Intrdocution

Frédéric Hourdin

LMDZ : a general circulation model

1. General Circulation Models
2. LMDZ
3. Splitting/coupling and modularity
4. Operating modes
5. Intercomparison exercises and reference configurations

1. General Circulation Models

The world of numerical models

appearances
theories (physics, chemistry, biologie, economy)
mathematics
numerics
computers

Mathematics constitute a common language

Modeling concerns all the layers

Always try to make links with the upper layers

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

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

1. General Circulation Models

The « layers » in LMDZ :

Appearances :
→ Meteorology, climate, atmospheric composition

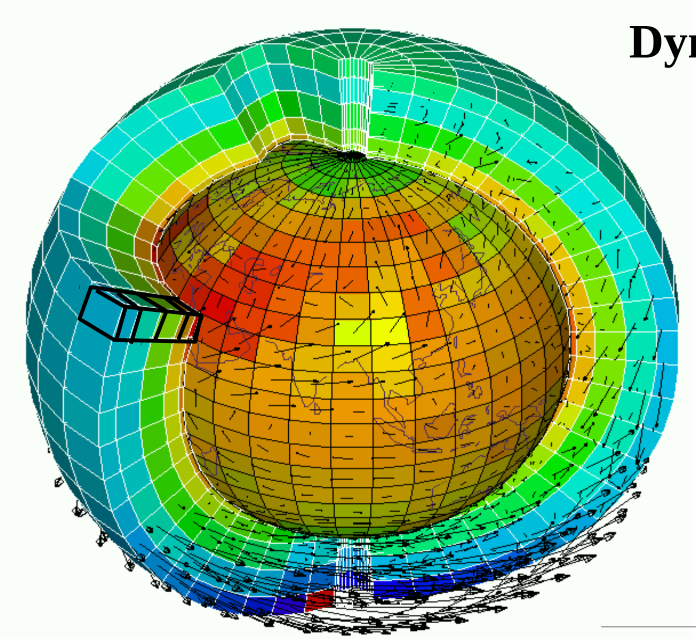
Theories :
→ Fluid mechanics
→ Gaz/radiation interaction
→ Phase changes/ Thermodynamics
→ Chemistry

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

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

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

1. General Circulation Models



Dynamical core : primitive equations discretized on the sphere

- Mass conservation

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

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

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

  $Dq/Dt = Sq$

Primitive equations of meteorology

→ Thin layer approximation

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

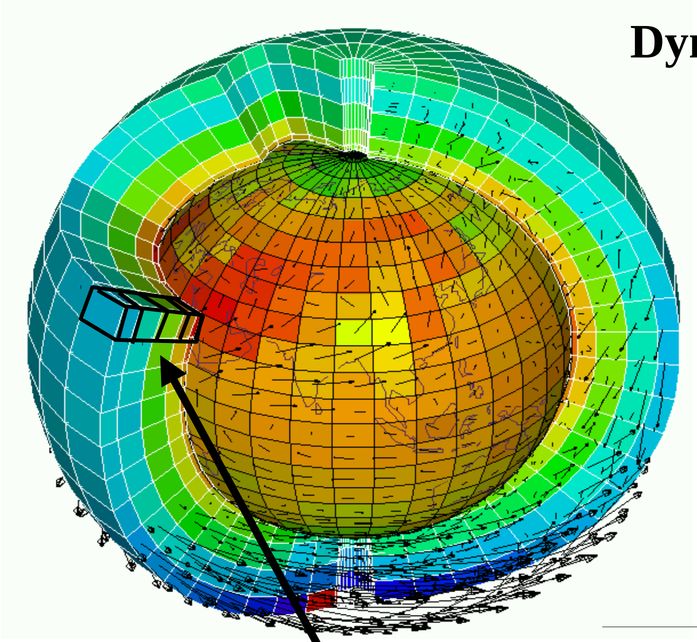
From physics to numerics :

→ Finite volume and finite differences

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

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

1. General Circulation Models



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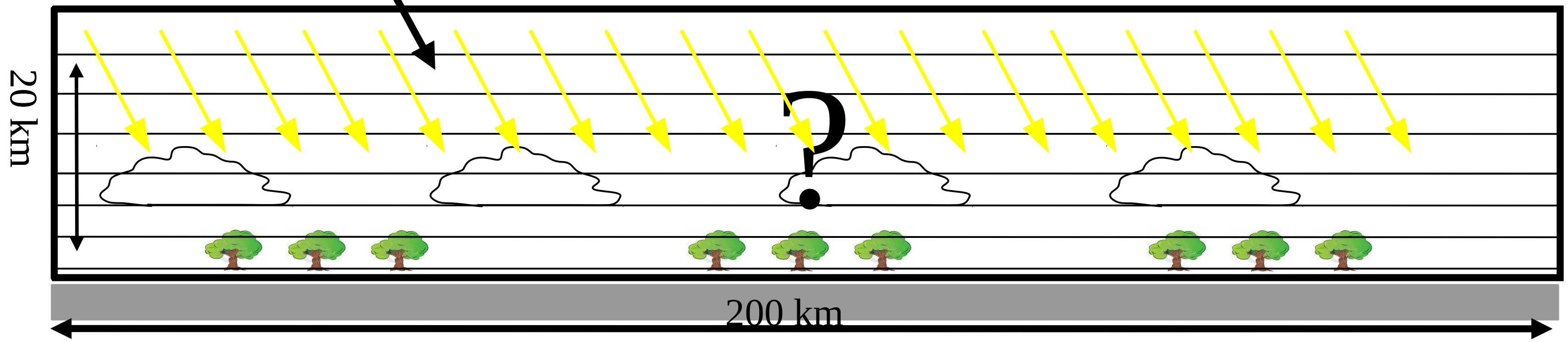

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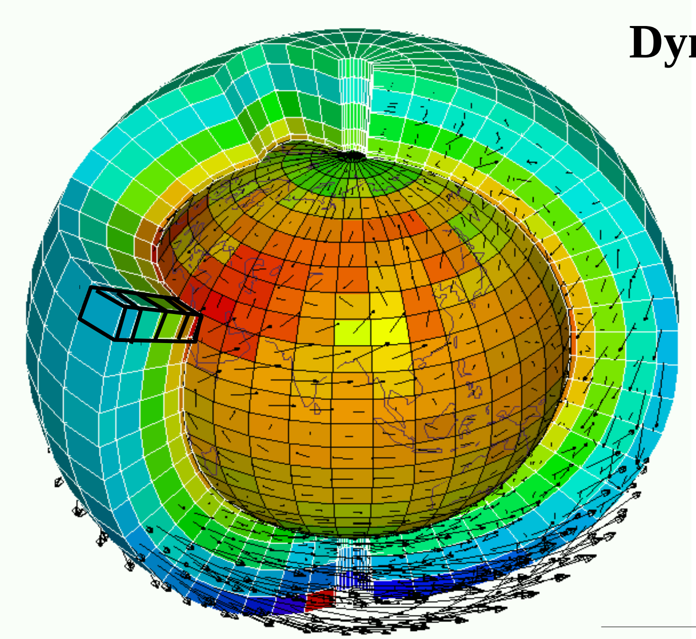

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Parameterizations purpose : account for the effect of processes non resolved by the dynamical core

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

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

Parameterizations : principles




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

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

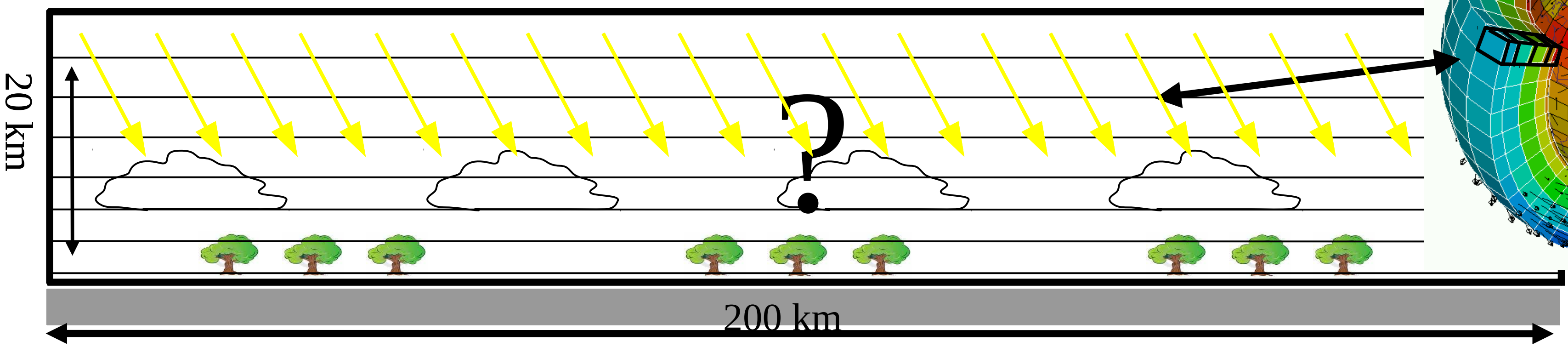
- Involve additional **parameterization internal variables** (cloud characteristics, standard deviation of the sub-grid scale distribution of a variable, …)

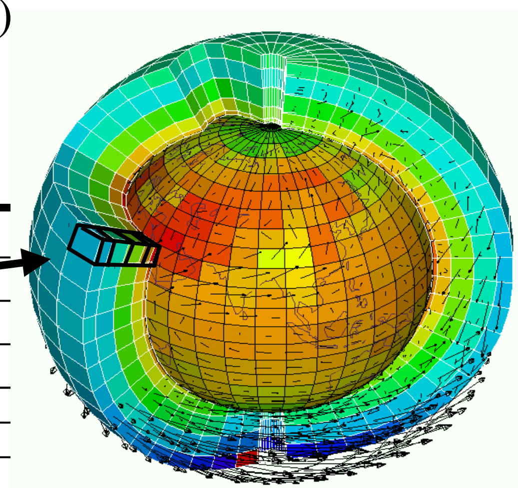
- Derive **equations** relating internal variables to the state variables

  $\underline{U}$, θ, q at time t → **internal variables** → $\underline{F}$, Q, Sq → $\underline{U}$, θ, q at t+δt

- **Homogeneity hypothesis** (statistical) on the horizontal of the targeted processes (like in the plane-parallel approximation of radiative transfer)
  → 1-dimensional equations in z (vertical exchanges only)
  → Independent atmospheric column

Inside an « atmospheric column » ...





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   1. General Circulation Models
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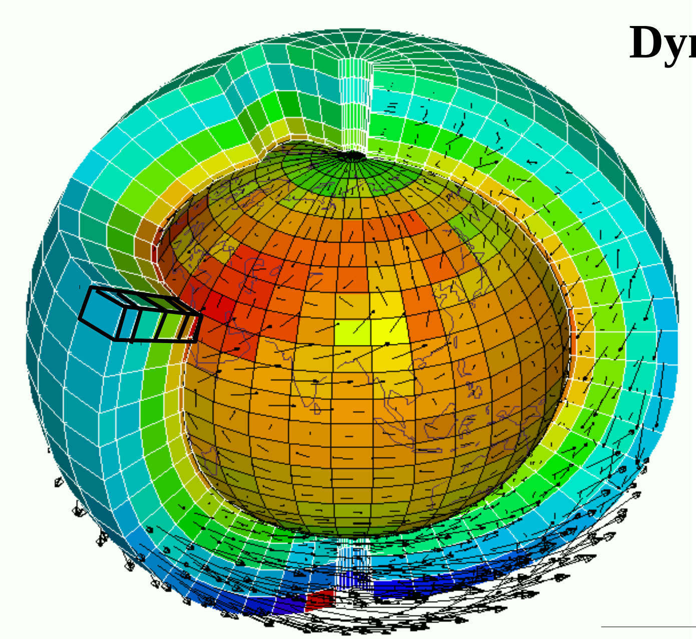
2. LMDZ



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

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  $Dq/Dt = Sq$

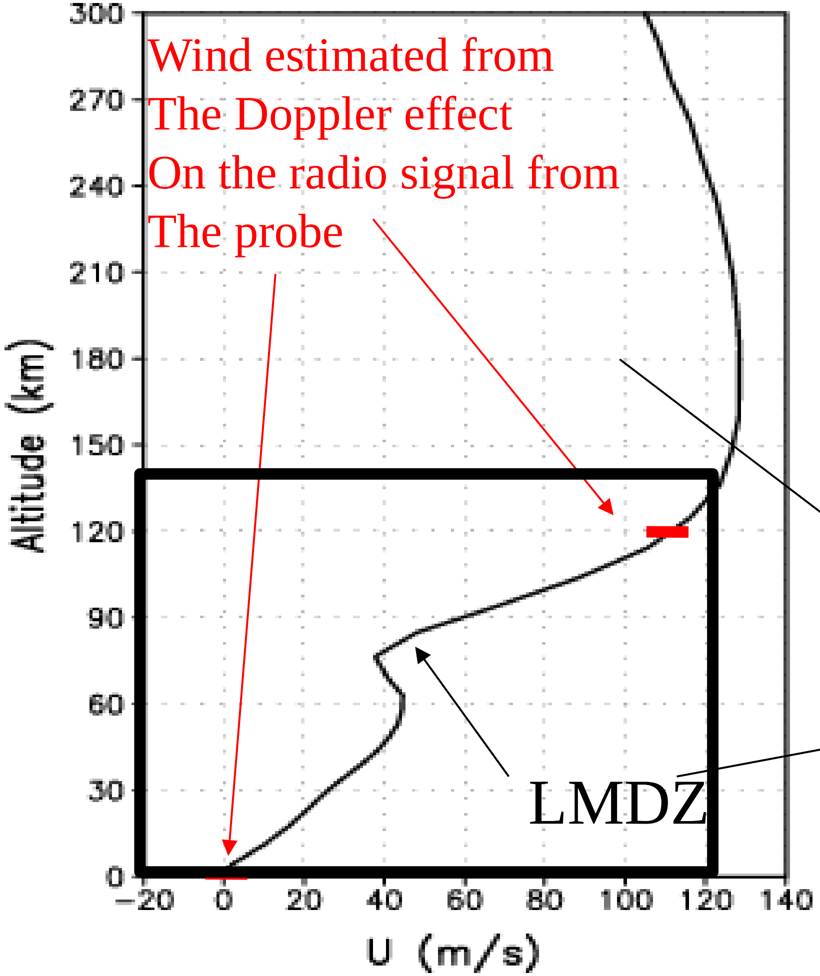
The LMDZ dynamical core :

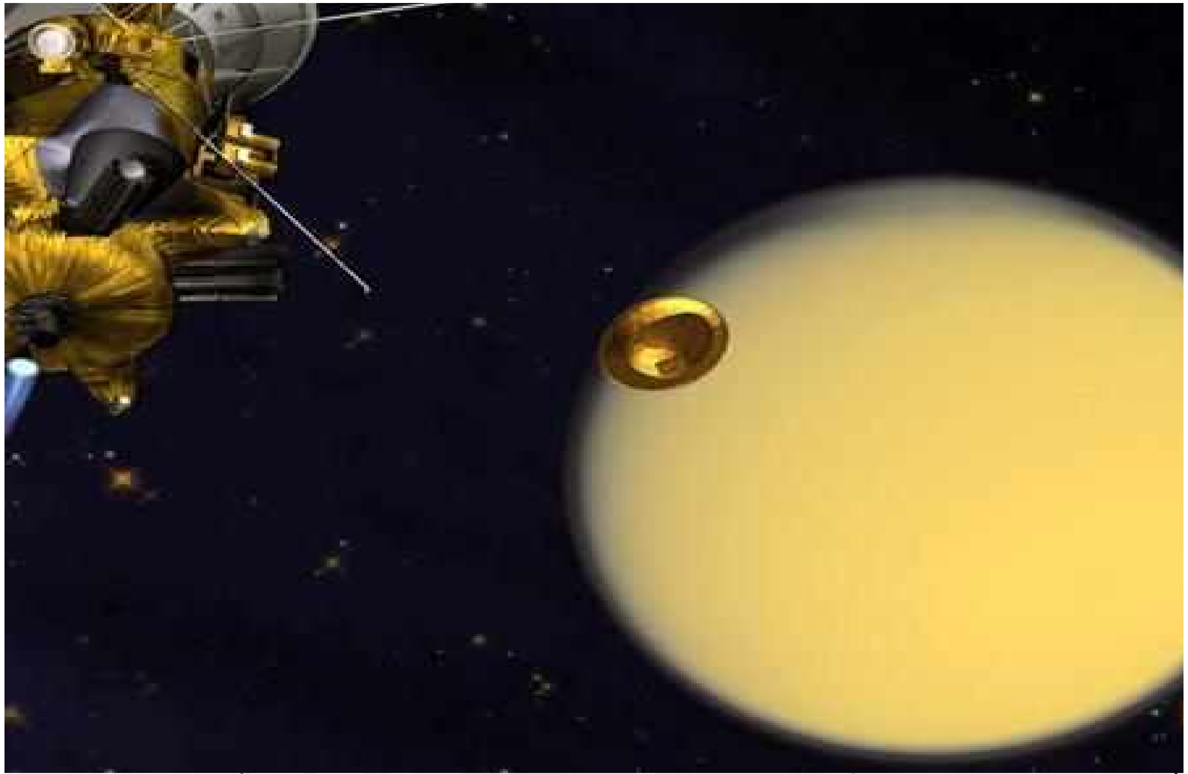
→ Global longitude-latitude grid
→ Zoom capability (« Z » of « LMDZ »)
→ Finite difference / finite volume numerical schemes
→ Conservation of air mass, enstrophy, partly angular momentum and energy
→ Positive/monotonic/conservative Van Leer schemes for tracer advection
→ Horizontal dissipation (stability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

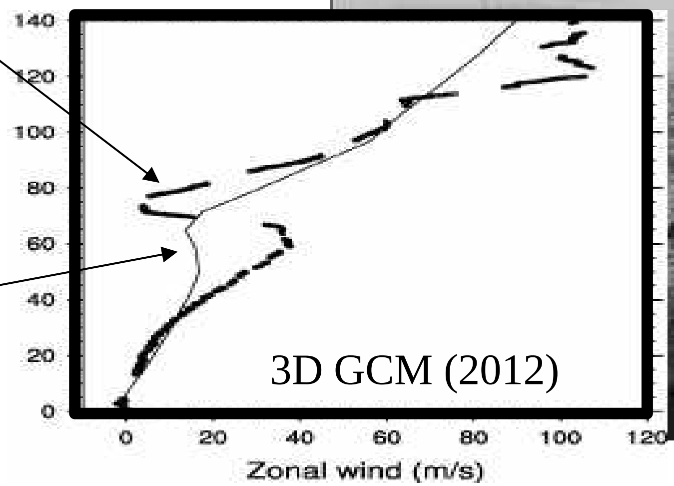
2. LMDZ

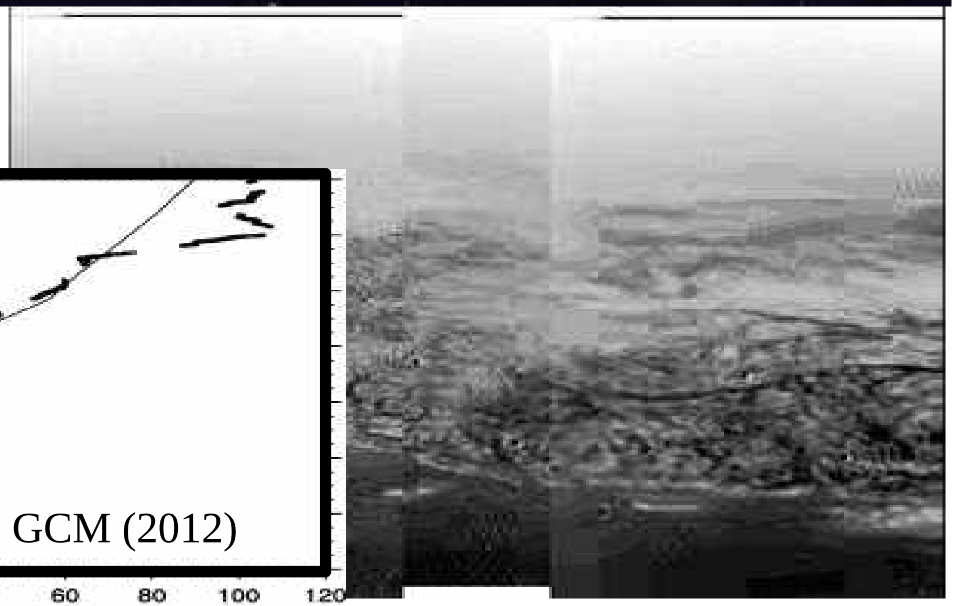
Planetary atmospheres
Mars, Titan, Venus, Triton, ...

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



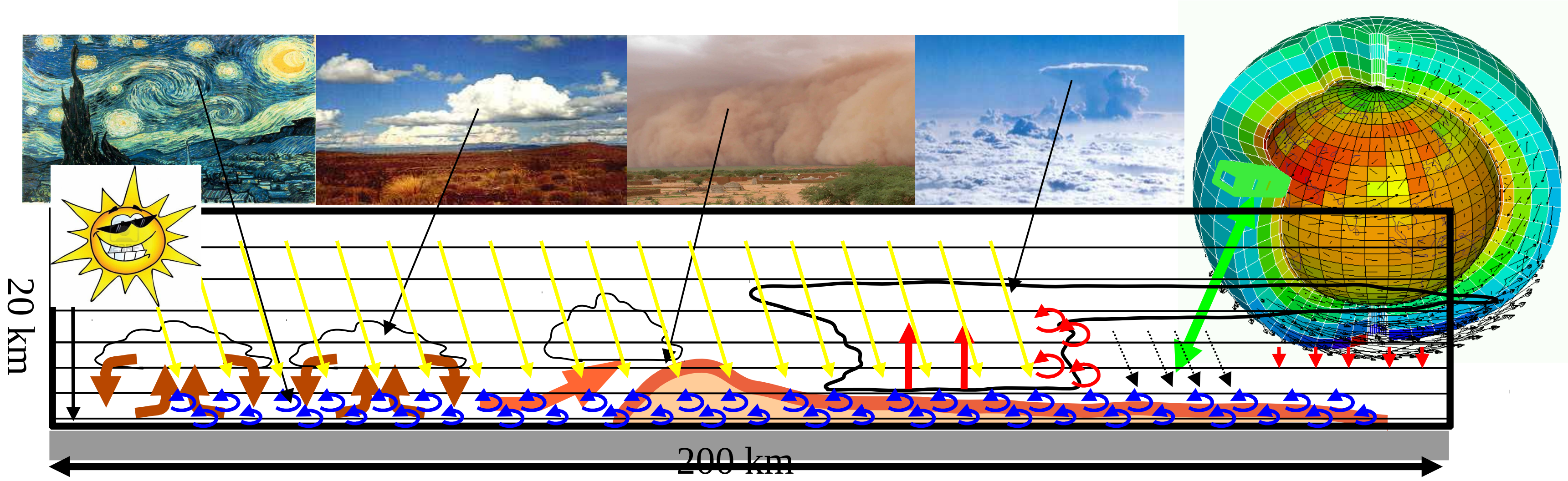






2. LMDZ

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



→ Couvreux, F., F. Hourdin, and C. Rio, **2010**, Resolved Versus Parametrized Boundary-Layer Plumes. Part I: A Parametrization-Oriented Conditional Sampling in Large-Eddy Simulations, Boundary-layer Meteorol., 134, 441–458, 2010.

→ Grandpeix, J., and J. Lafore, **2010**, A Density Current Parameterization Coupled with Emanuel's Convection Scheme. Part I: The Models, Journal of Atmospheric Sciences, 67, 881–897, 2010.

→ Grandpeix, J. Y., V. Phillips, and R. Tailleux, 2004, Improved mixing representation in Emanuel's convection scheme, Q. J. R. Meteorol. Soc., 130, 3207–3222, **2004**.

→ Grandpeix, J., J. Lafore 2010, A Density Current Parameterization Coupled with Emanuel's Convection Scheme. Part I Journal of Atmospheric Sciences, 67, 898–922, **2010**.

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→ Hourdin, F., F. Couvreux, and L. Menut, **2002**, Parameterisation of the dry convective boundary layer based on a mass flux representation of thermals, J. Atmos. Sci., 59, 1105–1123, 2002.

→ Hourdin, F., I. Musat, S. Bony, P. Braconnot, F. Codron, J.-L. Dufresne, L. Fairhead, M.-A. Filiberti, P. Friedlingstein, J.-Y. Grandpeix, G. Krinner, P. Levan, Z.-X. Li, and F. Lott, **2006**, The LMDZ4 general circulation model: climate performance and sensitivity to parametrized physics with emphasis on tropical convection, Climate Dynamics, 27, 787–813, 2006.

→ Hourdin, F., J.-Y. Grandpeix, C. Rio, S. Bony, A. Jam, F. Cheruy, N. Rochetin, L. Fairhead, A. Idelkadi, I. Musat, J.-L. Dufresne, A. Lahellec, M.-P. Lefebvre, and R. Roehrig, April 2012, LMDZ5B: the atmospheric component of the IPSL climate model with revisited parameterizations for clouds and convection, Clim. Dyn., 79, April **2012**.

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→ Rio, C., and F. Hourdin, 2008, A thermal plume model for the convective boundary layer : Representation of cumulus clouds, J. Atmos. Sci., 65, 407–425, **2008**.

