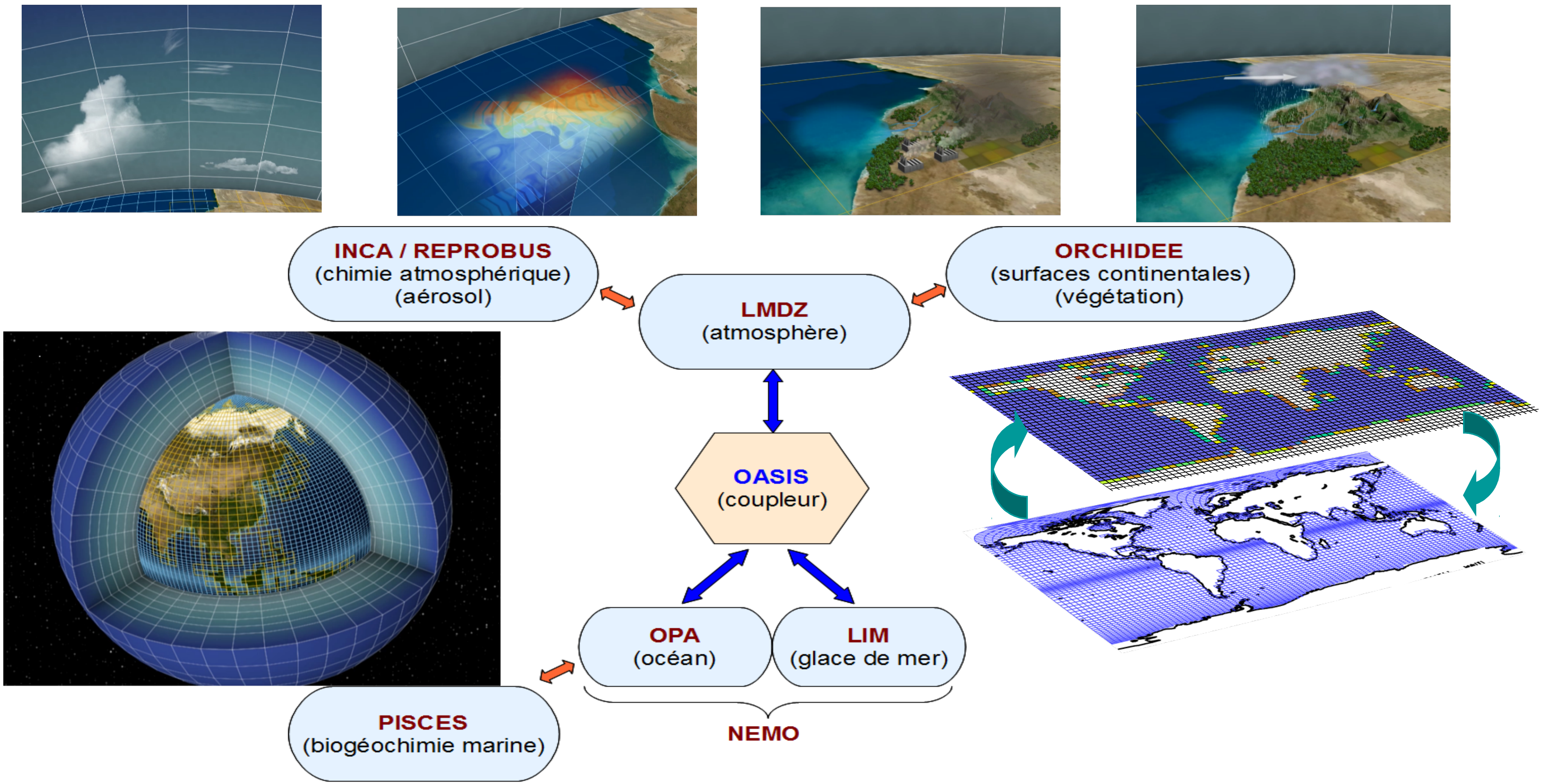
I. LMDZ : a general circulation model

1. General Circulation Models
2. LMDZ
3. Splitting/coupling and modularity
4. Operating modes
    a) Free climatic mode
    b) Zooming capability
    c) Nudging and off-line for tracer transport
    d) 3D nudging or 1D for process studies and parameterization development
5. **Intercomparison exercises and reference versions**
    a) CMIP exercises
    b) The IPSL model and LMDZ reference versions
    c) Biases and skill of LMDZ
6. Model development and tuning
    a) Choice of a new configuration : content and resolution
    b) Importance of tuning

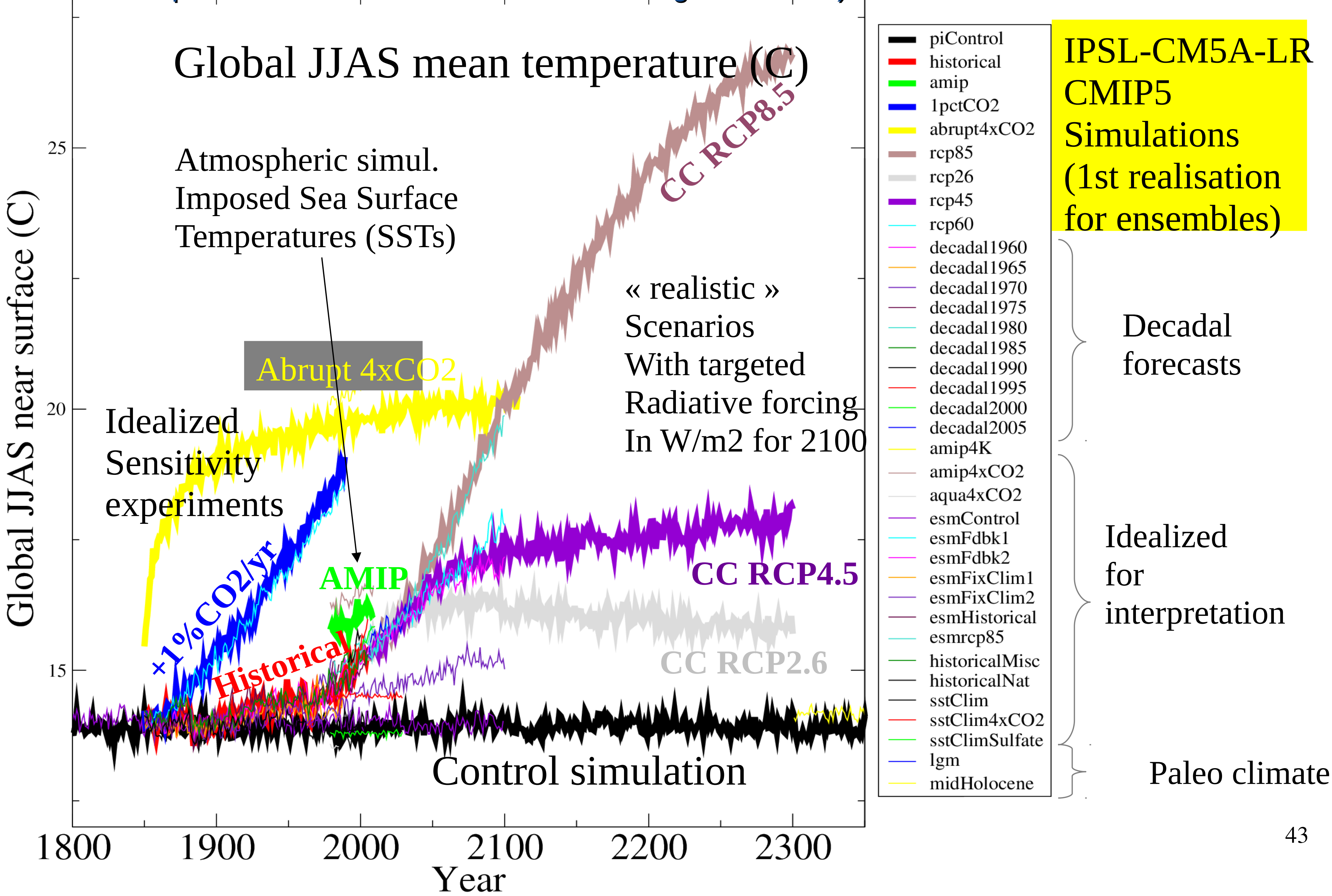
5. Intercomparison exercises and reference configurations : a) CMIP exercises

Coupled model Intercomparison Project (CMIP)
Comparison of coupled atmosphere/ocean models or ESM (for Earth System Models)
Each 7-year
Production of an ensemble of simulations with imposed boundary conditions / protocol

The IPSL coupled Model

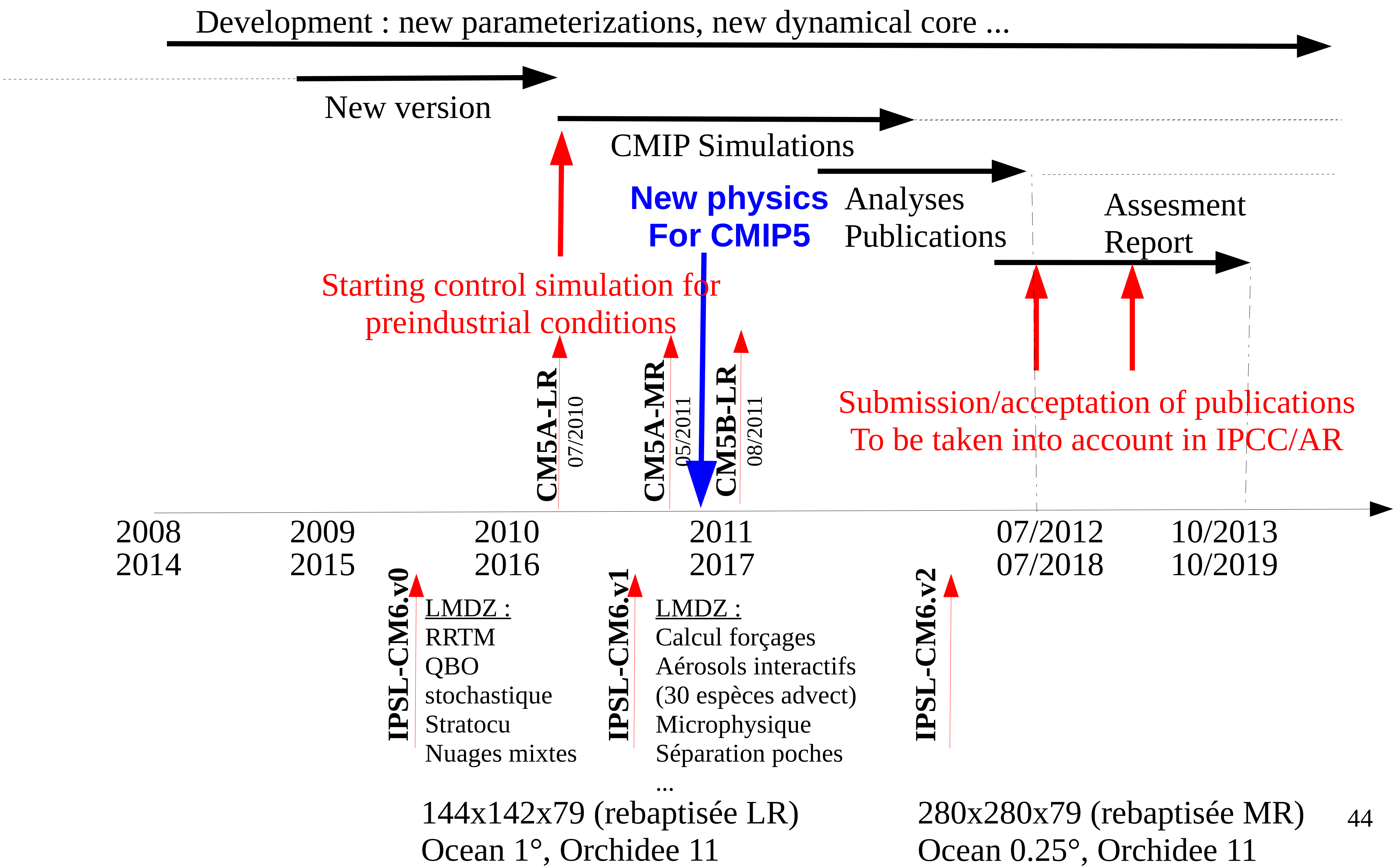


5. Intercomparison exercises and reference configurations : a) CMIP exercises



5. b) IPSLCM and LMDZ reference versions

Development of LMDZ and the CMIP rendez-vous CMIP

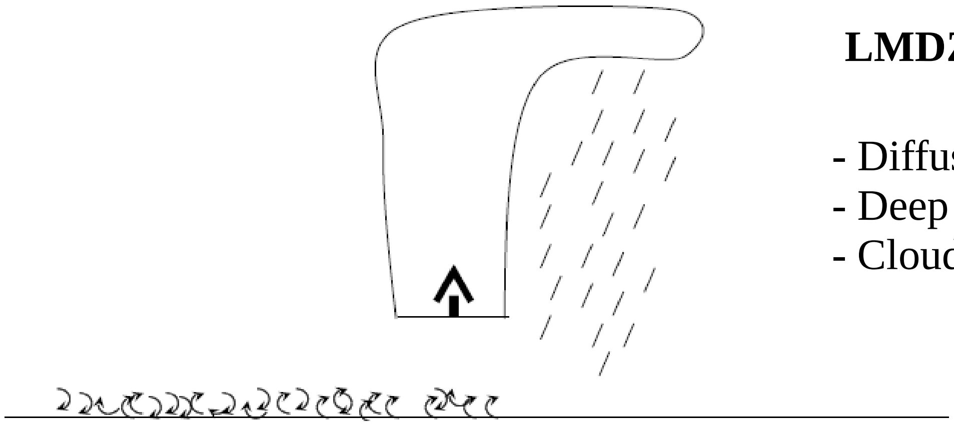


Summary of reference climate configurations

	Vertical resolution	Horizontal grid	Physical parameterizations	Name
CMIP3	L19	96x71	New convection scheme (Emanuel) Subgrid scale ororgaphy	IPSL-CM3 **LMDZ4**
CMIP5	L39 Extension to the stratosphere	LR = 96x95 MR = 144x143	2 versions A : Standard Physics (SP) same as CMIP3 B : New physics (NPv3) with thermal plumes and cold pools	IPSL-CMX **LMDZX** **X=** **5A-LR** **5A-MR** **5B-LR**
CMIP6	L79	VLR = 96x95 LR = 144x143 MR = 280x280 ?	NP v4,5,6 New radiation Stochastic closure Improved clouds Non orog. gravity waves	**LMDZ6**

5. b) IPSLCM and LMDZ reference versions

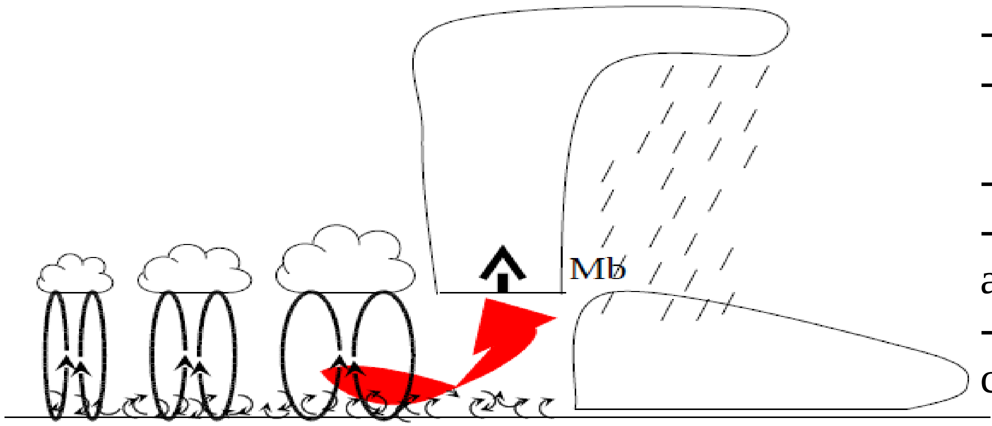
The different physical packages of LMDZ



LMDZ5A

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

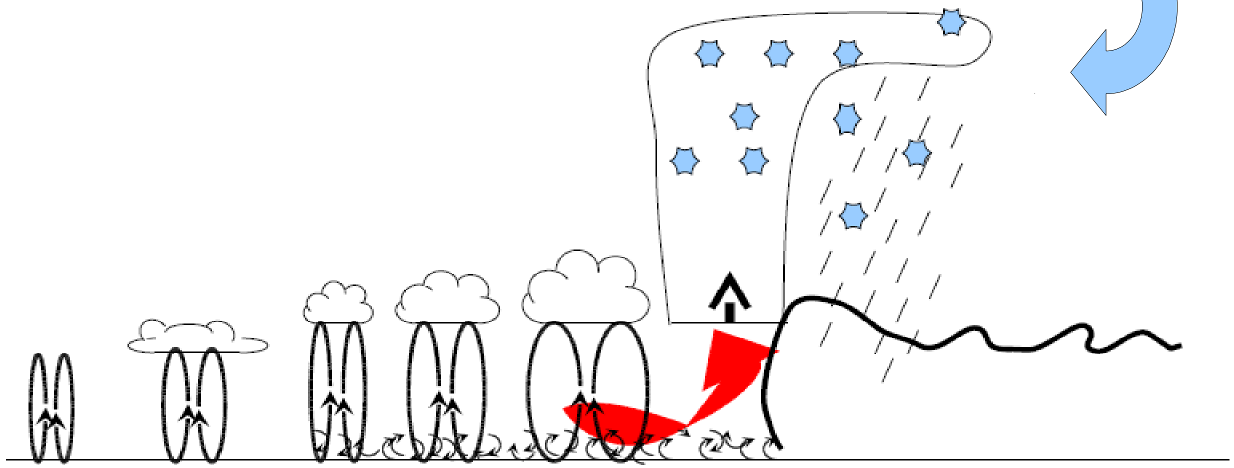
LMDZ5B



- Diffusion scheme (Yamada, 1983)
- Thermal plume model except in strato 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)

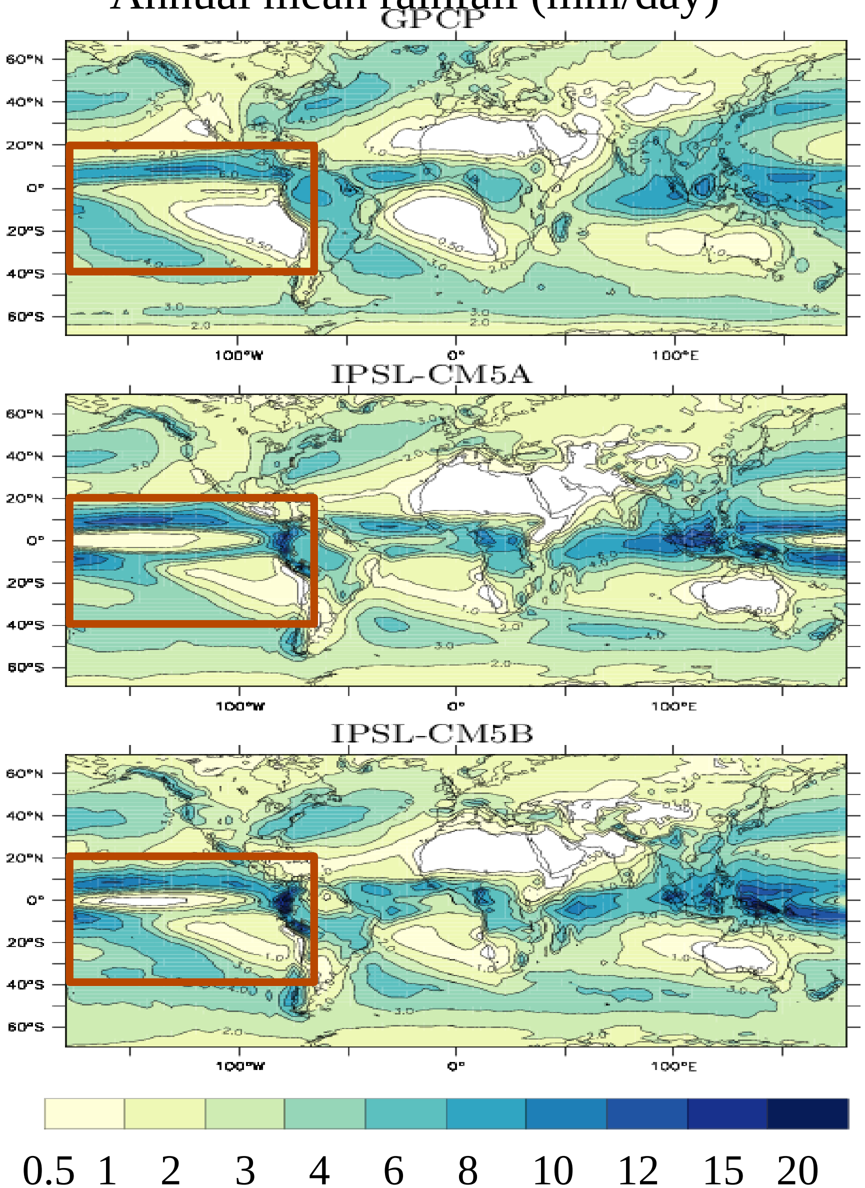
PRE-LMDZ6

LMDZ5B
+ Thermal plume model everywhere
+ Stochastic triggering of deep convection
+ Different convective mixing formulation
+ Thermodynamical effect of ice
+ RRTM for infrared radiation and SW 6 bands

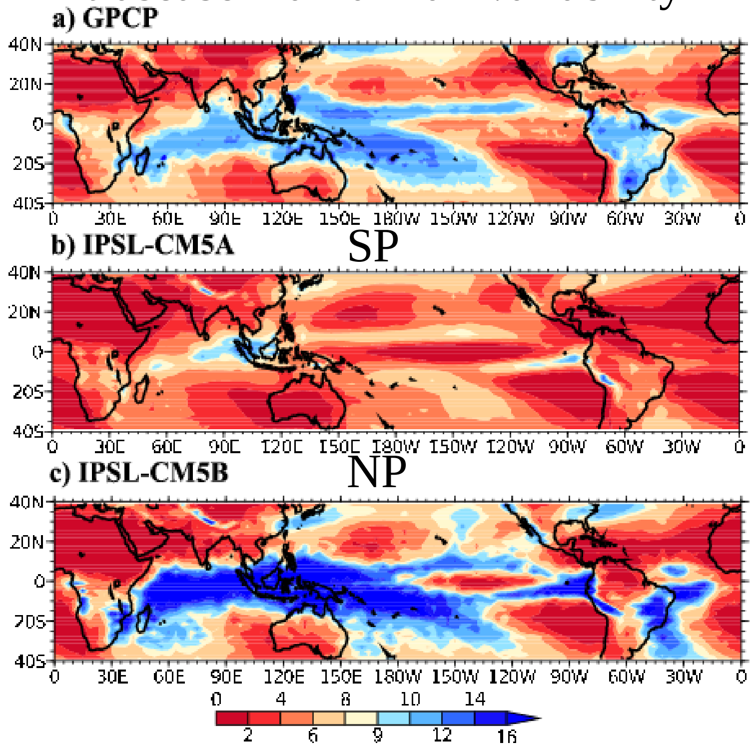


5. b) IPSLCM and LMDZ skill and weaknesses

Slight bias reduction for
Annual mean rainfall (mm/day)



Large positive impact on the
Intraseasonnal rainfall variability

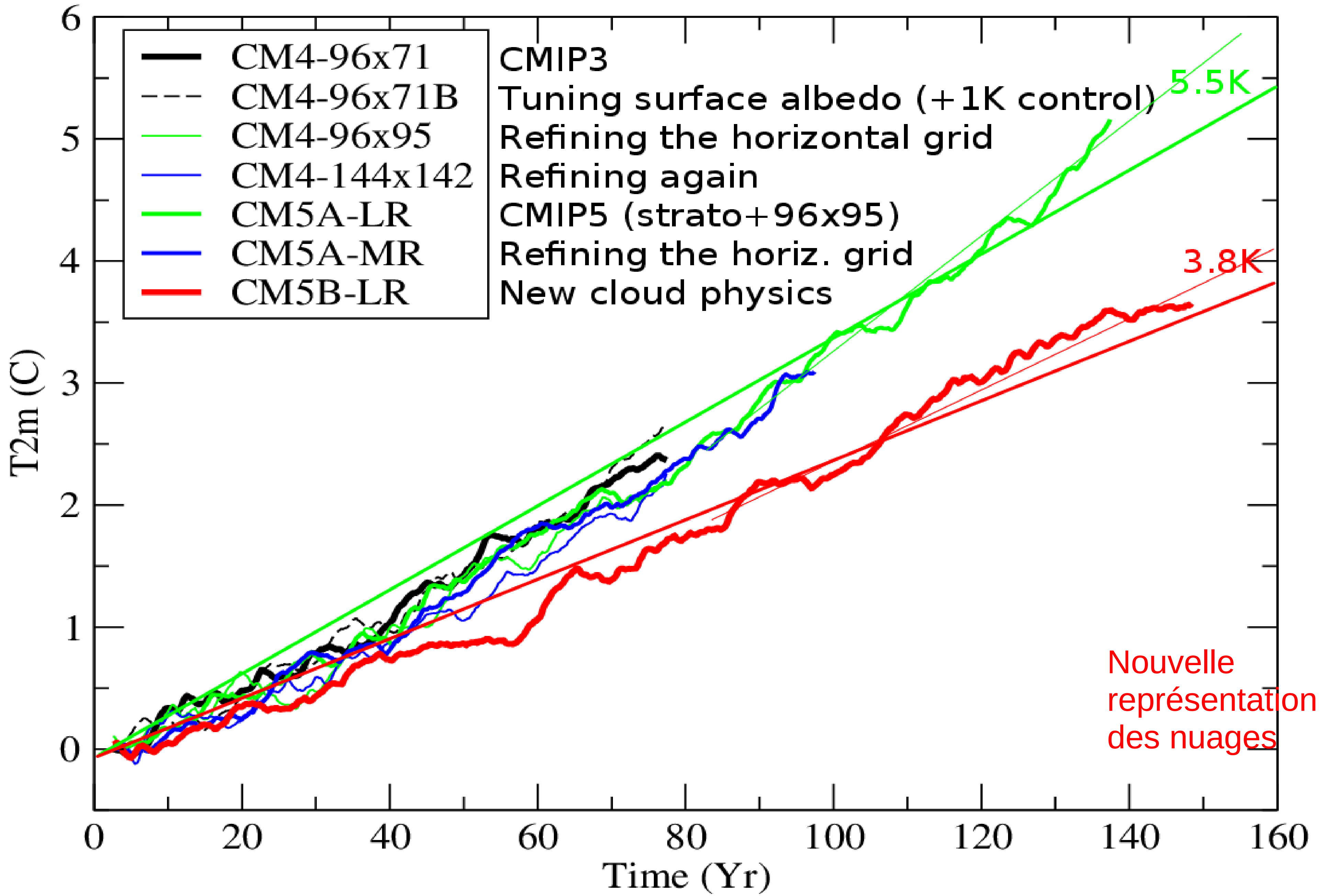


Standard deviation of daily rainfall anomalies (mm/day) of the a) GPCP dataset (1996-2009), b) IPSL-CM5A and c) IPSL-CM5B preindustrial simulations, for the winter season (November to April - NDJFMA)

Rainfall day-to-day variability highly dependent on physics parameterizations

Classical systematic biases on the mean rainfall -> like double ITCZ

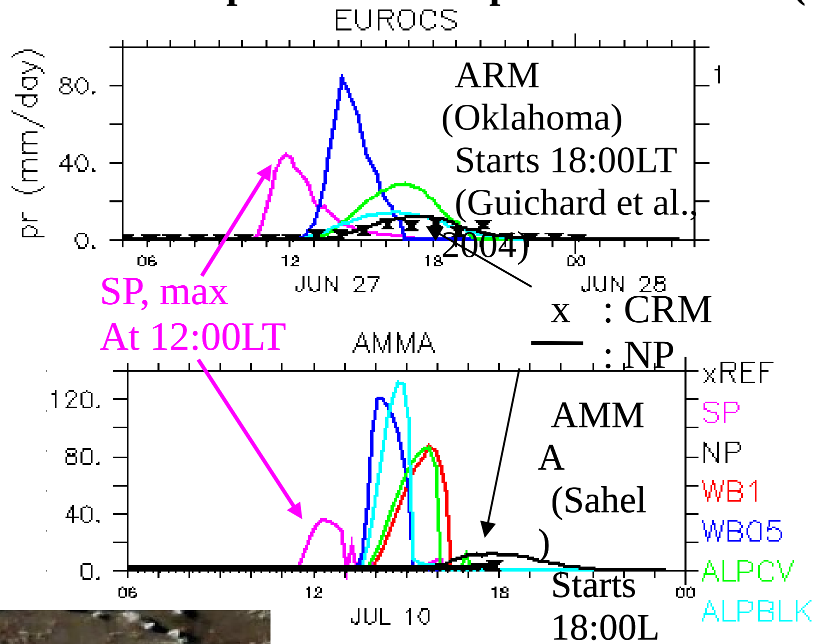
5. b) IPSLCM and LMDZ skill and weaknesses



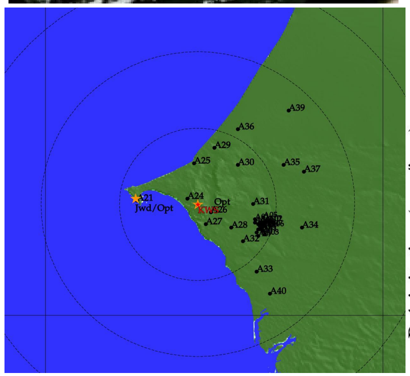
Climate sensitivity highly dependent on model physics.
IPSLCM among models with high climate sensitivity

