

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

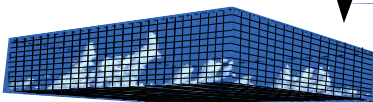
(Dephy/High-Tune)

LES à disposition
20 aine de cas

- Convection
- RCE
- Nuages bas
- Couplage surf.



Campagne



3D explicite (LES)



Modèle uni-colonne

Atmospheric component of the IPSL integrated climate

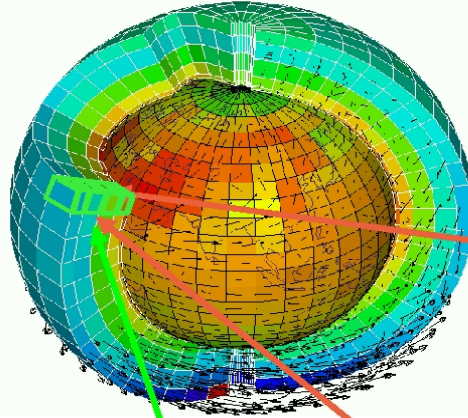
model LMDZ4

LMDZ 3D dynamical core

Finite difference formulation
conserving enstrophy and angular momentum

Single-column model

1D monitor for
academic or test cases



Atmospheric tracers

Transport by winds
Finite volume
methods

- ★ Turbulent mixing
- ★ Convective transport

LMDZ parametrized physics

Several "Physics":
Earth
Mars
Titan
Parametrized

- radiation (Fouquart/Morcrette)
- boundary layer (LDM + options)
- convection (Emanuel and Tiedtke)
- clouds (statistical scheme)
- orography (Lott)
- ...



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

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

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

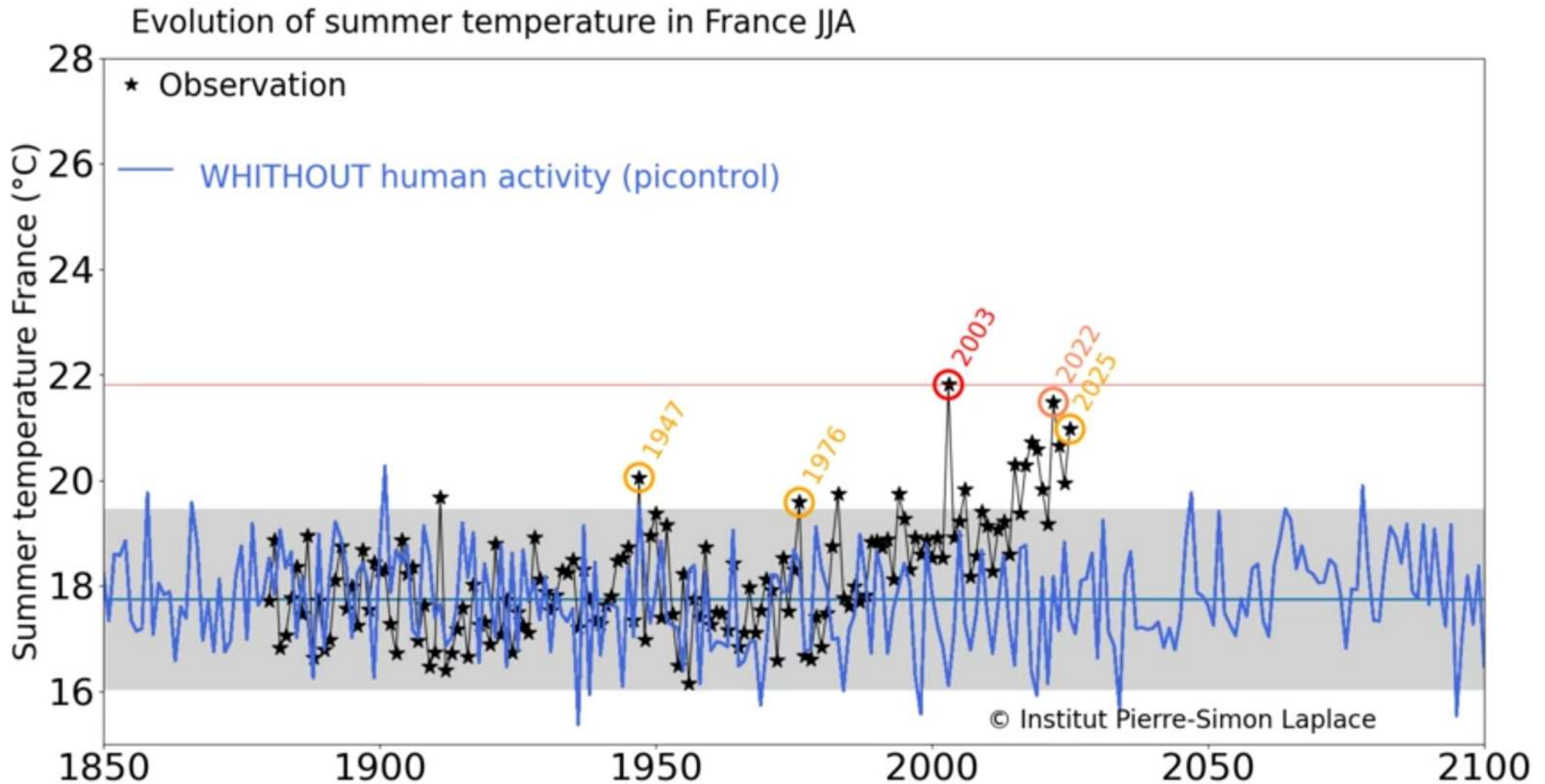
1. Operating modes : a) Global climate studies in free mode

Example 1 :

Coupled simulation for climate change projections

III. Climate system modeling

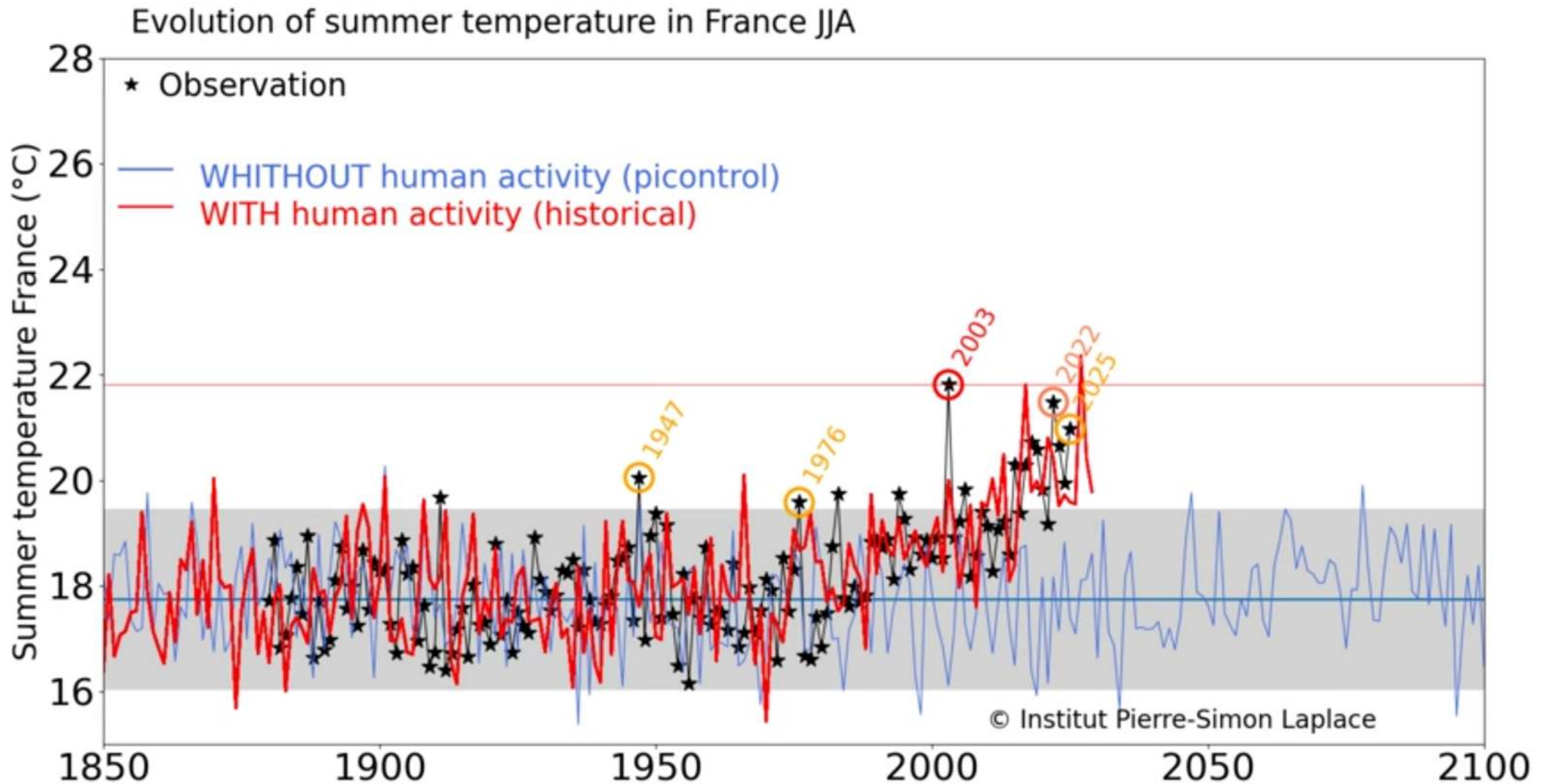
Climate change projections



- Global coupled ocean-atmosphere model. Model not perfect. Biases.
- Analyzed in terms of statistics. Averages, variances, ...

III. Climate system modeling

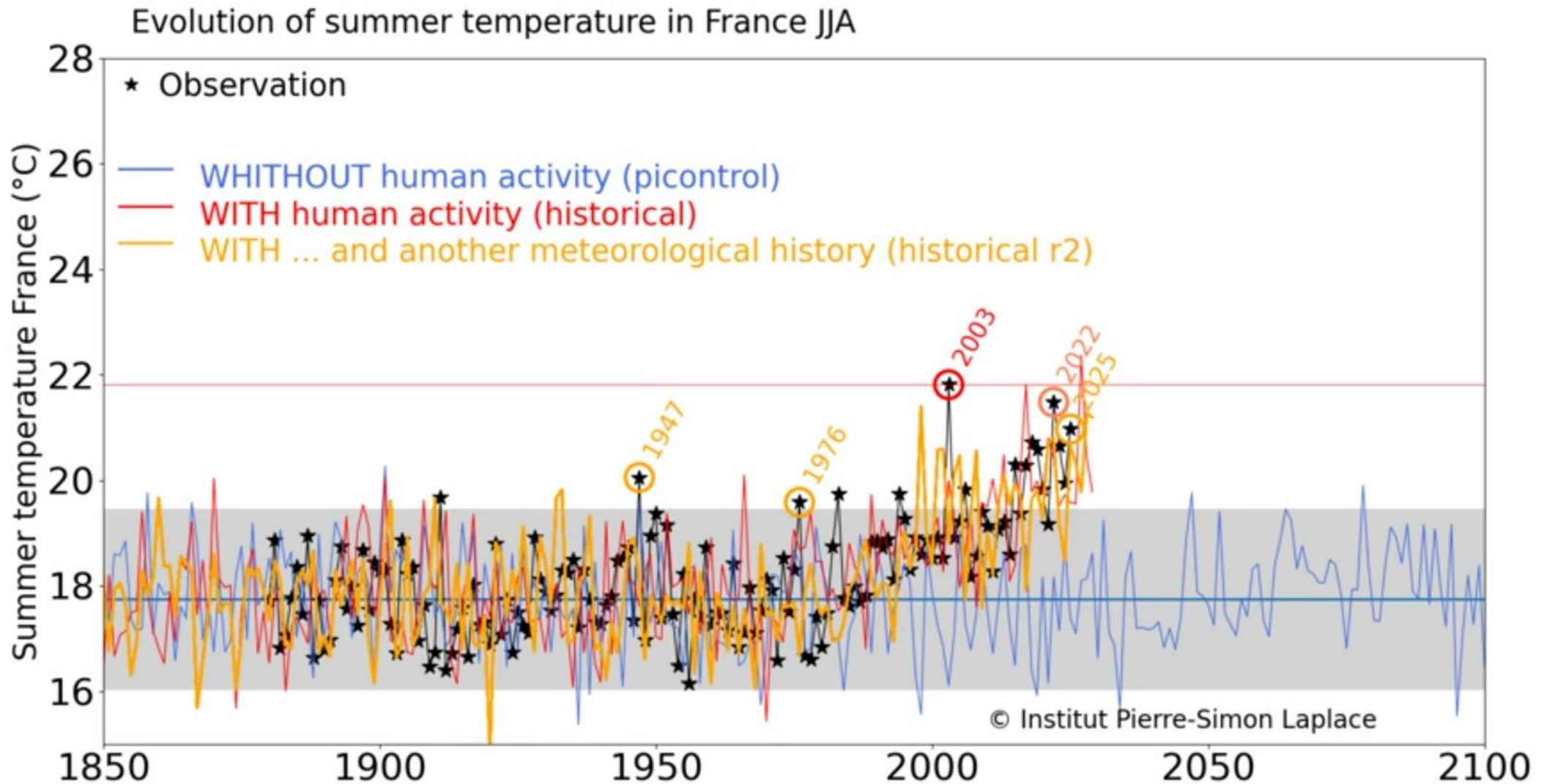
Climate change projections



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- Perturbed versus control run (small perturbation compared to biases)

III. Climate system modeling

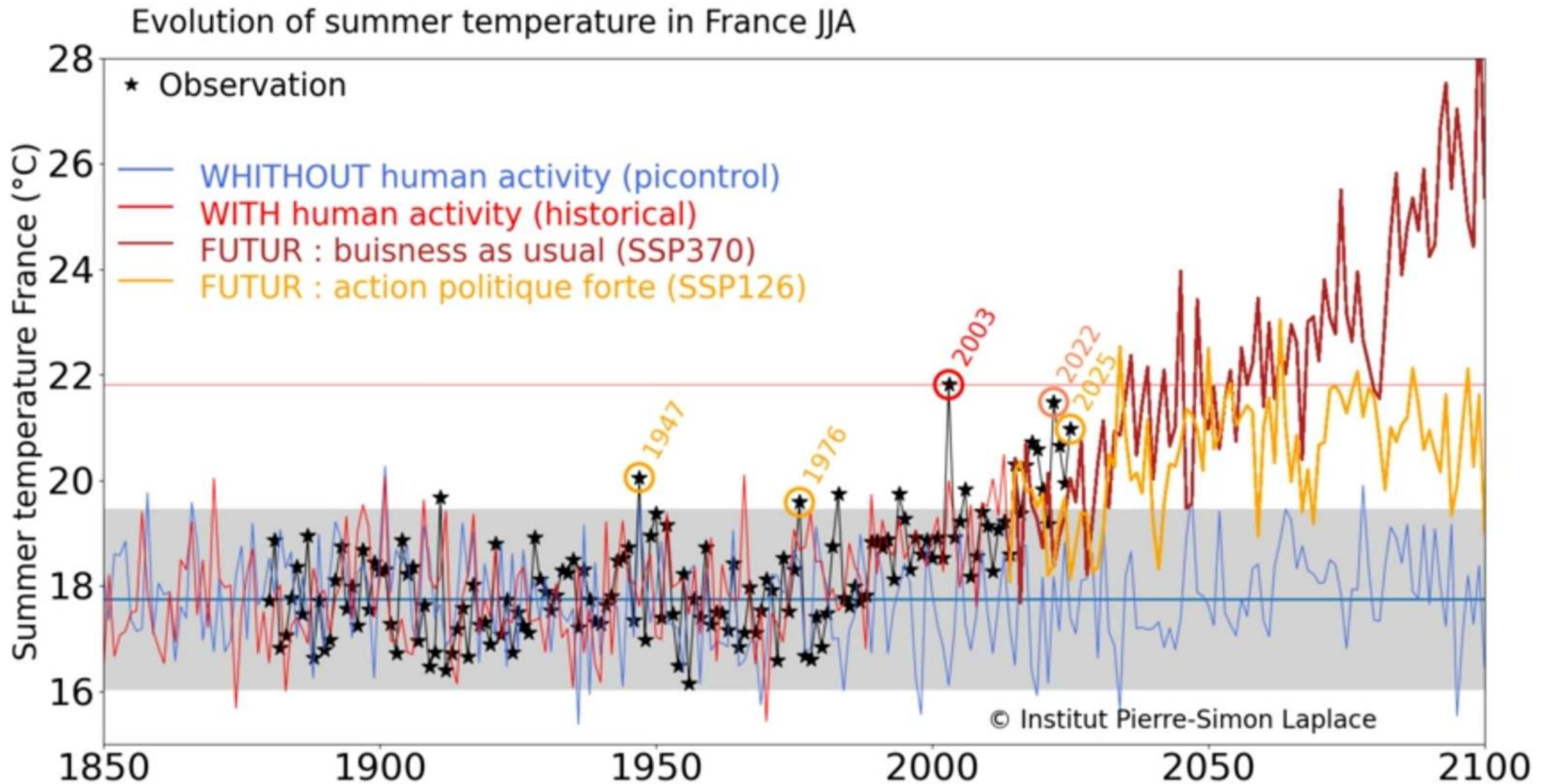
Climate change projections



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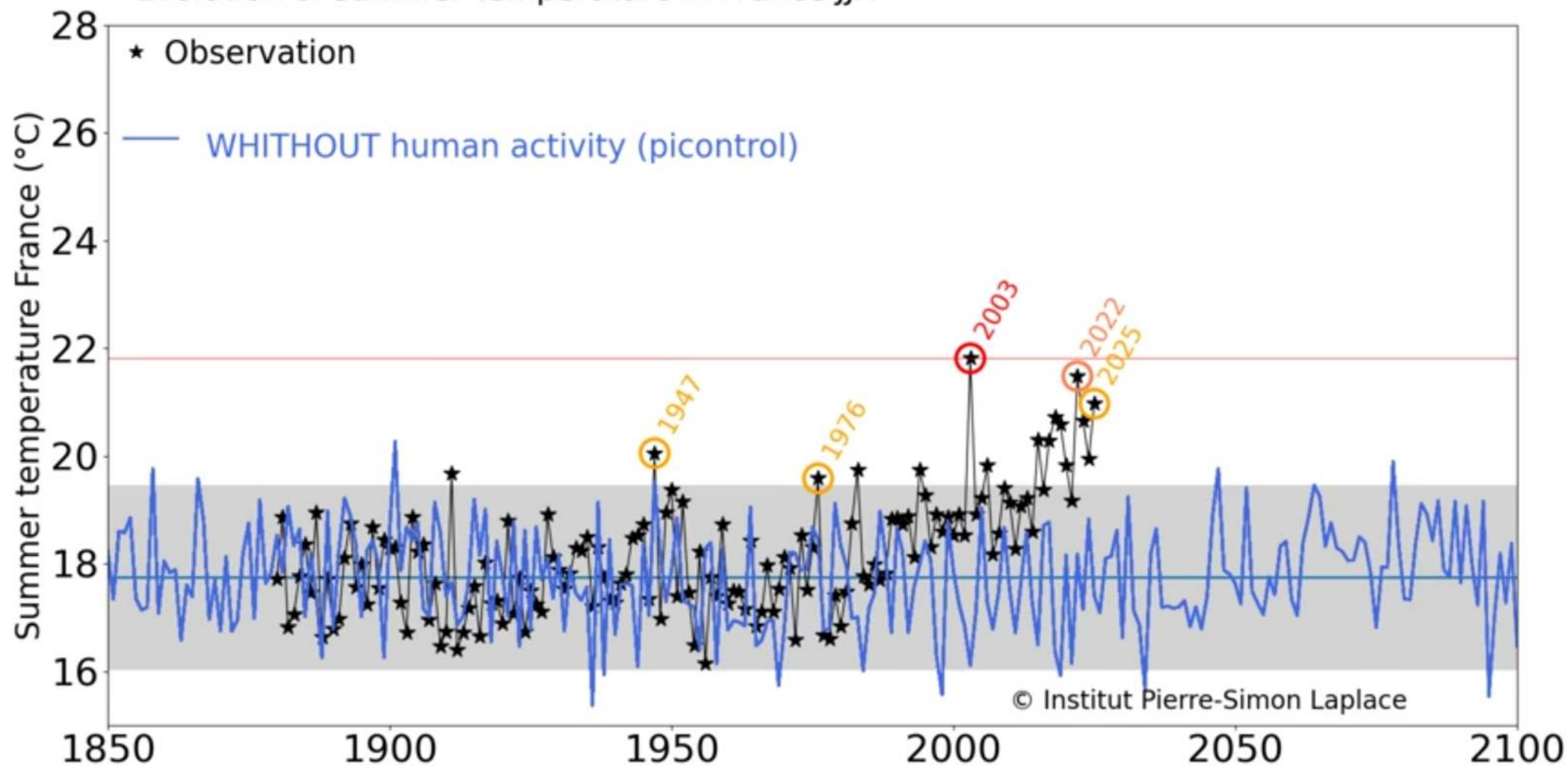
III. Climate system modeling

