LMDZ : use and configurations

1. Operating modes of the 3D GCM

a) Global climate studies in free mode
b) Zooming or/and nudging for climate
c) Tracer transport

2. Intercomparison exercises and reference versions

a) IPSL climate model and CMIP exercises
b) LMDZ reference versions
c) Robust improvements from version to version
d) Evolution of climatic biases and sensitivity

3. Model development and tuning

a) Choice of a new configuration : content and resolution
b) Importance of tuning
c) Methodology 1D/nudged simulations/tuning

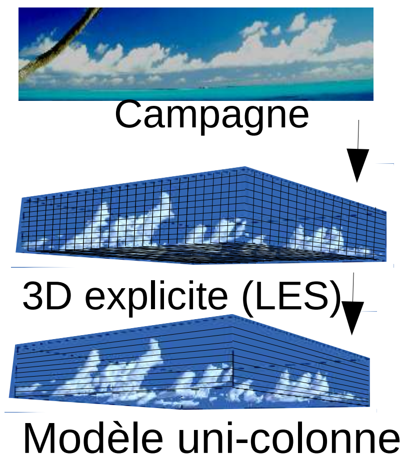
LMDZ : One model / many configurations

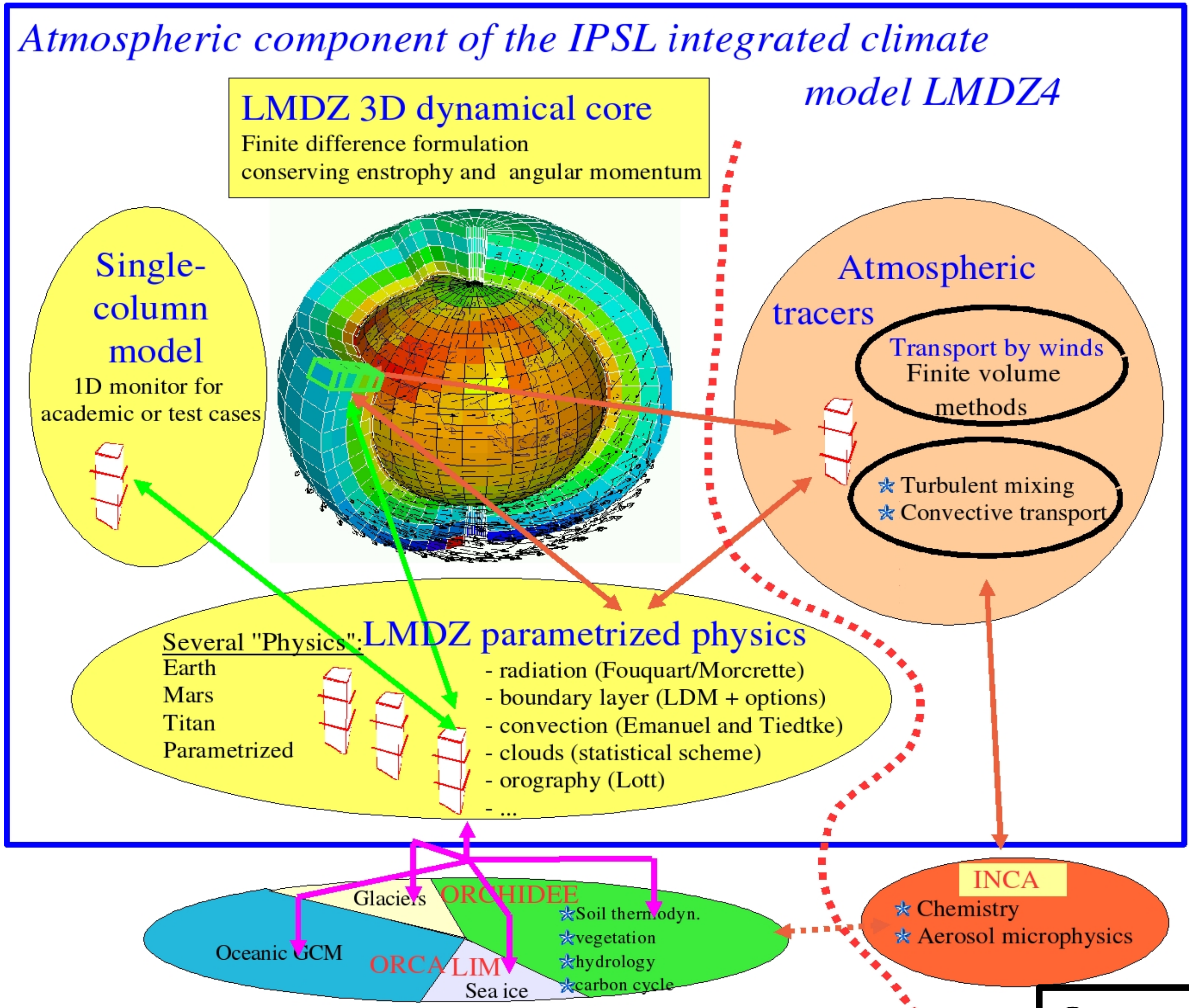
Coeurs 3D
- Longitude-latitude
- Icosaèdre (bientôt disponible)
- Aire limité (en préparation)

Cas 1D (Dephy/High-Tune)

LES à disposition

20 aine de cas
- Convection
- RCE
- Nuages bas
- Couplage surf.





Mode d'utilisation 3D
- Climatique couplé ou non
- Océan slab
- β-clim/bucket
- Zoomé
- Guidé ou initialisé
- Aqua ou terra planète

IO/Evaluation :
- Multi-atlas sur ciclad
- Pilotage xml de XIOS
- Simulateurs satellite

Couplage en surface (4 sous surface/maille)
- Océan : SST forcées, Nemo, Océan slab
- Banquise : imposée (conduction LMDZ), Lim, slab
- Continents : **Orchidee**, bucket, betaclim
- Glaciers : bucket ajusté

Composition
- **Inca** (chimie/aérosols)
- **Reprobus** (chim./strato)
- LMDZaer (arérosols)
- Isotopologues de l'eau

Which model version and which setup should I use for my work ?

Depends on the problem you want to address
The first question should be :

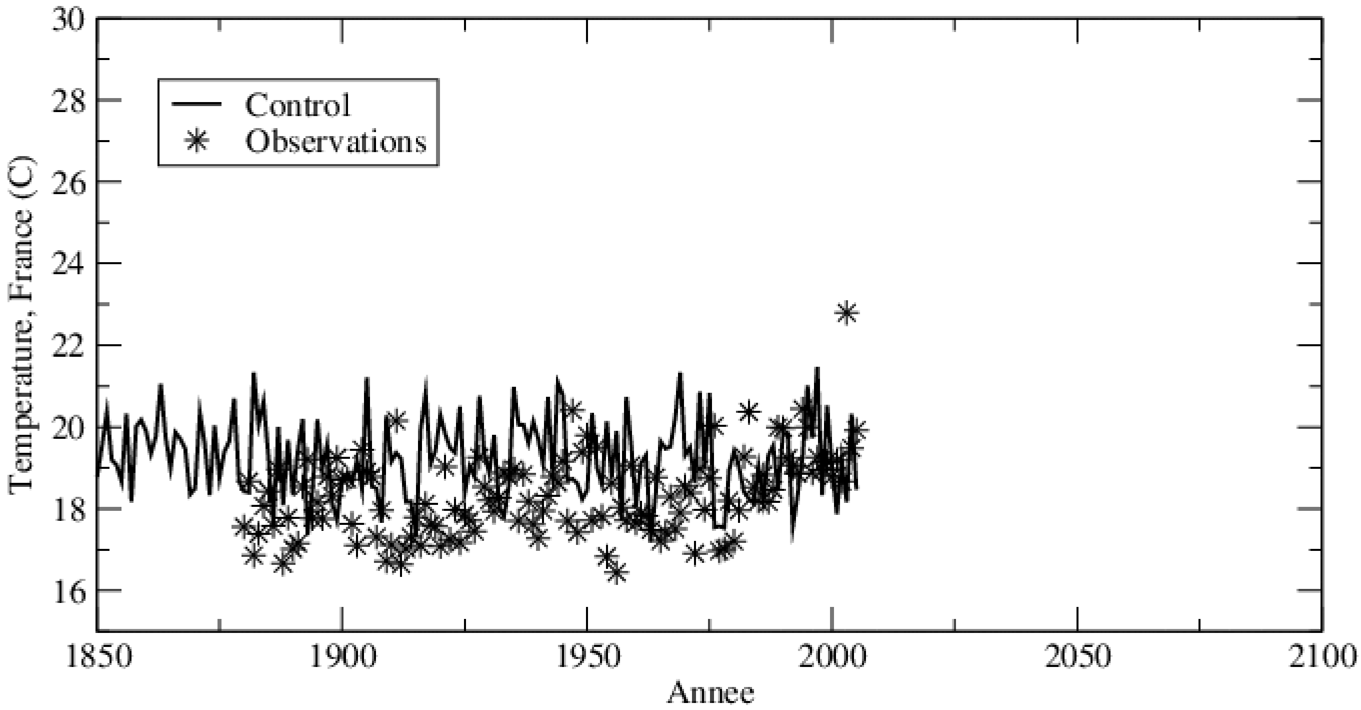
What do I need a model for ?

Those questions are a essential part of YOUR WORK

The presentation try to help you answer to question #1 once you have the answer to question #2

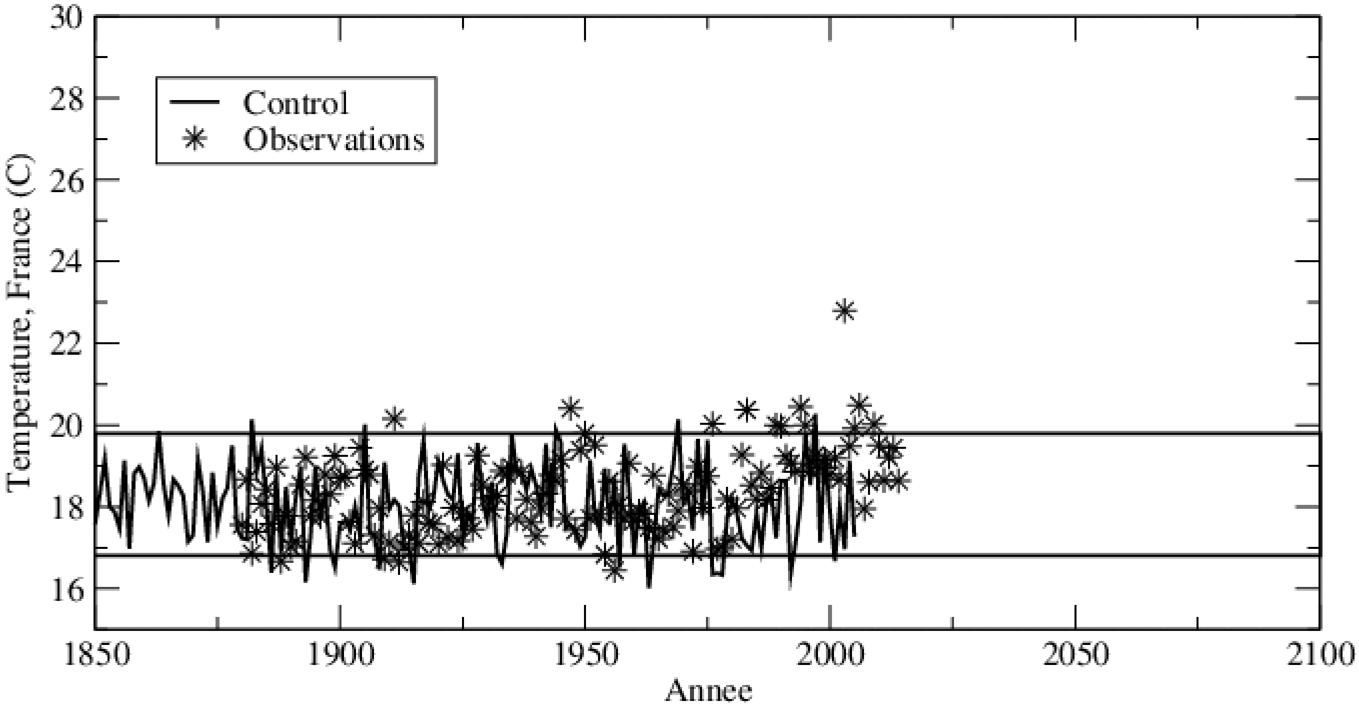
Example 1 :
Coupled simulation for climate change projections

Climate change projections



→ Global coupled ocean-atmosphere model. Model not perfect. Biases.

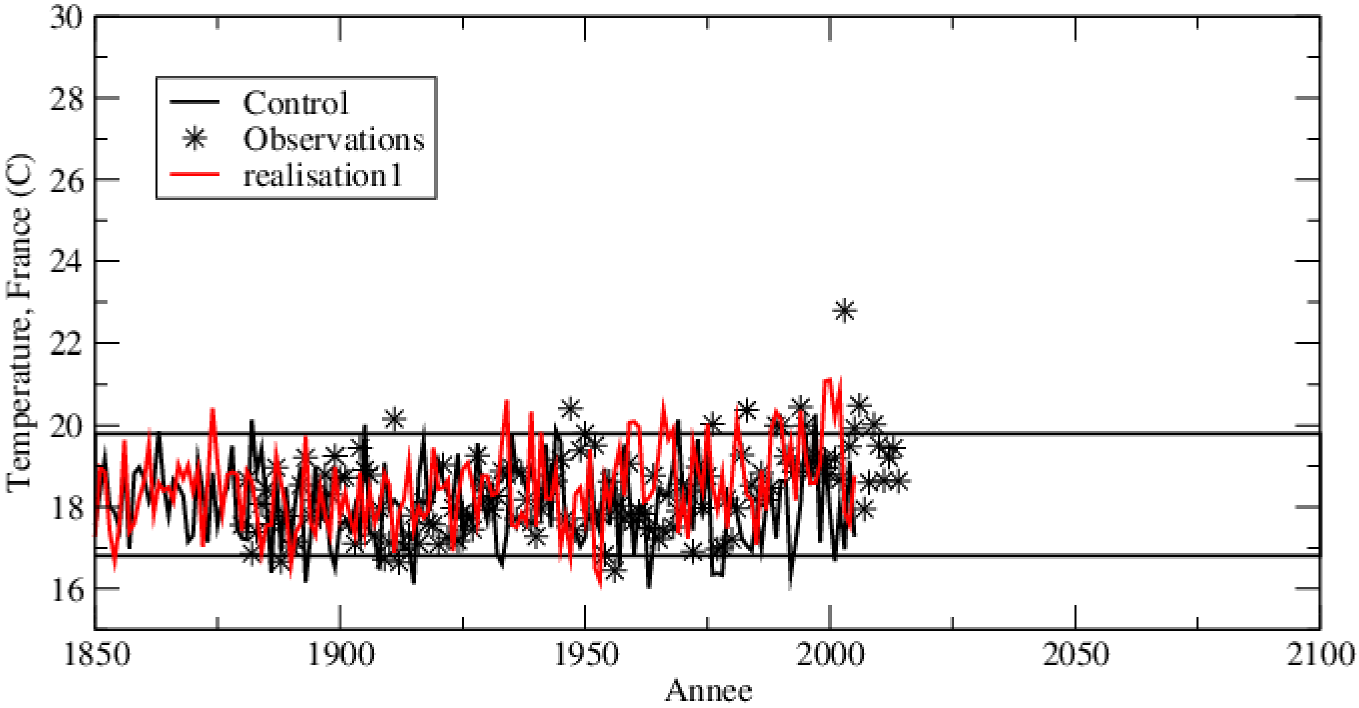
Climate change projections



→ Global coupled ocean-atmosphere model. Model not perfect. Biases.

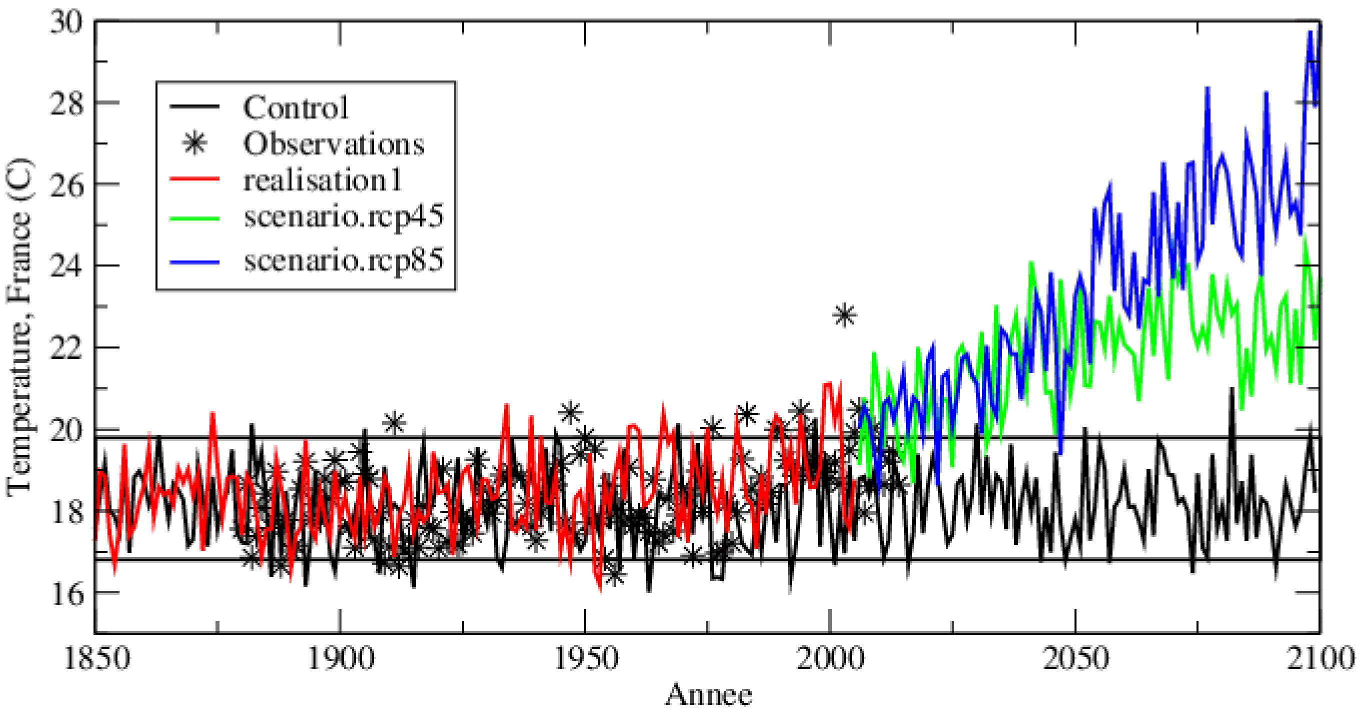
→ Analyzed in terms of statistics. Biased on average. Variance ...

Climate change projections



→ Global coupled ocean-atmosphere model. Model not perfect. Biases.
→ Analyzed in terms of statistics. Biased on average. Variance ...
→ Perturbed versus control run (small perturbation compared to biases)

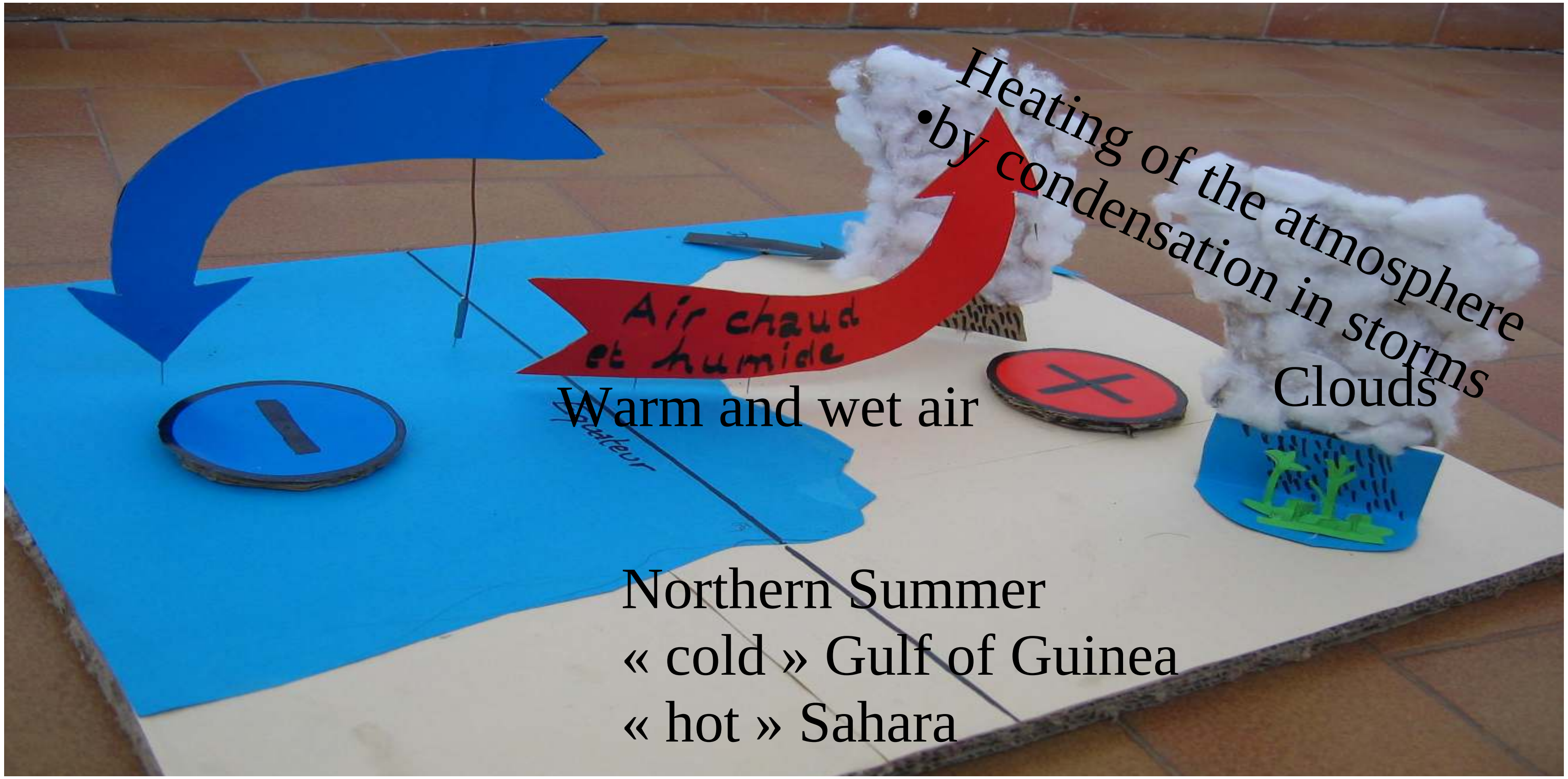
Climate change projections



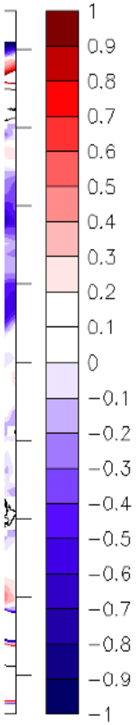
→ Global coupled ocean-atmosphere model. Model not perfect. Biases.
→ Analyzed in terms of statistics. Biased on average. Variance ...
→ Perturbed versus control run (small perturbation compared to biases)
→ Scenarios of future concentrations or emissions

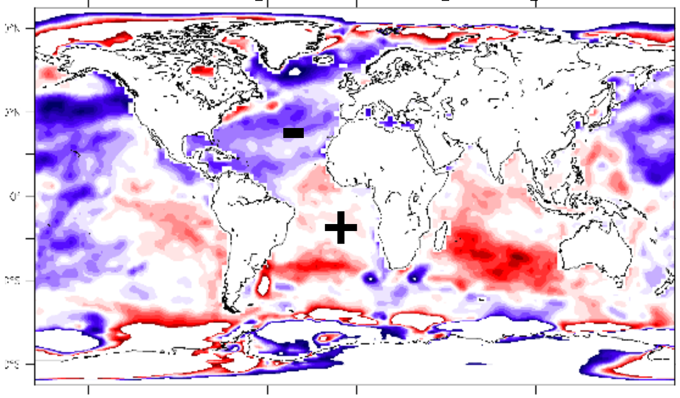
Example 2 :
Forced-by-SST simulations to understand the Sahelian drougth of the 70'

1. Operating modes : a) Global climate studies in free mode



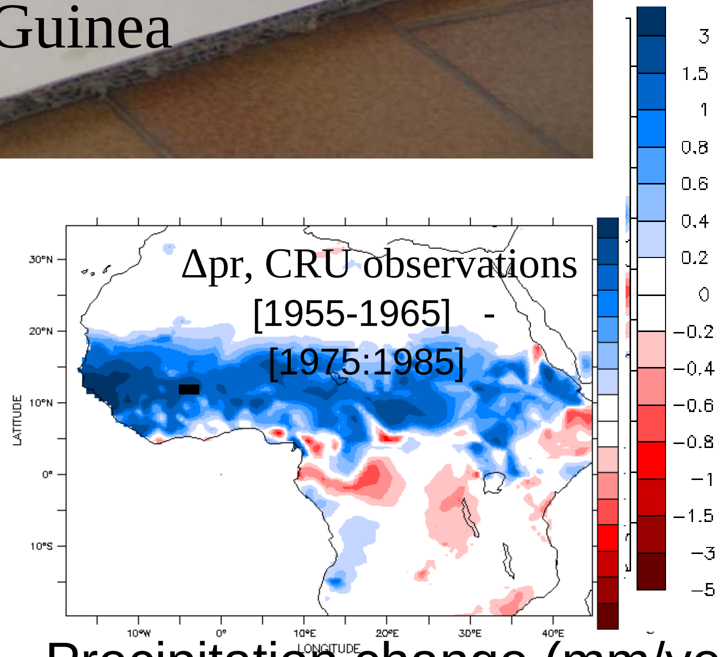
Δ SST : [1955-1965] - [1975:1985]