→ Rio, C., F. Hourdin, J. Grandpeix, and J. Lafore, 2009, Shifting the diurnal cycle of parameterized deep convection over land, Geophys. Res. Lett., 36, 7809–+, **2009**.

→ Rio, C., F. Hourdin, F. Couvreux, and A. Jam, **2010**, Resolved Versus Parametrized Boundary-Layer Plumes. Part II: Continuous Formulations of Mixing Rates for Mass-Flux Schemes, Boundary-layer Meteorol., 135, 469–483, 2010.

→ Rio et al., **2012** : closure revisited

LMDZ – a brief history

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

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

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

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

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

1995-1999 : transport of trace species

2005 : First participation to CMIP exercise with LMDZ

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

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

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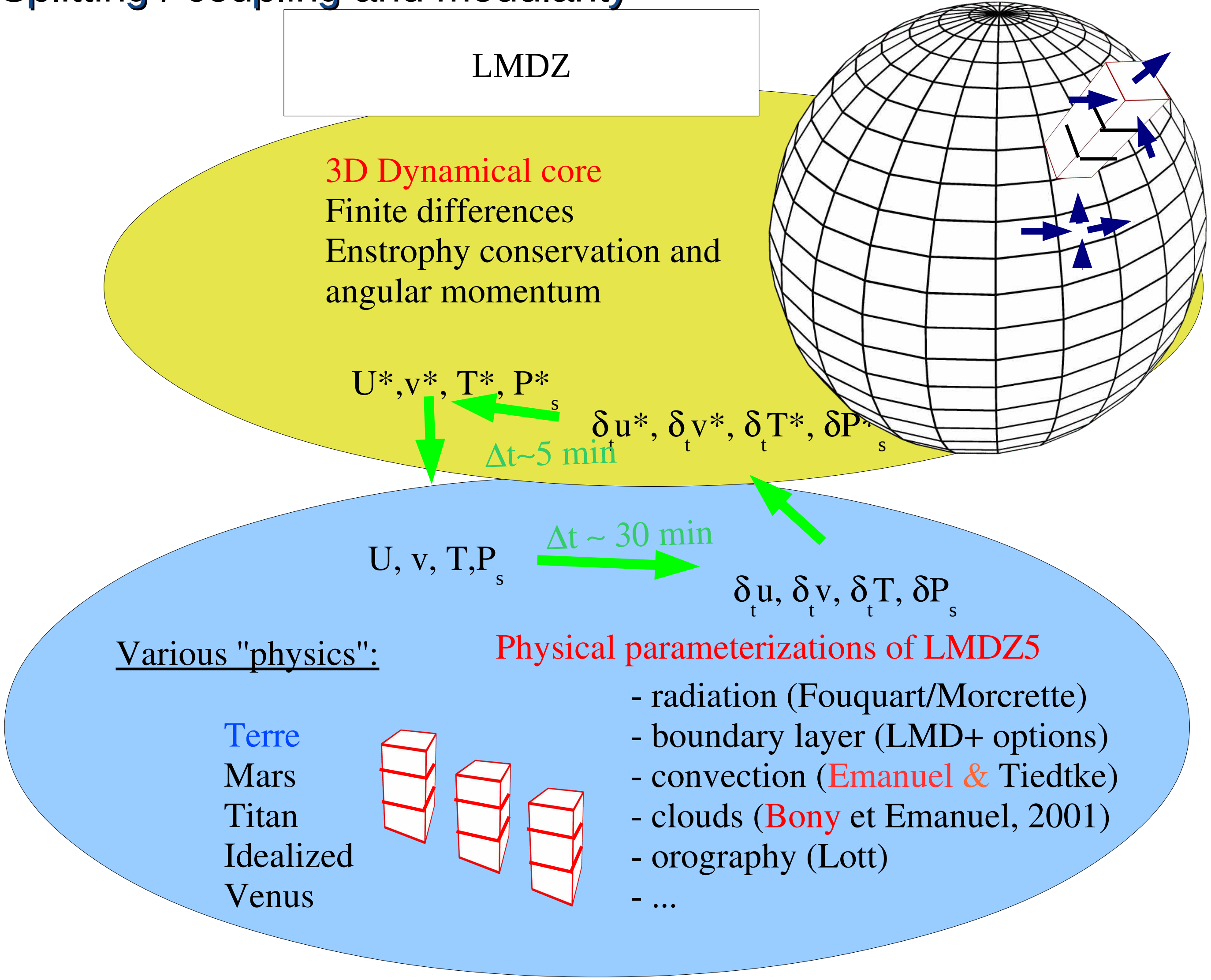
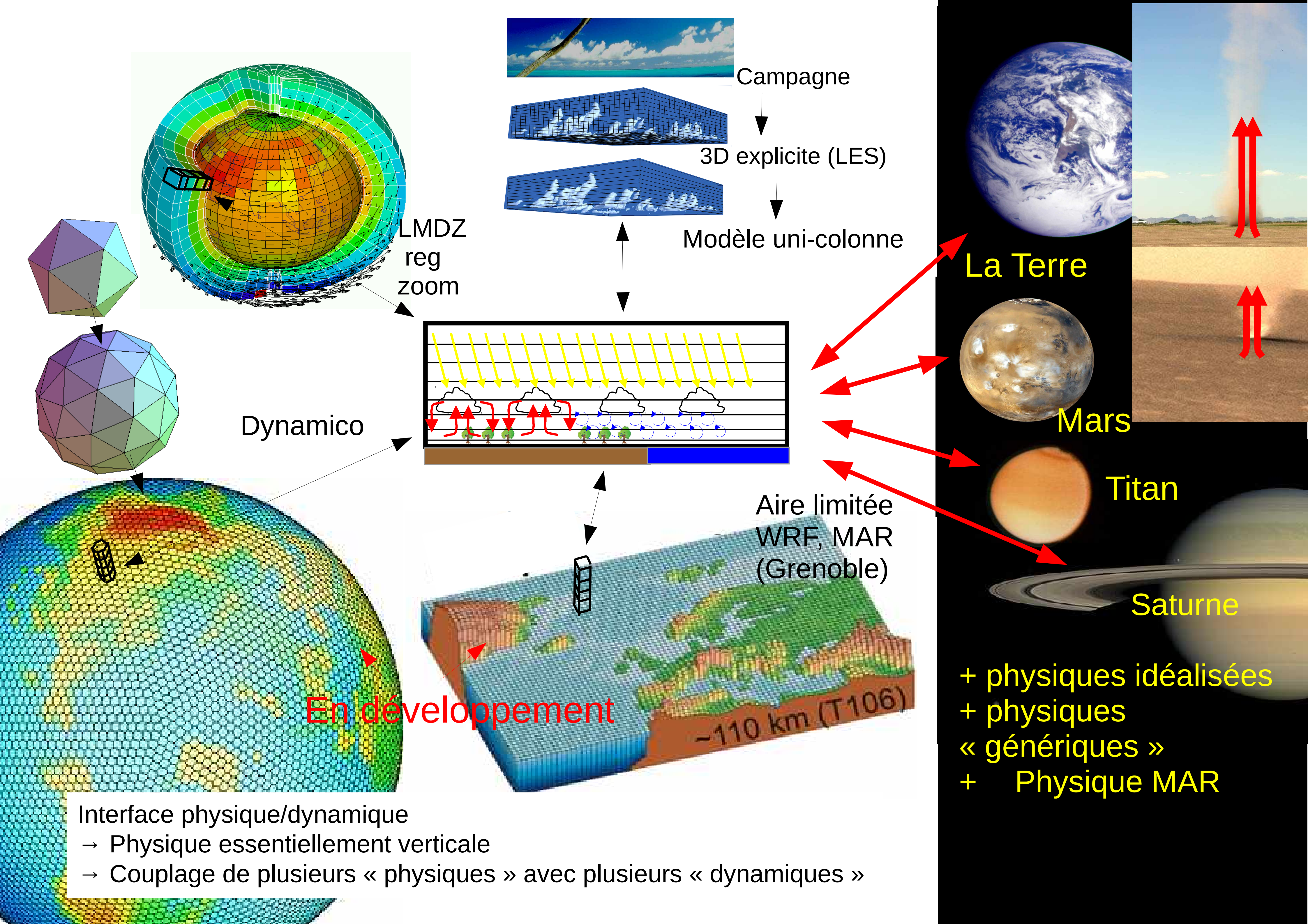
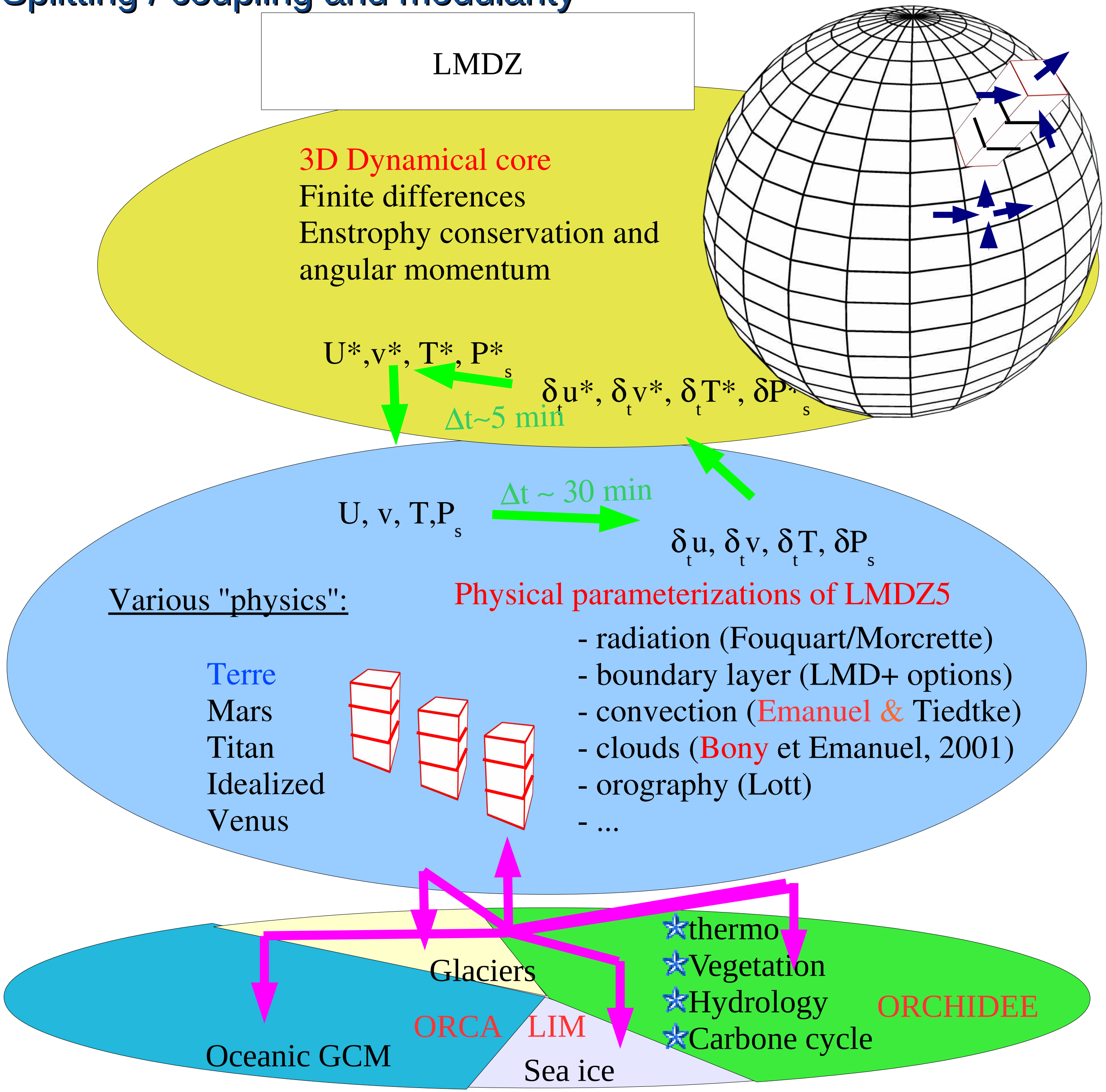
3. Splitting / coupling and modularity




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

3. Splitting / coupling and modularity



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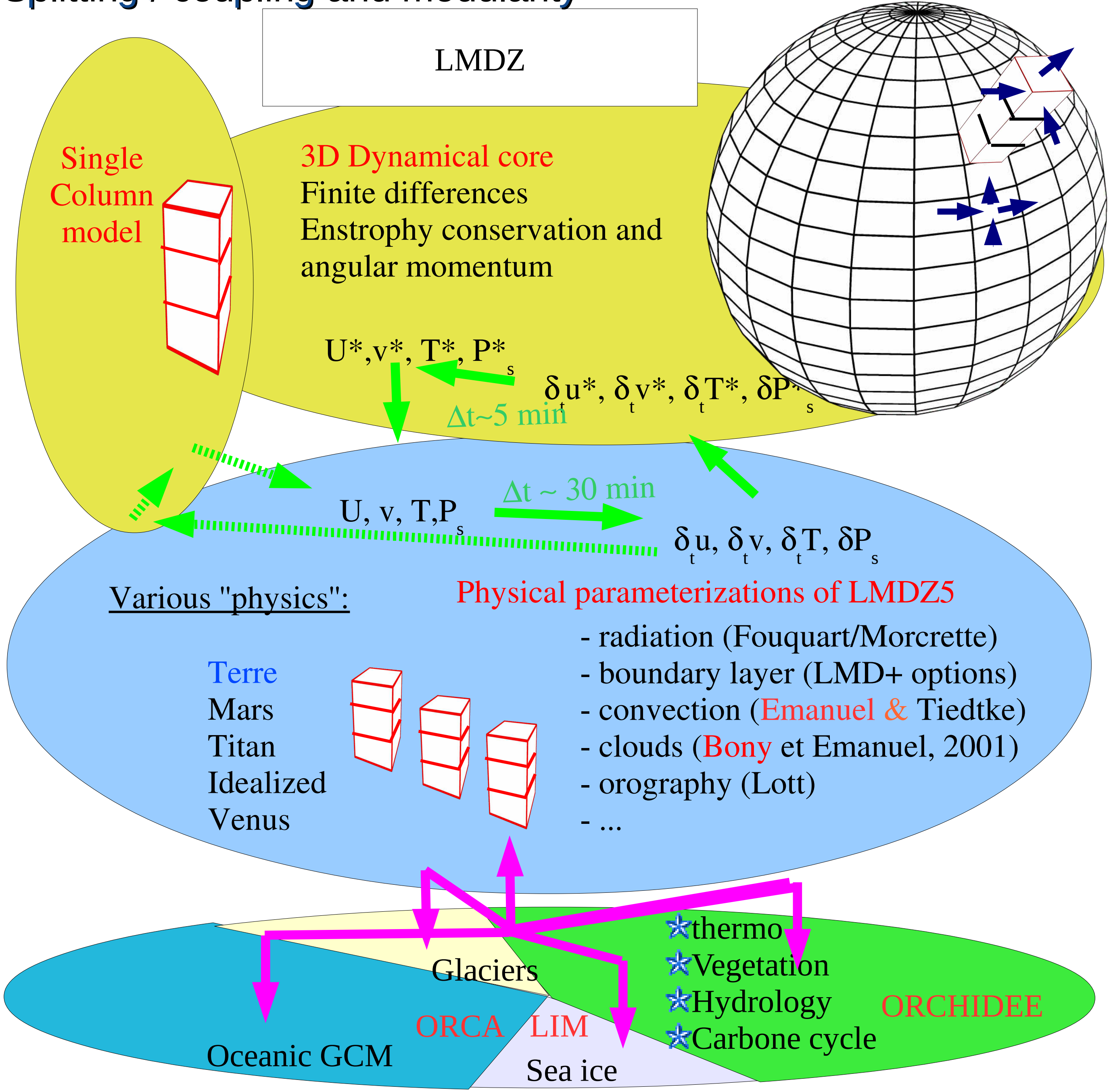

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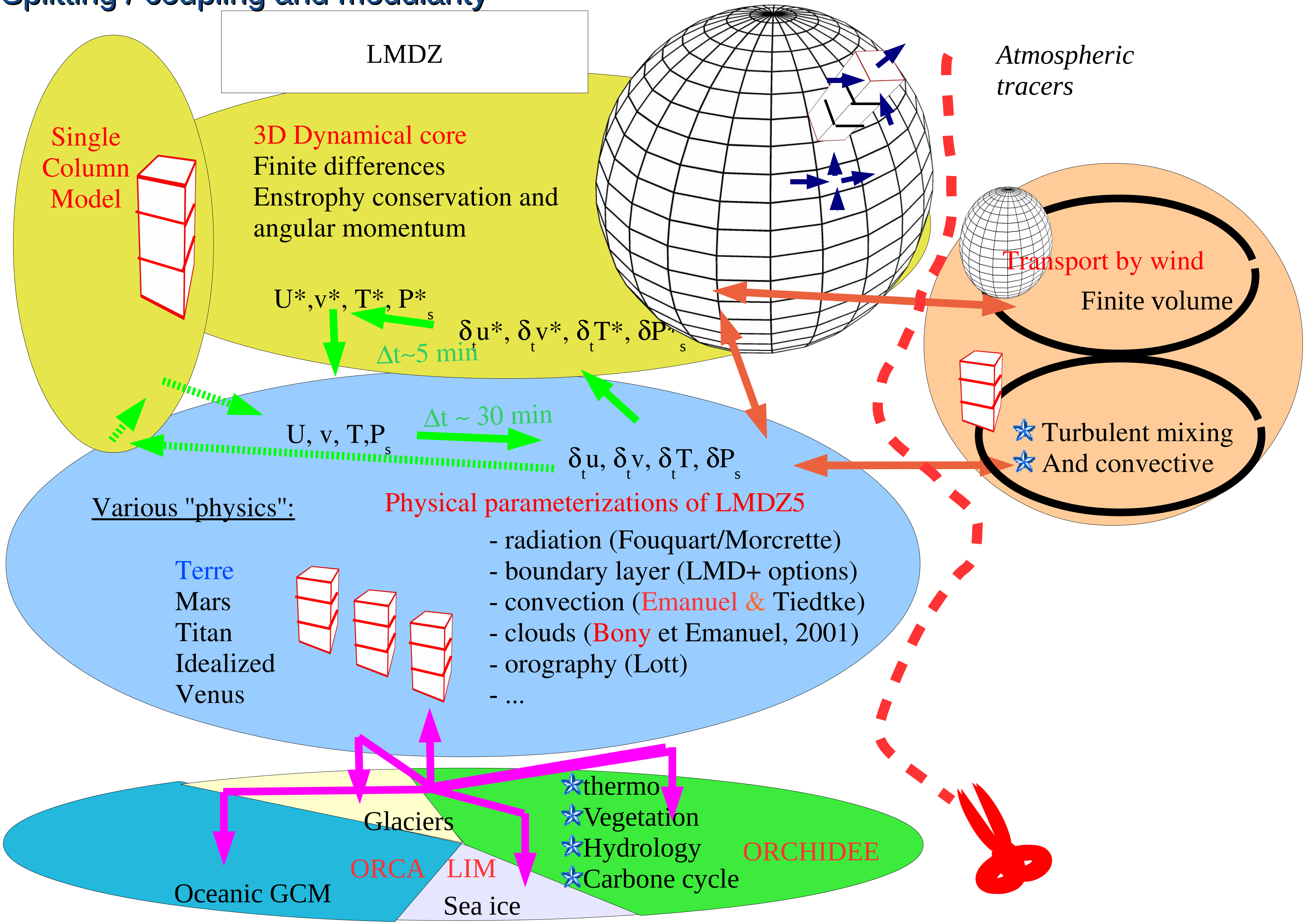

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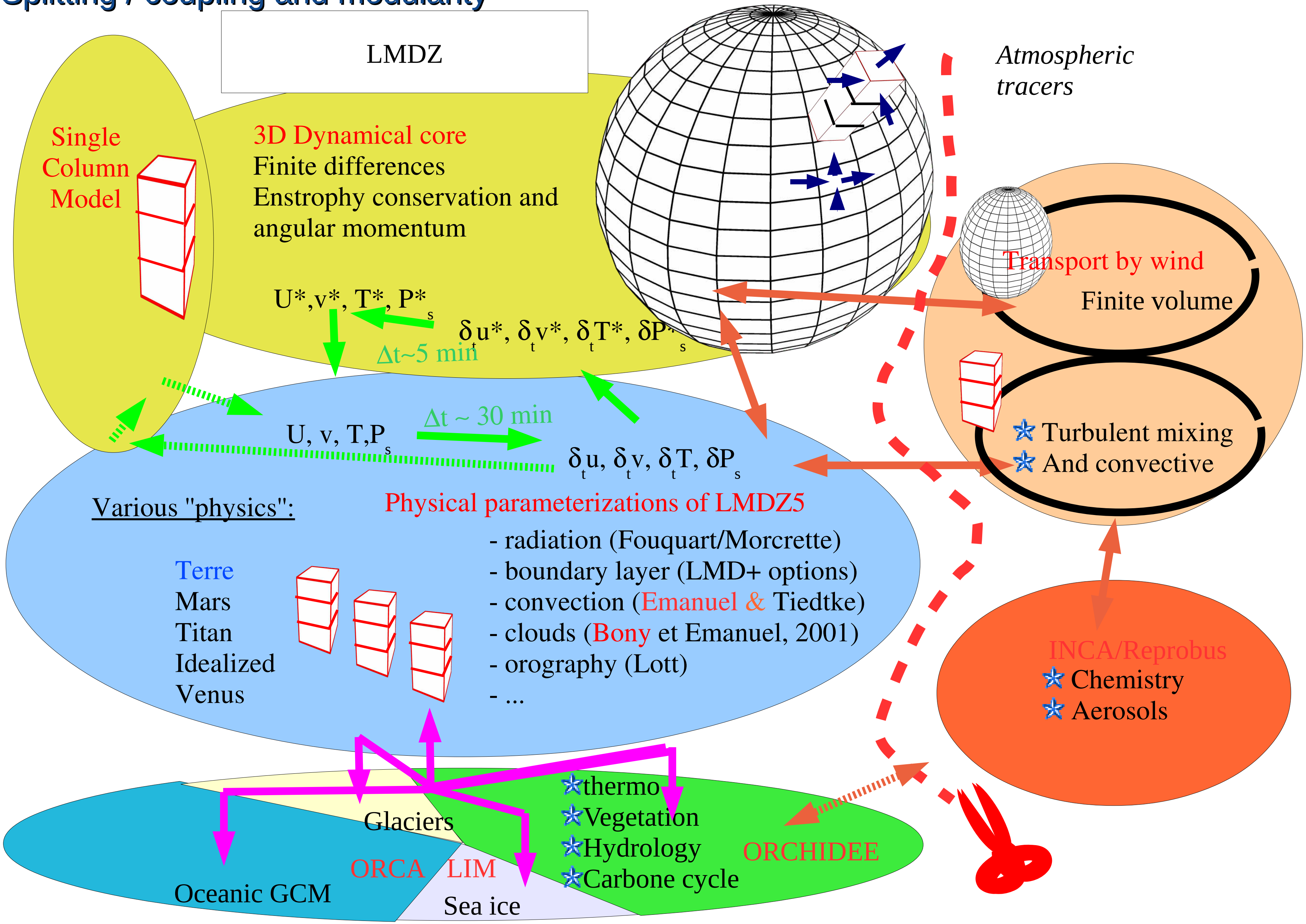

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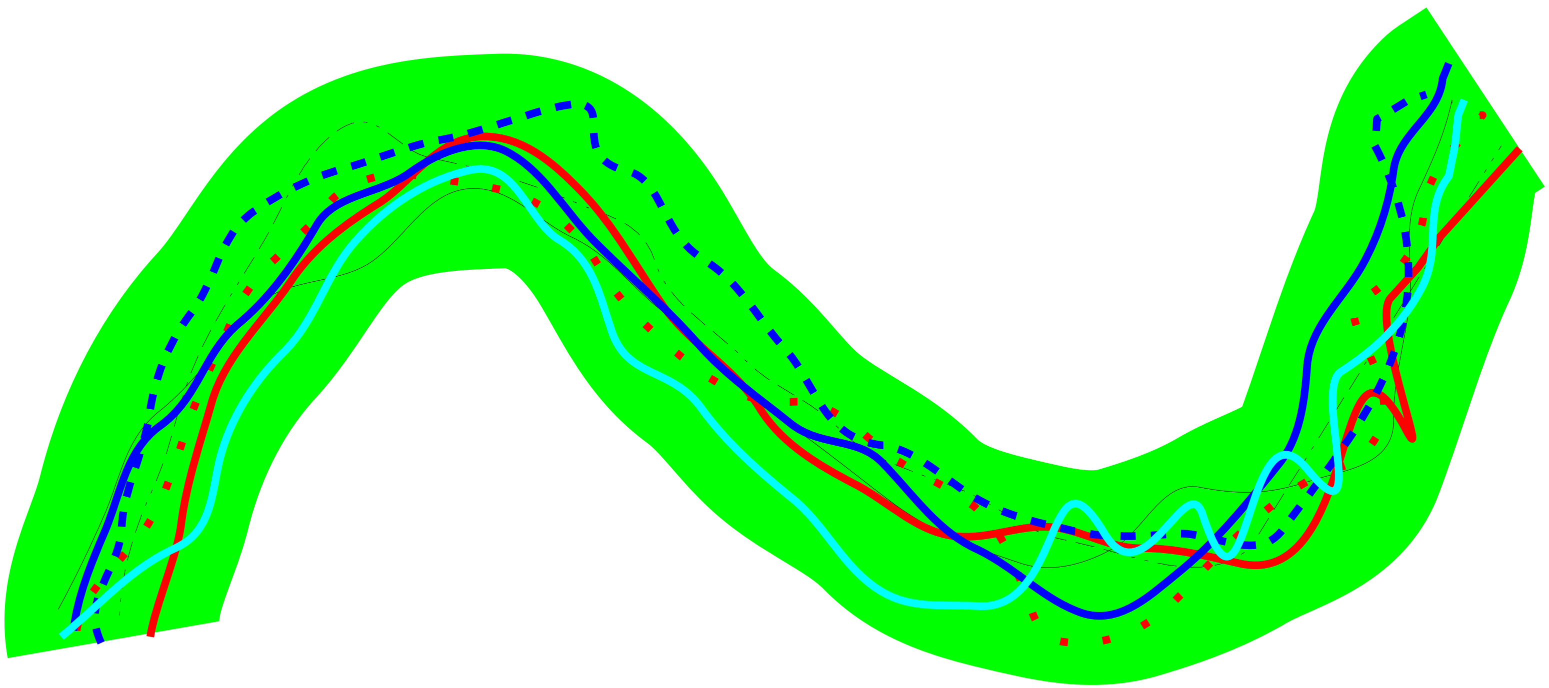
4. **Operating modes**
5. Intercomparison exercises and referenced versions