Climate change projections



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

Evolution of summer temperature in France JJA

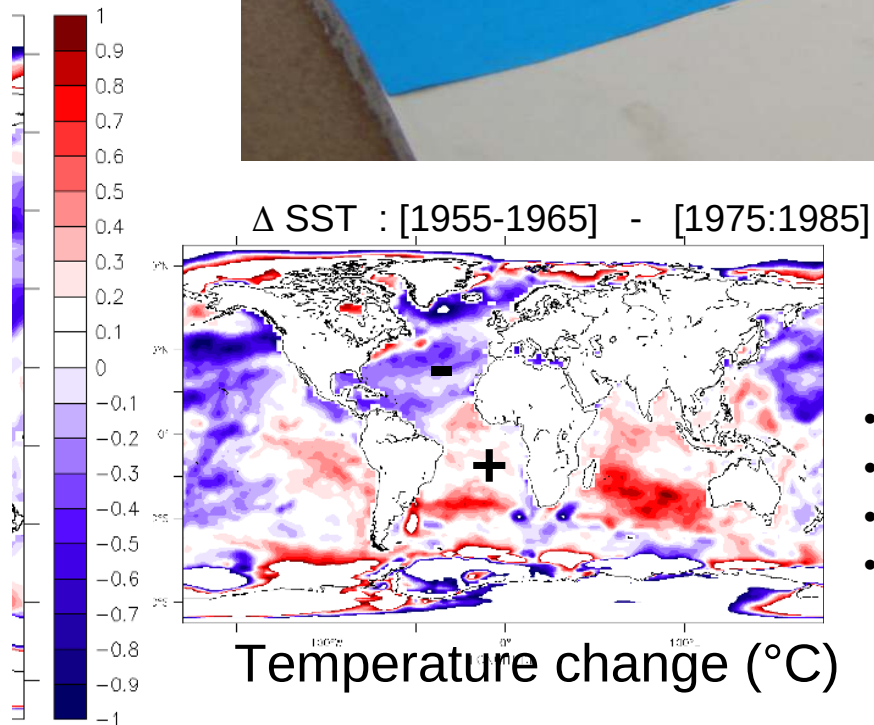
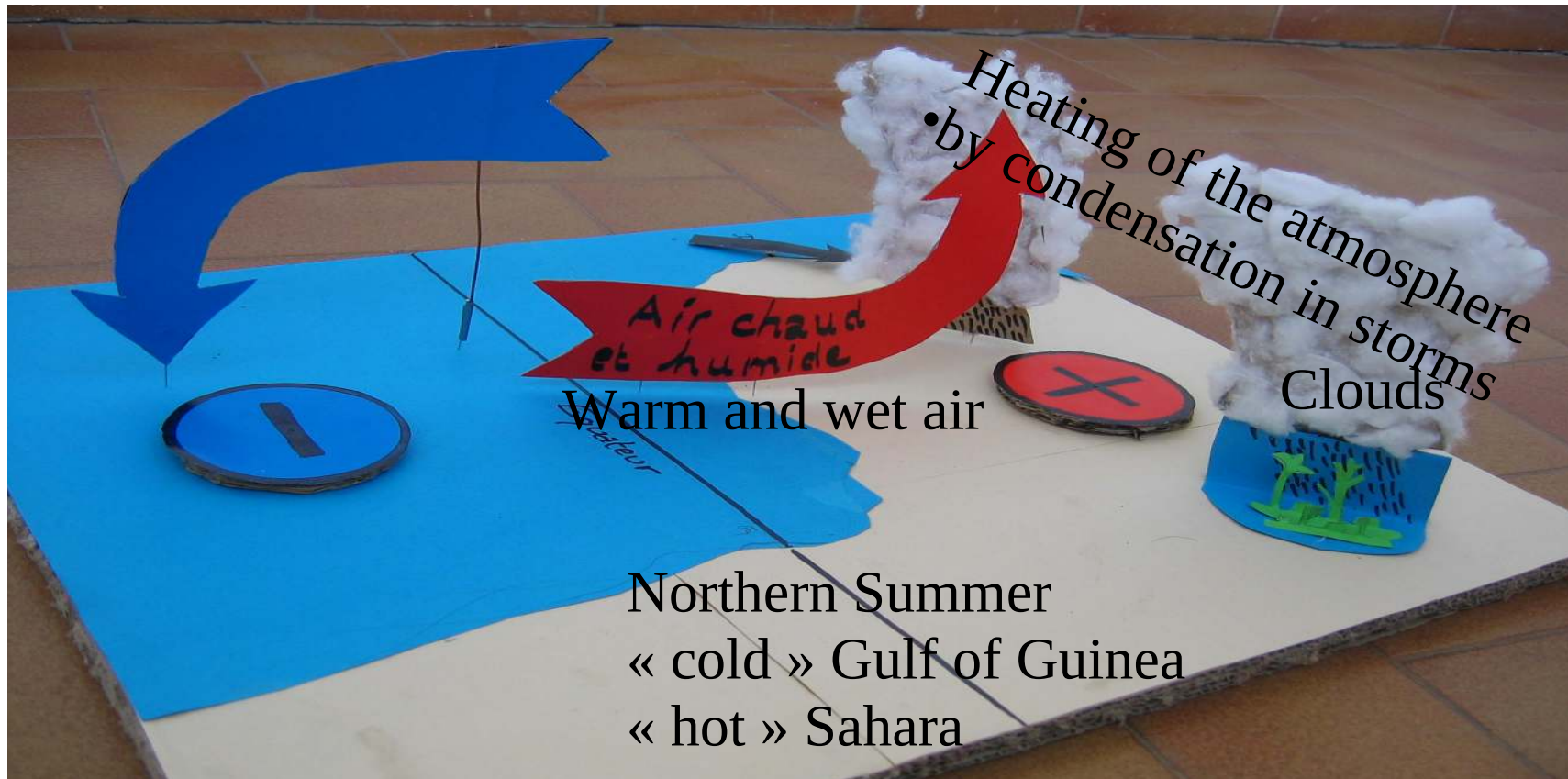


1. Operating modes : a) Global climate studies in free mode

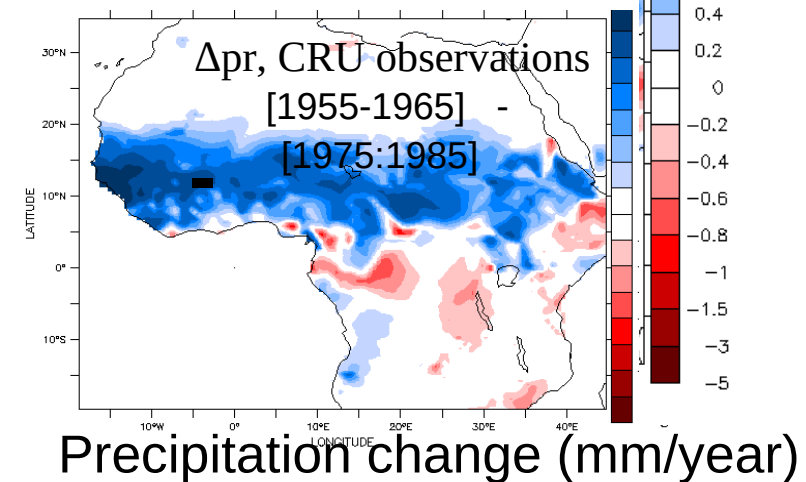
Example 2 :

Forced-by-SST simulations to understand the Sahelian drought of the 70'

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



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

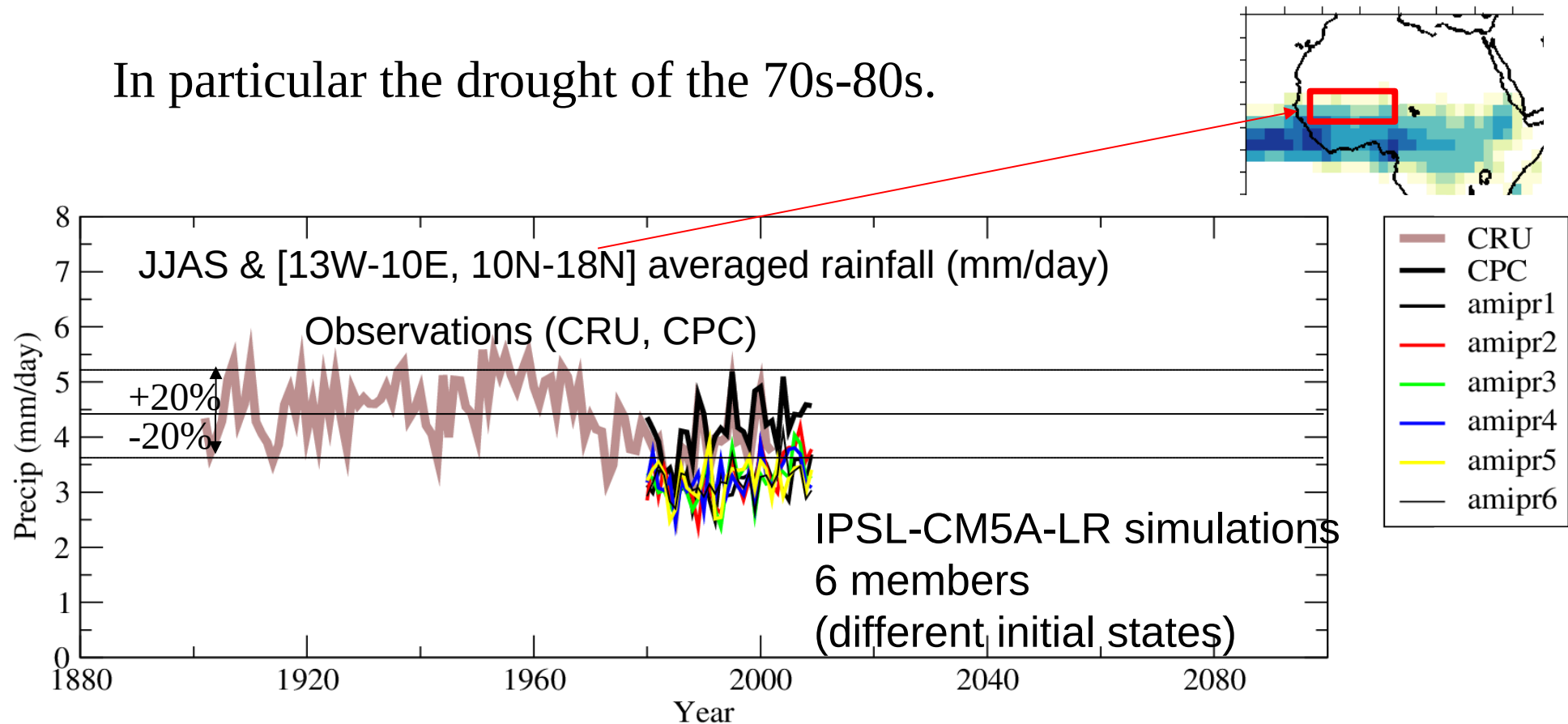


Example 2 : the Sahelian drought

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

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

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



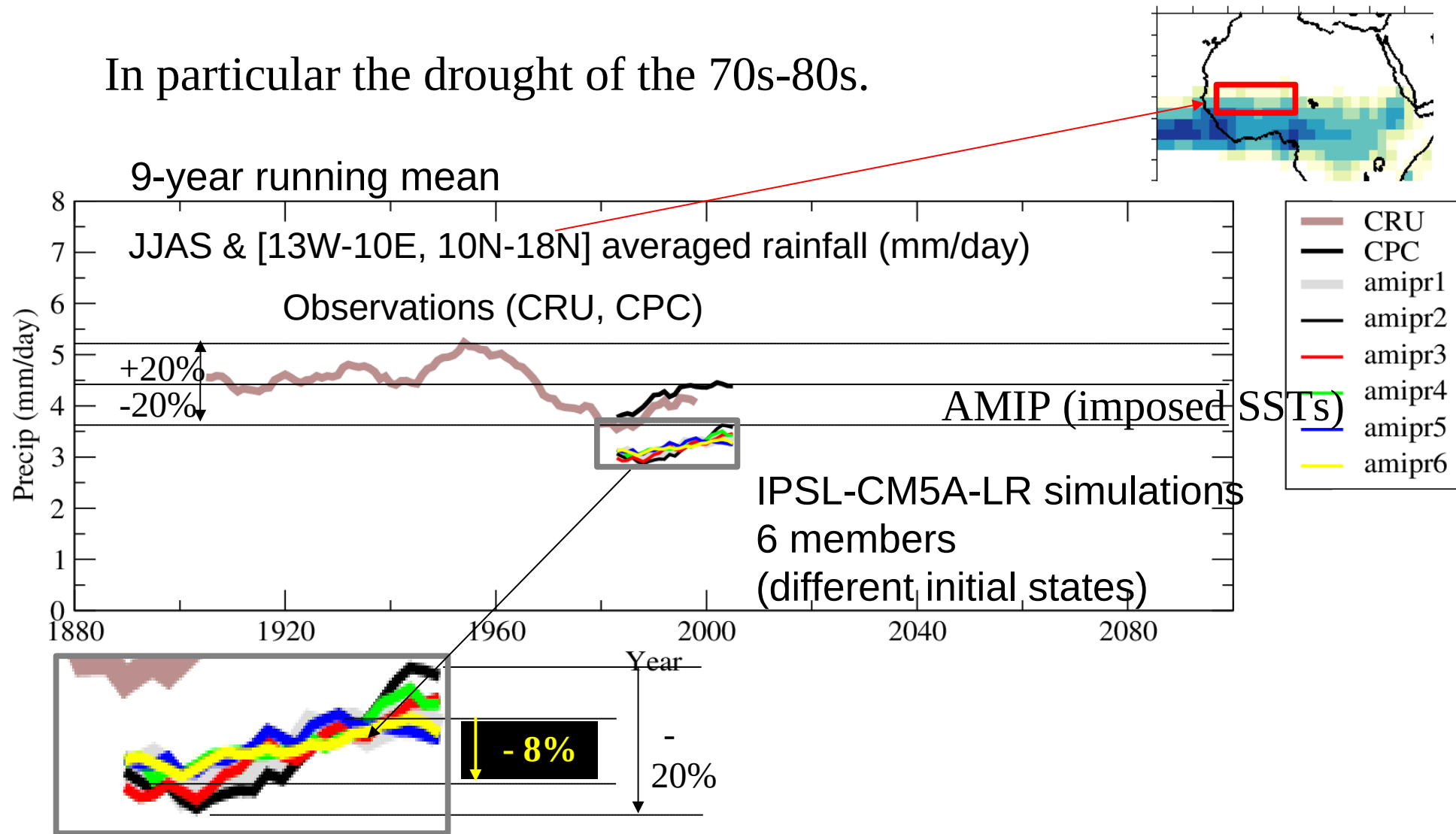
AMIP with imposed Sea Surface Temperature (SST)

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

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

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



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

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

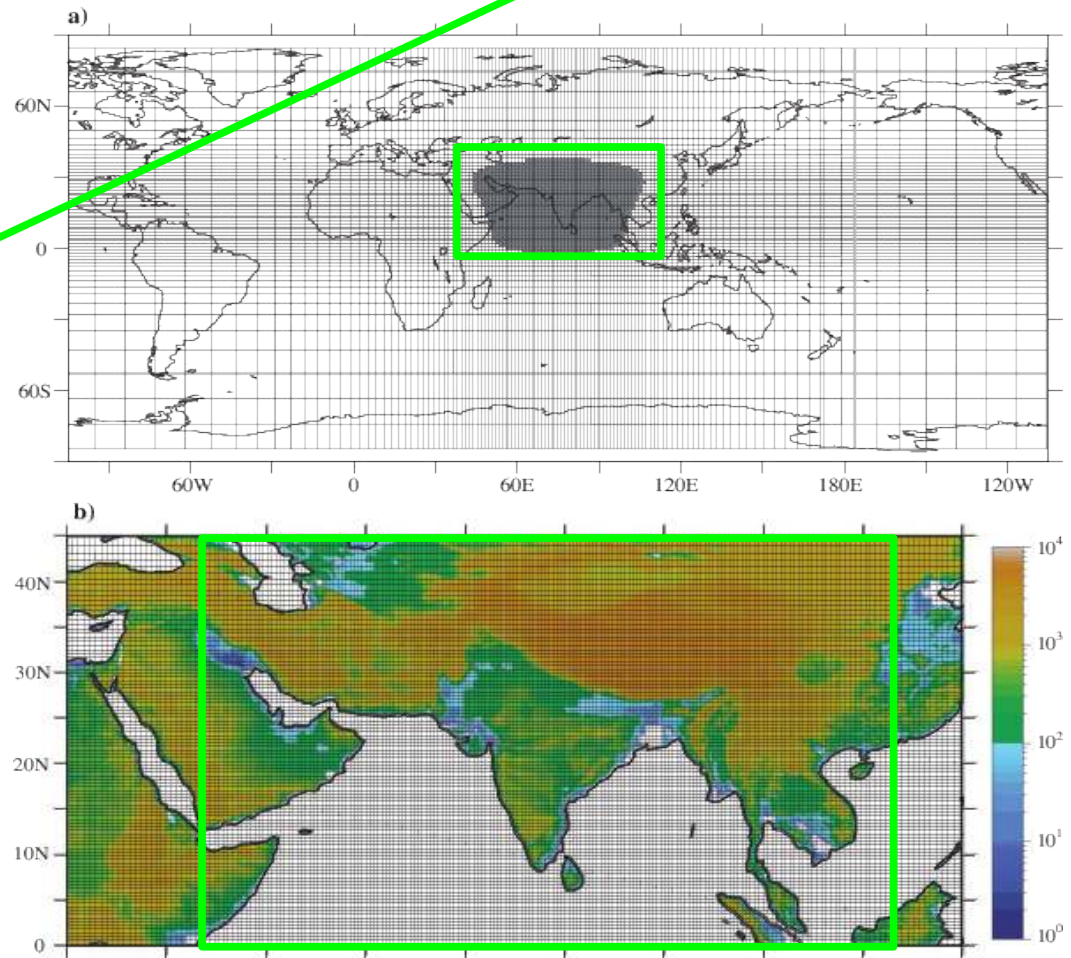
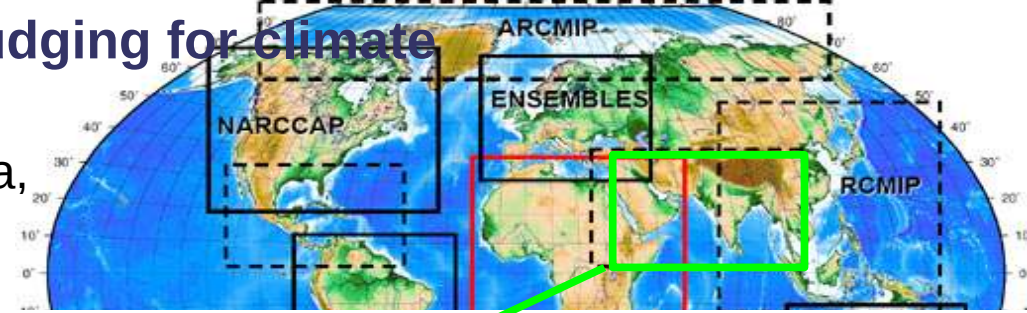
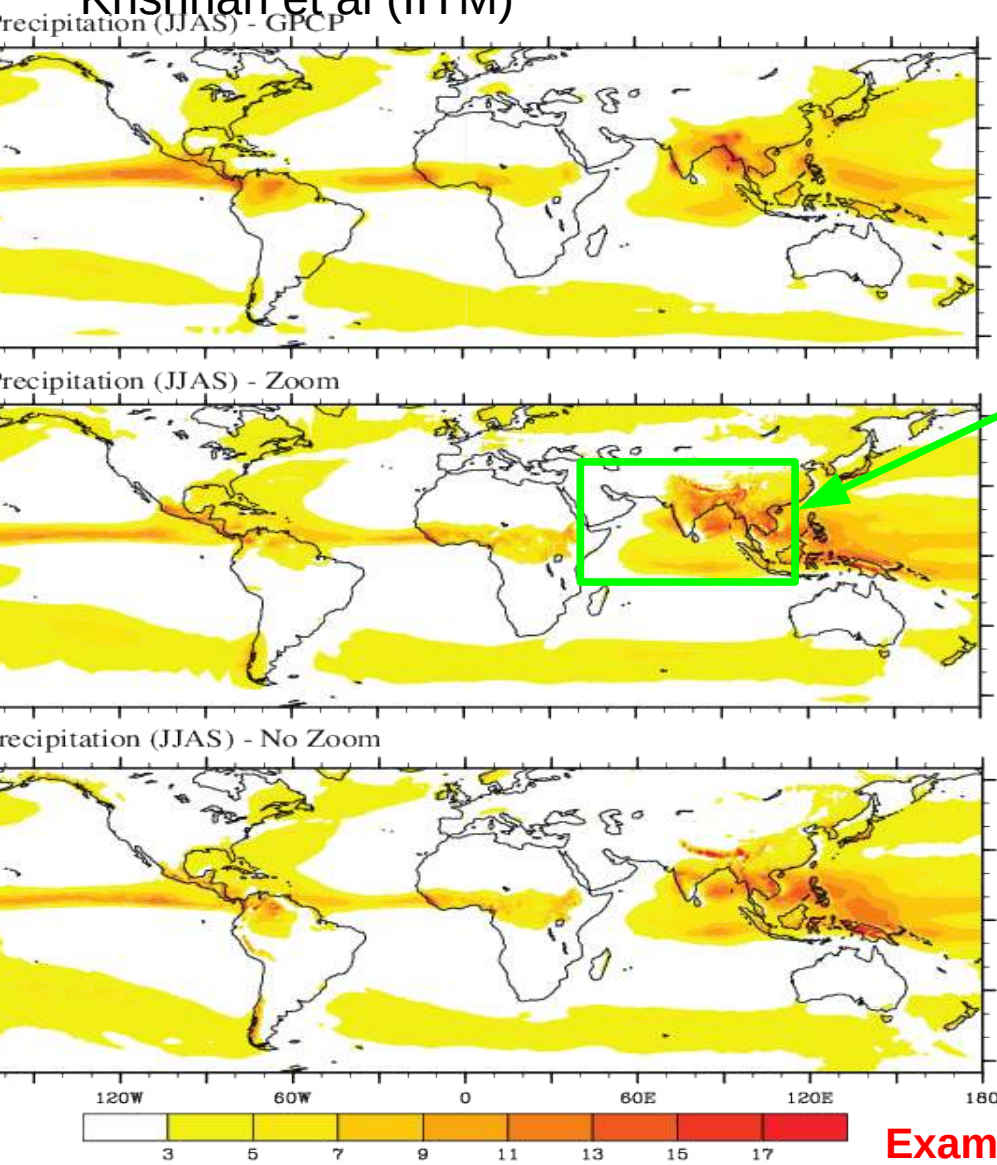
Example 3 :