Temperature change (°C)

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

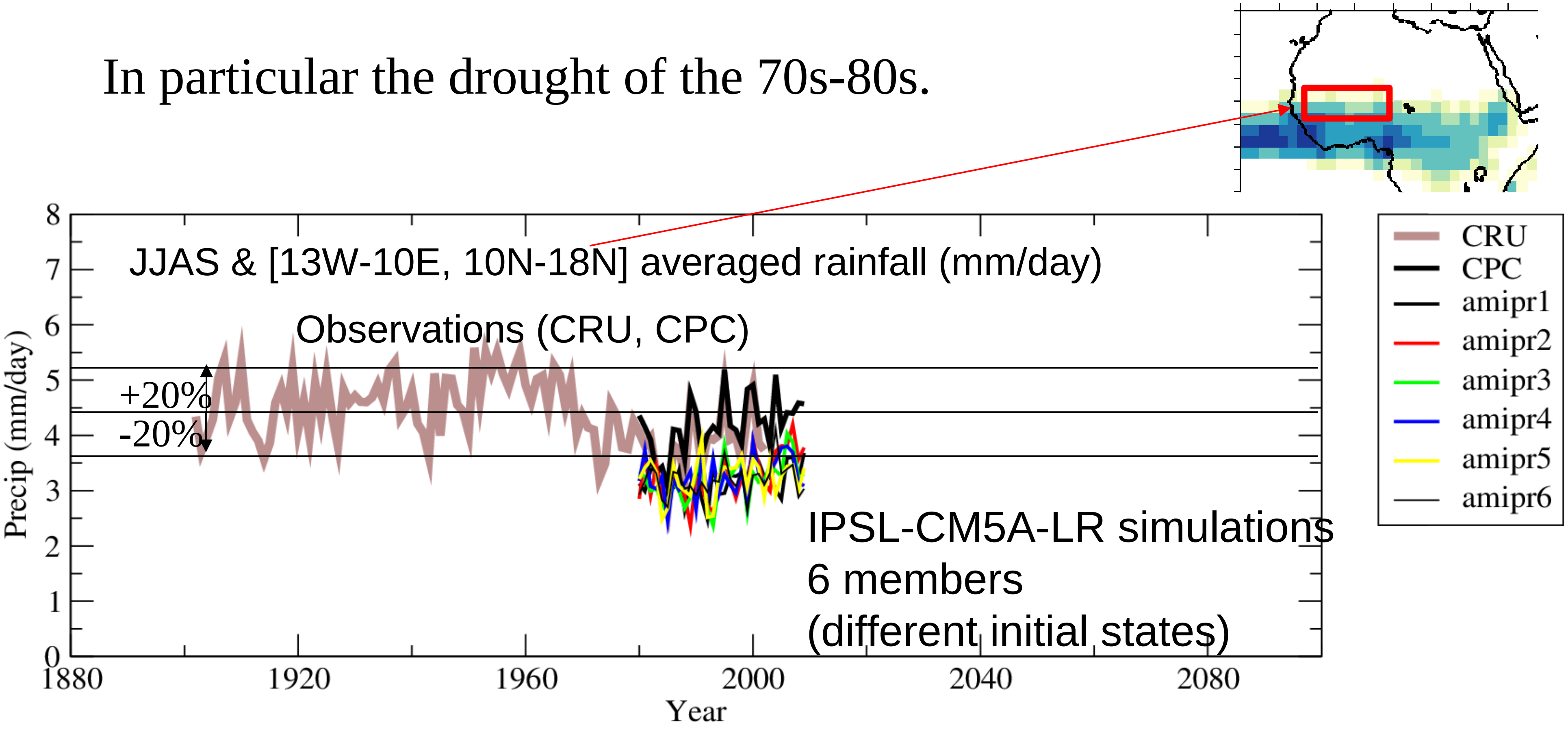


Precipitation change (mm/year)

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.



AMIP with imposed Sea Surface Temperature (SST)

Roehrig, R., D. Bouniol, F. Guichard, F. Hourdin and J.-L. Redelsperger, 2012, The present and future of the West African monsoon: a2 process-oriented assessment of CMIP5 simulations along the3 AMMA transect., J. Climate, 26, 6471–6505. doi: http://dx.doi.org/10.1175/JCLI-D-12-00505.1

1. Operating modes : a) Global climate studies in free mode

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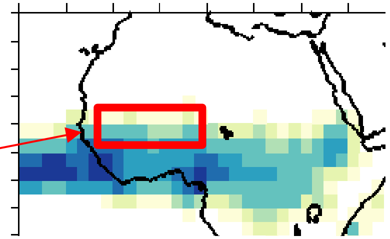
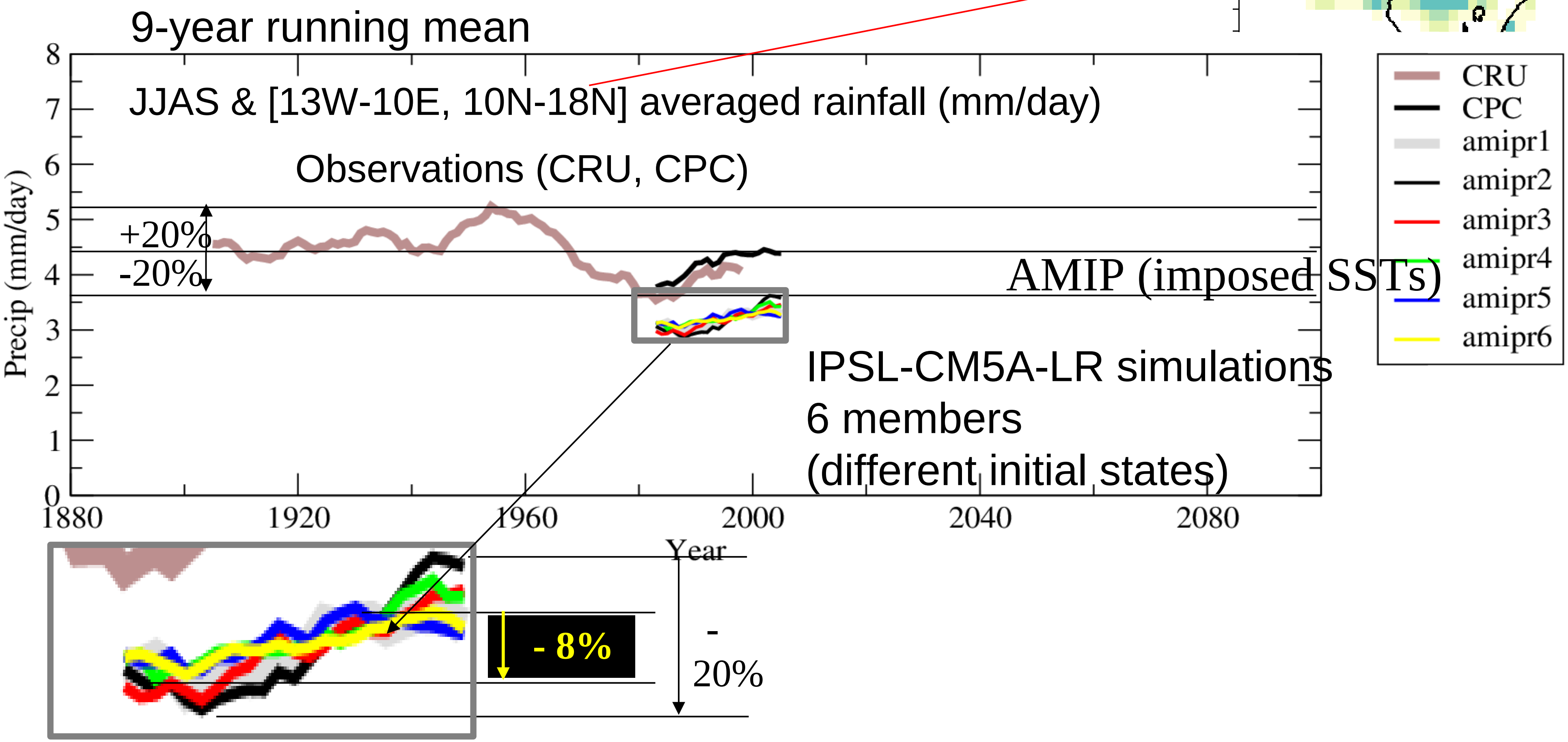




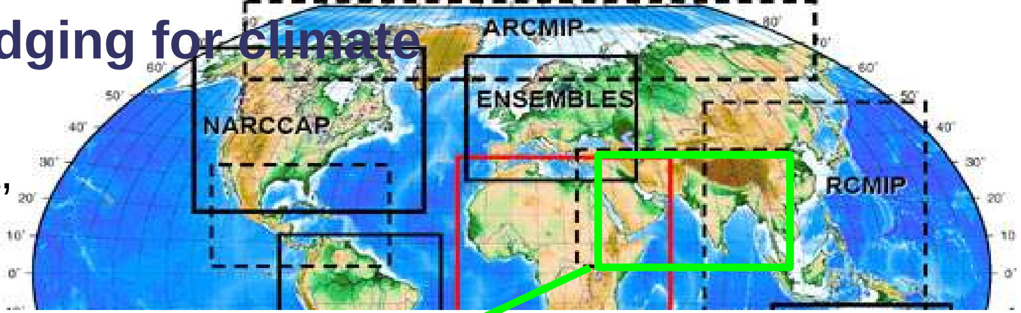
Simulations have a skill to reproduce decadal variations of monsoon rainfall in response to sea surface temperature changes
But strong internal variability even with imposed SSTs
The observation is one possible experience

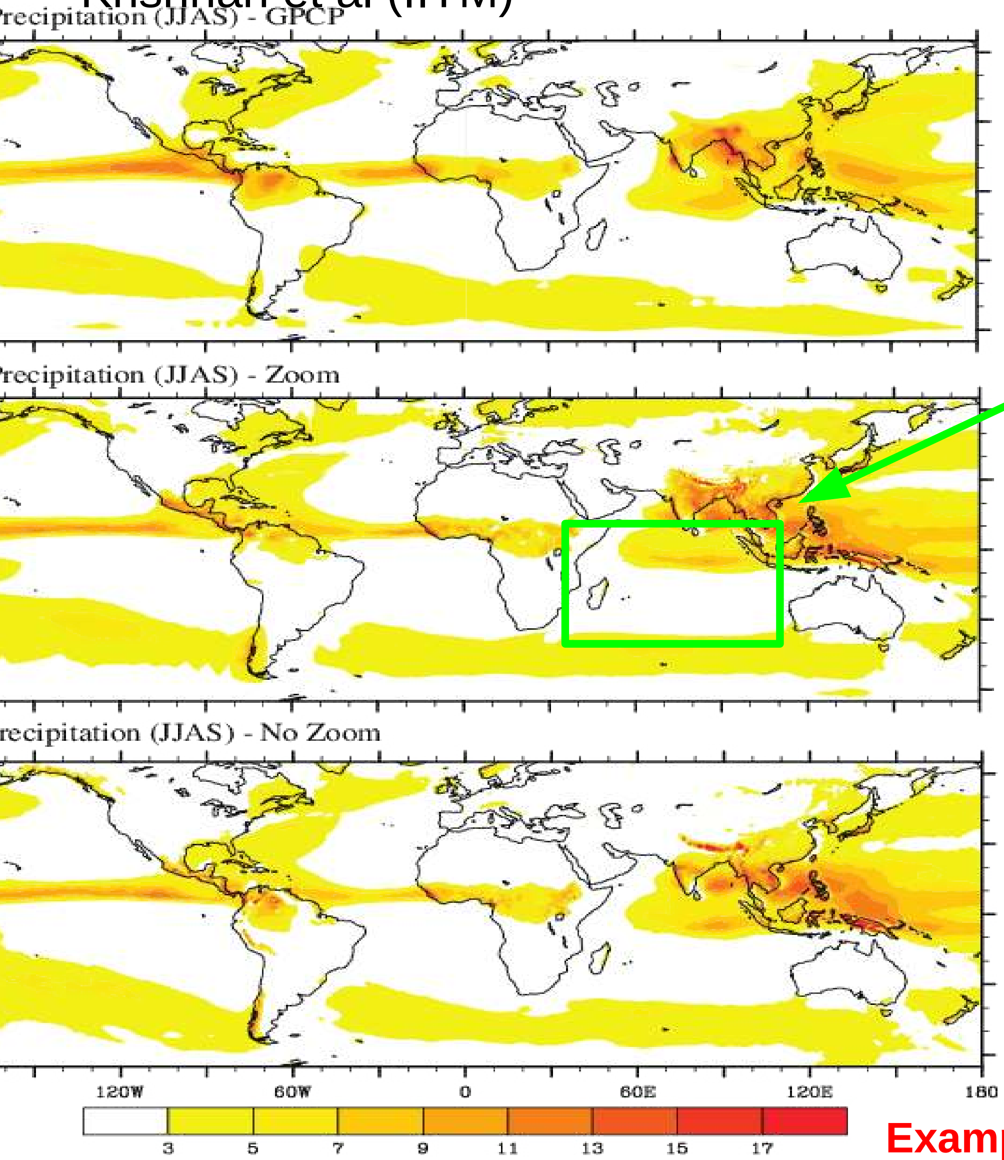
Example 3 :
Forced-by-SST simulations with zoom to improve the representation of monsoon rainfall over India

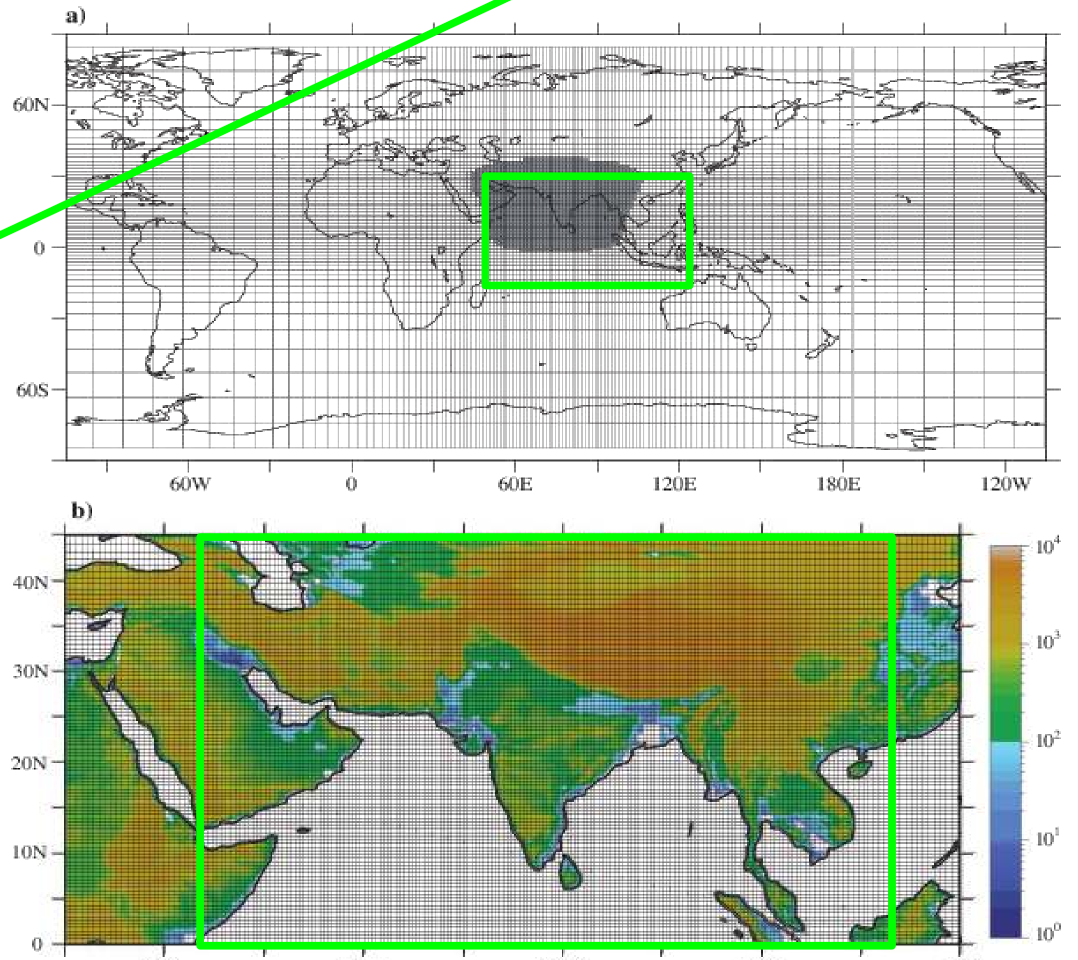
1. Operating modes : b) Zooming or/and nudging for climate

Free climate simulation with zoom

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







Example of improvement due to increased resolution

- **Better representation of depressions coming from Bay of Benghal**

R. Krishnan,T. P. Sabin, R. Vellore, M. Mujumdar, J. Sanjan, B. N. Goswami, F. Hourdin, J.-L. Dufresne, P. Terray
Deciphering the desiccation trend of the South Asian monsoon hydroclimate in a warming world, Climate Dynamics, Volume 47, Issue 3–4, pp 1007–1027, 2016

Example 4 :
Forced-by-SST simulations with zoom and nudging to evaluate and improve the parameterized physics using site observations

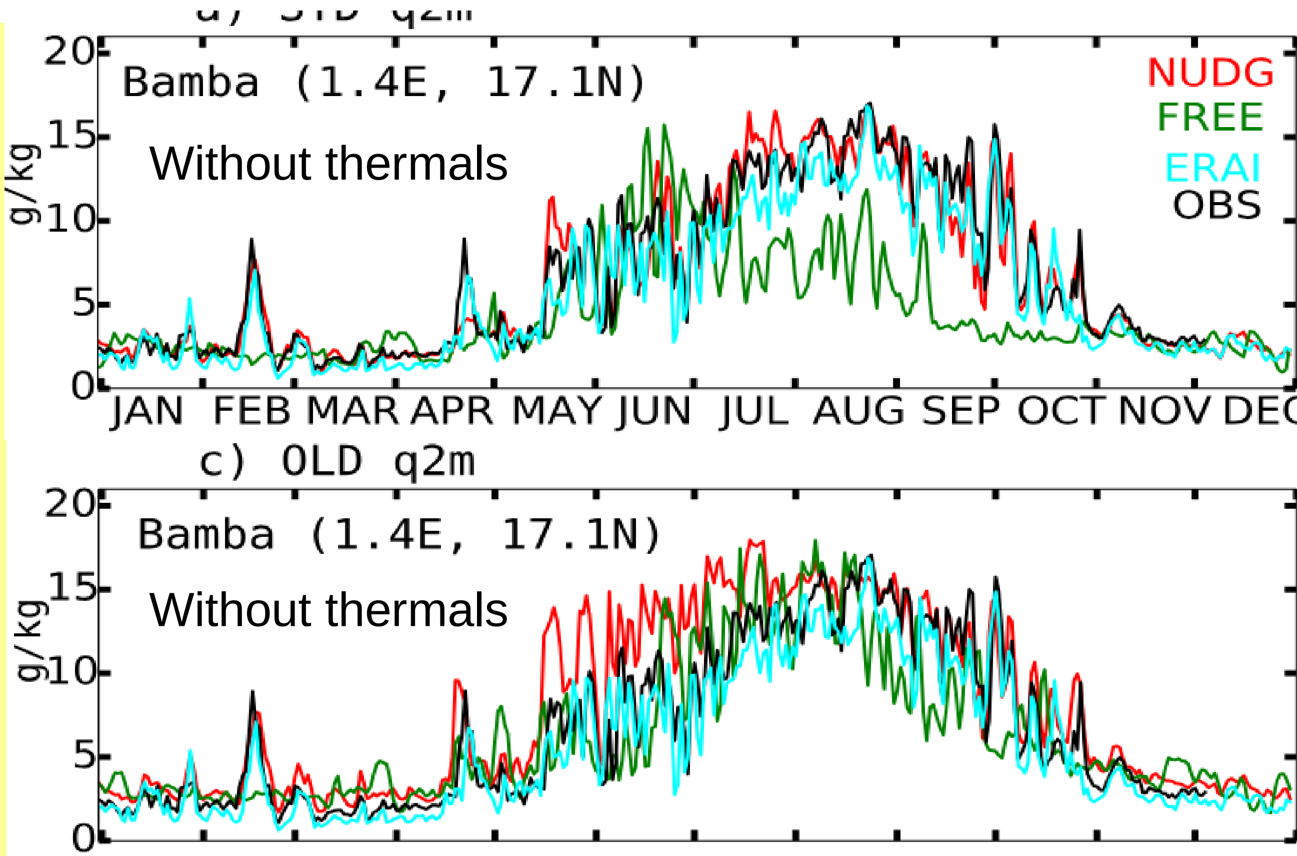
1. Operating modes : b) Zooming or/and nudging for climate

Nudging capability

$$\frac{\partial X}{\partial t} = F(X) + \frac{X^a - X}{\tau}$$

X : model state variables, u, v, T, q
Xa : X from (re)analysis regrided on the model grid
F(X) : state variables model tendencies
τ : time constant

Often using nudging in u and v only relying on the model physics for the thermodynamics (~ simulations with imposed large scale dynamics)



Time evolution of near surface specific humidity over Sahel

F. B. Diallo 1 , F. Hourdin 1 , C. Rio 2 , A.-K. Traore 1 , L. Mellul 1 , F. Guichard 2 and L. Kergoat 3, The surface energy budget computed at the grid-scale of aclimate model challenged by station data in West Africa, James, https://doi.org/10.1002/2017MS001081, 2017

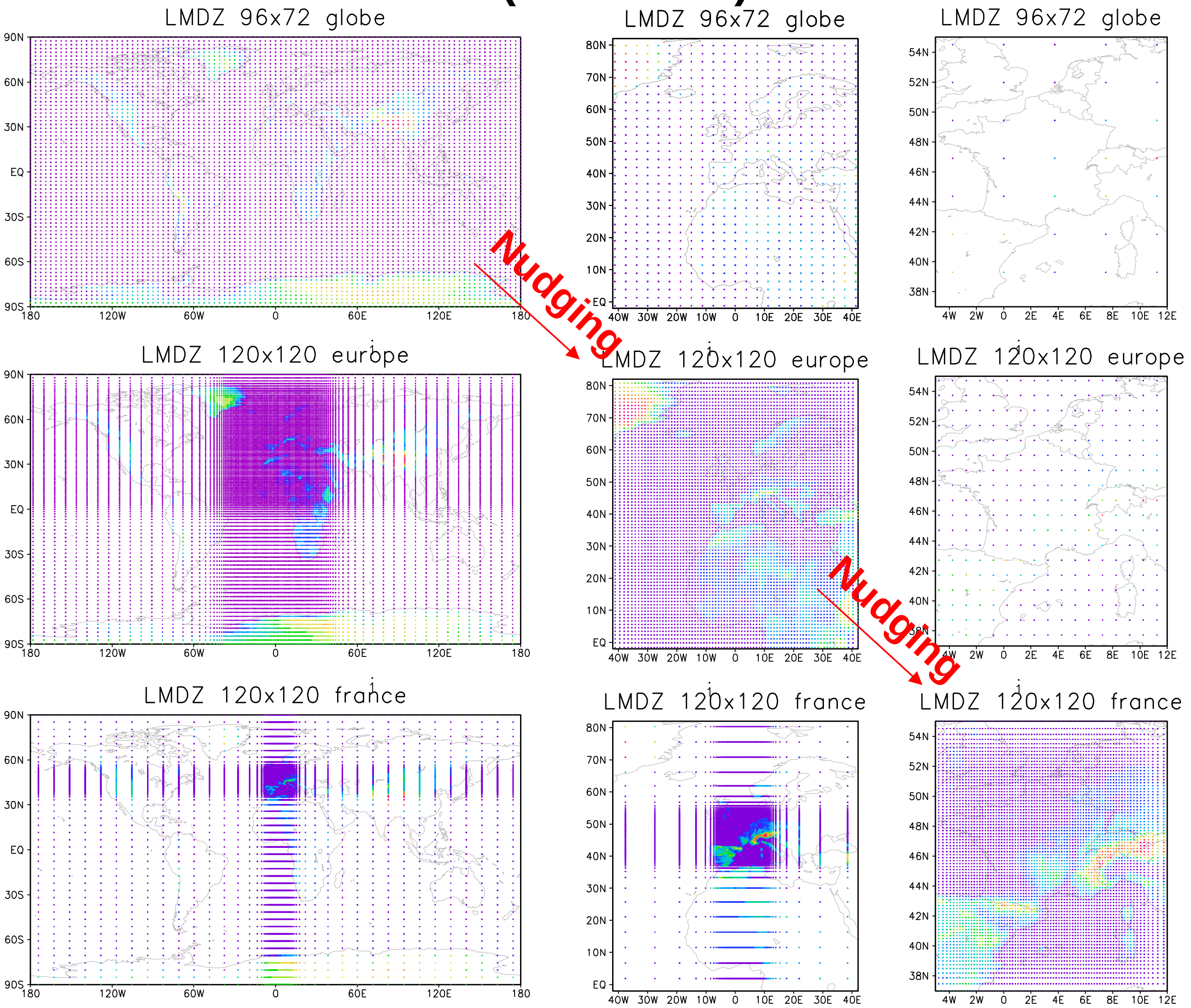
Cheruy, F., A. Campoy, J.-C. Dupont, A. Ducharne, F. Hourdin, M. Haeffelin, M. Chiriaco, and A. Idelkadi , Combined influence of atmospheric physics and soil hydrology on thesimulated meteorology at the SIRTA atmospheric observatory, Clim. Dyn., 2251–2269, 2013, (DOI) 10.1007/s00382-012-1469-y.