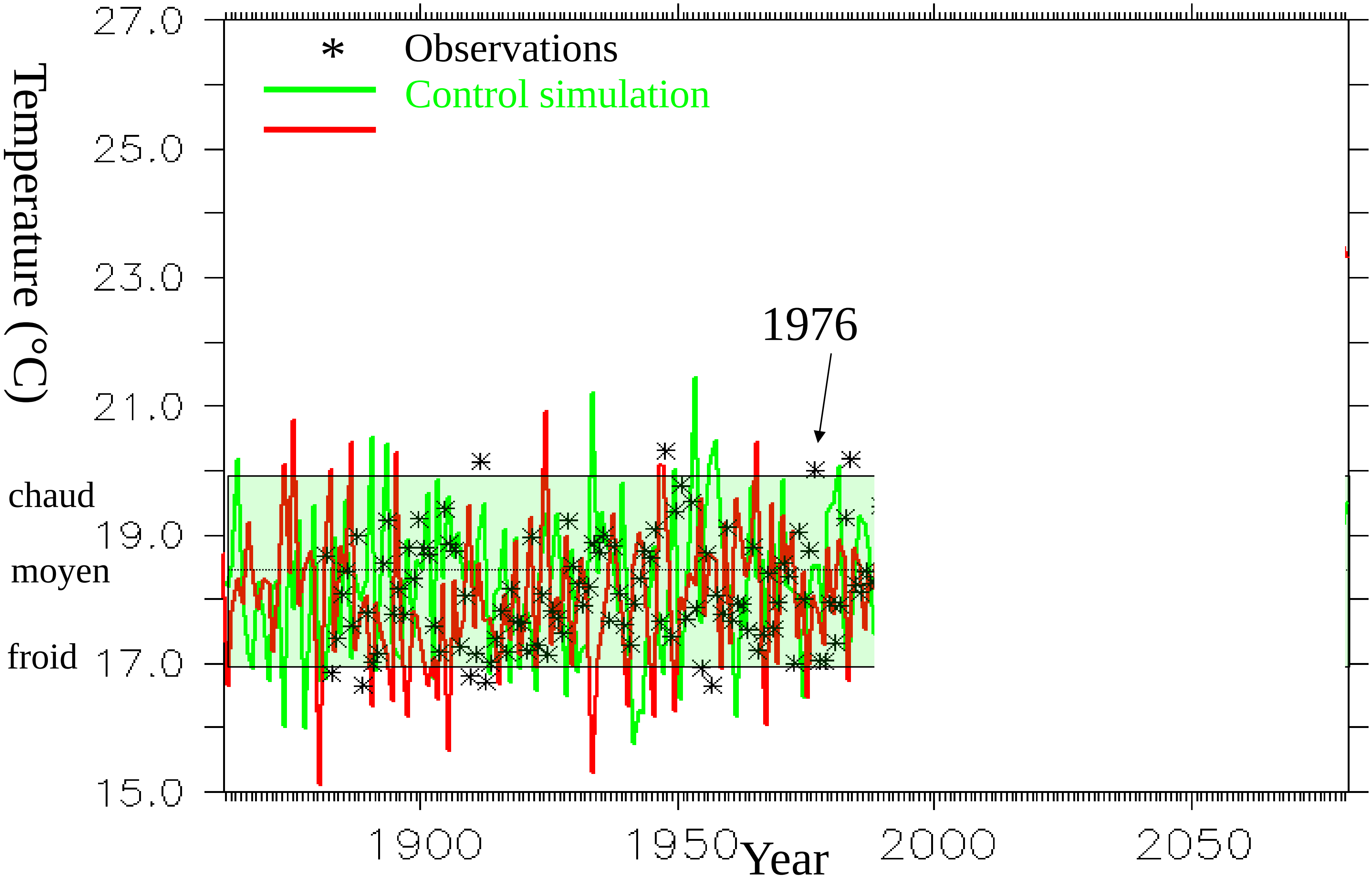
Climate modeling / numerical weather forecast

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



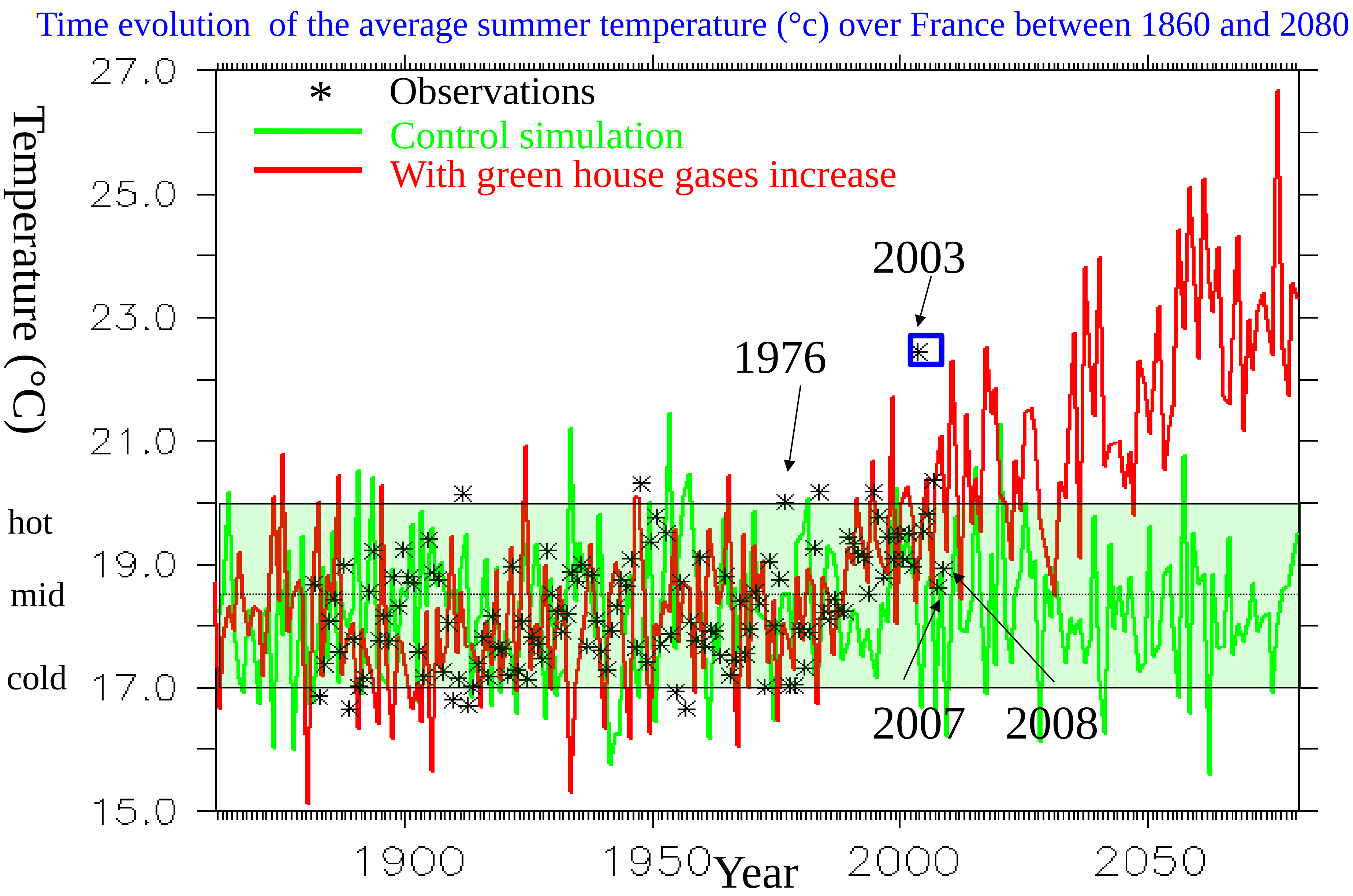
4. Operating modes

Time evolution of the average summer temperature (°c) over France between 1860 and 2080



(IPCC Scenario SRESA2, IPSL coupled model)

4. Operating modes



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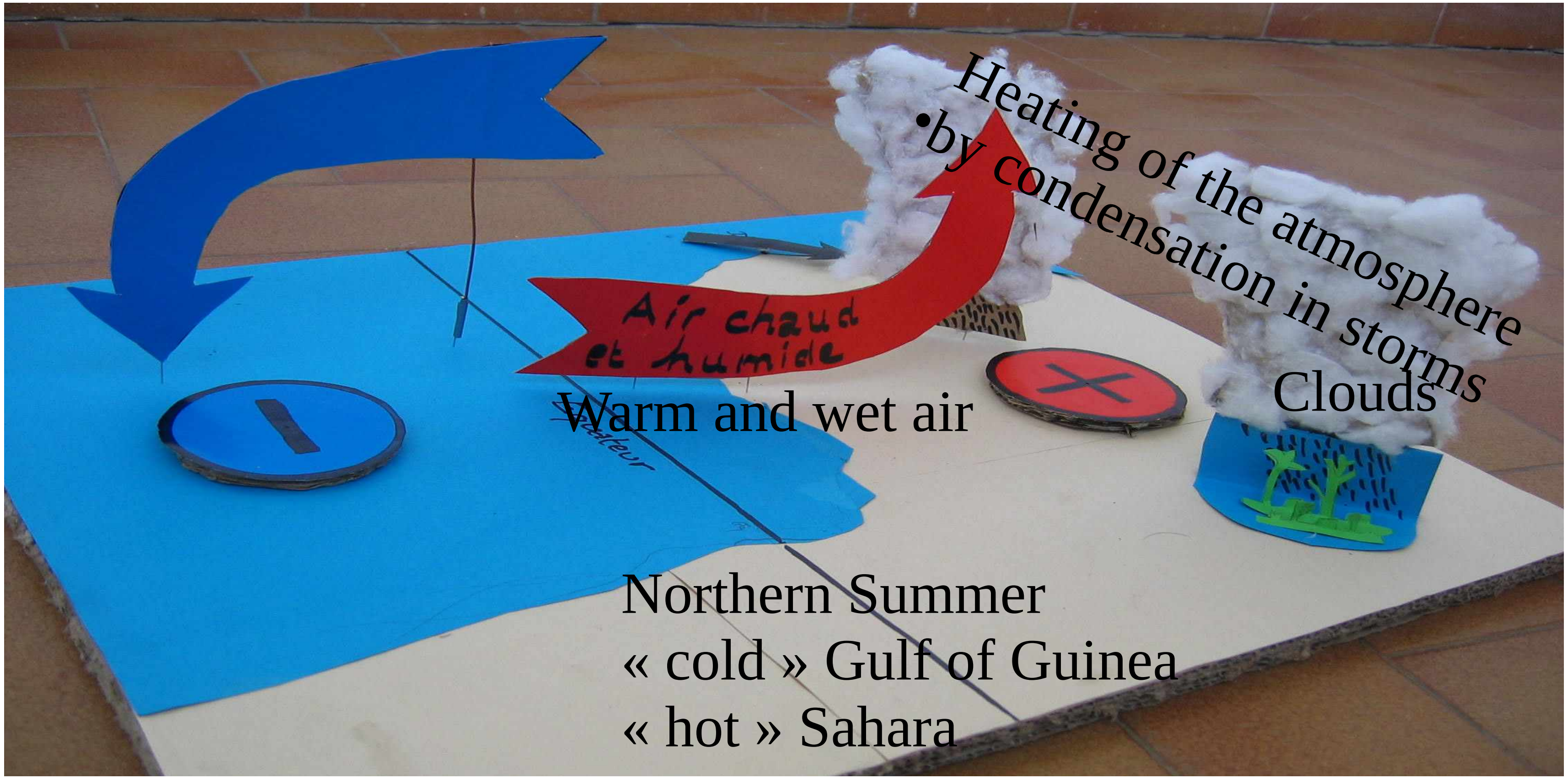
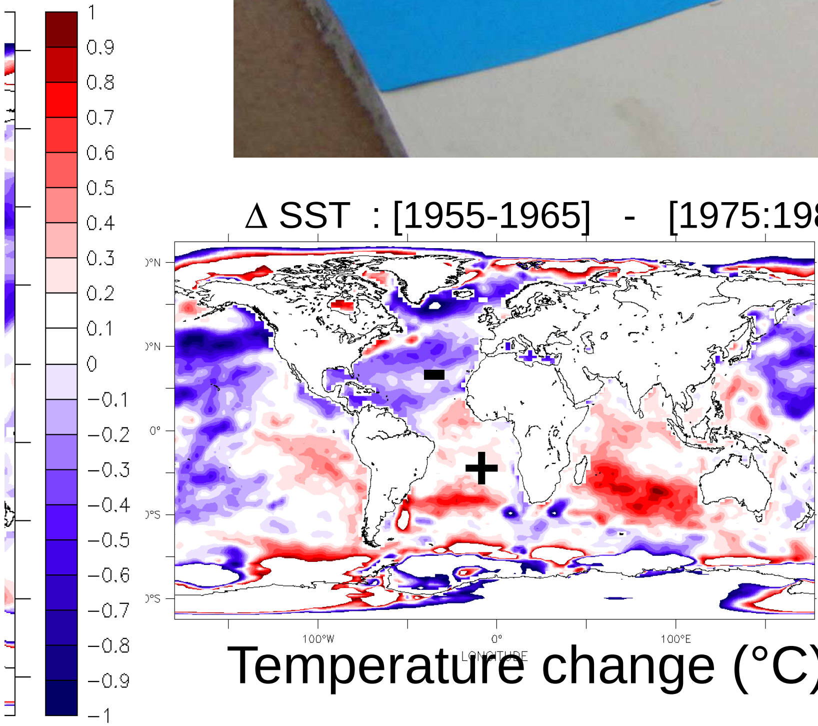


Δ SST : [1955-1965] - [1975:1985]

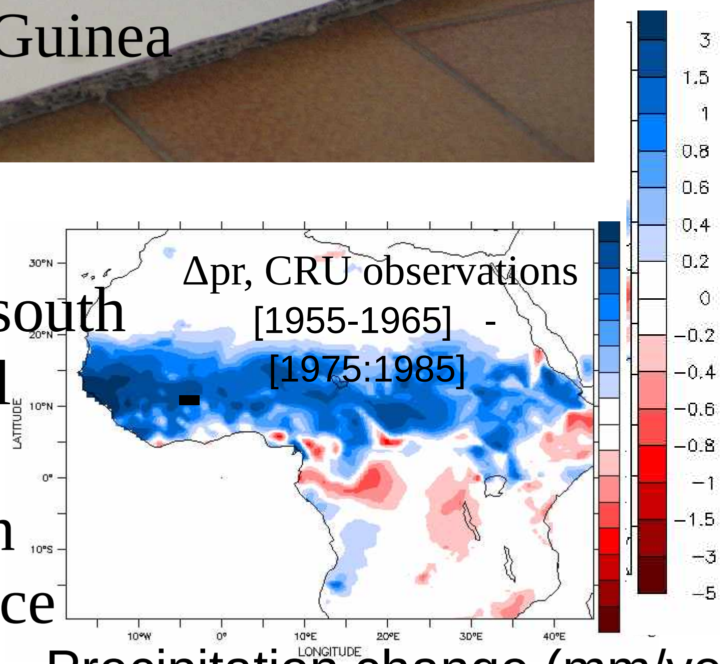


Temperature change (°C)

1975-1985 :
Warm SSTs in the south
Drought over Sahel

•

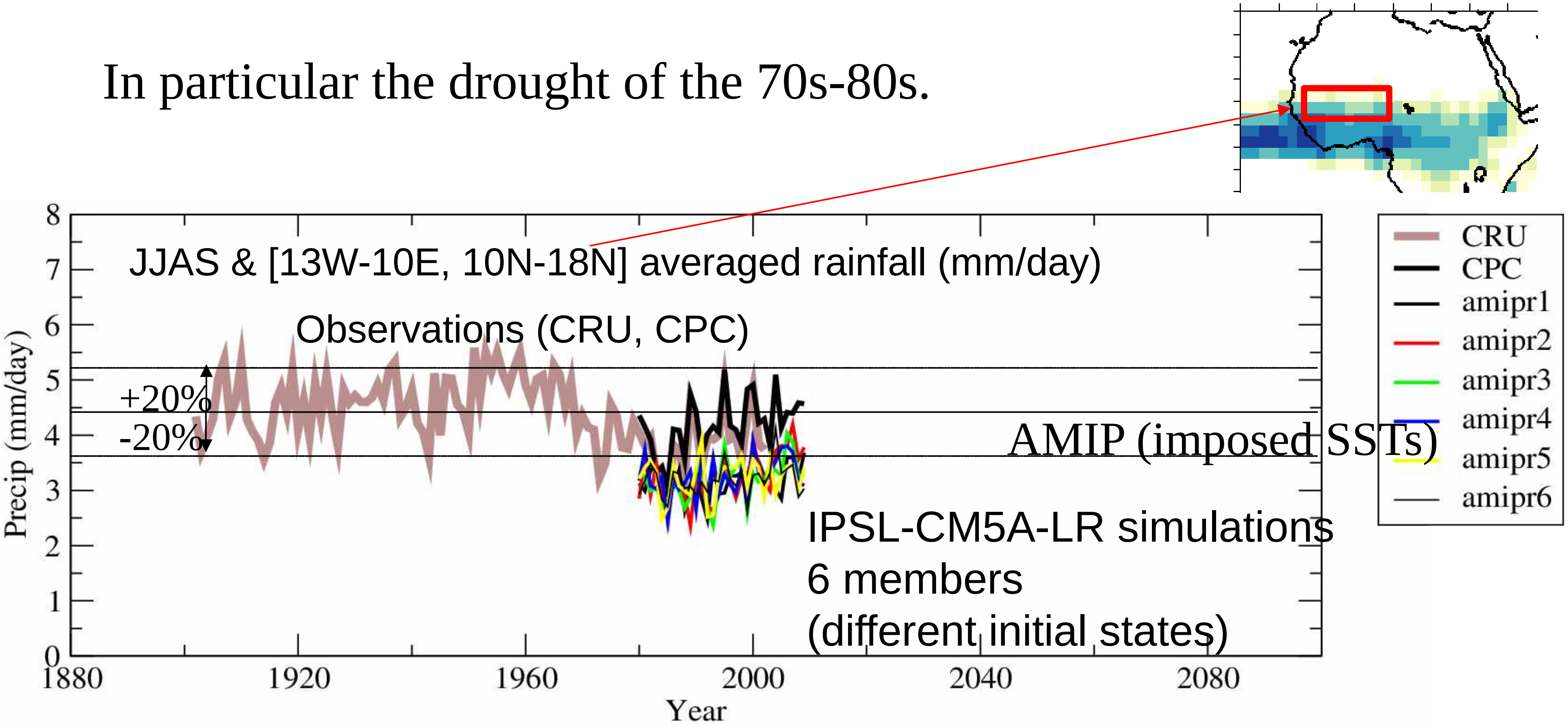
• A large scale patern
• Linked to sea surface
• Temperature changes.



Precipitation change (mm/year)

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

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



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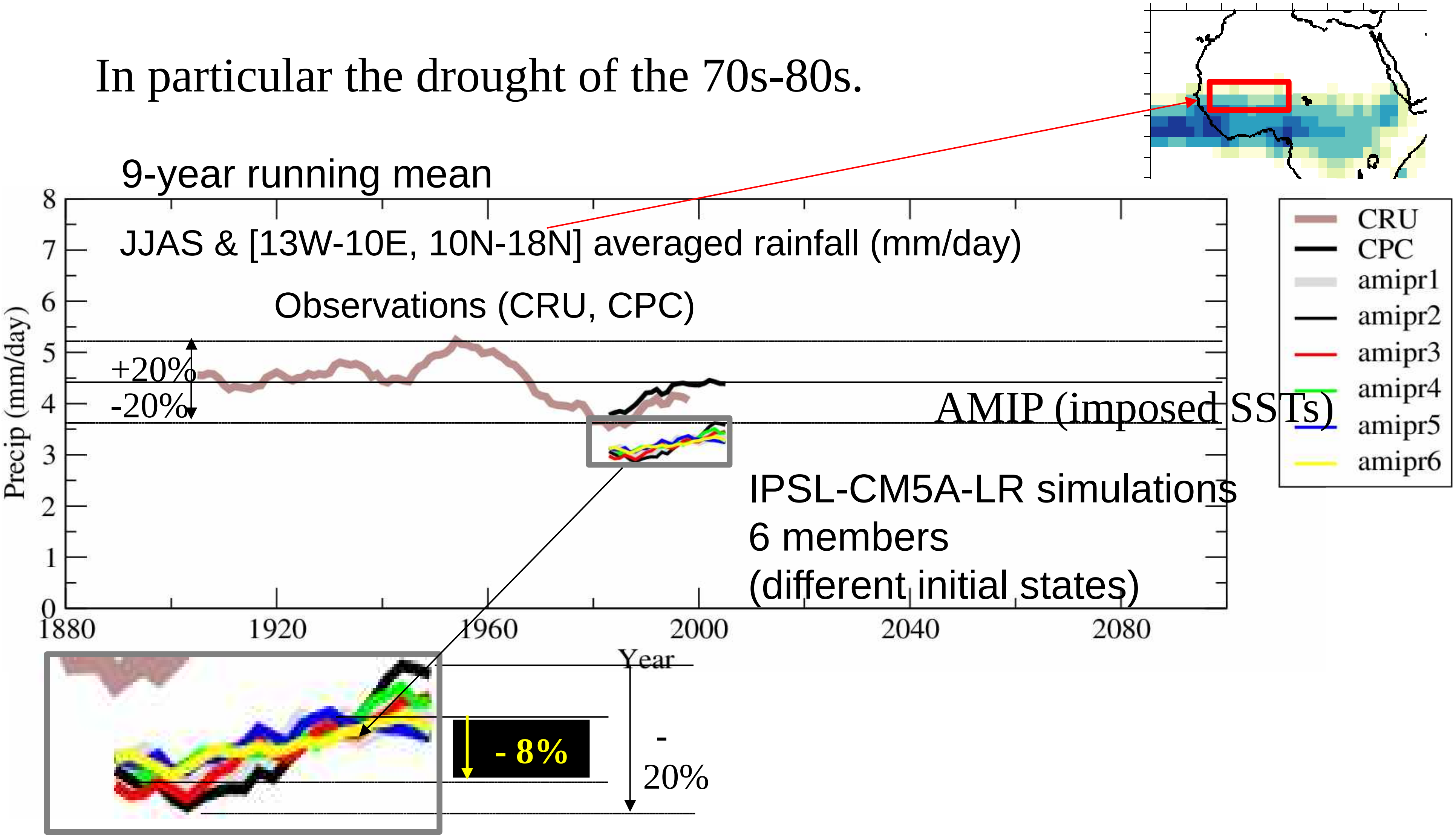
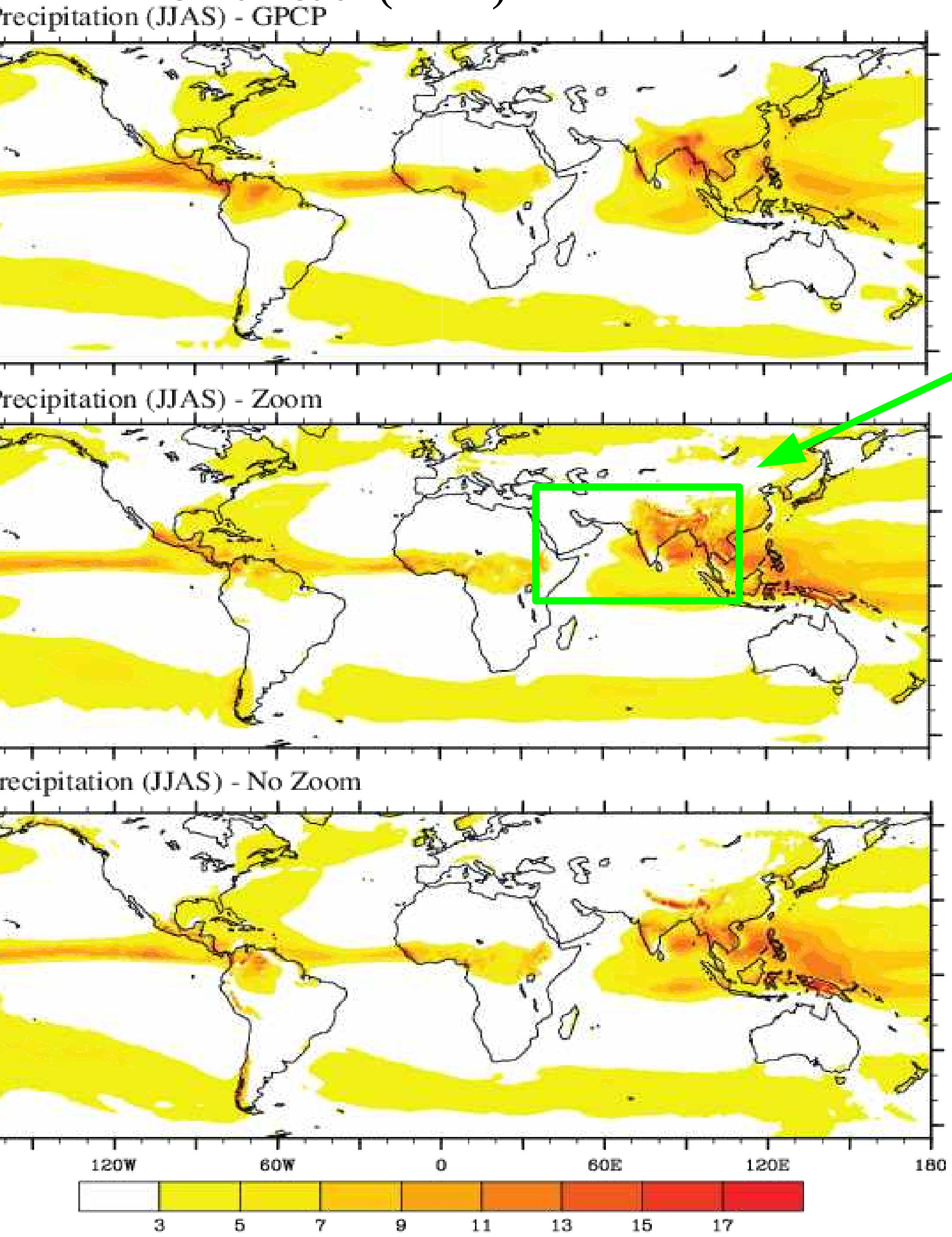