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 Bengal**

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

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

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

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

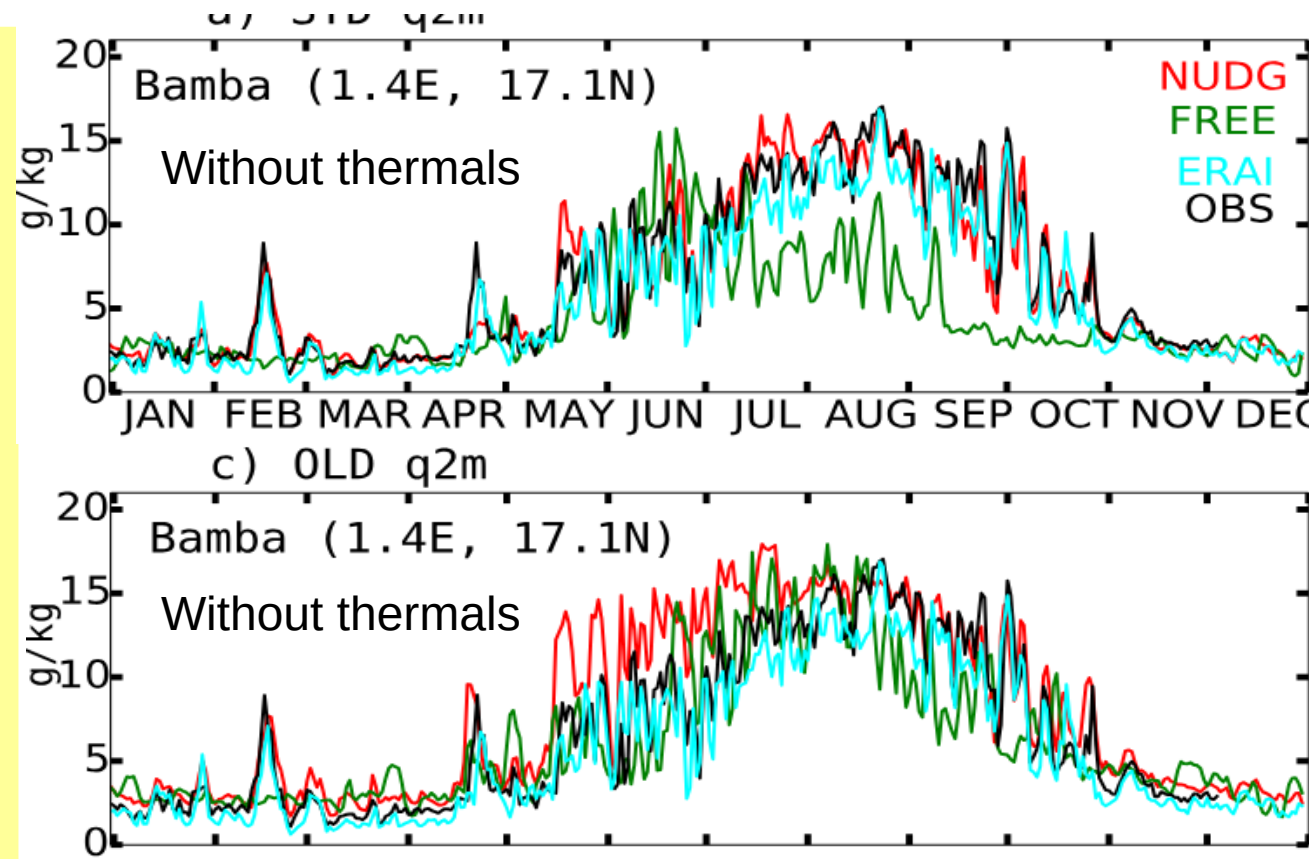
X : model state variables, u, v, T, q

X^a : X from (re)analysis regridded 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 a climate 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. Haefelin, M. Chiriaco, and A. Idelkadi , Combined influence of atmospheric physics and soil hydrology on the simulated 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 stretchable grid and nudging, Monthly Weather Review, 135:1474-1489 PDF

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

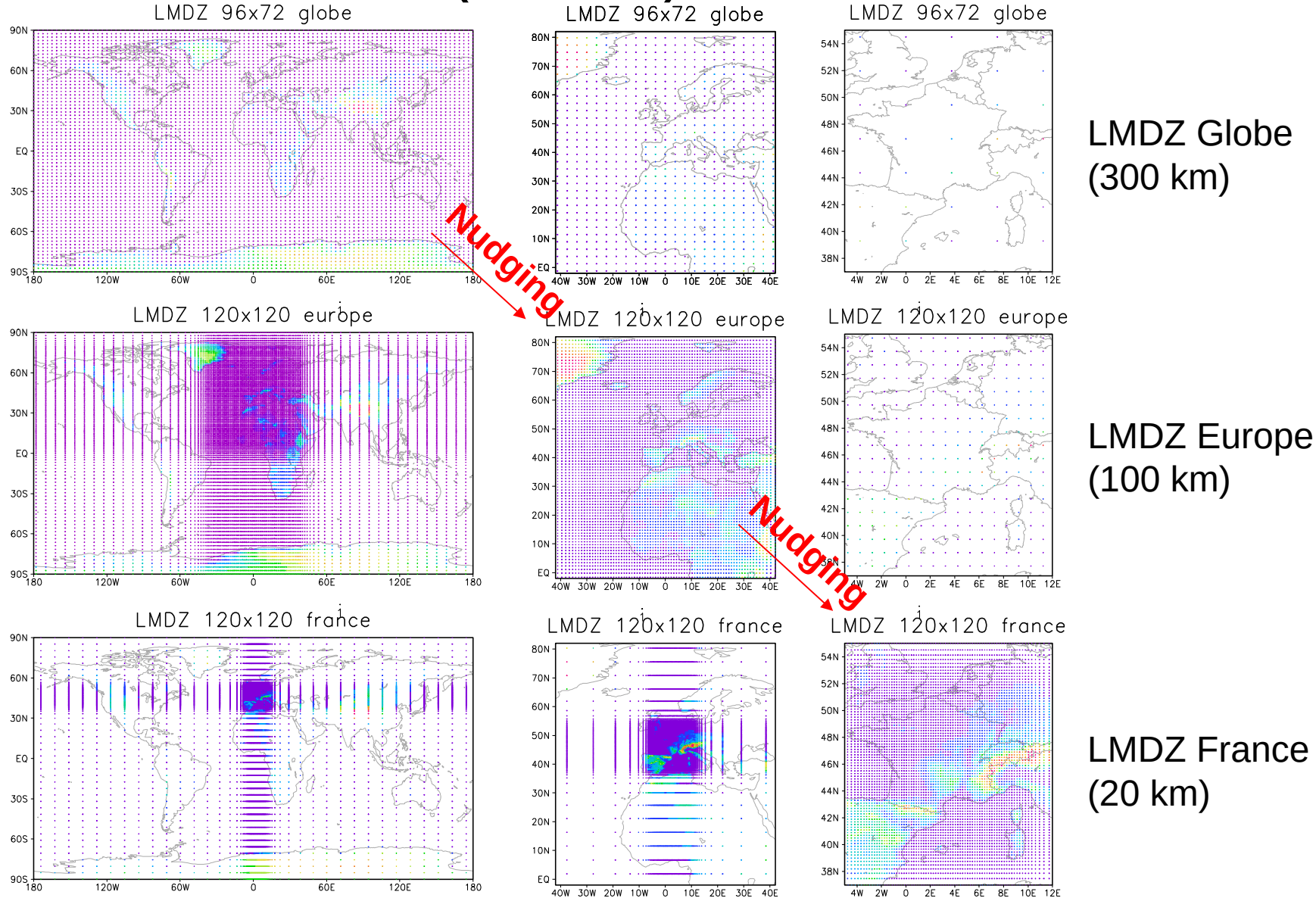
Example 5 :

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

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9

LMDZ - Grid Cascade - (Laurent Li)



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

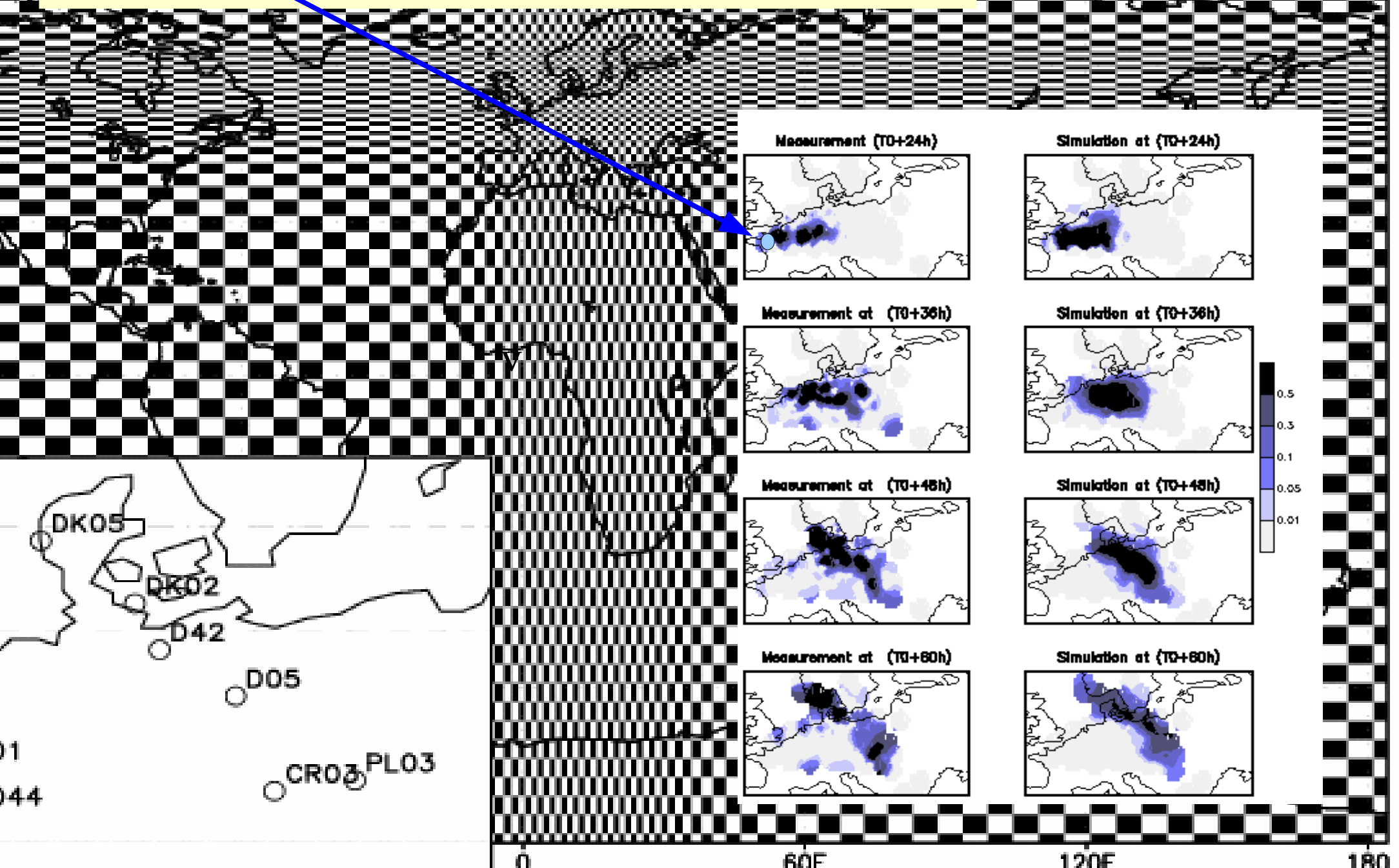
1. Operating modes : c) tracer transport

Example 6 : with tracer transport

1. Operating modes : c) tracer transport

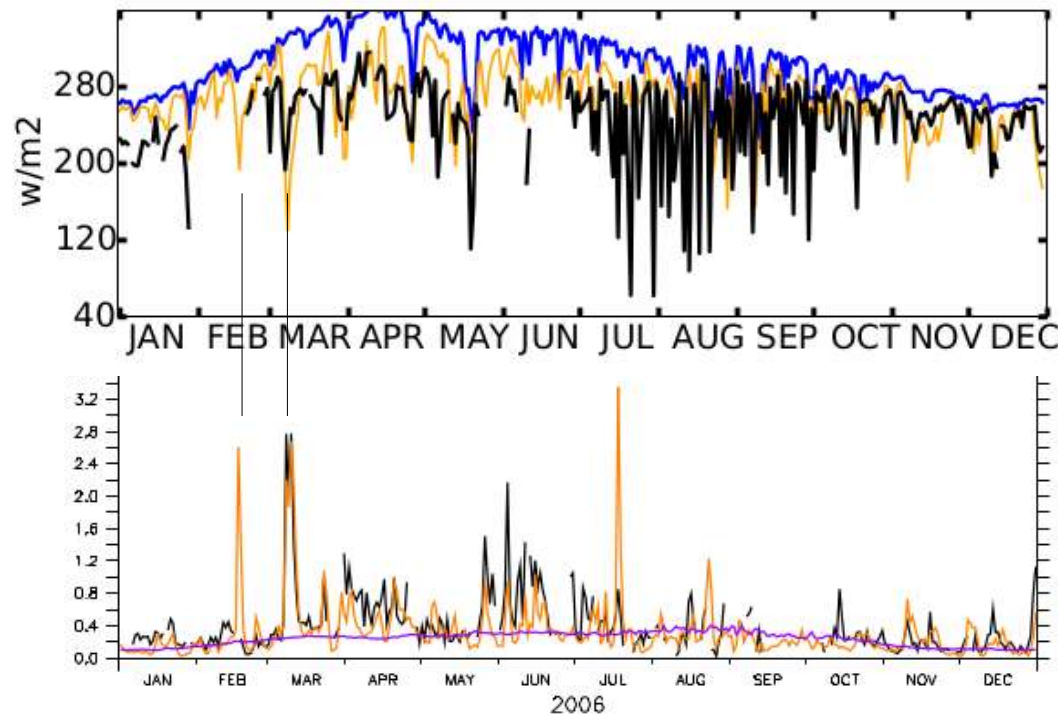
Numerical simulation with LMDZ

Chemical tracer (PMCH) emitted in French Brittany (ETEX)

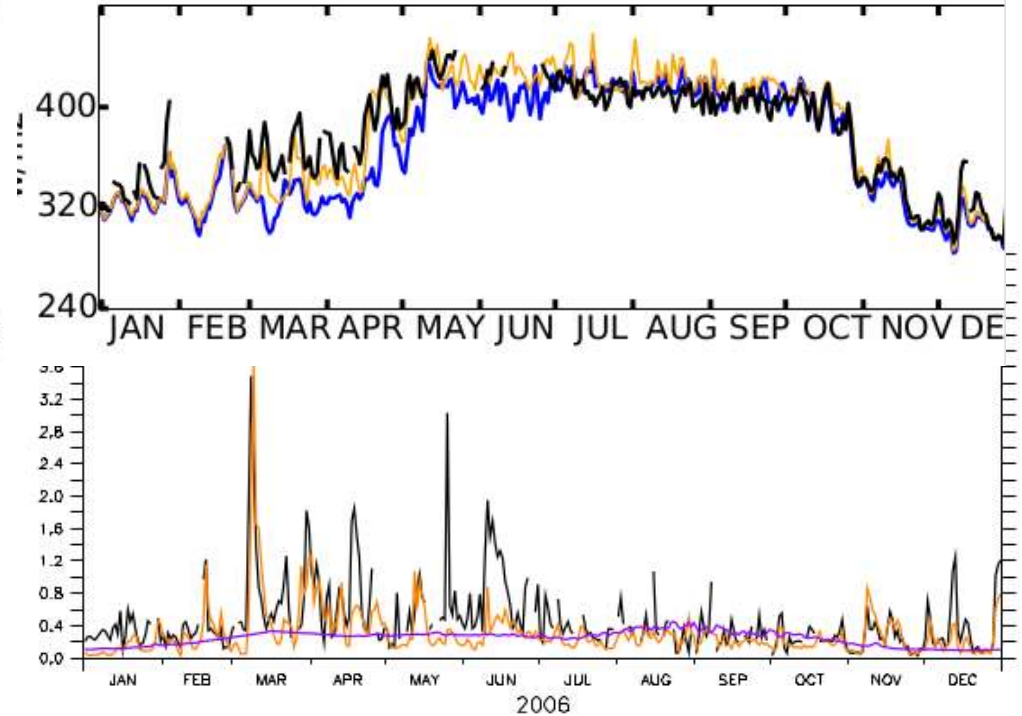


1. Operating modes : c) tracer transport

SW downward flux surf. (W/m²)

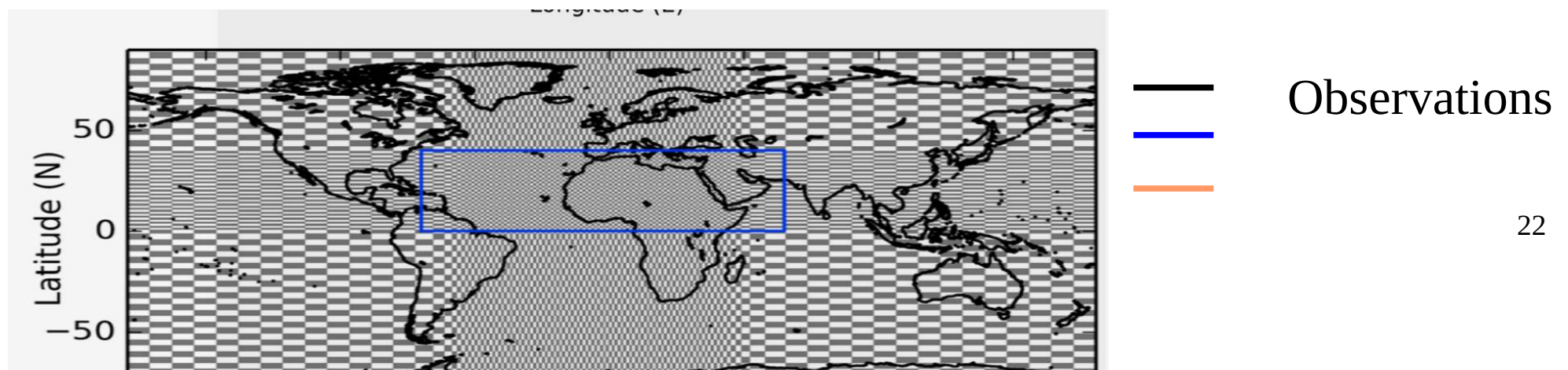


LW downward flux surf. (W/m²)



Coupled simulations with interactive aerosols (Dialo et al., 2017)

Tracer concentrations in $\mu\text{g} / \text{kg}$, 2006



1. Operating modes : c) tracer transport

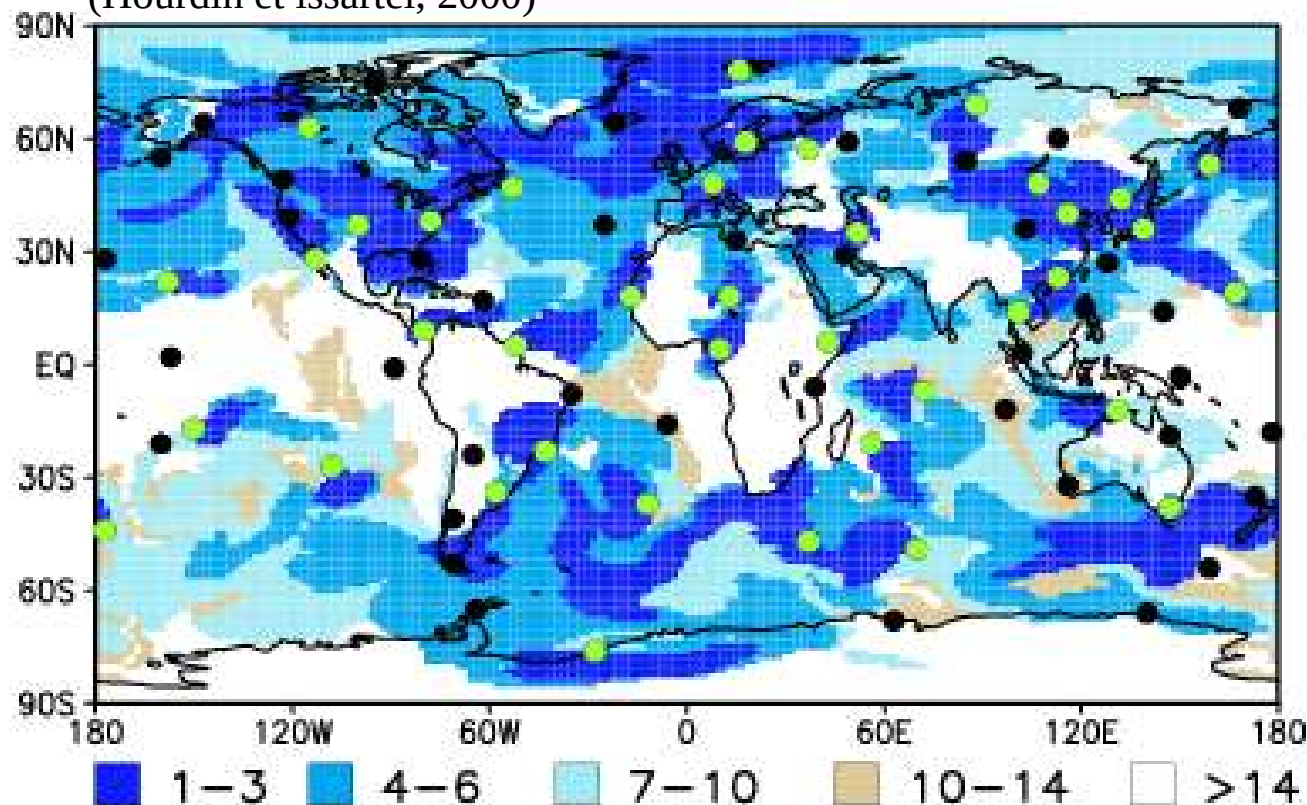
Use in off-line transport model, direct and inverse

- 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 CO₂ and CH₄ inversions.