O. Coindreau, F. Hourdin, M. Haffelin, A. Mathieu, C. Rio, 2006, Assessment of physical parameterizations using a global climate model with strechable grid and nudging, Monthly Weather Review, 135:1474-1489 PDF

Example 5 :
Forced-by-SST simulations with zoom and nudging by other coarser grid for down-scaling

1. Operating modes : b) Zooming or/and nudging for climate

LMDZ - Grid Cascade - (Laurent Li)



LMDZ Globe (300 km)

LMDZ Europe (100 km)

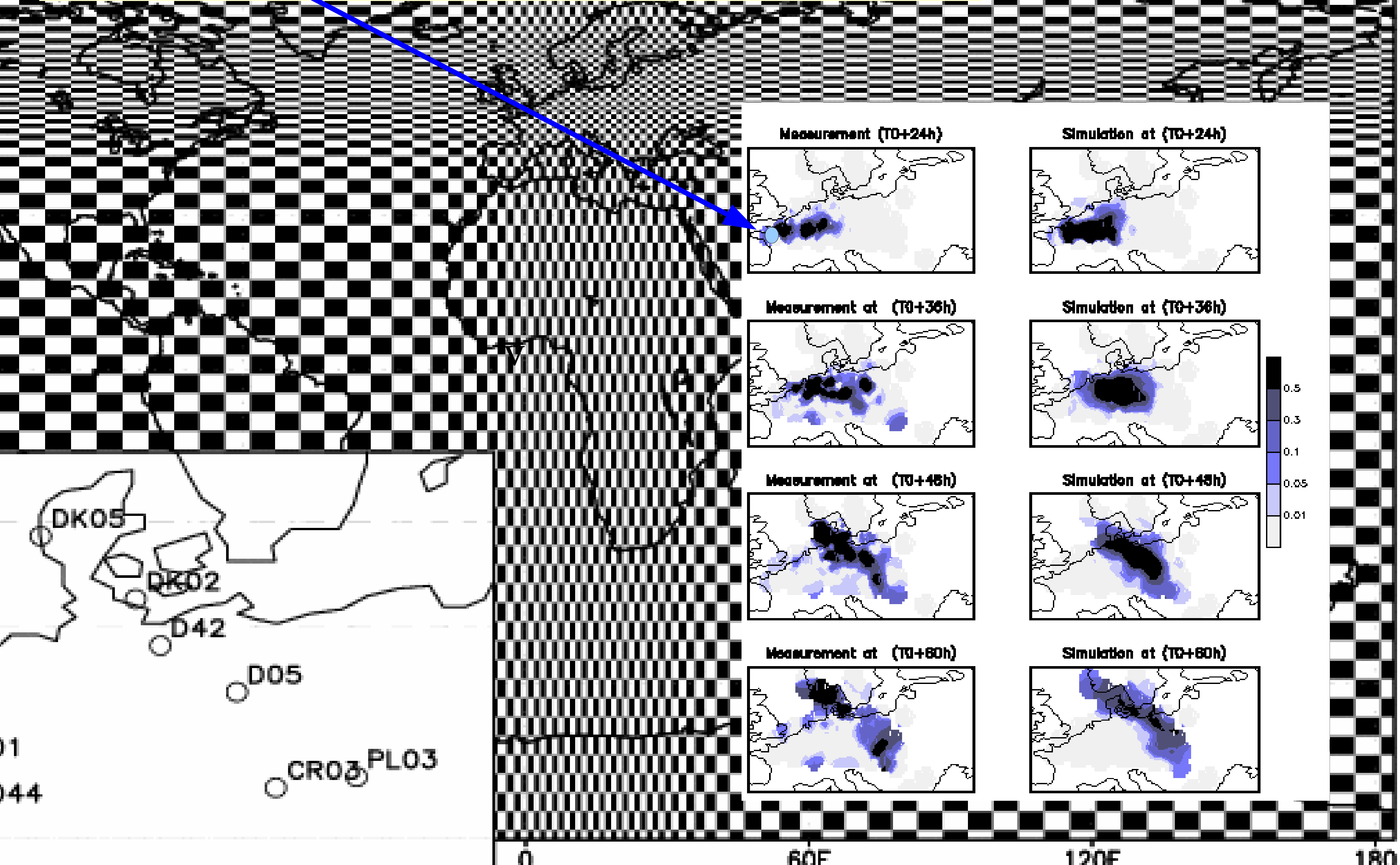
LMDZ France (20 km)

Similar to what is done with limited area models (like WRF)

Example 6 : with tracer transport

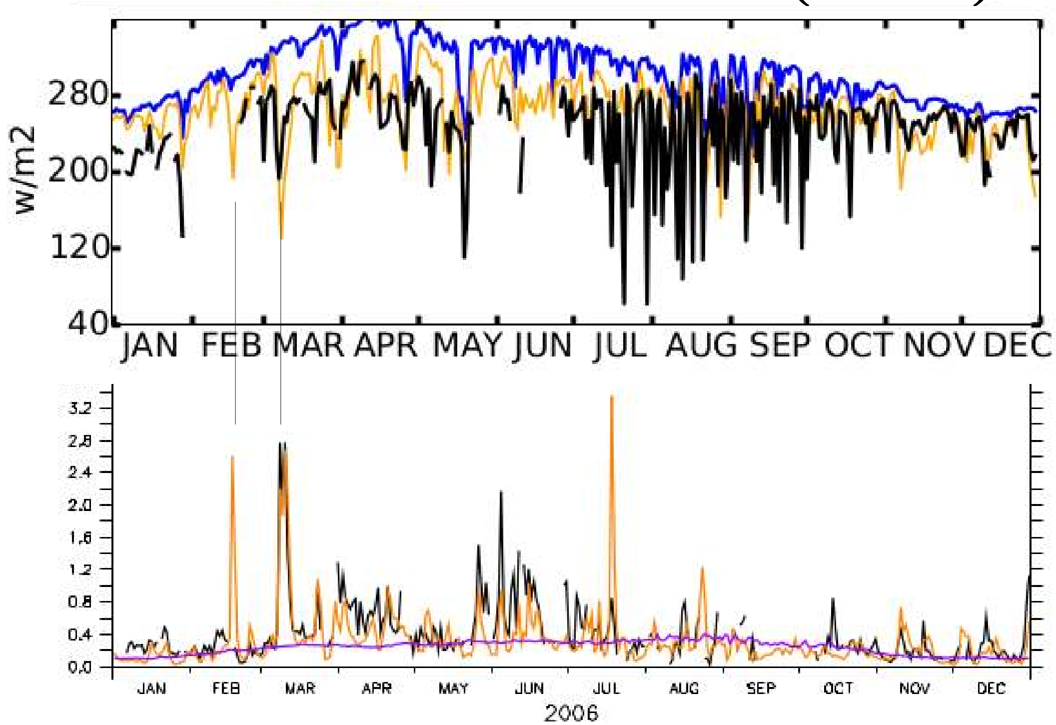
1. Operating modes : c) tracer transport

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

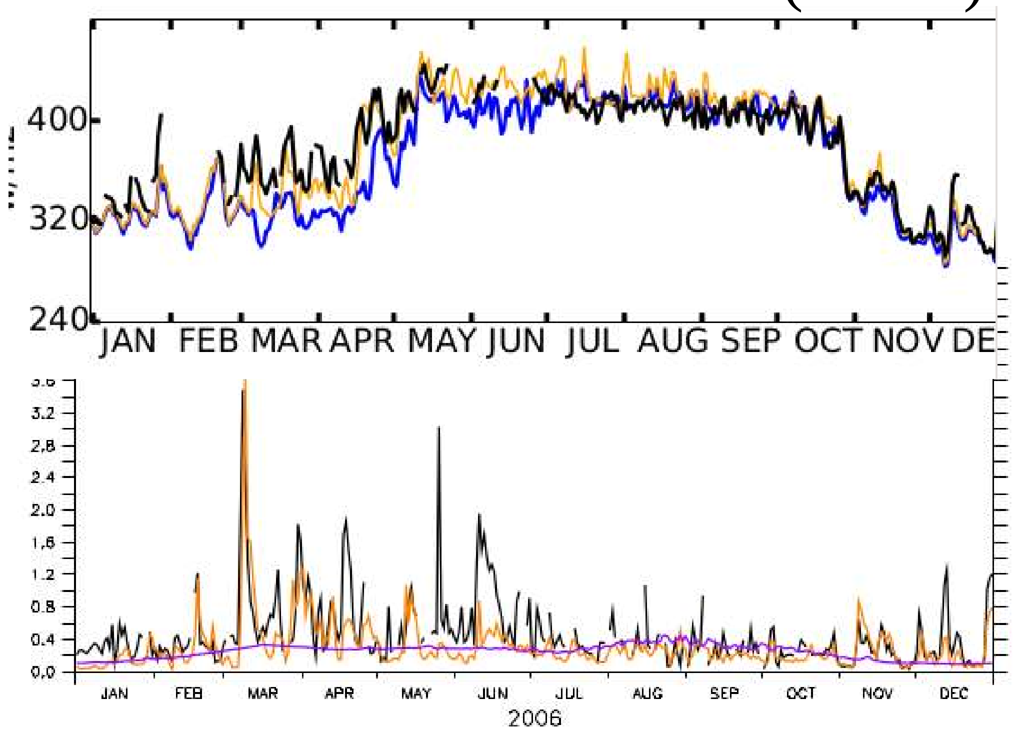


1. Operating modes : c) tracer transport

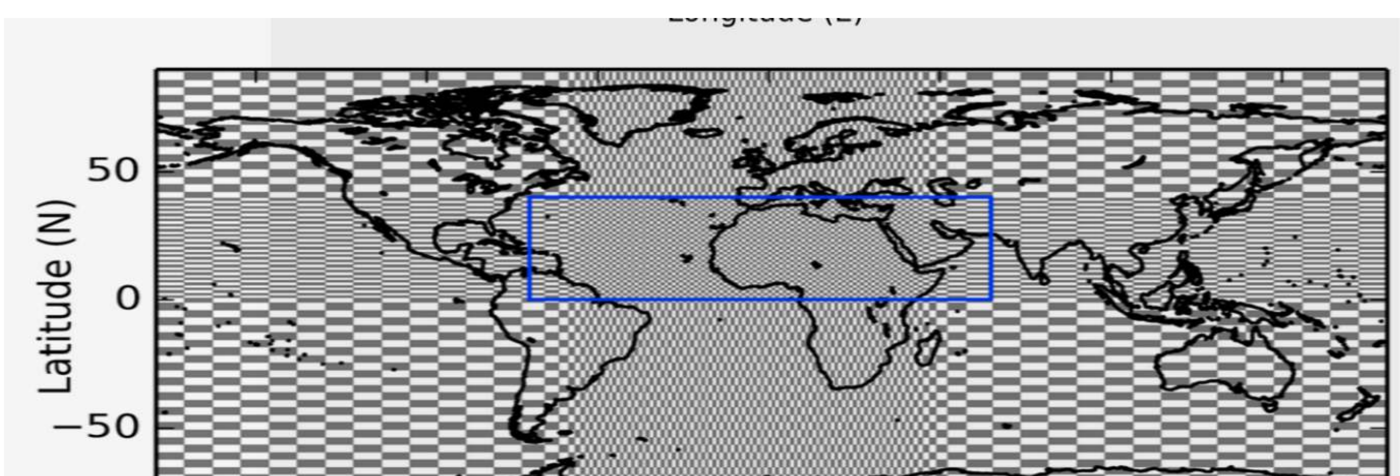
SW downward flux surf. (W/m2)



LW downward flux surf. (W/m2)



Coupled simulations with interactive aerosols (Dialo et al., 2017)
Tracer concetrations in µg / kg, 2006



Observations

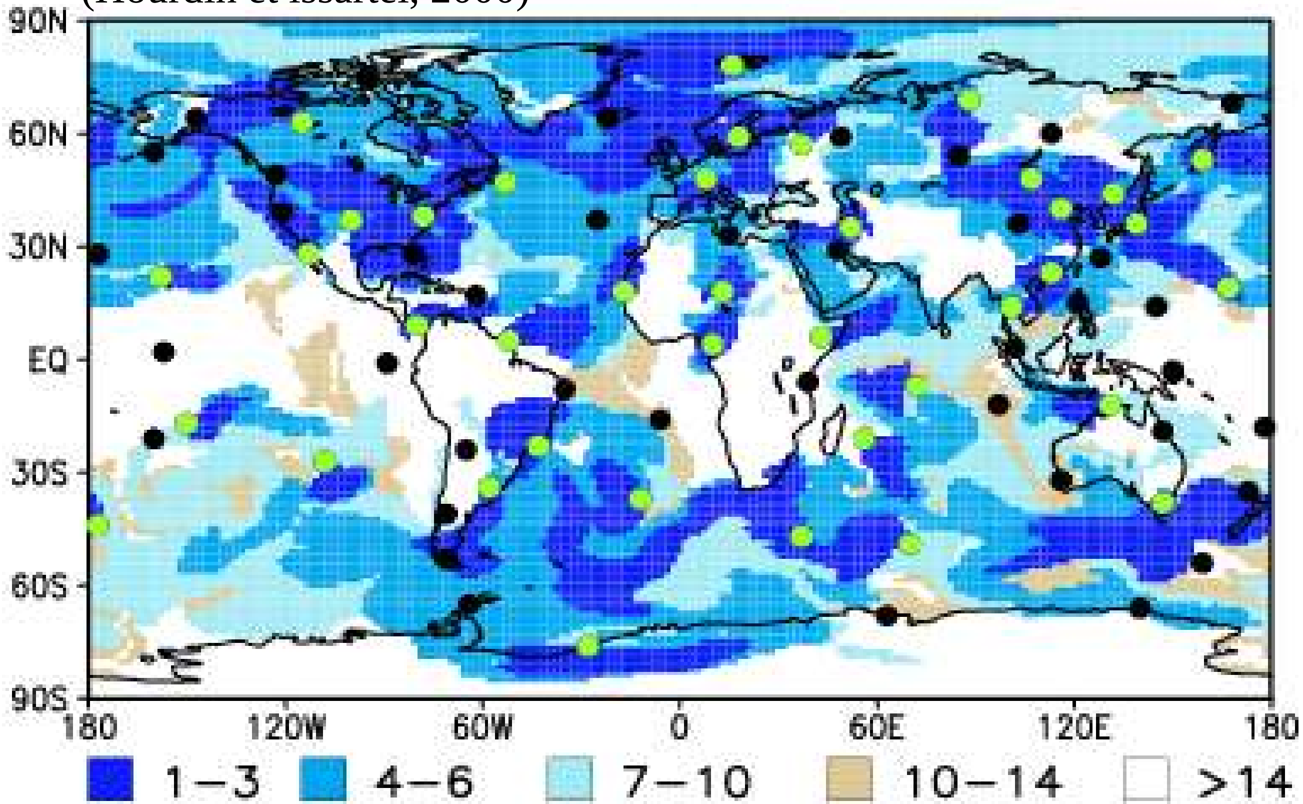
1. Operating modes : c) tracer transport

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

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.

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



F. Hourdin et J.-P. Issartel , 2000, Sub-surface nuclear tests monitoring through the CTBT 133Xe network, Geophysical Research Letters, Vol. 27, p. 2245-2248, 2000

F. Hourdin et O. Talagrand, 2006, Eulerian backtracking of atmospheric tracers: I Adjoint derivation and parametrization of subgrid-scale transport, Q. J. R. M. S., 132 : 567-583 PDF, 2006

F. Hourdin, O. Talagrand et A. Idelkadi, 2006, Eulerian backtracking of atmospheric tracers: II Numerical aspects , Q. J. R. M. S. , 132 : 585-603, 2006

Summary of 3D operating modes

	Global regular	Zoomed
Free	**« Earth system » modeling** Forced by SST (clim or interannual) 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 and source invesion (coupled to Inca, Reprobus or LMDZ aerosol component) *everywhere, u & v or u, v, T & q Evaluation of physical parameterizations with imposed dynamics (*everywhere, u & v only) **Analyses/evaluation on day-by-day baises** **Can be used in quasi real-time / forecast mode**	Analysis of field campaign experiments and site observations Climate downscaling (*everywhere) Regionalmodeling (*outside zoom)

LMDZ : use and configurations

1. Operating modes of the 3D GCM

   a) Free climatic mode
   b) Zooming or/and nudging for climate
   c) Tracer transport

2. Intercomparison exercises and reference versions

   a) The IPSL climate model and CMIP exercises
   b) LMDZ reference versions
   c) Robust improvements from version to version
   d) Evolution of climatic biases and sensitivity

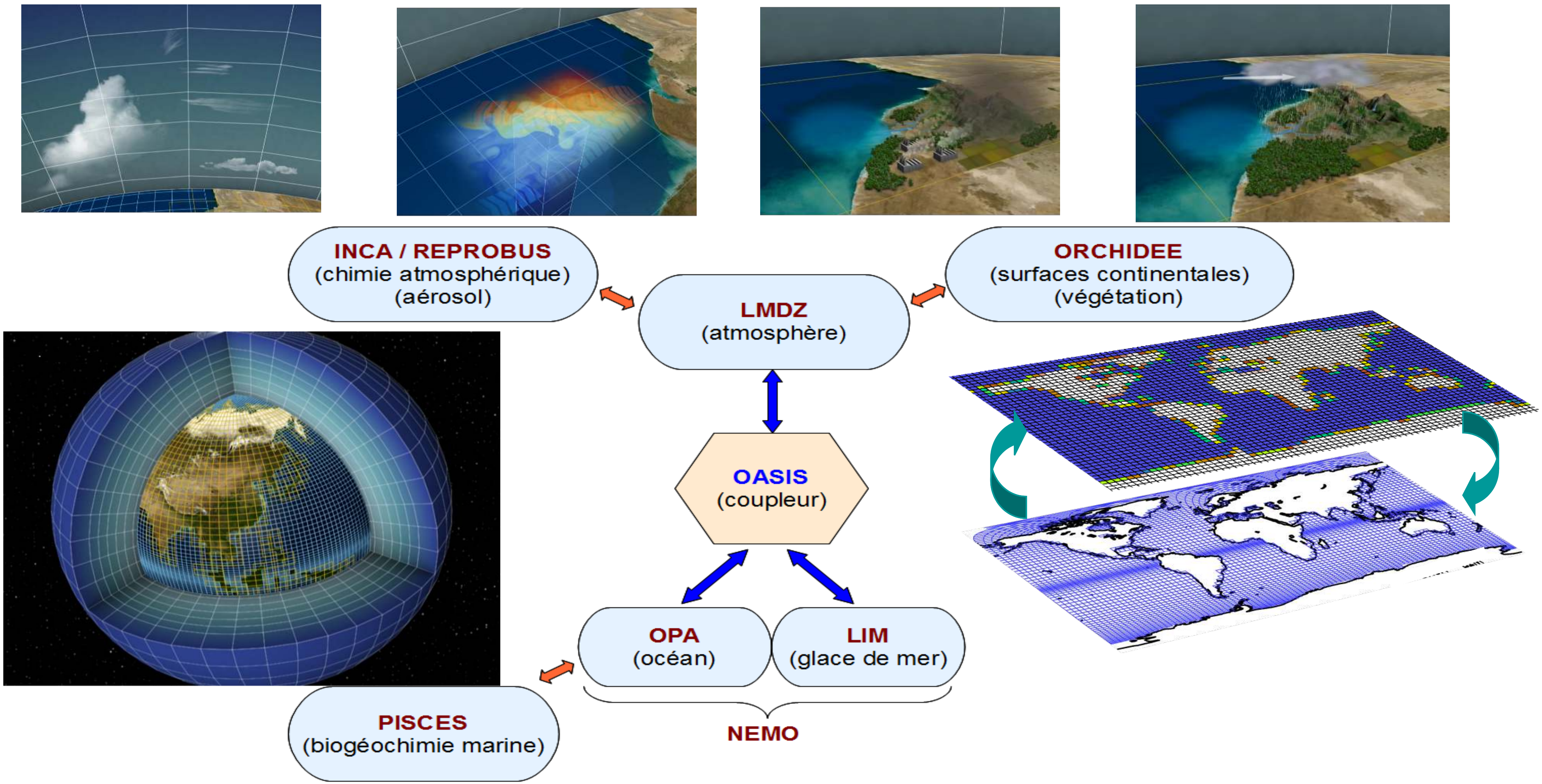
3. Model development and tuning

   a) Choice of a new configuration : content and resolution
   b) Importance of tuning
   c) Methodology 1D/nudged simulations/tuning

2. Reference configurations : a) The IPSL climate model and the 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



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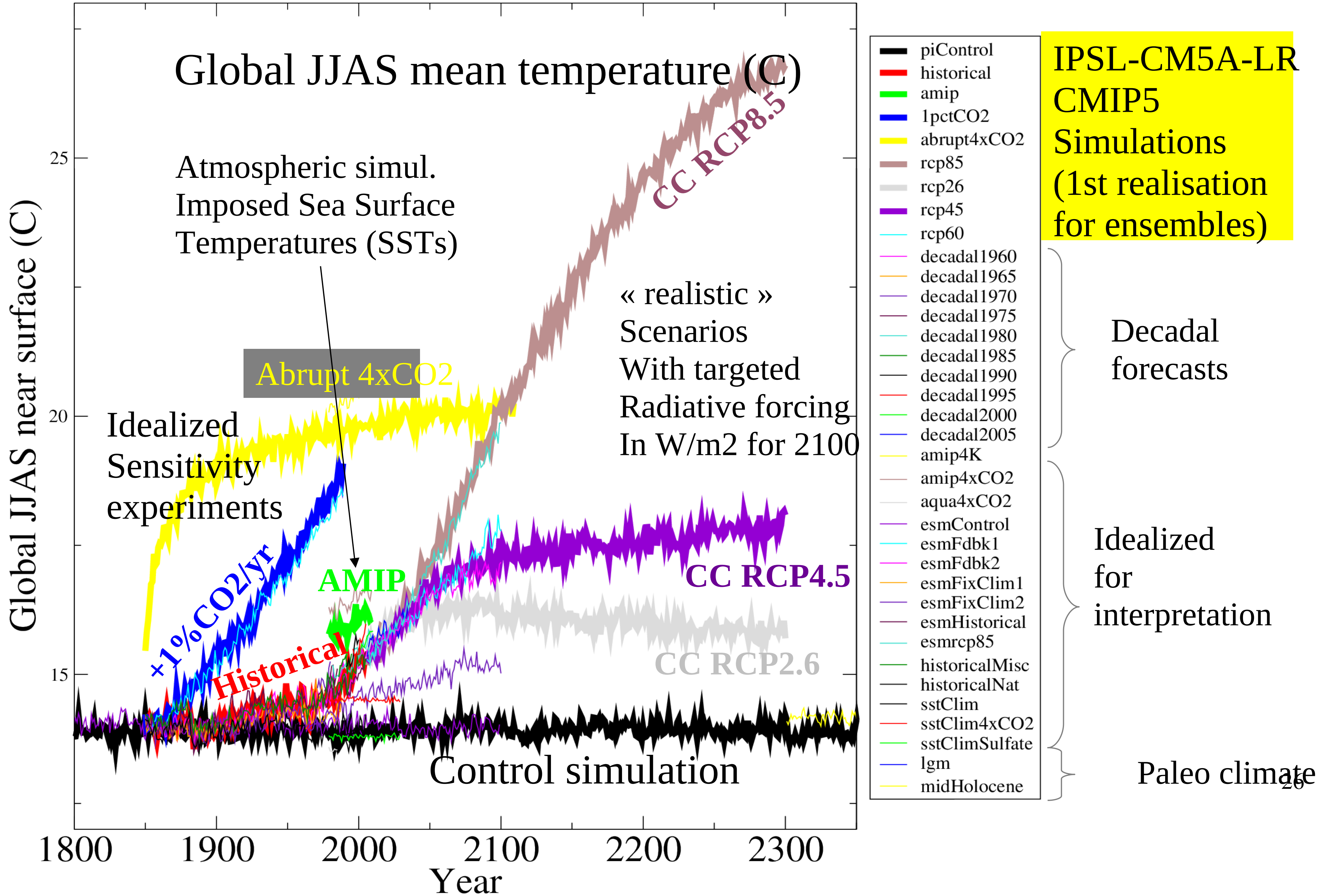
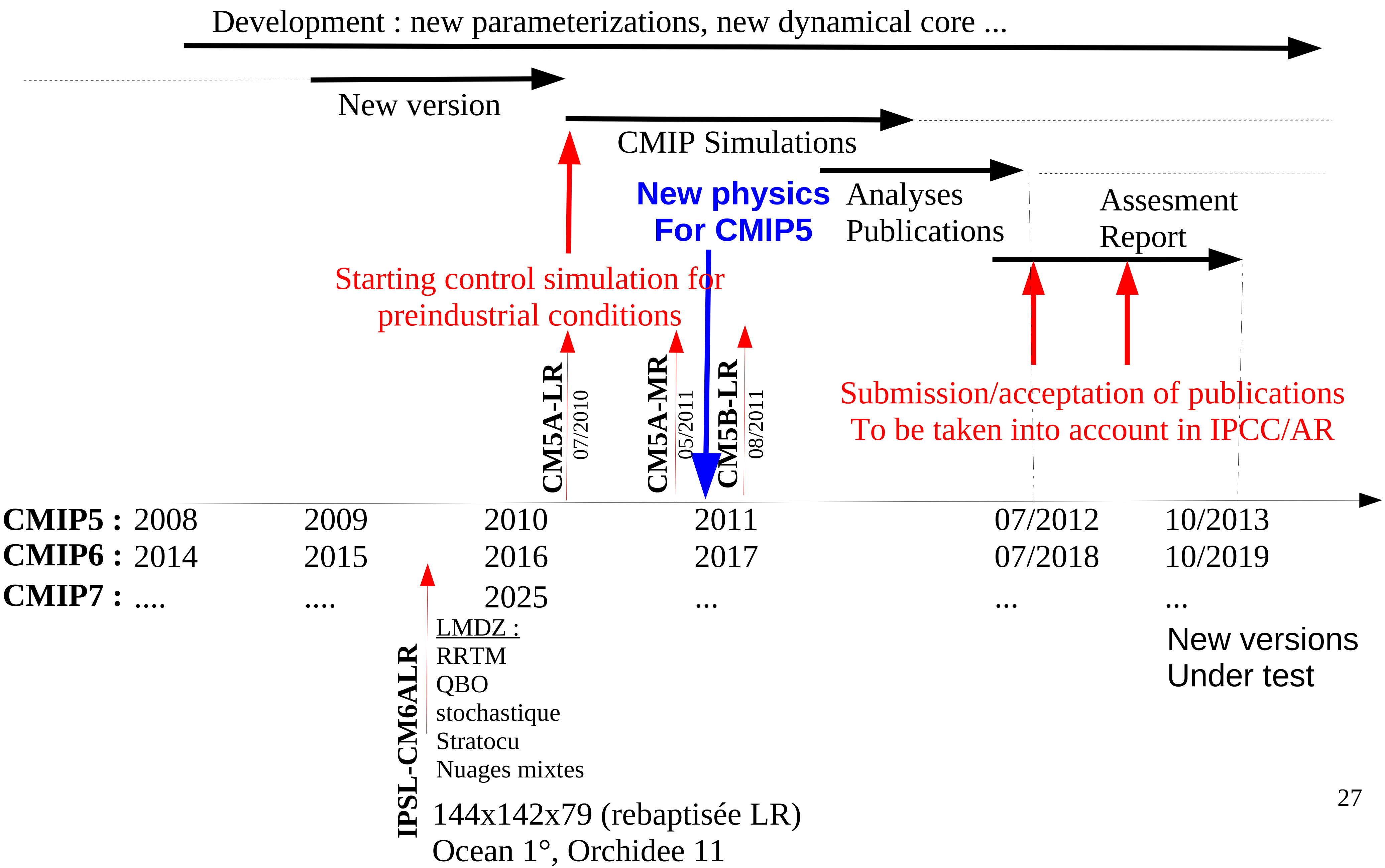