Shifting the diurnal cycle of convective rainfall : possible with parameterized convection

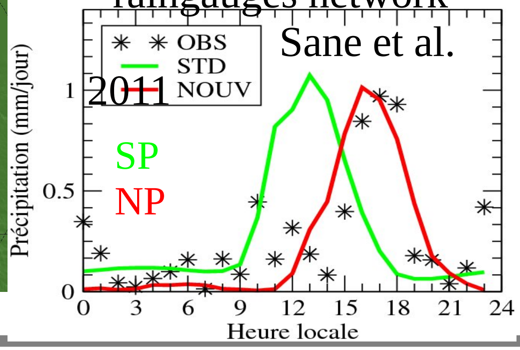
1D test cases/ comparison with explicit simulations (MesoNH)



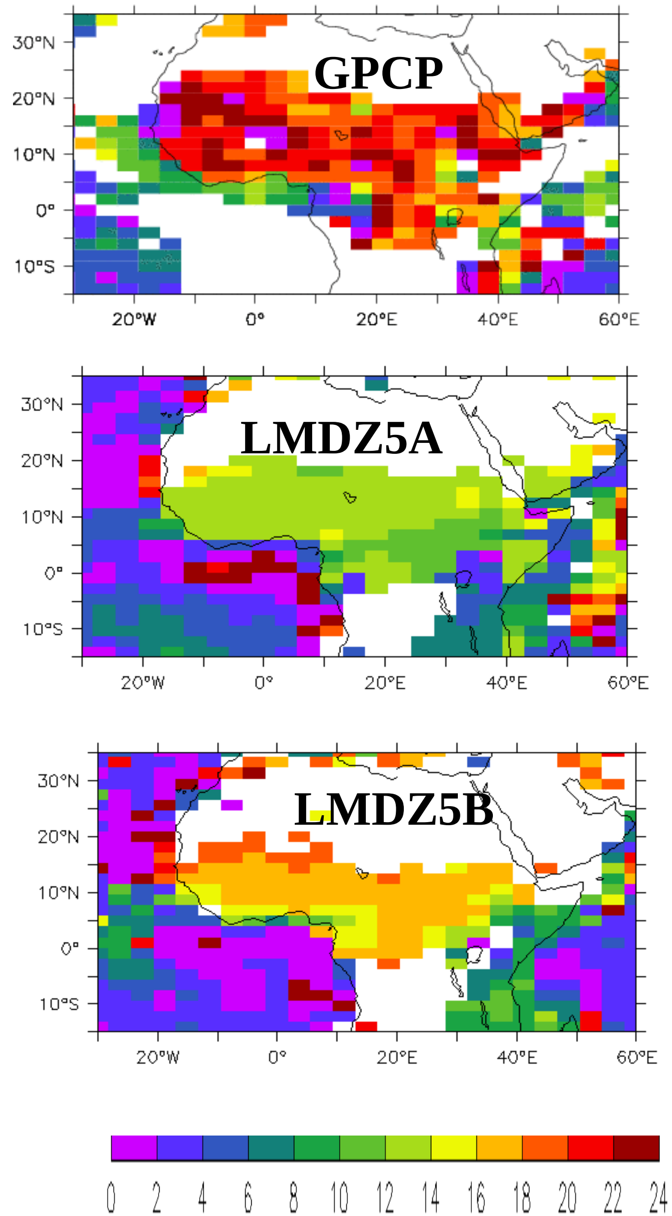
AMMA 10 July case, convection initiation, Niamey
Couvreux et al., 2012
Rio et al., 2012



Dakar LPAOSF/NASA raingauges network



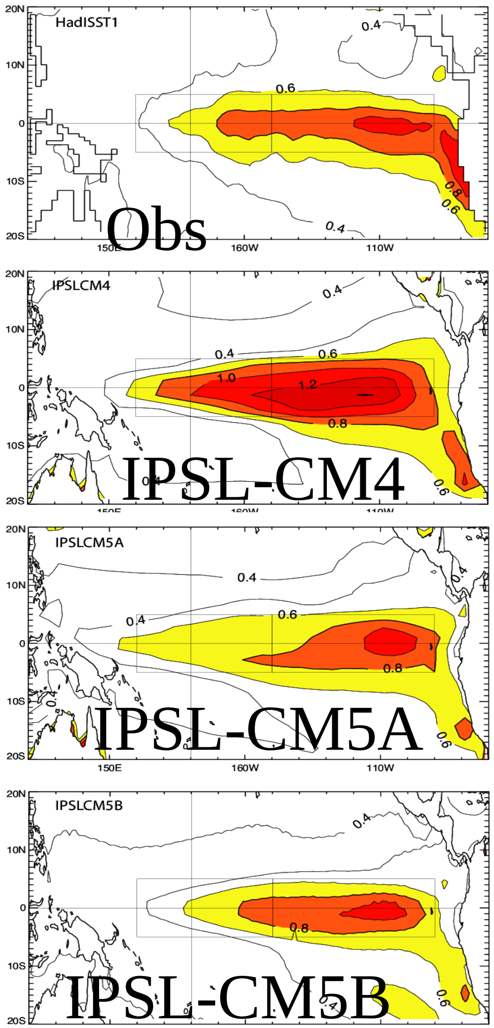
Local hour of maximum rainfall in July



Evolution moyenne
de la pluie dans
la journée

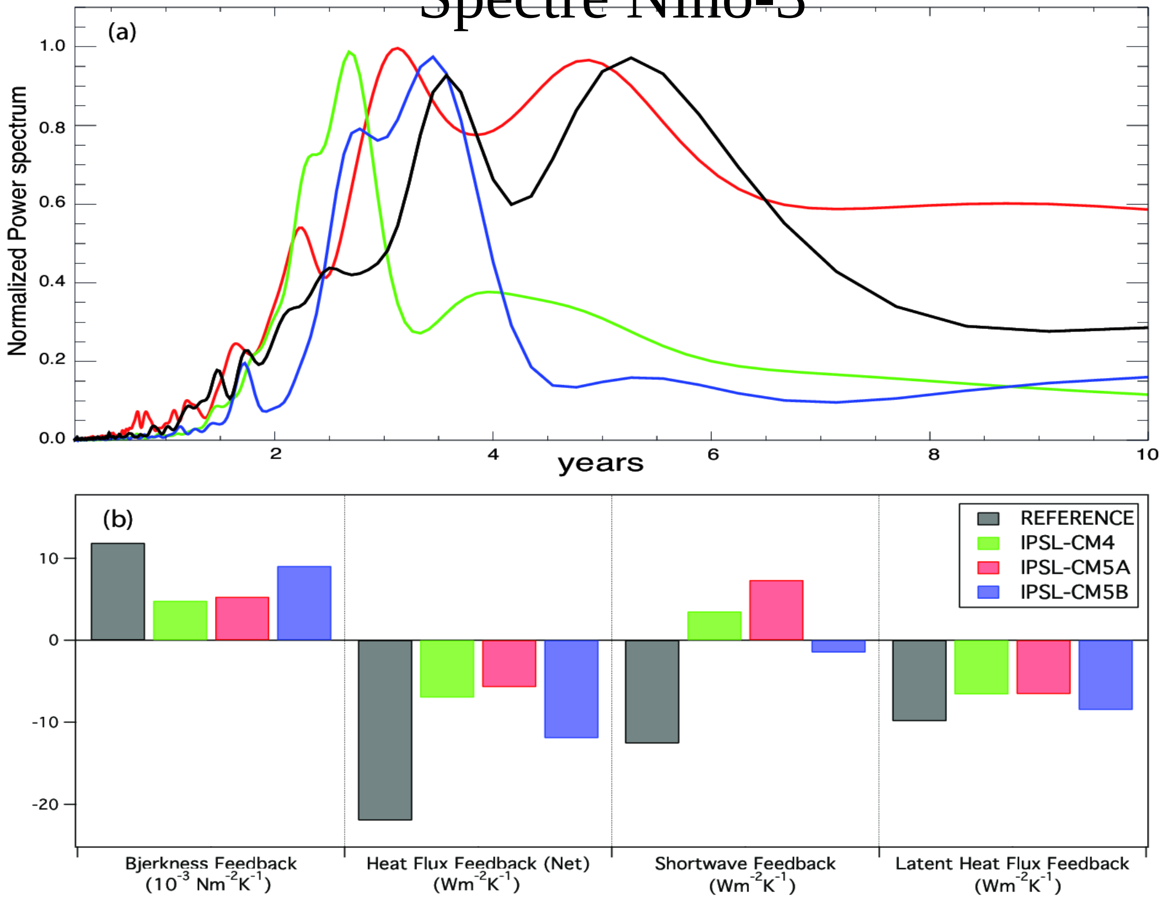
A good representation of the diurnal cycle of rainfall over continents

5. b) IPSLCM and LMDZ skill and weaknesses



El Nino dans les versions successives de IPSL-CM

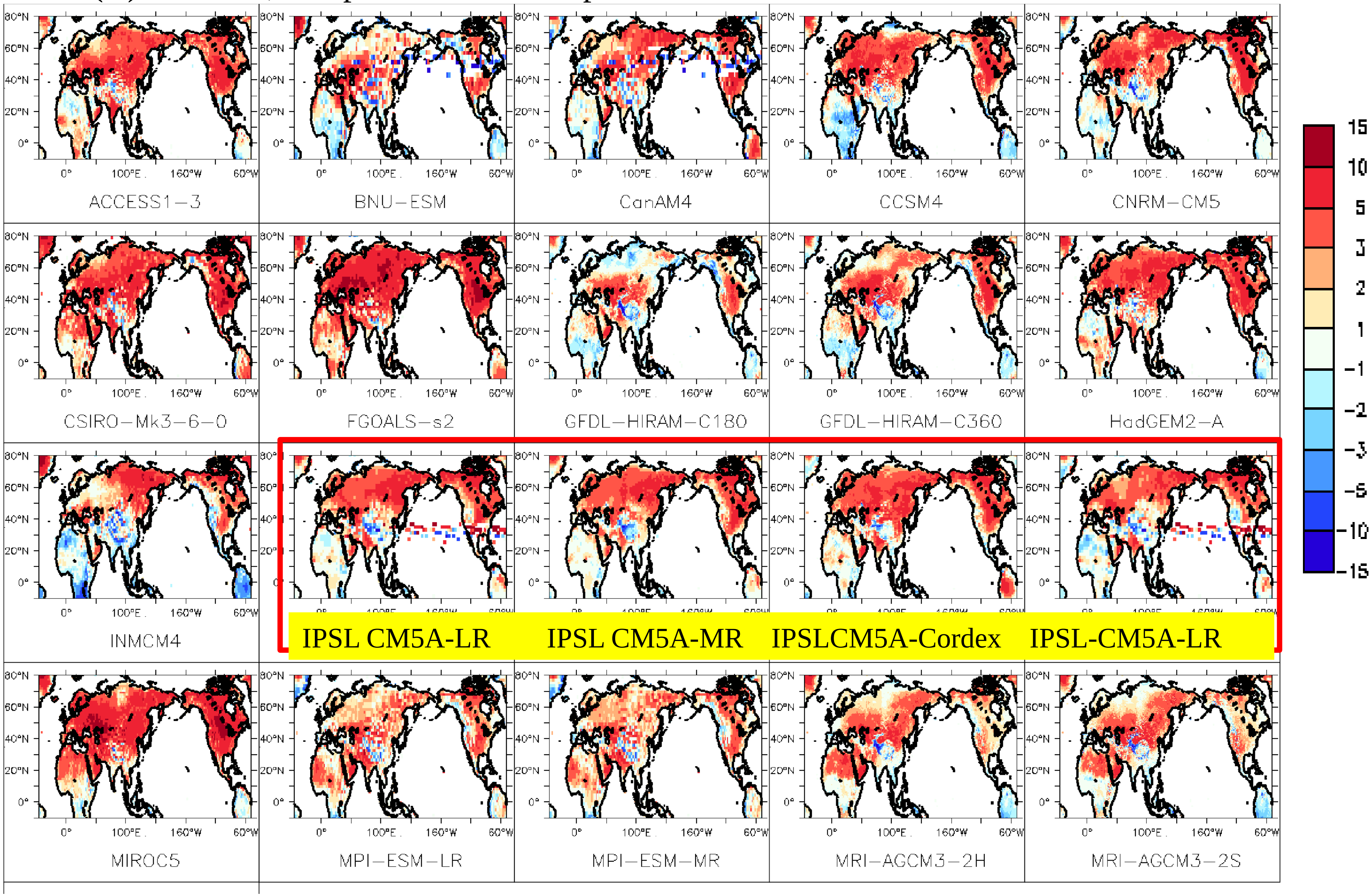
Spectre Nino-3



A reasonable representation of ENSO variability

5. b) IPSLCM and LMDZ skill and weaknesses

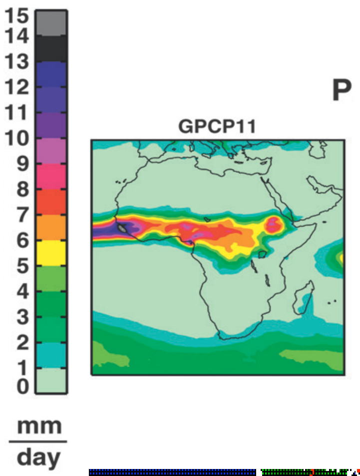
T2m (K) JAS bias, Amip/CMIP5 with imposed Sea Surface Temerature

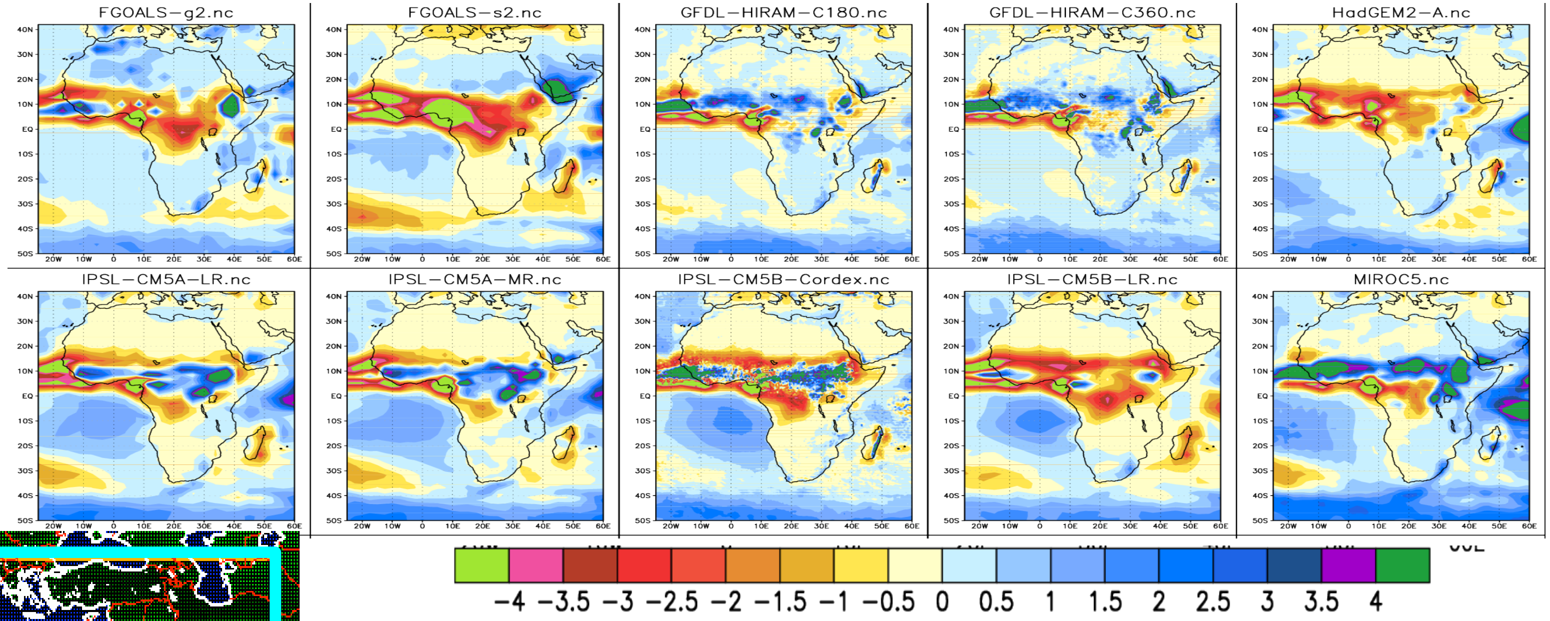


Classical temperature warm biases over continents in summer in LMDZ5
In forced by SSTs simulations -> Cold biases in LMDZ6-beta

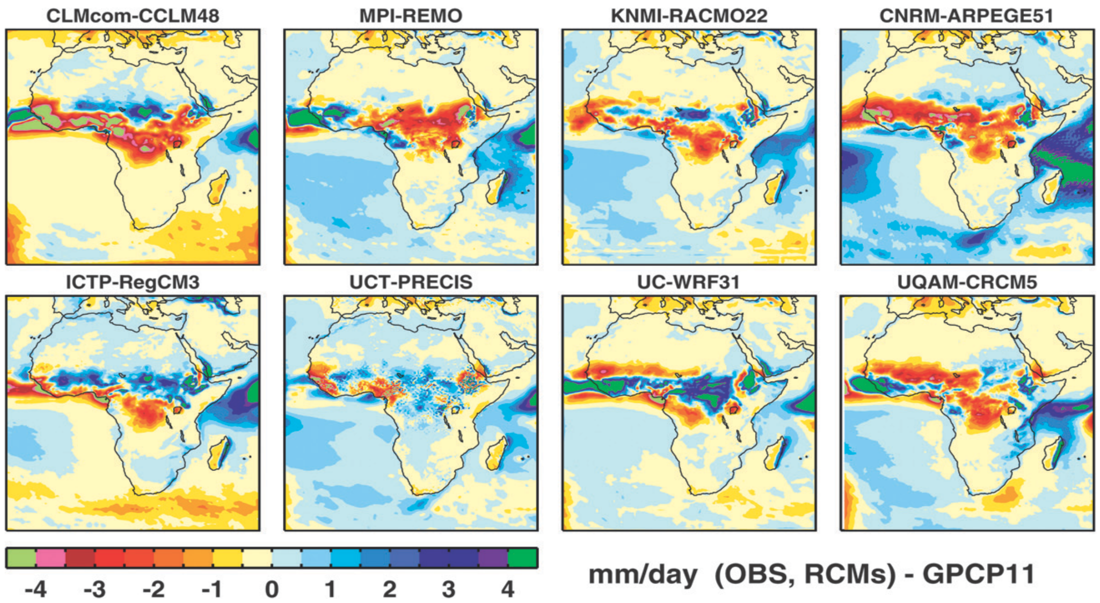
Rainfall biases, July-August-September

subset of CMIP5 models





subset of Cordex models

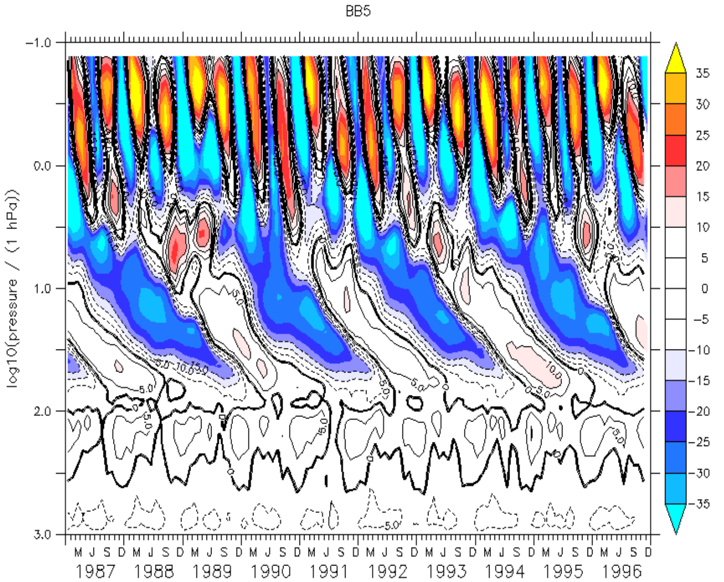


mm/day (OBS, RCMs) - GPCP11

Nikulin et al., 2012, J. Clim.

Classical biases on monsoon rainfall (not enough rainfall over Sahel and North india)

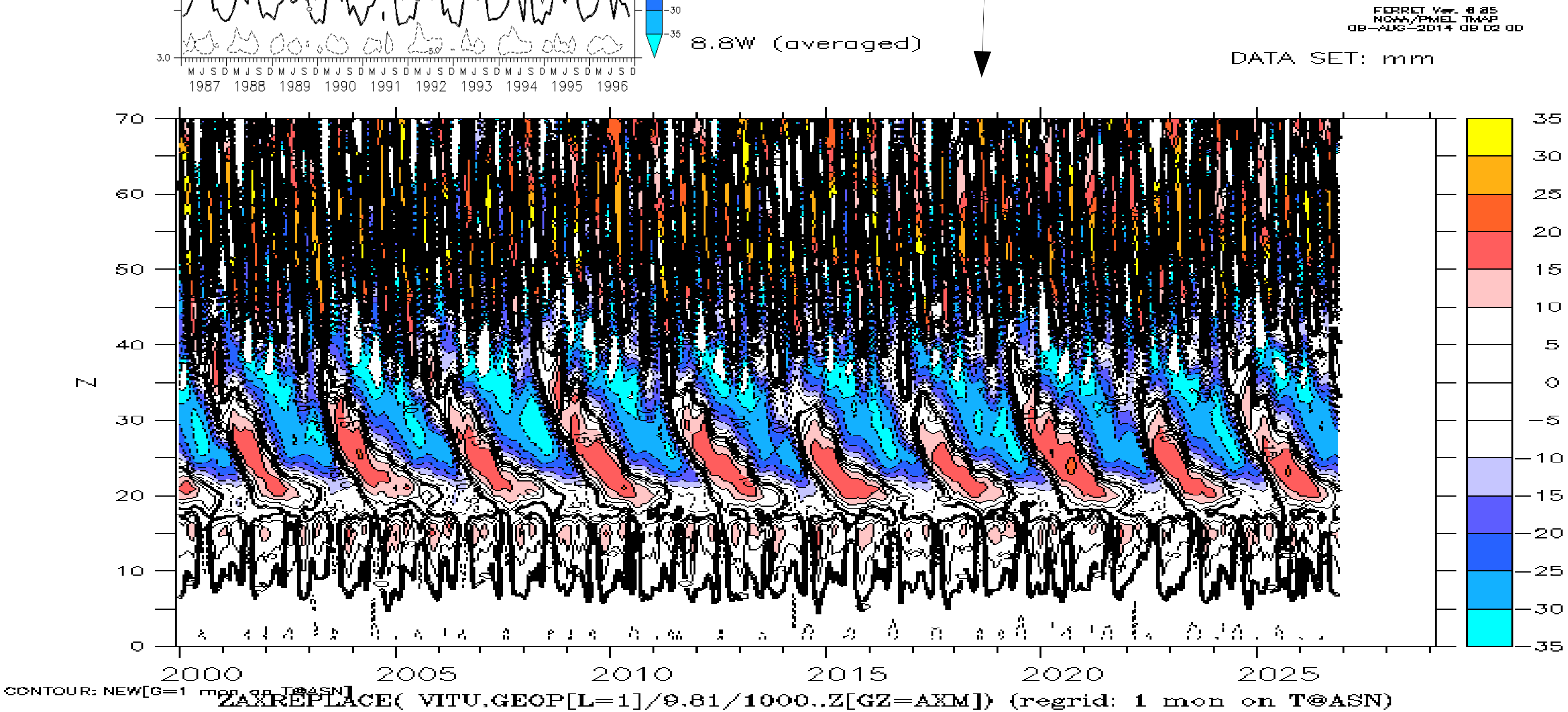
5. b) IPSLCM and LMDZ skill and weaknesses



QBO

Obs

Modèle



Among the models with a Quasi Bienal Oscillation

I. LMDZ : a general circulation model

1. General Circulation Models
2. LMDZ
3. Splitting/coupling and modularity
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    a) Free climatic mode
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    c) Nudging and off-line for tracer transport
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6. Model development and tuning
  a) Choice of a new configuration : content and resolution
  b) Tuning of free parameters

Definition of model configurations

1. Horizontal resolution and vertical discretization

2. Physical content – Choice of a particular set of parameterizations

3. **Tuning of free parameters !**

Preparation of a configuration is a long process
Sensitivity tests to the grid, physical parameterizations, free parameters
Compromises. Can depend on team priorities.

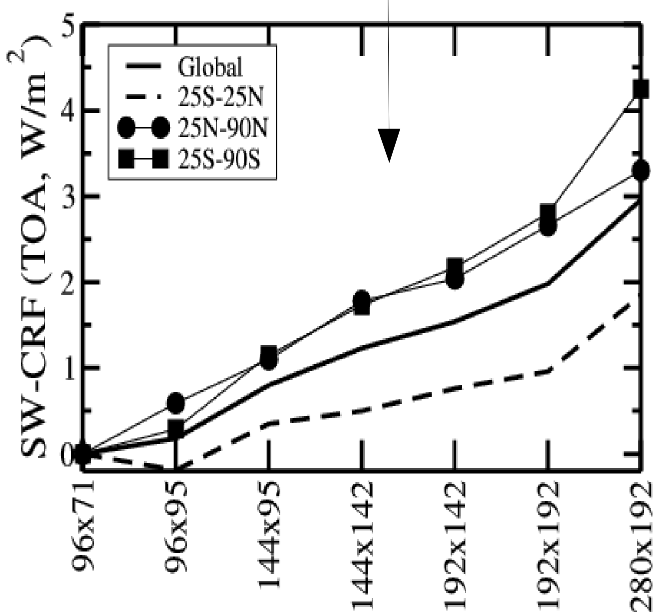
For global climate coupled atmosphere/ocean modeling the tuning of the radiative forcing is a key issue. Several months of tuning for one version.

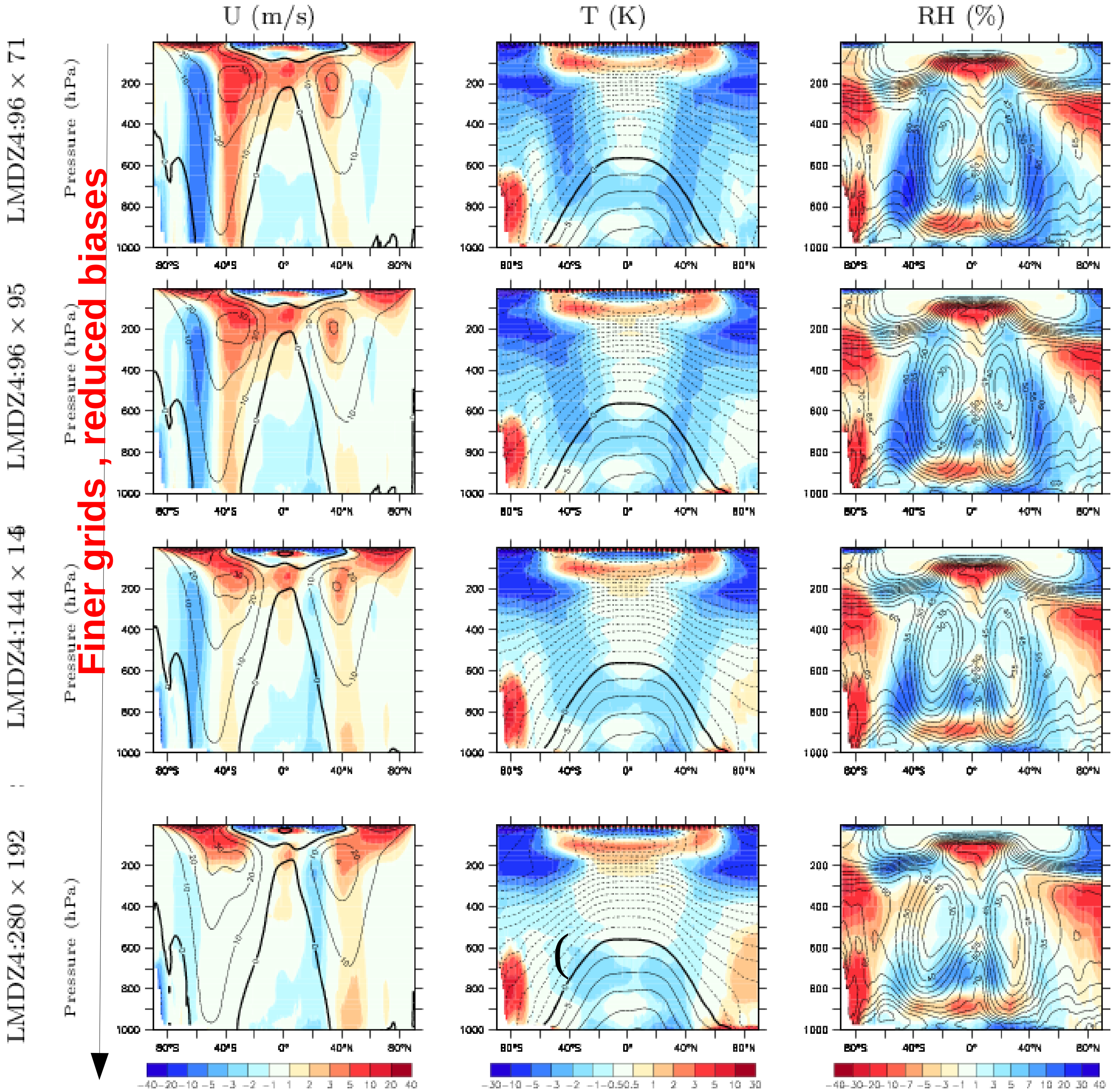
From LMDZ4 to LMDZ5 and LMDZ6 : change of horizontal resolution

Dependance of model biases to the horizontal resolution.