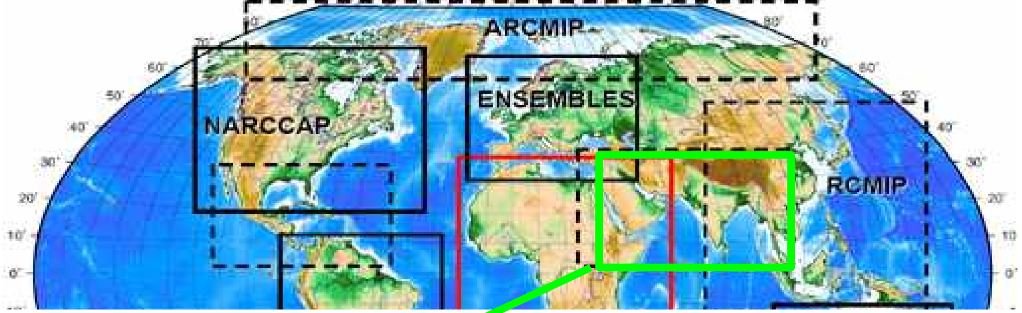
Simulations have a skill to reproduce decadal variations of monsoon rainfall in response to sea surface temperature changes
But strong internal variability (the observation is one possible experience)

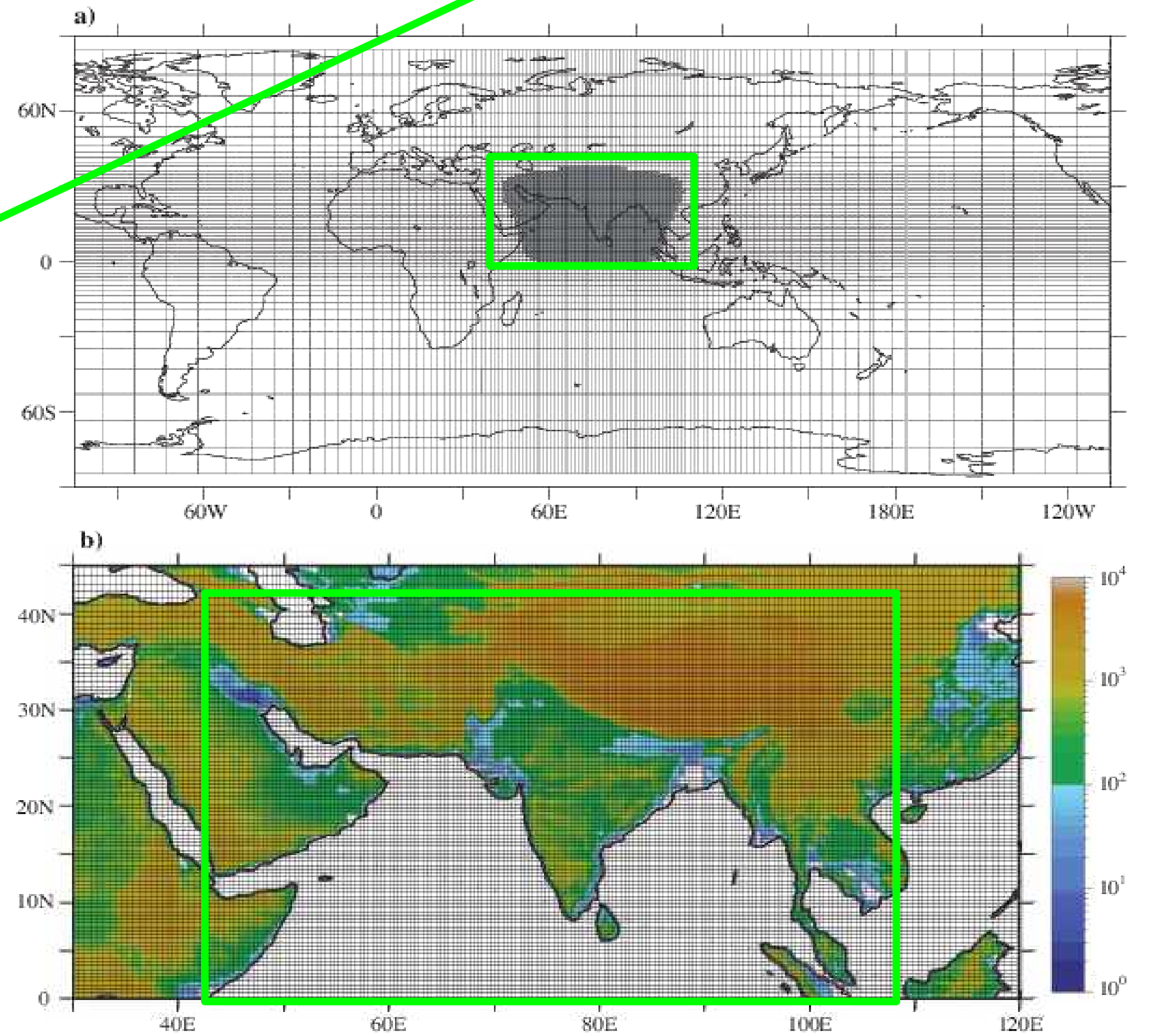
4. Operating modes

Zooming capability

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

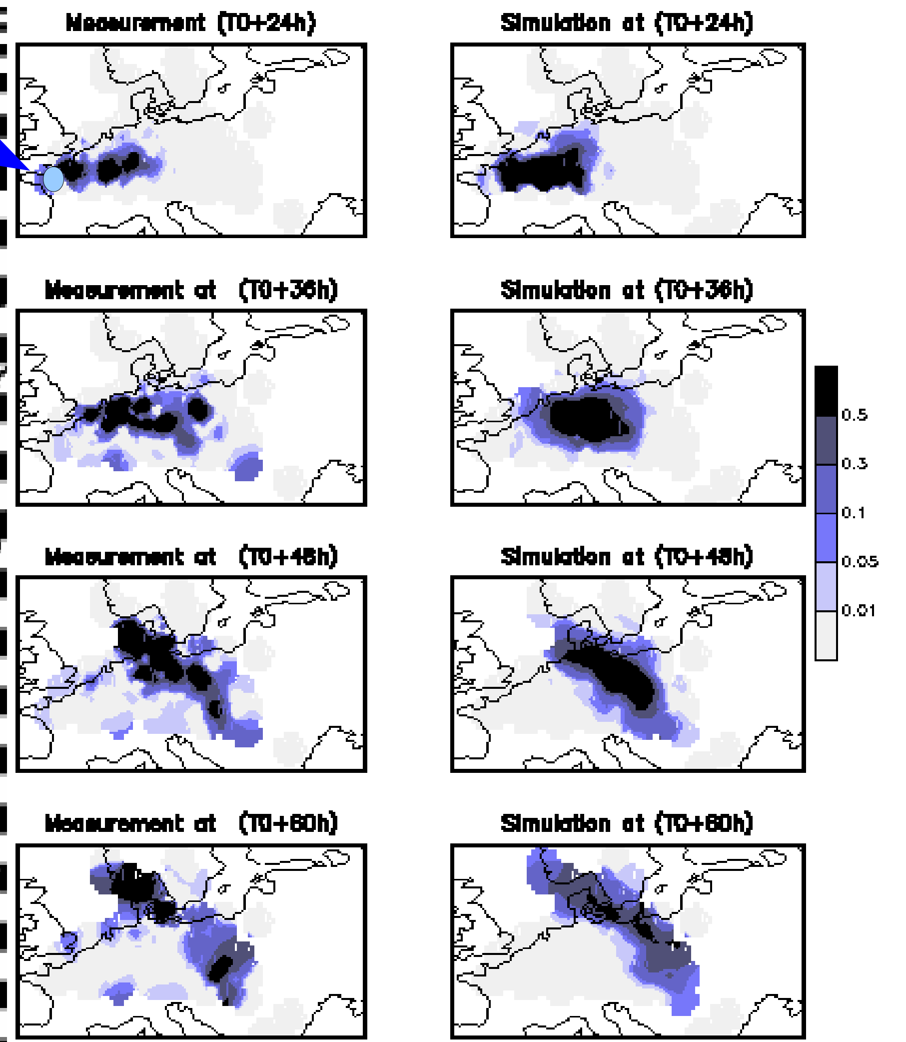






4. Operating modes

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



Nudging capability

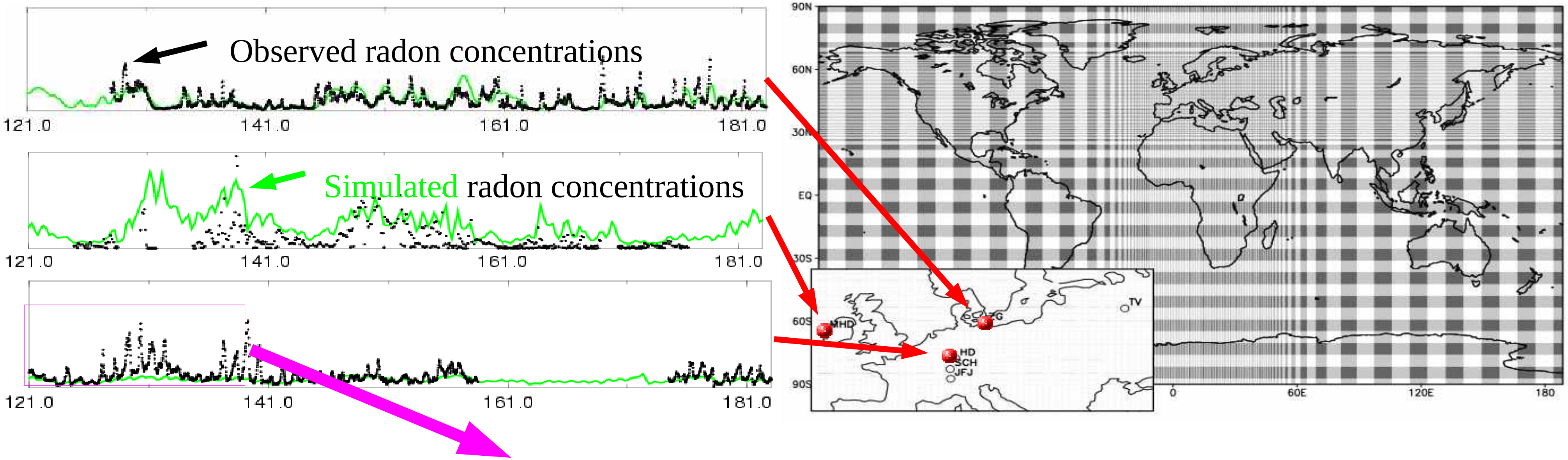
$$\frac{\partial u}{\partial t} = \frac{\partial u}{\partial t}_{GCM} + \frac{u_{analysis} - u}{\tau}$$

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

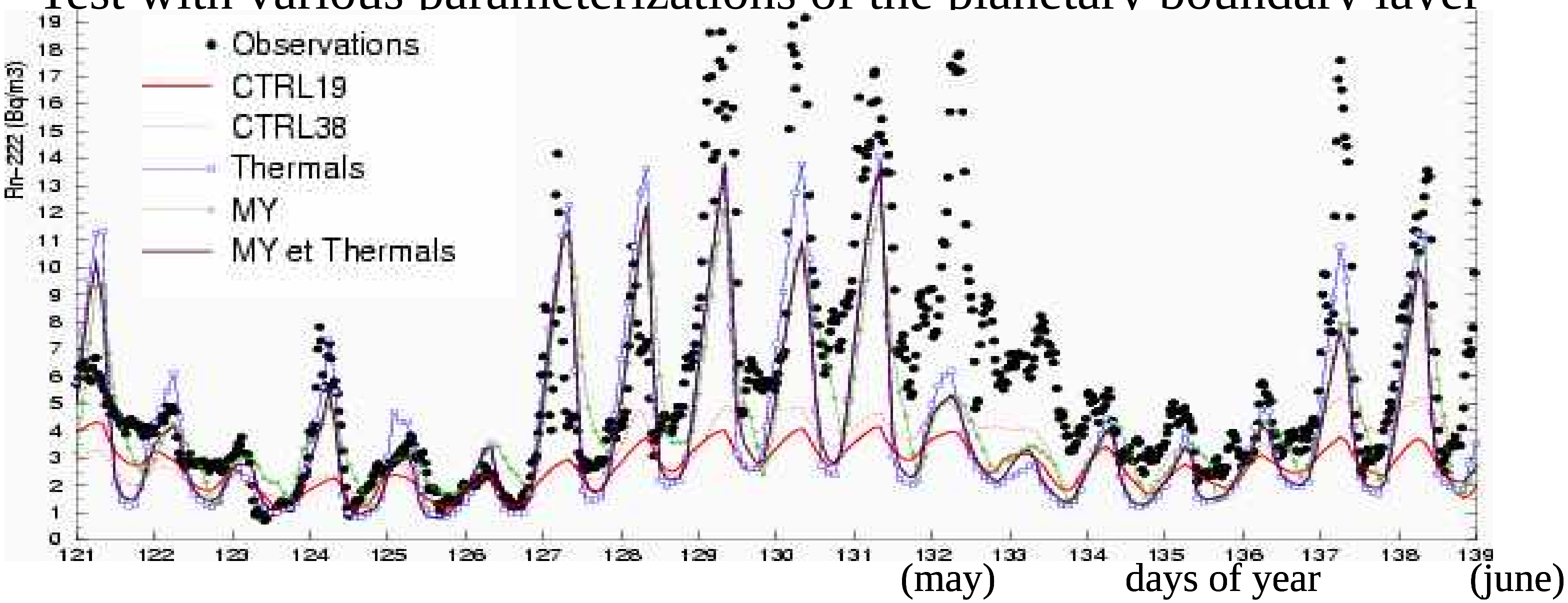
τ Time constant for the relaxation of the model wind toward analyses

$u_{analysis}\, v_{analysis}$

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



Test with various parameterizations of the planetary boundary layer

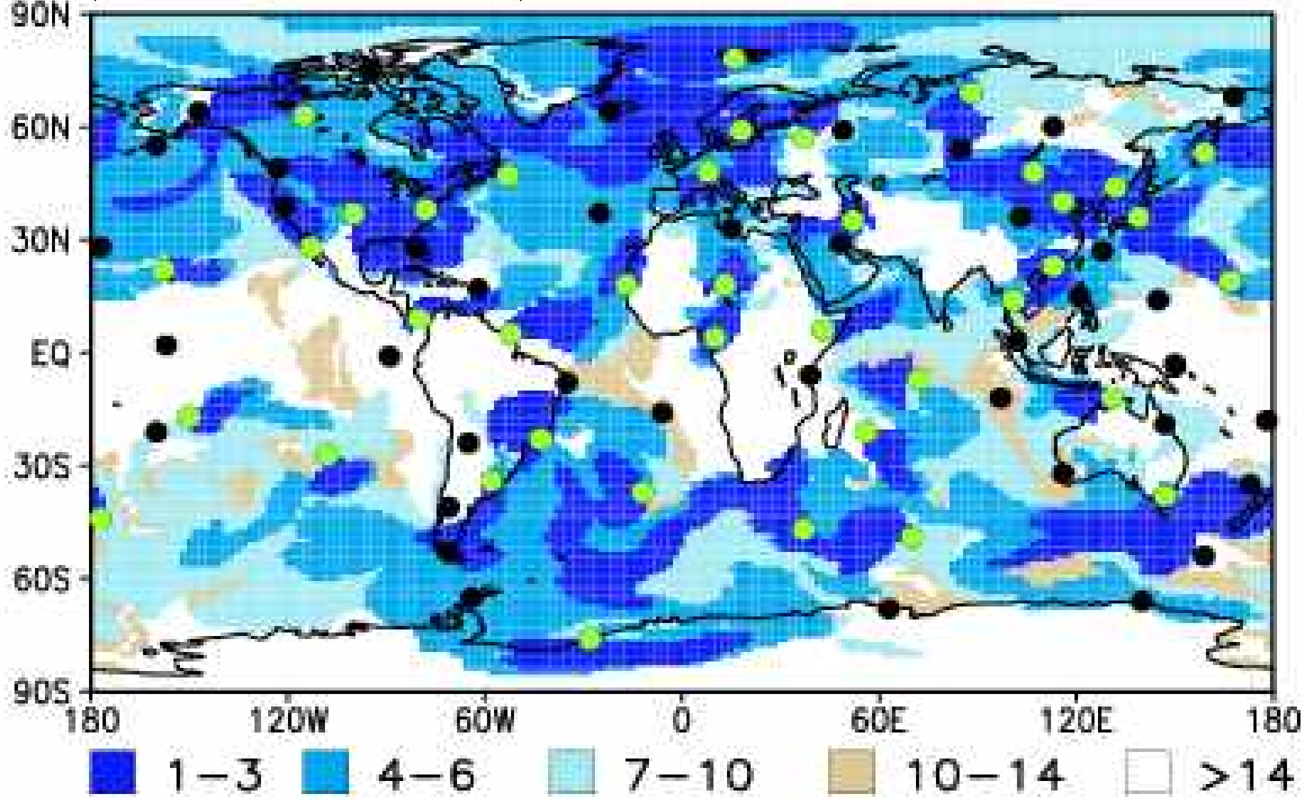


* Radon is a tracer of continental air masses, emitted almost uniformly by continents only. Life time of about 4 days.

Use in off-line transport model, direct and inverse

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

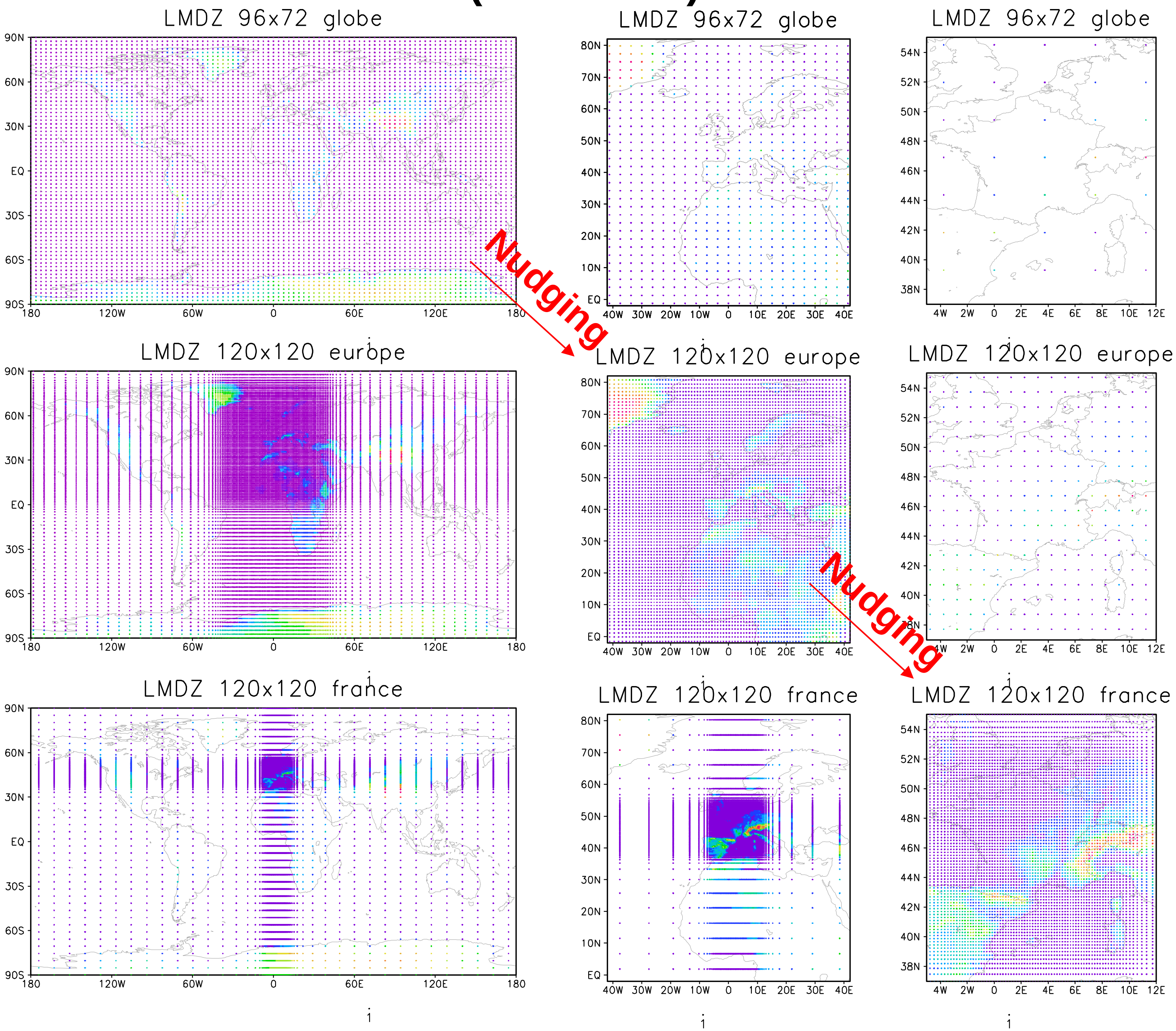
14-day Visibility of the Xenon detection network
(Hourdin et issartel, 2000)



Retro-transport : transport is computed injecting a tracer at the detection stations (green) reversing the time to come back to the possible origins.
Equivalent to an adjoint computation
Used also for estimation of CO2 and CH4 inversions.