Development of LMDZ and the CMIP rendez-vous CMIP

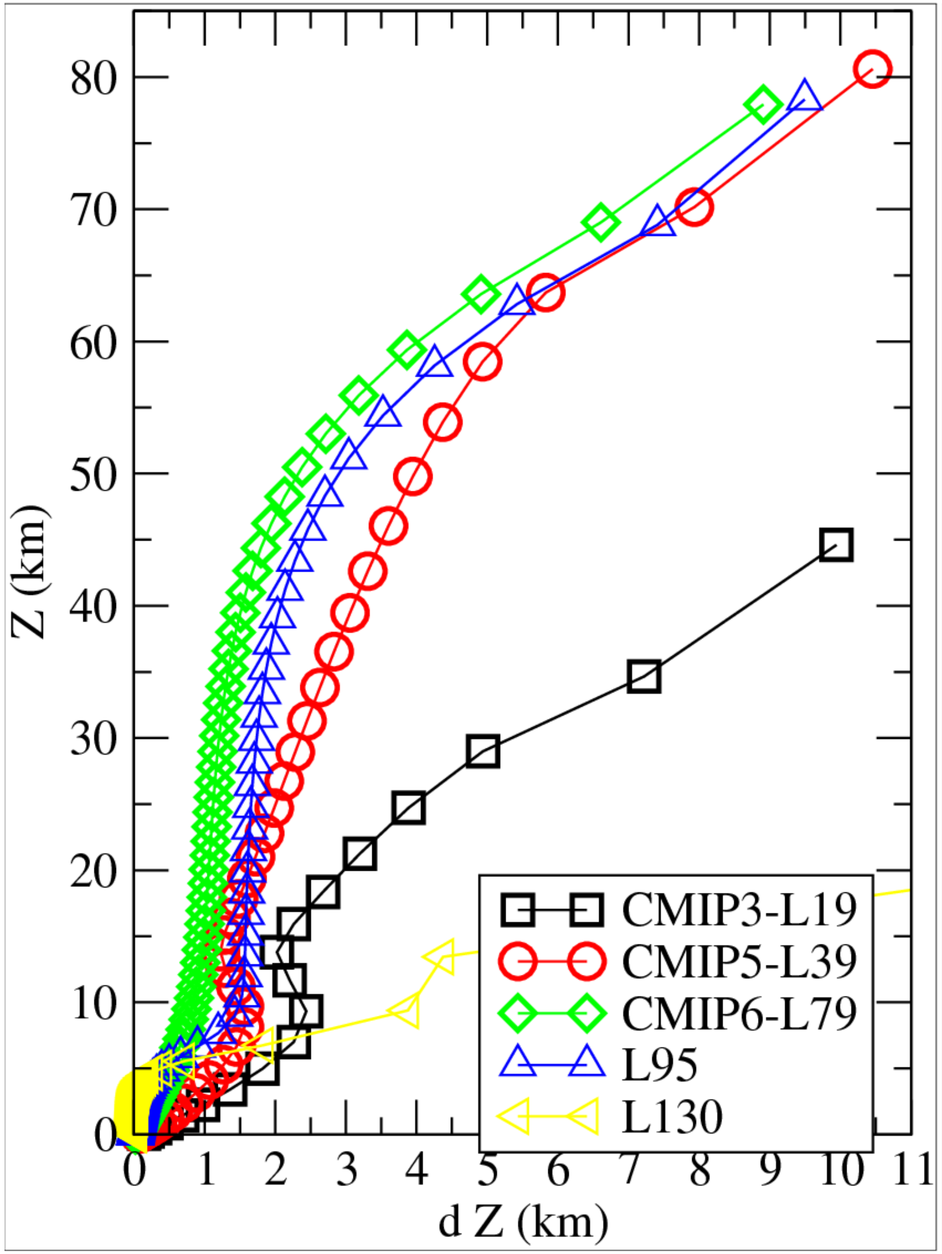


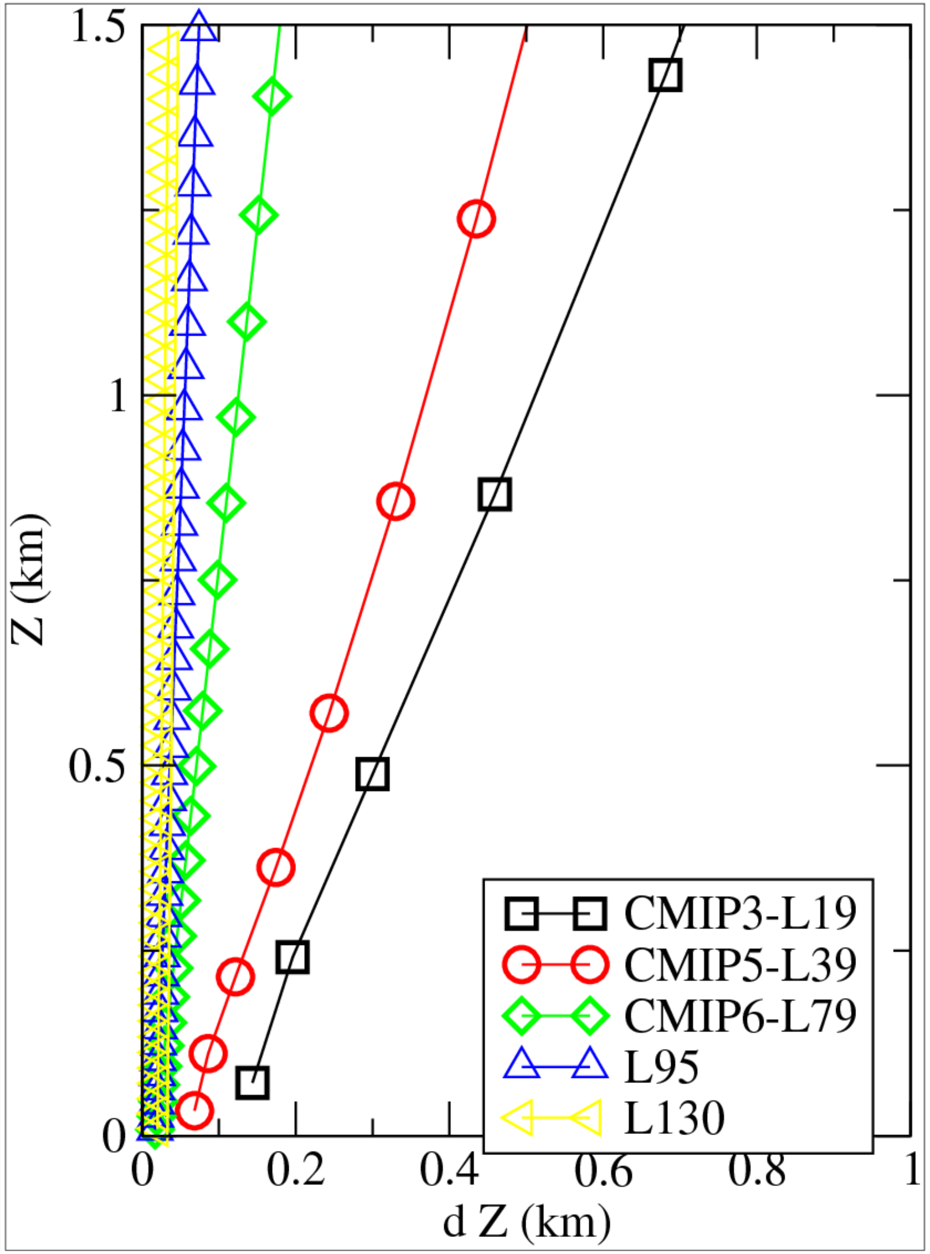
Summary of reference climate configurations

	Horizontal grid	Vertical grid	Physics content	Name
CMIP3	96 x 71	L19	Changing convection from Tiedtke to Emanuel Subgrid scale orography	LMDZ4 IPSL-CM3
CMIP5	LR : 96 x 71	L39	Standard Physics (SP) : same as LMDZ4	IPSL-CM5A
	MR : 144 x 142	Extension to stratosph.	**New Physics (NP) : SP + thermals and cold pools + ALE/ALP clousre for deep convection**	IPSL-CM5B
CMIP6	VLR : 96 x 71	L39	Standard Physics (SP) : same as LMDZ4	IPSL-CM5A2
	LR : 144 x 142 MR : 256 x 256 HR : 512 x 360	L79 $\delta z/z$ 0.1, for z <3 km $\delta z/z \leq 1$ km, for z <50 km	**New Physics (NP) + New radition : RRTM + SW 6 bands Stochastic triggering of deep convection Straocumulus from thermal plumes Ice thermodynamics Improve coupling with surface Non ogrographic gravity wave**	IPSL-CM6A

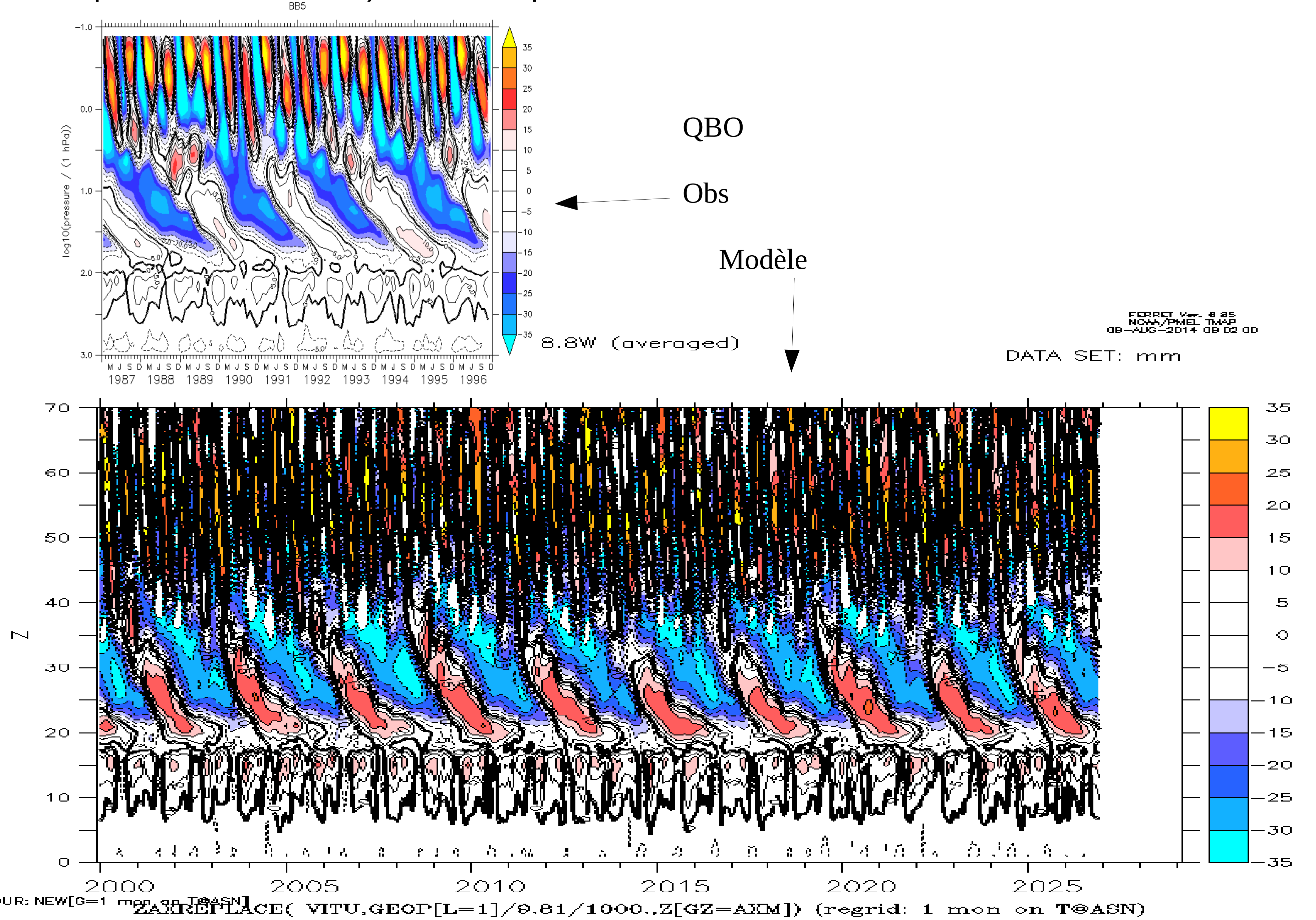
Hourdin, F., C. Rio, J.-Y. Grandpeix, J.-B. Madeleine, F. Cheruy, N. Rochetin, A. Jam, I. Musat, A. Idelkadi, L. Fairhead, M.-A. Foujols, L. Mellul, A. Traore, J.-L. Dufresne, O. Boucher, M.-P. Lefebvre, E. Millour, E. Vignon, J. Jouhaud, B. Diallo, F. Lott, G. Gastineau, A. Caubel, Y. Meurdesoif, and J. Ghattas,
LMDZ6A: the atmospheric component of the IPSL climate model with improved and better tuned physics, James,
http://dx.doi.org/10.1029/2019MS001892

Evolution of the vertical discretization in LMDZ reference configurations





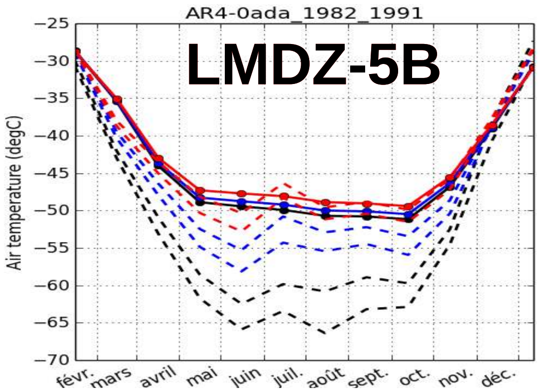
2. Inter-comparison exercises c) Robust improvements from version to version

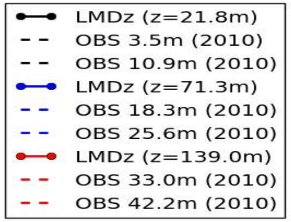


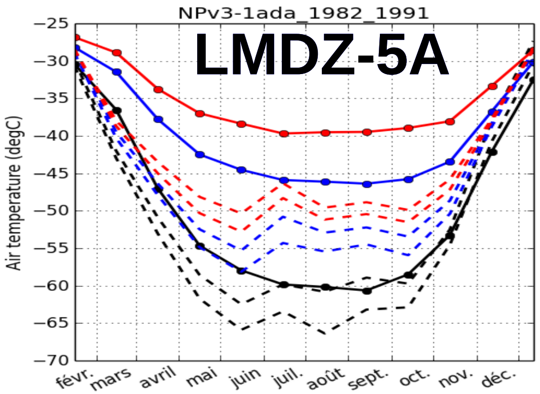
Among the models with a Quasi Bienal Oscillation

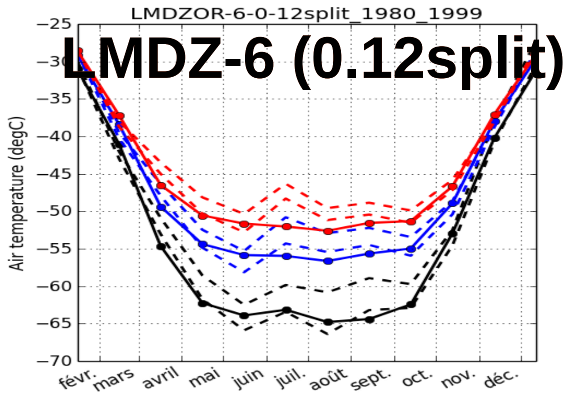
2. Inter-comparison exercises c) Robust improvements from version to version

T at Dome C
Antartic Plateau



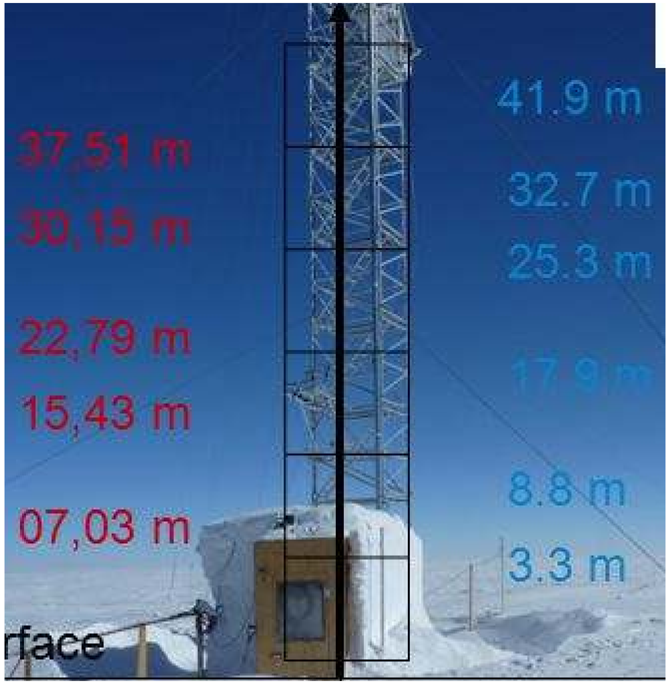


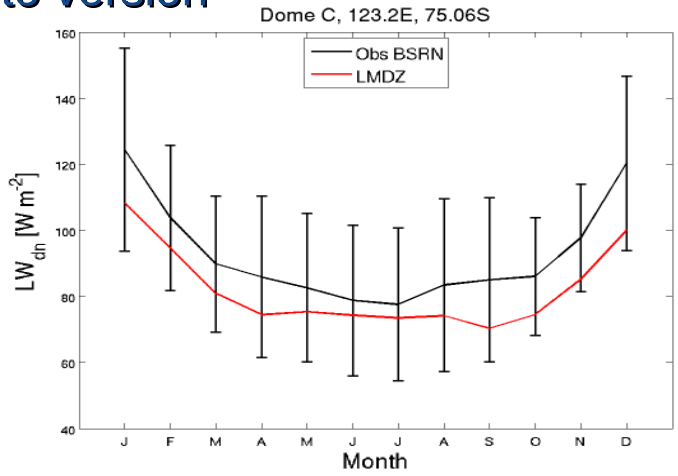


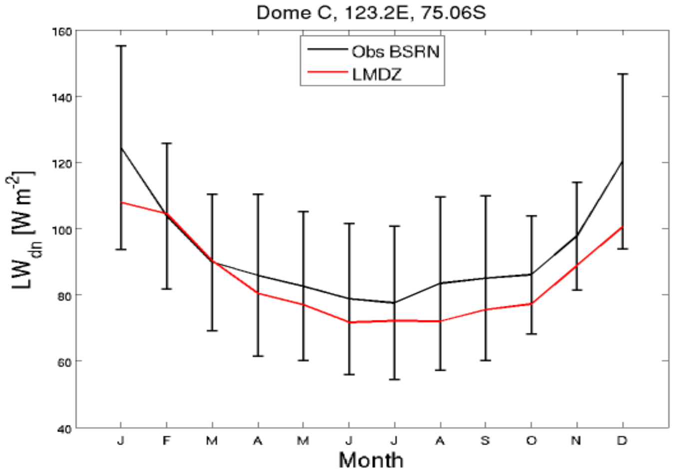


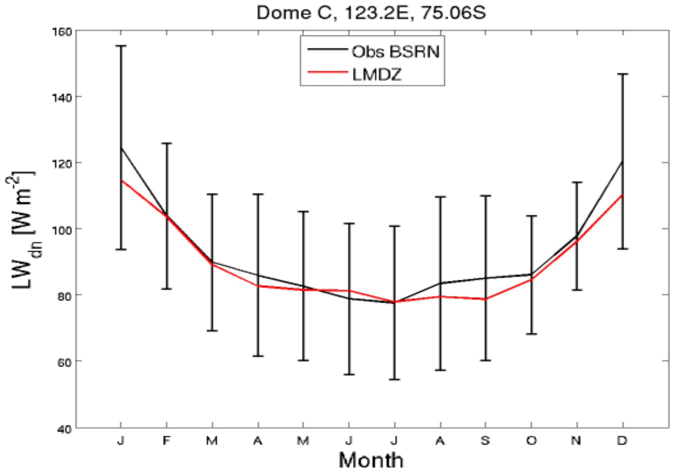
Improvement of the respresentation of the stable boundary layer.
Vignon et al. 2017

Compared to observations at 5 levels over a 40m measurement tower at Dome C

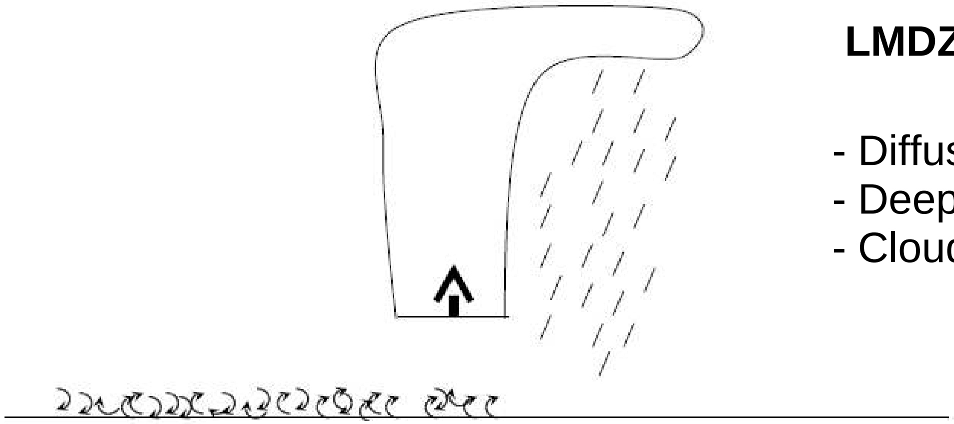






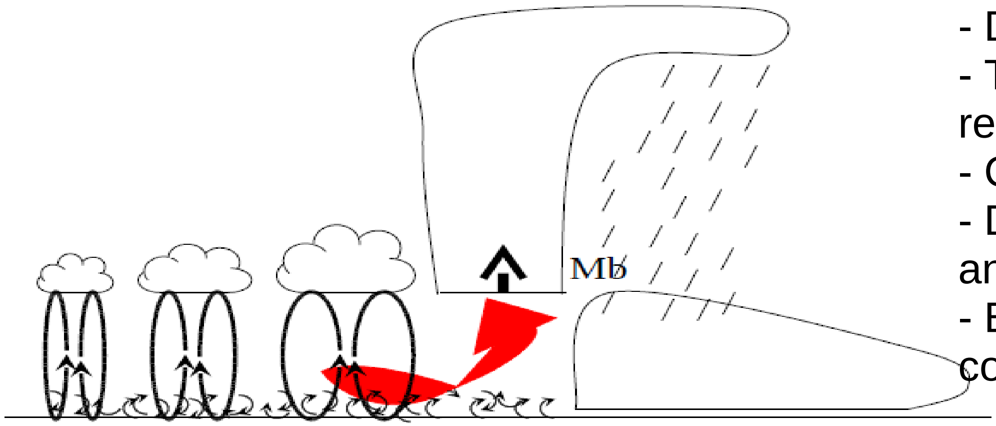


The different physical packages of LMDZ reference versions



LMDZ5A (old or standard physics)