Because of the number of simulations to be performed in CMIP exercises, the reference configurations are a compromise.

The global energy balance is sensitive to the horizontal resolution





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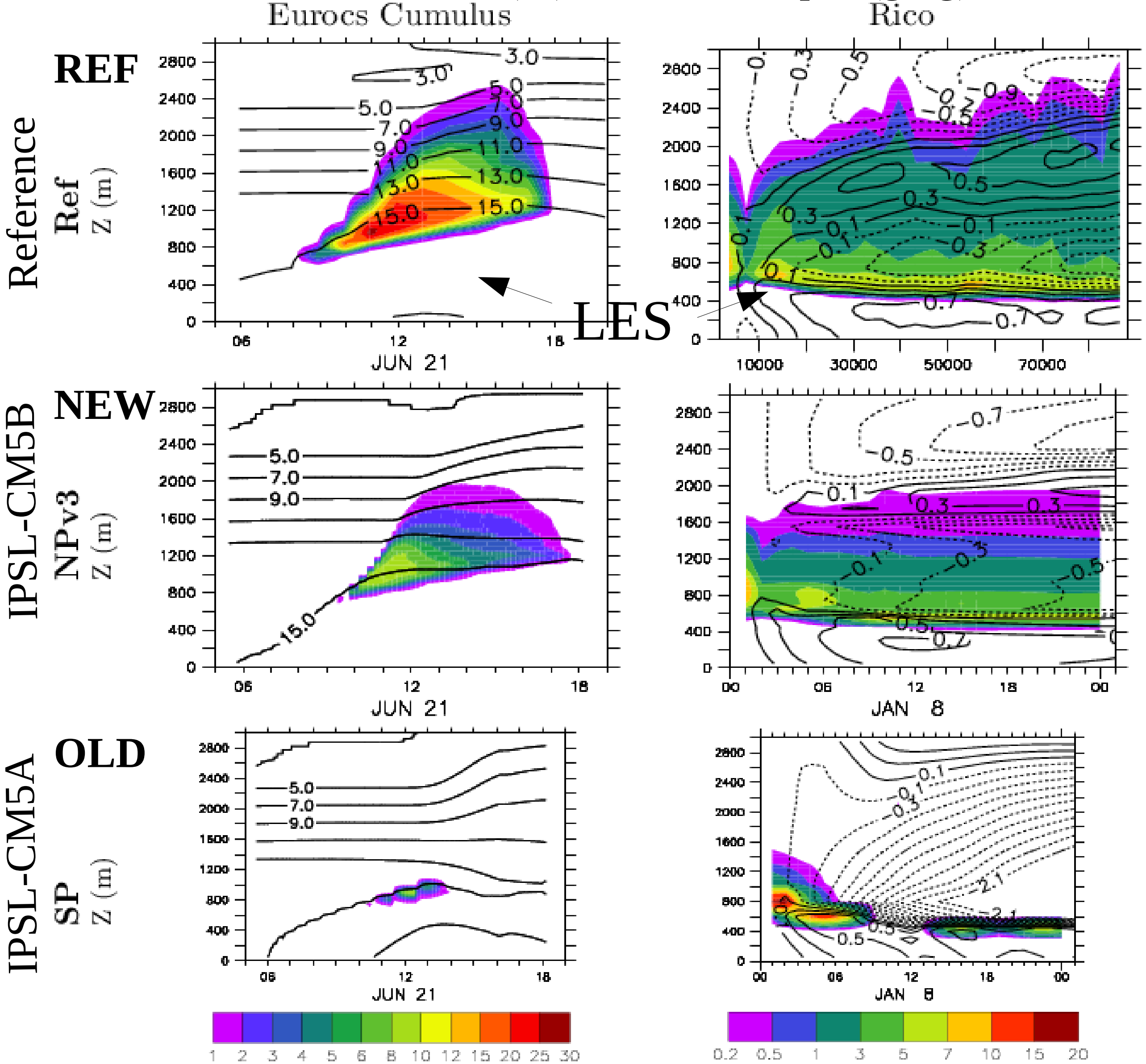
From LMDZ5A to 5B : change of physics

1D test cases

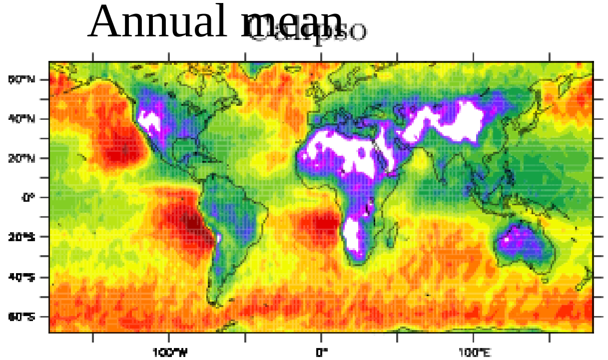
Cloud fraction (%) and water vapor (g/kg)



Simulations 3D

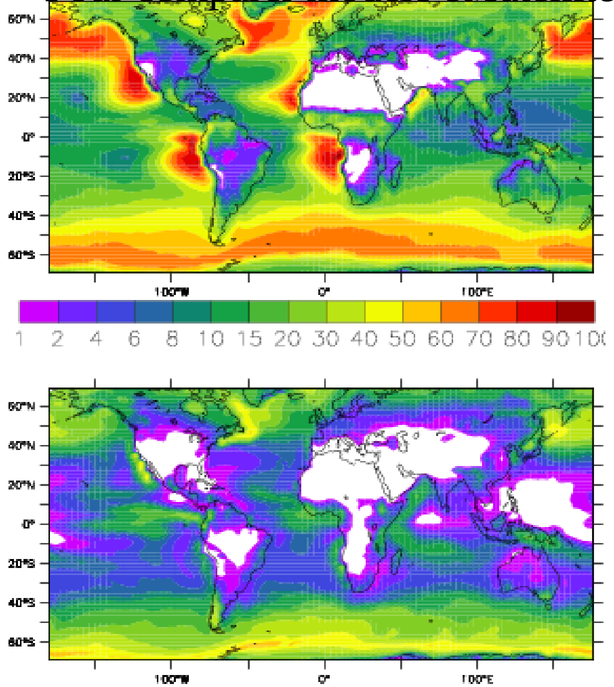
Low cloud cover (%)

Annual mean



Utilisant le simulateur Cosp

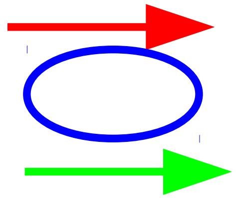
Pour comparer modèle et satellite



6. Model development and tuning : a) choice of a new configuration

Successive activation of the thermal plume model

Results from atmospheric simulations forced by climatic sea surface temperature



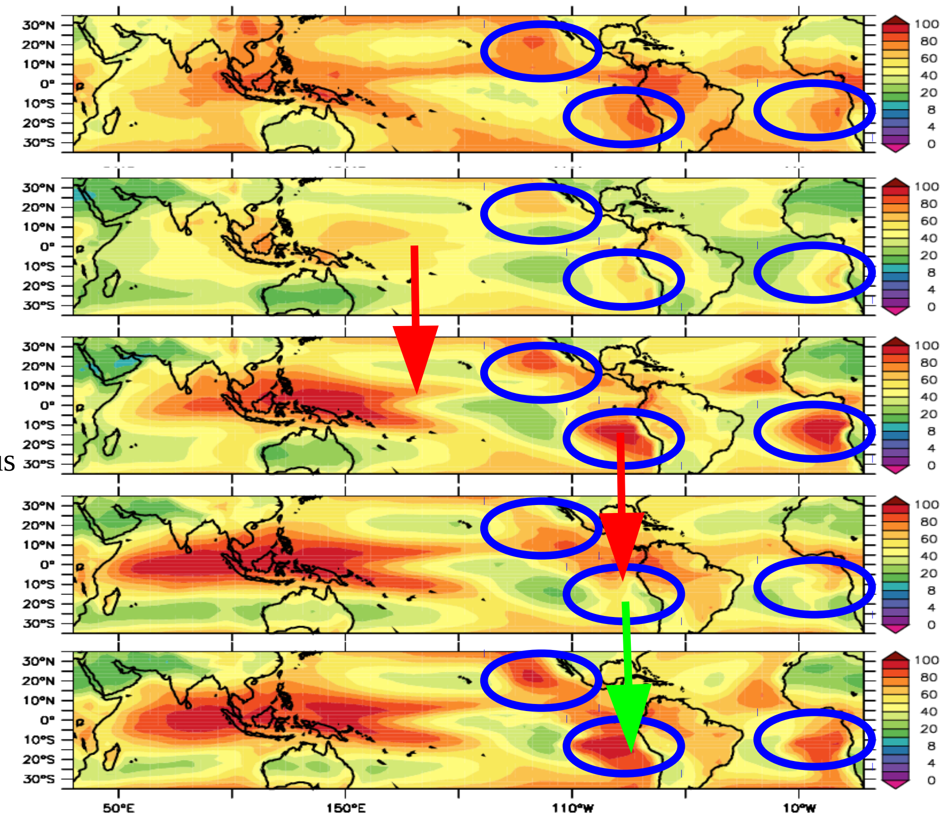
: activating thermal plumes
: Subsidence regions
: Detrainement modifié

Observations

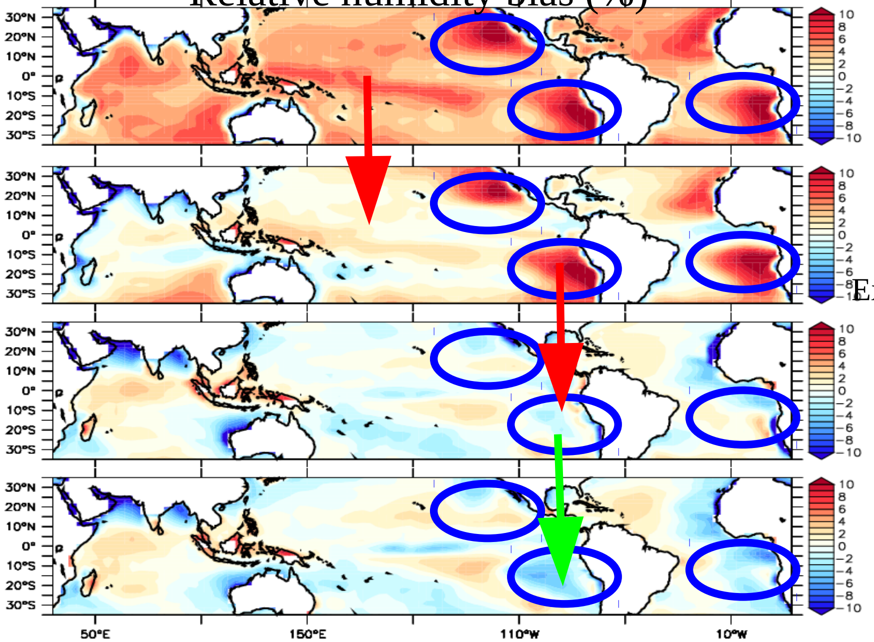
Da Silva

Calipso GOCCP

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

Definition of model configurations

1. Horizontal resolution and vertical discretization

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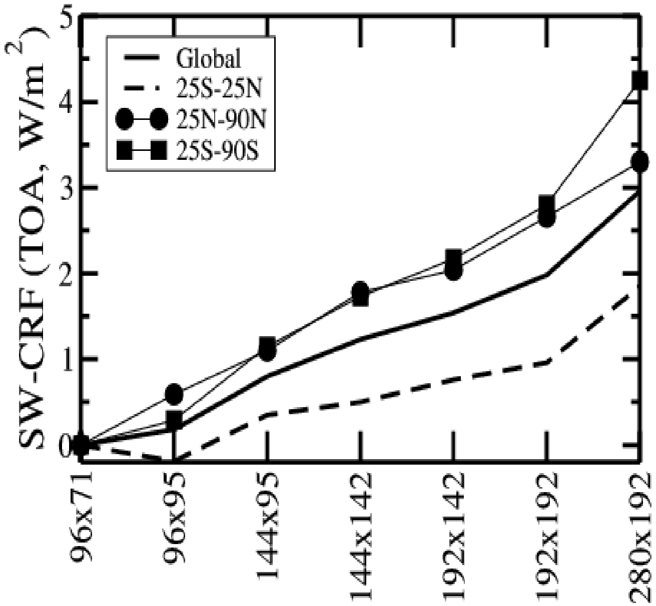
For global climate coupled atmosphere/ocean modeling the tuning of the radiative forcing is a key issue. Several months of tuning for one version.

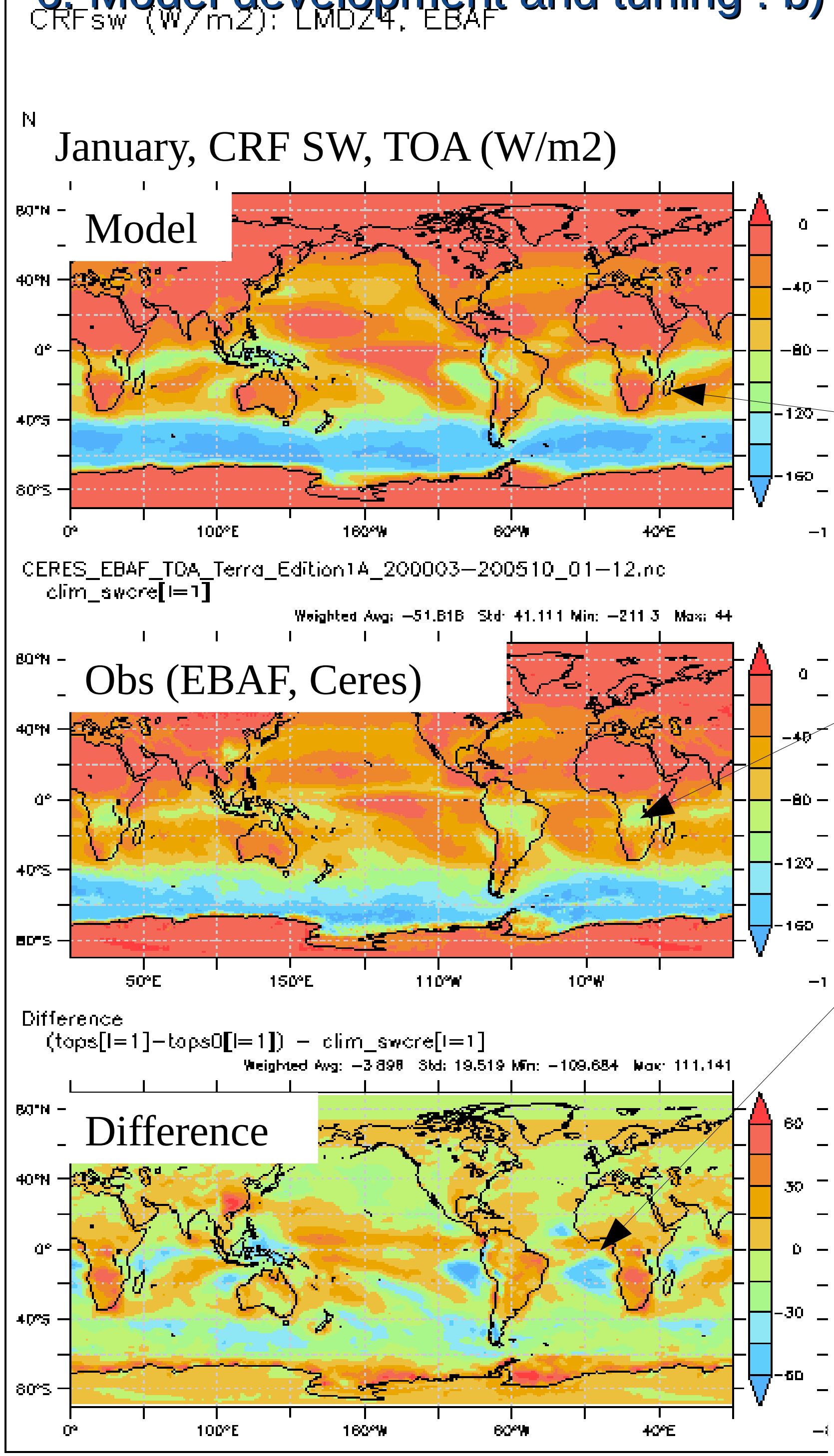
1W/m² in radiative balance translates into 1K temperature bias in the coupled model

Much below uncertainties in modeling and observation of radiative fluxes

So the global temperature of climate models is a result of tuning !!!



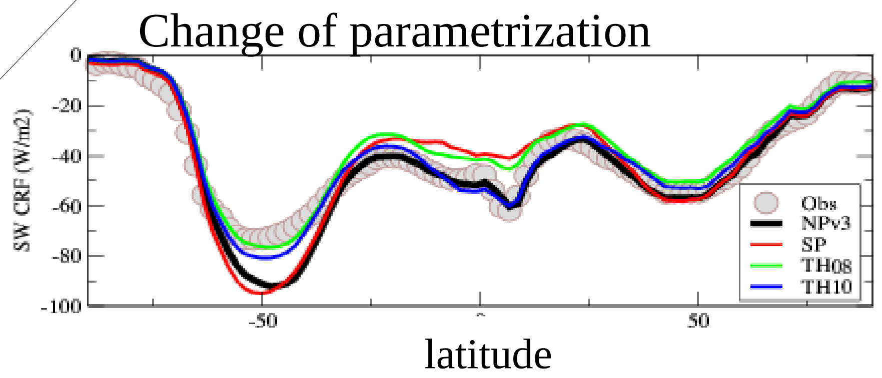
6. Model development and tuning : b) tuning of free parameters

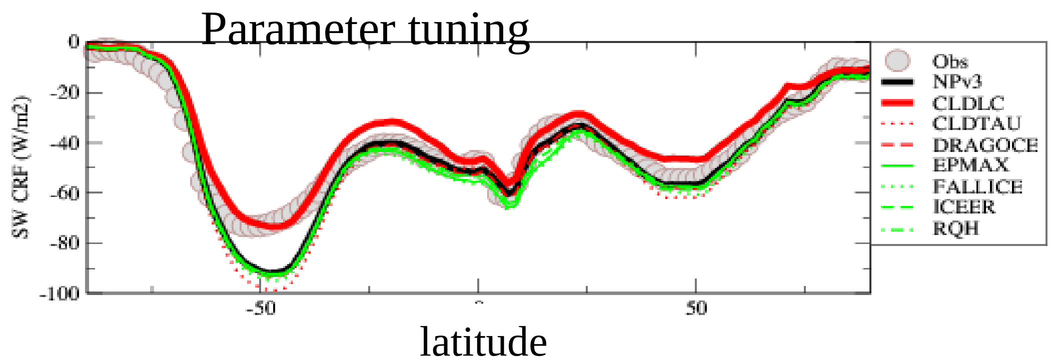


Relative importance of model improvements and tuning

SW Cloud Radiative Effect at Top-of-Atmosphere in W/m2

Model
Difference

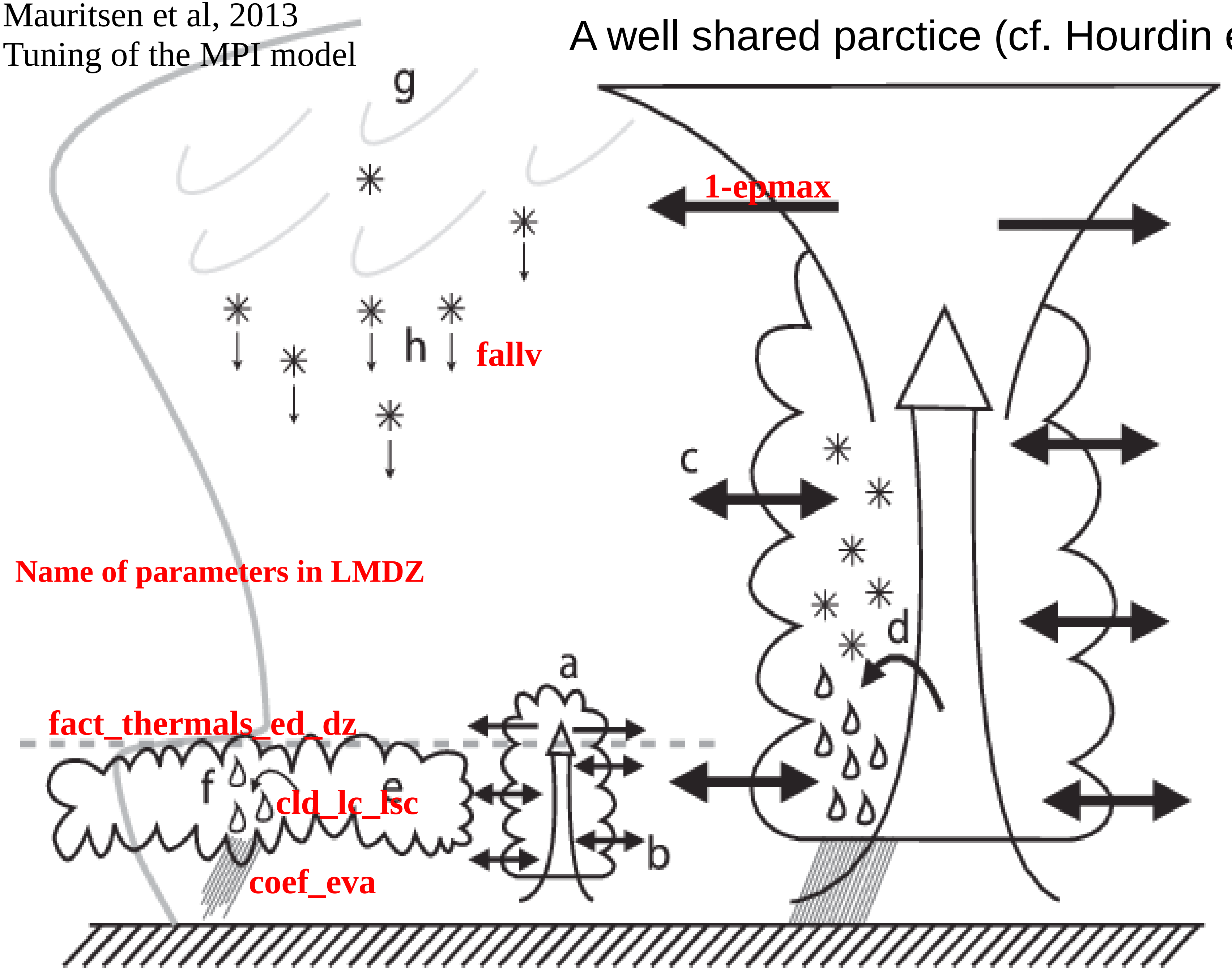




Tuning of cloud parameters

Mauritsen et al, 2013
Tuning of the MPI model

A well shared parctice (cf. Hourdin et al., 2016)

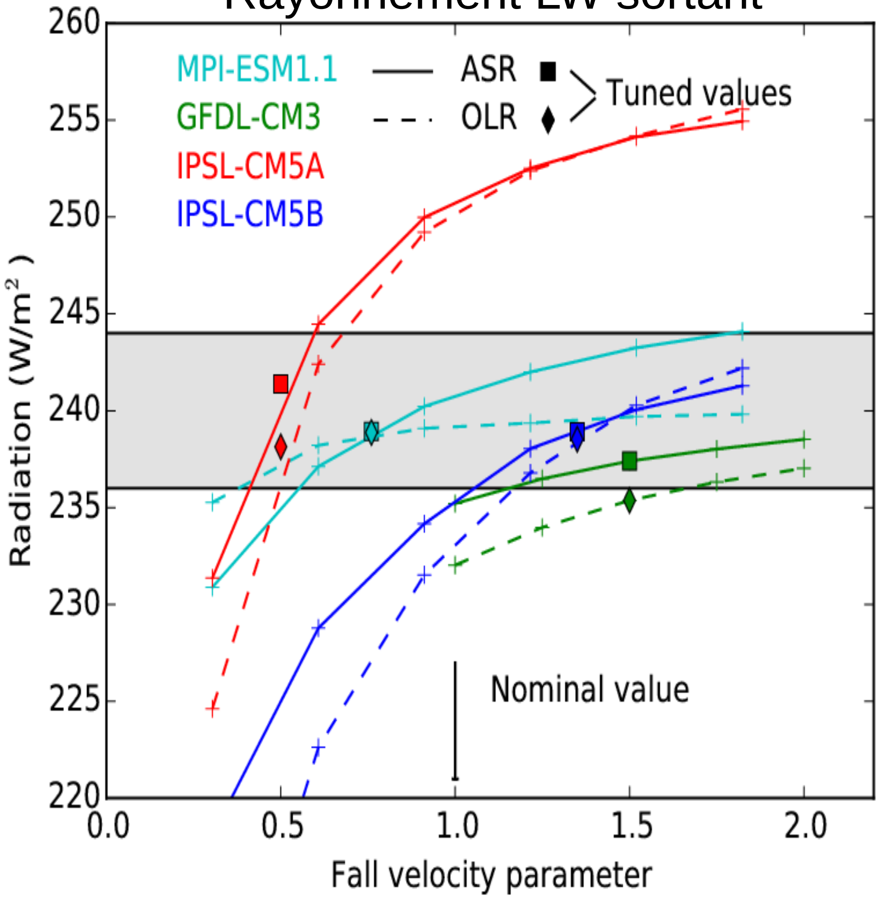


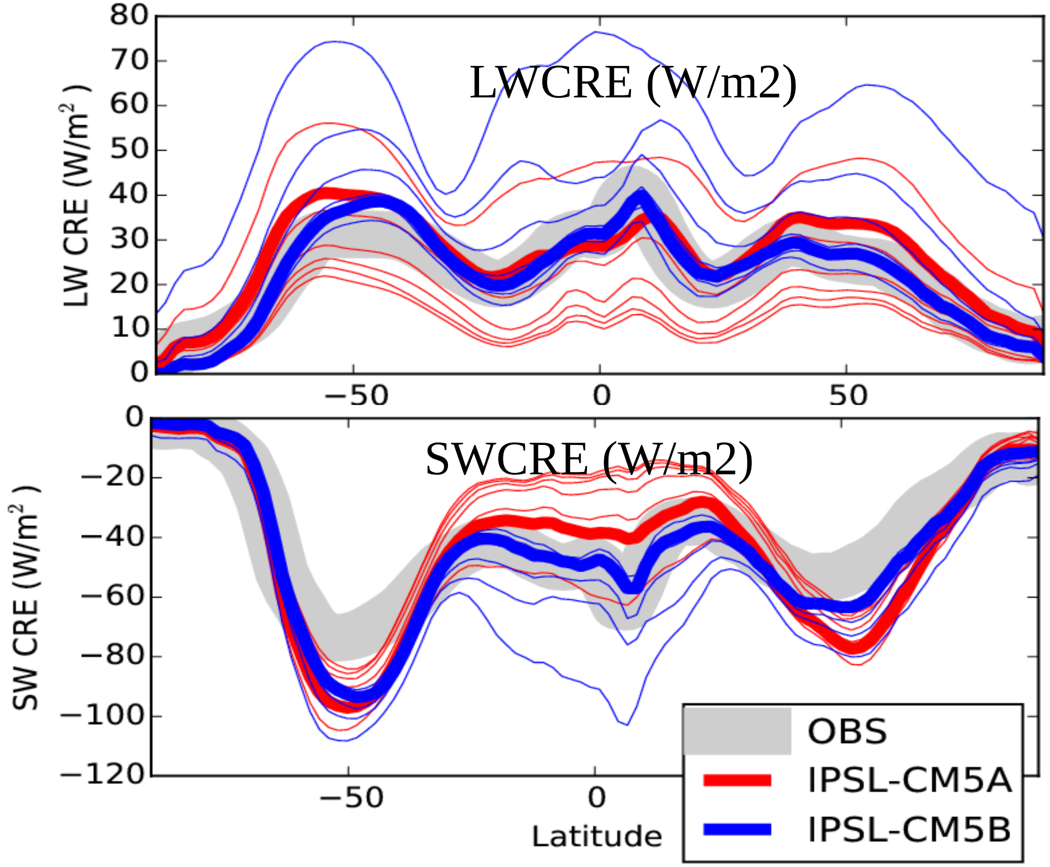
Use of a scalling factor on the fall velocity of cloud ice particles
Impact on global radiative balance and latitudinal radiative forcing of the circulation