4. Operating modes
Use for climate downscaling

LMDZ - Grid Cascade - (Laurent Li)



LMDZ Globe
(300 km)

LMDZ Europe
(100 km)

LMDZ France
(20 km)

4. Operating modes

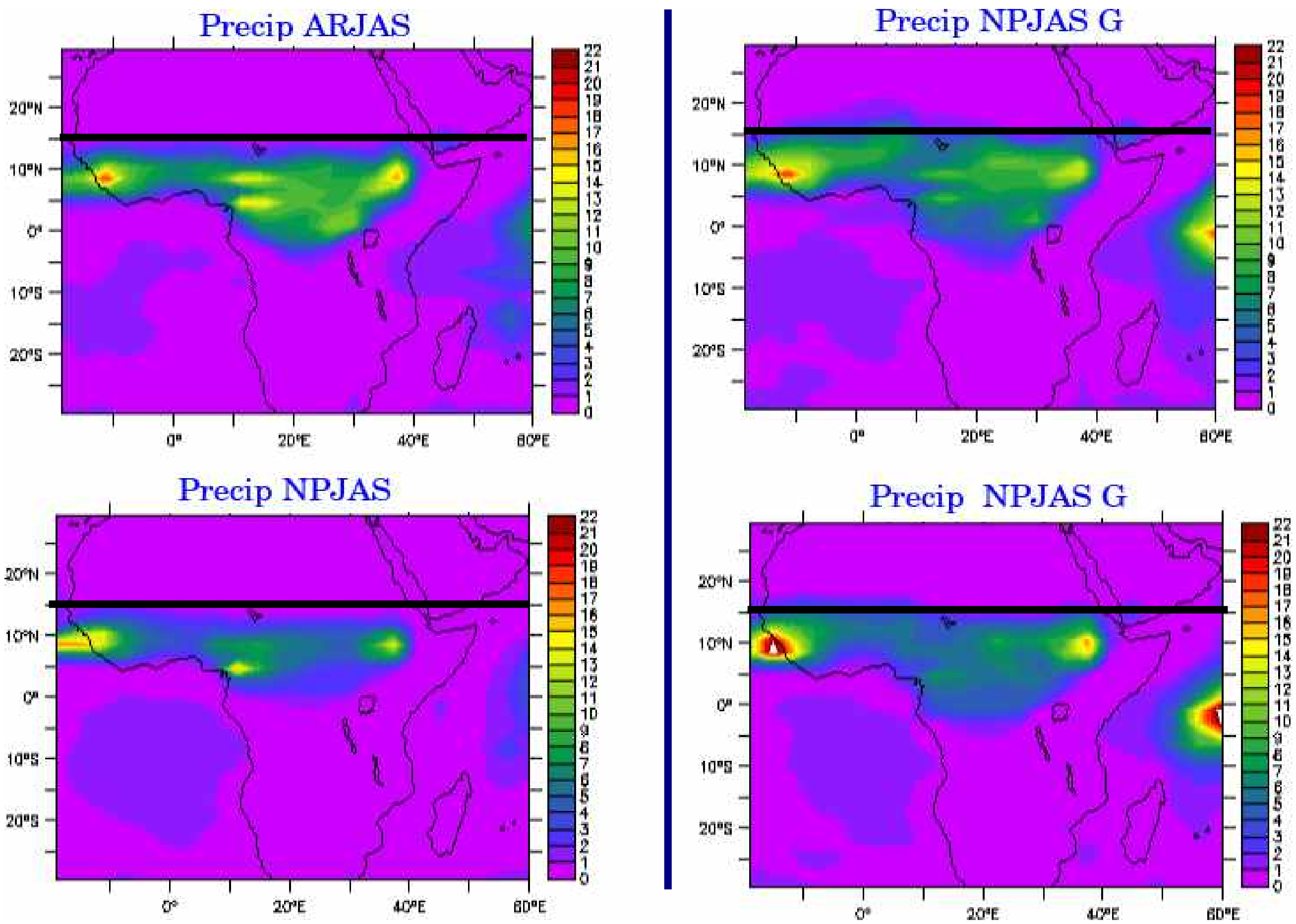
Use for model evaluation and improvement

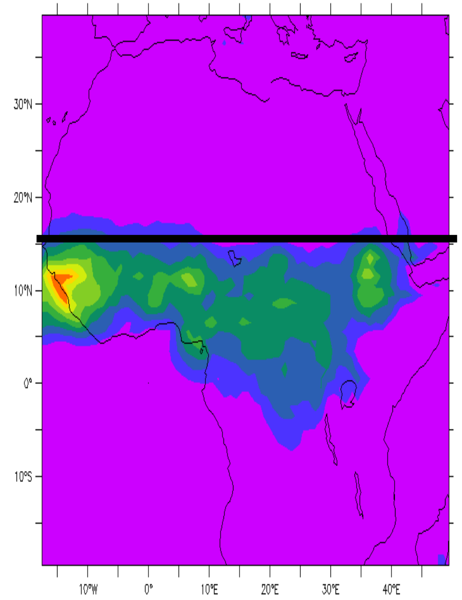
July-August-September mean rainfall

Free | Nudging by ERAI

Standard Physics

New Physics





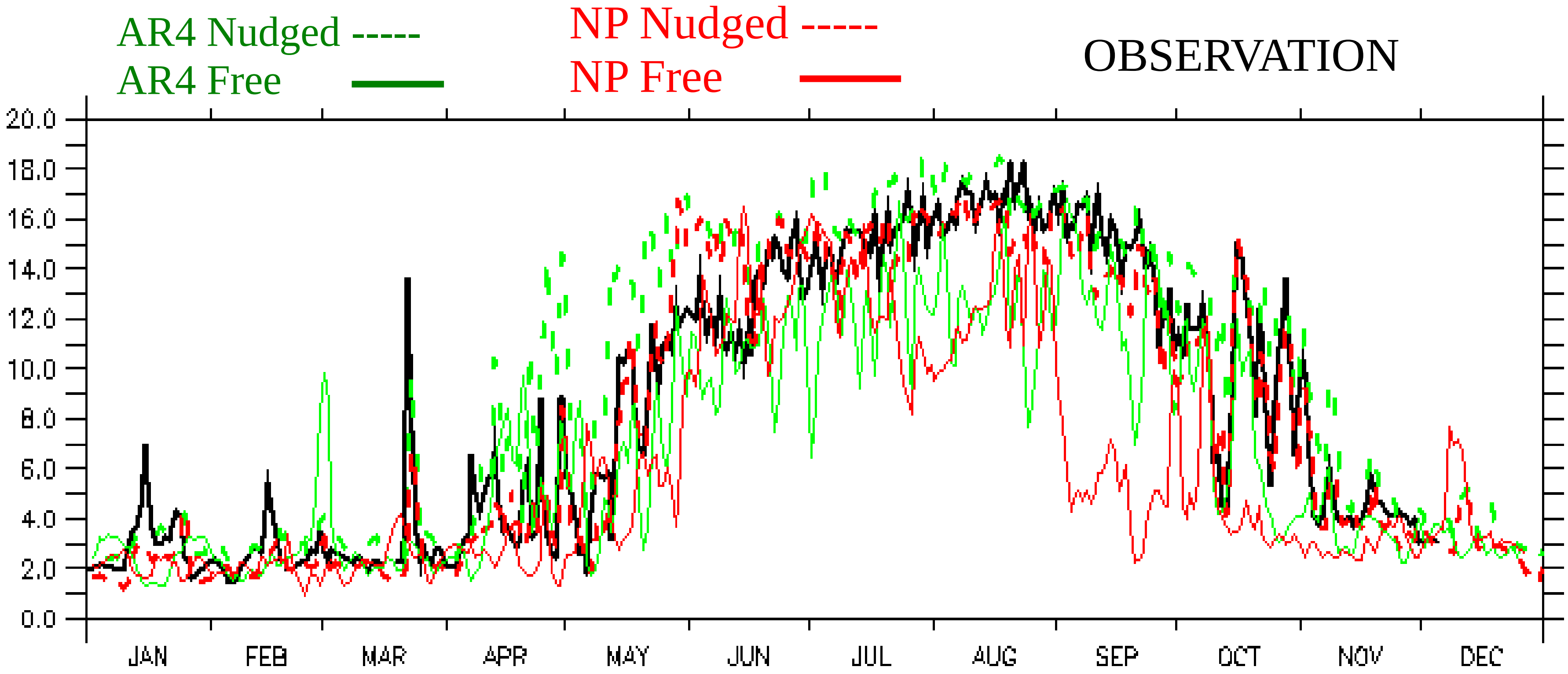
GPCP observations

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

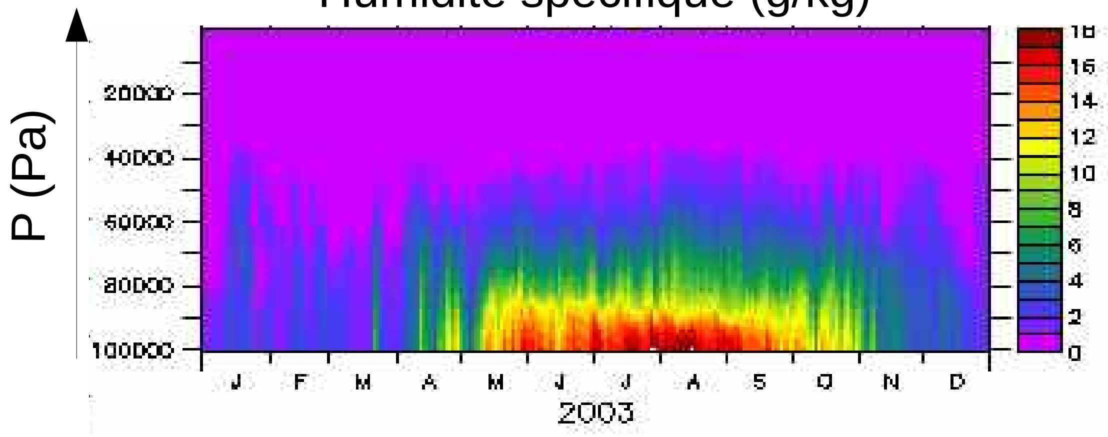
4. Operating modes

Use for model evaluation and improvement

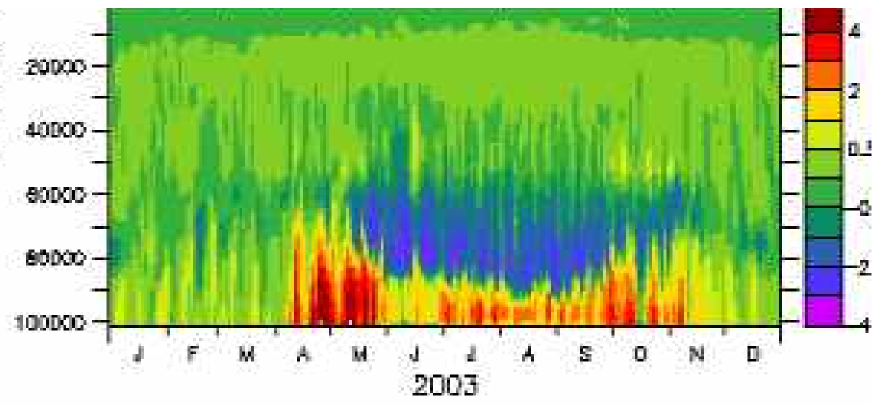
2m specific humidiy, Agoufou (1.5W, 15.3N), year 2003



Humidité spécifique (g/kg)



Différence ancien - nouveau (g/kg)



Summary of 3D operating modes

Global regular

Zoomed

Free

« Earth system » modeling

Forced by SST climate

Idealized experiments (aquaplanets, ...)

Analyzes/evaluation in terms of statistics
Need for ensemble and/or long simulations
Strongly depends on model parameters tuning

Nudged

Chemistry-Transport model
(coupled to Inca or Reprobus)

Source inversion

Evaluation of physical parameterizations with imposed dynamics

Analysis of field campaign experiments and site observations

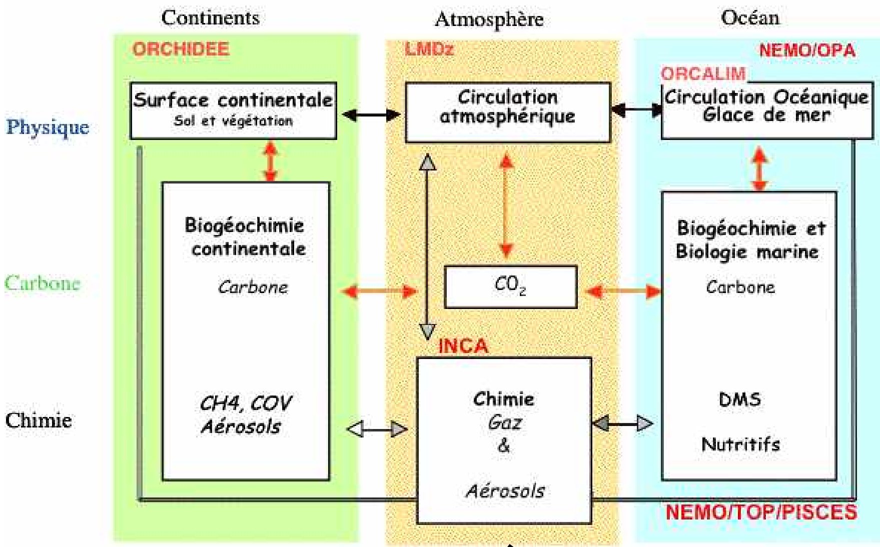
Climate downscaling

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

I. LMDZ : a general circulation model
   1. General Circulation Models
   2. LMDZ
   3. Splitting/coupling and modularity
   4. Operating modes
   5. **Intercomparison exercises and reference versions**

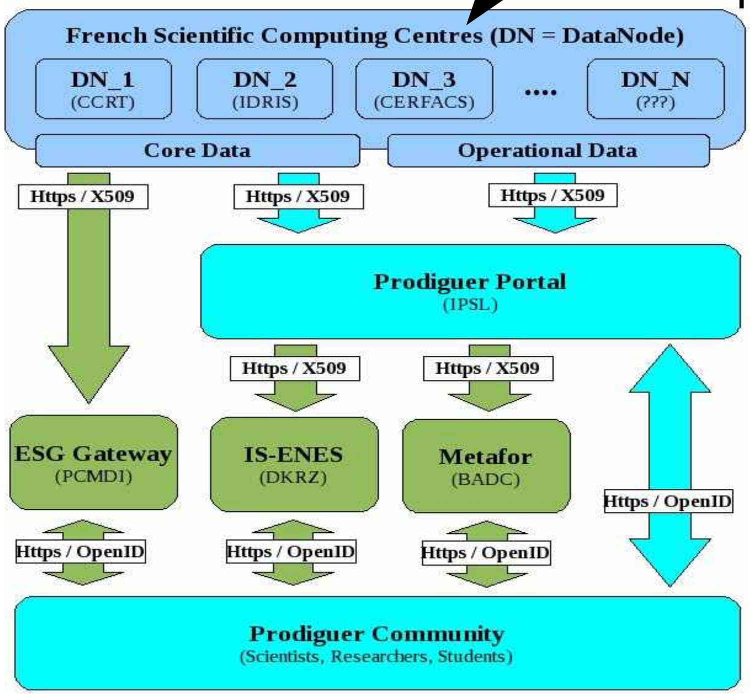
5. Intercomparison exercises and reference configurations

Participation to Coupled Model Intercomparison Project : CMIP

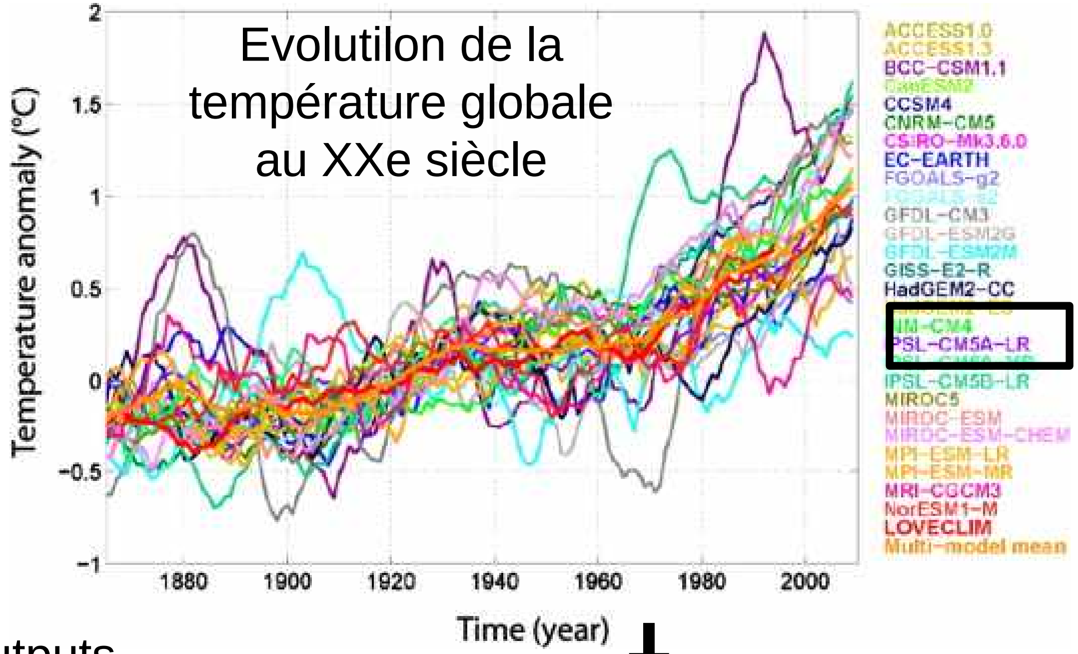


IPSL Earth System Model
=
Physical component (océan/atm/hydro)
LMDZ/NEMO/Orchidee
+
Cycle (CO2, bio-chemistry, aérosols)

Simulations
On computer centers



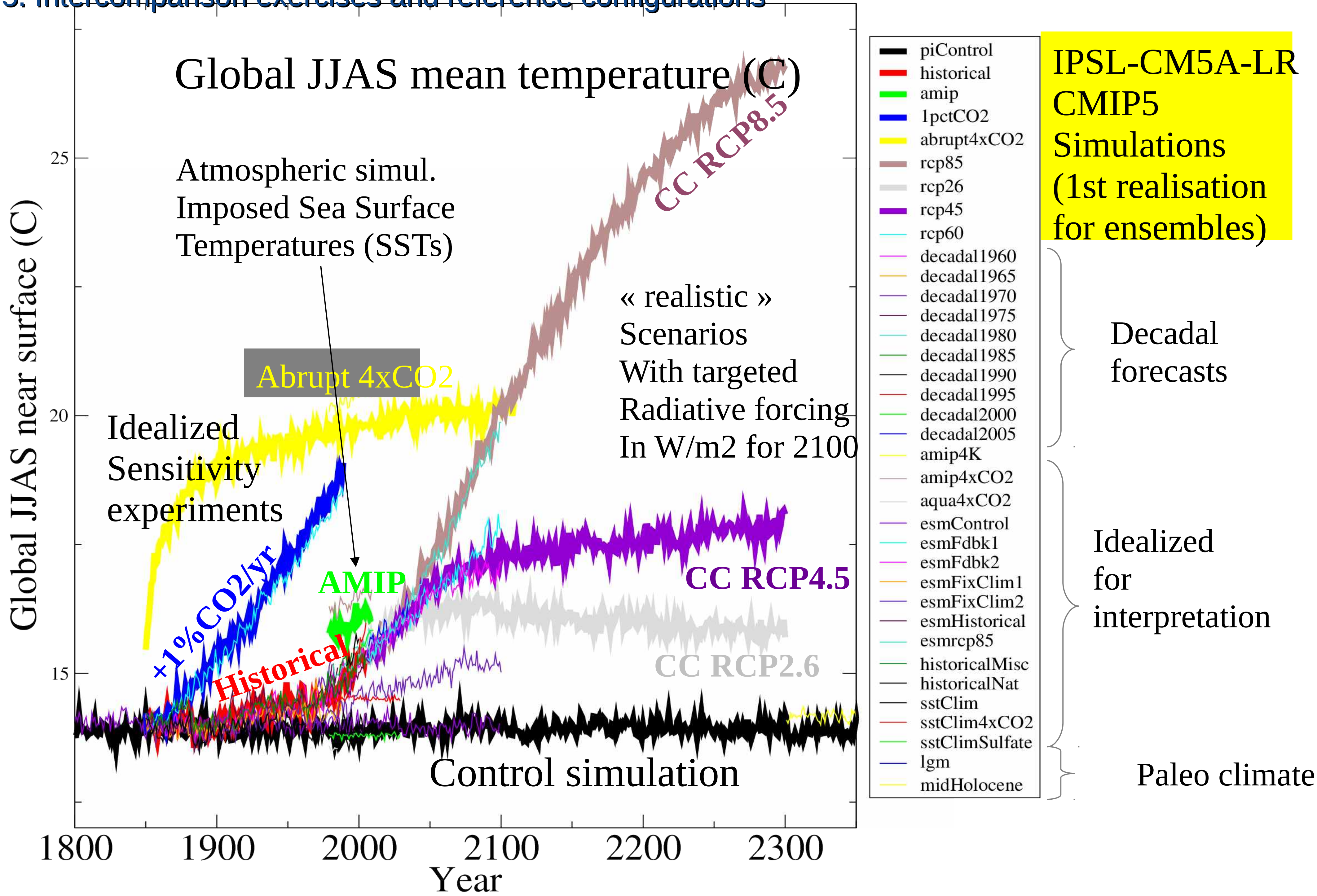
Result analysis (500 publis in 2 years)



Model outputs
Distributed openly
ICM DATA / ISIS

IPCC Assessment Reports

5. Intercomparison exercises and reference configurations



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.

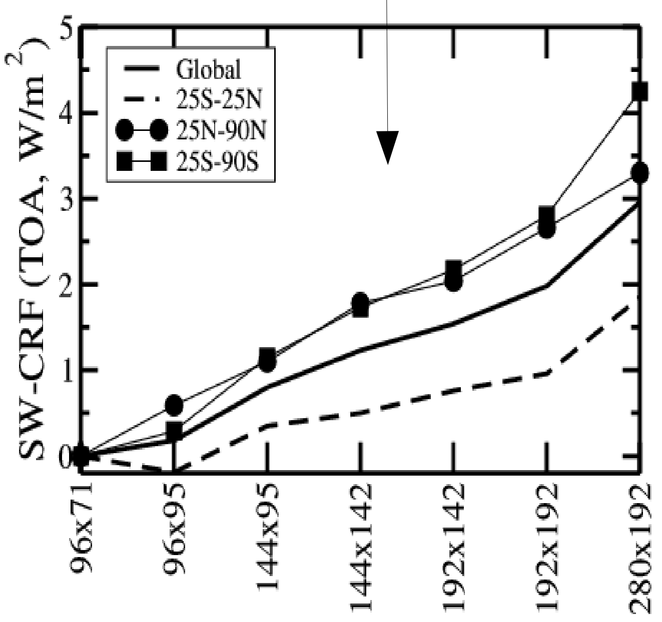
For global climate coupled atmosphere/ocean modeling the tuning of the radiative forcing is a key issue. Several months of tuning for one version.