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

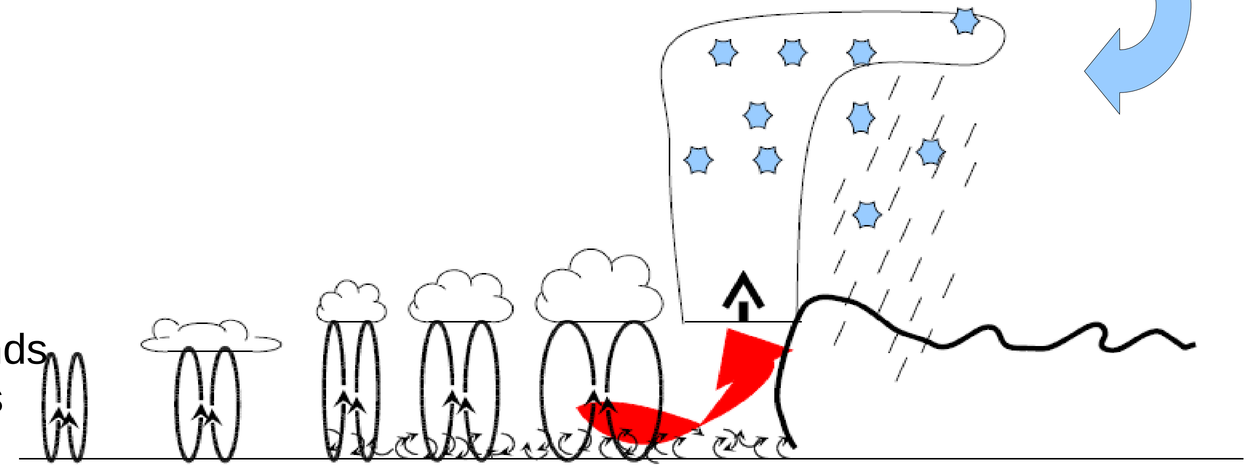


LMDZ5B (« new physics »)

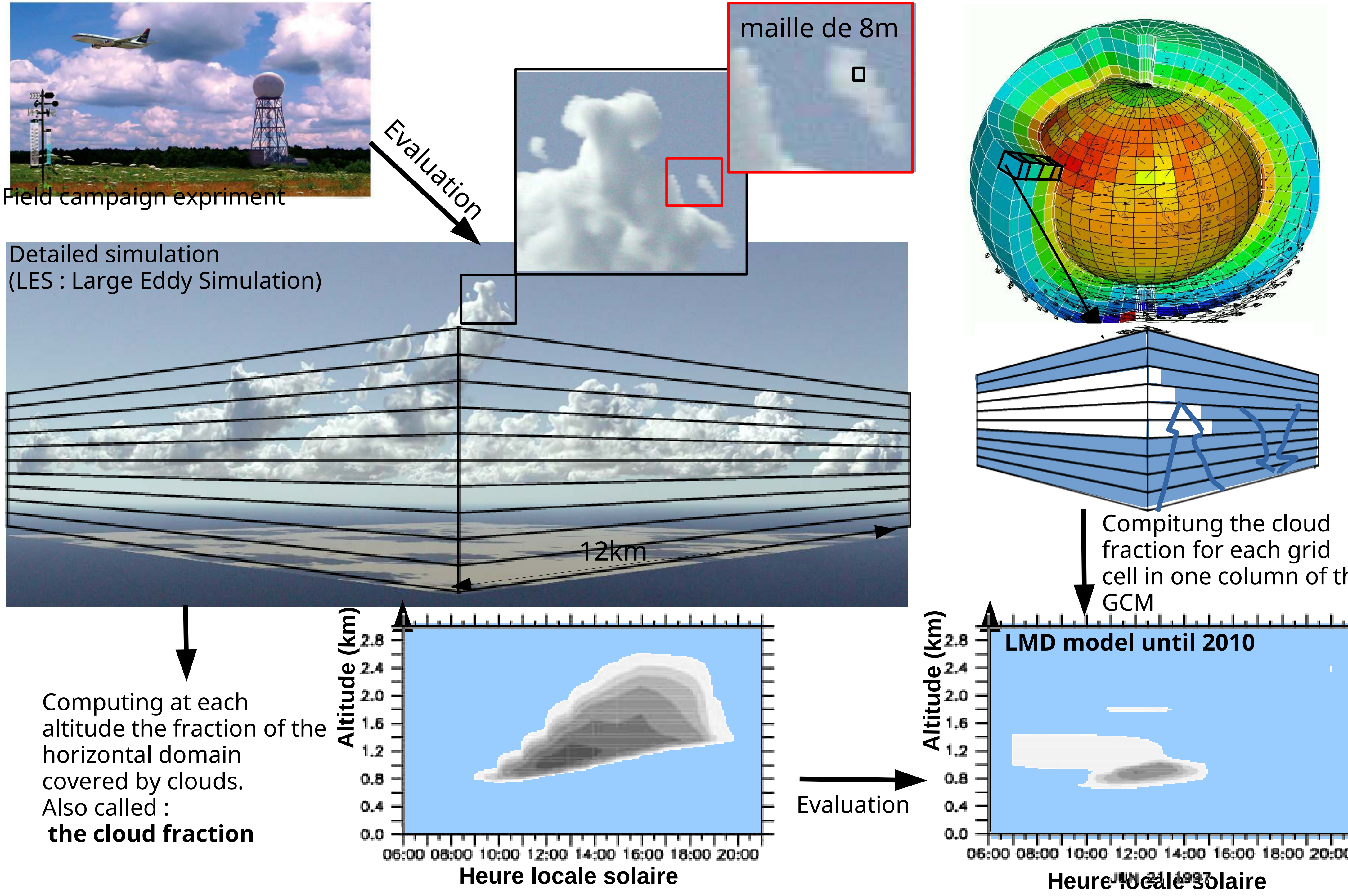
- Diffusion scheme (Yamada, 1983)
- Thermal plume model except in strato cumulus regions (Rio et al., 2010)
- Cold pools (Grandpeix et Lafore, 2010)
- Deep convection controlled by thermals and wakes (Rio et al., 2012)
- Bi-gaussian cloud scheme for shallow convection (Jam et al., 2013)

LMDZ6 = LMDZ5B ++

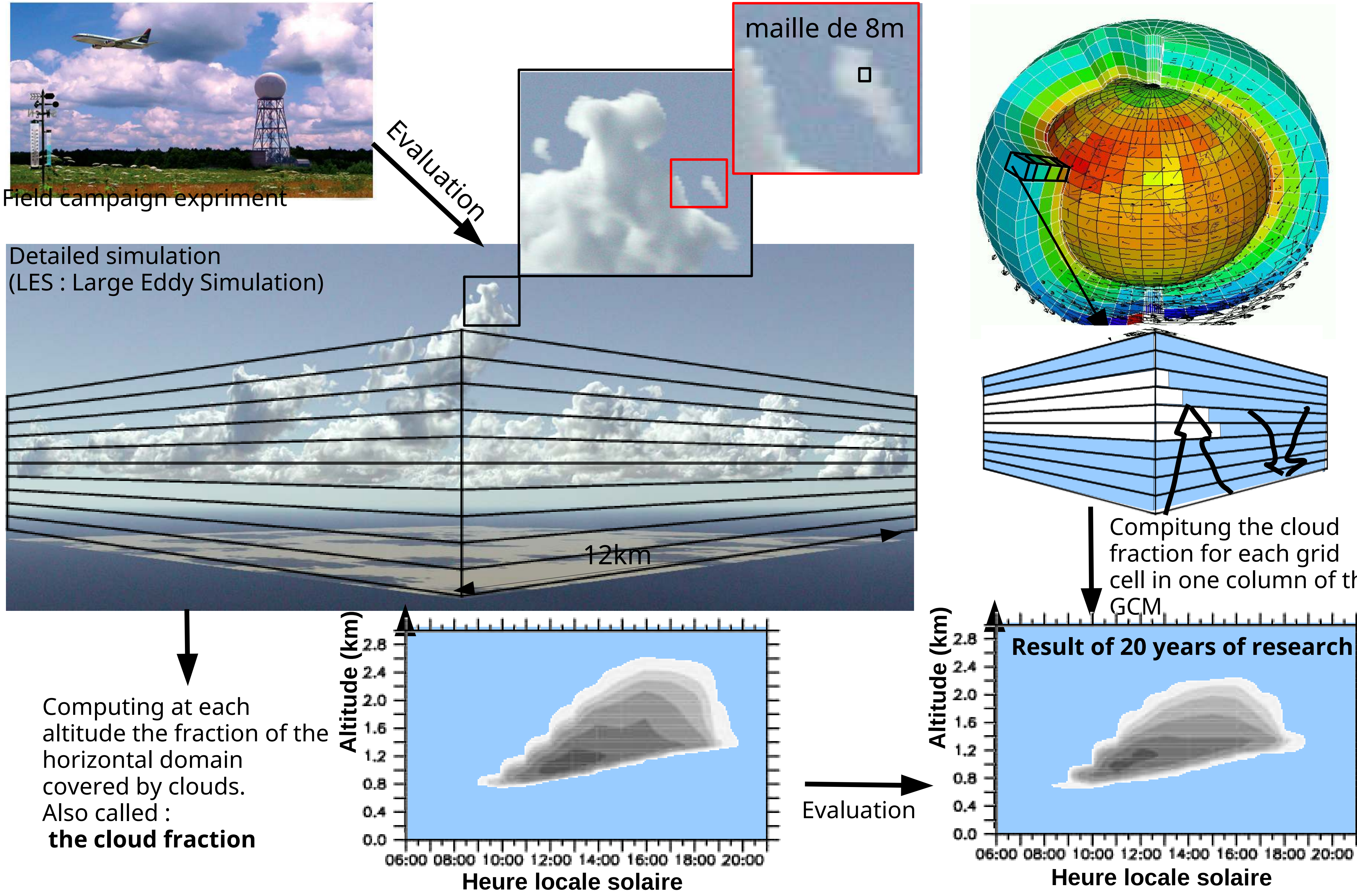
+ Thermal plume model everywhere
+ Stochastic triggering of deep convection
+ Different convective mixing formulation
+ Thermodynamical effect of ice
+ RRTM for infrared radiation and SW 6 bands
+ Better boundary layer for stable conditions
+ Non orographic gravity waves



2. Inter-comparison exercises c) Robust improvements from version to version



2. Inter-comparison exercises c) Robust improvements from version to version



Successive activation of the thermal plume model

Results from atmospheric simulations forced by climatic sea surface temperature

: activating thermal plumes

: Subsidence regions

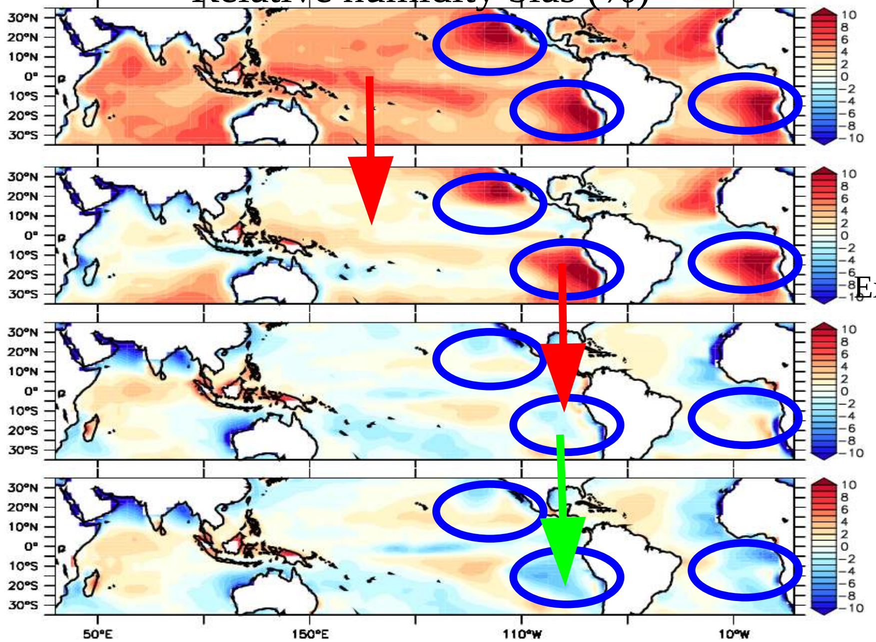
: Detrainement modifié

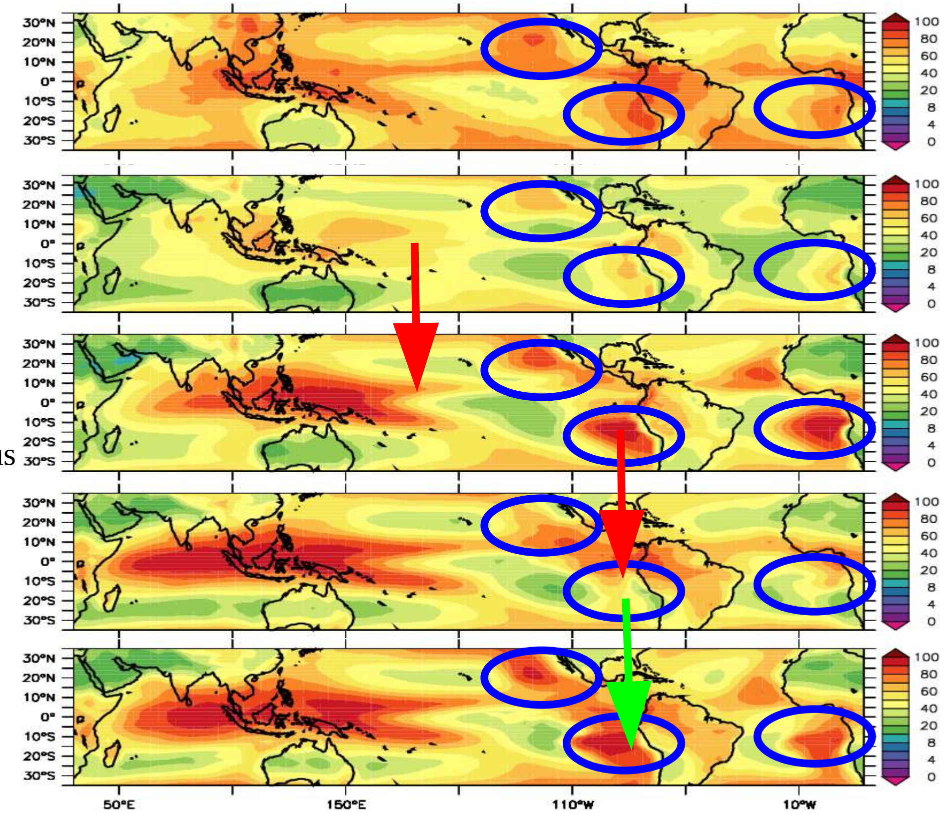
Observations Calipso GOCCP

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

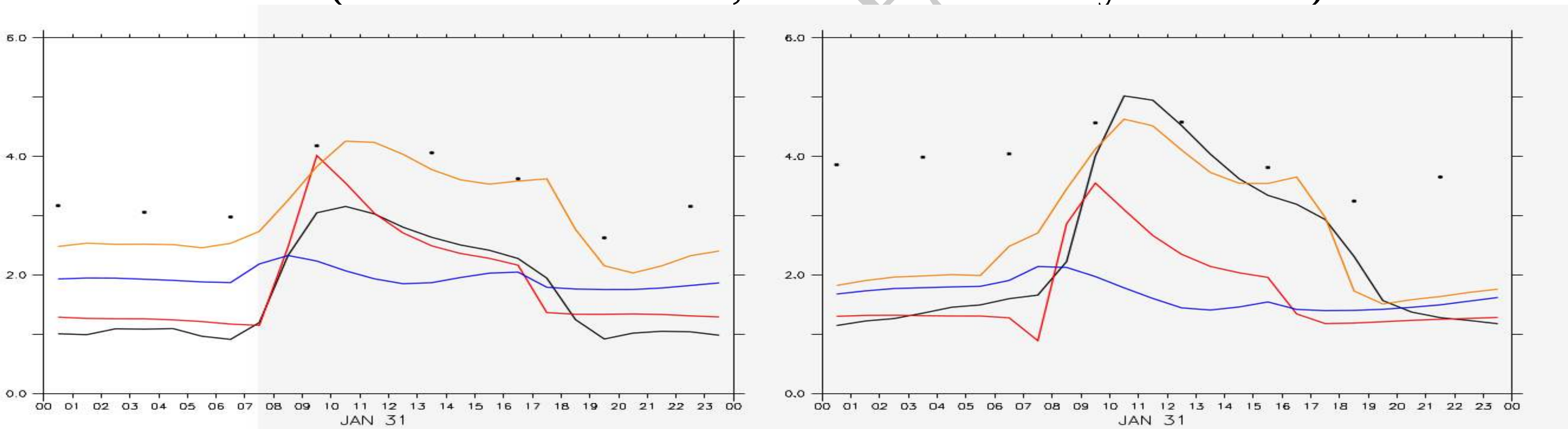
Frédéric Hourdin, Arnaud Jam, Catherine Rio, Fleur Couvreux, Irina Sandu,Marie-Pierre Lefebvre, Florent Brient, and Abderrahmane Idelkadi, Unified Parameterization of Convective Boundary LayerTransport and Clouds With the Thermal Plume Model, James, 2019, https://doi.org/10.1029/2019MS001666

Hourdin, Frédéric and Rio, Catherine and Jam , Arnaud and Traore , Abdoul Khadre and Musat , Ionela, Convective boundary layer control of the sea surfacetemperature in the tropics, Journal of Advances in Modeling Earth Systems, 12, https://doi.org/10.1029/2019MS001988

2. Inter-comparison exercises c) Robust improvements from version to version

• • • Observations
—— Reanalyses (used to nudge)
—— 5A
—— 5B
—— 6

Wind speed diurnal cycle over Sahel
(Jan. to March 2006, Cinzana and Banyzoumbou)

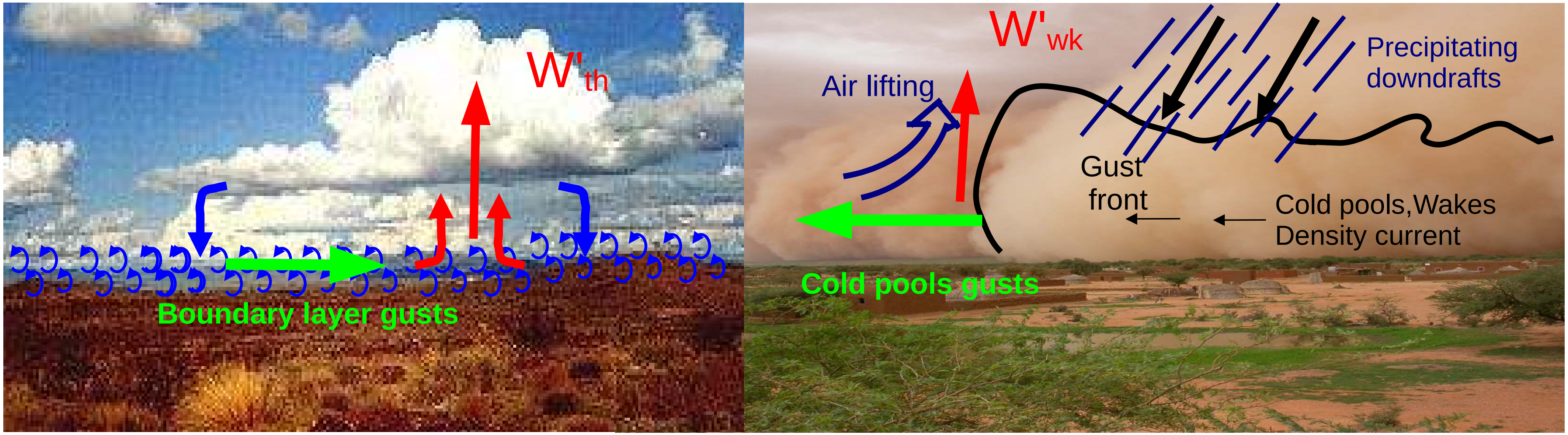


Summary of « thermal plume » model added value :
→ Better vertical transport
→ Drying of the surface
→ Better representation of winds
→ Coupled to bi-gaussian cloud scheme: representation of cumulus and strato-cumulus clouds

F. Hourdin, M. Gueye, B. Diallo, J.-L. Dufresne, J. Escribano, L. Menut, B. Marticoréna, G. Siour, and F. Guichard, 2015, Parameterization of convective transport in the boundary layerand its impact on the representation of the diurnal cycleof wind and dust emissions , 2015, Atmos. Chem. Phys., 15, 6775-6788 doi:10.5194/acp-15-6775-2015

2. Inter-comparison exercises c) Robust improvements from version to version

New physics (LMDZ5B)
Deep convection closure (trigerring and intensity) controled by sub-cloud processes :
Using vertical velocity coming from the thermals and cold pools

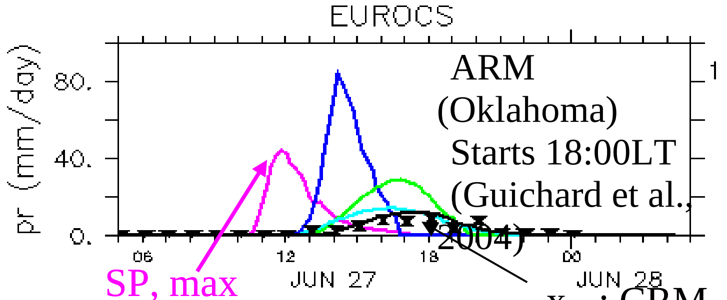


Improvements since LMDZ5 :
Random triggering
Accounting for gusts

2. Inter-comparison exercises c) Robust improvements from version to version

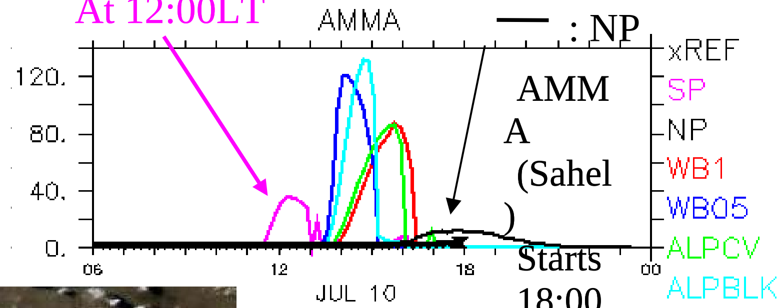
Shifting the diurnal cycle of convective rainfall : possible with parameterized convection

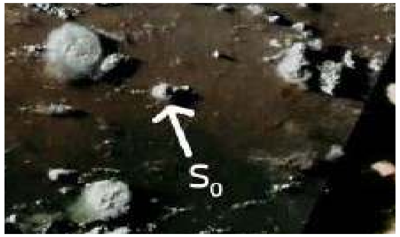
1D test cases/ comparison with explicit simulations (MesoNH)