Impact sur les flux globaux au sommet

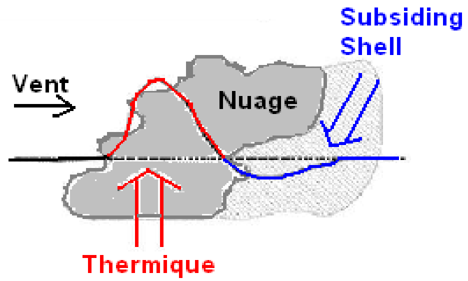
— Rayonnement SW absorbé

- - - Rayonnement LW sortant

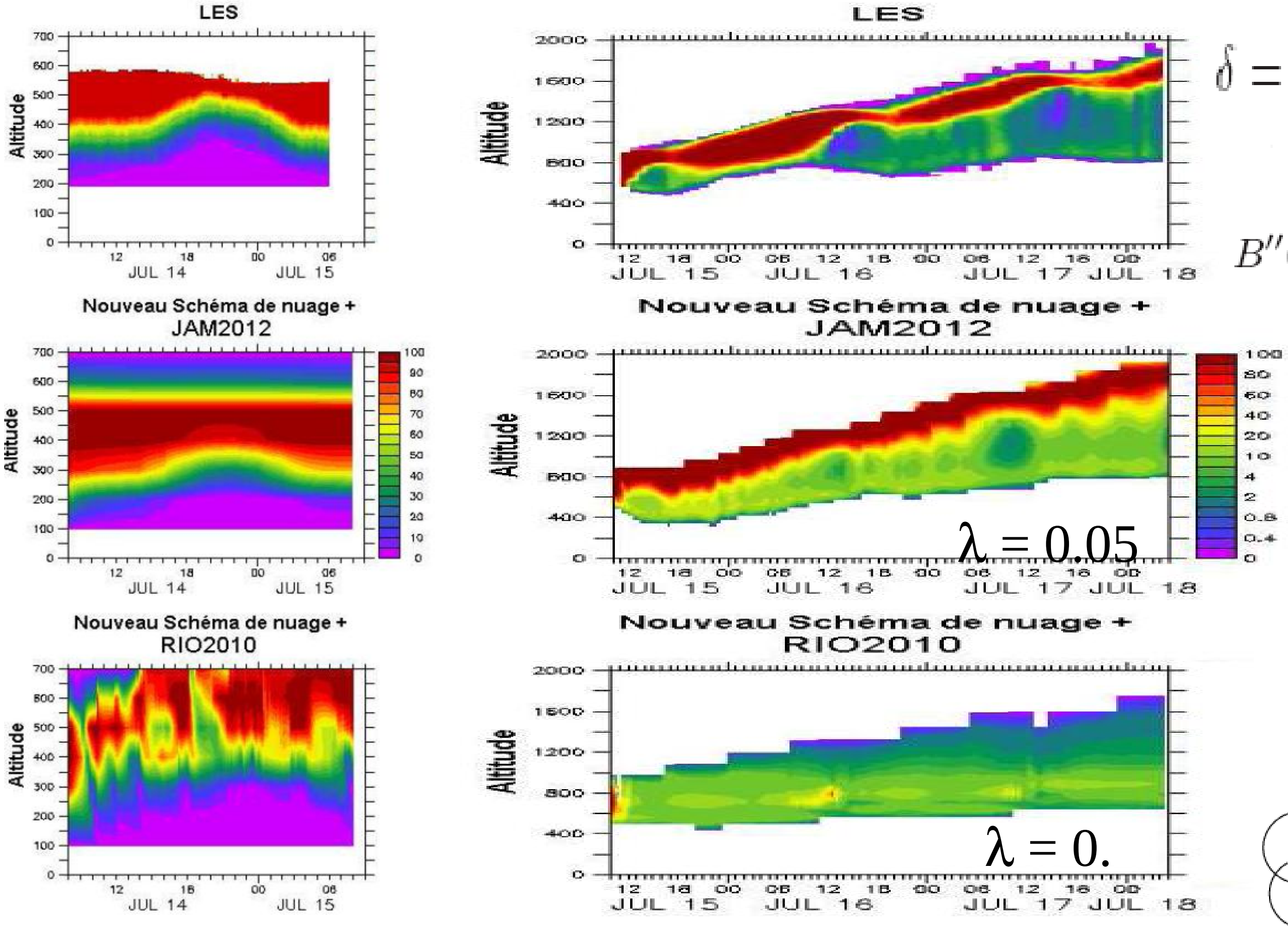




Improvement and tuning of strato-cumulus clouds



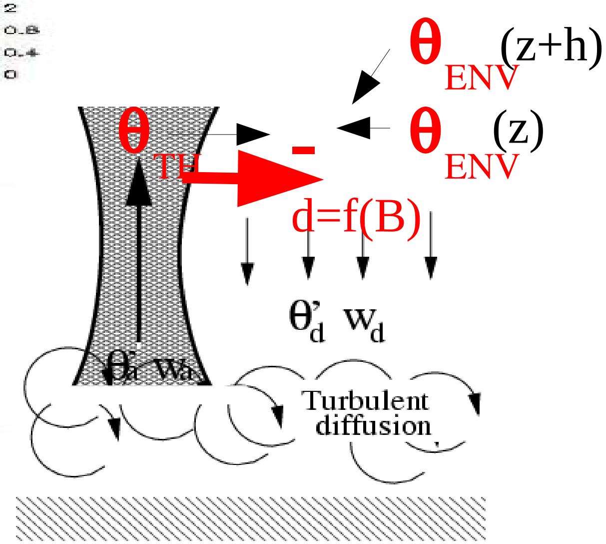
Modification du détrainement



$$\delta = max\left(0, -\frac{a_1\beta_1}{1+\beta_1}\frac{B''}{w_{th}^2} + c\left(\frac{\Delta q_t/q_t}{w_{th}^2}\right)^d\right)$$

$$B''(z) = g \times \frac{\theta_{v,th}(z) - \theta_{v,env}(z+h)}{\theta_{v,env}(z+h)}$$

$$h = \lambda \times z$$

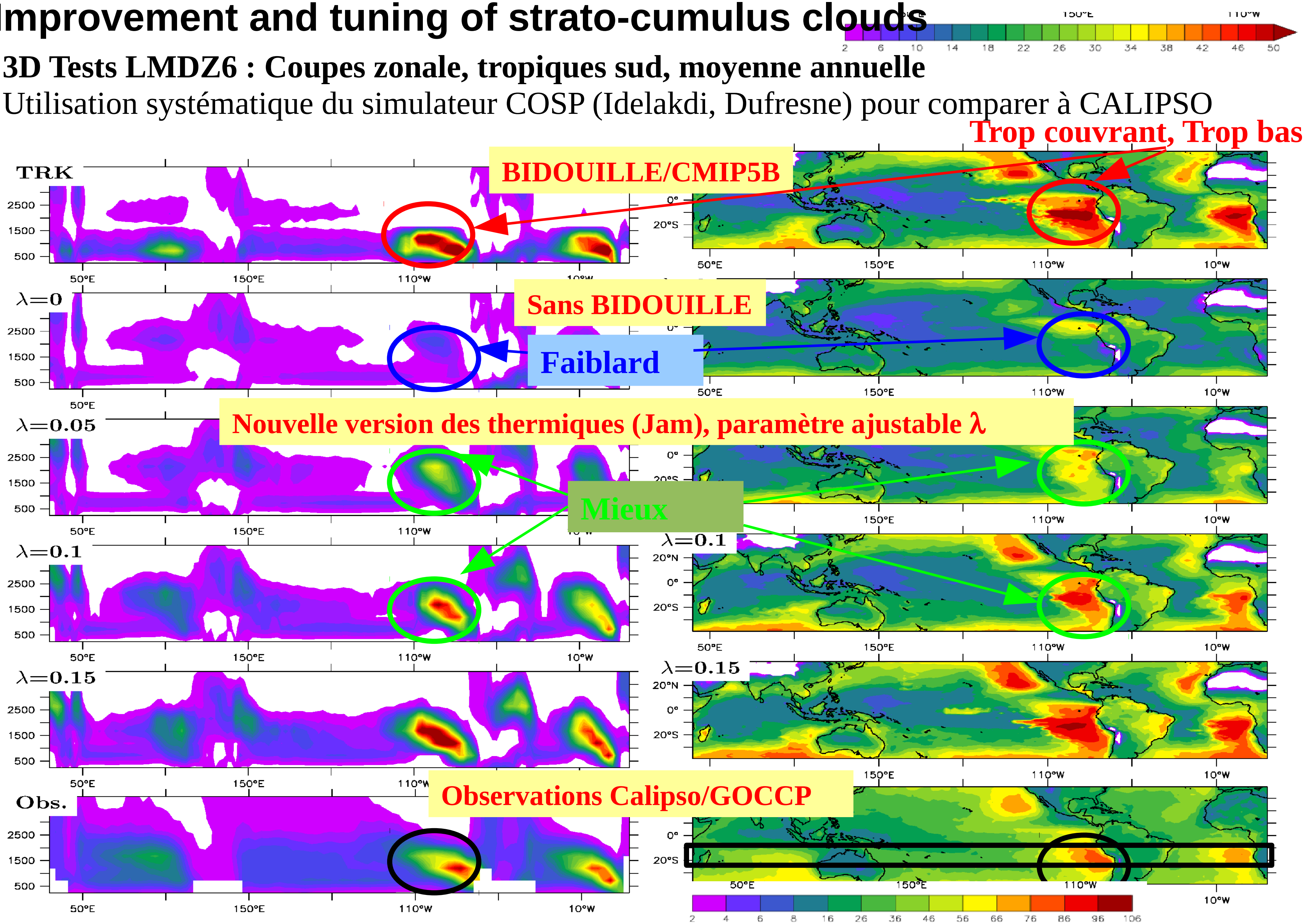


Thèse Arnaud Jam, Article quasi finalisé

Improvement and tuning of strato-cumulus clouds

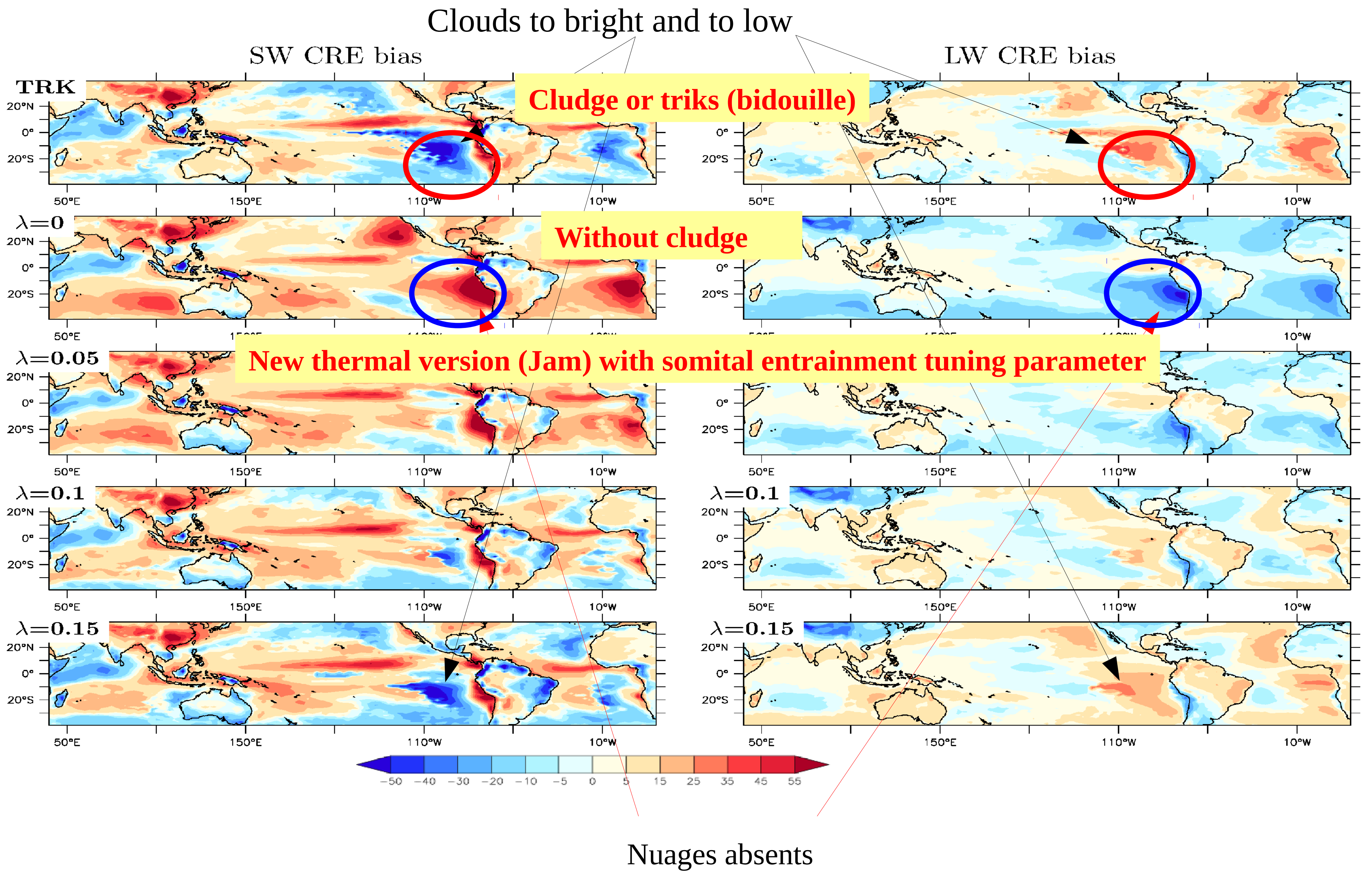
3D Tests LMDZ6 : Coupes zonale, tropiques sud, moyenne annuelle

Utilisation systématique du simulateur COSP (Idelakdi, Dufresne) pour comparer à CALIPSO



Improvement and tuning of strato-cumulus clouds

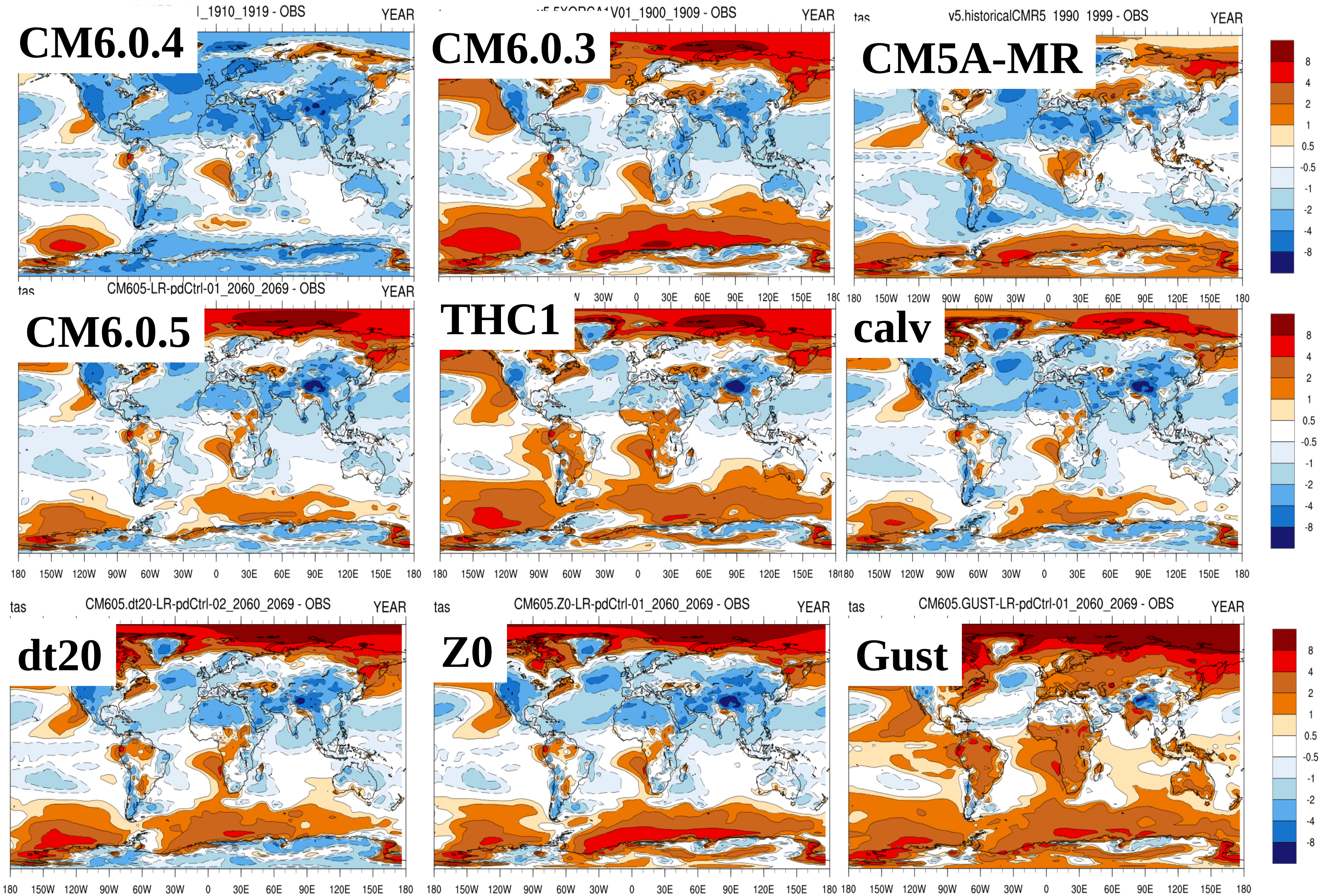
Impact on cloud radiative forcing (bias compared to EBAF)



6. Model development and tuning : b) tuning of free parameters

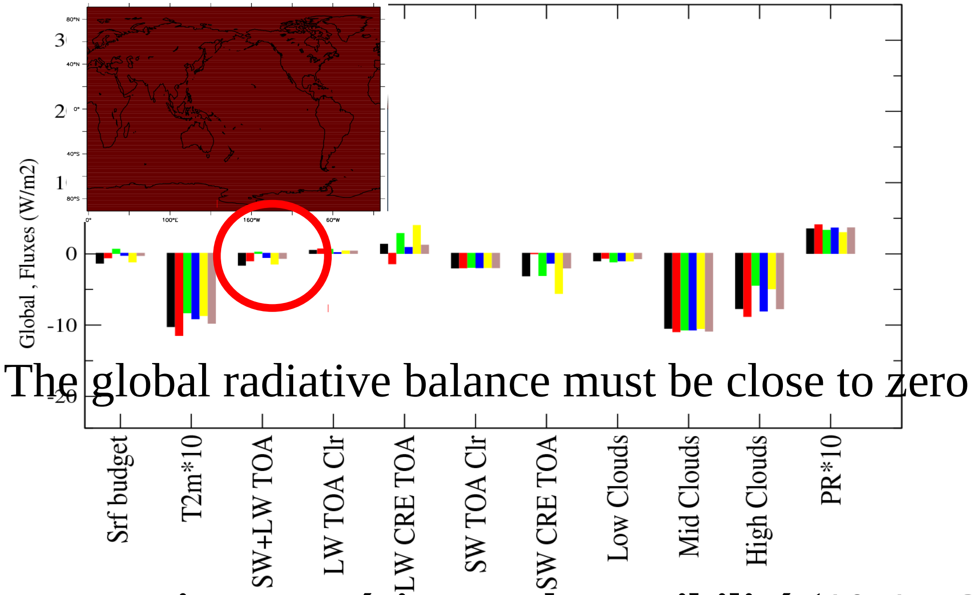
Preparation of IPSLCM6 : struggling with SST biases

In particular systematic biases : in partcular warm biases and Eastern tropical ocean

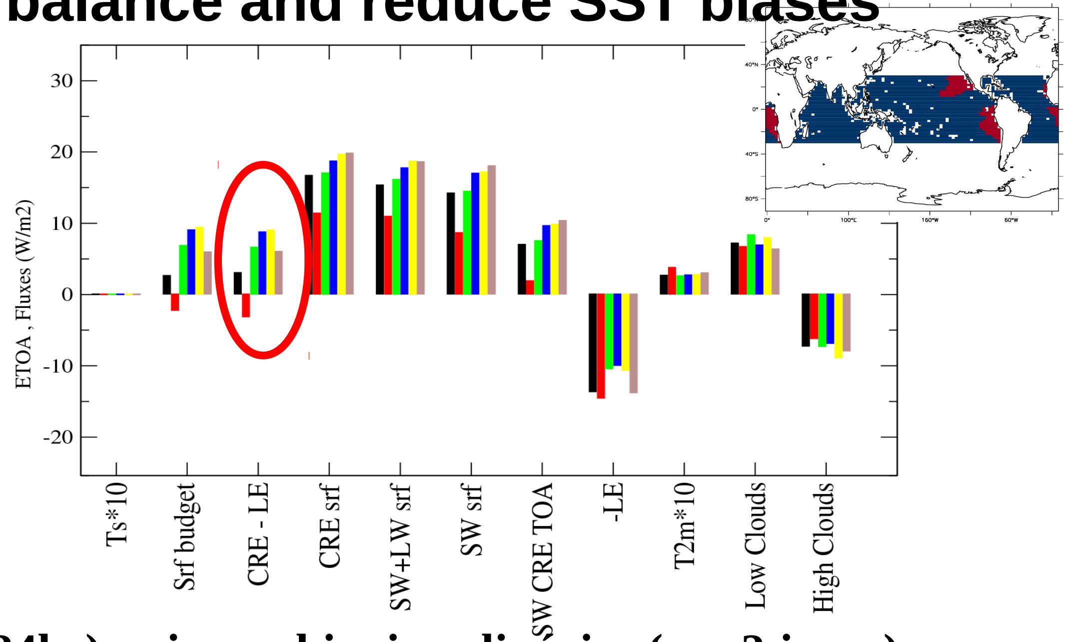


6. Model development and tuning : b) tuning of free parameters

Tuning strategy : reach a global balance and reduce SST biases

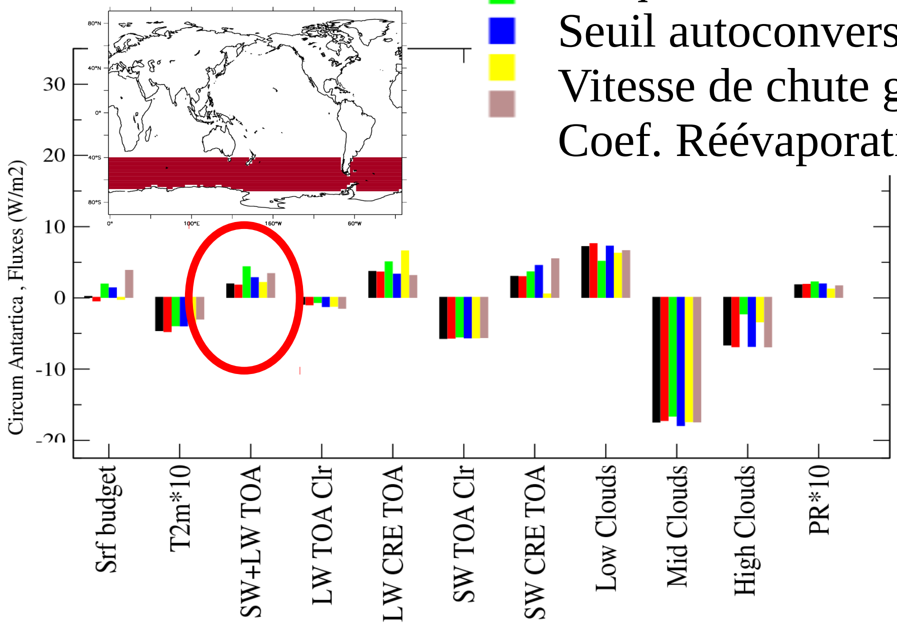


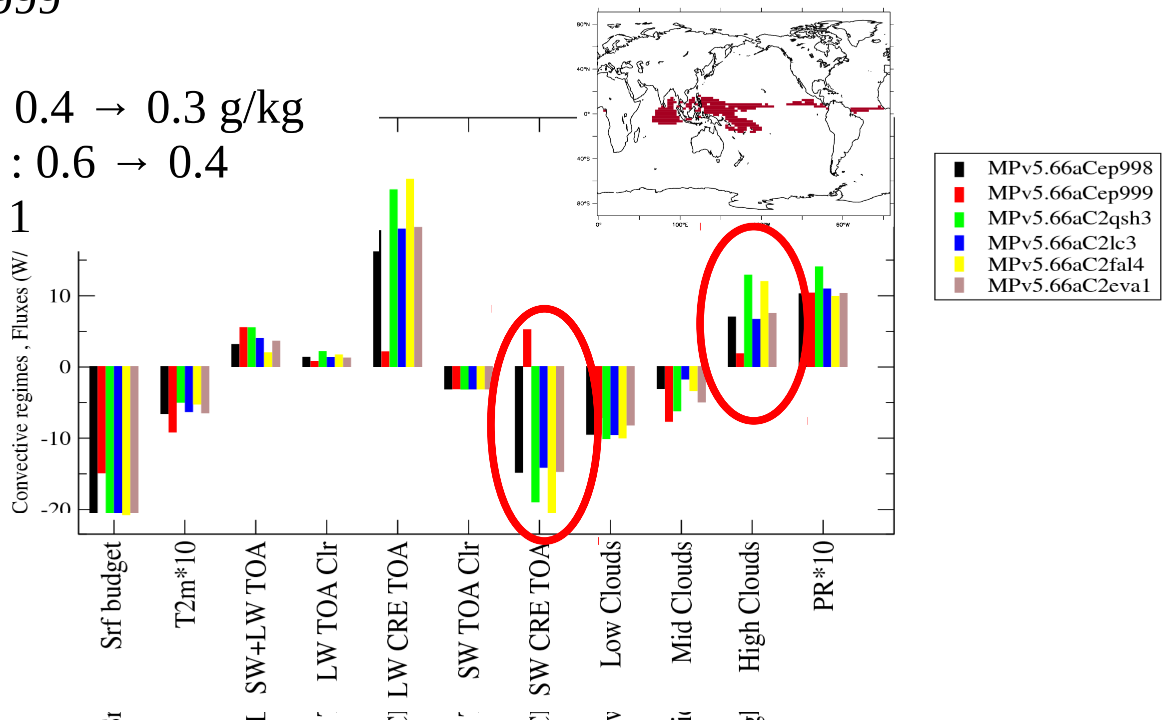
The global radiative balance must be close to zero



Tuning : expériences de sensibilité (10-15, 24hr) puis combinaison linéaire (sur 2 jours)

- EP max = 0.998 → 0.999
- Ratq haut= 0.4 → 0.3
- Seuil autoconversion : 0.4 → 0.3 g/kg
- Vitesse de chute glace : 0.6 → 0.4
- Coef. Réévaporation : 1





6. Model development and tuning : b) tuning of free 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	PDF for mixing	qqa1=1
qqa2=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

6. Model development and tuning : b) tuning of free parameters

LMDZ5A (AR4_physiq.def)		LMDZ5B (Npv3.1_physiq.def) (NPv5.3) 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=2
qqa1=0	PDF for mixing	qqa1=1
qqa2=1		qqa2=0
iflag_clw=1	Computation of condensate	iflag_clw=0
epmax=0.999	Efficiency of precipitation	Epmax=0.997 (0.97)
	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 (0.24)
		iflag_t_glace=1
cld_lc_lsc=4.16e-4	Threshold cloudy water LS	cld_lc_lsc=6e-4 (1.92e-4)
cld_lc_con=4.16e-4	Threshold cloudy water CV	cld_lc_con=6e-4(1.92e-4)
ffallv_lsc=0.5	Ice crystals fall speed LS	ffallv_lsc=1.35 (0.9504)
ffallv_con=0.5	Ice crystals fall speed CV	ffallv_con=1.35 (0.9504)
coef_eva=2e-5	Coefficient of evaporation	coef_eva=1e-4 (1e-5)

6. Model development and tuning : b) tuning of free parameters

LMDZ5A (AR4_physiq.def)		LMDZ5B (Npv3.1_physiq.def) (NPv5.70) 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
qqa1=0	PDF for mixing	qqa1=1
qqa2=1		qqa2=0
iflag_clw=1	Computation of condensate	iflag_clw=0
epmax=0.999	Efficiency of precipitation	Epmax=0.997 (0.999)
	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 (0.4)
		iflag_t_glace=2
cld_lc_lsc=4.16e-4	Threshold cloudy water LS	cld_lc_lsc=6e-4 (2e-4)
cld_lc_con=4.16e-4	Threshold cloudy water CV	cld_lc_con=6e-4(2e-4)
ffallv_lsc=0.5	Ice crystals fall speed LS	ffallv_lsc=1.35 (0.5)
ffallv_con=0.5	Ice crystals fall speed CV	ffallv_con=1.35 (0.5)
coef_eva=2e-5	Coefficient of evaporation	coef_eva=1e-4 (2e-4)

Concluding remarks / recommendations

recommendation when using LMDZ (or analyzing model results)

LMDZ is a flexible tool (3D, with or without nudging, 1D, coupled or not, aquaplanets, run on HPC computers or laptops, ...)

→ The model setup should depend on the question you want to address.

Try to use referenced configuration when possible

Don't forget that a model is defined by its grid configuration, physical content, tuning parameters, forcing files (aerosols, ozone, ...)

Don't forget the internal variability. Often underestimated.

Model evaluation (classical approach) :

→ Running long simulations or ensembles of them→ until you reach robust statistics : depends on the variable and question addressed

→ Compare observations and models in terms of statistics (taking into account that you have only one trajectory among other possible for observations)

Alternatives :

→ Run nudged simulations to get rid of chaos and have the meteorological trajectory in phase with the observed one. Then you can compare model and observation day-by-day. Of course you can not evaluate the large scale circulation itself which is imposed

→ Using 1D simulations for parameterization development and evaluation

Concluding remarks / recommendations

Importance of tuning

A parameterization or a model : Grid configuration + set of equations + tuning

→ Tuning parameters are often uncertain and even not observables
→ Tuning is often seen as a dirty part of modeling. It is a misunderstanding !!!!
→ Tuning is an intrinsic and very important aspect of climate modeling.
→ Especially the tuning of the energetics of atmospheric models
→ Tuning should be considered when intercomparing models (if parts of the models use a particular metrics for tuning for instance)

Tuned versions are available for LMDZ : LMDZ5A, 5B, and the pre-6 versions, 5.3, 5.4, 5.5, 5.6, 5.7
Tuning could/should be revisited if the model is significantly modified for an application

Classical approach for tuning :

→ Run a series of sensitivity experiments
→ Summarize the skill and deficiencies as a series of metrics or numbers.
→ Choose a satisfactory set of parameters values « by hands »
→ Limited by the number of parameters that you can explore and by the brain of the scientists who try to make the choice from sensitivity experiments.