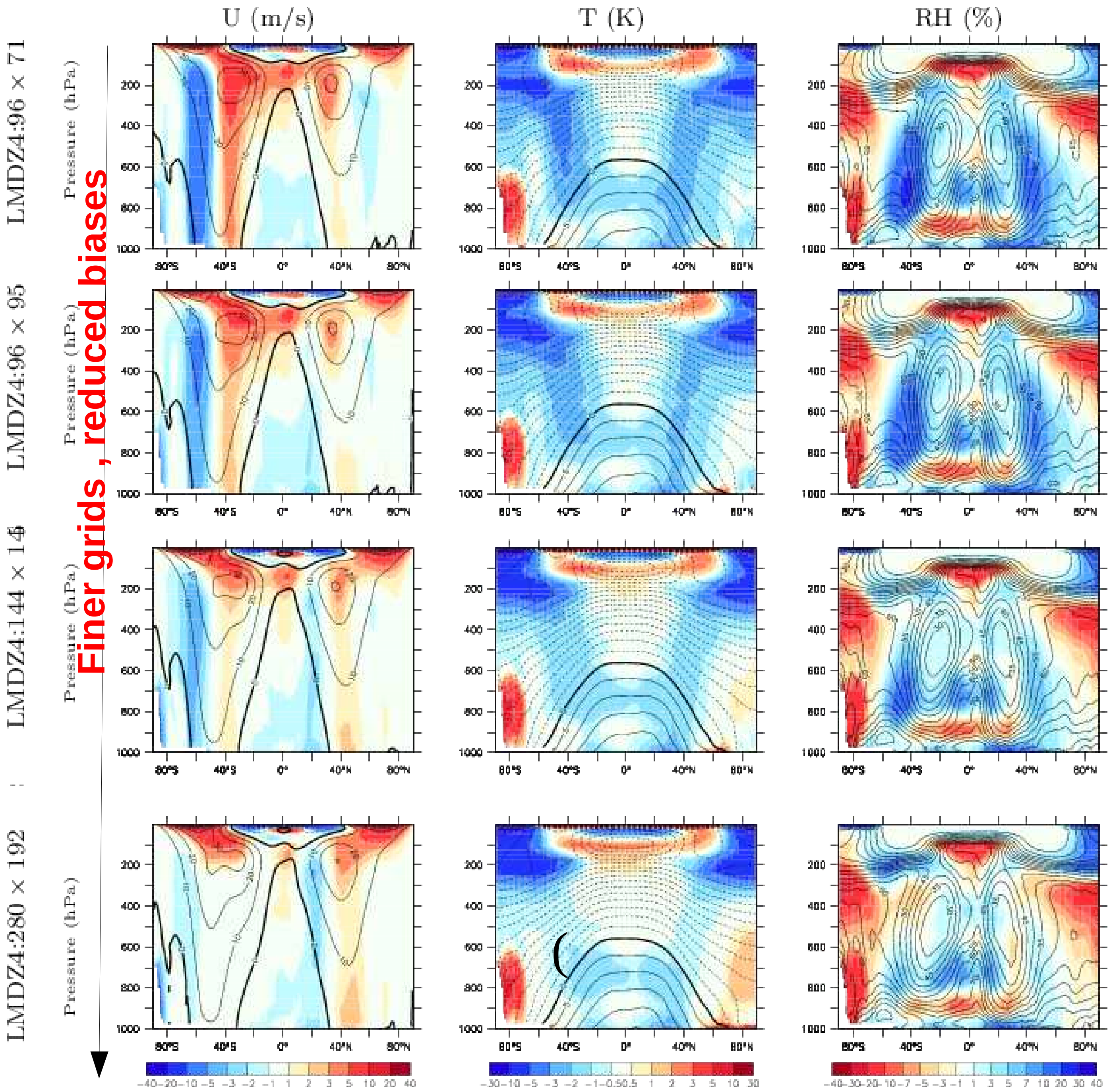
Participation to the last **CMIP5** exercise with 2 grids and 2 physical contents
Standard Physics, already used in CMIP3
New physics, with par

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





New physics improvements (robust 1D&3D) of low clouds simulations

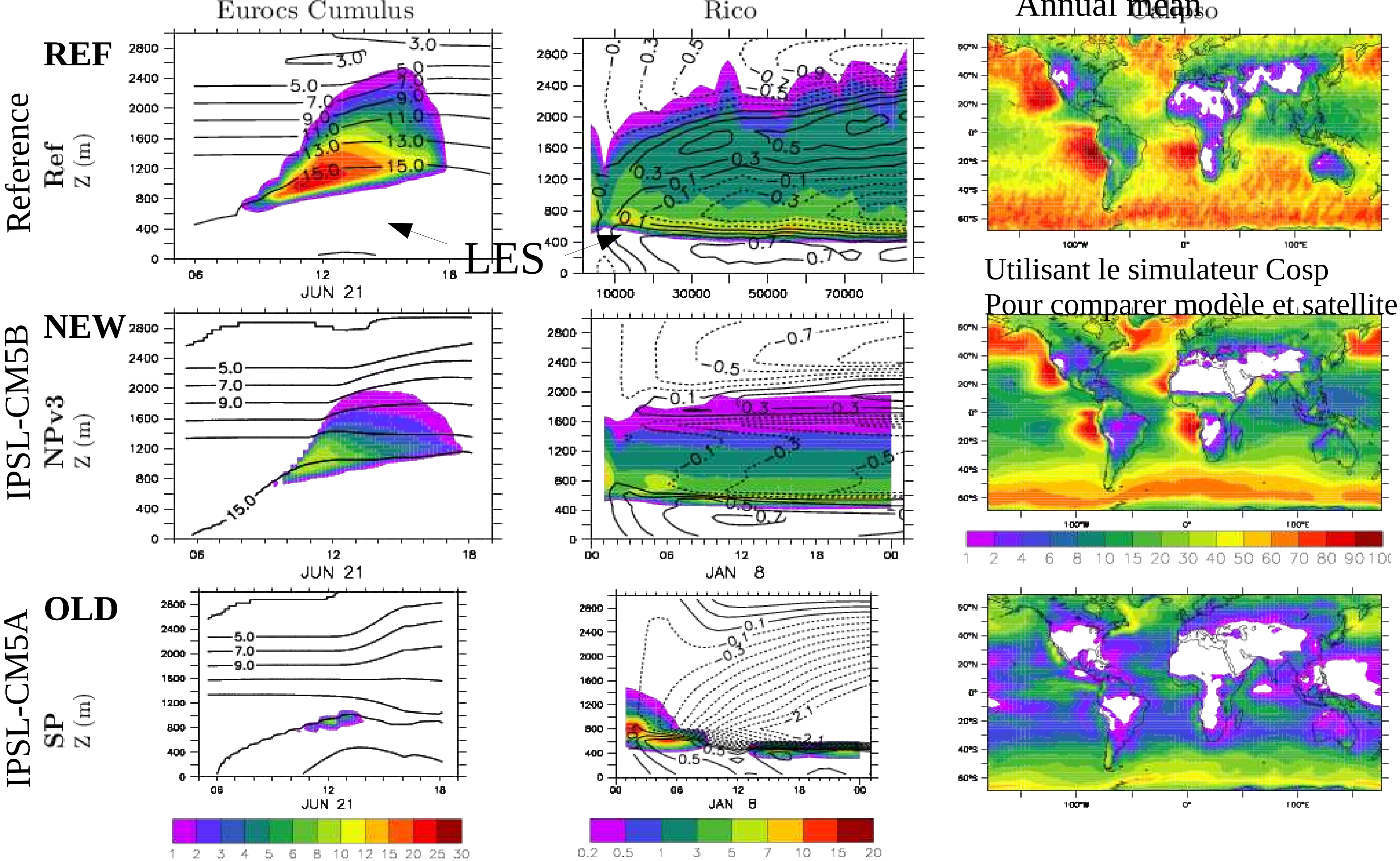
1D test cases

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

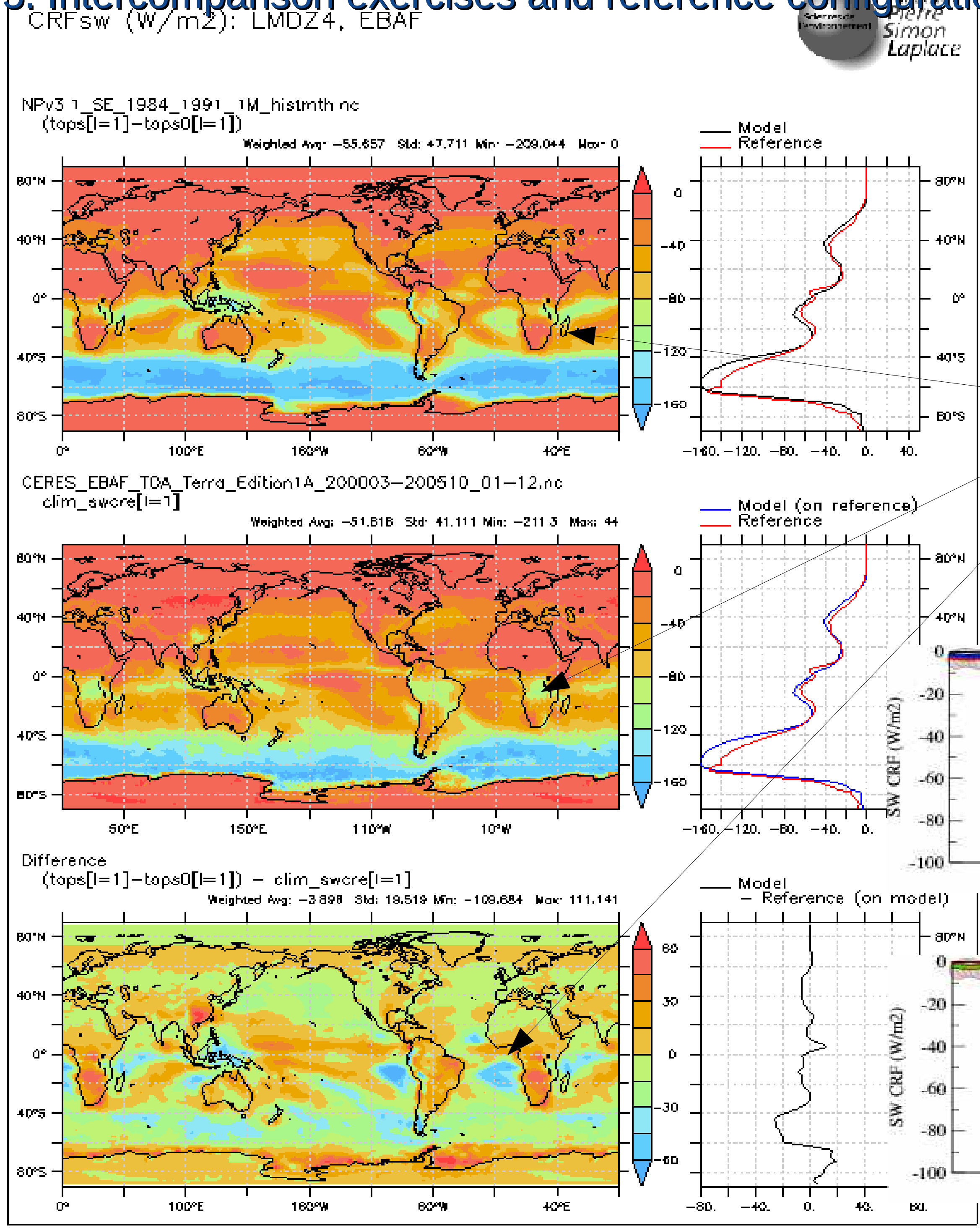
Simulations 3D

Low cloud cover (%)

Annual mean



5. Intercomparison exercises and reference configurations

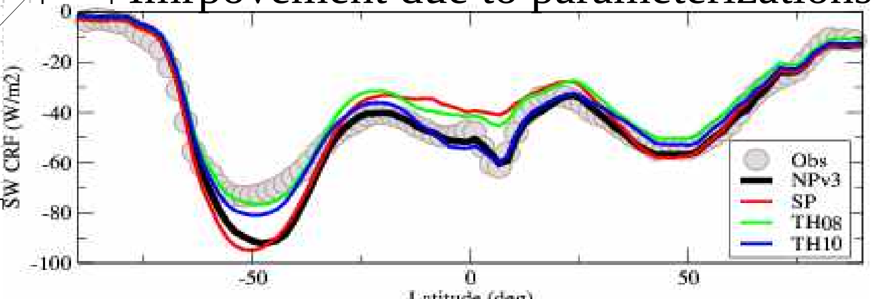


Importance of tuning of free parameters

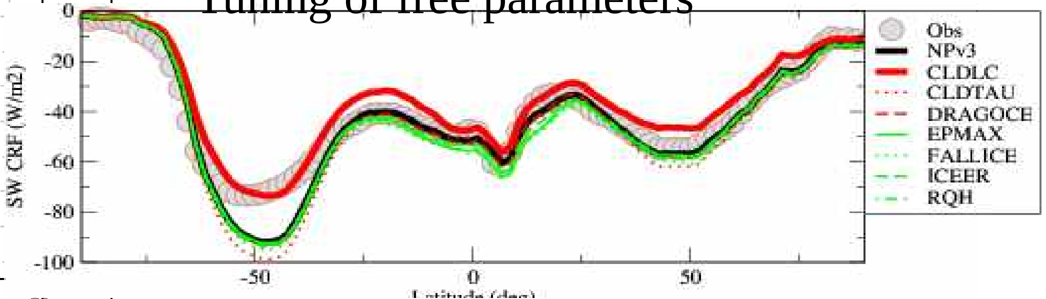
SW cloud radiative effect SW-CRE at top-of-atmosphere, in W/m2

Modele
Observations
Difference

Imrpovement due to parameterizations change

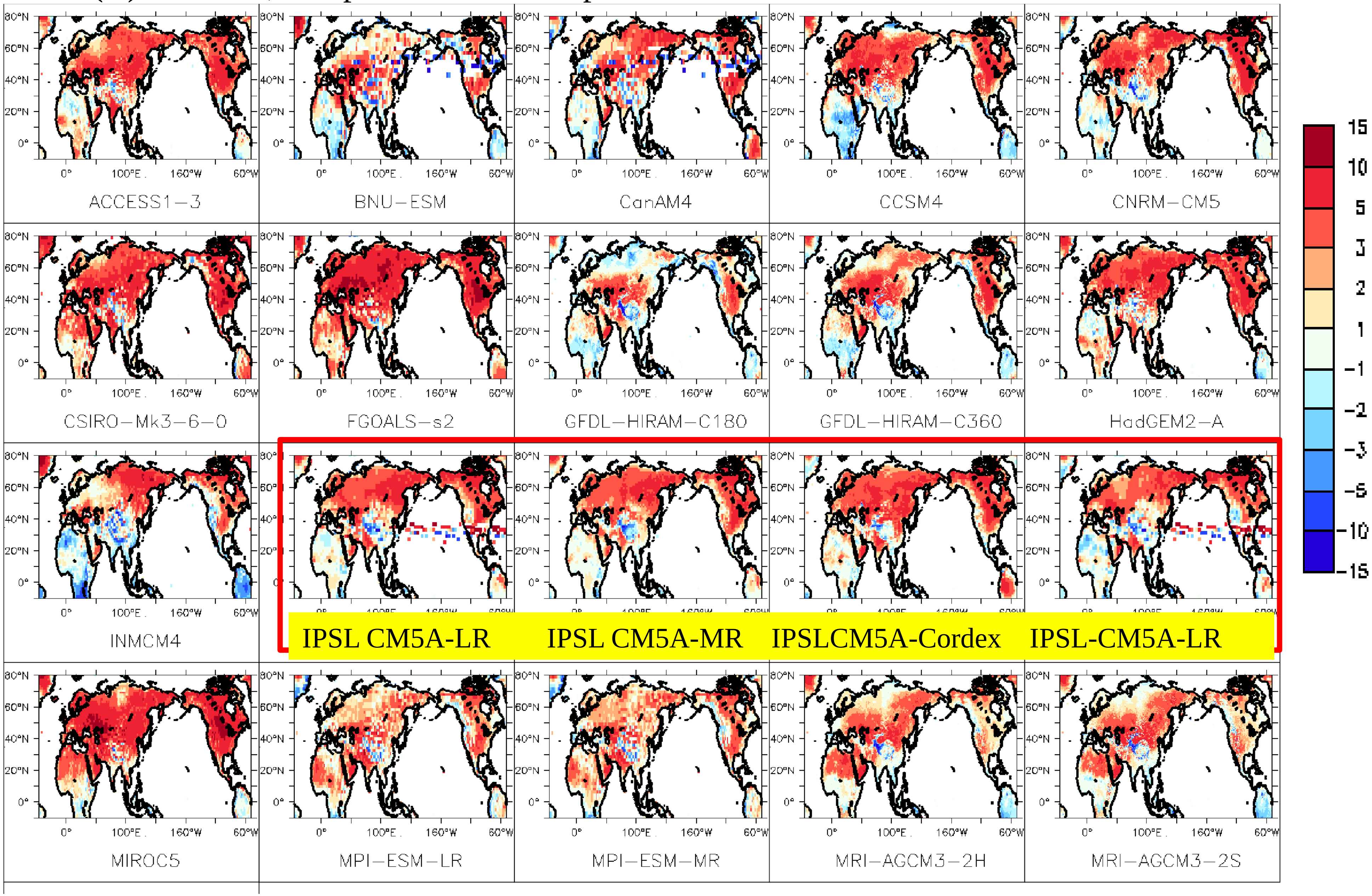


Tuning of free parameters



5. Intercomparison exercises and reference configurations

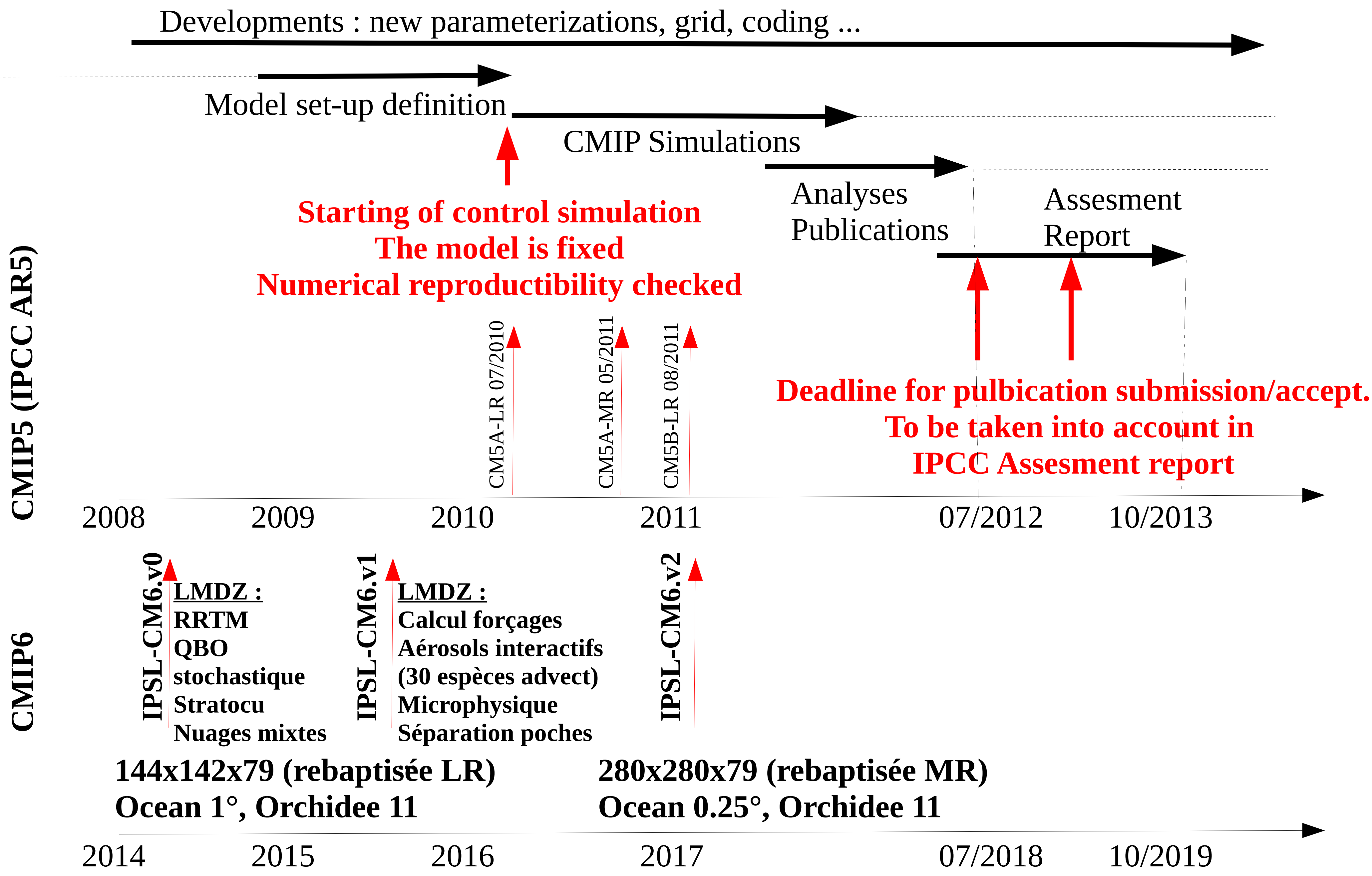
T2m (K) JAS bias, Amip/CMIP5 with imposed Sea Surface Temerature



Typical systematic biases

5. Intercomparison exercises and reference configurations

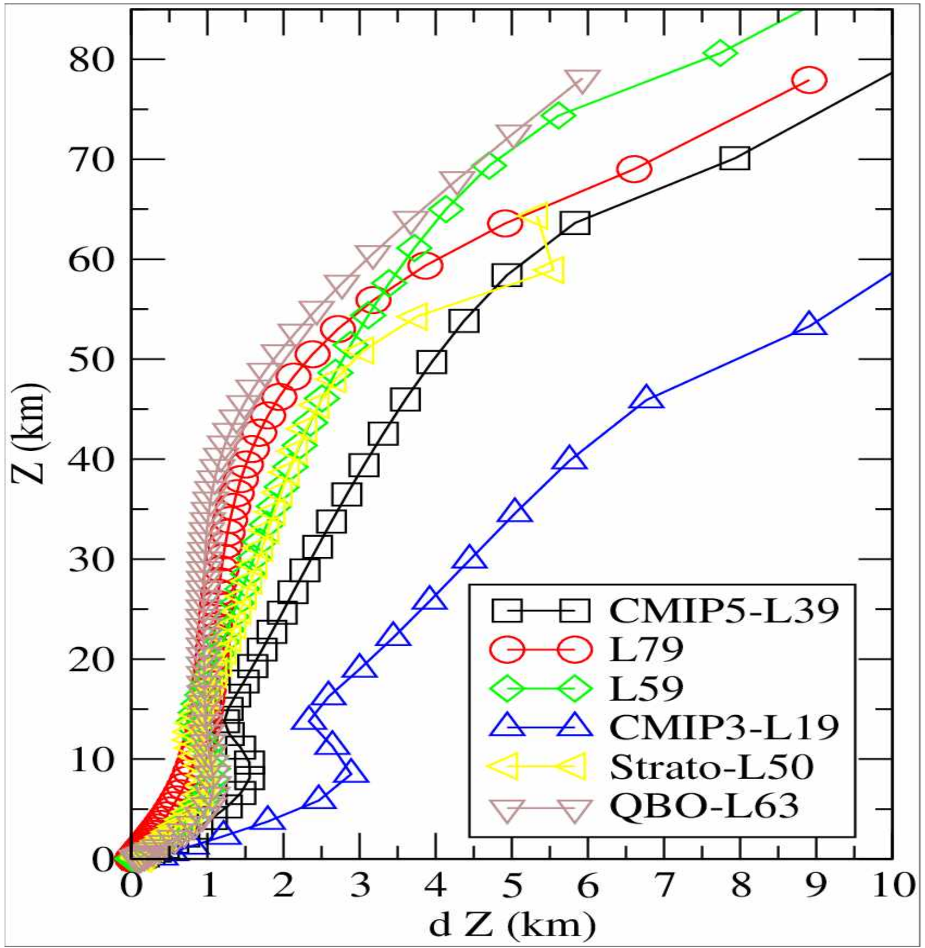
LMDZ development and CMIP « rendez-vous »

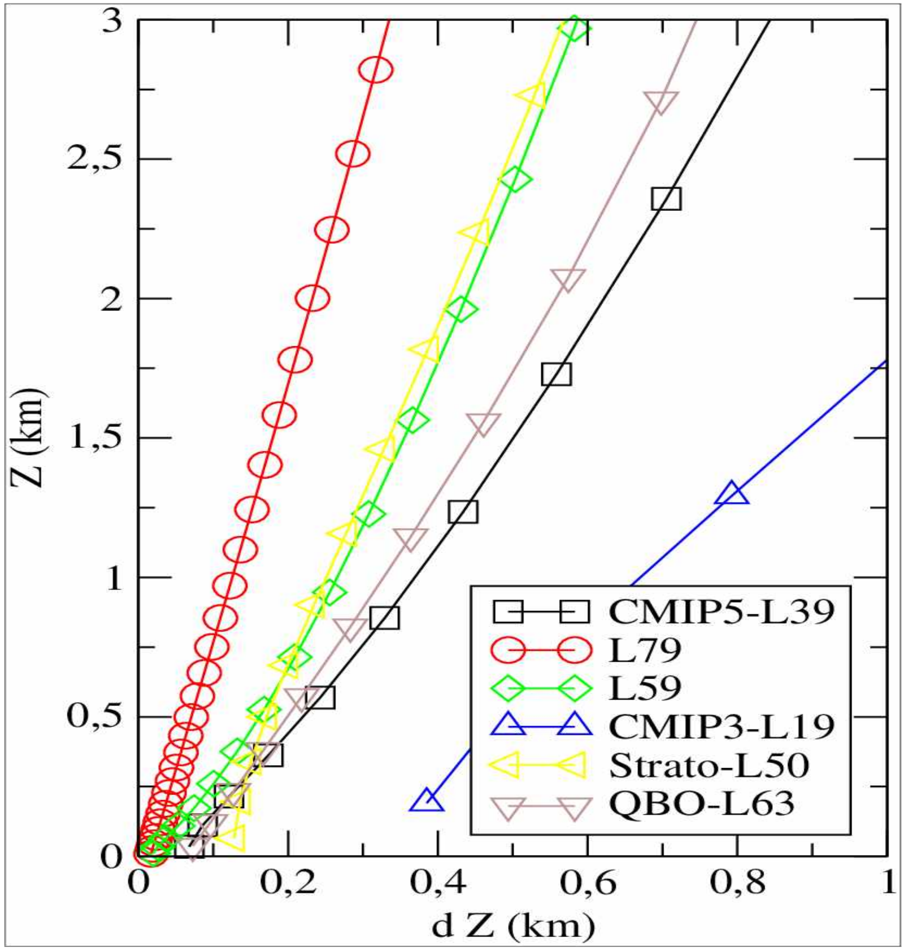


Summary of reference climate configurations

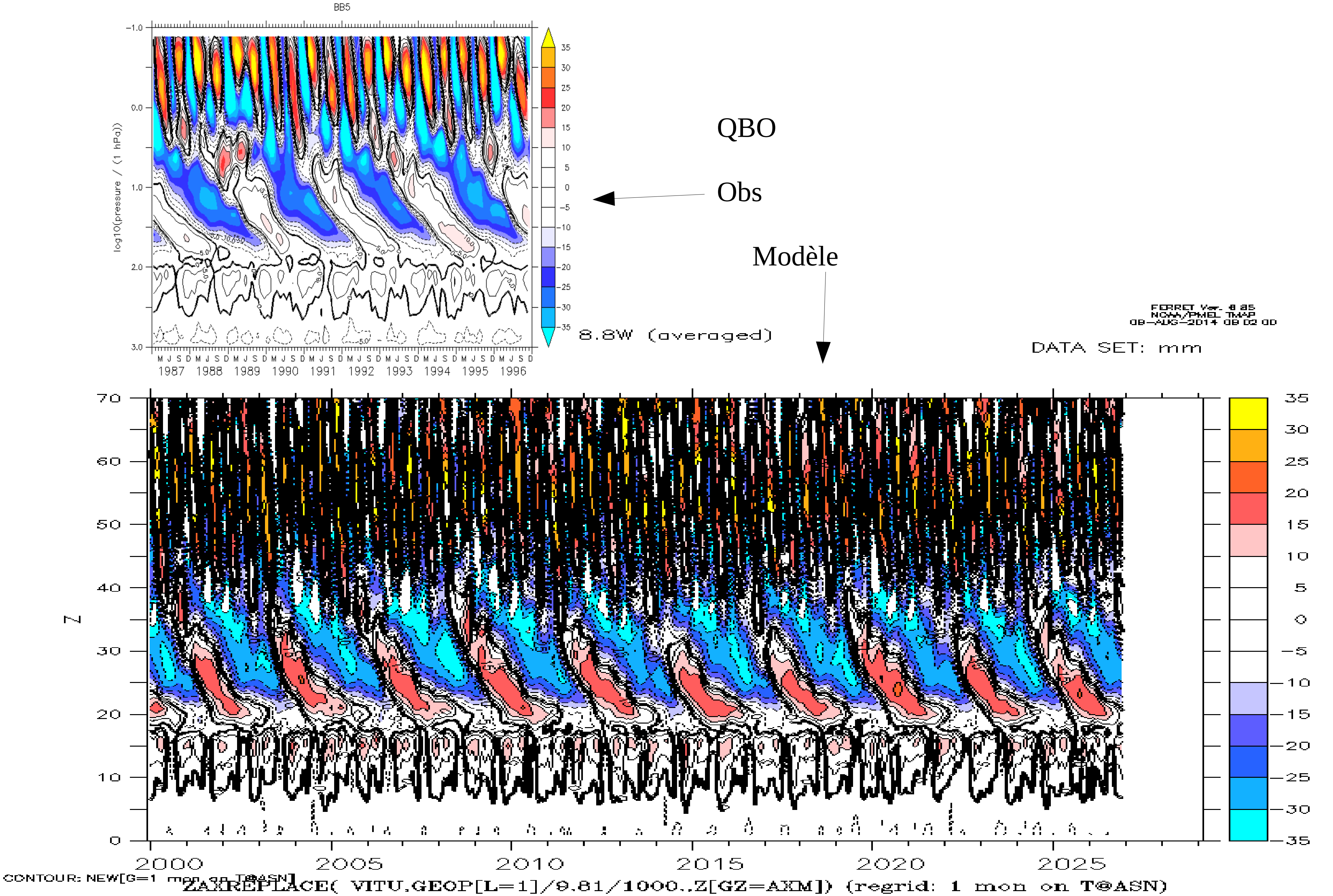
	Vertical resolution	Horizontal grid	Physical parameterizations	Name
CMIP3	L19	96x71	New convection scheme (Emanuel) Subgrid scale rorgaphy	IPSL-CM3 LMDZ4
CMIP5	L39 Extension to the stratosphere	LR = 96x95 MR = 144x143	2 versions A : Standard Physics (SP) same as CMIP3 B : New physics (NPv3) with thermal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