14-day Visibility of the Xenon detection network
(Hourdin et al., 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

1. Operating modes

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 invasion (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)	Analysis of field campaign experiments and site observations Climate downscaling (*everywhere) Regional modeling (*outside zoom) Analyses/evaluation on day-by-day baisses Can be used in quasi real-time / forecast mode

LMDZ : use and configurations

1. Operating modes of the 3D GCM

- a) Free climatic mode
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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
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2. Reference configurations : a) The IPSL climate model and the CMIP exercises

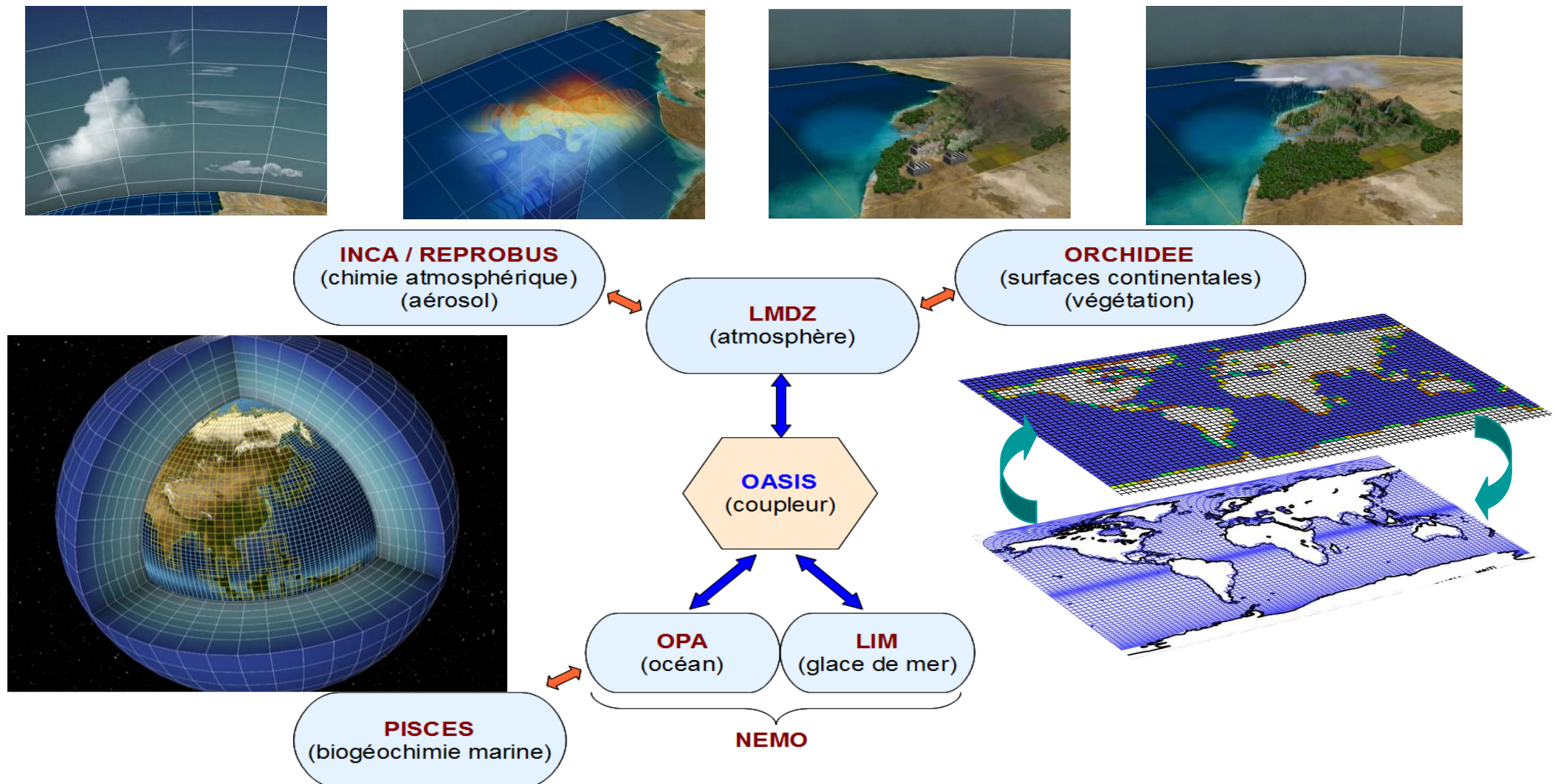
Coupled model Intercomparison Project (CMIP)

Comparison of coupled atmosphere/ocean models or ESM (for Earth System Models)

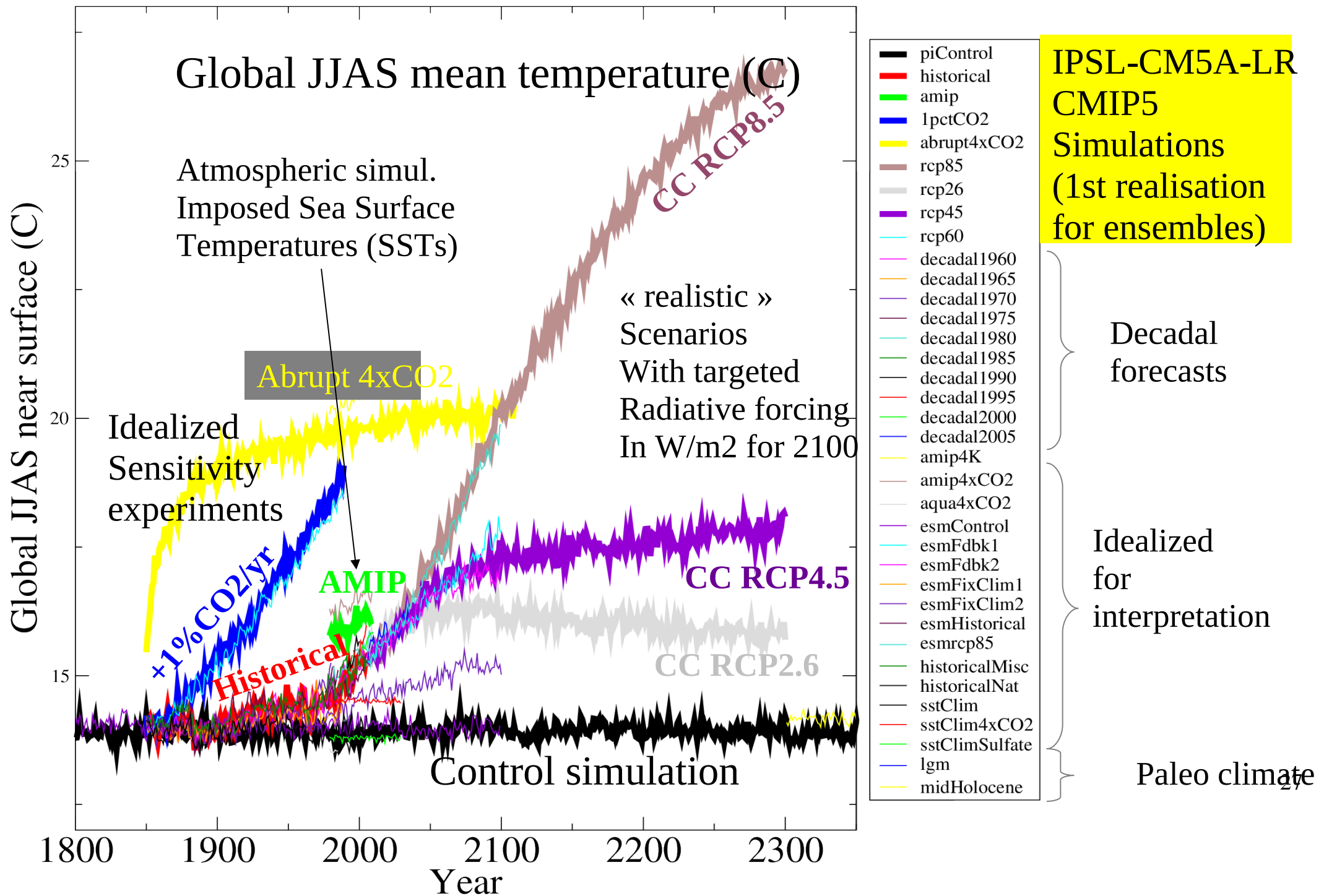
Each 7-year

Production of an ensemble of simulations with imposed boundary conditions / protocol

The IPSL coupled Model

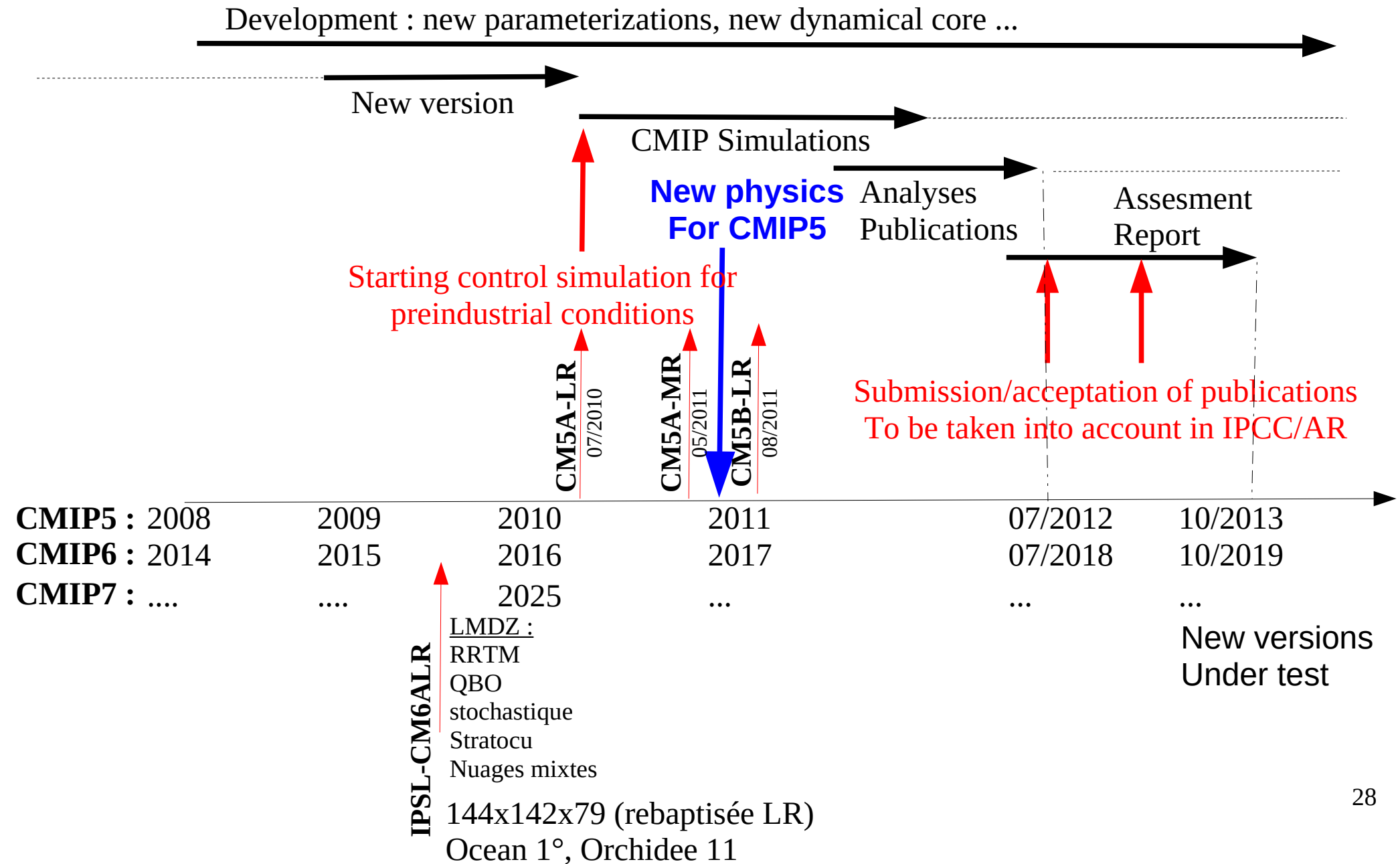


2. Reference configurations : a) The IPSL climate model and the CMIP exercises



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

Development of LMDZ and the CMIP rendez-vous CMIP



2. Reference configurations : b) LMDZ reference configurations

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 closure 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 $\delta z/z \leq 0.1$, for $z < 3$ km $\delta z/z \leq 1$ km, for $z < 50$ km	New Physics (NP) + New radiation : RRTM + SW 6 bands Stochastic triggering of deep convection Stratocumulus from thermal plumes Ice thermodynamics Improve coupling with surface Non orographic 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>

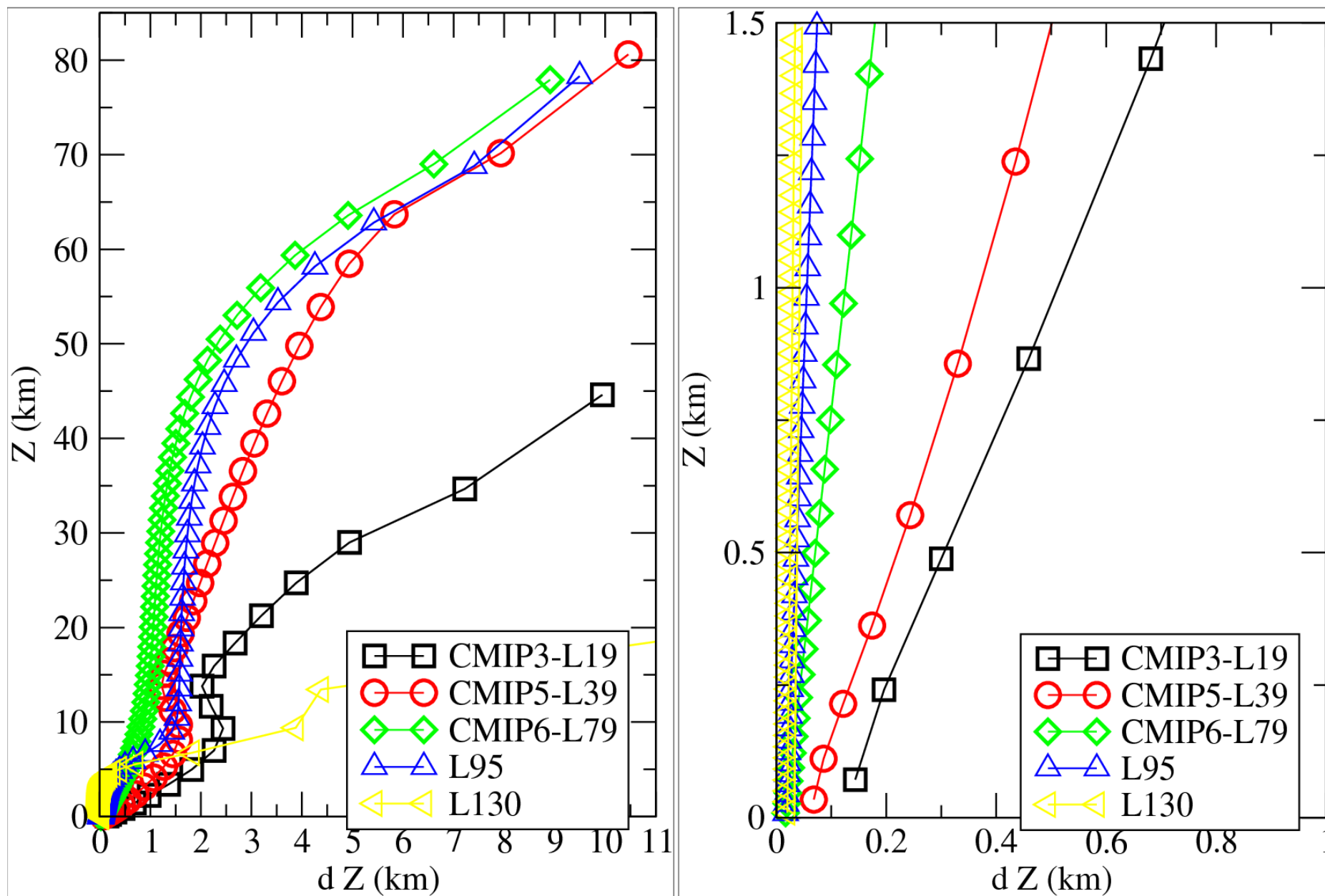
Coming soon :

CMIP7 Fast Track version

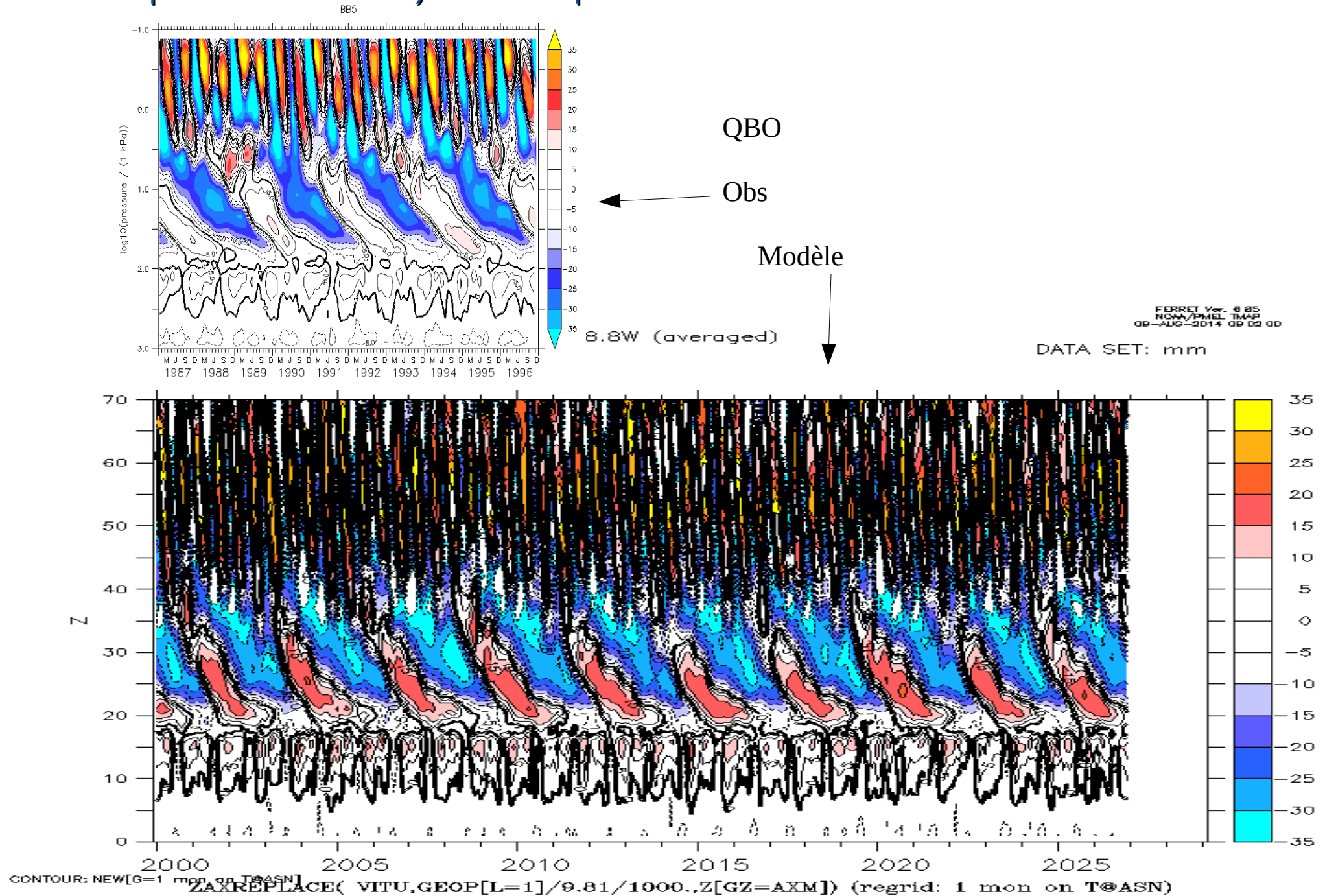
Dynamico NBP60, L95, physics tuned with htexplo (semi automatic and objective)

2. Reference configurations : b) LMDZ reference configurations

Evolution of the vertical discretization in LMDZ reference configurations



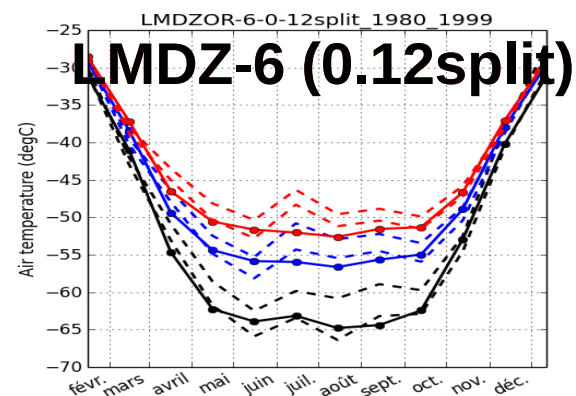
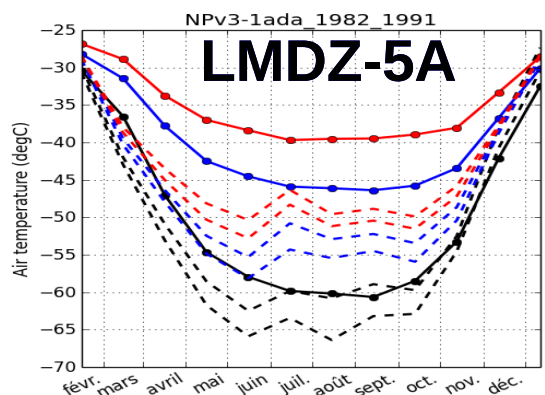
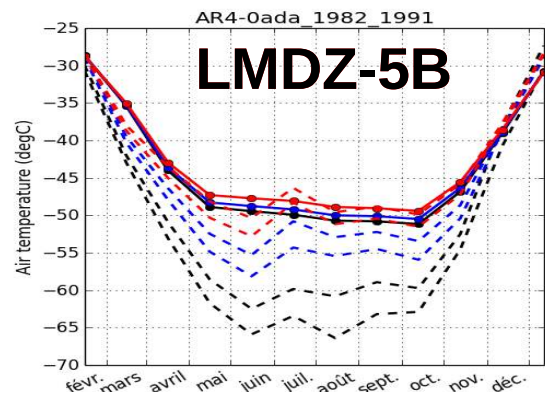
2. Inter-comparison exercises c) Robust improvements from version to version