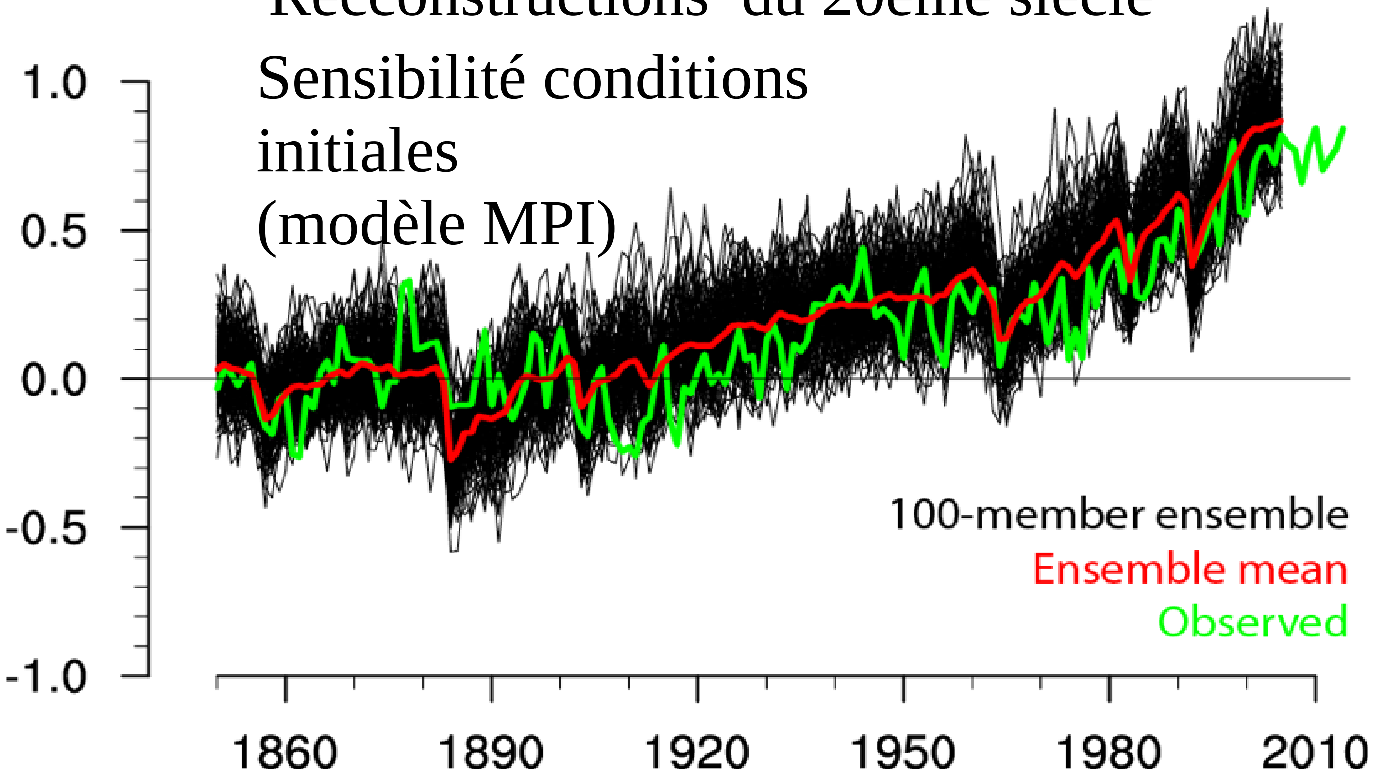
Coming soon :

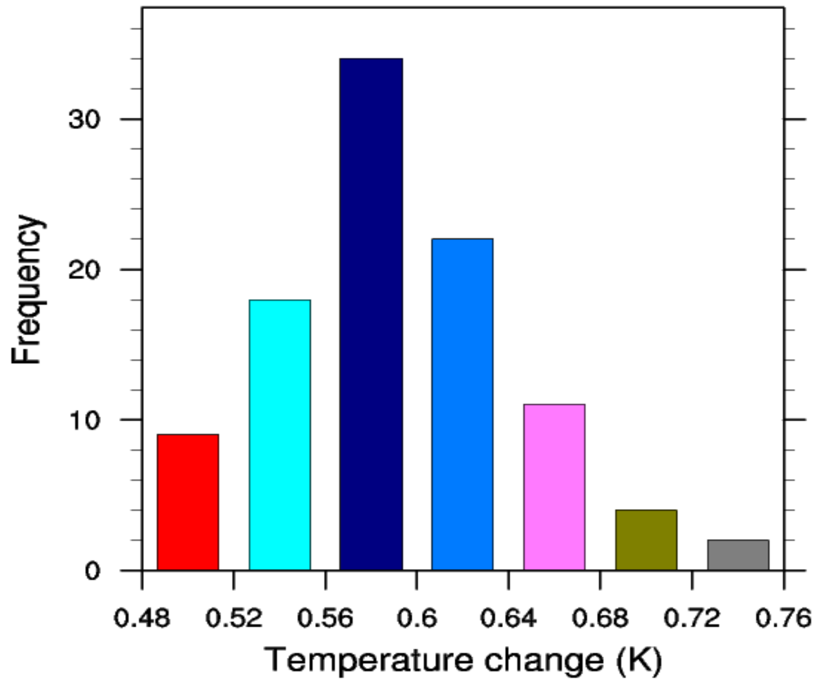
→ Run a series of simulations with a subset of parameter values and use meta-models or emulators to produce the metrics in parameter values which were not explored.
→ apply so called objective methods

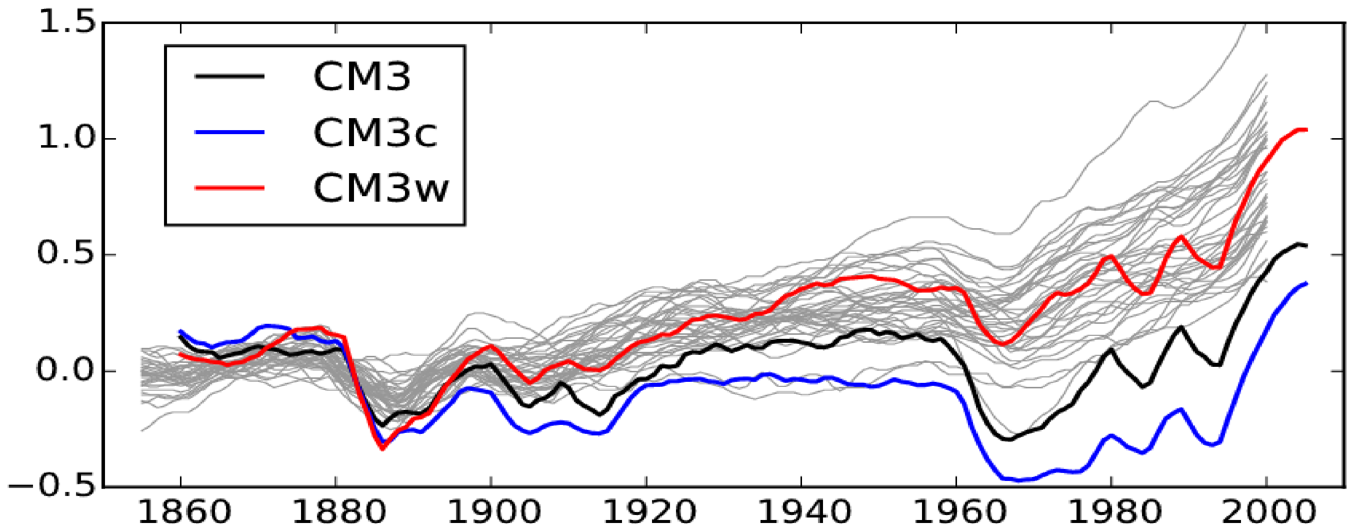
6. Model development and tuning : b) tuning of free parameters

Recconstructions du 20eme siècle

Sensibilité conditions
initiales
(modèle MPI)







Effet du tuning
Modèle du GFDL

Concluding remarks / recommandations

Approche classique :

On effectue des simulations longues ou ensembles de simulations
→ statistiques robustes pour le modèle
→ On compare ces statistiques aux observations (pour lesquelles on ne dispose que d'une seule réalisation).
→ On peut résumer la différence aux observations à un ensemble de métriques (qui peuvent dépendre du but assigné au modèle).
→ On effectue des simulations de sensibilité à des paramètres incertains.
→ On choisit des jeux de paramètres plus favorables.
→ Emergence de méthodes automatiques et « objectives » (met le choix des objectifs est toujours subjectif)

Mais système couplé, chaotique, variable à toutes les échelles de temps et d'espace.
Nécessite des jeux d'observations très complets (spatial et temporel)

Strengths and weaknesses of the different physical packages of LMDZ

Catherine Rio
LMDZ Development Team

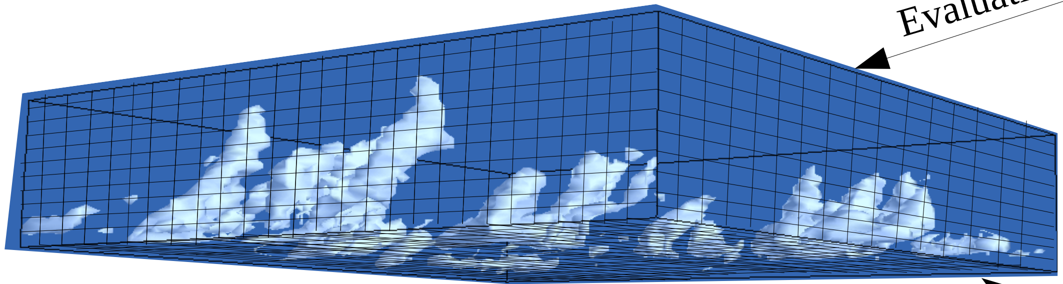
LMDZ training course – 7/8/9 December 2015 – LMD Jussieu

I.2 Cloud process studies and the use of high resolution explicit models0

Test case, field campaign experiment

Observation

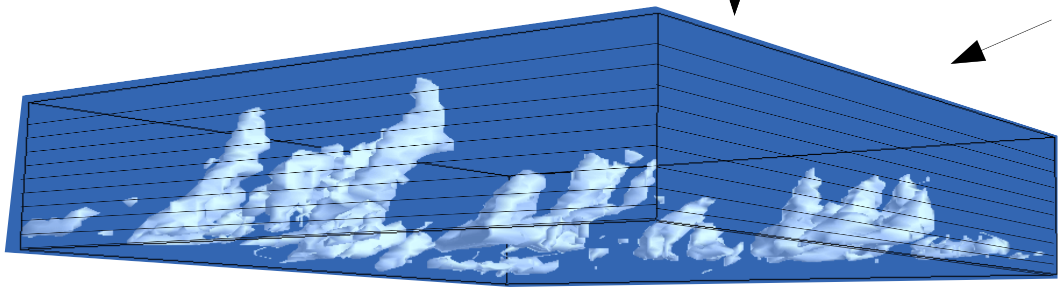
Evaluation

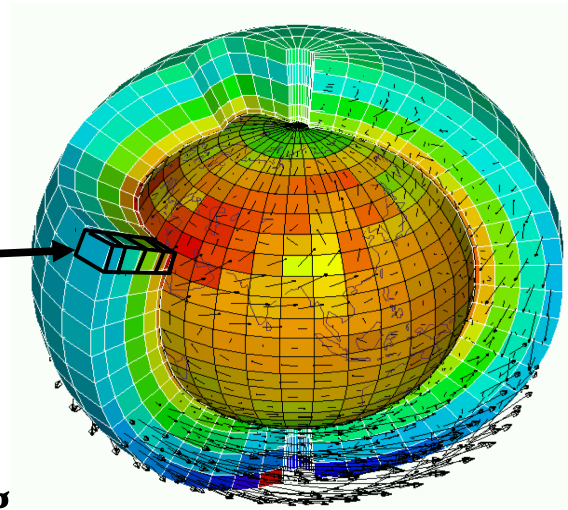


Explicit simulations, Grid cell, 20-100 m

Evaluation

« Large scale » conditions imposed





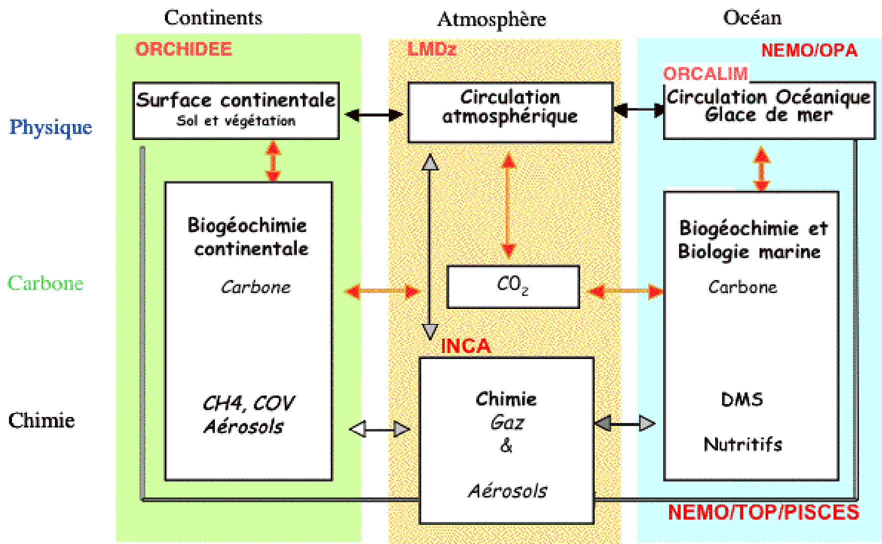
Climate model, parameterizations, « single-column » mode

→ **Parameterizations are evaluated against other models**

→ **Can be done for realistic test cases but also with more idealized forcing (check the response of the parameterization to perturbations)**

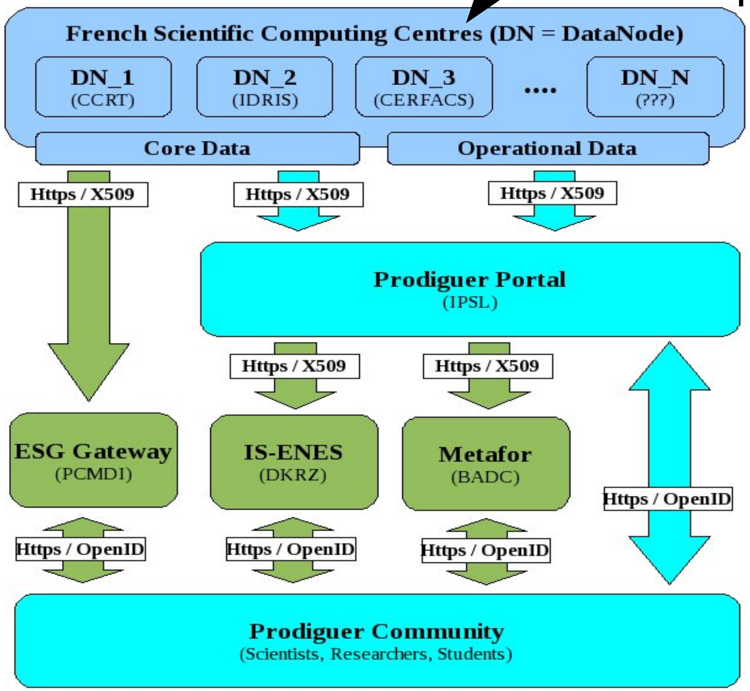
5. Intercomparison exercises and reference configurations : a) CMIP exercises

Participation to Coupled Model Intercomparison Project : CMIP

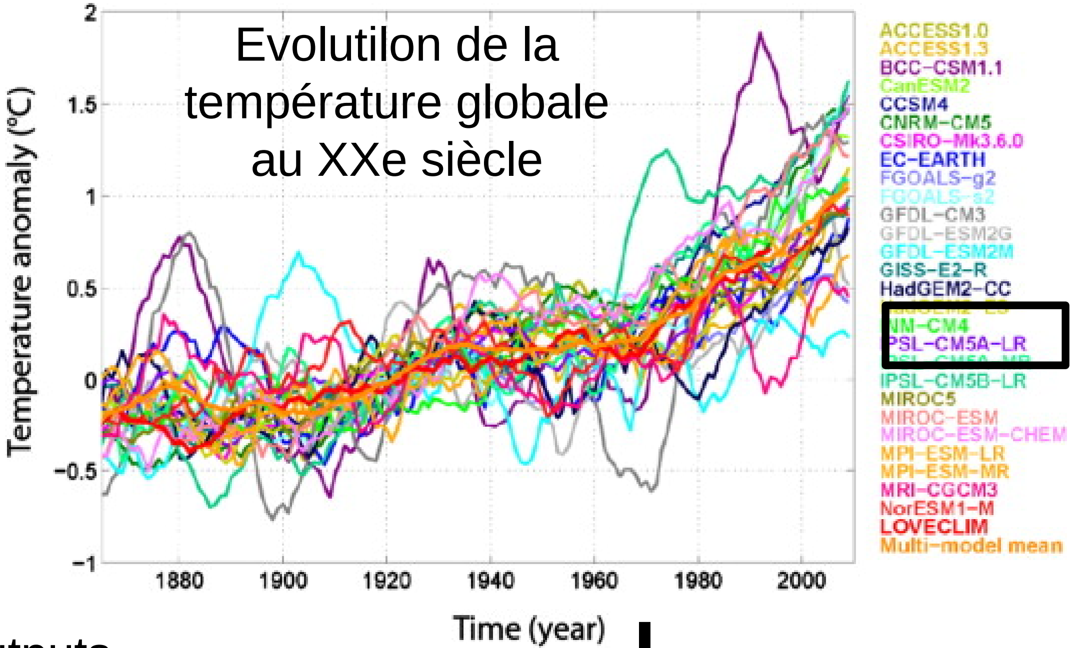


IPSL Earth System Model
=
Physical component (océan/atm/hydro)
LMDZ/NEMO/Orchidee
+
Cycle (CO2, bio-chemistry, aérosols)

Simulations
On computer centers



Result analysis (500 publis in 2 years)

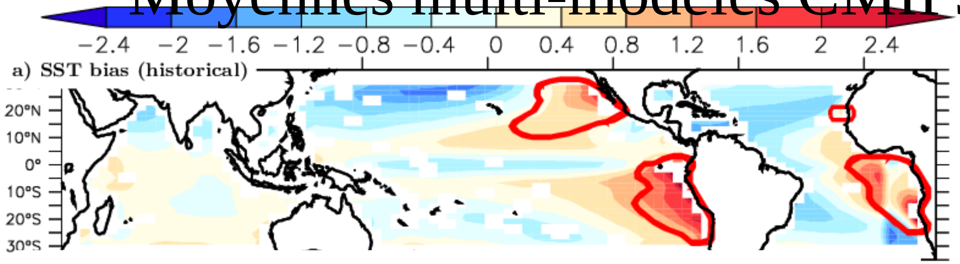


Model outputs
Distributed openly
ICM DATA / ISIS

IPCC Assessment Reports

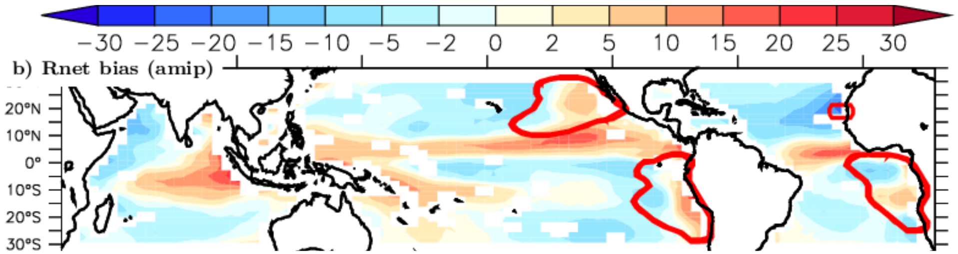
II – Origine atmosphérique des biais de SST

Moyennes multi-modèles CMIP5

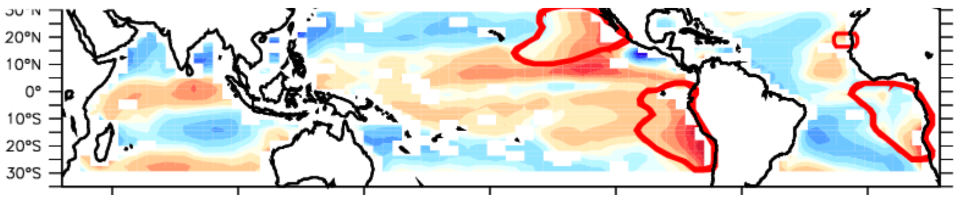


Biais de SST multi-modèle (K), en couplé

SST couplées



Biais radiatif multi-modèle (W/m2), en forcé



Biais Latent multi-modèle (W/m2), en forcé

Flux forcés

F. Hourdin, A. Gunaisa-Bogdan, P. Braconnot, J.-L. Dufresne, A.-K. Traore and C. Rio, 2016, GRLw

General remarks

1. LMDZ is a flexible tools

2. For climate studies, a few reference configurations are defined which include, a long phase of tuning and evaluation.

3. The reference simulations are widely published, documented, distributed on LMDZ site or from CMIP database.

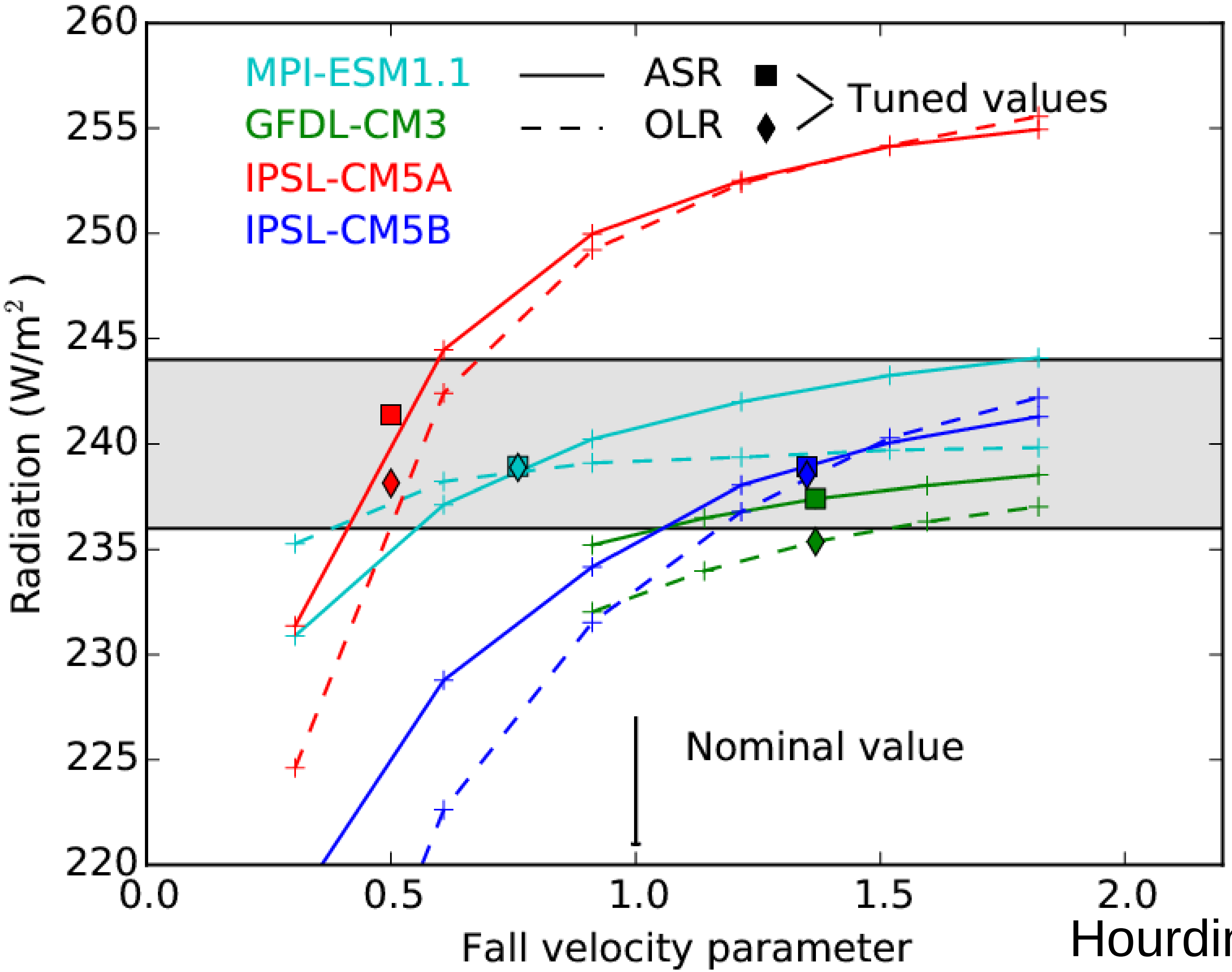
4. LMDZ shows some systematic biases as well as specific ones (part of which are linked to the rather coarse horizontal grid), and also some specific skills.

5. Climate models can not be ran as a black box.

6. Any study with such a model requires a phase of specific evaluation for the specific goals of the study

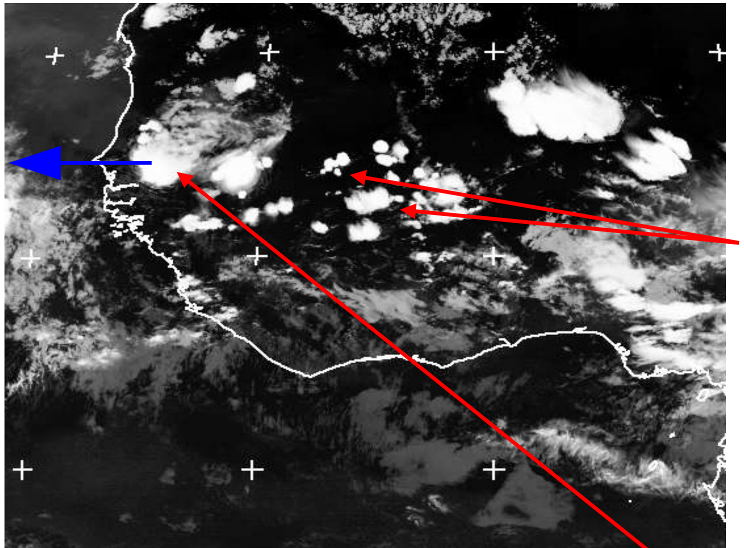
6. Model development and tuning : b) tuning of free parameters

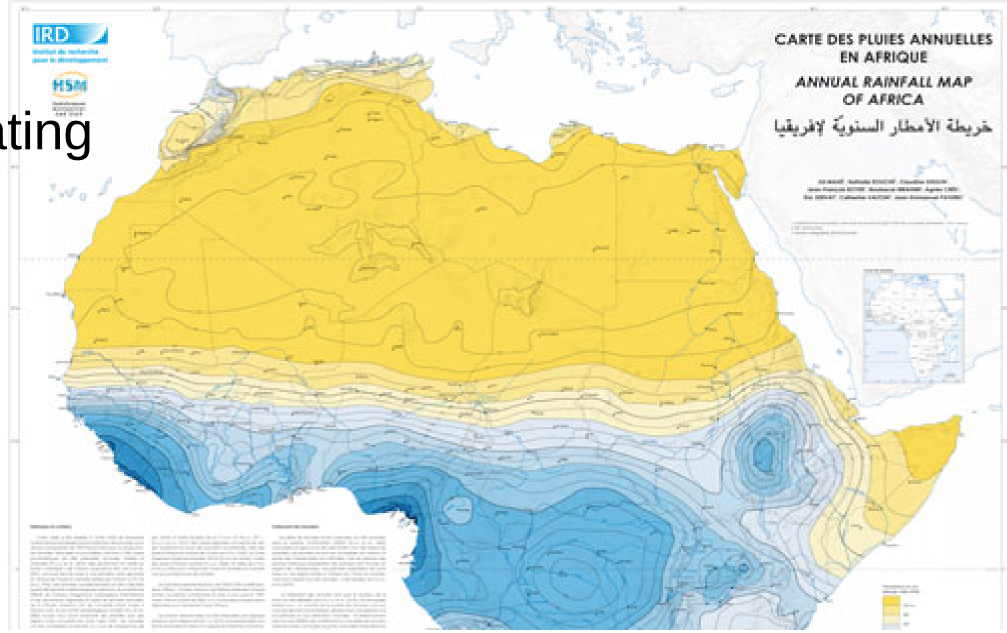
Tuning of a factor on the fall velocity on ice particles in 3 CMIP-class models
Several W/m² for the global balance at Top of Atmosphere

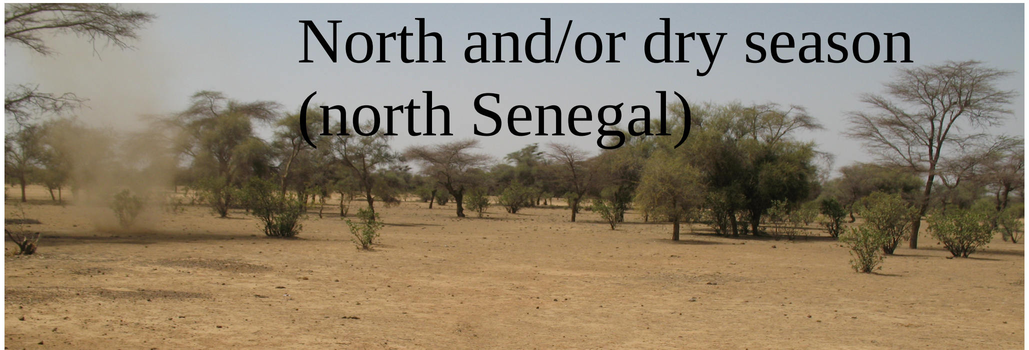


Hourdin et al 2016, BAMS

Monsoon rainfall : multi-scale
Local thunderstorms to squall lines, propagating
Locally : raining one hour each 3 day
Cumulated rainfall much more uniform