LMDZ4, 5, 6 vertical grids





5. Intercomparison exercises and reference configurations



General remarks

1. LMDZ is a flexible tools

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

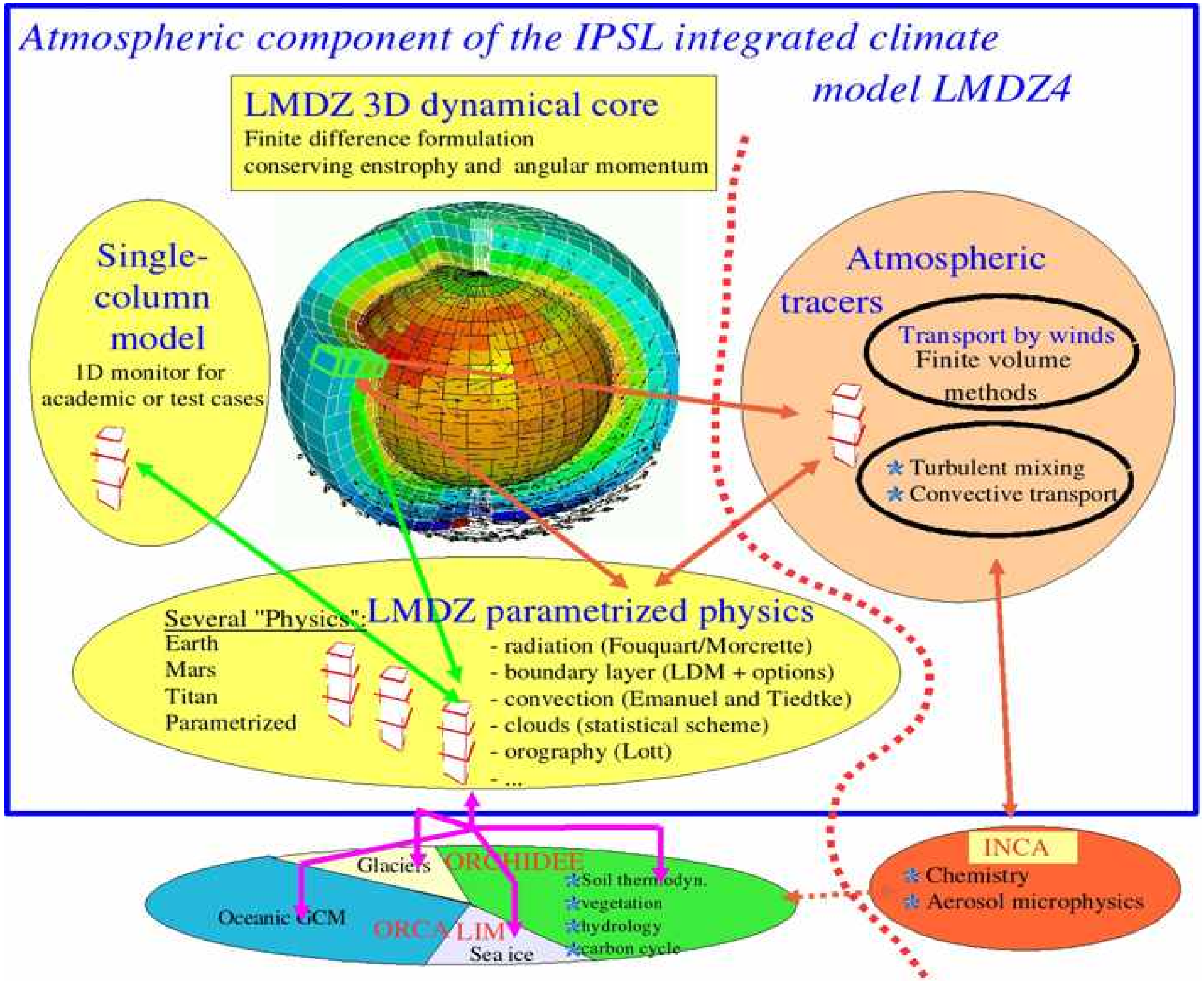
3. The reference simulations are widely published, documented, distributed on LMDZ site or from CMIP database.

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

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

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

4. LMDZ : A tool for a wide community



230 users, 31 teams

- 13 IPSL teams
- 6 in france outside IPSL
- 12 abroad

Configurations

- Climate imposed SSTs (18 teams)
- Zoom (17 teams)
- nudging (16 teams)
- Climate coupled to ocean (11 teams)

Used for

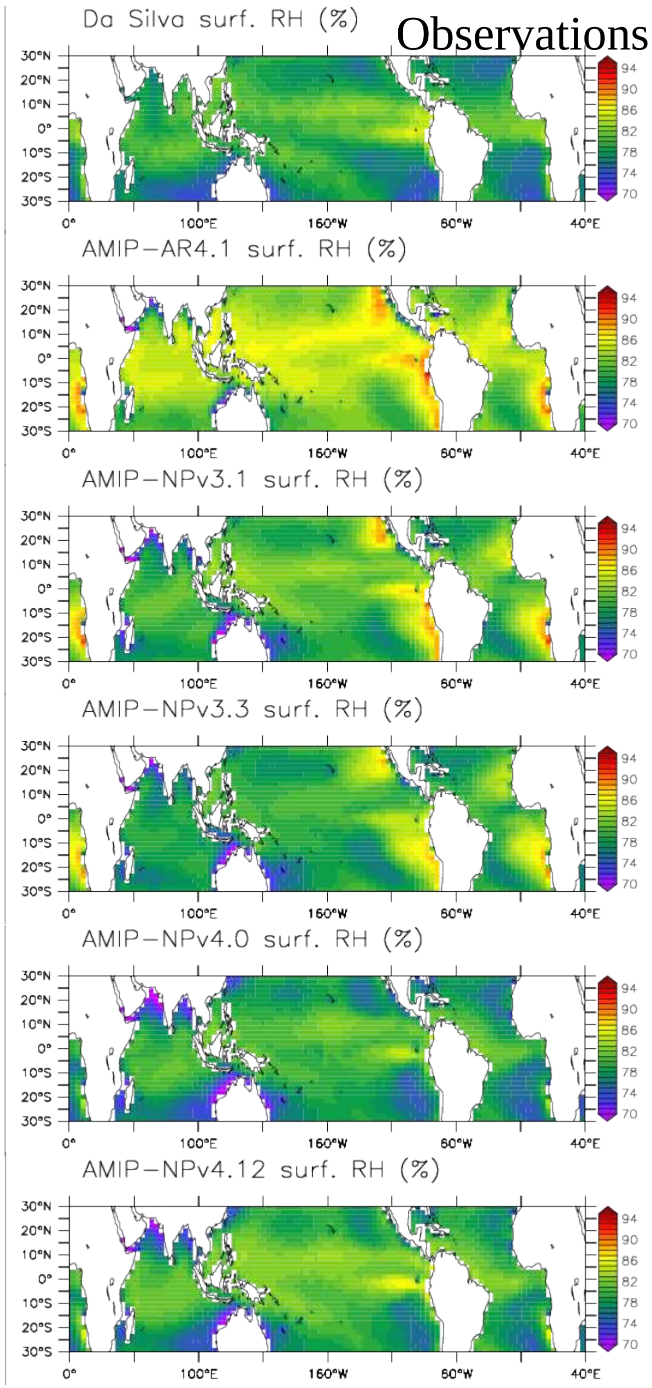
- Tropical variability (13)
- Climate changes (12)
- Analyis of in situ observations (10)
- Cliamte studies in China (9)
- Model/satellite (8) , Plantets, isotopic versions …

Organisation

- Weekly meeting of the development team (contribution from 8 other teams)
- Scientific comitee + users meeting (~1 each year)
- Mailing list, web http://lmdz.lmd.jussieu.fr, LMDZinfo
- training (1 or 2 each year, french and english

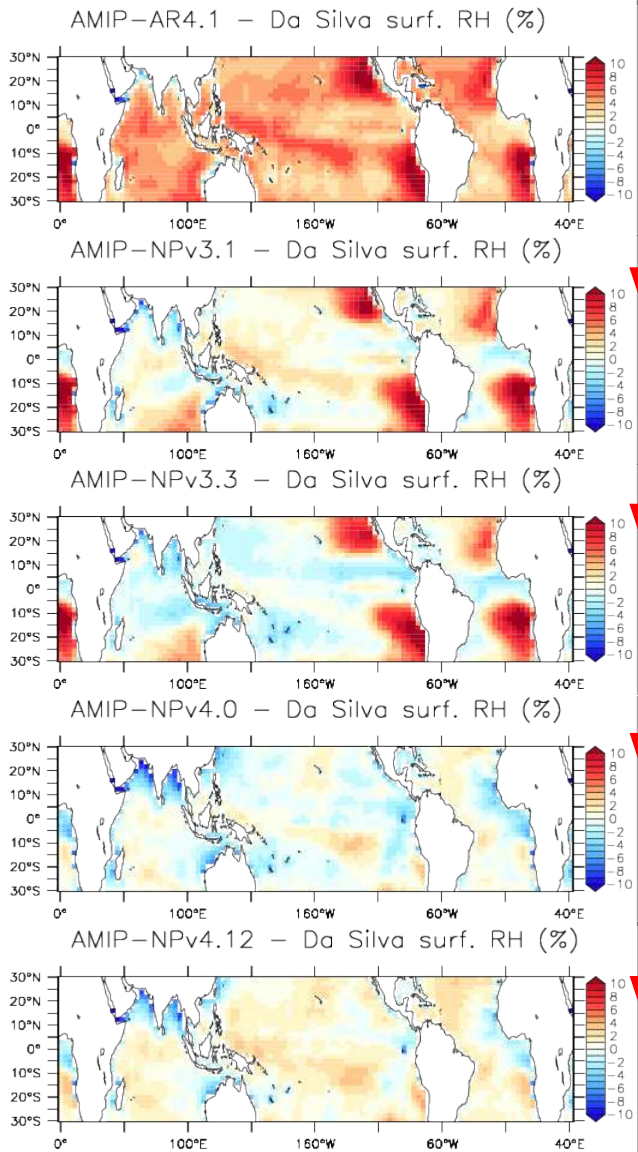
Results from a pool done in 2012

http://lmdz.lmd.jussieu.fr/actualites-container/enquete-sur-les-utilisateurs-de-lmdz



Humidité relative (%) en surface dans différentes configurations.

→ **L'activation des thermiques assèche la surface**



LMDZ5A « physique standard » L39

Activation des thermiques sauf sur les « bord Est »

LMDZ5B « nouvelle physique » L39

Changement resolution vert. 1ère couche 10m

LMDZ5B « nouvelle physique » L39

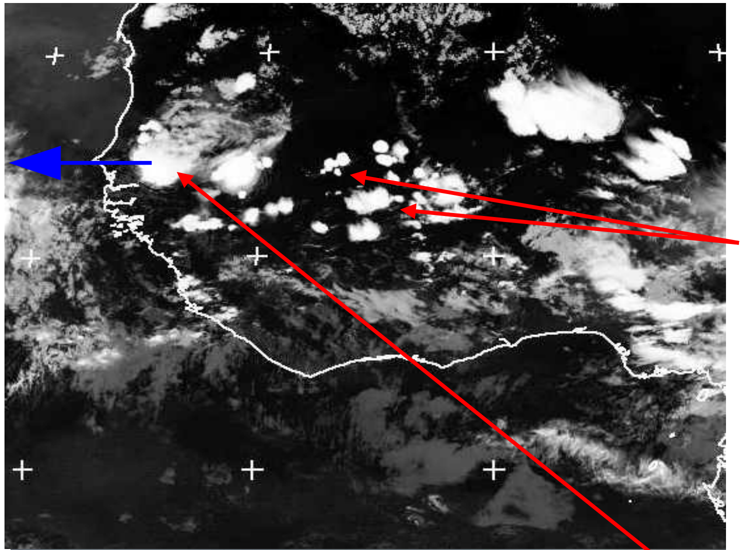
Nouvelle physique NPv4
Thermiques actifs partout

LMDZ5B « nouvelle physique » L39

Ajustement du bilan radiatif

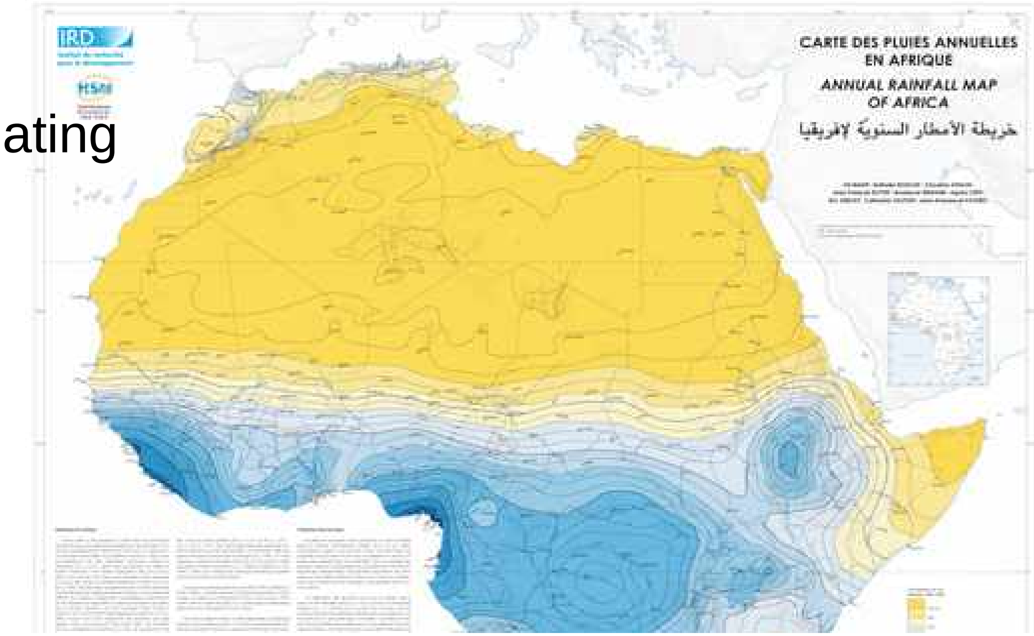
LMDZ5B « nouvelle physique » L39

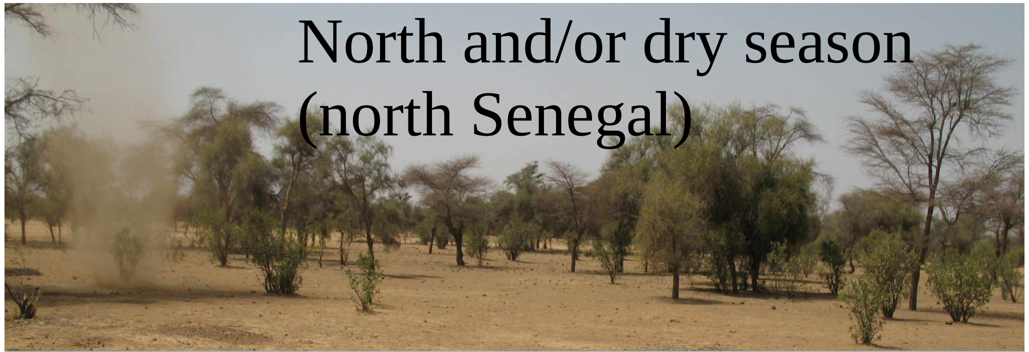
Monsoon rainfall : multi-scale
Local thunderstorms to squall lines, propagating
Locally : raining one hour each 3 day
Cumulated rainfall much more uniform

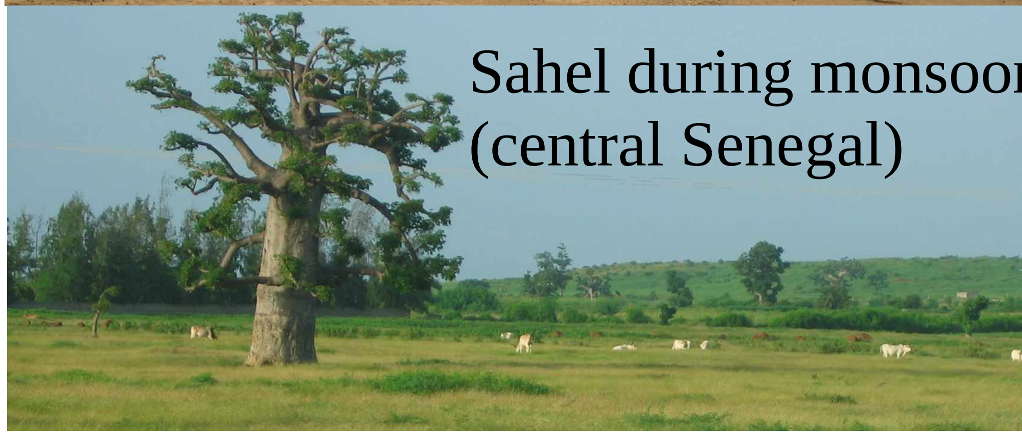


Local
•storms

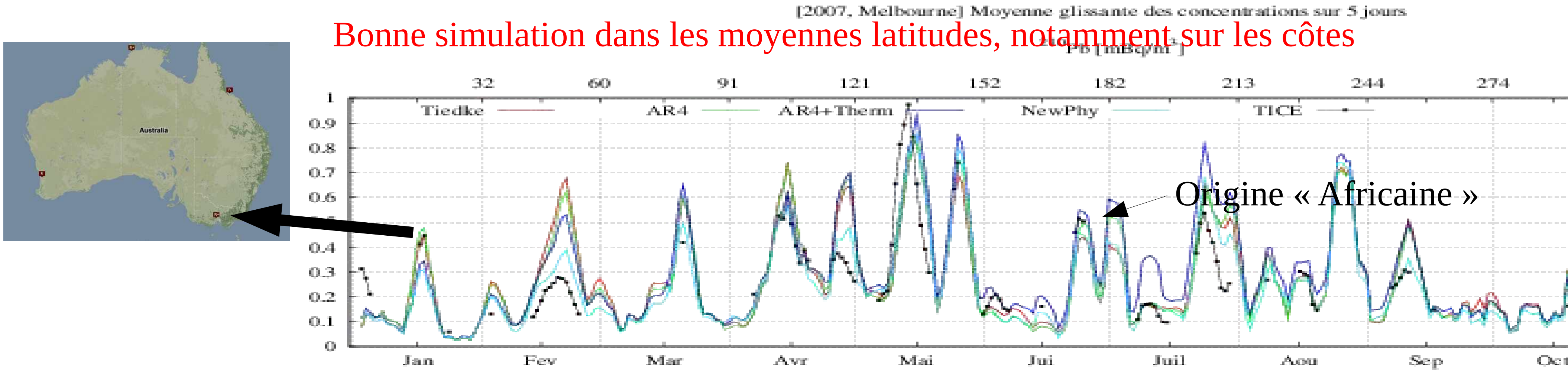
Squall
•lines

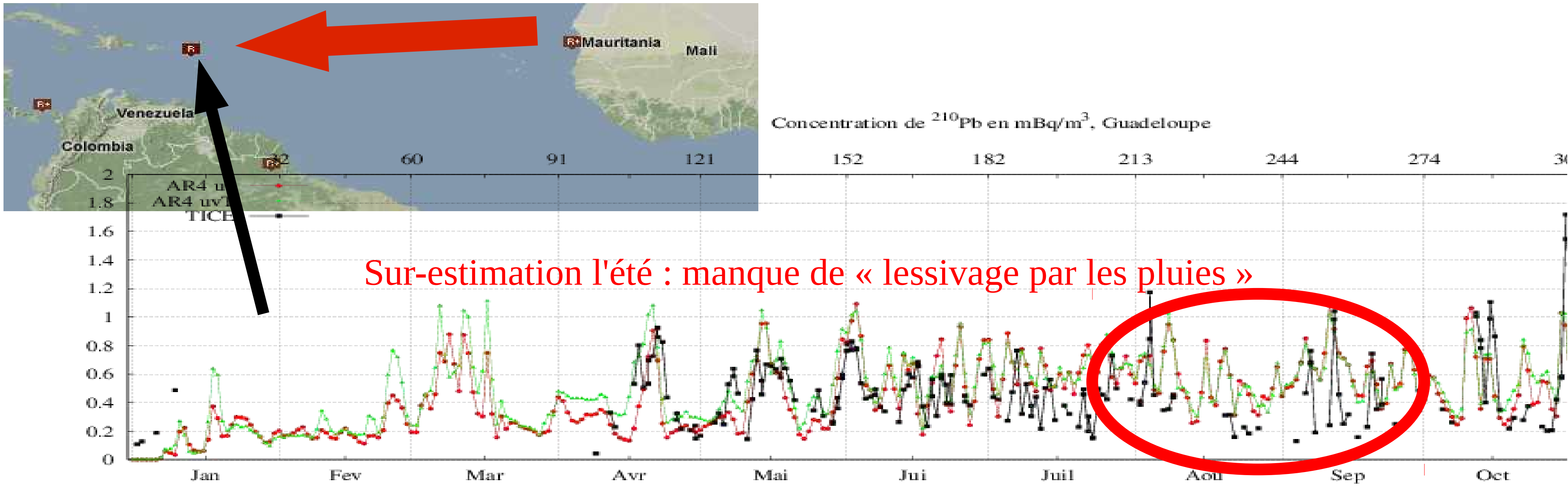






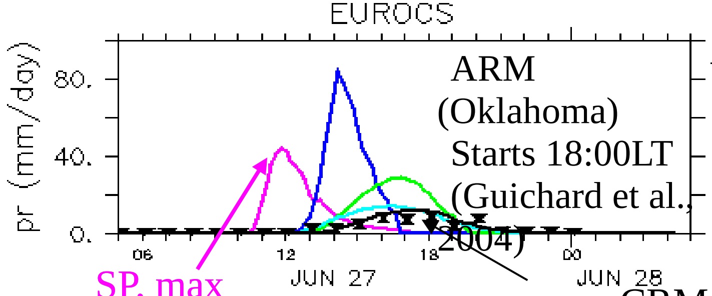
Validation des simulations de transport sur les données du TICE
Radio-éléments naturels. Ici le PB210, produit du radon émis par les continents.
Philippe Heinrich et Anthony Jamelot





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

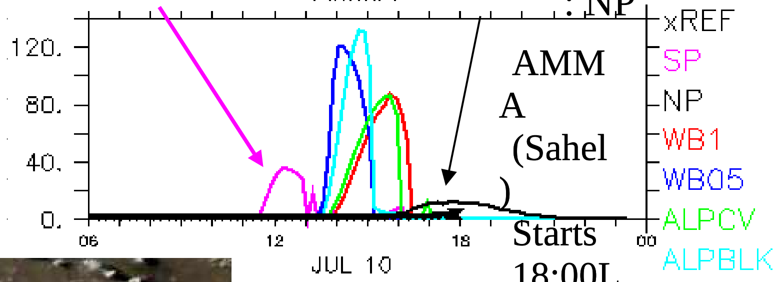
1D test cases/ comparison with explicit simulations (MesoNH)



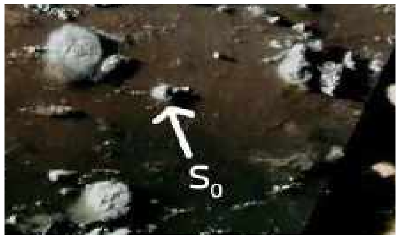
ARM (Oklahoma) Starts 18:00LT (Guichard et al., 2004)