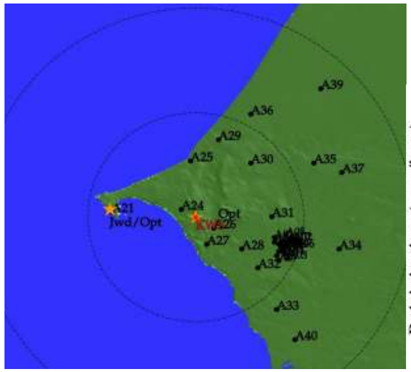
SP, max
At 12:00LT

x : CRM
— : NP

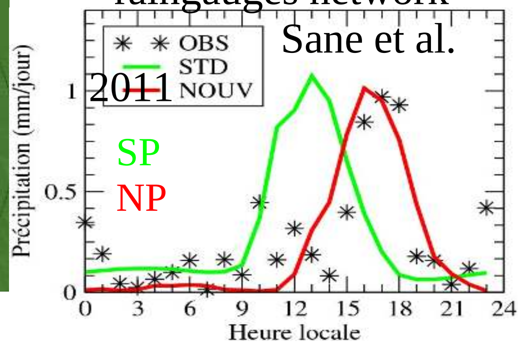




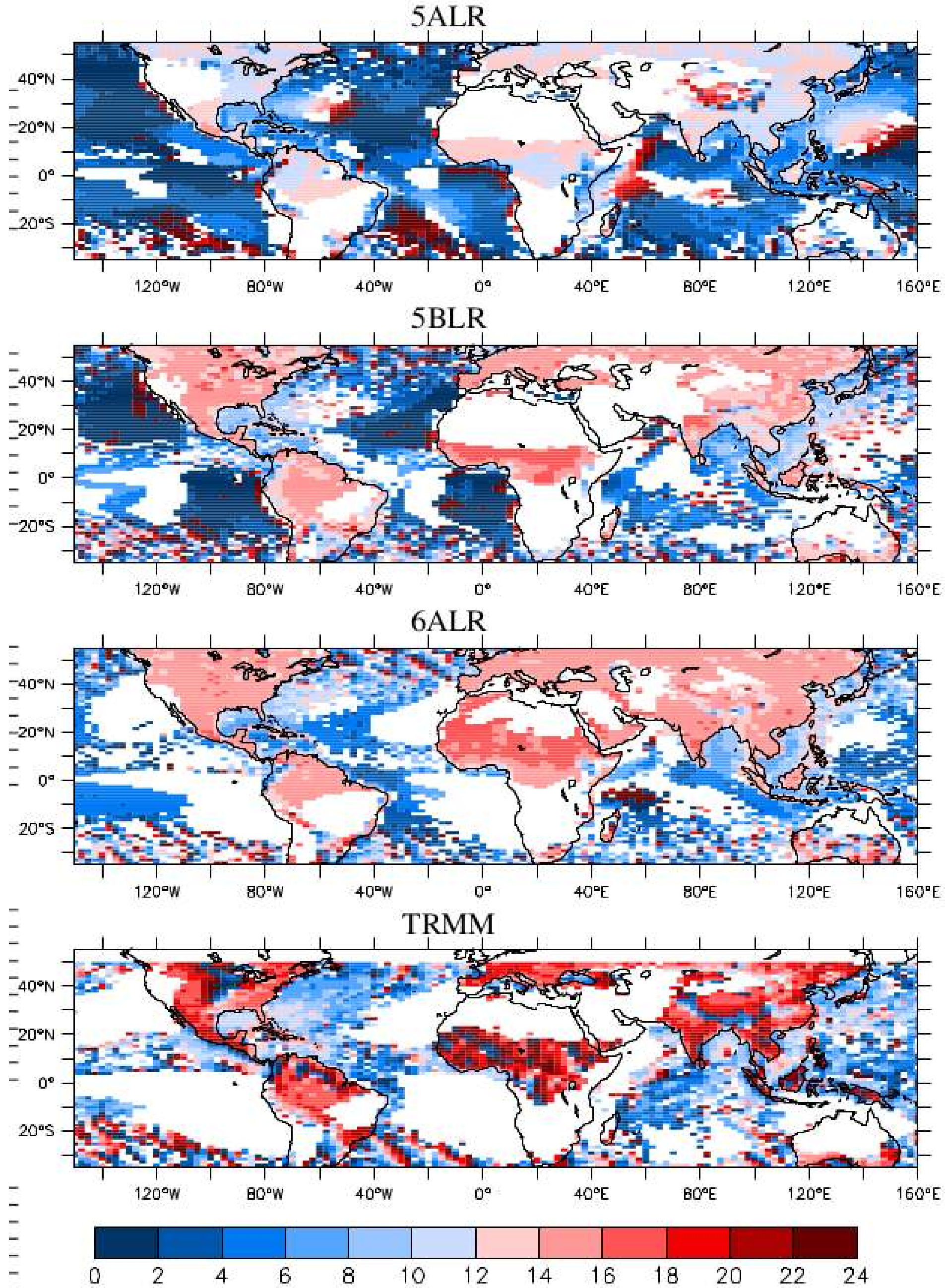
AMMA 10 July case,
convection initiation, Niamey
Couvreux et al., 2012
Rio et al., 2012



Dakar LPAOSF/NASA
raingauges network

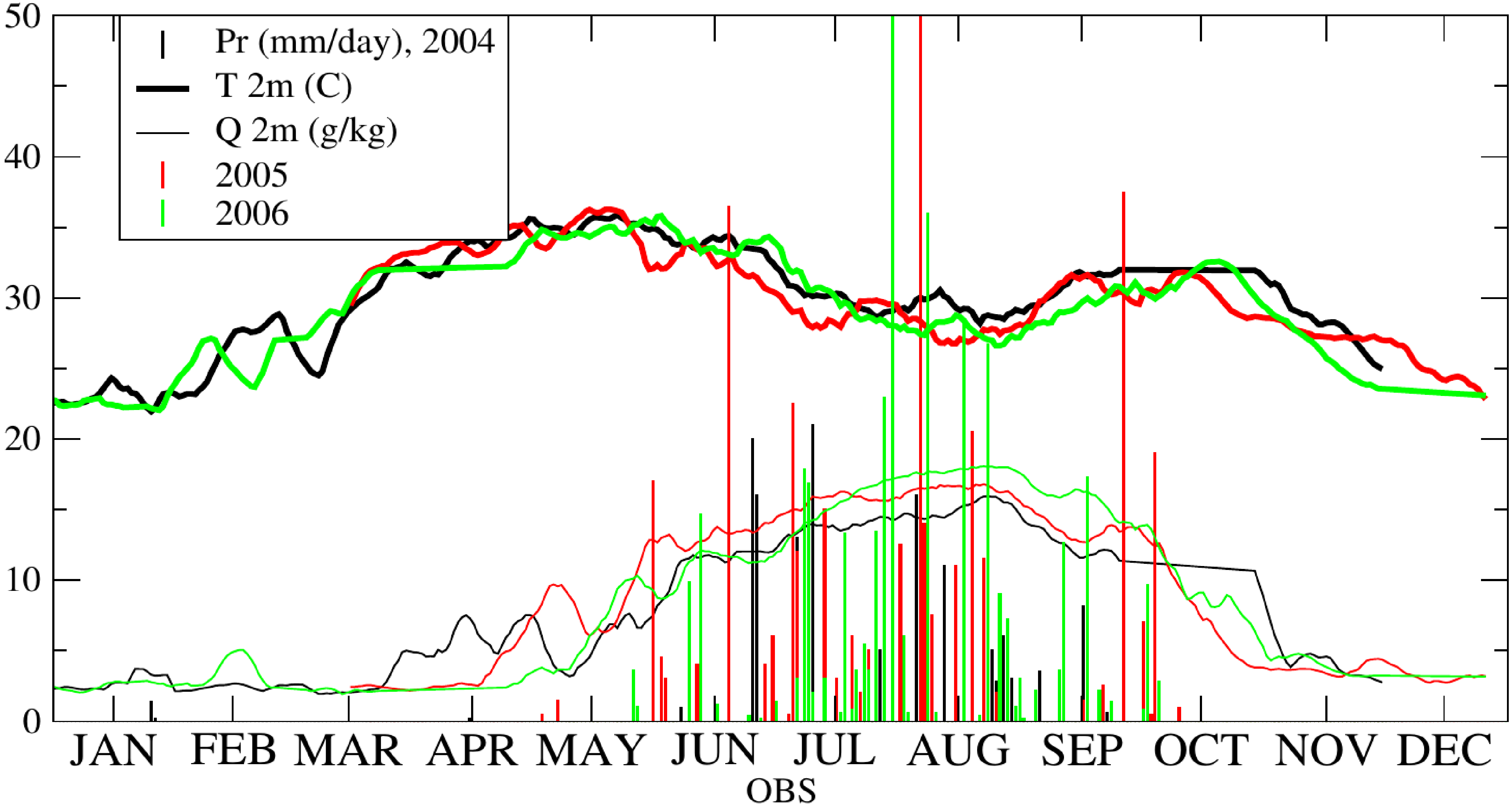


- Evolution moyenne de la pluie dans la journée
- au Sénégal dans une Simulation 3D

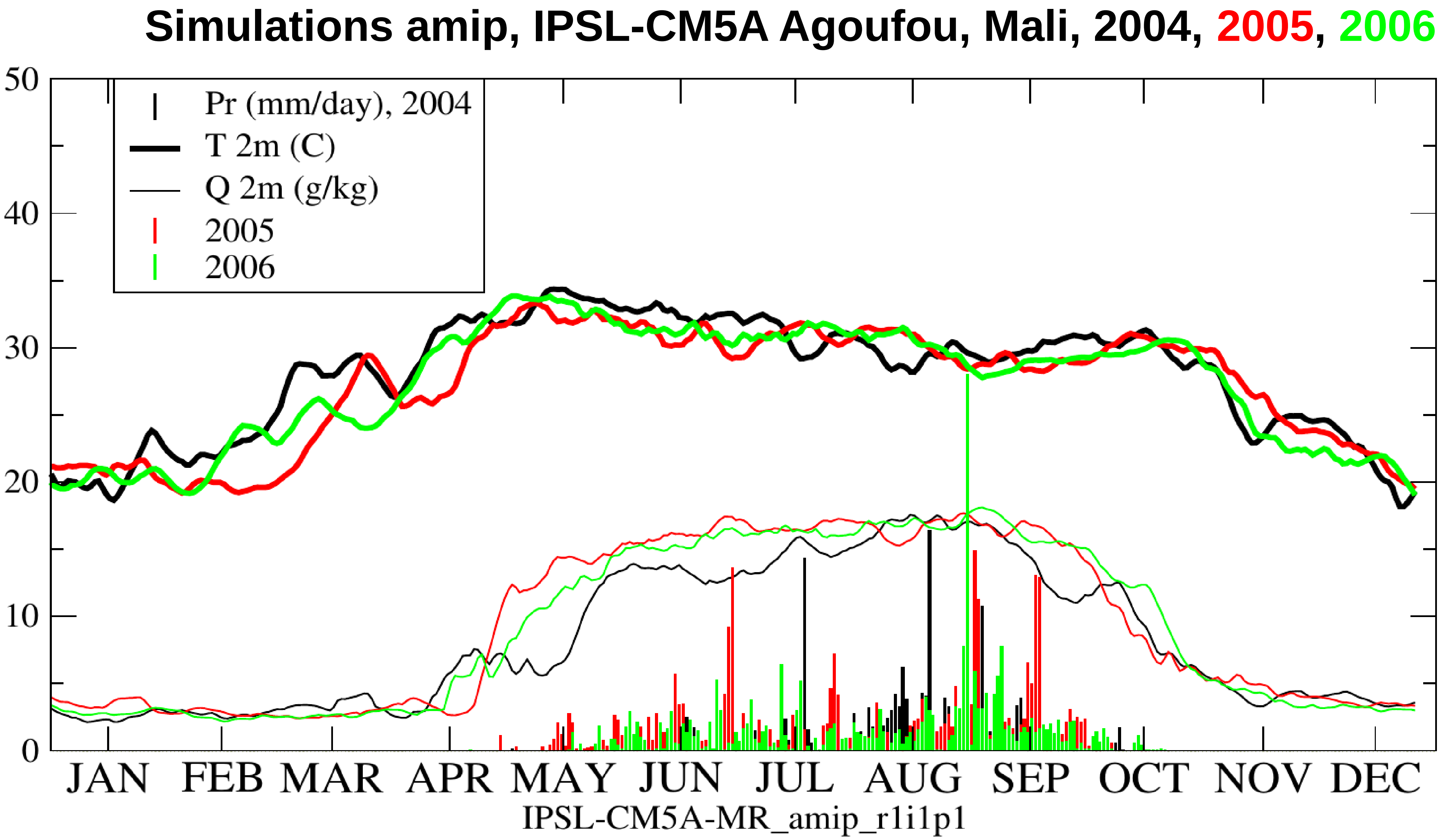


A good representation of the diurnal cycle of rainfall over continents

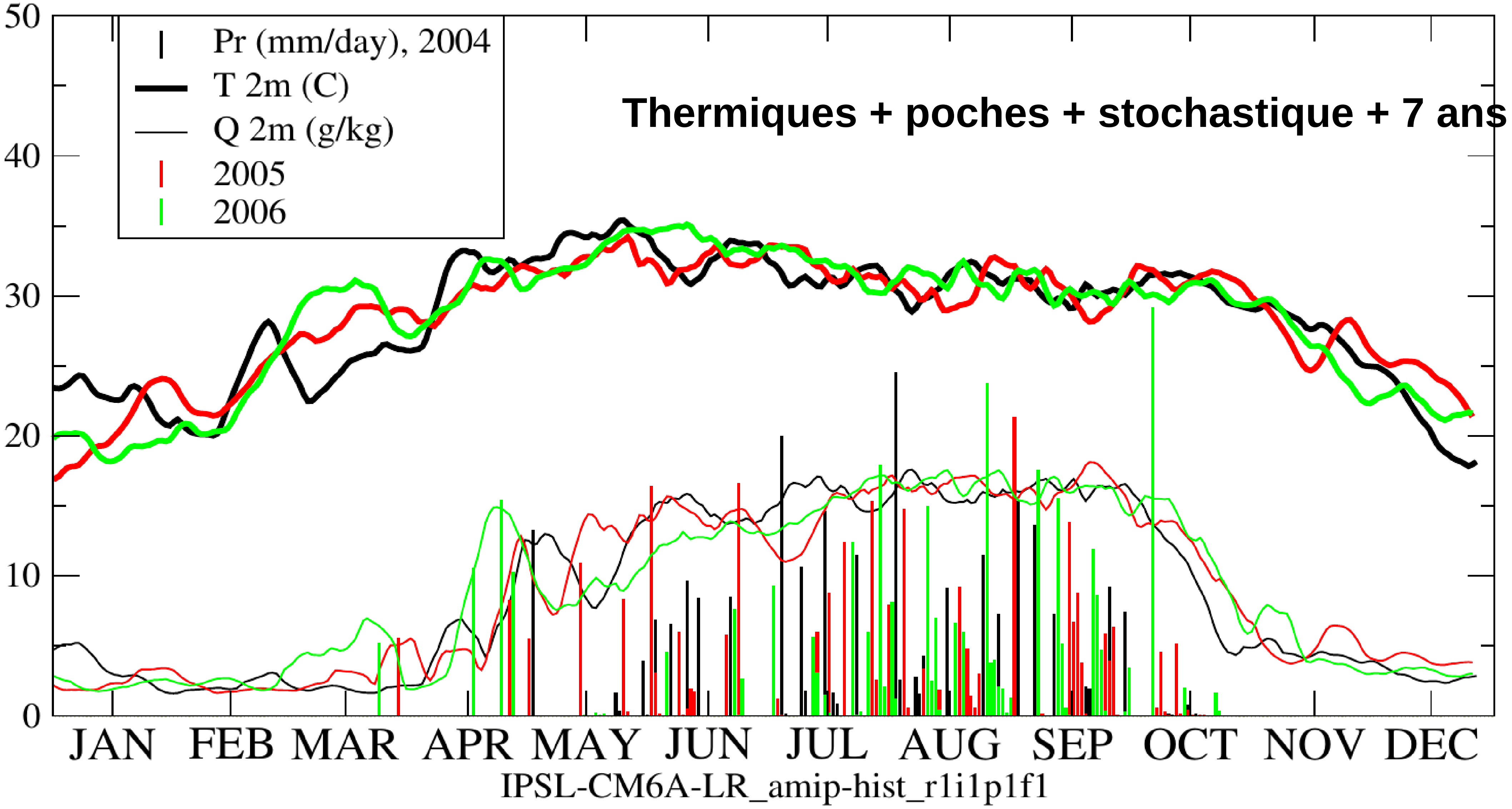
Observations Agoufou, Mali, 2004, 2005, 2006



2. Inter-comparison exercises c) Robust improvements from version to version

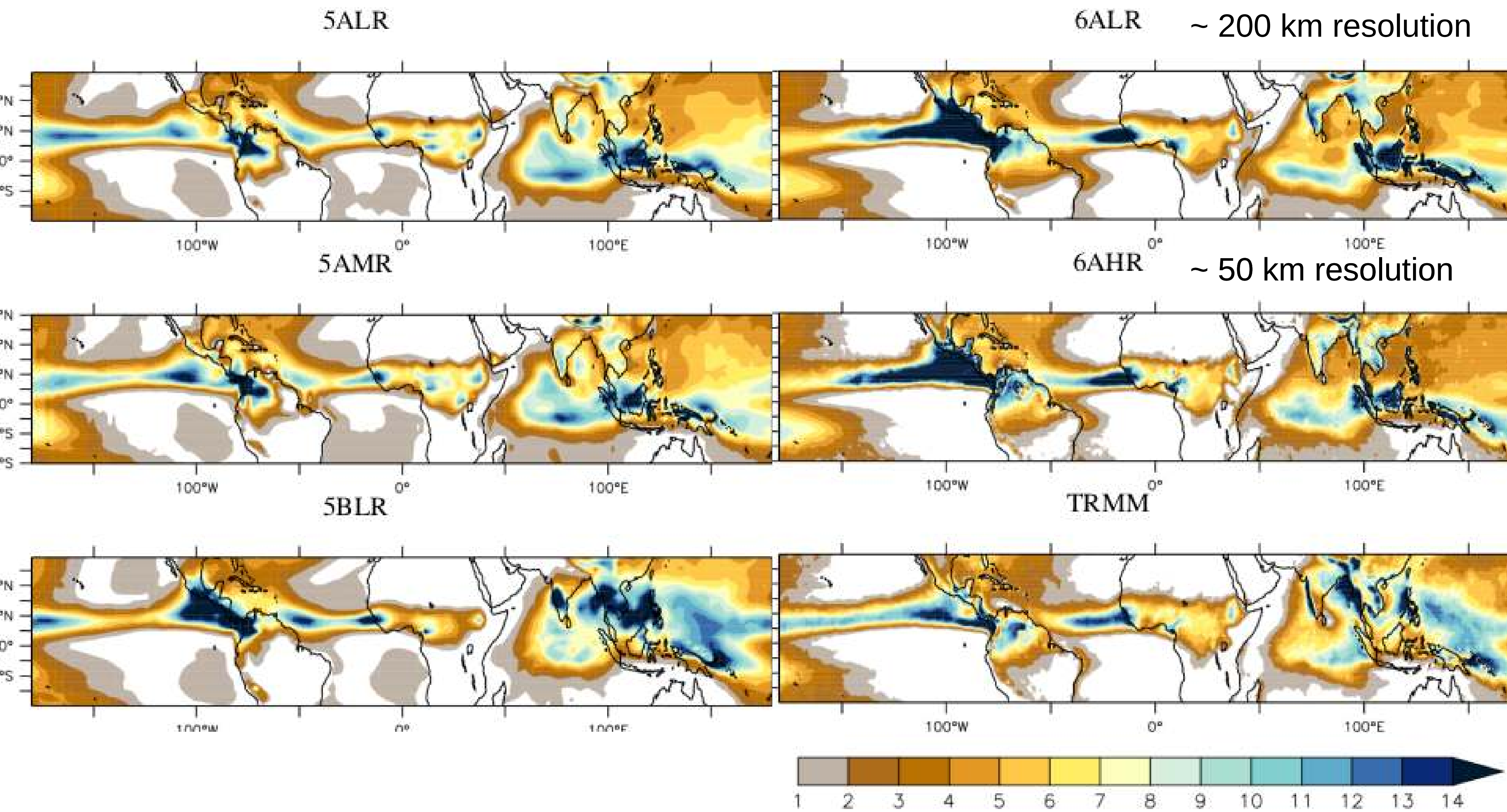


Simulations amip, IPSL-CM6A Agoufou, Mali, 2004, 2005, 2006



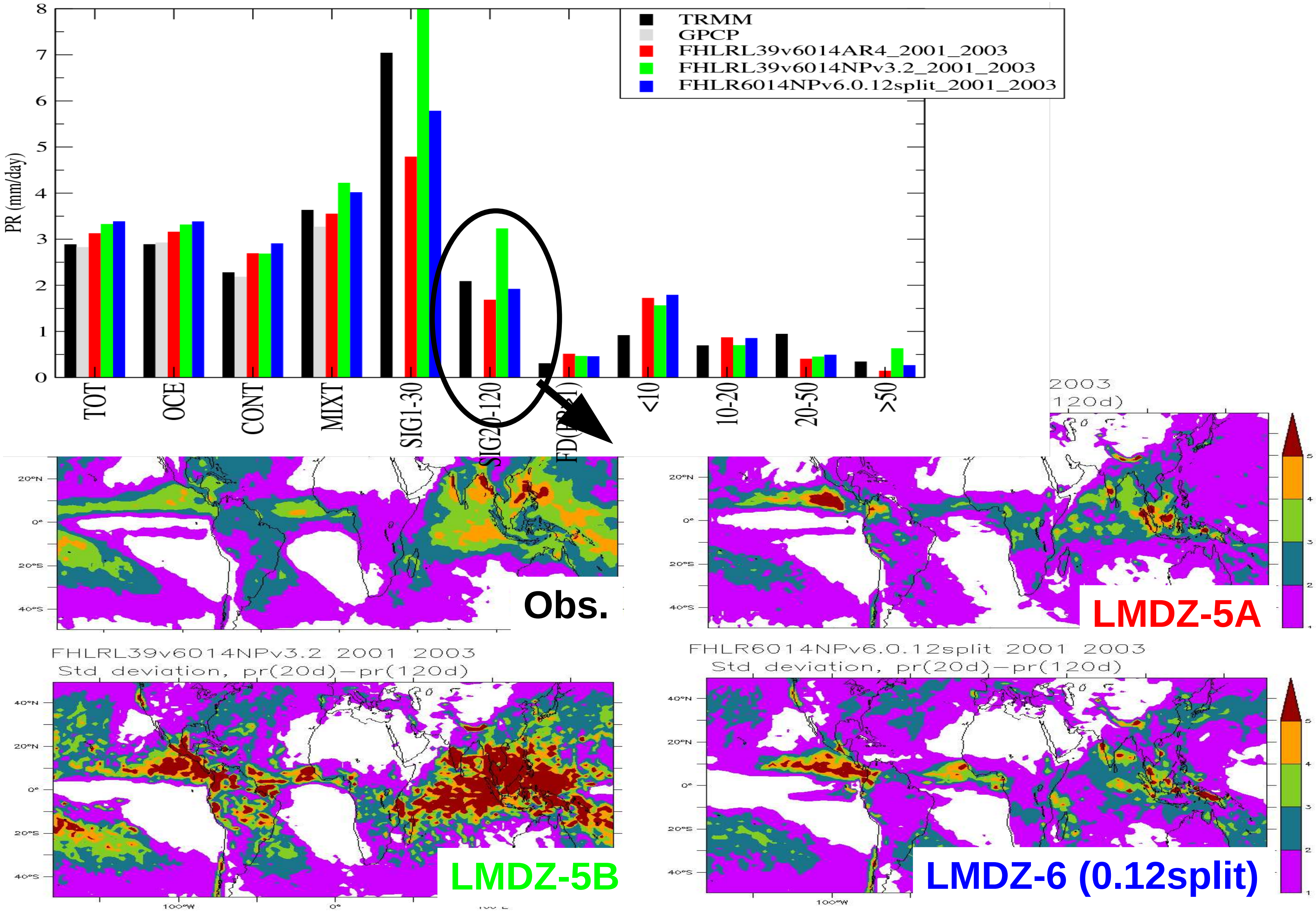
Improved representation of rainfall intermittency over tropical continents

2. Inter-comparison exercises c) Robust improvements from version to version



Improved and satisfactory rainfall over continents. Improved at high resolution.
Strongly overestimate rainfall over the East side of ITCZ over ocean
Excessive rainfall over islands over the maritime continent

2. Reference versions d) Evolution of climatic biases and sensitivity

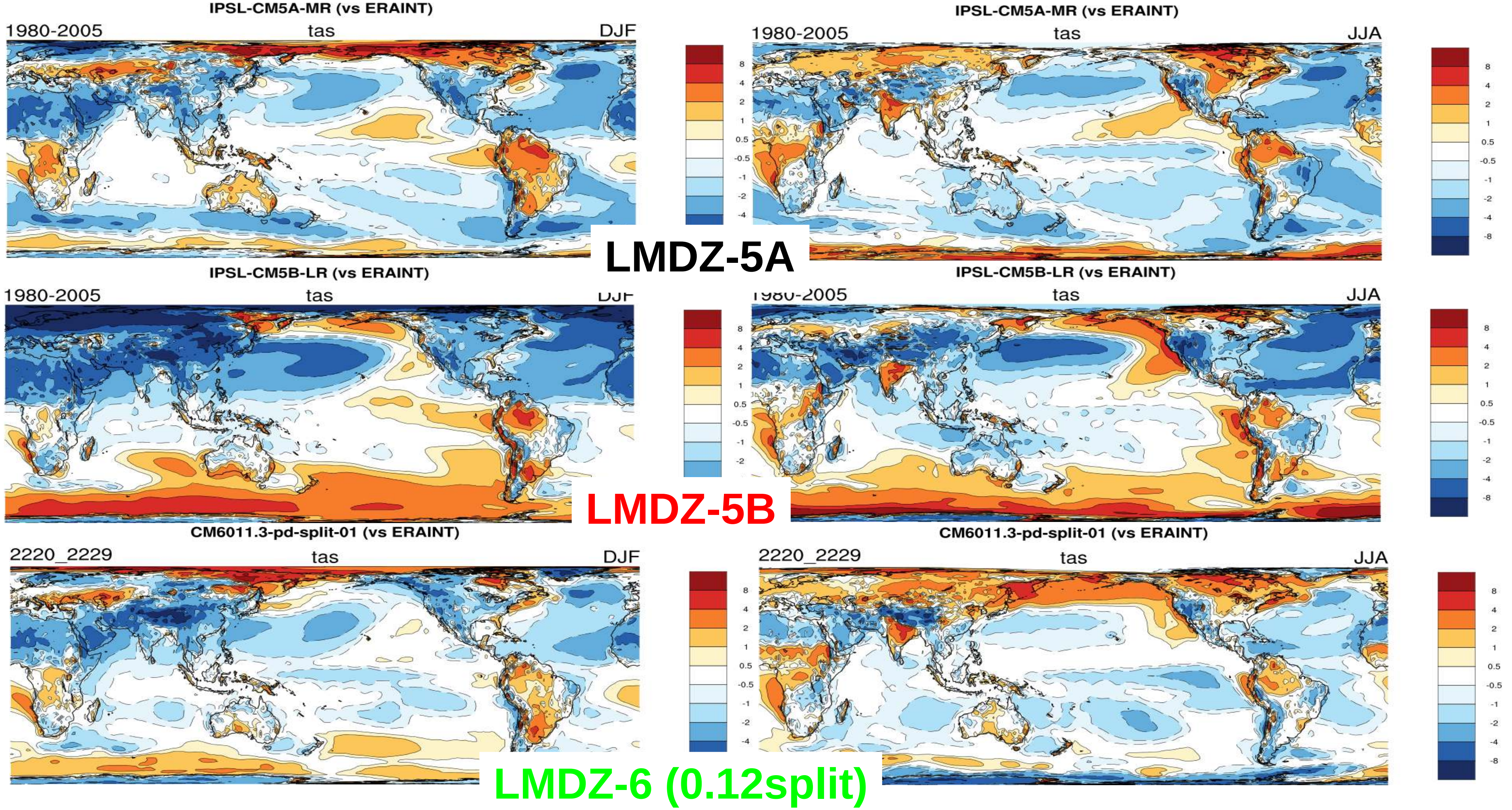


Rainfall variability in the 20 – 120 day period range

2. Reference versions d) Evolution of climatic biases and sensitivity

Air surface temperature bias (°C), coupled simulations

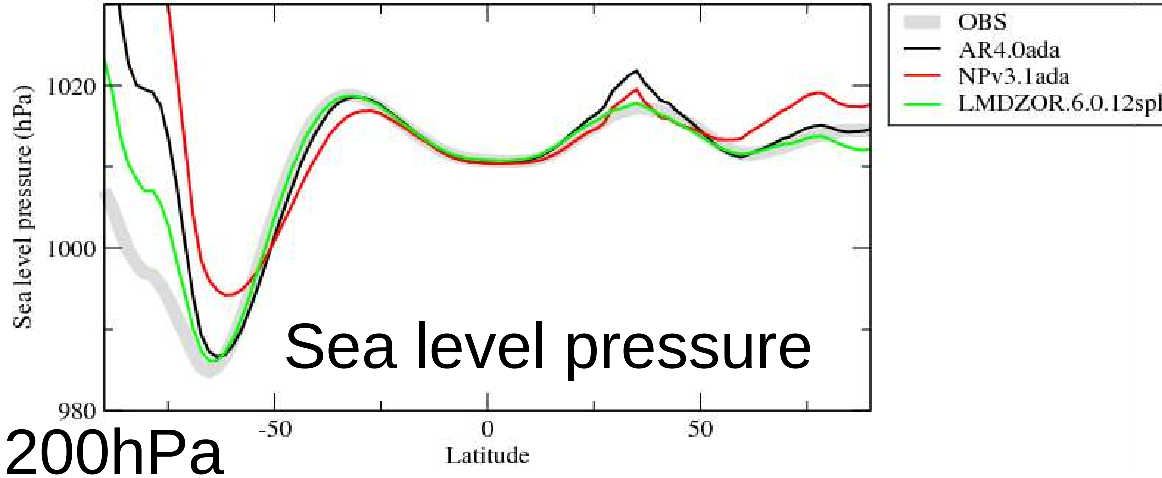
Dec.-Jan.-Feb. Jun.-Jul.-Aug.