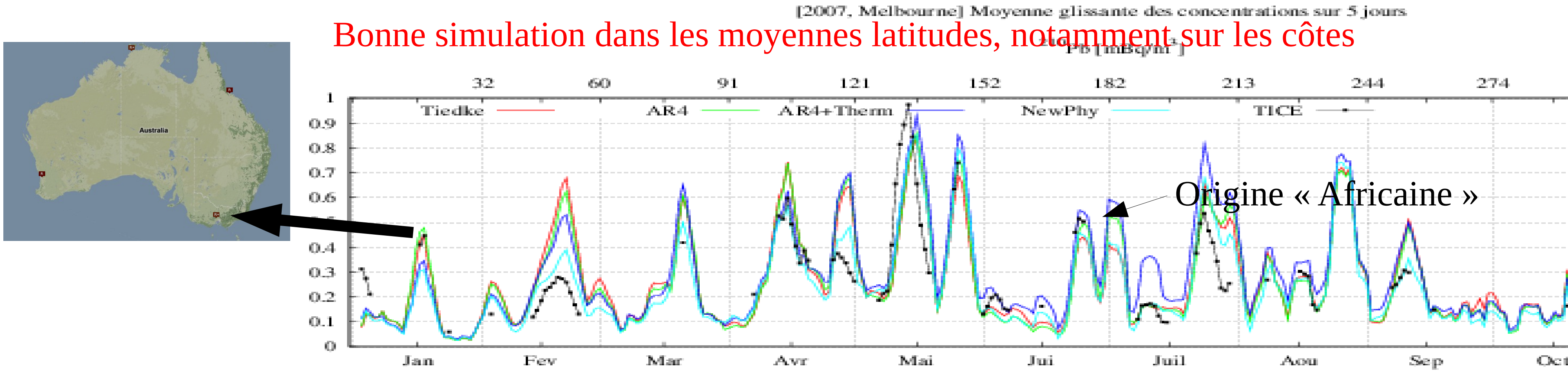
Local
•storms

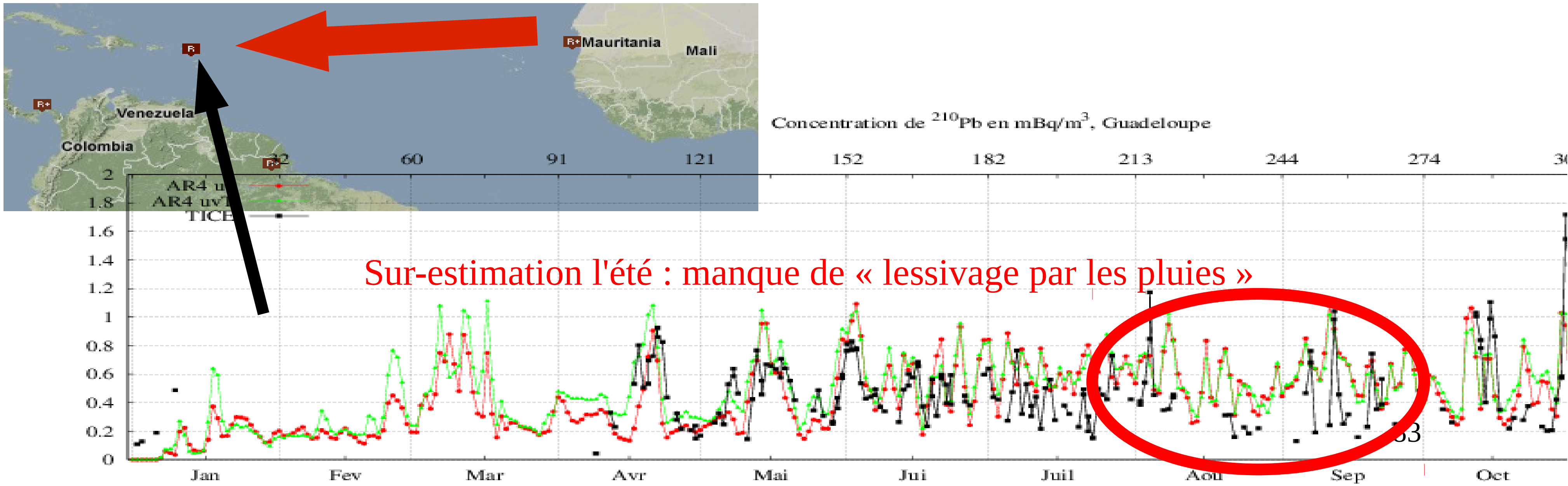
Squall
•lines

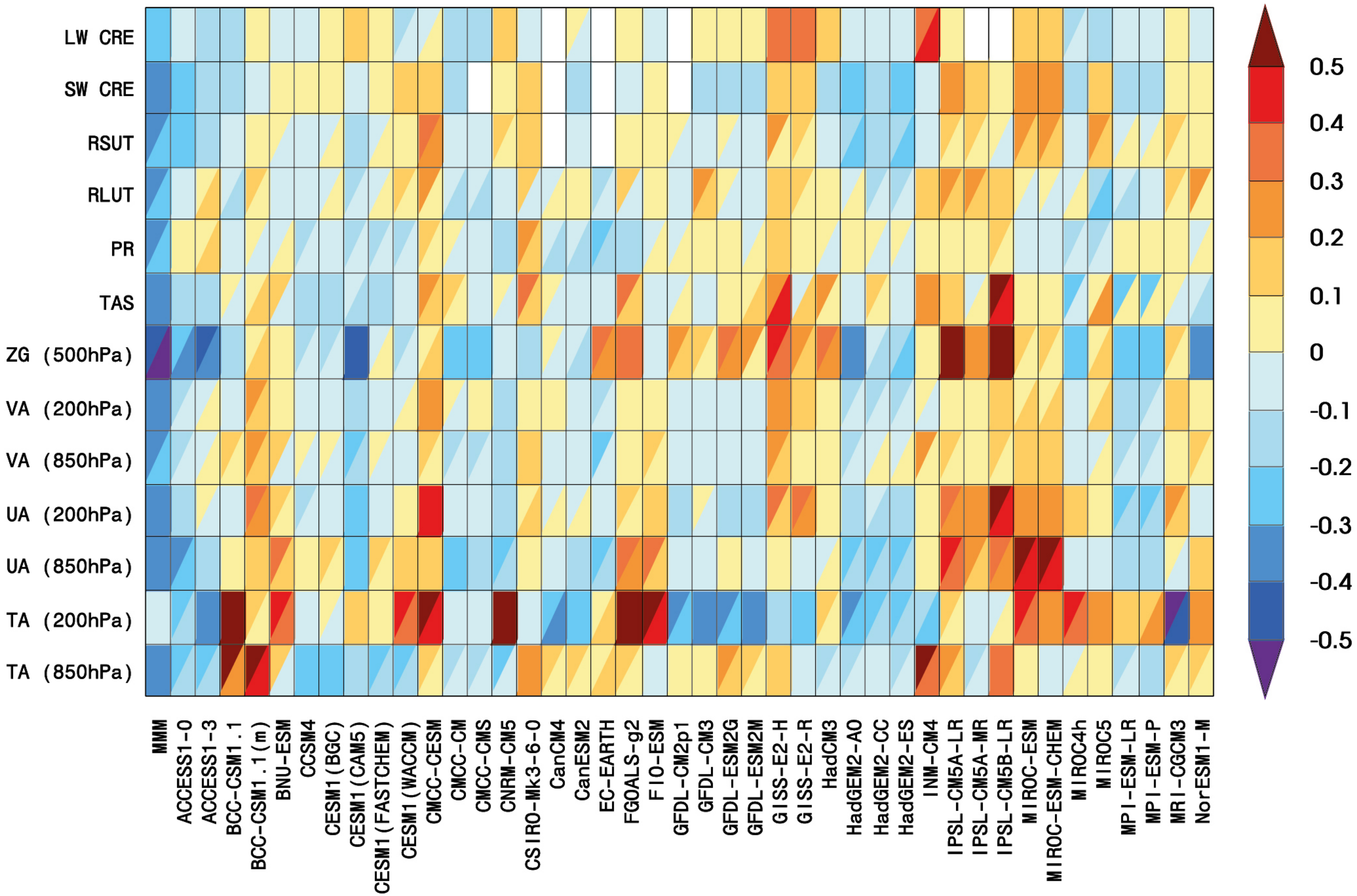
Validation des simulations de transport sur les données du TICE

Radio-éléments naturels. Ici le PB210, produit du radon émis par les continents.

Philippe Heinrich et Anthony Jamelot






LW CRE
SW CRE
RSUT
RLUT
PR
TAS
ZG (500hPa)
VA (200hPa)
VA (850hPa)
UA (200hPa)
UA (850hPa)
TA (200hPa)
TA (850hPa)
MMM
ACCESS1-0
ACCESS1-3
BCC-CSM1.1
BCC-CSM1.1(m)
BNU-ESM
CCSM4
CESM1(BGC)
CESM1(CAM5)
CESM1(FASTCHEM)
CESM1(WACCM)
CMCC-CESM
CMCC-CM
CMCC-CMS
CNRM-CM5
CSIRO-Mk3-6-0
CanCM4
CanESM2
EC-EARTH
FGOALS-g2
FIO-ESM
GFDL-CM2p1
GFDL-CM3
GFDL-ESM2G
GFDL-ESM2M
GISS-E2-H
GISS-E2-R
HadCM3
HadGEM2-AO
HadGEM2-CC
HadGEM2-ES
INM-CM4
IPSL-CM5A-LR
IPSL-CM5A-MR
IPSL-CM5B-LR
MIROC-ESM
MIROC-ESM-CHEM
MIROC4h
MIROC5
MPI-ESM-LR
MPI-ESM-P
MRI-CGCM3
NorESM1-M
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5

Une variabilité intra-saisonnière … pitoyable, mais ...

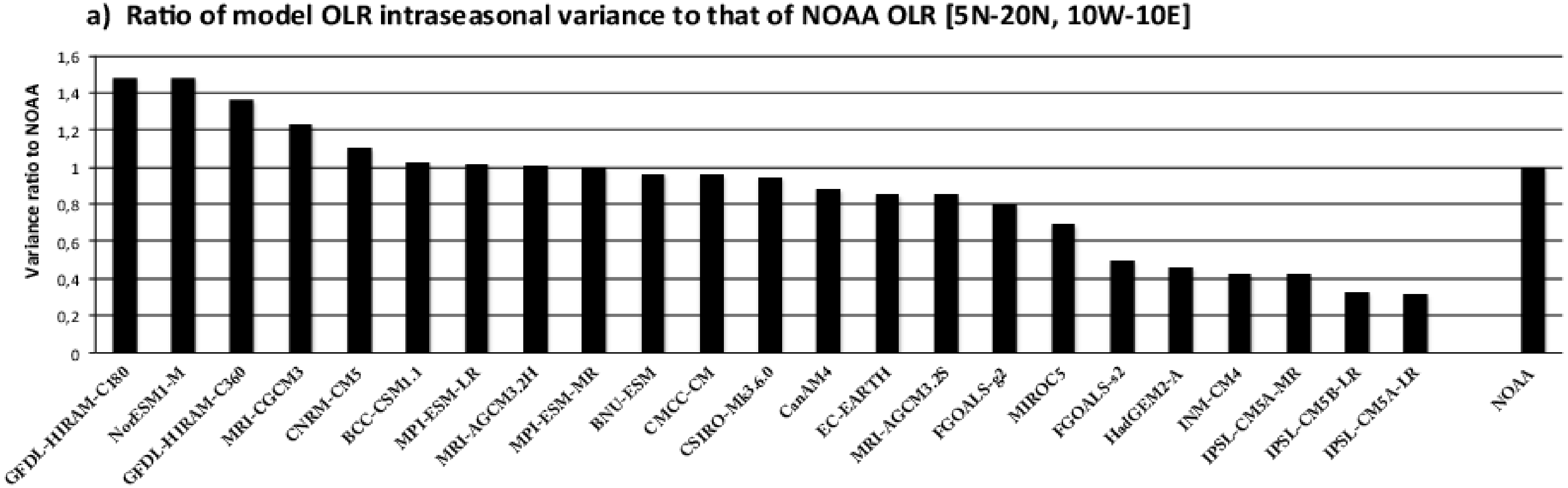
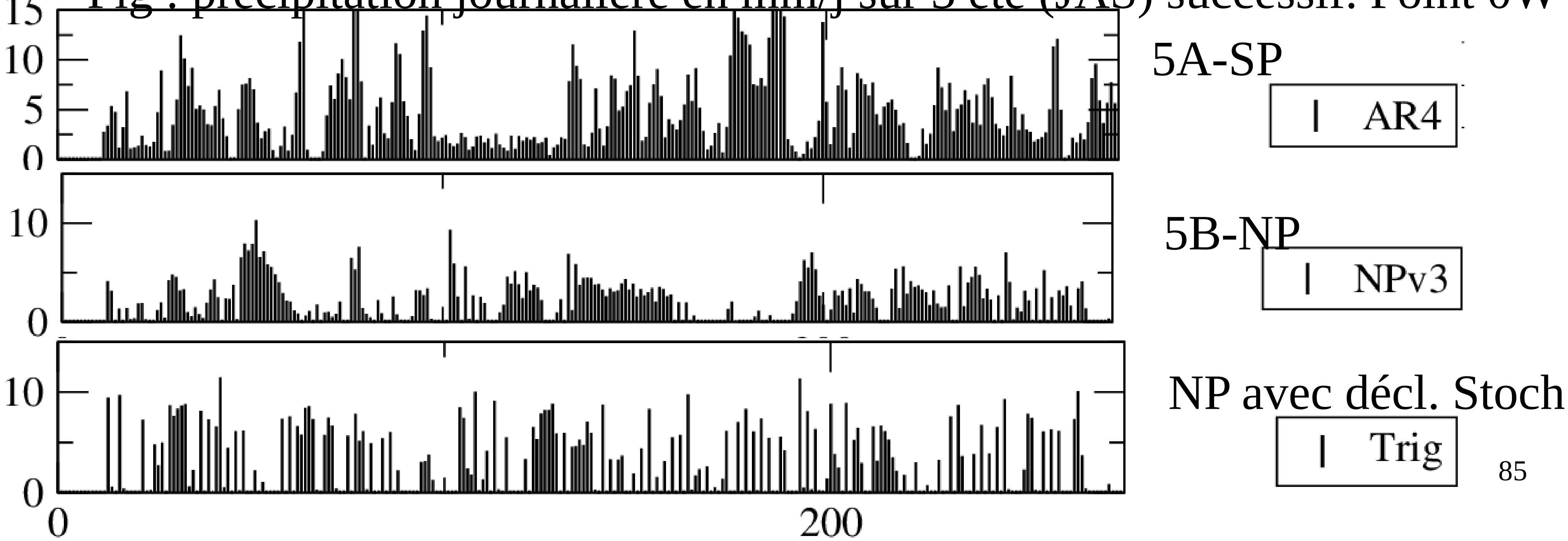


Fig : précipitation journalière en mm/j sur 3 été (JAS) successif. Point 0W-13N



Utilisation de simulations guidées ou initialisées

On élimine le chaos en forçant la trajectoire météo à suivre la trajectoire observée. Permet de travailler sur les paramétrisations physique à situation synoptique connue, et de comparer au jour le jour a des données insitu.

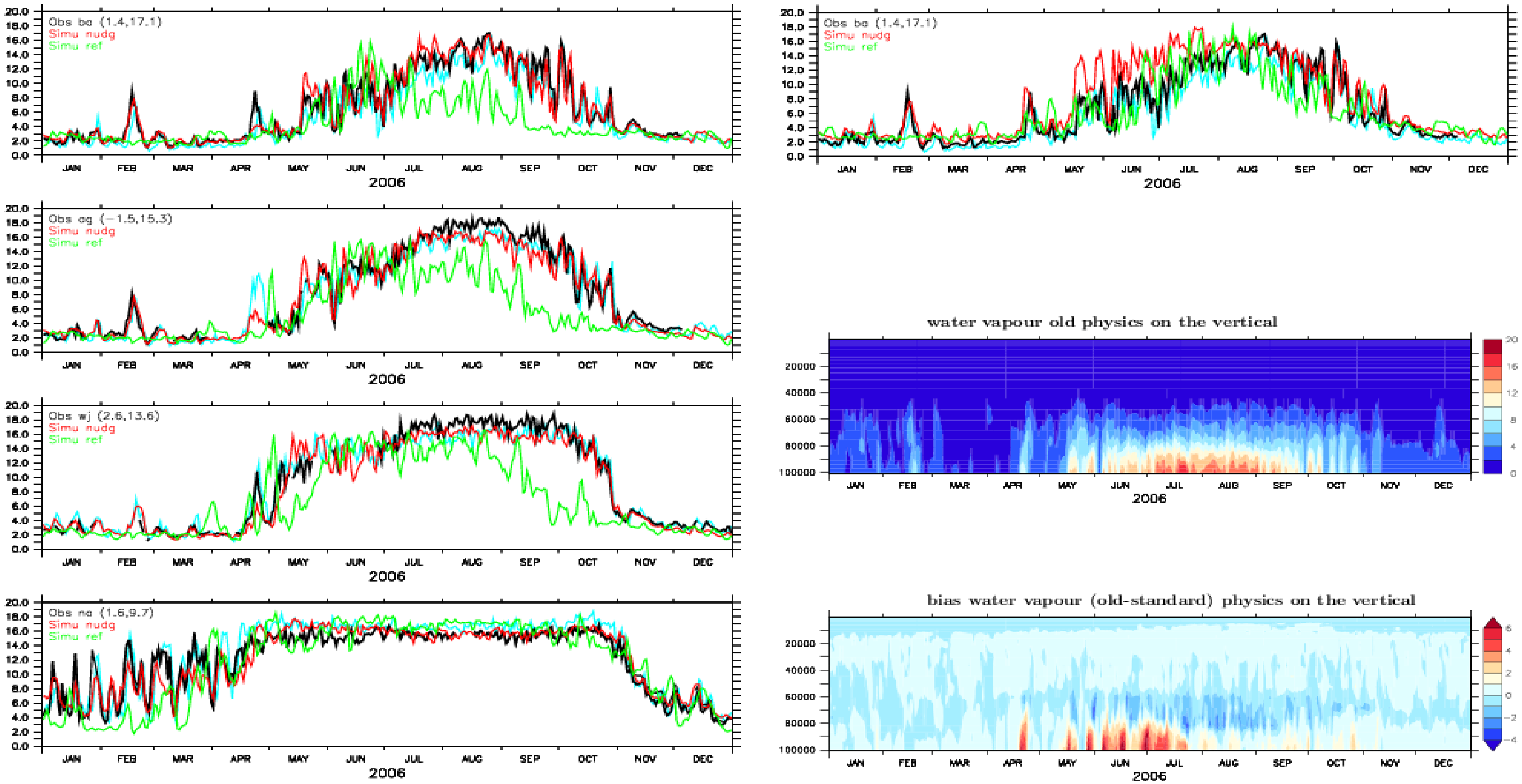
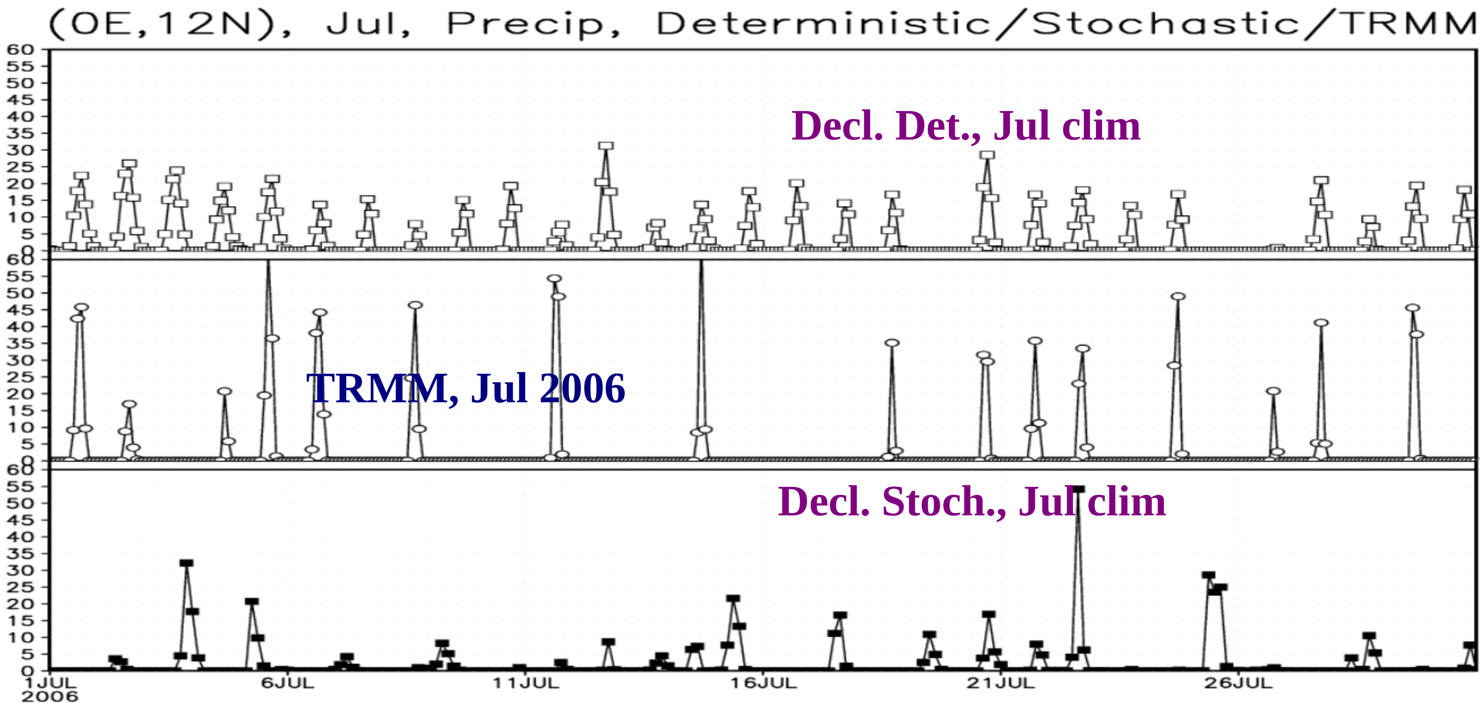


Figure 3: 1^{st} column 1 top-down : evolution of specific humidity at 2 meters in 2006, Top-down:Bamba , Agoufou (1.5 W, 15.3N), Wankama (2.6E, 13.6N) Bira(1.7E, 9.8N) and Nahohoulou(1.6E, 9.7N) with addition Bira (1.7E, 9.8N) .local Observations (black), ERAI(blue bright) nudged simulation(red), reference simulations (green).column 2, top-down : evolution of specific humidity at 2 meters and precipitable water, old physic and difference between old and standard in Bamba (1.4E, 17.1N) in 2006 . 2^{nd}

Nouveau déclenchement :
On demande en plus que la surface d'un thermique soit plus grande qu'une taille critique Sc
Modèle du thermique → distribution de taille des thermiqes → tirage aléatoire

Si on met un seuil fixe sur la probabilité d'avoir un nuage plus grand que Sc, et dans des conditions assez homogènes, on se retrouve à déclencher beaucoup plus pour des mailles plus petites



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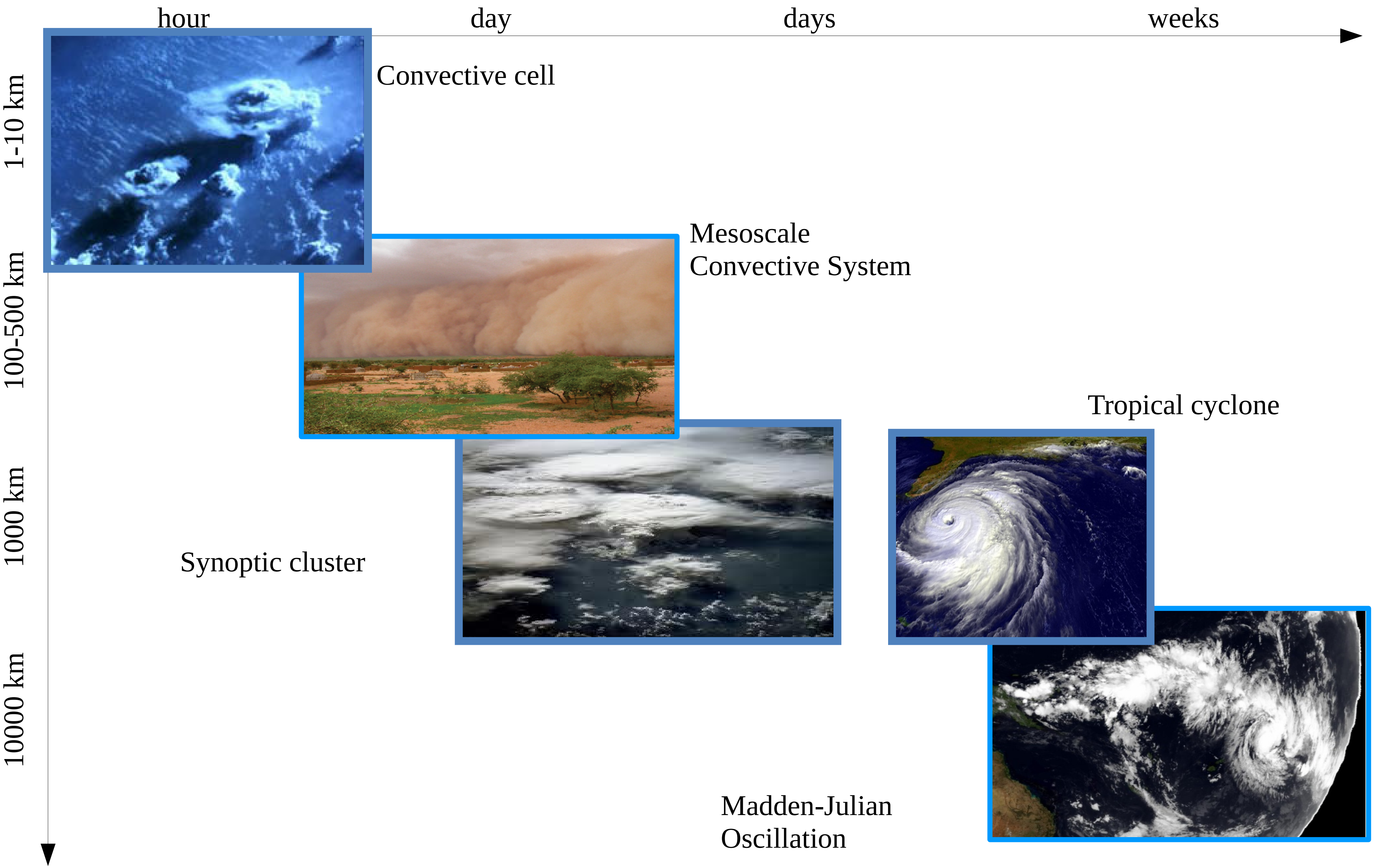
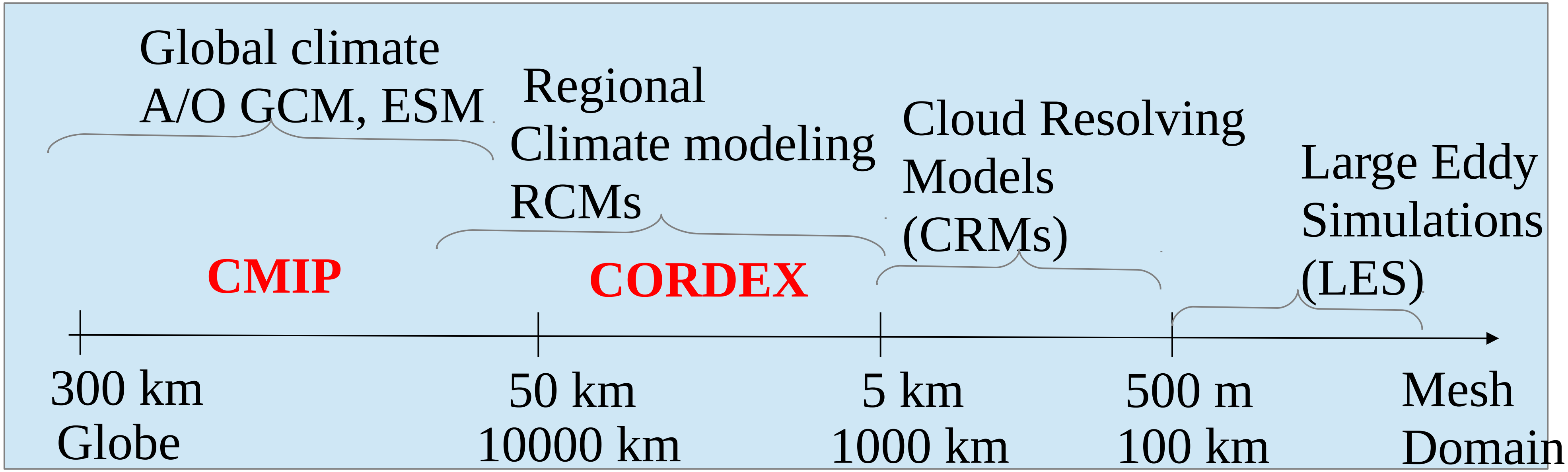
Les paramétrisations des modèles de climat

1. Introduction et principes des paramétrisations
2. Un aperçu des questions de la modélisation du transfert radiatif
3. Décomposition de Reynolds et fermetures en diffusion turbulente
4. Couche limite convective
5. Convection / échelles / zone grises
6. Les modèles et leur utilisation