Among the models with a Quasi Biennial Oscillation

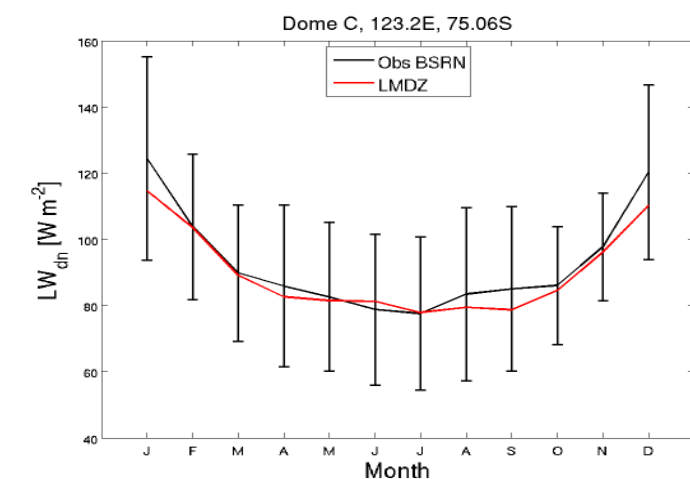
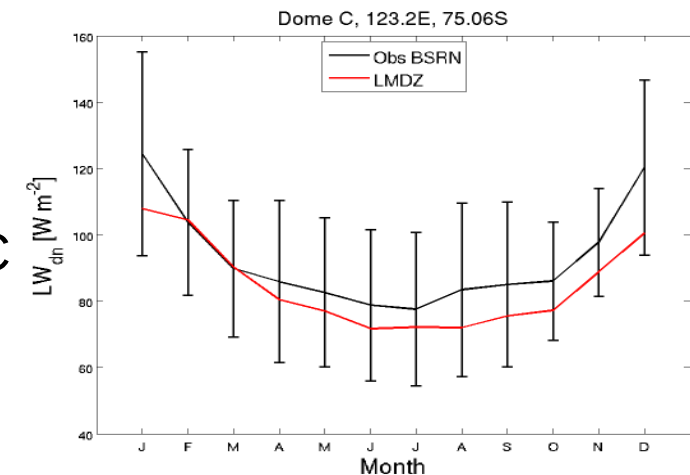
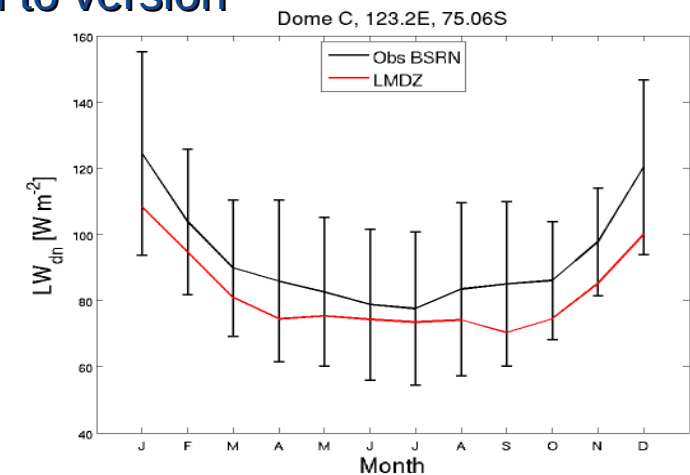
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T at Dome C Antarctic Plateau



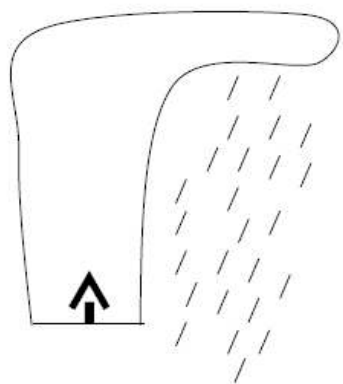
Improvement of the
representation of the stable
boundary layer.
Vignon et al. 2017

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



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

The different physical packages of LMDZ reference versions

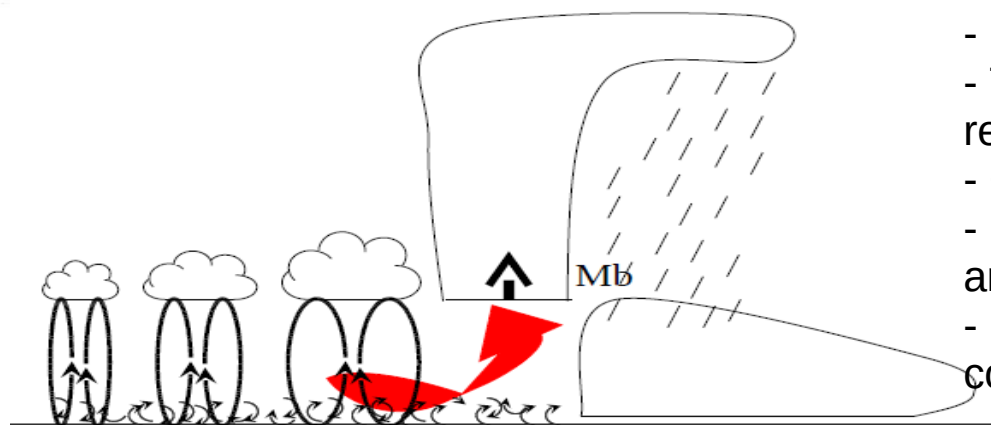


LMDZ5A (old or standard physics)

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

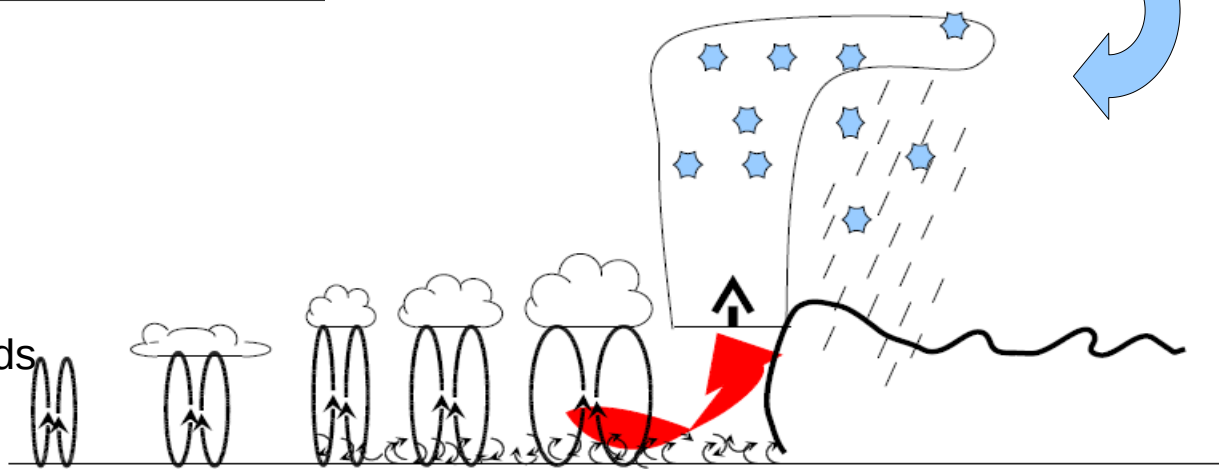
LMDZ5B (« new physics »)

- 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

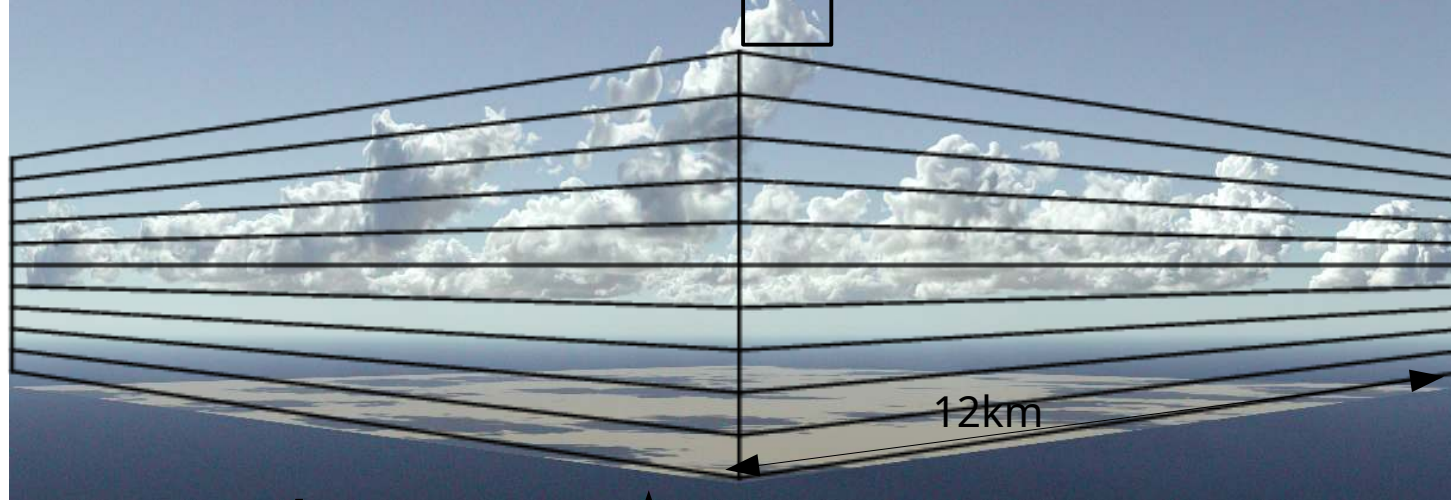


2. Inter-comparison exercises c) Robust improvements from version to version



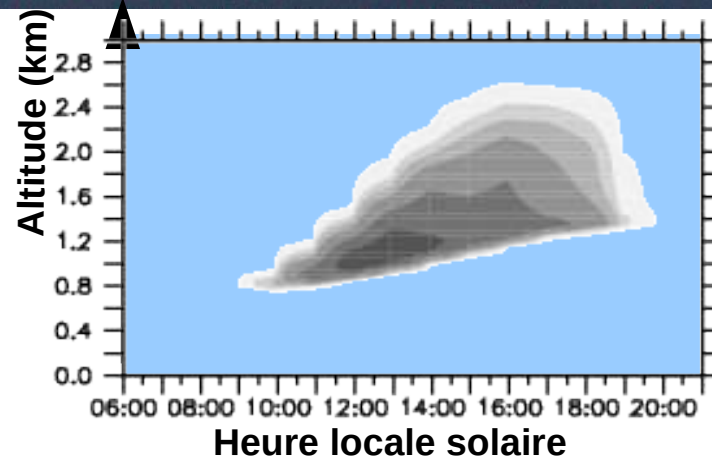
Evaluation

Detailed simulation
(LES : Large Eddy Simulation)

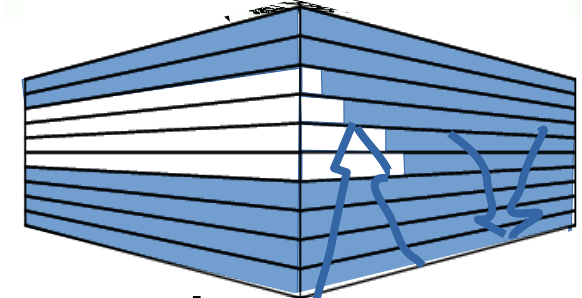
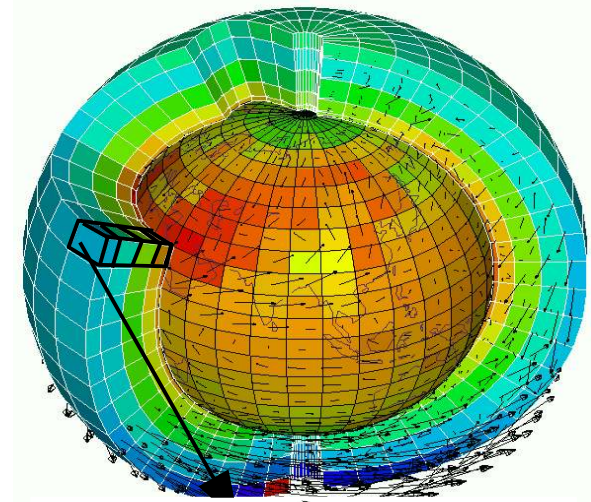
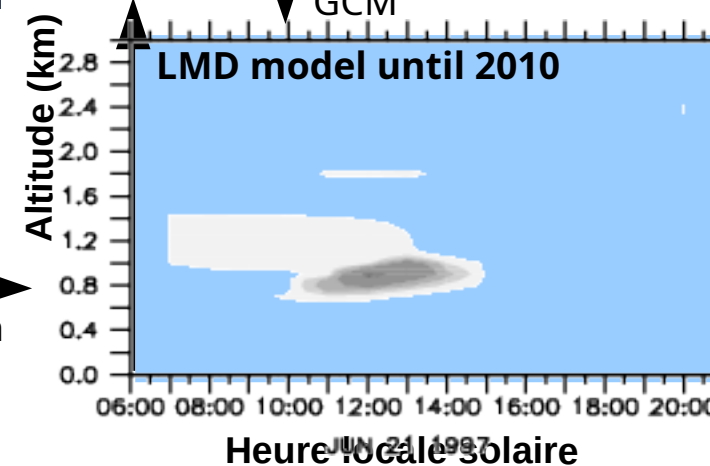


maille de 8m

Computing at each altitude the fraction of the horizontal domain covered by clouds.
Also called :
the cloud fraction

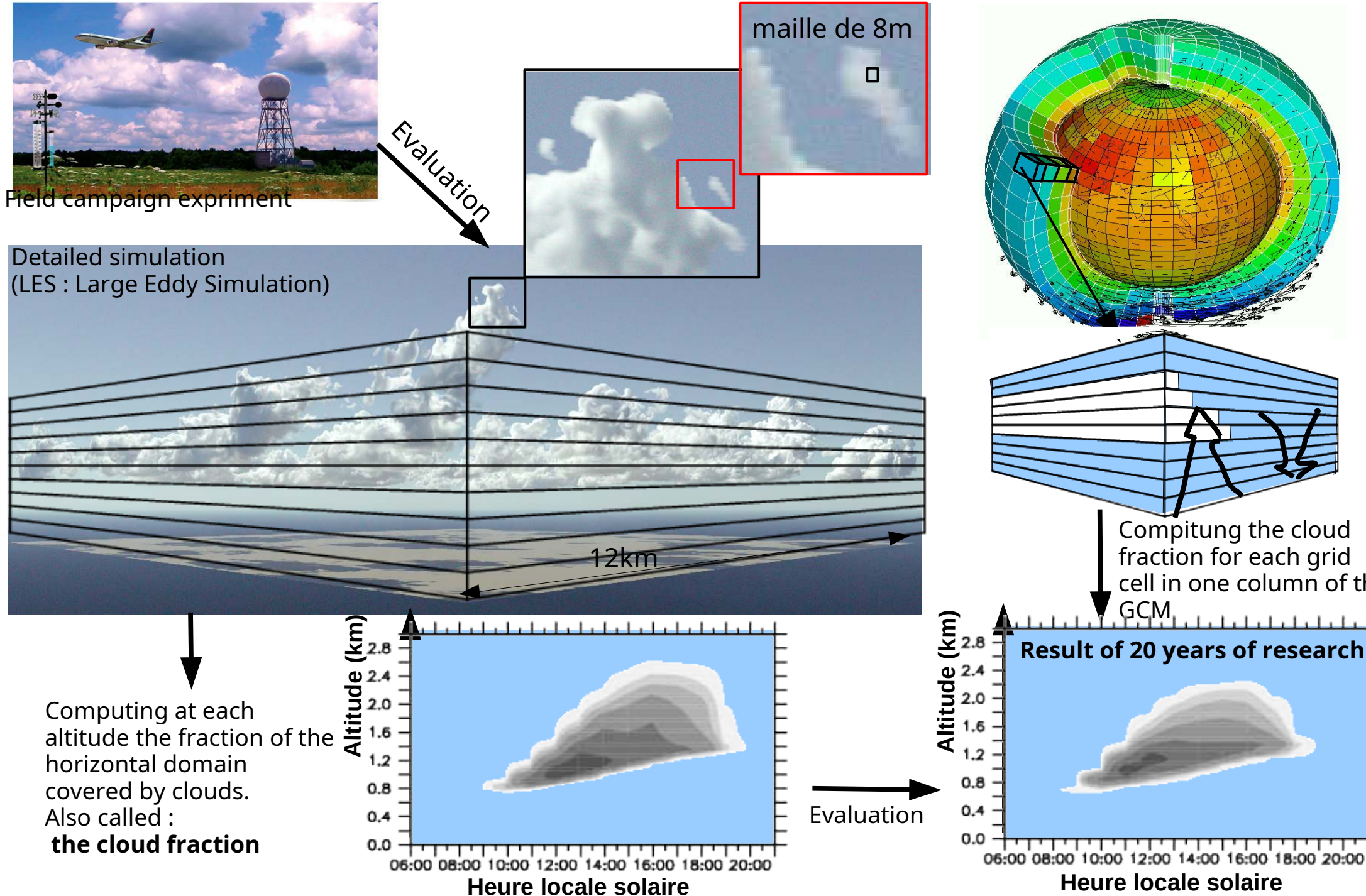


Evaluation



Computing the cloud fraction for each grid cell in one column of the GCM

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

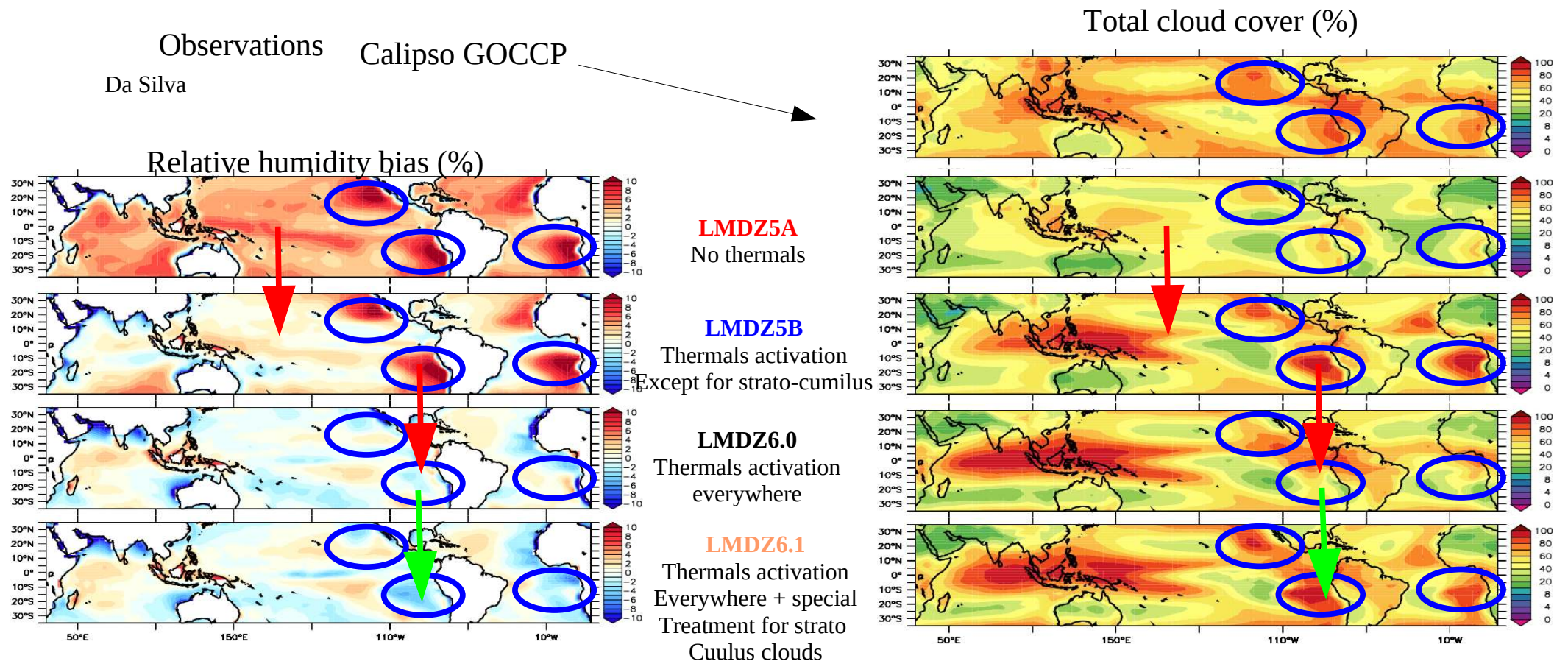


2. Inter-comparison exercises c) Robust improvements from version to version

Successive activation of the thermal plume model

Results from atmospheric simulations forced by climatic sea surface temperature

→ : activating thermal plumes
○ : Subsidence regions
→ : Detrainement modifié



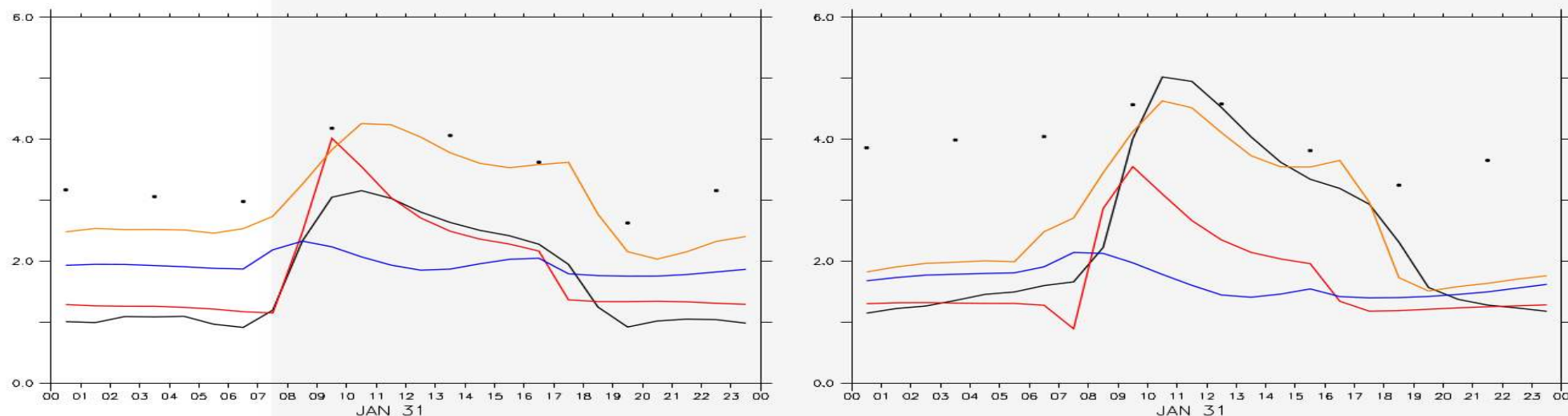
Frédéric Hourdin, Arnaud Jam, Catherine Rio, Fleur Couvreur, Irina Sandu, Marie-Pierre Lefebvre, Florent Briant, and Abderrahmane Idelkadi, Unified Parameterization of Convective Boundary Layer Transport and Clouds With the Thermal Plume Model, James, 2019, <https://doi.org/10.1029/2019MS001666>