2. Reference versions d) Evolution of climatic biases and sensitivity

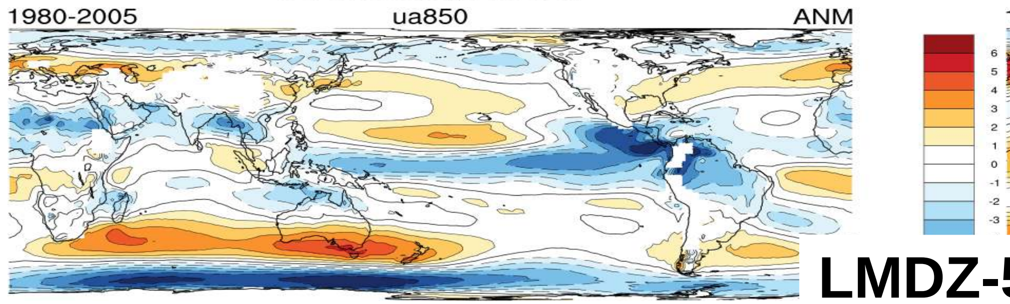
Zonal wind (m/s), coupled model

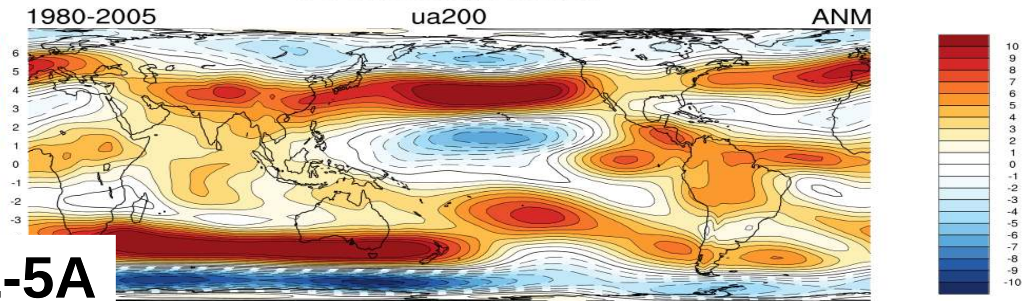
850hPa



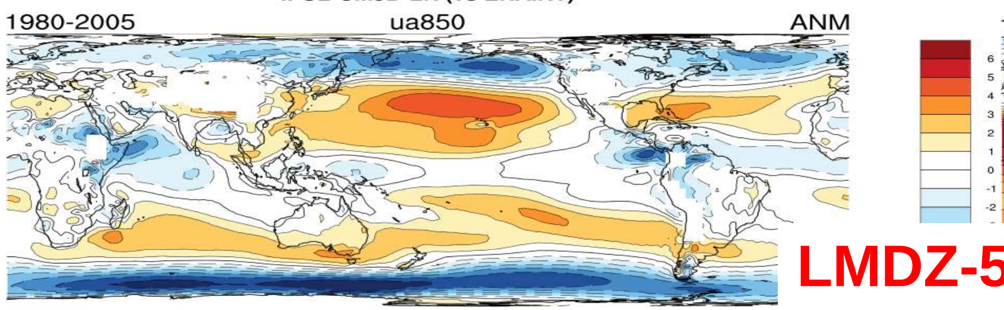
Sea level pressure

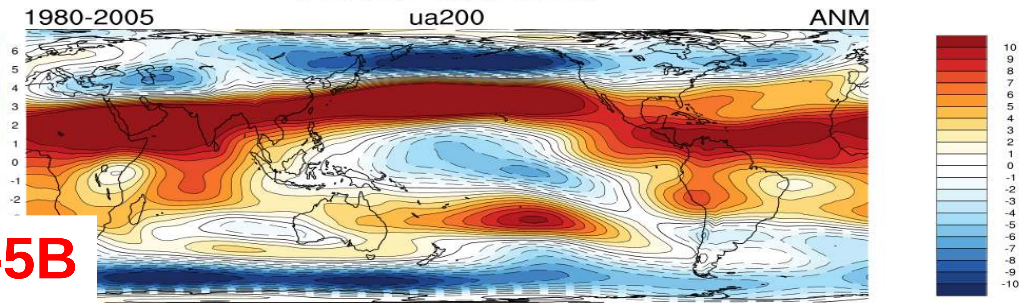
200hPa



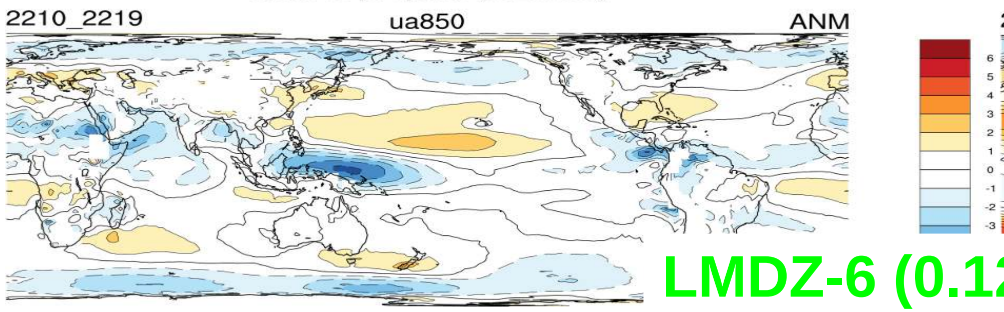


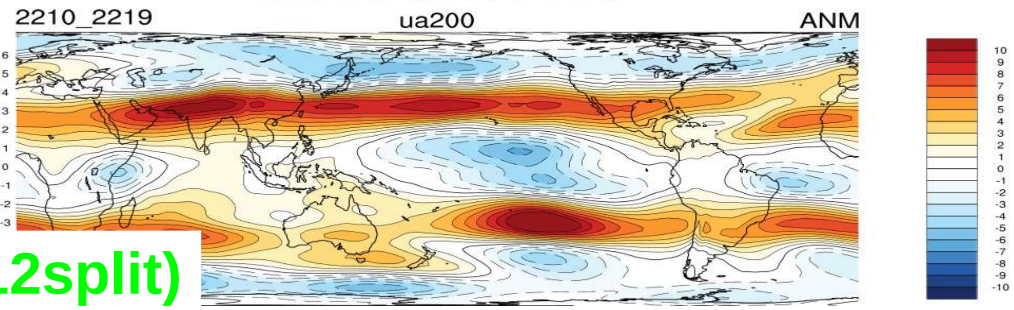
LMDZ-5A





LMDZ-5B





LMDZ-6 (0.12split)

Summary

Robust improvements

Convective boundary layer : diurnal cycle of clouds and wind
Better cumulus and straocumulus clouds
Better phasing of the diurnal cycle of deep convection
Intermitency of convection over continents
Better representation of stable boundary layer
QBO representation

Some important biases

Reduced summer continental warm biases in LMDZ6
Better position of the mid-latitude jets
Reduced bias of monsoon rainfall
Reduced warm biases over oceans
Reduced continental surface temperature biases (?)
Enso acceptable but room for improvement
Variability of rainfall too small in LMDZ6 (>LMDZ5A (low) and <B (high))
Double ITCZ : better but room for improvement
Too much rainfall over the East of the ITCZ and islands in the tropics

LMDZ : use and configurations

1. Operating modes of the 3D GCM

   a) Free climatic mode
   b) Zooming or/and nudging for climate
   c) Tracer transport

2. Intercomparison exercises and reference versions

   a) IPSL climate model and CMIP exercises
   b) LMDZ reference versions
   c) Robust improvements from version to version
   d) Evolution of climatic biases and sensitivity

3. **Model development and tuning**

   a) Choice of a new configuration : content and resolution
   b) Importance of tuning
   c) Semi automatic tuning with history matching

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.

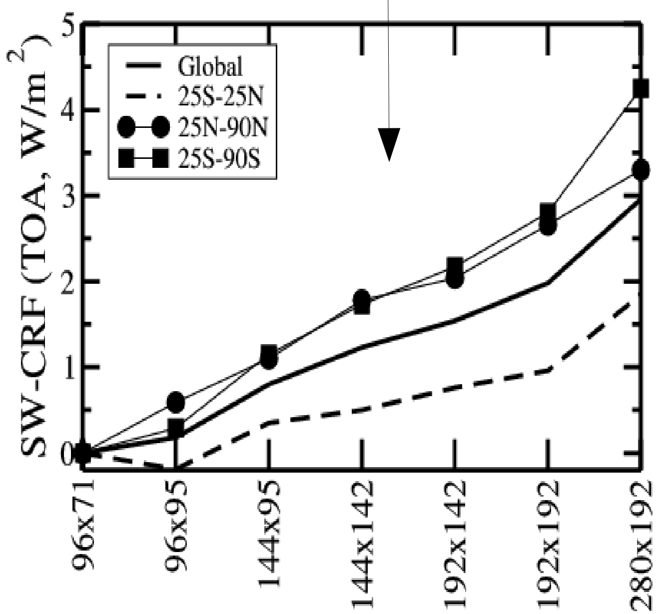
For global climate coupled atmosphere/ocean modeling the tuning of the radiative forcing is a key issue. Several months of tuning for one version.

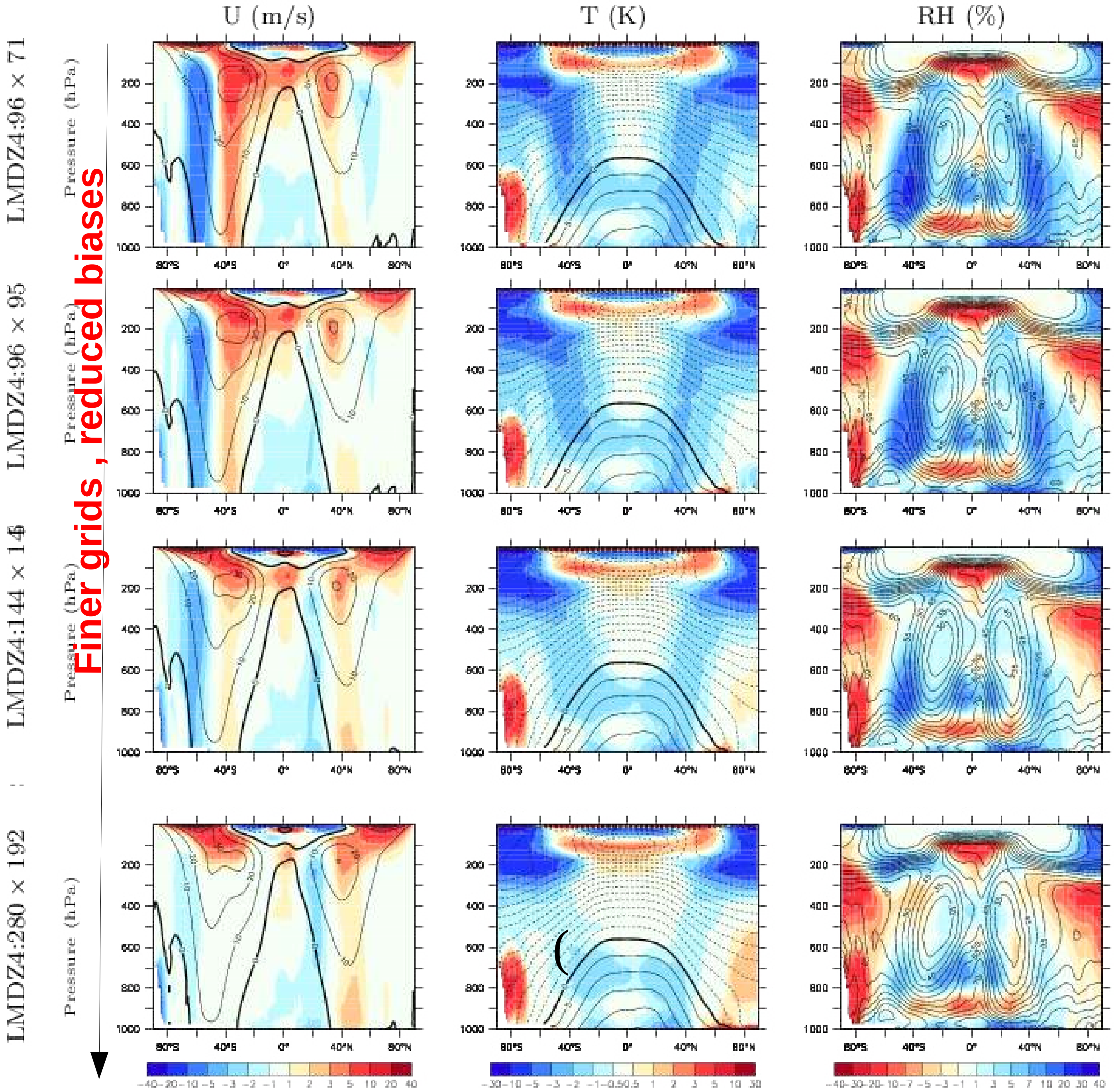
From LMDZ4 to LMDZ5 and LMDZ6 : change of horizontal resolution

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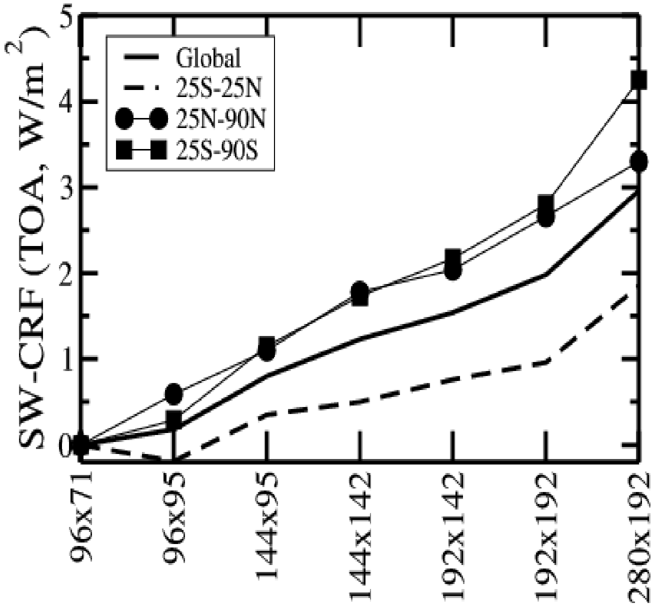
For global climate coupled atmosphere/ocean modeling the tuning of the radiative forcing is a key issue. Several months of tuning for one version.

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 !!!



Tuning of free parameter : a fundamental aspect of climate modeling

Feeling that this question was not discussed enough, we organized a one-week workshop on model tuning with Torsten Mauritsen in October 2014 in Garmisch-Partenkirchen.
The Art and Science of Climate Model Tuning, Hourdin et al., **BAMS**, march **2017**

One particularly important aspect shared by most groups:
tuning of cloud parameters to obtain a reasonable representation of radiative forcing

Example of tuning of a scale factor on the fall velocity of ice particles shared by several models

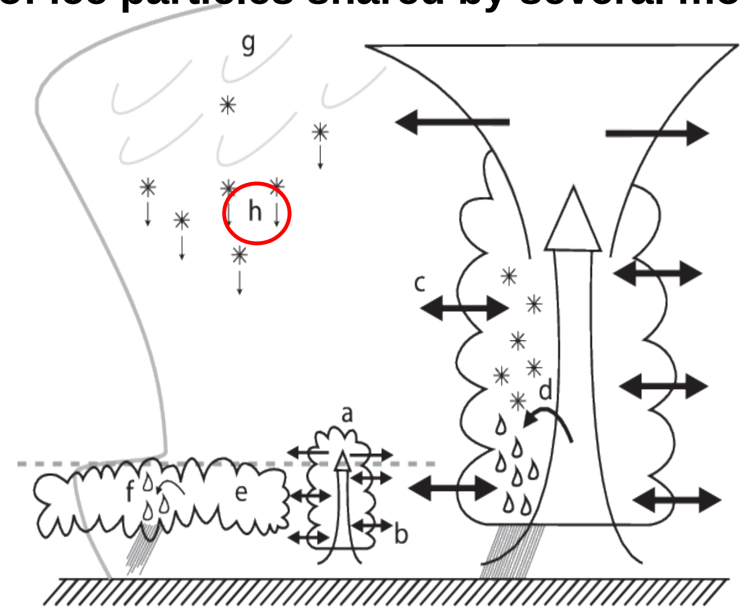
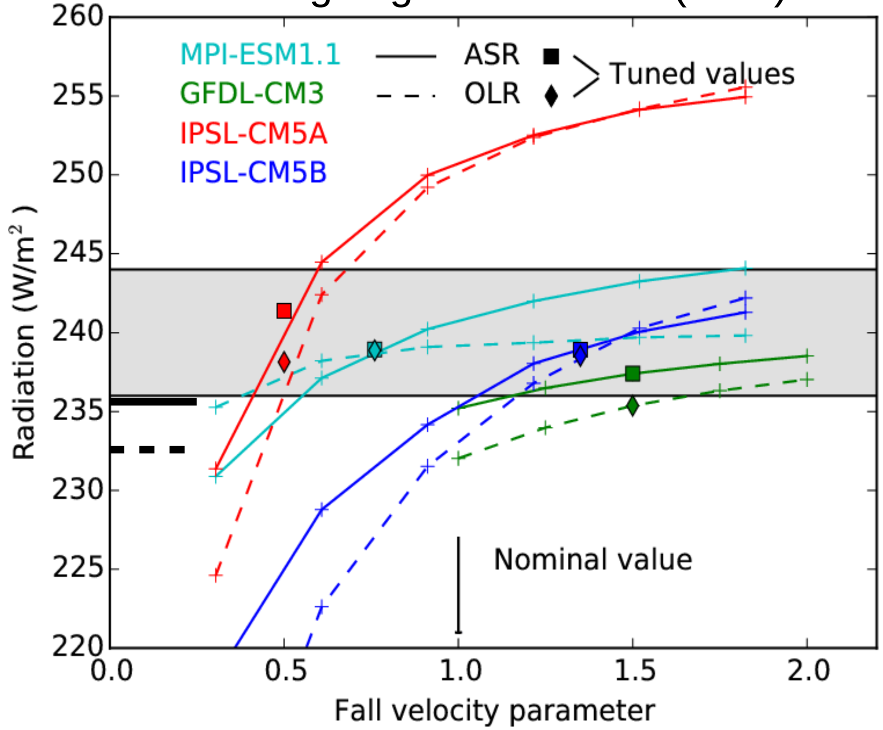
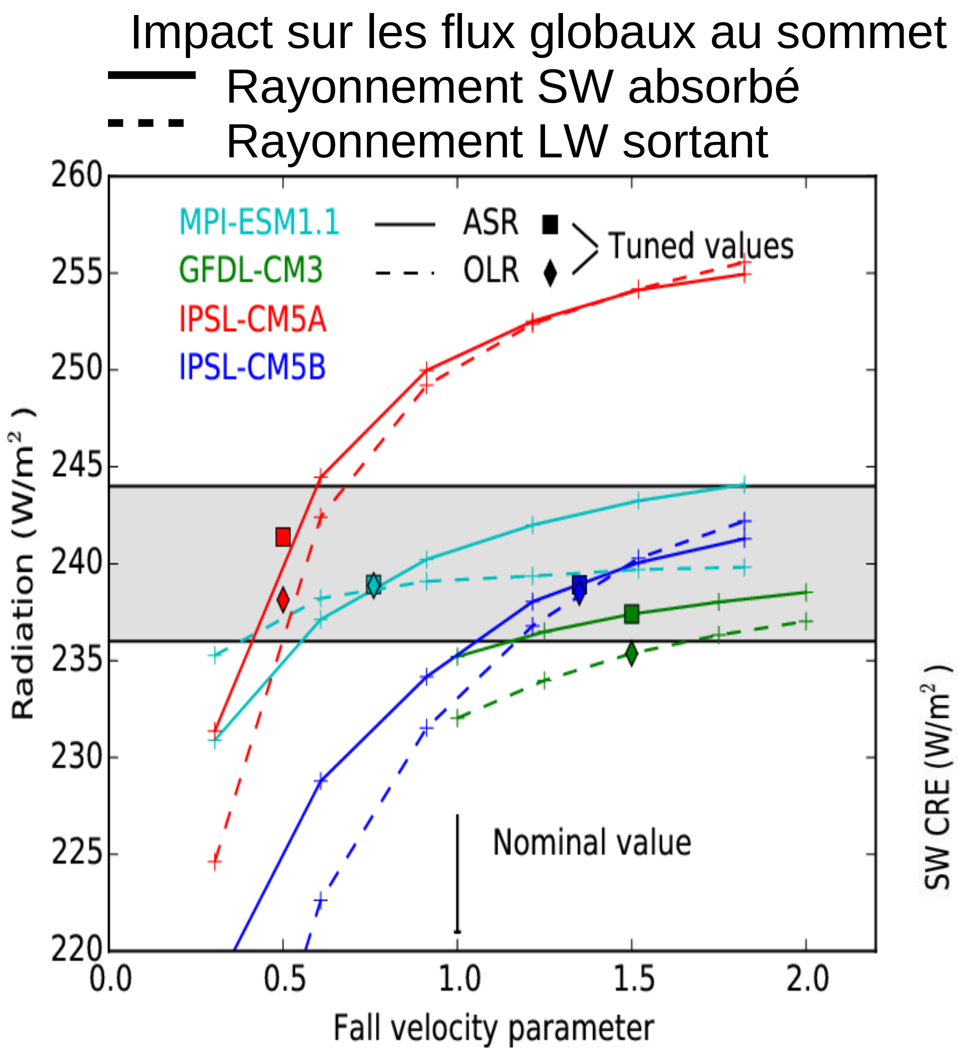