6. Les modèles et leur utilisation - 6.2 Questions d'échelles

Spatial and temporal scales of convection: a challenge for models





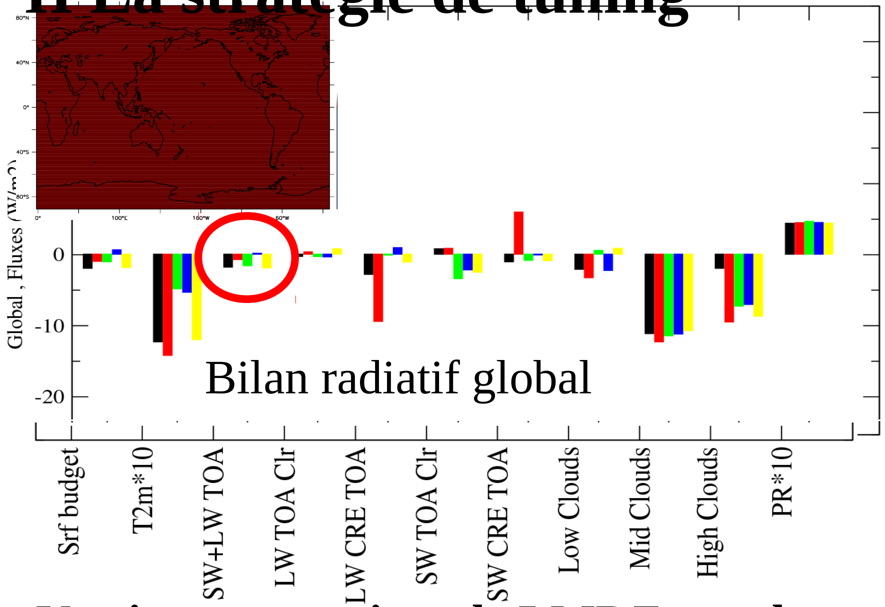
Parameterized convection
Subrid scale clouds, poor microphysics
Climate studies (CMIP)

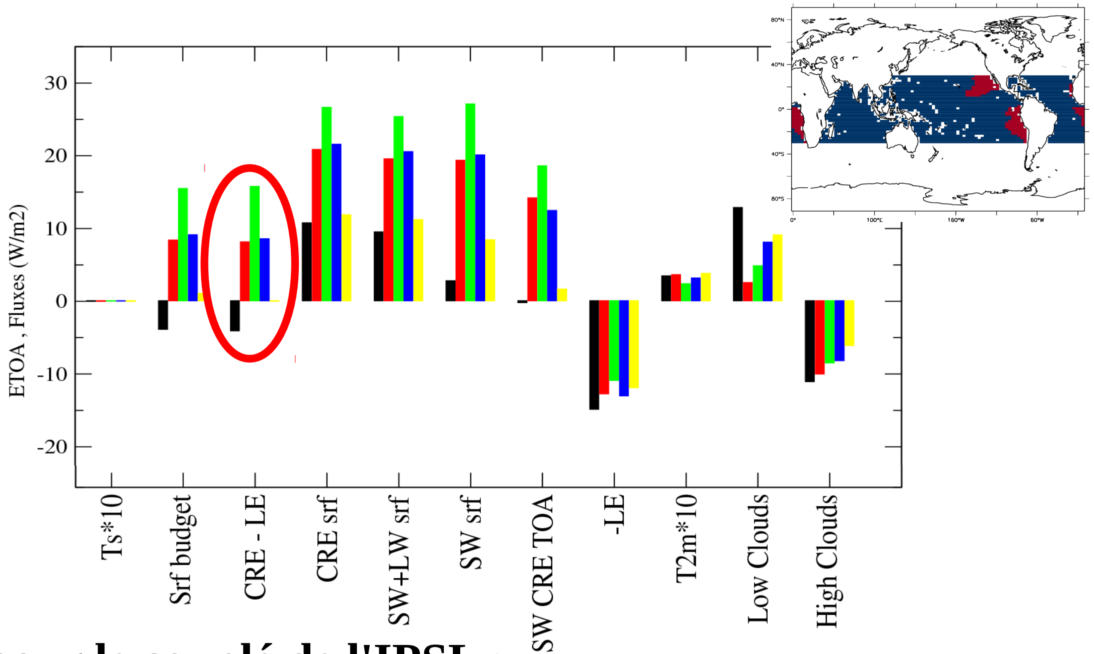
Explicit convection
1/0 clouds, sophisticated microphysics
Process studies (GASS)

Zone grise convection

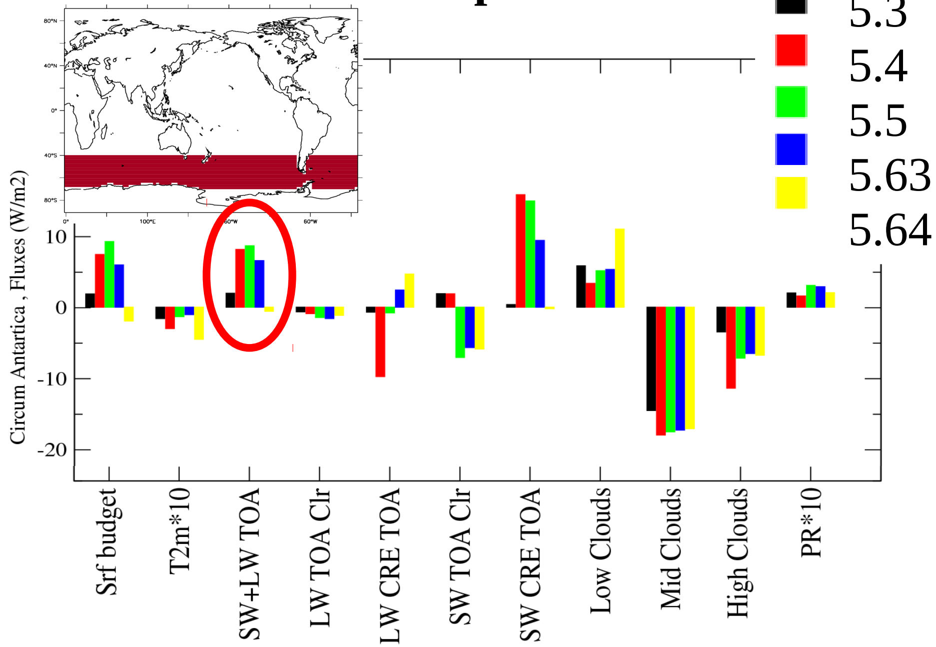
Zone grise couche limite

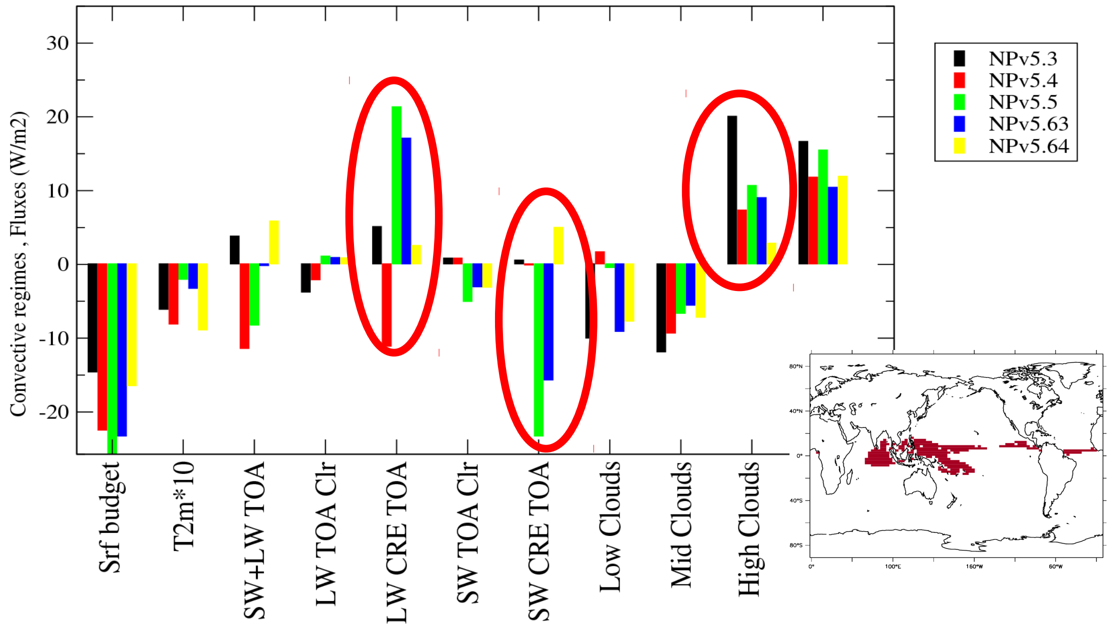
II La stratégie de tuning



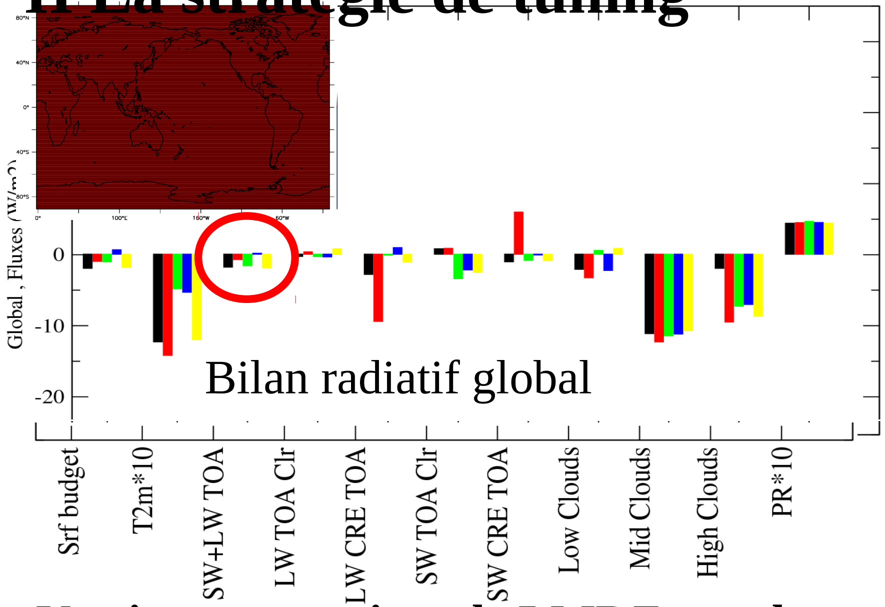


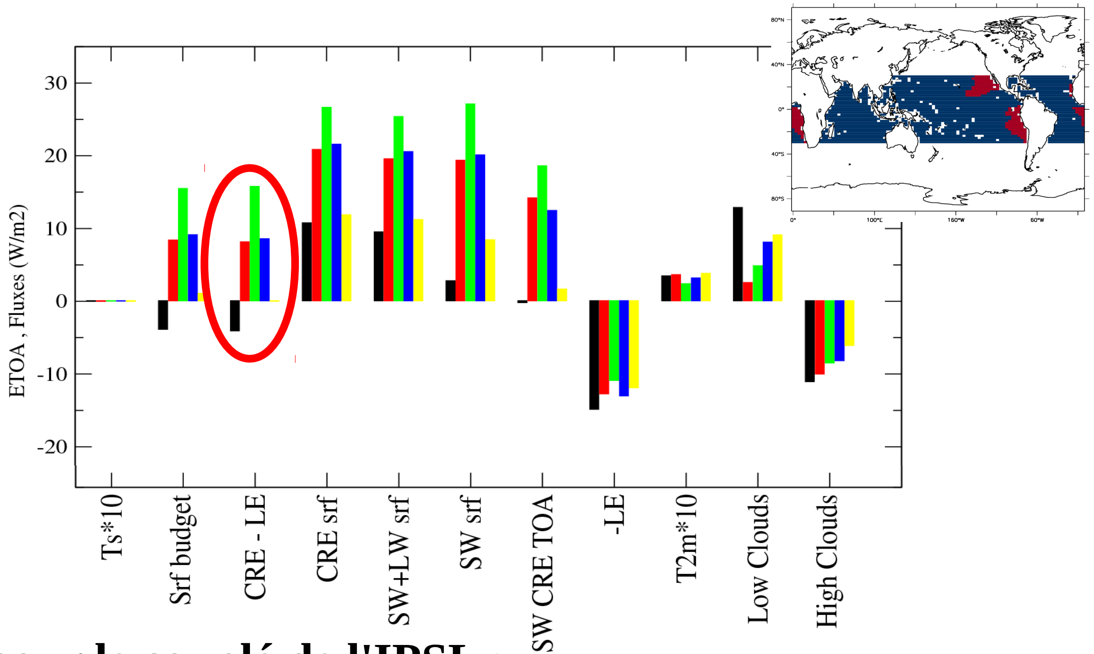
Versions successives de LMDZ tous les mois pour le couplé de l'IPSL :
1/ nouveaux choix ou paramétrisations suivi 2/ d'un ajustement (15 jours = 3 x 2 jours)





II La stratégie de tuning





Versions successives de LMDZ tous les mois pour le couplé de l'IPSL :
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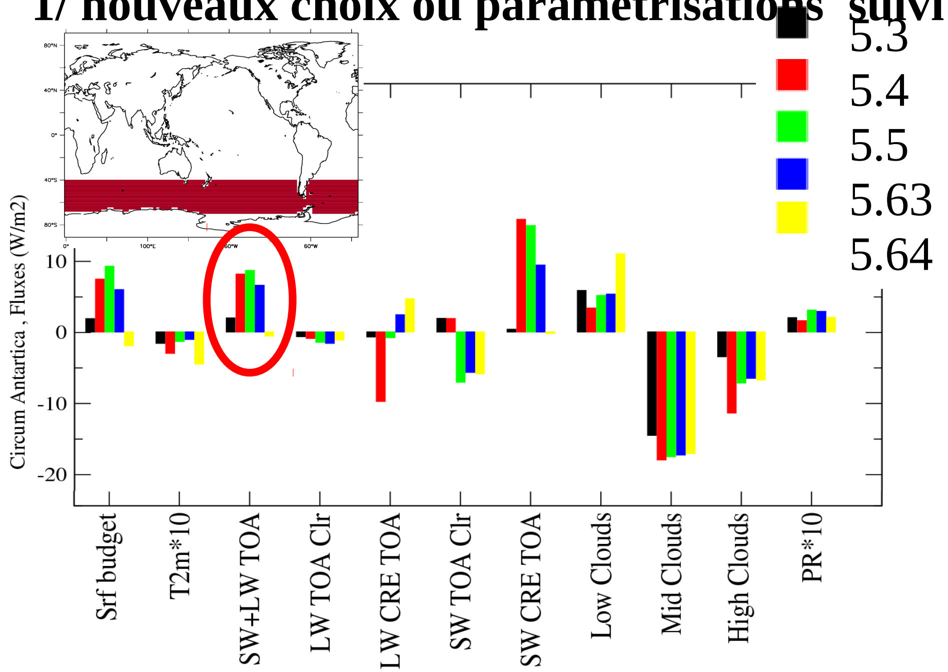
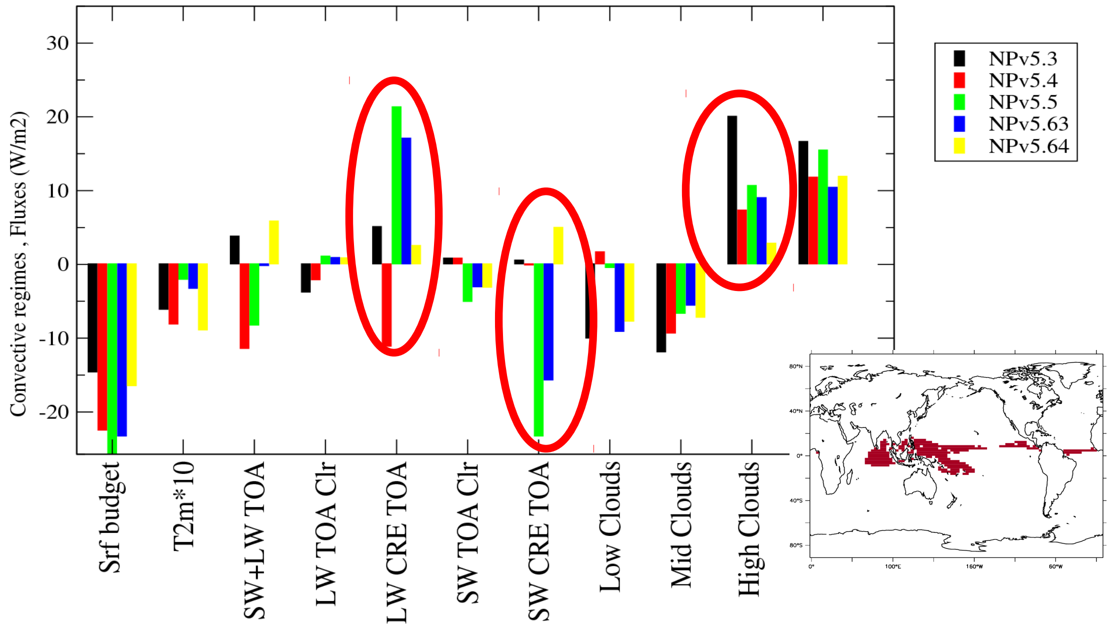
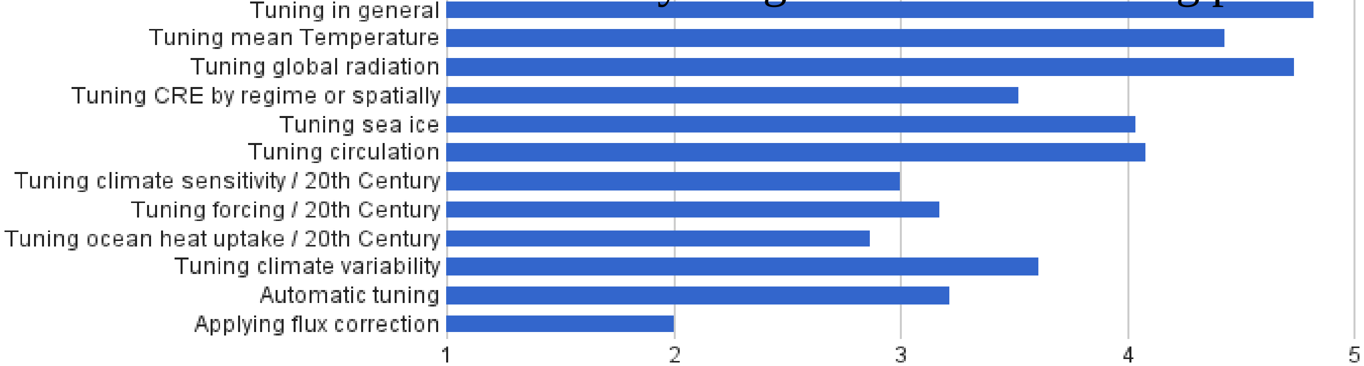
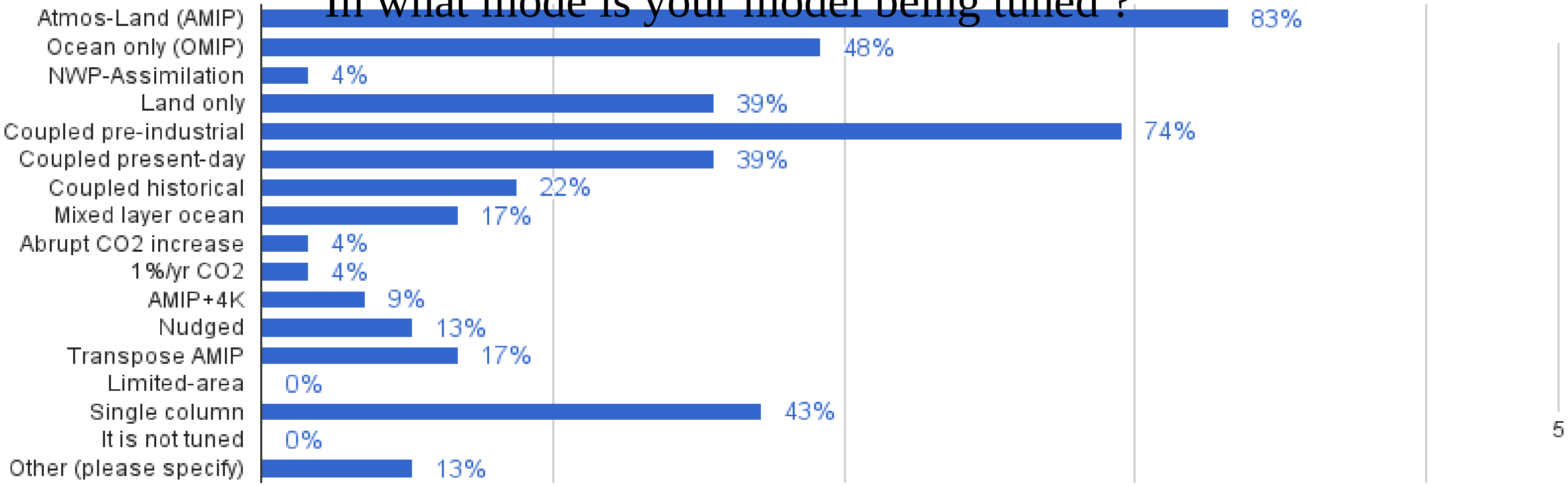




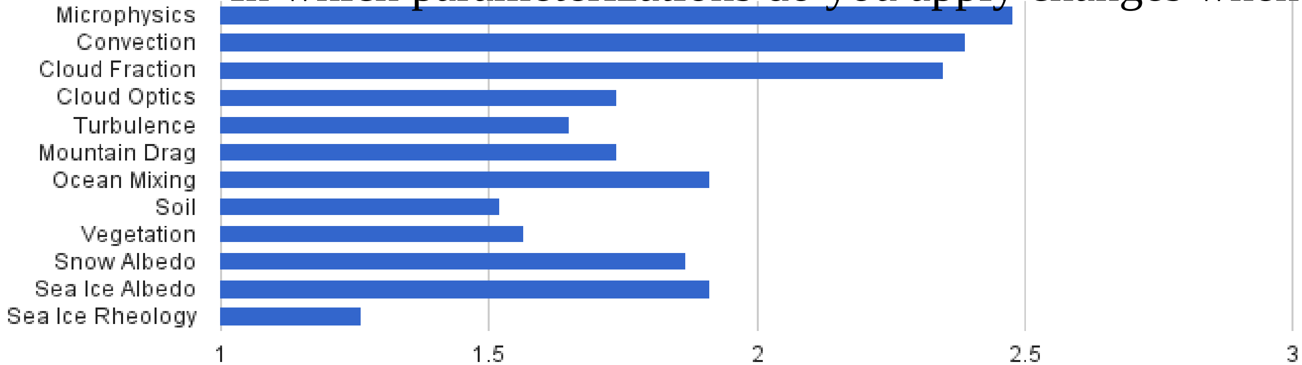
Please evaluate weather you agree that the following practices are eligible ?



In what mode is your model being tuned ?

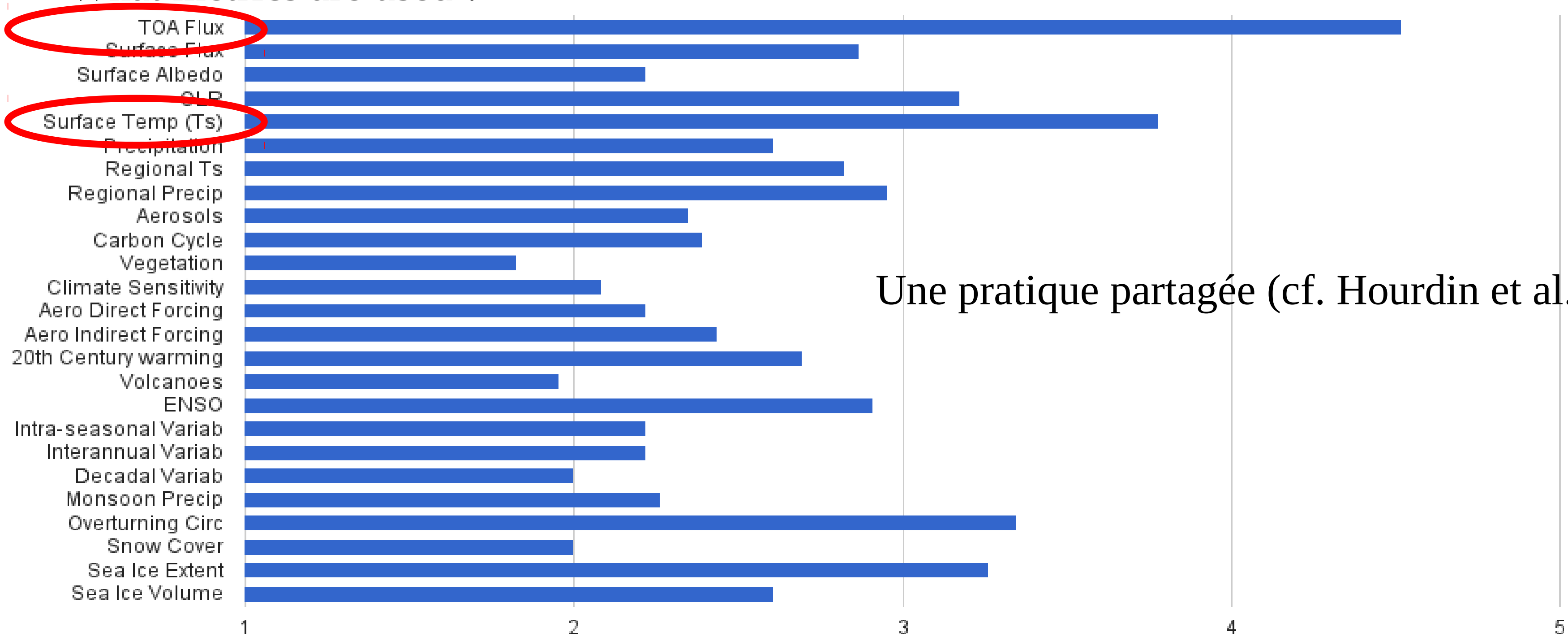


In which parameterizations do you apply changes when tuning ?



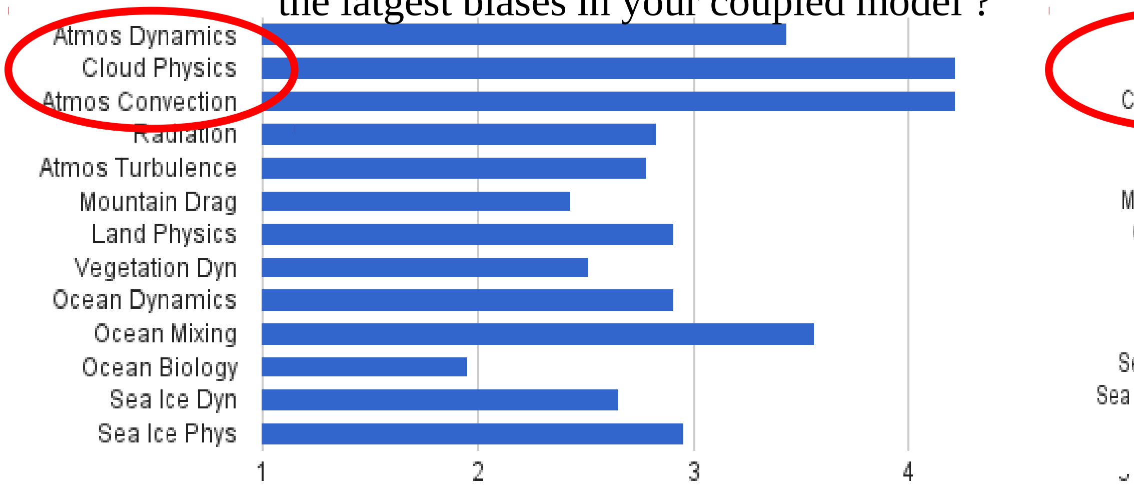
III – Ajustement des paramètres nuageux pour la réduction des biais de SST

What metrics are used ?

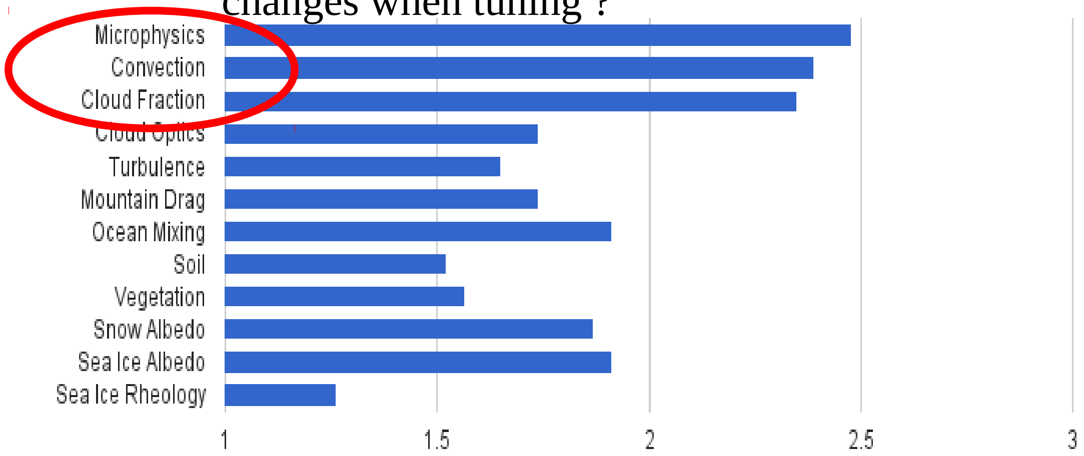


Une pratique partagée (cf. Hourdin et al., 2016)

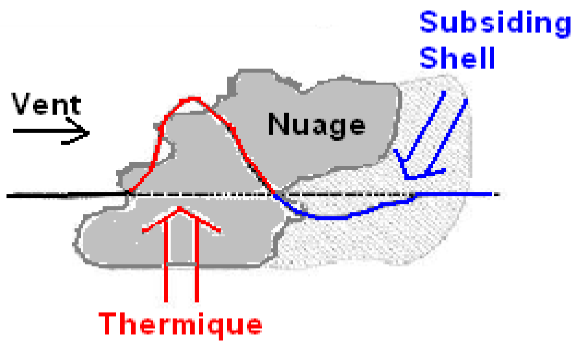
Which process do you believe introduce the latgest biases in your coupled model ?