Hourdin, Frédéric and Rio, Catherine and Jam, Arnaud and Traore, Abdoul Khadre and Musat, Ionela, Convective boundary layer control of the sea surface temperature 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)



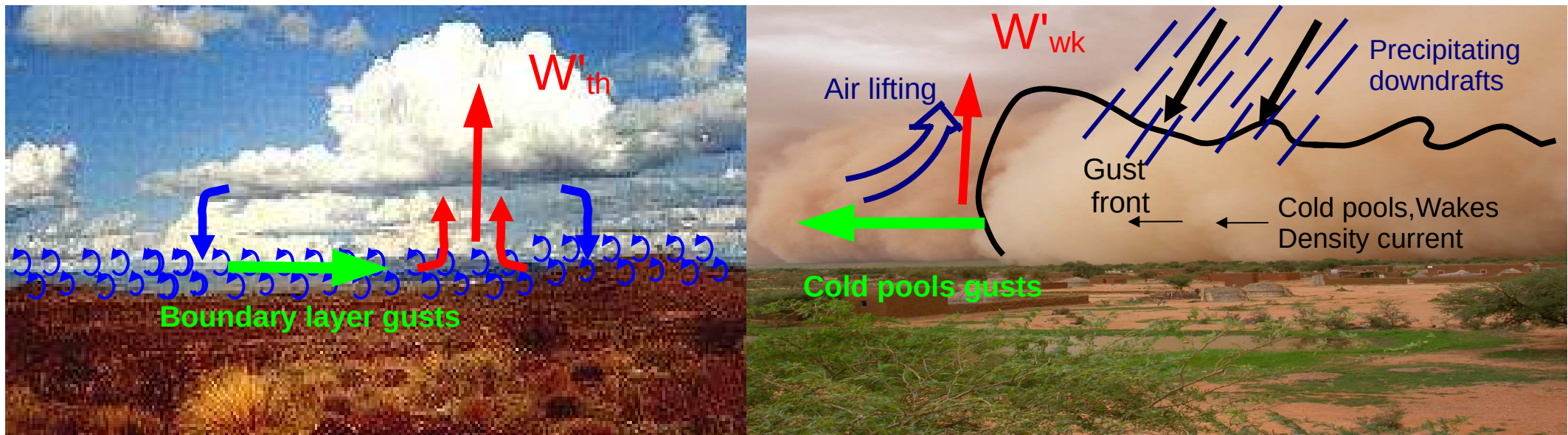
Summary of « thermal plume » model added value :

- Better vertical transport
- Drying of the surface
- Better representation of winds
- Coupled to bi-gaussian cloud scheme: representation of cumulus and strato-cumulus clouds

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

New physics (LMDZ5B)

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

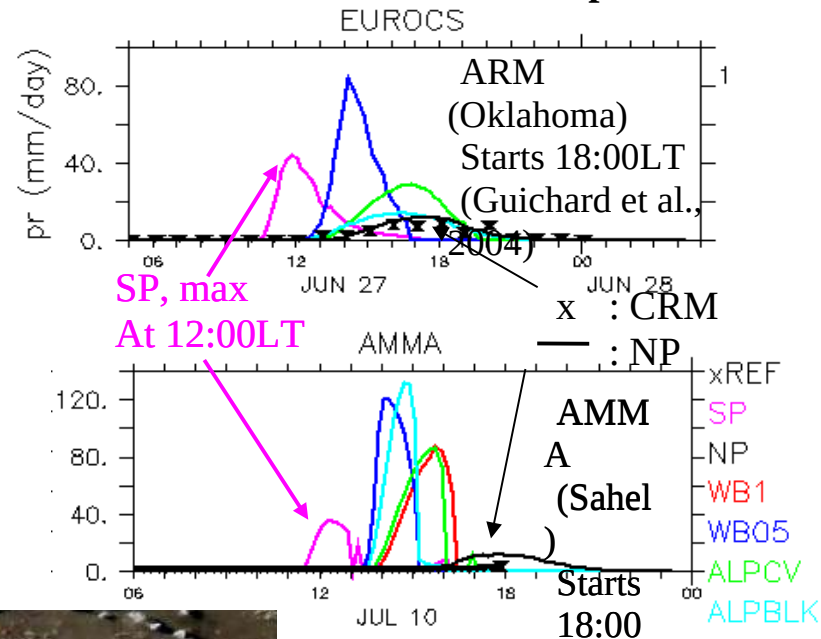


Improvements since LMDZ5 :
Random triggering
Accounting for gusts

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

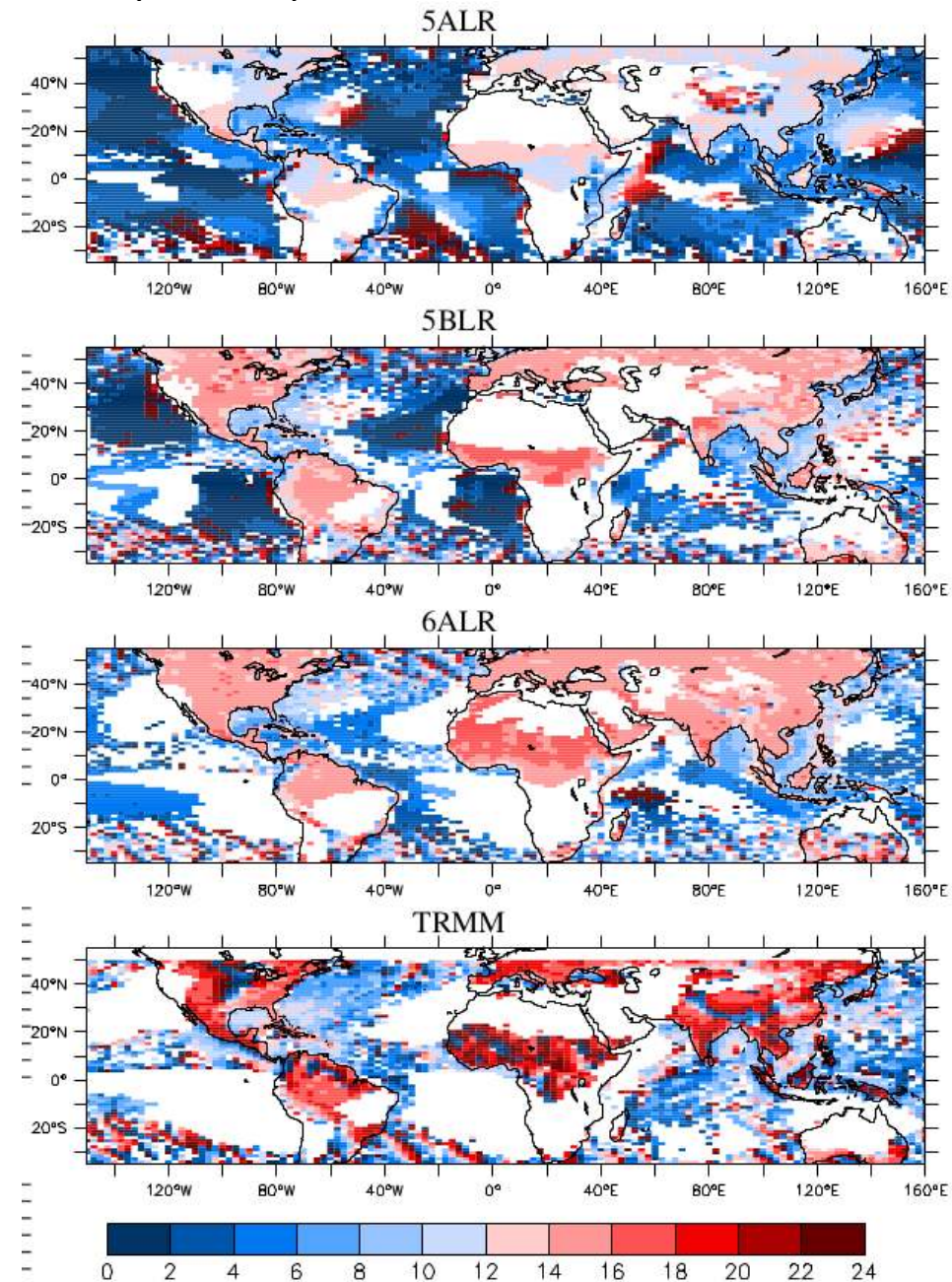
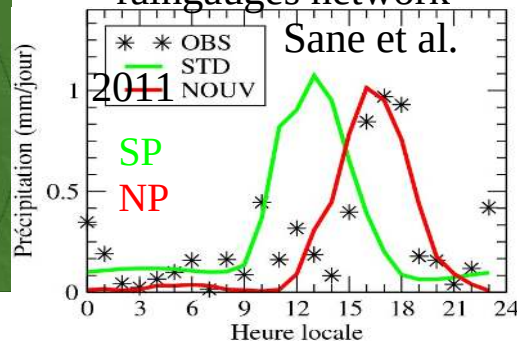
Shifting the diurnal cycle of convective rainfall : possible with parameterized convection

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



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

Dakar LPAOSF/NASA
raingauges network

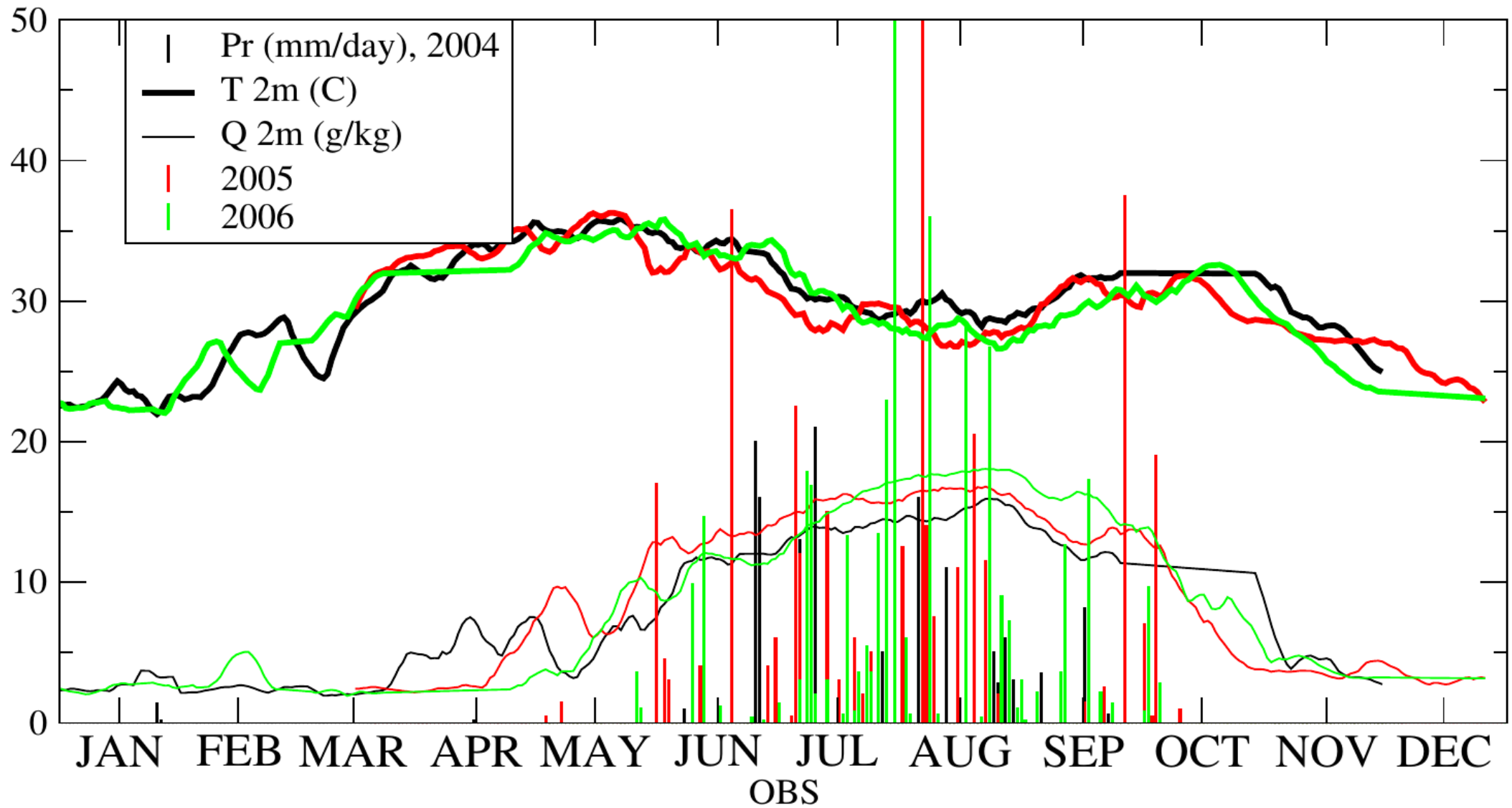


- Evolution moyenne de la pluie dans la journée
- au Sénégal dans une Simulation 3D

A good representation of the diurnal cycle of rainfall over continents

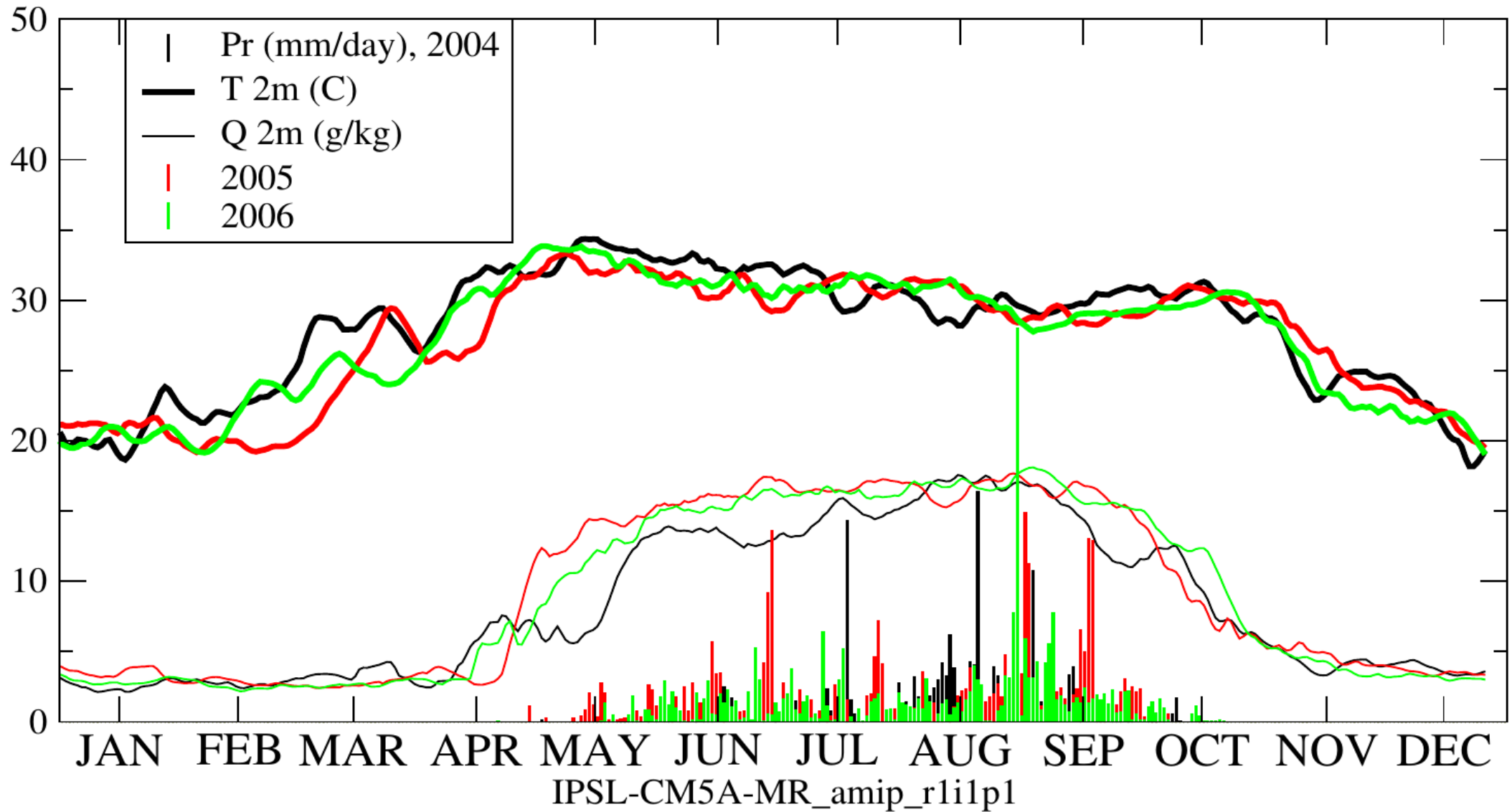
2. Inter-comparison exercises c) Robust improvements from version to version

Observations Agoufou, Mali, 2004, 2005, 2006



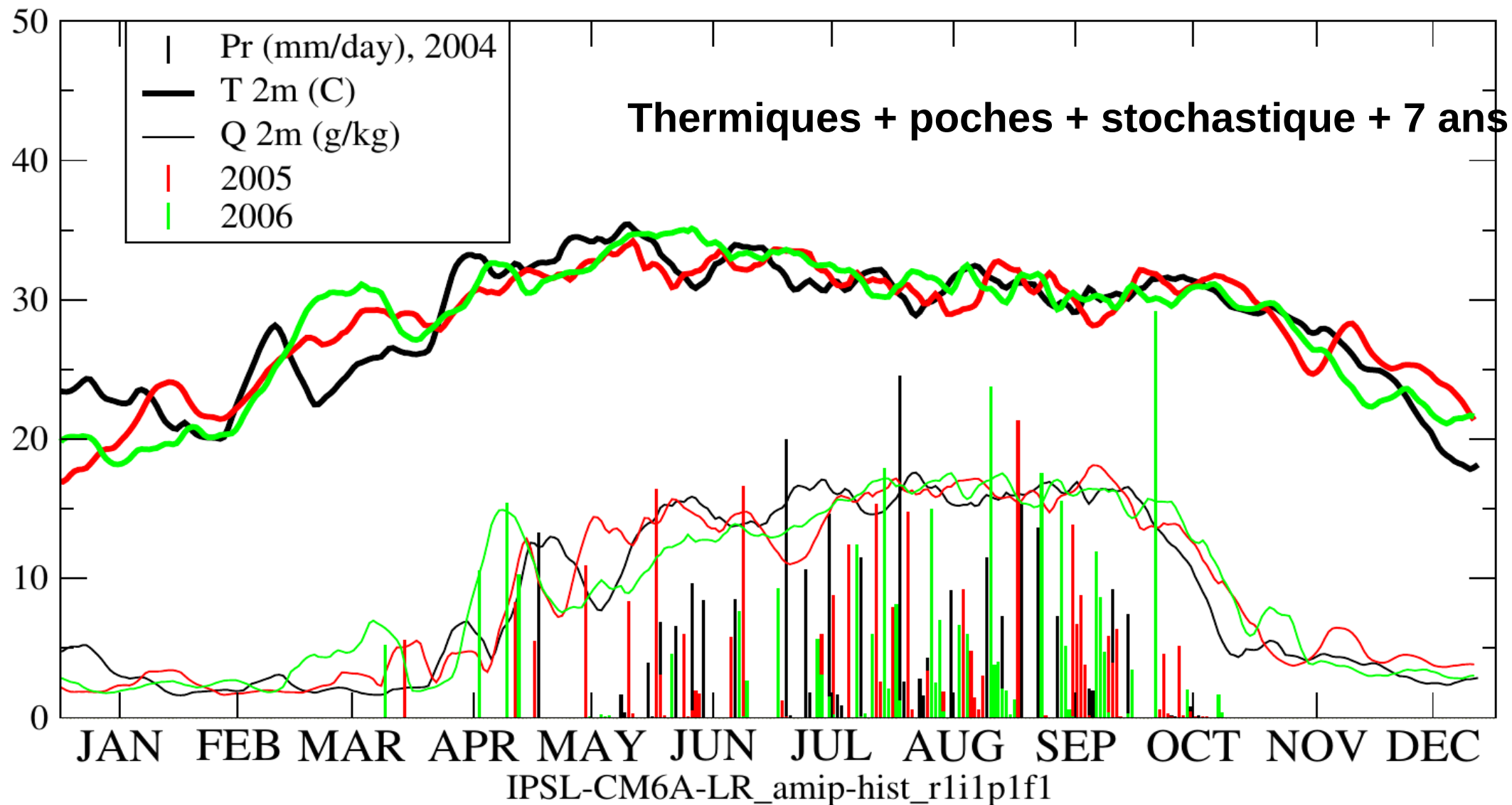
2. Inter-comparison exercises c) Robust improvements from version to version