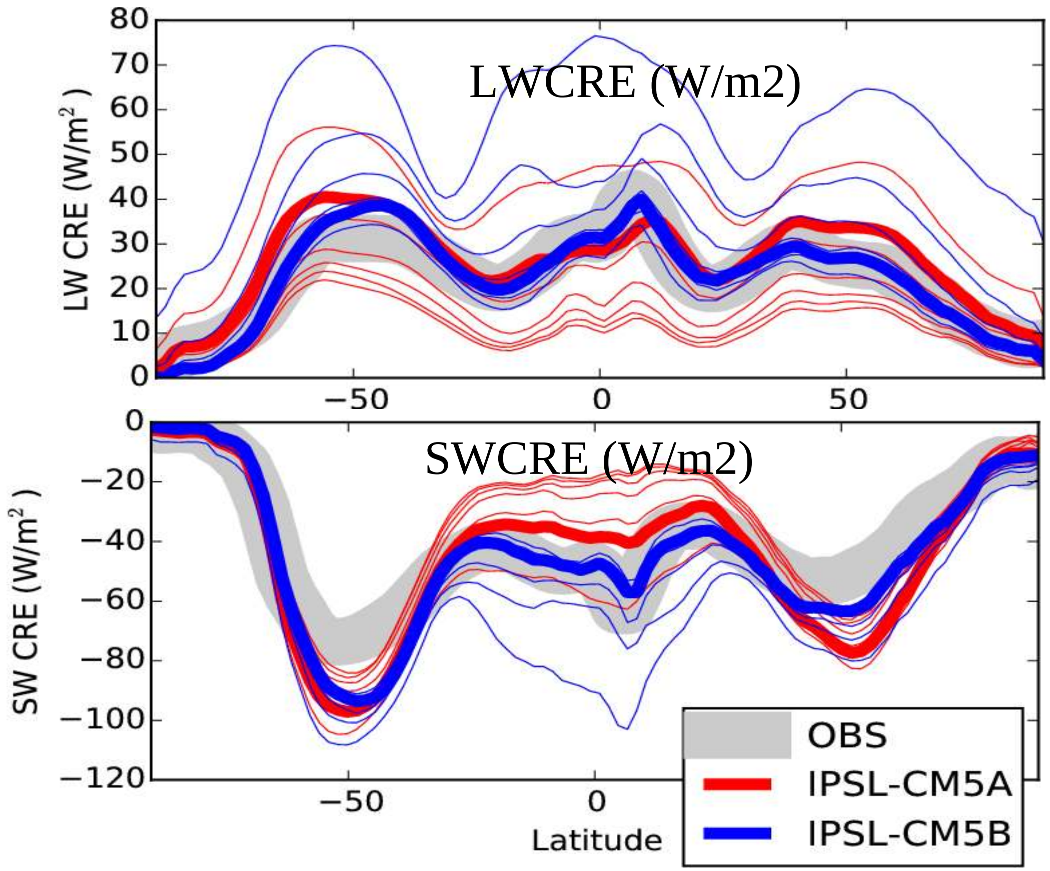
Figure from Mauritsen et al, 2013 (MPI model)

Impact on the global Top-Of-Atmosph. fluxes
Absorbed SW radiation (ASR)
Outgoing LW radiation (OLR)



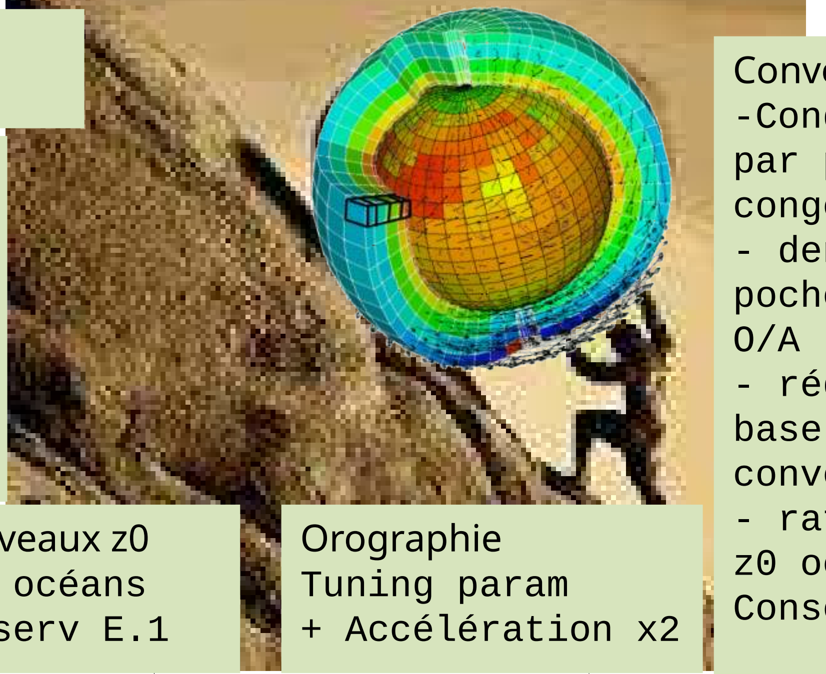
Use of a scalling factor on the fall velocity of cloud ice particles
Impact on global radiative balance and latitudinal radiative forcing of the circulation





2012 : CMIP5B « nouvelle physique »
Thermiques + poches + fermeture

Eté 2015, 1eres simulations longues :
- Stabilisation num couche lim.
- Déclench. Stochast. Convect.
- Strato-cus avec thermiques.
- Microphysique glace
- Ondes non orog. → QBO
- L39 → L79



Convection
-Conditionnée par point de congélation
- densité de poches diff. O/A
- réglage w base convection
- rafales → z0 océaniques
Conserv. E.2

Thermiques à l'exterieur des poches.
Effet des arbres et des colines

Rereglage des nuages bas :
Nb noyaux
réévaporation

Nuages-convection
iflag_mix=1
iflag_coud_vert=1

RRTM
+fisrt+
lmix

Nouveaux z0
Sur océans
Conserv E.1

Orographie
Tuning param
+ Accélération x2

IPSLCM6.0.1
IPSLCM6.0.2
IPSLCM6.0.3
IPSLCM6.0.4
IPSLCM6.0.5
IPSLCM6.0.6
IPSLCM6.0.7
IPSLCM6.0.8
IPSLCM6.0.9
IPSLCM6.0.10
IPSLCM6.0.11split(cvoro,trig)
IPSLCM6.0.12split(cvor
IPSLCM6.0.14splith
IPSLCM6.1

Ete 2015 — Ete 2016 — Printemps 2017 — Eté 2017 — Début 2018

New Tmix

Calving

Température de la neige (SST->Tice)
Température de la pluie pondérée

Améliorations de code

Tests de paramètres

Corrections de bugs

paramètres liés à la glace de mer
Conductivité de la neige
Lmixmin, amaxn,
amaxs,hstar

paramètres liés à la glace de mer
Albedo, amaxn, amaxs,pstar

Juliette Mignot, Frédéric Hourdin, Julie Deshayes, Olivier Boucher, Guillaume Gastineau, Ionela Musat, Martin Vancoppenolle, Jérôme Servonnat, Arnaud Caubel, Frédérique Chéruy, Sébastien Denvil , Jean-Louis Dufresne, Christian Ethé, Laurent Fairhead, Marie-Alice Foujols, Jean-Yves Grandpeix, Guillaume Levavasseur, Olivier Marti, Matthew Menary, Catherine Rio, Clément Rousset, The tuning strategy of IPSL-CM6A-LR, soumis James

2006 : IPSL-CM4 (CMIP3)
2012 : IPSL-CM5A (CMIP5)
2016 : IPSL-CM5A2
(used for paleo climates)

	LMDZ5A
Boundary-layer	
Mellor et Yamada	iflag_pbl=1
Thermals	iflag_thermals=0
Mixing rates in thermals	iflag_thermals_ed=0
Thermals top mixing	fact_thermals_ed_dz UNDEF
Coupling with deep convection	iflag_coupl=0
Convection	
Emanuel old/new	iflag_con=30
Closure CAPE/ALP	iflag_clos=1
Cold pools	iflag_wake=0
Stochastic closure	iflag_trig_bl UNDEF
PDF for mixing	iflag_mix=1
Computation of condensate	iflag_clw=1
Efficiency of precipitation	epmax=0.999
Clouds	
Ice thermodynamics	iflag_ice_thermo UNDEF
Cloud scheme	iflag_cldcon=3
Profile of σ/qt	iflag_ratqs=0
σ/qt min	ratqsbas=0.005
σ/qt max	ratqshaut=0.33
Mixed phase of clouds	iflag_t_glace UNDEF
Threshold cloudy water LS	cld_lc_lsc=0.000416
Threshold cloudy water CV	cld_lc_con=0.000416
Ice crystals fall speed LS	ffallv_lsc=0.5
Ice crystals fall speed CV	ffallv_con=0.5
Coefficient of evaporation	coef_eva=2e-05
Radiation	iflag_rrtm=0

2012 : IPSL-CM5B (CMIP5)
First version with the
New Physics
(thermal plumes and
Cold pools)

	NPv3.1 (LMDZ5B)
Boundary-layer	
Mellor et Yamada	iflag_pbl=8
Thermals	iflag_thermals=15
Mixing rates in thermals	iflag_thermals_ed=10
Thermals top mixing	fact_thermals_ed_dz=0.1
Coupling with deep convection	iflag_coupl=5
Convection	
Emanuel old/new	iflag_con=3
Closure CAPE/ALP	iflag_clos=2
Cold pools	iflag_wake=1
Stochastic closure	iflag_trig_bl=0
PDF for mixing	iflag_mix=1
Computation of condensate	iflag_clw=0
Efficiency of precipitation	epmax=0.997
Clouds	
Ice thermodynamics	iflag_ice_thermo=0
Cloud scheme	iflag_cldcon=6
Profile of σ/qt	iflag_ratqs=2
σ/qt min	ratqsbas=0.002
σ/qt max	ratqshaut=0.25
Mixed phase of clouds	iflag_t_glace=0
Threshold cloudy water LS	cld_lc_lsc=0.0006
Threshold cloudy water CV	cld_lc_con=0.0006
Ice crystals fall speed LS	ffallv_lsc=1.35
Ice crystals fall speed CV	ffallv_con=1.35
Coefficient of evaporation	coef_eva=0.0001
radiation	iflag_rrtm=0

2014 : toward IPSL-CM6
First version with
Stratocumulus and
Stochastic closure

	NPv4.12
Boundary-layer	
Mellor et Yamada	iflag_pbl=11
Thermals	iflag_thermals=18
Mixing rates in thermals	iflag_thermals_ed=8
Thermals top mixing	fact_thermals_ed_dz=0.1
Coupling with deep convection	iflag_coupl=5
Convection	
Emanuel old/new	iflag_con=3
Closure CAPE/ALP	iflag_clos=2
Cold pools	iflag_wake=1
Stochastic closure	iflag_trig_bl=2
PDF for mixing	iflag_mix=1
Computation of condensate	iflag_clw=0
Efficiency of precipitation	epmax=0.97
Clouds	
Ice thermodynamics	iflag_ice_thermo=0
Cloud scheme	iflag_cldcon=6
Profile of σ/qt	iflag_ratqs=4
σ/qt min	ratqsbas=0.002
σ/qt max	ratqshaut=0.24
Mixed phase of clouds	iflag_t_glace=1
Threshold cloudy water LS	cld_lc_lsc=0.000192
Threshold cloudy water CV	cld_lc_con=0.000192
Ice crystals fall speed LS	ffallv_lsc=0.9504
Ice crystals fall speed CV	ffallv_con=0.9504
Coefficient of evaporation	coef_eva=1e-05
radiation	iflag_rrtm=0

Summer 2015
Ice thermo dynamics
First multi decadal simulations

	NPv5.17h (IPSL-CM 6.0.1)
Boundary-layer	
Mellor et Yamada	iflag_pbl=11
Thermals	iflag_thermals=18
Mixing rates in thermals	iflag_thermals_ed=8
Thermals top mixing	fact_thermals_ed_dz=0.1
Coupling with deep convection	iflag_coupl=5
Convection	
Emanuel old/new	iflag_con=3
Closure CAPE/ALP	iflag_clos=2
Cold pools	iflag_wake=1
Stochastic closure	iflag_trig_bl=1
PDF for mixing	iflag_mix=0
Computation of condensate	iflag_clw=0
Efficiency of precipitation	epmax=0.998
Clouds	
Ice thermodynamics	iflag_ice_thermo=1
Cloud scheme	iflag_cldcon=6
Profile of σ/qt	iflag_ratqs=4
σ/qt min	ratqsbas=0.002
σ/qt max	ratqshaut=0.312
Mixed phase of clouds	iflag_t_glace=1
Threshold cloudy water LS	cld_lc_lsc=0.0003
Threshold cloudy water CV	cld_lc_con=0.0003
Ice crystals fall speed LS	ffallv_lsc=0.66528
Ice crystals fall speed CV	ffallv_con=0.66528
Coefficient of evaporation	coef_eva=2e-05
radiation	iflag_rrtm=0

LMDZ 5.4 (IPSL-CM 6.0.2)

Feb 2016

New mixing
+ crash fixed

Boundary-layer	
Mellor et Yamada	iflag_pbl=11
Thermals	iflag_thermals=18
Mixing rates in thermals	iflag_thermals_ed=8
Thermals top mixing	fact_thermals_ed_dz=0.1
Coupling with deep convection	iflag_coupl=5
Convection	
Emanuel old/new	iflag_con=3
Closure CAPE/ALP	iflag_clos=2
Cold pools	iflag_wake=1
Stochastic closure	iflag_trig_bl=1
PDF for mixing	iflag_mix=1
Computation of condensate	iflag_clw=0
Efficiency of precipitation	epmax=0.9995
Clouds	
Ice thermodynamics	iflag_ice_thermo=1
Cloud scheme	iflag_cldcon=6
Profile of σ/qt	iflag_ratqs=4
σ/qt min	ratqsbas=0.002
σ/qt max	ratqshaut=0.312
Mixed phase of clouds	iflag_t_glace=1
Threshold cloudy water LS	cld_lc_lsc=0.0001
Threshold cloudy water CV	cld_lc_con=0.0001
Ice crystals fall speed LS	ffallv_lsc=1
Ice crystals fall speed CV	ffallv_con=1
Coefficient of evaporation	coef_eva=2e-05
radiation	iflag_rrtm=0

April 2016

+ RRTM !
Minimum mixing length

	LMDZ 5.5 (IPSL-CM 6.0.3)
Boundary-layer	
Mellor et Yamada	iflag_pbl=11
Thermals	iflag_thermals=18
Mixing rates in thermals	iflag_thermals_ed=8
Thermals top mixing	fact_thermals_ed_dz=0.1
Coupling with deep convection	iflag_coupl=5
Convection	
Emanuel old/new	iflag_con=3
Closure CAPE/ALP	iflag_clos=2
Cold pools	iflag_wake=1
Stochastic closure	iflag_trig_bl=1
PDF for mixing	iflag_mix=1
Computation of condensate	iflag_clw=0
Efficiency of precipitation	epmax=0.999
Clouds	
Ice thermodynamics	iflag_ice_thermo=1
Cloud scheme	iflag_cldcon=6
Profile of σ/qt	iflag_ratqs=4
σ/qt min	ratqsbas=0.002
σ/qt max	ratqshaut=0.312
Mixed phase of clouds	iflag_t_glace=1
Threshold cloudy water LS	cld_lc_lsc=0.00022
Threshold cloudy water CV	cld_lc_con=0.00022
Ice crystals fall speed LS	ffallv_lsc=0.67
Ice crystals fall speed CV	ffallv_con=0.67
Coefficient of evaporation	coef_eva=2e-05
radiation	iflag_rrtm=1

July 2016

Tuning of sub grid
Scale orography
Dt phys : 10 → 15 min

	NPv5.70 (IPSL-CM 6.0.5)
Boundary-layer	
Mellor et Yamada	iflag_pbl=11
Thermals	iflag_thermals=18
Mixing rates in thermals	iflag_thermals_ed=8
Thermals top mixing	fact_thermals_ed_dz=0.1
Coupling with deep convection	iflag_coupl=5
Convection	
Emanuel old/new	iflag_con=3
Closure CAPE/ALP	iflag_clos=2
Cold pools	iflag_wake=1
Stochastic closure	iflag_trig_bl=1
PDF for mixing	iflag_mix=1
Computation of condensate	iflag_clw=0
Efficiency of precipitation	epmax=0.999
Clouds	
Ice thermodynamics	iflag_ice_thermo=1
Cloud scheme	iflag_cldcon=6
Profile of σ/qt	iflag_ratqs=4
σ/qt min	ratqsbas=0.002
σ/qt max	ratqshaut=0.4
Mixed phase of clouds	iflag_t_glace=2
Threshold cloudy water LS	cld_lc_lsc=0.0002
Threshold cloudy water CV	cld_lc_con=0.0002
Ice crystals fall speed LS	ffallv_lsc=0.5
Ice crystals fall speed CV	ffallv_con=0.5
Coefficient of evaporation	coef_eva=0.0002
radiation	iflag_rrtm=1

January 2017

	LMDZ6.0.9
Boundary-layer	
Mellor et Yamada	iflag_pbl=11
Thermals	iflag_thermals=18
Mixing rates in thermals	iflag_thermals_ed=8
Thermals top mixing	fact_thermals_ed_dz=0.1
Coupling with deep convection	iflag_coupl=5
Convection	
Emanuel old/new	iflag_con=3
Closure CAPE/ALP	iflag_clos=2
Cold pools	iflag_wake=1
Stochastic closure	iflag_trig_bl=1
PDF for mixing	iflag_mix=1
Computation of condensate	iflag_clw=0
Efficiency of precipitation	epmax=0.997
Clouds	
Ice thermodynamics	iflag_ice_thermo=1
Cloud scheme	iflag_cldcon=6
Profile of σ/qt	iflag_ratqs=4
σ/qt min	ratqsbas=0.002
σ/qt max	ratqshaut=0.4
Mixed phase of clouds	iflag_t_glace=2
Threshold cloudy water LS	cld_lc_lsc=0.00015
Threshold cloudy water CV	cld_lc_con=0.00015
Ice crystals fall speed LS	ffallv_lsc=1
Ice crystals fall speed CV	ffallv_con=1
Coefficient of evaporation	coef_eva=0.0002
radiation	iflag_rrtm=1

LMDZ6.0.12

May 2017

Convection triggering if
Ttop < Ttopmax
Energy conservation (partial)
MY improved for stable conditions

Boundary-layer	
Mellor et Yamada	iflag_pbl=12
Thermals	iflag_thermals=18
Mixing rates in thermals	iflag_thermals_ed=8
Thermals top mixing	fact_thermals_ed_dz=0.07
Coupling with deep convection	iflag_coupl=5
Convection	
Emanuel old/new	iflag_con=3
Closure CAPE/ALP	iflag_clos=2
Cold pools	iflag_wake=1
Stochastic closure	iflag_trig_bl=1
Mixing with env	iflag_mix=1
Computation of condensate	iflag_clw=0
Efficiency of precipitation	epmax=0.9985
Clouds	
Ice thermodynamics	iflag_ice_thermo=1
Cloud scheme	iflag_cldcon=6
Profile of σ/qt	iflag_ratqs=4
σ/qt min	ratqsbas=0.002
σ/qt max	ratqshaut=0.4
Mixed phase of clouds	iflag_t_glace=2
Threshold cloudy water LS	cld_lc_lsc=0.00012
Threshold cloudy water CV	cld_lc_con=0.00012
Ice crystals fall speed LS	ffallv_lsc=0.6
Ice crystals fall speed CV	ffallv_con=0.6
Coefficient of evaporation	coef_eva=0.0001
radiation	iflag_rrtm=1

June 2017

Accounting for gustiness in surface oeceanic fluxes

	LMDZ6.0.12ttop
Boundary-layer	
Mellor et Yamada	iflag_pbl=12
Thermals	iflag_thermals=18
Mixing rates in thermals	iflag_thermals_ed=8
Thermals top mixing	fact_thermals_ed_dz=0.07
Coupling with deep convection	iflag_coupl=5
Convection	
Emanuel old/new	iflag_con=3
Closure CAPE/ALP	iflag_clos=2
Cold pools	iflag_wake=1
Stochastic closure	iflag_trig_bl=1
PDF for mixing	iflag_mix=1
Computation of condensate	iflag_clw=0
Efficiency of precipitation	epmax=0.998
Clouds	
Ice thermodynamics	iflag_ice_thermo=1
Cloud scheme	iflag_cldcon=6
Profile of σ/qt	iflag_ratqs=4
σ/qt min	ratqsbas=0.002
σ/qt max	ratqshaut=0.4
Mixed phase of clouds	iflag_t_glace=2
Threshold cloudy water LS	cld_lc_lsc=0.000106
Threshold cloudy water CV	cld_lc_con=0.000106
Ice crystals fall speed LS	ffallv_lsc=0.6
Ice crystals fall speed CV	ffallv_con=0.6
Coefficient of evaporation	coef_eva=0.0001
radiation	iflag_rrtm=1

June 2017

Thermals plume accounted for outside cold pools only

	LMD6 split
Boundary-layer	
Mellor et Yamada	iflag_pbl=12
Thermals	iflag_thermals=18
Mixing rates in thermals	iflag_thermals_ed=8
Thermals top mixing	fact_thermals_ed_dz=0.1
Coupling with deep convection	iflag_coupl=5
Convection	
Emanuel old/new	iflag_con=3
Closure CAPE/ALP	iflag_clos=2
Cold pools	iflag_wake=1
Stochastic closure	iflag_trig_bl=1
PDF for mixing	iflag_mix=1
Computation of condensate	iflag_clw=0
Efficiency of precipitation	epmax=0.9997
	wbmax=3, flag_wb=30
Clouds	
Ice thermodynamics	iflag_ice_thermo=1
Cloud scheme	iflag_cldcon=6
Profile of σ/qt	iflag_ratqs=4
σ/qt min	ratqsbas=0.002
σ/qt max	ratqshaut=0.4
Mixed phase of clouds	iflag_t_glace=3
Threshold cloudy water LS	cld_lc_lsc=0.000205
Threshold cloudy water CV	cld_lc_con=0.000205
Ice crystals fall speed LS	ffallv_lsc=0.6
Ice crystals fall speed CV	ffallv_con=0.6
Coefficient of evaporation	coef_eva=0.0001
radiation	iflag_rrtm=1
	iflag_prce=2

April 2018

Thermals plume accounted for outside cold pools only

	LMD6.1
Boundary-layer	
Mellor et Yamada	iflag_pbl=12
Thermals	iflag_thermals=18
Mixing rates in thermals	iflag_thermals_ed=8
Thermals top mixing	fact_thermals_ed_dz=0.07
Coupling with deep convection	iflag_coupl=5
Convection	
Emanuel old/new	iflag_con=3
Closure CAPE/ALP	iflag_clos=2
Cold pools	iflag_wake=1
Stochastic closure	iflag_trig_bl=1
PDF for mixing	iflag_mix=1
Computation of condensate	iflag_clw=0
Efficiency of precipitation	epmax=0.9997
	wbmax=3, flag_wb=30
Clouds	
Ice thermodynamics	iflag_ice_thermo=1
Cloud scheme	iflag_cldcon=6
Profile of σ/qt	iflag_ratqs=4
σ/qt min	ratqsbas=0.002
σ/qt max	ratqshaut=0.4
Mixed phase of clouds	iflag_t_glace=3
Threshold cloudy water LS	cld_lc_lsc=0.00065
Threshold cloudy water CV	cld_lc_con=0.00065
Ice crystals fall speed LS	ffallv_lsc=0.8
Ice crystals fall speed CV	ffallv_con=0.8
Coefficient of evaporation	coef_eva=0.0001
radiation	iflag_rrtm=1
	iflag_prec=3

3. Model development and tuning. c) Semi automatic tuning with history matching

NEW : semi-automatic tuning with « history matching »

→ 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 to select acceptable model configurations

Tuning is not defined anymore as a way so select a « best » configuration but to select the subspace of some free parameters for which the simulated climate matches some observed « metrics » given a tolerance to error.

Review on tuning of climate models 10 years ago :

- F. Hourdin, Mauritsen, T., Gettelman, A., Golaz, J.-C., Balaji, V., Duan, Q., Folini, D., Ji, D., Klocke, D., Qian, Y., Rauser, F. Rio, C. Tomassini, L., Watanabe, M. and Williamson, D. 2017, The art and science of climate model tuning, BAMS, https://doi.org/10.1175/BAMS-D-15-00135.1

A series of 3 papers about the use of History Matching for climate model tuning

- Couvreux, F., Hourdin, F., Williamson, D., Roehrig, R., Volodina, V., Villefranque, N., Rio, C., Audouin, O., Salter, J., Bazile, E., Brient, F., Favot, F., Honnert, R., Lefebvre, M.-P., Madeleine, J.-B., Rodier, Q. and Xu, W., Process-based climate model development harnessing machine learning: I. a calibration tool forparameterization improvement, vol. 13, no. 3, 2021. doi:10.1029/2020MS002217.
- Hourdin, F., Williamson, D., Rio, C., Couvreux, F., Roehrig, E., Villefranque, N., Musat, I., Fairhead, L., Diallo, F. B. and Volodina, V., Process-based climate model development harnessing machine learning: II. model calibration from single column to global, James, vol. 13, no. 6, 2021. doi:10.1029/2020MS002225.
- Villefranque, N., Blanco, S., Couvreux, F., Fournier, R., Gautrais, J., Hogan, R. J., Hourdin, F., Volodina, V. and Williamson, D., Process-based climate model development harnessing machine learning: I. The Representation of Cumulus Geometry and Their 3D Radiative Effec ts , James, vol. 13, no. 4, 2021. doi:10.1029/2020MS002423.

Exploring the uncertainty in climate sensitivity thanks to history matching

- Hourdin, F , Ferster, B., Deshayes, J., Mignot, J., Musat, I. and Williamson, D., Toward machine-assisted tuning avoiding the underestimation of uncertainty in climate change projections, Science Advances, 2023, Vol 9, Issue 29, DOI: 10.1126/sciadv.adf2758 . SUPLEMENTARY MATERIAL

3. Model development and tuning. c) Semi automatic tuning with history matching

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 configurations when possible. In particular **LMDZ6A**
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 or studies dedicated to tracer transport and chemistry

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 LMDZ6
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.

NEW : semi-automatic tuning with « history matching »

→ 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

Concluding remarks / recommendations

Reference tuned versions are available for LMDZ : LMDZ5A, 5B, and almost for LMDZ6A

Which means :

→ Long term investment on physical parameterizations. In particular with 1D vs LES

→ Long phases of evaluation and tuning (nudged, forced by SST, coupled ...)

~ 2400 simulations, 650 multi-atlas for CMIP6

→ Constant evolution and improvement of coding (parallelism, modularity, post-processing , efficiency, flexibility)

TEAM EFFORT

Made possible thanks to all the LMDZ Team !!