In which parameterizations do you apply changes when tuning ?



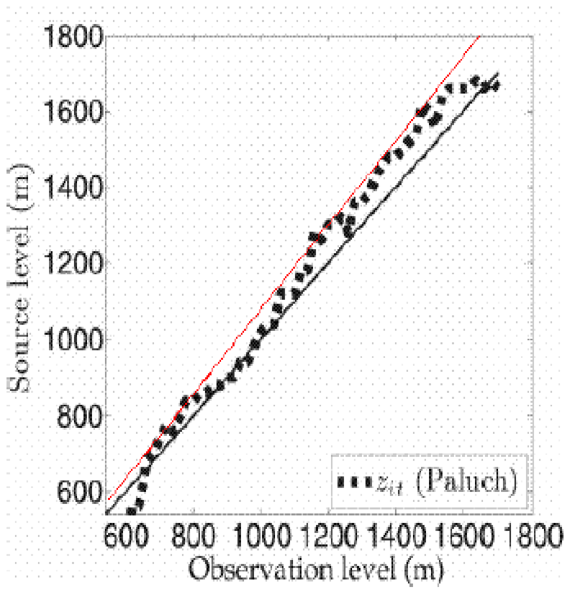
Nouvelle formulation de la flottabilité d'une particule



On suppose que l'air des subsiding shells possède les propriétés de l'air situé au-dessus

La flottabilité est calculée comme si le thermique « voyait » les propriétés le l'air situé h mètres au-dessus:

$$B''(z) = g \times \frac{\theta_{v,th}(z) - \theta_{v,env}(z+h)}{\theta_{v,env}(z+h)}$$

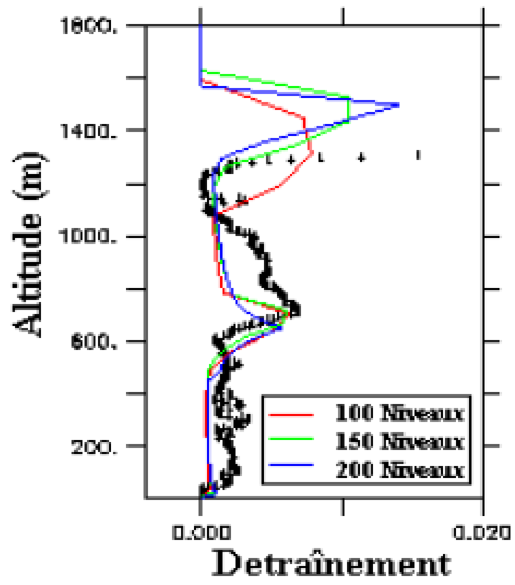


D'après Paluch (1979), on peut supposer que $h = 0.1 \times z$

Le detraînement s'écrit:

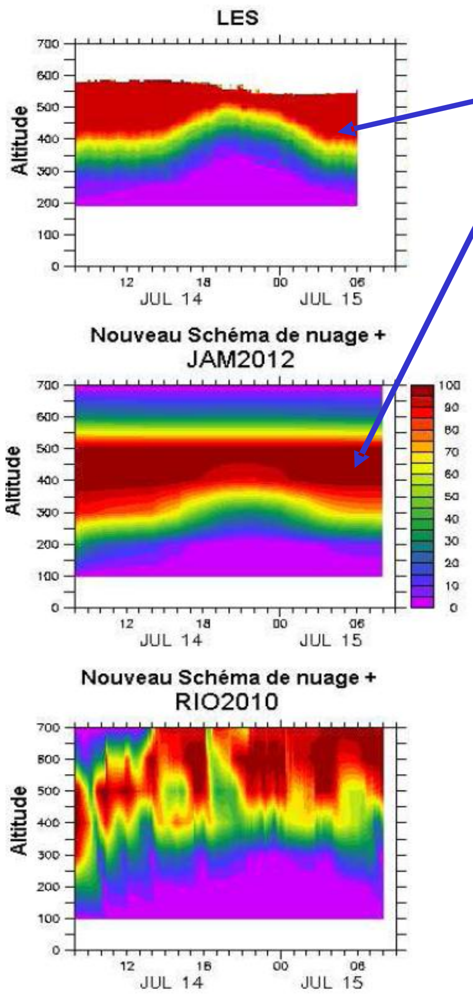
$$\delta = max(0, -\frac{a_1\beta_1}{1+\beta_1}\frac{B''}{w_{th}^2} + c(\frac{\Delta q_t/q_t}{w_{th}^2})^d)$$

Le thermique est ainsi suffisamment détraîné à la limite d'inversion



LES/1D

Amélioration de la couverture nuageuse simulée dans les cas de stratocumulus

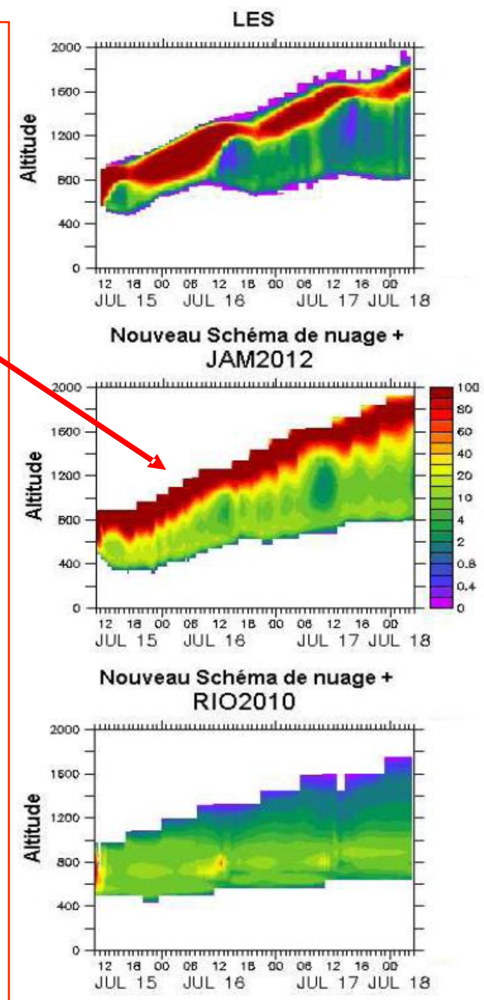


Bonne cohérence avec les simulations LES

On arrive en 1D à obtenir une couche nuageuse uniforme en 1D.

Couverture nuageuse parfois un peu haute due à un détraînement un peu trop haut.

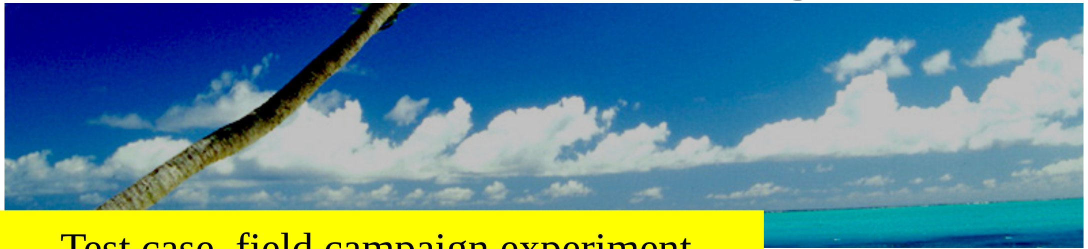
On conserve le même schéma de nuage. Seul la formulation de la flottabilité est changée, sans incidence sur les cas de petits cumulus.



LES/1D

LES/1D

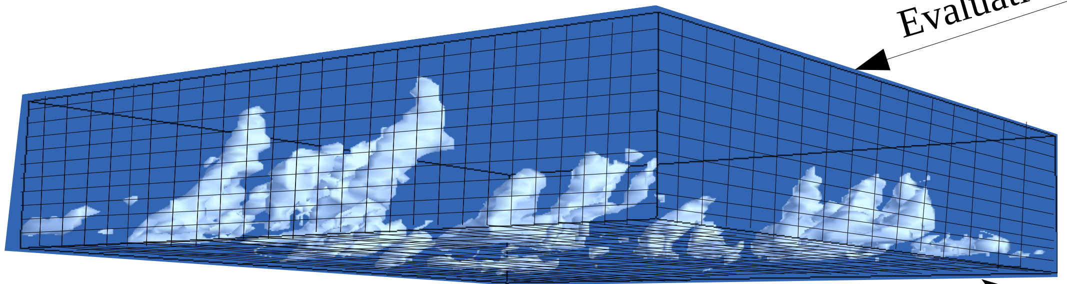
II – Paramétrisation des nuages bas : principes et méthodologie



Test case, field campaign experiment

Observation

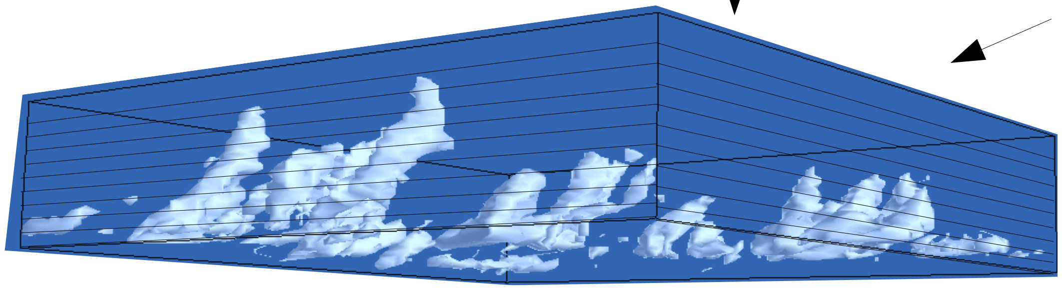
Evaluation

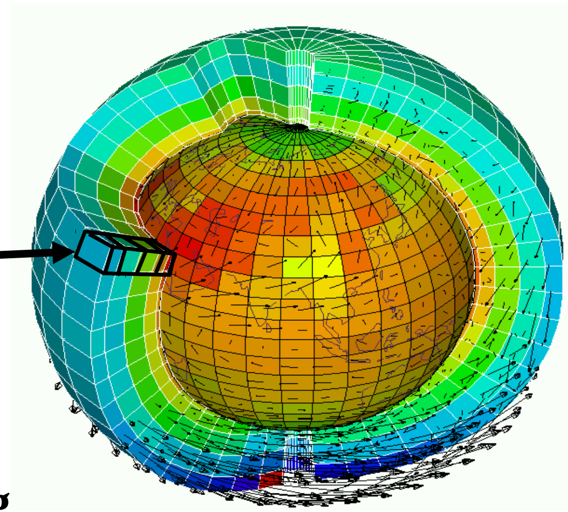


Explicit simulations, Grid cell, 20-100 m

Evaluation

« Large scale » conditions imposed





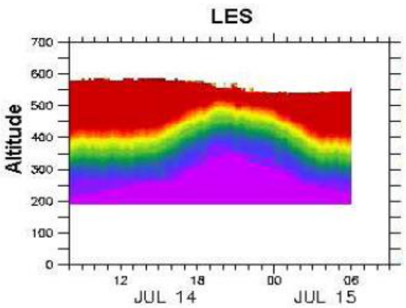
Climate model, parameterizations, « single-column » mode

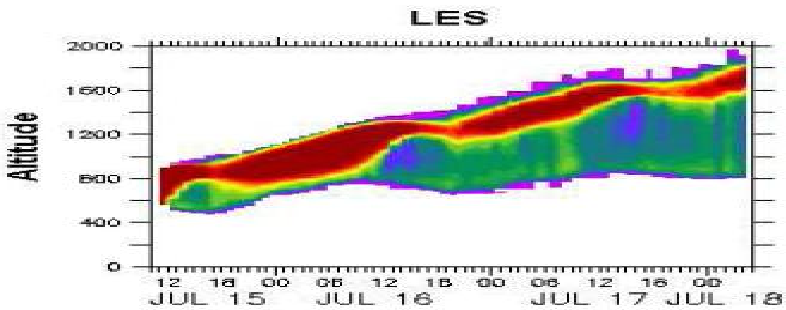
→ **Parameterizations are evaluated against other models**

→ **Can be done for realistic test cases but also with more idealized forcing (check the response of the parameterization to perturbations)**

III – Représentation des strato-cumulus

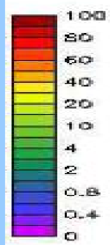
Difficulté du modèle du thermiques à représenter les strato-cumulus

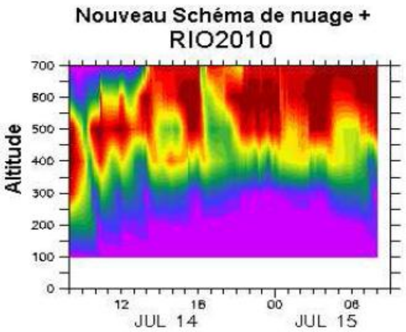


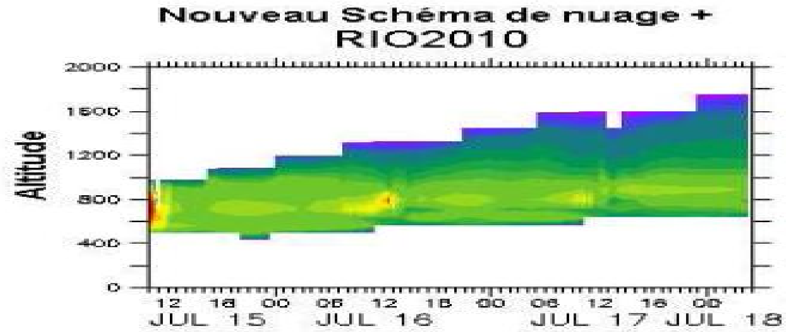


Cas Fire :
Cycle diurne
Strato-cumulus
marins

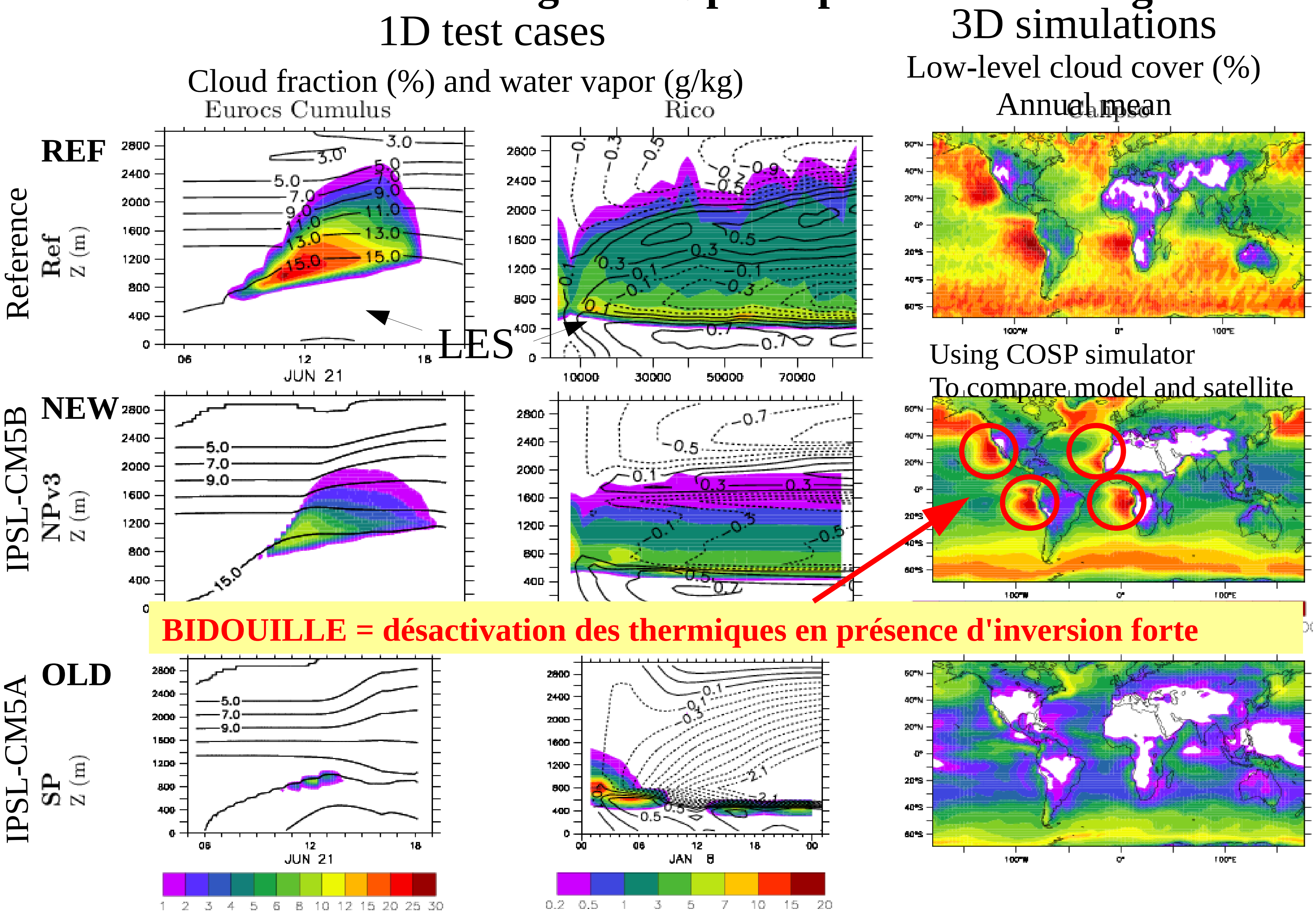
Cas Sandu :
Transition strato-cumulus
→ cumulus d'alisées



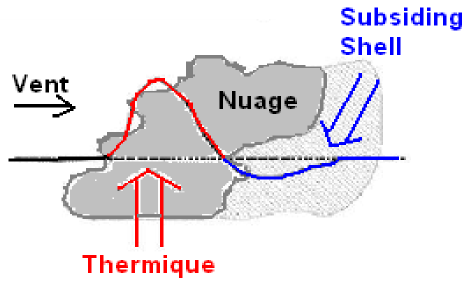




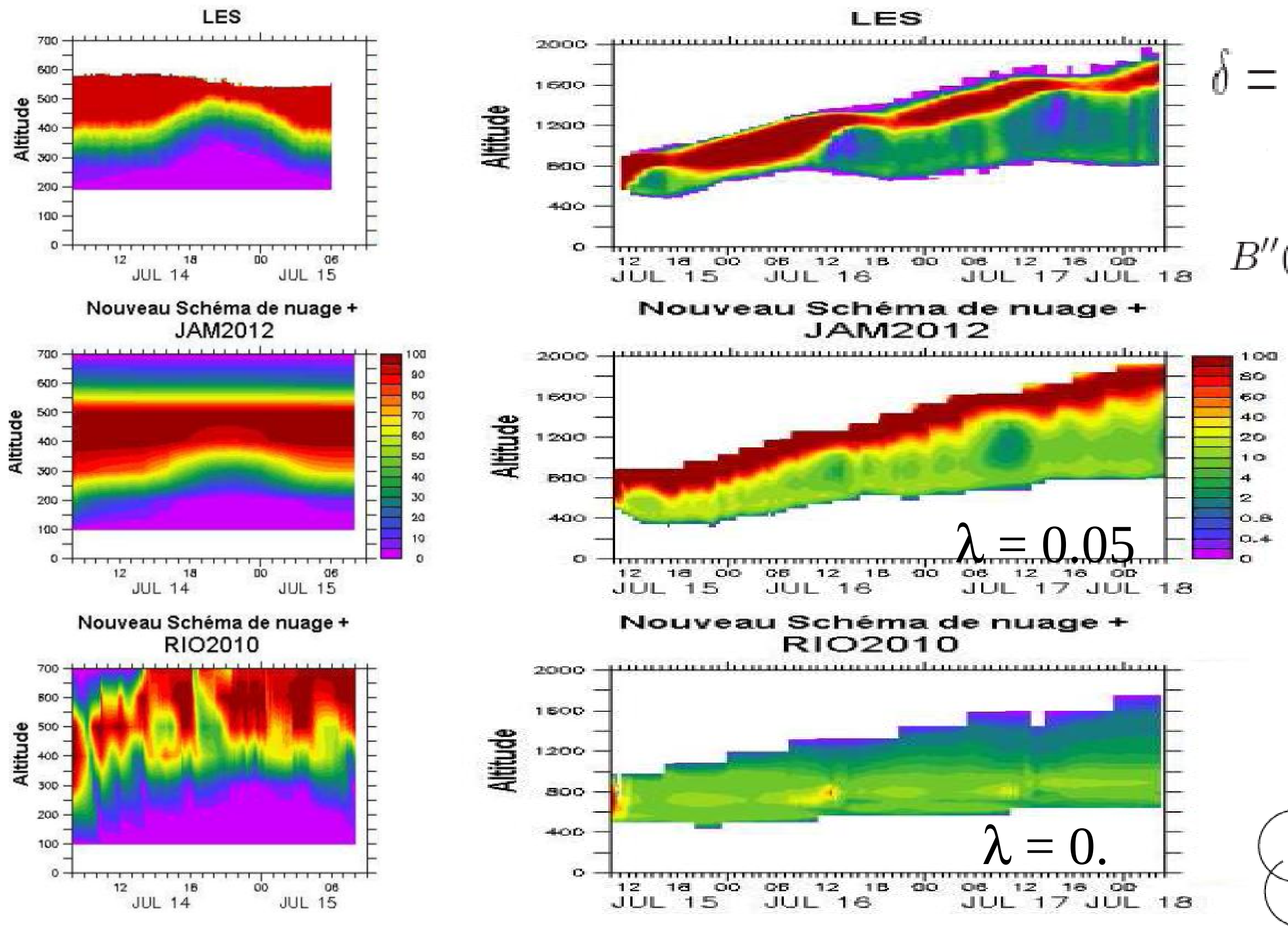
II – Paramétrisation des nuages bas : principes et méthodologie



III – Représentation des strato-cumulus



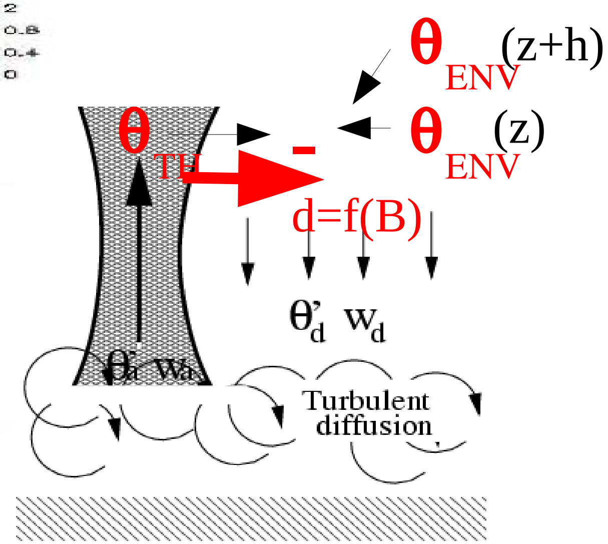
Modification du détrainement



$$\delta = max\left(0, -\frac{a_1\beta_1}{1+\beta_1}\frac{B''}{w_{th}^2} + c\left(\frac{\Delta q_t/q_t}{w_{th}^2}\right)^d\right)$$

$$B''(z) = g \times \frac{\theta_{v,th}(z) - \theta_{v,env}(z+h)}{\theta_{v,env}(z+h)}$$

$$h = \lambda \times z$$

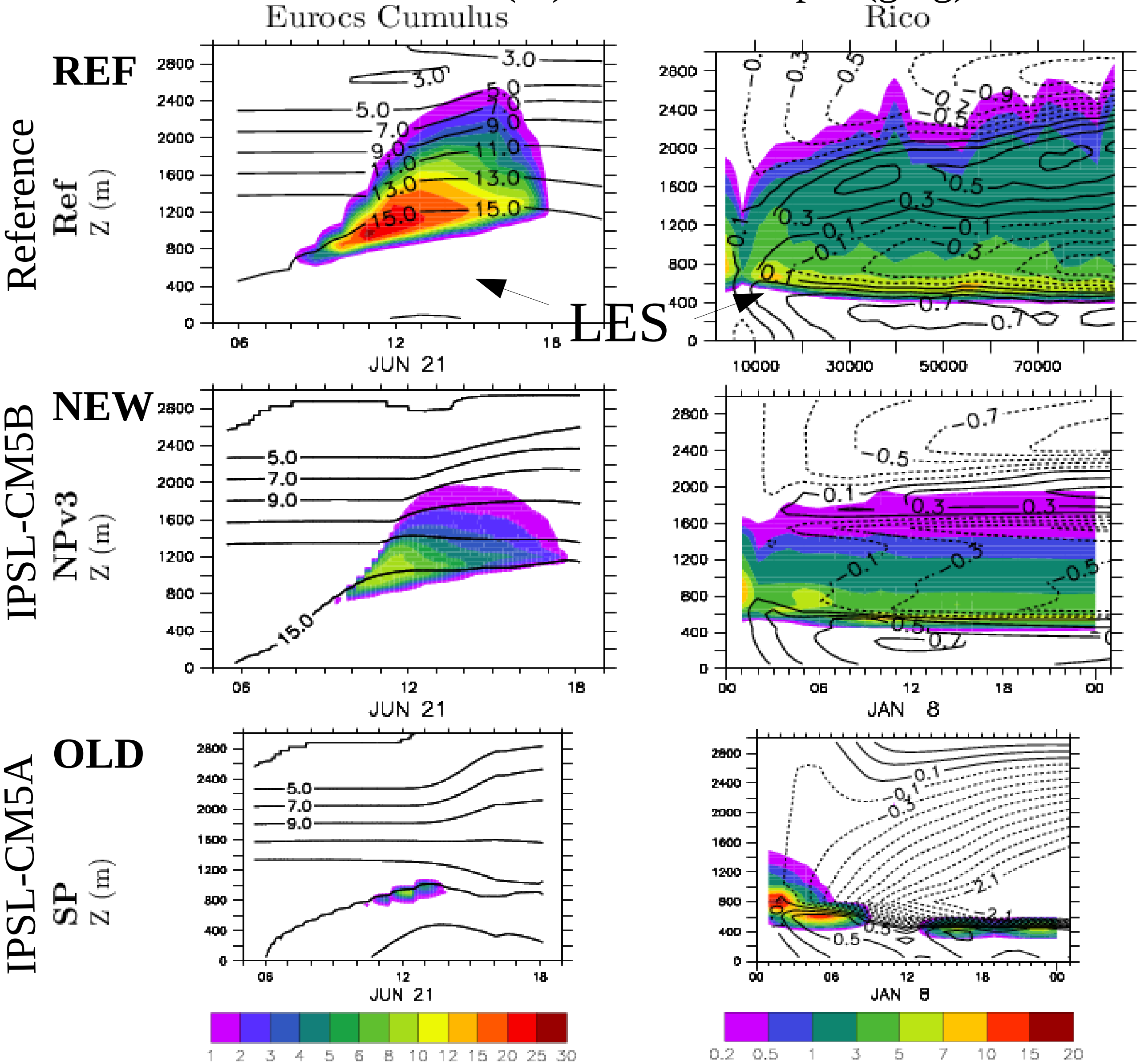


Thèse Arnaud Jam, Article quasi finalisé

II – Paramétrisation des nuages bas : principes et méthodologie

1D test cases

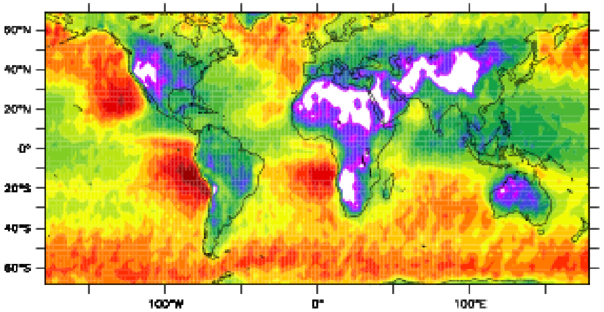
Cloud fraction (%) and water vapor (g/kg)



3D simulations

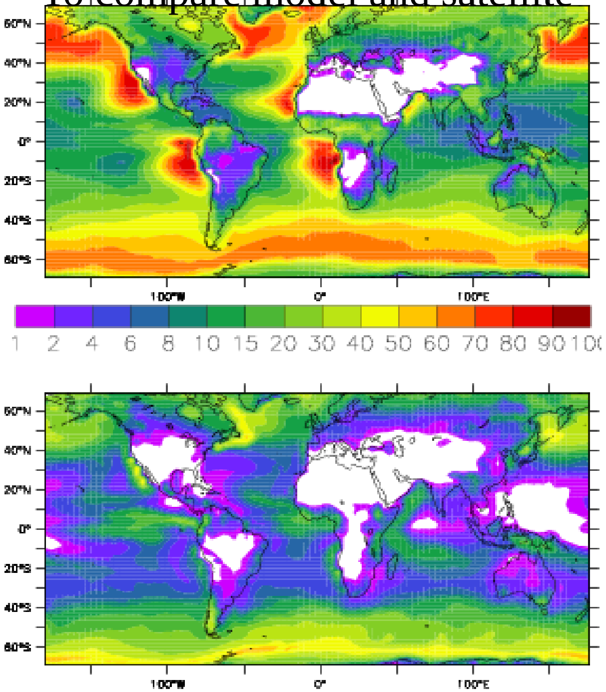
Low-level cloud cover (%)

Annual mean



Using COSP simulator

To compare model and satellite



IV – Ajustement : cibles, méthodologie et illustration