Simulations amip, IPSL-CM5A Agoufou, Mali, 2004, 2005, 2006



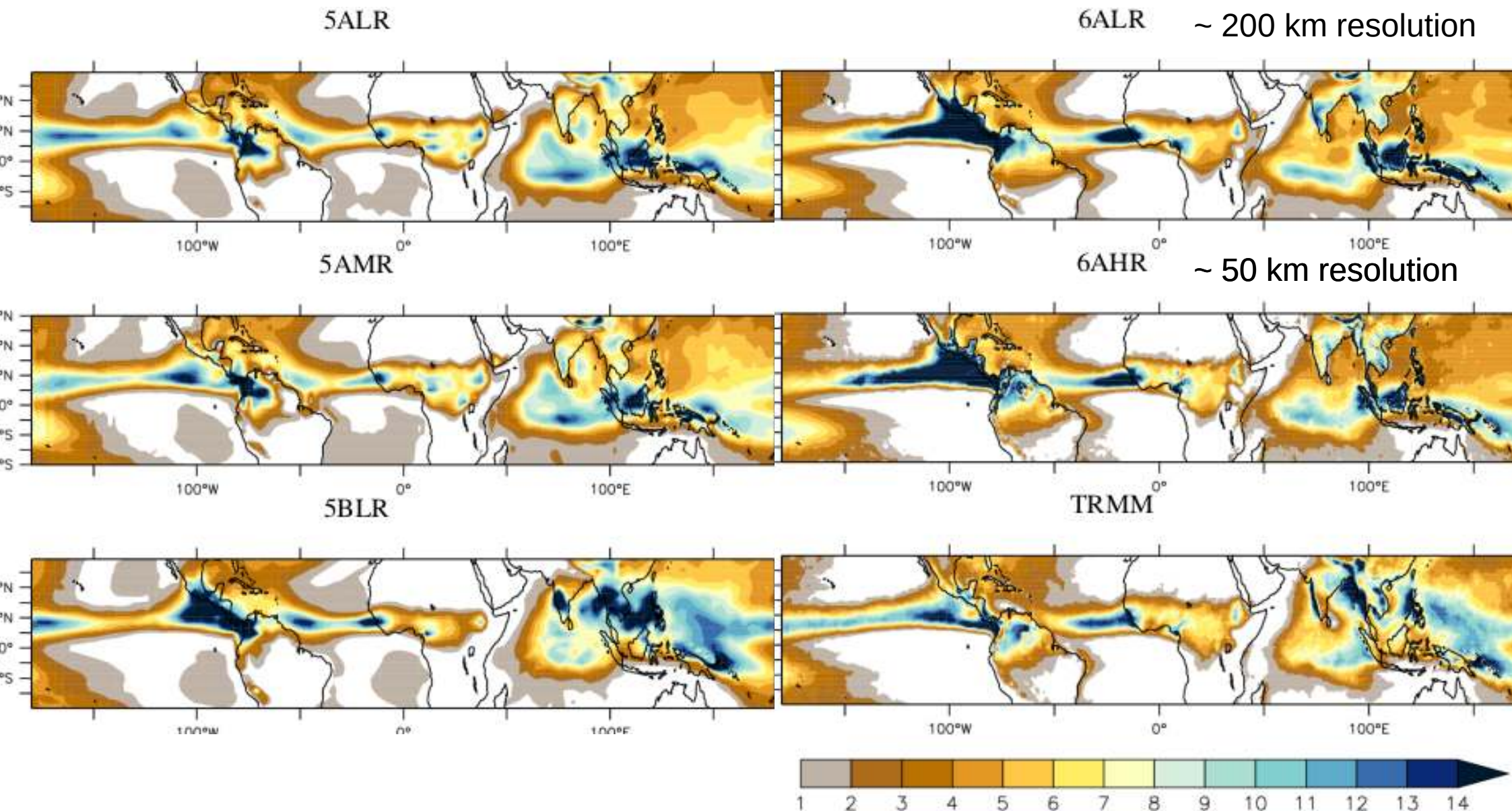
2. Inter-comparison exercises c) Robust improvements from version to version

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



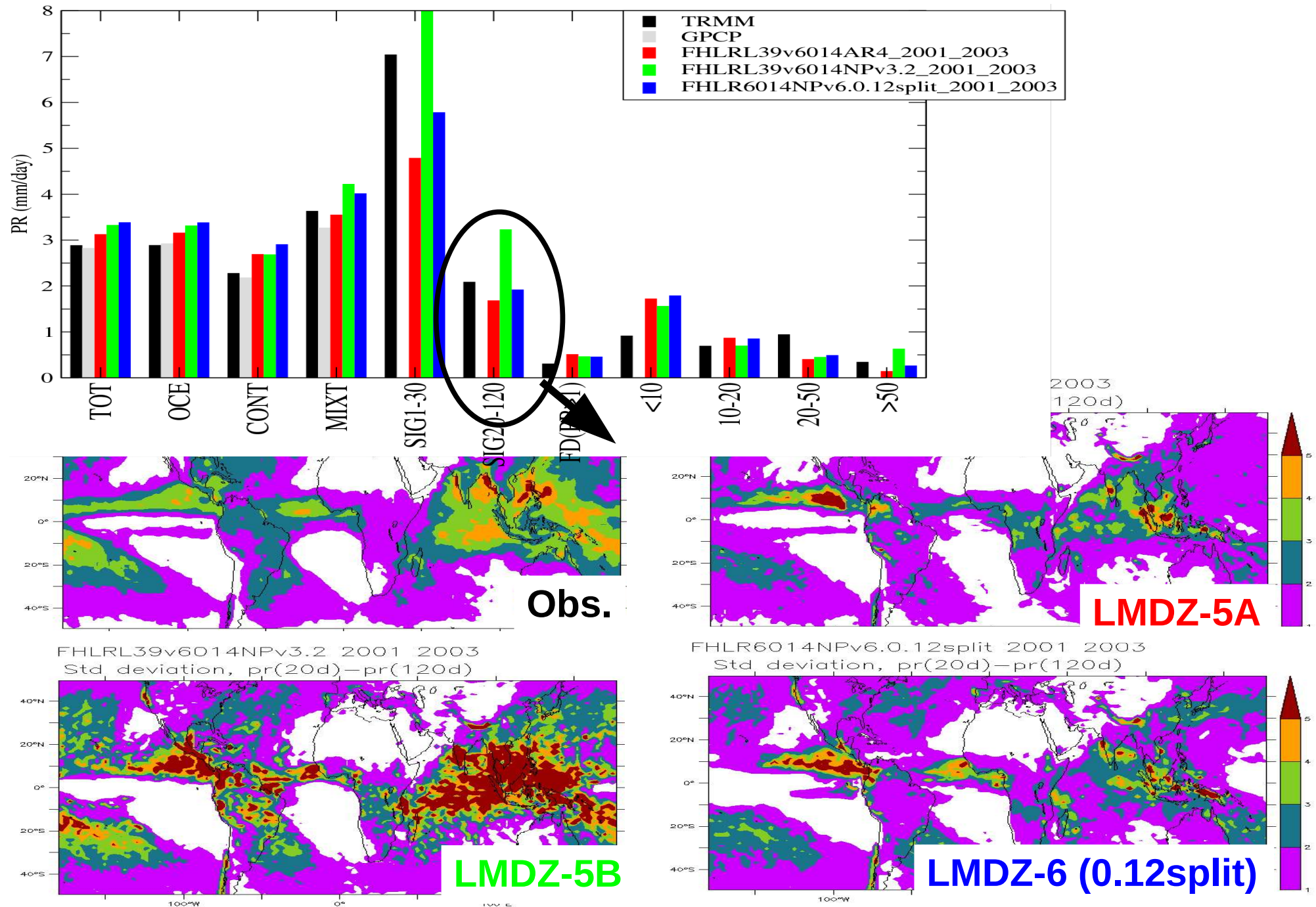
Improved representation of rainfall intermittency over tropical continents

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



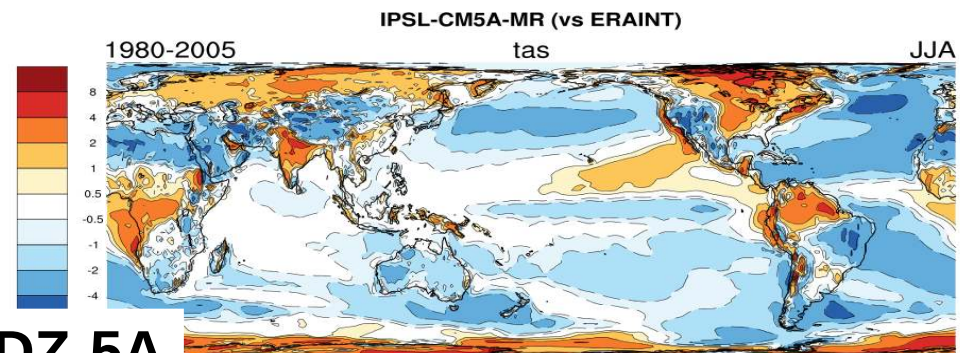
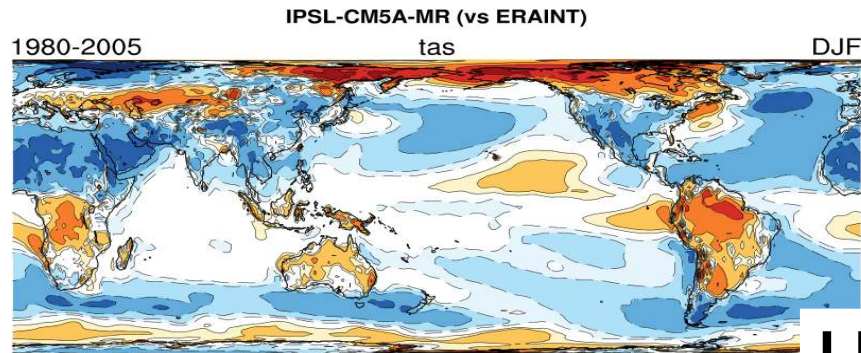
Rainfall variability in the 20 – 120 day period range

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

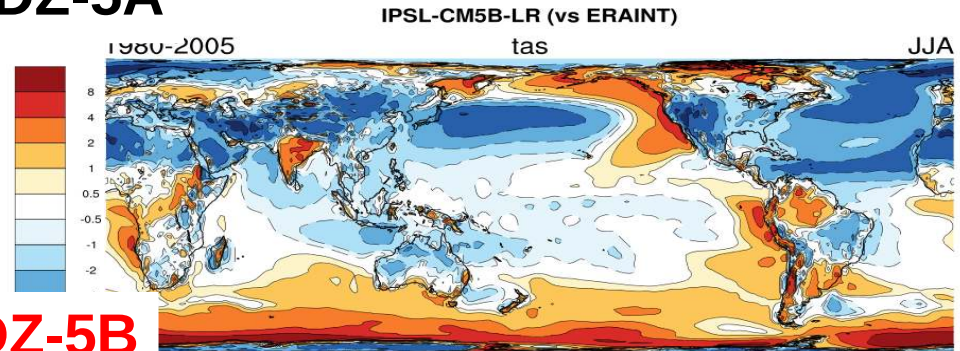
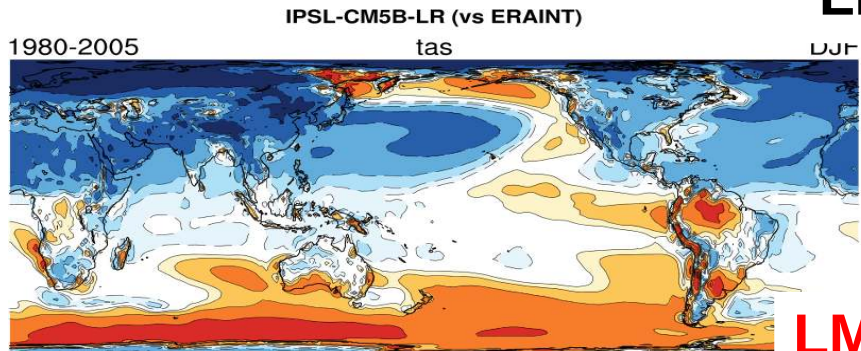
Air surface temperature bias ($^{\circ}\text{C}$), coupled simulations

Dec.-Jan.-Feb.

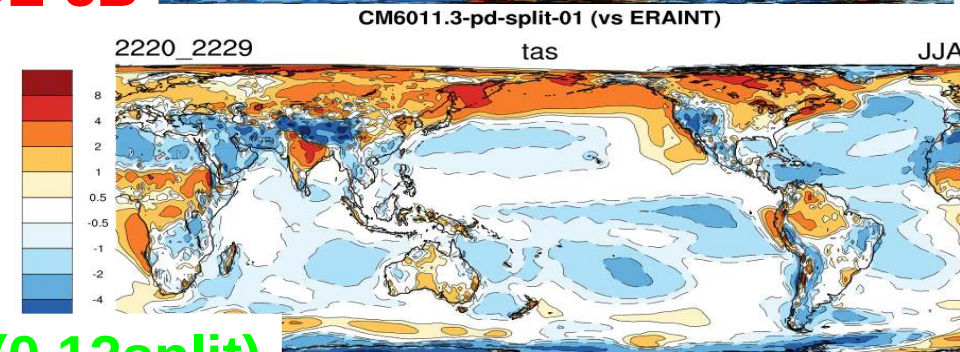
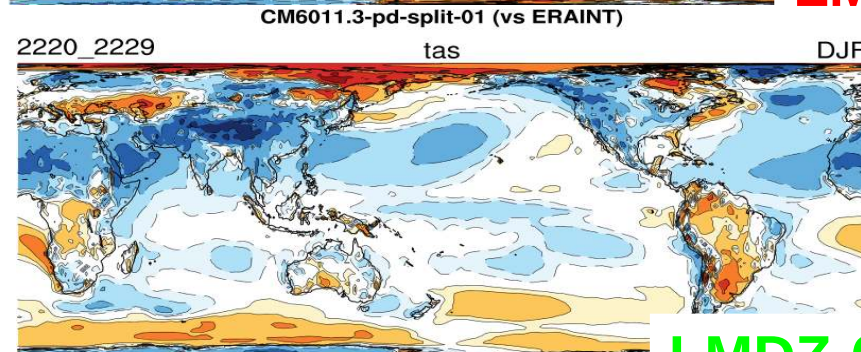
Jun.-Jul.-Aug.



LMDZ-5A



LMDZ-5B



LMDZ-6 (0.12split)

2. Reference versions

Summary

Robust improvements

Convective boundary layer : diurnal cycle of clouds and wind

Better cumulus and stratocumulus clouds

Better phasing of the diurnal cycle of deep convection

Intermittency 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

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

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.

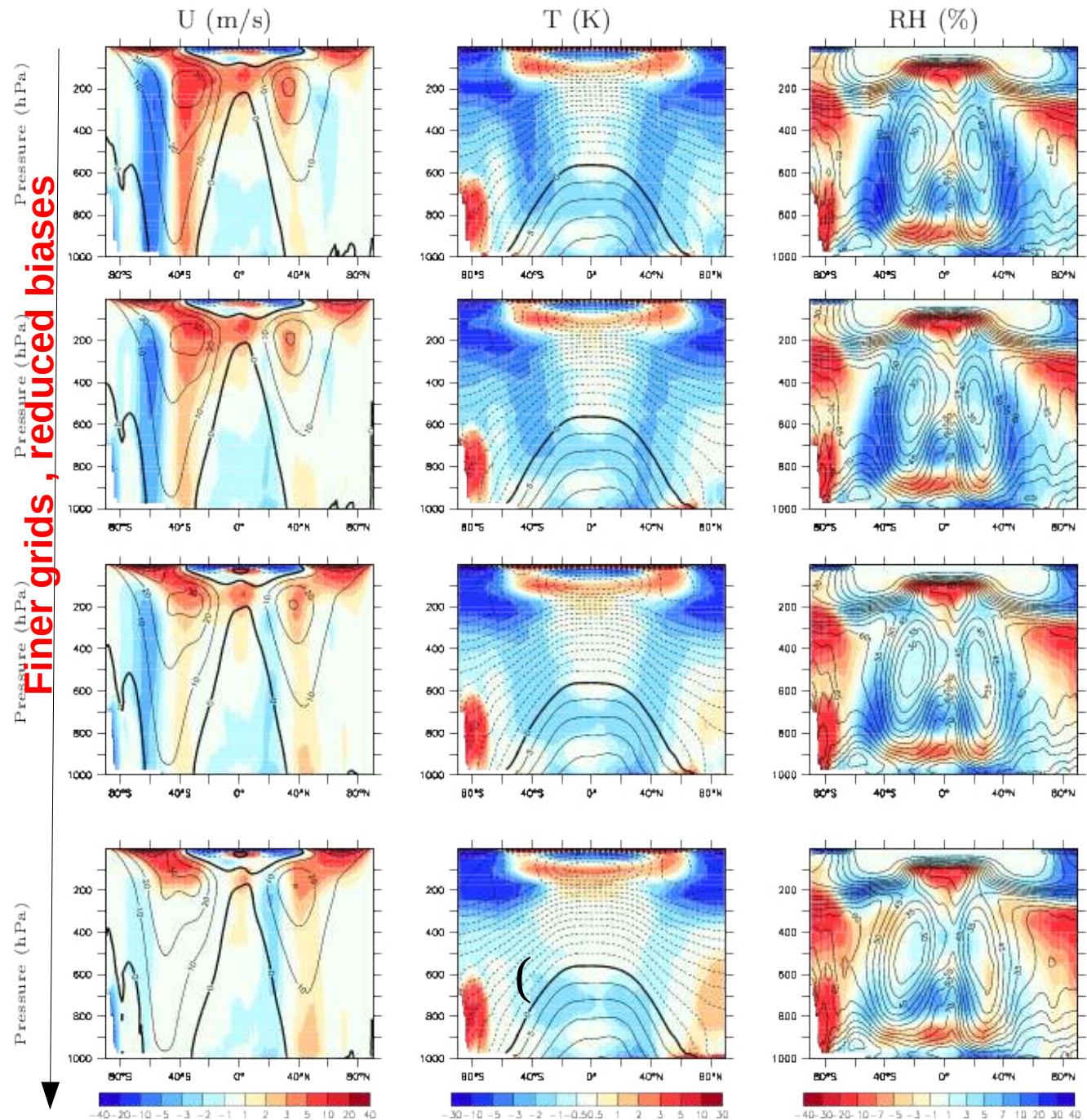
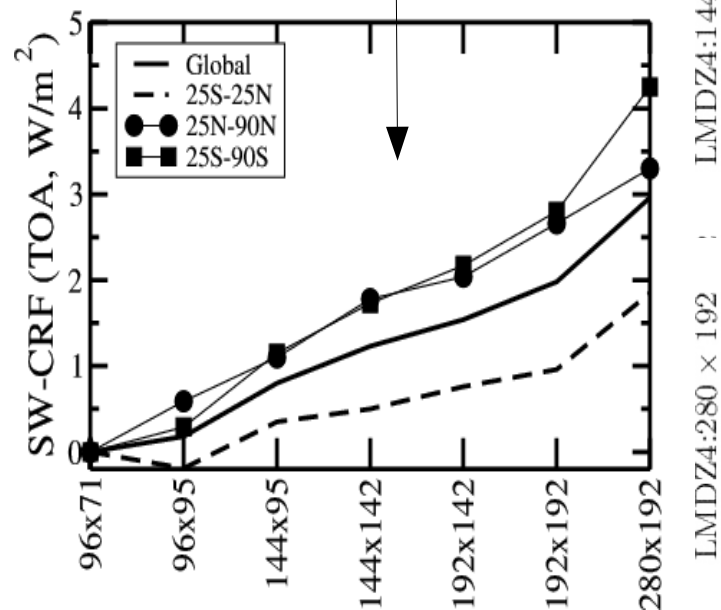
3. Model development and tuning : a) choice of a new configuration

From LMDZ4 to LMDZ5 and LMDZ6 : change of horizontal resolution

Dependence 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



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

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.

3. Model development and tuning : b) importance of free parameter tuning

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

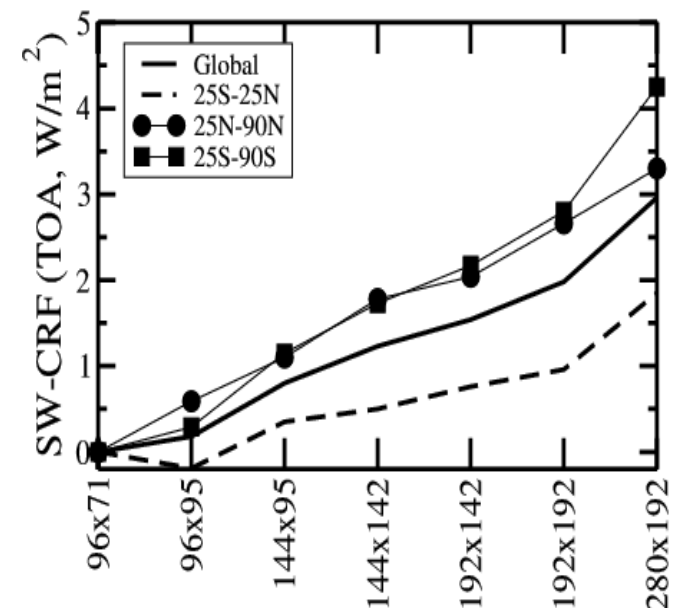
Compromises. Can depend on team priorities.

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

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 !!!



3. Model development and tuning : b) importance of free parameter 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

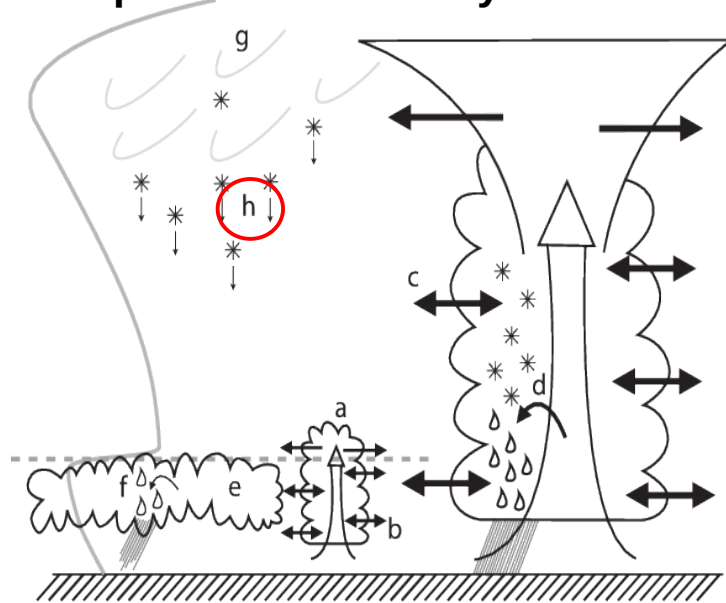
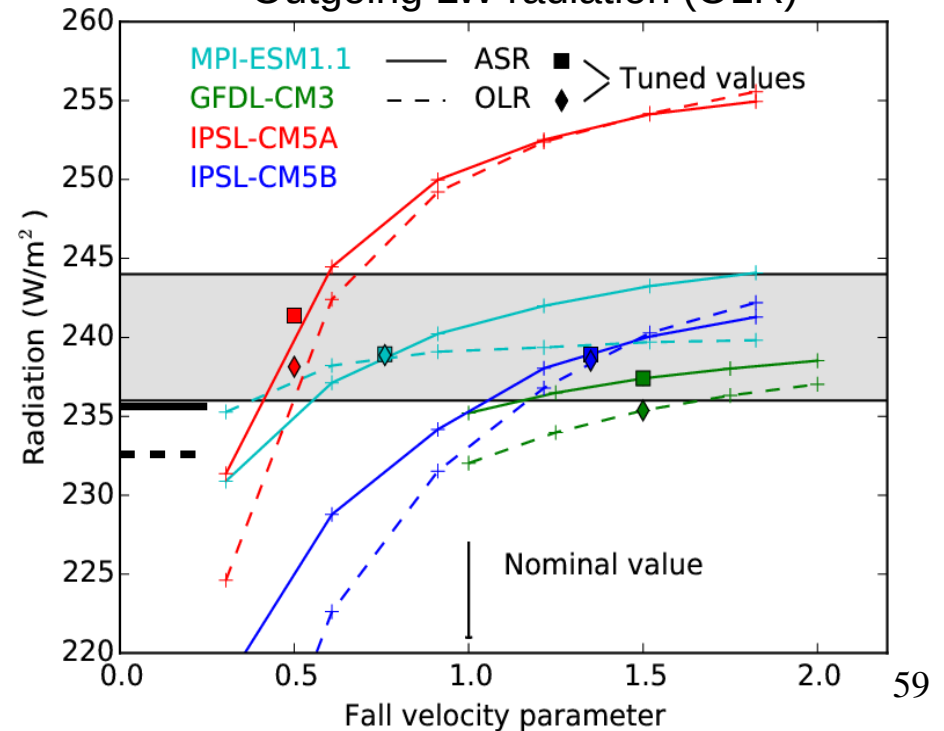


Figure from Mauritsen et al, 2013 (MPI model)

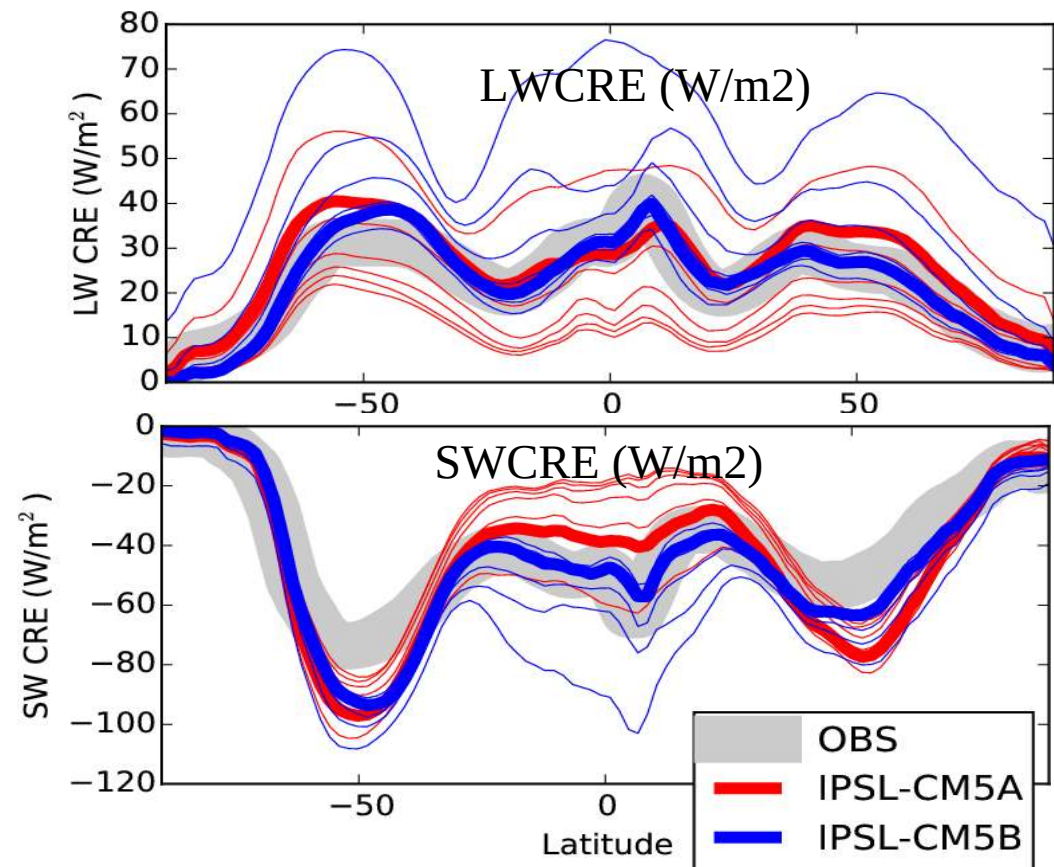
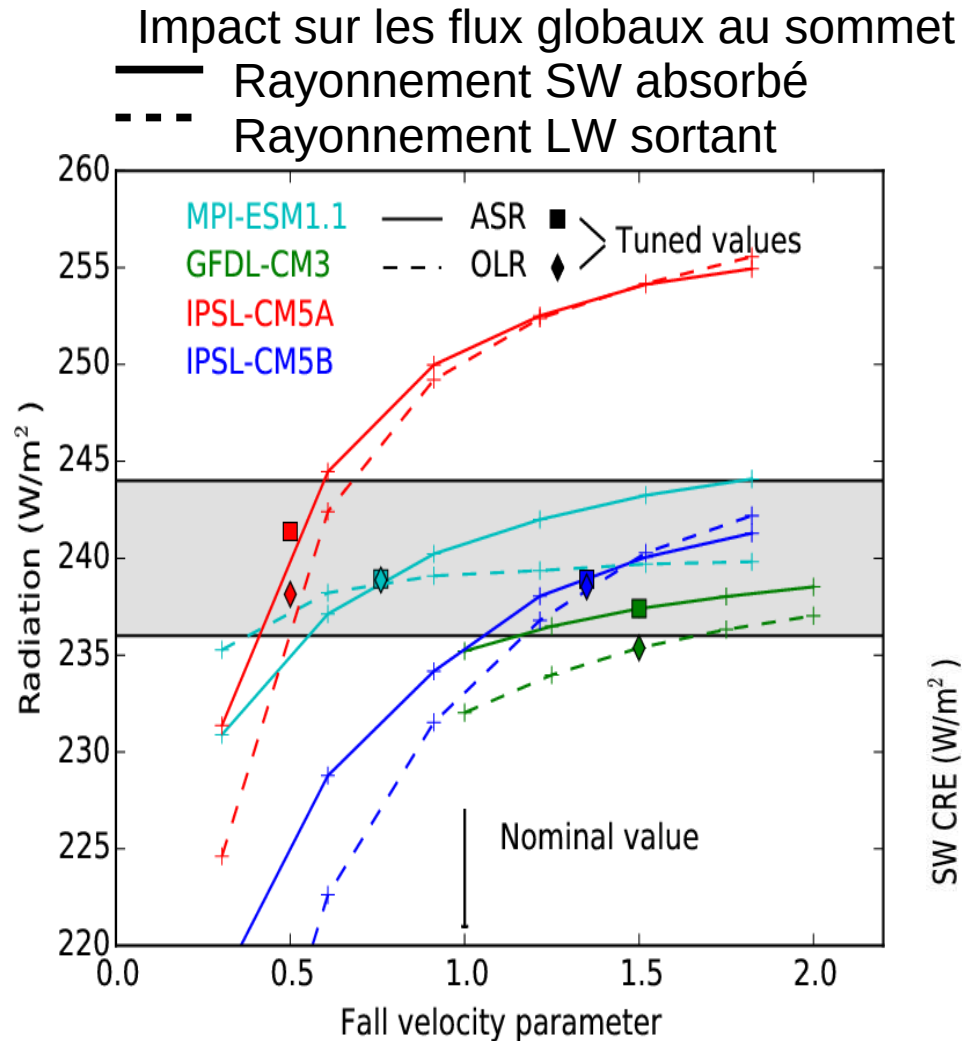
Impact on the global Top-Of-Atmosph. fluxes
Absorbed SW radiation (ASR)
Outgoing LW radiation (OLR)



3. Model development and tuning : b) importance of free parameter tuning

Use of a scaling factor on the fall velocity of cloud ice particles

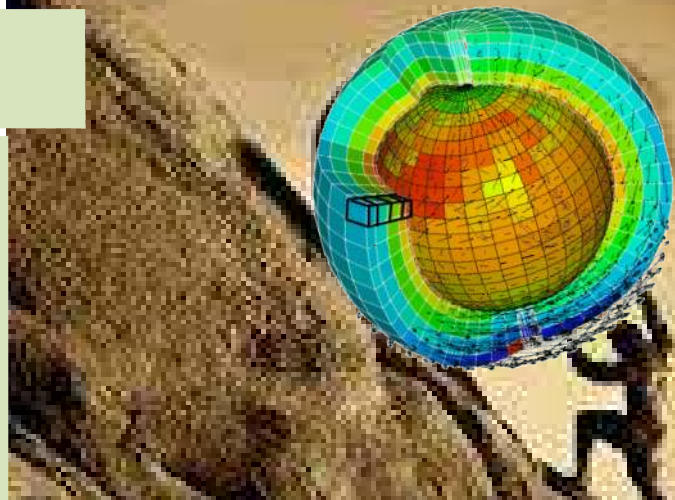
Impact on global radiative balance and latitudinal radiative forcing of the circulation



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

Été 2015, 1eres simulations longues :

- Stabilisation num couche lim.
- Déclench. Stochast. Convect.
- Strato-cus avec thermiques.
- Microphysique glace
- Ondes non orog. → QB0
- L39 → L79



Convection
- Conditionnée par point de congélation
- densité de poches diff. 0/A
- réglage w base convection
- rafales → z0 océaniques
Conserv. E.2

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

Reréglage 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 (cvoro,trig)
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)

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

Convection
Emanuel old/new
Closure CAPE/ALP
Cold pools
Stochastic closure
PDF for mixing
Computation of condensate
Efficiency of precipitation

Clouds
Ice thermodynamics
Cloud scheme
Profile of σ/qt
 σ/qt min
 σ/qt max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
Radiation

LMDZ5A

iflag_pbl=1
iflag_thermals=0
iflag_thermals_ed=0
fact_thermals_ed_dz UNDEF
iflag_coupl=0

iflag_con=30
iflag_clos=1
iflag_wake=0
iflag_trig_bl UNDEF
iflag_mix=1
iflag_clw=1
epmax=0.999

iflag_ice_thermo UNDEF
iflag_cldcon=3
iflag_ratqs=0
ratqsbas=0.005
ratqshaut=0.33
iflag_t_glance UNDEF
cld_lc_lsc=0.000416
cld_lc_con=0.000416
ffallv_lsc=0.5
ffallv_con=0.5
coef_eva=2e-05
iflag_rrtm=0

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

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

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Emanuel old/new
Closure CAPE/ALP
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Stochastic closure
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Efficiency of precipitation

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Cloud scheme
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 σ/qt min
 σ/qt max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
radiation

NPv3.1 (LMDZ5B)

iflag_pbl=8
iflag_thermals=15
iflag_thermals_ed=10
fact_thermals_ed_dz=0.1
iflag_coupl=5

iflag_con=3
iflag_clos=2
iflag_wake=1
iflag_trig_bl=0
iflag_mix=1
iflag_clw=0
epmax=0.997

iflag_ice_thermo=0
iflag_cldcon=6
iflag_ratqs=2
ratqsbas=0.002
ratqshaut=0.25
iflag_t_glance=0
cld_lc_lsc=0.0006
cld_lc_con=0.0006
ffallv_lsc=1.35
ffallv_con=1.35
coef_eva=0.0001
iflag_rrtm=0

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

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

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 σ/qt min
 σ/qt max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
radiation

NPv4.12

iflag_pbl=11
iflag_thermals=18
iflag_thermals_ed=8
fact_thermals_ed_dz=0.1
iflag_coupl=5

iflag_con=3
iflag_clos=2
iflag_wake=1
iflag_trig_bl=2
iflag_mix=1
iflag_clw=0
epmax=0.97

iflag_ice_thermo=0
iflag_cldcon=6
iflag_ratqs=4
ratqsbas=0.002
ratqshaut=0.24
iflag_t_glance=1
cld_lc_lsc=0.000192
cld_lc_con=0.000192
ffallv_lsc=0.9504
ffallv_con=0.9504
coef_eva=1e-05
iflag_rrtm=0

Summer 2015
Ice thermo dynamics
First multi decadal simulations

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

NPv5.17h (IPSL-CM 6.0.1)

iflag_pbl=11
iflag_thermals=18
iflag_thermals_ed=8
fact_thermals_ed_dz=0.1
iflag_coupl=5

Convection
Emanuel old/new
Closure CAPE/ALP
Cold pools
Stochastic closure
PDF for mixing
Computation of condensate
Efficiency of precipitation

iflag_con=3
iflag_clos=2
iflag_wake=1
iflag_trig_bl=1
iflag_mix=0
iflag_clw=0
epmax=0.998

Clouds
Ice thermodynamics
Cloud scheme
Profile of σ/qt
 σ/qt min
 σ/qt max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
radiation

iflag_ice_thermo=**1**
iflag_cldcon=6
iflag_ratqs=4
ratqsbas=0.002
ratqshaut=0.312
iflag_t_glance=1
cld_lc_lsc=0.0003
cld_lc_con=0.0003
ffallv_lsc=0.66528
ffallv_con=0.66528
coef_eva=2e-05
iflag_rrtm=0

Feb 2016

New mixing
+ crash fixed

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

Convection
Emanuel old/new
Closure CAPE/ALP
Cold pools
Stochastic closure
PDF for mixing
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Efficiency of precipitation

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 σ/qt min
 σ/qt max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
radiation

LMDZ 5.4 (IPSL-CM 6.0.2)

iflag_pbl=11
iflag_thermals=18
iflag_thermals_ed=8
fact_thermals_ed_dz=0.1
iflag_coupl=5

iflag_con=3
iflag_clos=2
iflag_wake=1
iflag_trig_bl=1
iflag_mix=1
iflag_clw=0
epmax=0.9995

iflag_ice_thermo=1
iflag_cldcon=6
iflag_ratqs=4
ratqsbas=0.002
ratqshaut=0.312
iflag_t_glance=1
cld_lc_lsc=0.0001
cld_lc_con=0.0001
ffallv_lsc=1
ffallv_con=1
coef_eva=2e-05
iflag_rrtm=0

April 2016

+ RRTM !
Minimum mixing length

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

Convection
Emanuel old/new
Closure CAPE/ALP
Cold pools
Stochastic closure
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Computation of condensate
Efficiency of precipitation

Clouds
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Cloud scheme
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 σ/qt min
 σ/qt max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
radiation

LMDZ 5.5 (IPSL-CM 6.0.3)

iflag_pbl=11
iflag_thermals=18
iflag_thermals_ed=8
fact_thermals_ed_dz=0.1
iflag_coupl=5

iflag_con=3
iflag_clos=2
iflag_wake=1
iflag_trig_bl=1
iflag_mix=1
iflag_clw=0
epmax=0.999

iflag_ice_thermo=1
iflag_cldcon=6
iflag_ratqs=4
ratqsbas=0.002
ratqshaut=0.312
iflag_t_glance=1
cld_lc_lsc=0.00022
cld_lc_con=0.00022
ffallv_lsc=0.67
ffallv_con=0.67
coef_eva=2e-05
iflag_rrtm=1

July 2016

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

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

Convection
Emanuel old/new
Closure CAPE/ALP
Cold pools
Stochastic closure
PDF for mixing
Computation of condensate
Efficiency of precipitation

Clouds
Ice thermodynamics
Cloud scheme
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 σ/qt min
 σ/qt max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
radiation

NPv5.70 (IPSL-CM 6.0.5)

iflag_pbl=11
iflag_thermals=18
iflag_thermals_ed=8
fact_thermals_ed_dz=0.1
iflag_coupl=5

iflag_con=3
iflag_clos=2
iflag_wake=1
iflag_trig_bl=1
iflag_mix=1
iflag_clw=0
epmax=0.999

iflag_ice_thermo=1
iflag_cldcon=6
iflag_ratqs=4
ratqsbas=0.002
ratqshaut=0.4
iflag_t_glance=2
cld_lc_lsc=0.0002
cld_lc_con=0.0002
ffallv_lsc=0.5
ffallv_con=0.5
coef_eva=0.0002
iflag_rrtm=1

January 2017

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

LMDZ6.0.9

iflag_pbl=11
iflag_thermals=18
iflag_thermals_ed=8
fact_thermals_ed_dz=0.1
iflag_coupl=5

Convection
Emanuel old/new
Closure CAPE/ALP
Cold pools
Stochastic closure
PDF for mixing
Computation of condensate
Efficiency of precipitation

iflag_con=3
iflag_clos=2
iflag_wake=1
iflag_trig_bl=1
iflag_mix=1
iflag_clw=0
epmax=0.997

Clouds
Ice thermodynamics
Cloud scheme
Profile of σ/qt
 σ/qt min
 σ/qt max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
radiation

iflag_ice_thermo=1
iflag_cldcon=6
iflag_ratqs=4
ratqsbas=0.002
ratqshaut=0.4
iflag_t_glance=2
cld_lc_lsc=0.00015
cld_lc_con=0.00015
ffallv_lsc=1
ffallv_con=1
coef_eva=0.0002
iflag_rrtm=1

May 2017

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

LMDZ6.0.12

iflag_pbl=12
iflag_thermals=18
iflag_thermals_ed=8
fact_thermals_ed_dz=0.07
iflag_coupl=5

Convection
Emanuel old/new
Closure CAPE/ALP
Cold pools
Stochastic closure
Mixing with env
Computation of condensate
Efficiency of precipitation

iflag_con=3
iflag_clos=2
iflag_wake=1
iflag_trig_bl=1
iflag_mix=1
iflag_clw=0
epmax=0.9985

Clouds
Ice thermodynamics
Cloud scheme
Profile of σ/qt
 σ/qt min
 σ/qt max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
radiation

iflag_ice_thermo=1
iflag_cldcon=6
iflag_ratqs=4
ratqsbas=0.002
ratqshaut=0.4
iflag_t_glance=2
cld_lc_lsc=0.00012
cld_lc_con=0.00012
ffallv_lsc=0.6
ffallv_con=0.6
coef_eva=0.0001
iflag_rrtm=1

Convection triggering if
 $T_{top} < T_{topmax}$
Energy conservation (partial)
MY improved for stable conditions

June 2017

Accounting for
gustiness in surface
oceanic fluxes

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

Convection
Emanuel old/new
Closure CAPE/ALP
Cold pools
Stochastic closure
PDF for mixing
Computation of condensate
Efficiency of precipitation

Clouds
Ice thermodynamics
Cloud scheme
Profile of σ/q_t
 σ/q_t min
 σ/q_t max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
radiation

LMDZ6.0.12ttop

iflag_pbl=12
iflag_thermals=18
iflag_thermals_ed=8
fact_thermals_ed_dz=0.07
iflag_coupl=5

iflag_con=3
iflag_clos=2
iflag_wake=1
iflag_trig_bl=1
iflag_mix=1
iflag_clw=0
epmax=0.998

iflag_ice_thermo=1
iflag_cldcon=6
iflag_ratqs=4
ratqsbas=0.002
ratqshaut=0.4
iflag_t_glance=2
cld_lc_lsc=0.000106
cld_lc_con=0.000106
ffallv_lsc=0.6
ffallv_con=0.6
coef_eva=0.0001
iflag_rrtm=1

June 2017

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

Convection
Emanuel old/new
Closure CAPE/ALP
Cold pools
Stochastic closure
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Computation of condensate
Efficiency of precipitation

Clouds
Ice thermodynamics
Cloud scheme
Profile of σ/qt
 σ/qt min
 σ/qt max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
radiation

LMD6 split

iflag_pbl=12
iflag_thermals=18
iflag_thermals_ed=8
fact_thermals_ed_dz=0.1
iflag_coupl=5

iflag_con=3
iflag_clos=2
iflag_wake=1
iflag_trig_bl=1
iflag_mix=1
iflag_clw=0
epmax=0.9997
wbmax=3, flag_wb=30

iflag_ice_thermo=1
iflag_cldcon=6
iflag_ratqs=4
ratqsbas=0.002
ratqshaut=0.4
iflag_t_glance=3
cld_lc_lsc=0.000205
cld_lc_con=0.000205
ffallv_lsc=0.6
ffallv_con=0.6
coef_eva=0.0001
iflag_rrtm=1
iflag_prce=2

Thermals plume
accounted for outside
cold pools only

April 2018

Boundary-layer
Mellor et Yamada
Thermals
Mixing rates in thermals
Thermals top mixing
Coupling with deep convection

Convection
Emanuel old/new
Closure CAPE/ALP
Cold pools
Stochastic closure
PDF for mixing
Computation of condensate
Efficiency of precipitation

Clouds
Ice thermodynamics
Cloud scheme
Profile of σ/q_t
 σ/q_t min
 σ/q_t max
Mixed phase of clouds
Threshold cloudy water LS
Threshold cloudy water CV
Ice crystals fall speed LS
Ice crystals fall speed CV
Coefficient of evaporation
radiation

LMD6.1
iflag_pbl=12
iflag_thermals=18
iflag_thermals_ed=8
fact_thermals_ed_dz=0.07
iflag_coupl=5

iflag_con=3
iflag_clos=2
iflag_wake=1
iflag_trig_bl=1
iflag_mix=1
iflag_clw=0
epmax=0.9997
wbmax=3, flag_wb=30

iflag_ice_thermo=1
iflag_cldcon=6
iflag_ratqs=4
ratqsbas=0.002
ratqshaut=0.4
iflag_t_glance=3
cld_lc_lsc=0.00065
cld_lc_con=0.00065
ffallv_lsc=0.8
ffallv_con=0.8
coef_eva=0.0001
iflag_rrtm=1
iflag_prec=3

Thermals plume
accounted for outside
cold pools only

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

- Couvreur, F., Hourdin, F., Williamson, D., Roehrig, R., Volodina, V., Villefranche, 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 for parameterization improvement, vol. 13, no. 3, 2021. doi:10.1029/2020MS002217.

- Hourdin, F., Williamson, D., Rio, C., Couvreur, F., Roehrig, E., Villefranche, 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.

- Villefranche, N., Blanco, S., Couvreur, 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 Effect
S
, 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 . SUPPLEMENTARY 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

[illegible]