SP, max At 12:00LT

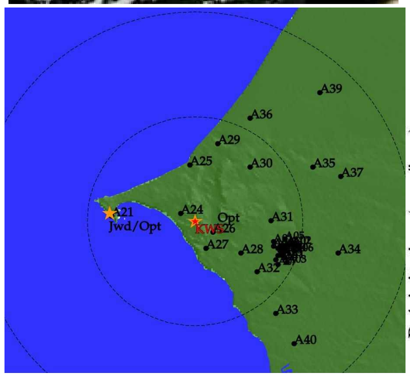
x : CRM
— : NP



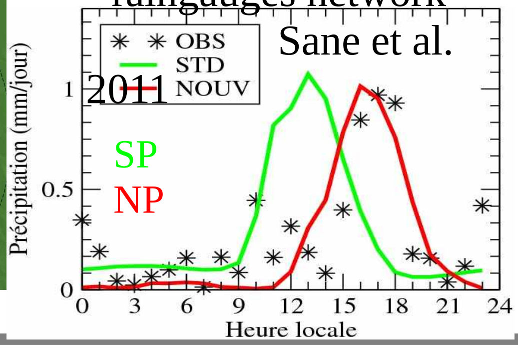
AMMA (Sahel) Starts 18:00LT



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



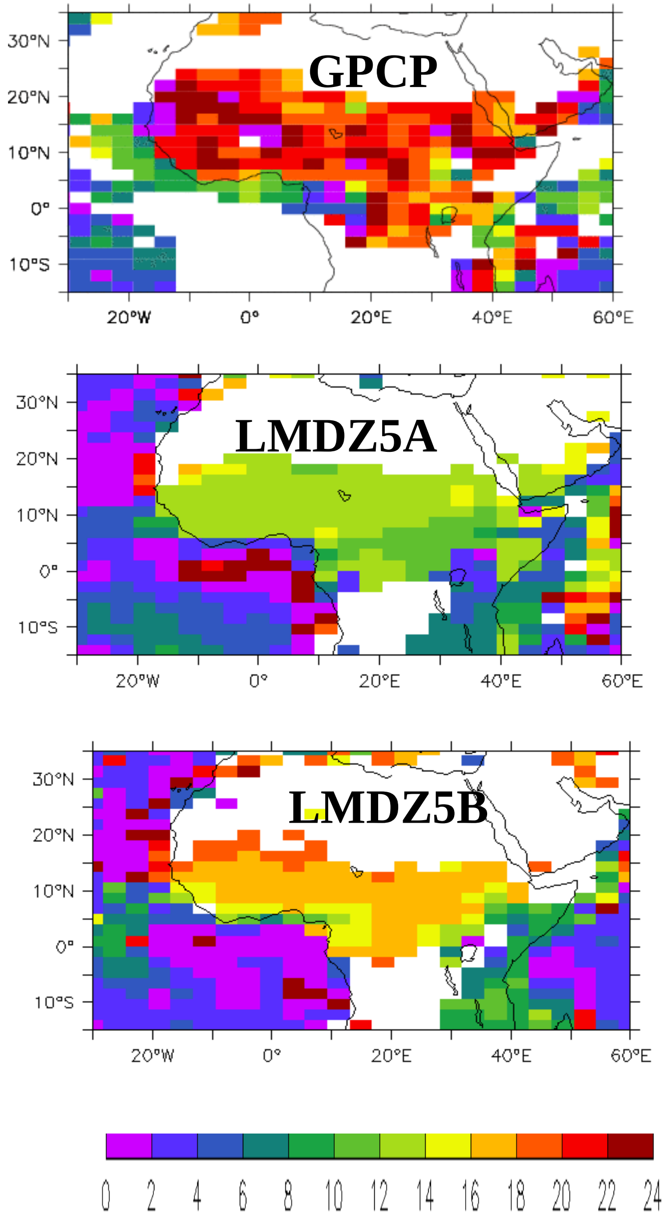
Dakar LPAOSF/NASA raingauges network



Sane et al. 2011

SP
NP

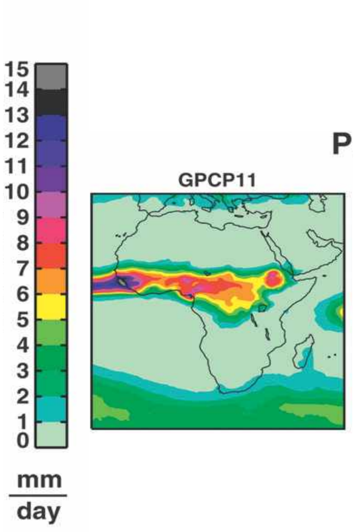
Local hour of maximum rainfall in July

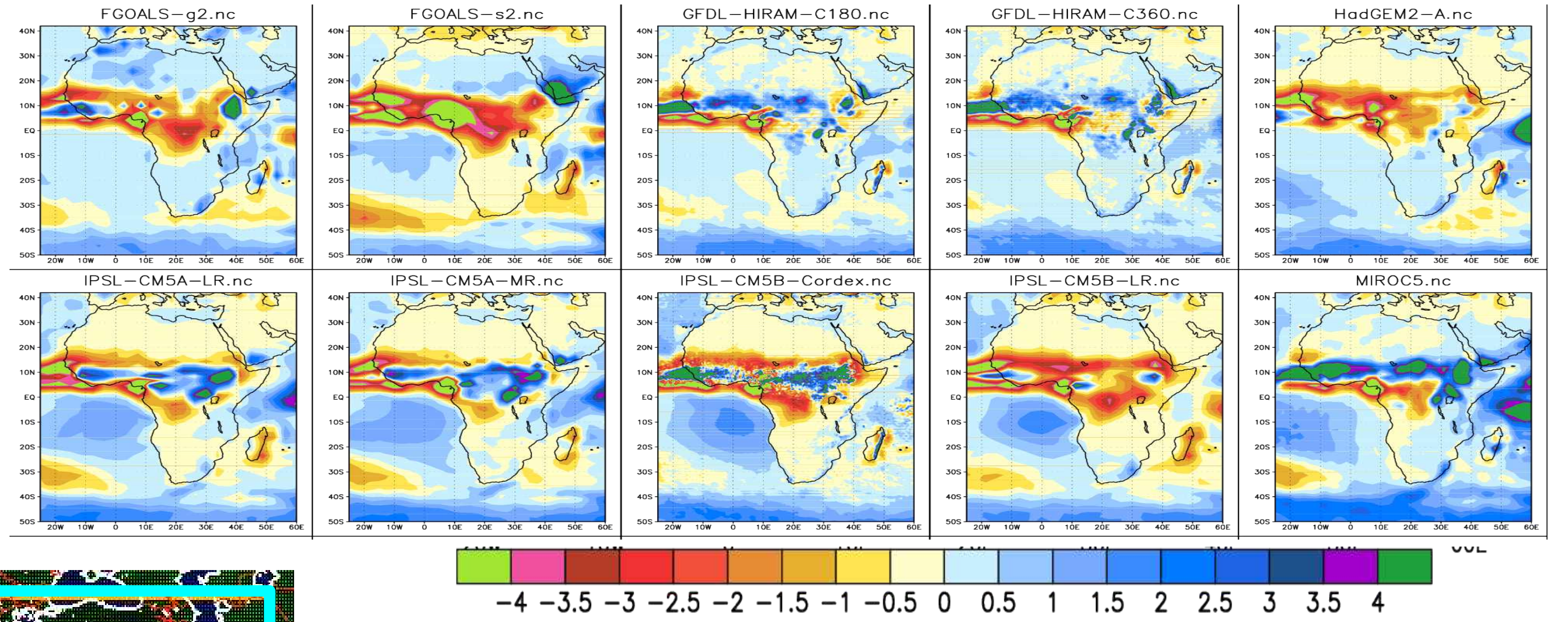


Evolution moyenne

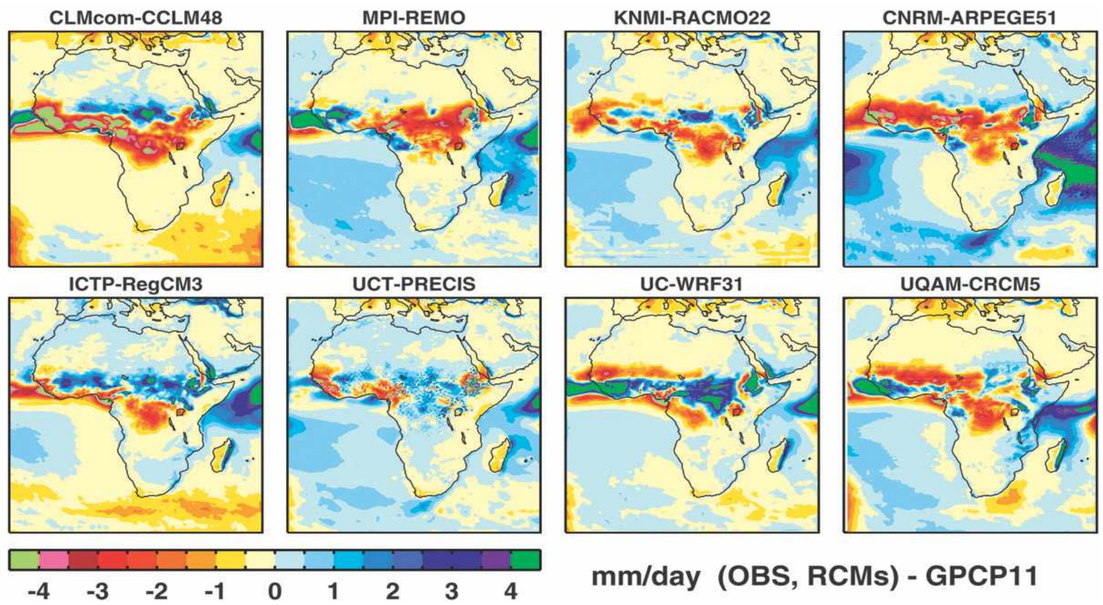
Rainfall biases, July-August-September

subset of CMIP5 model





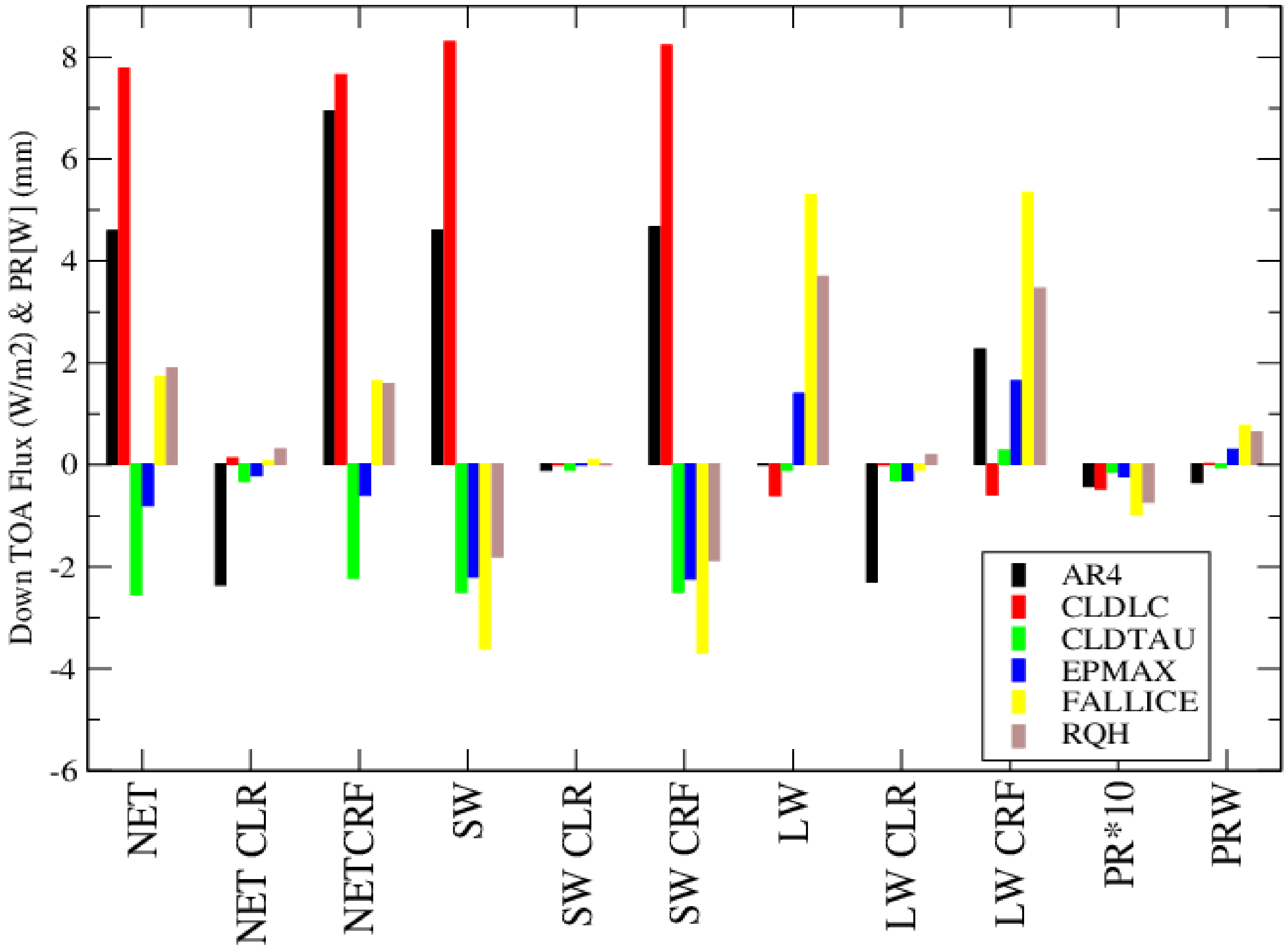
subset of Cordex models

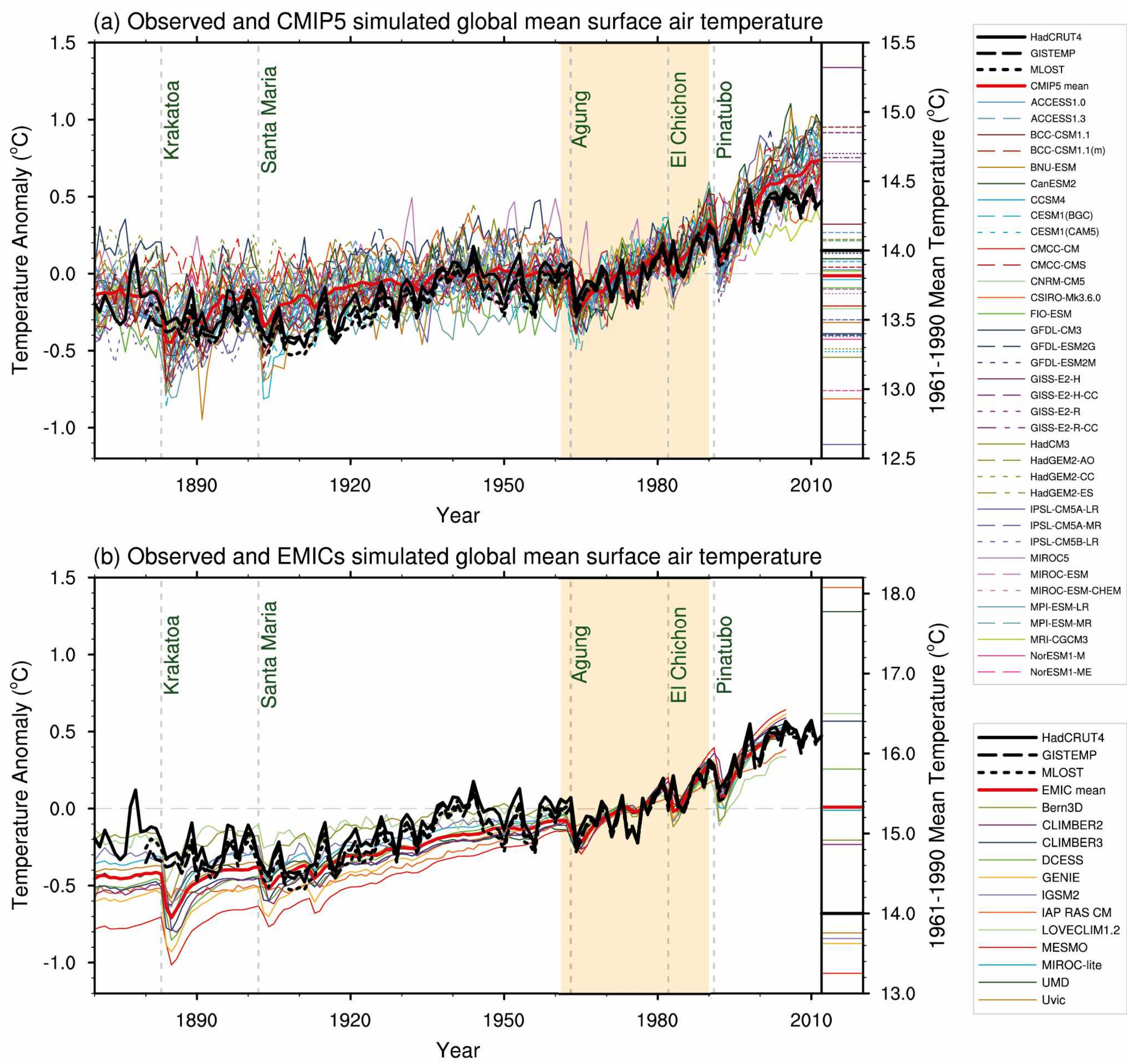


Nikulin et al., 2012, J. Clim.

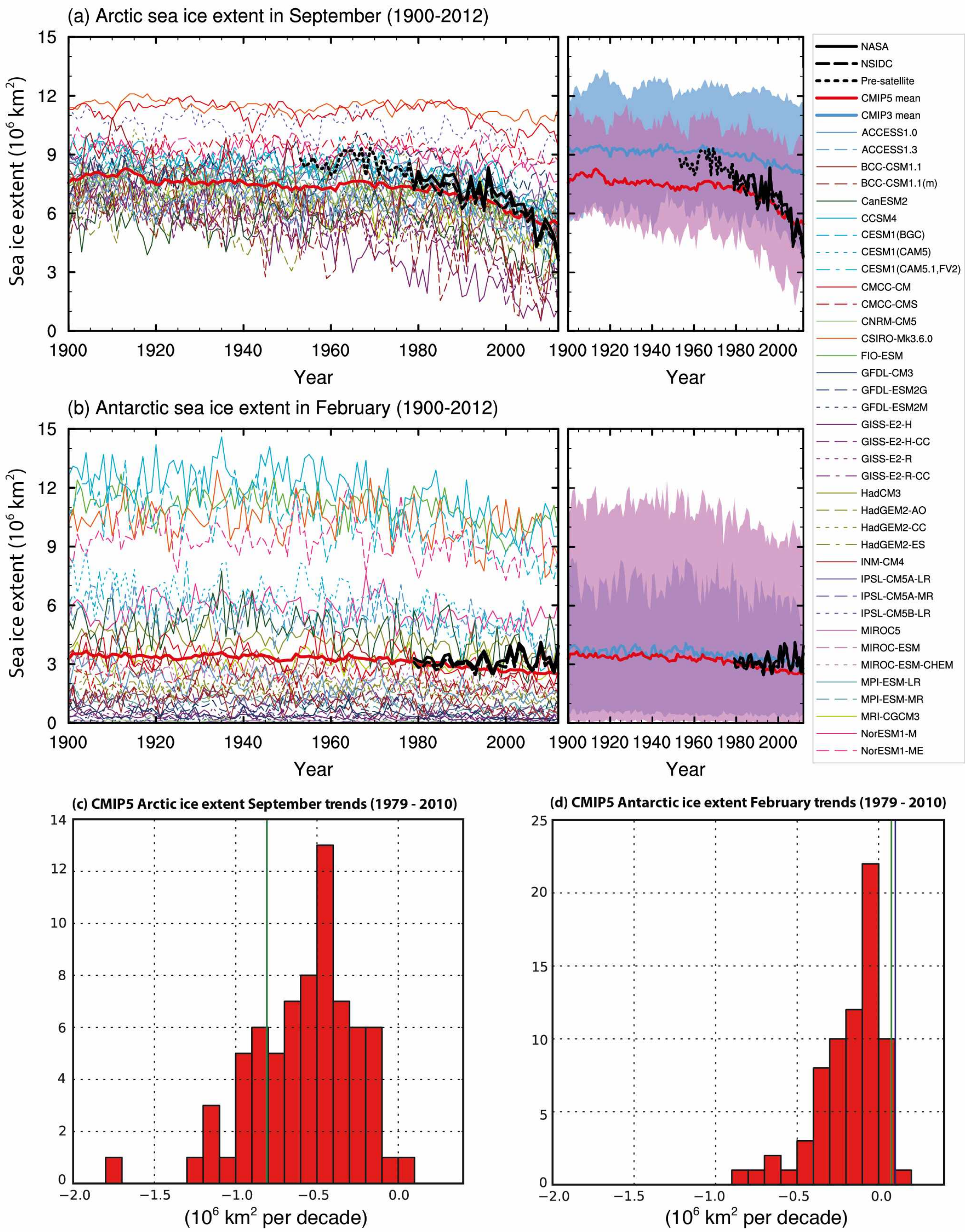
5. Intercomparison exercises and reference configurations

Simulations AMIP papier LMDZ5B
Moyennes globales sur plusieurs années
Différence par rapport au run de contrôle NP

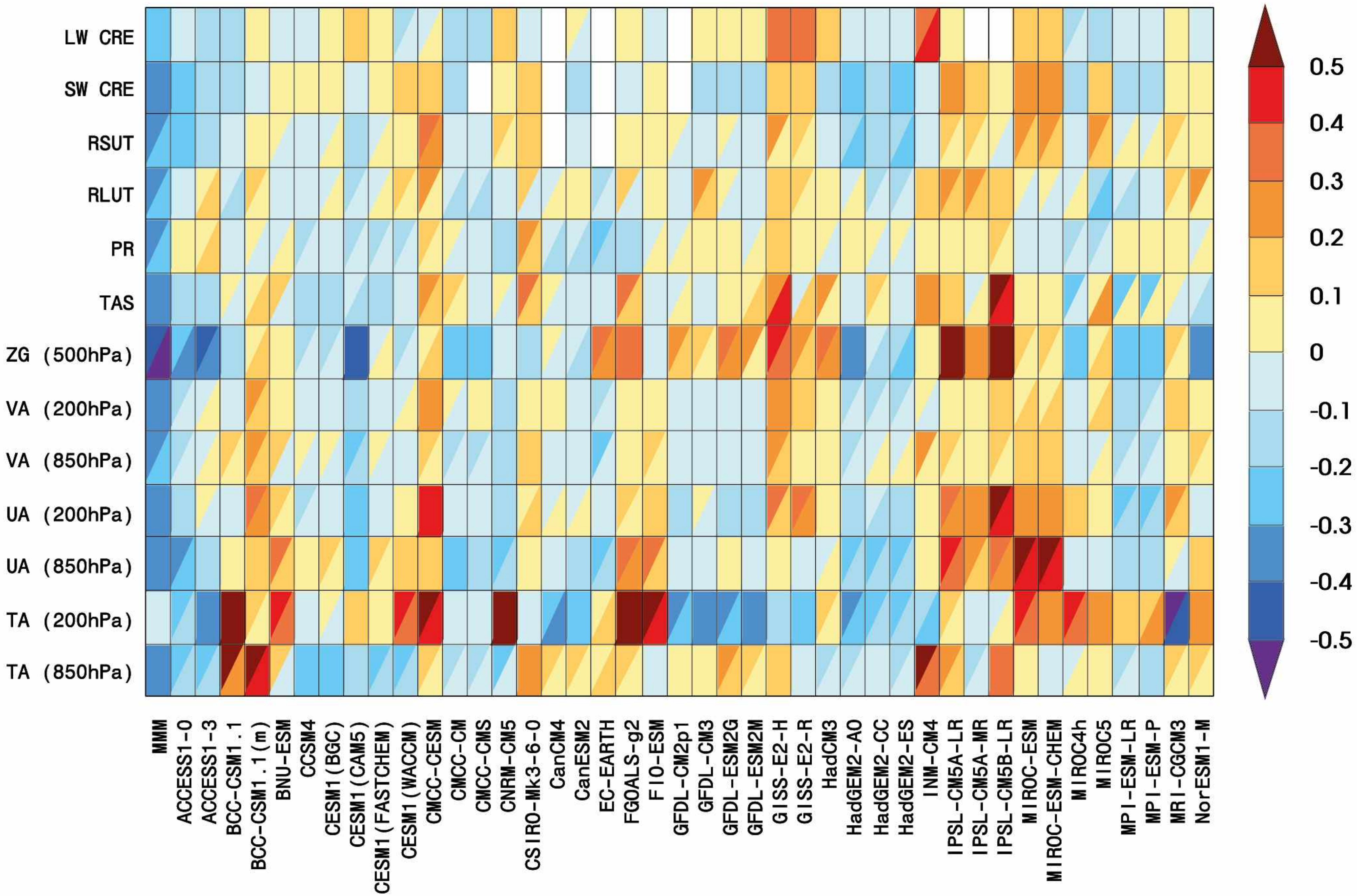




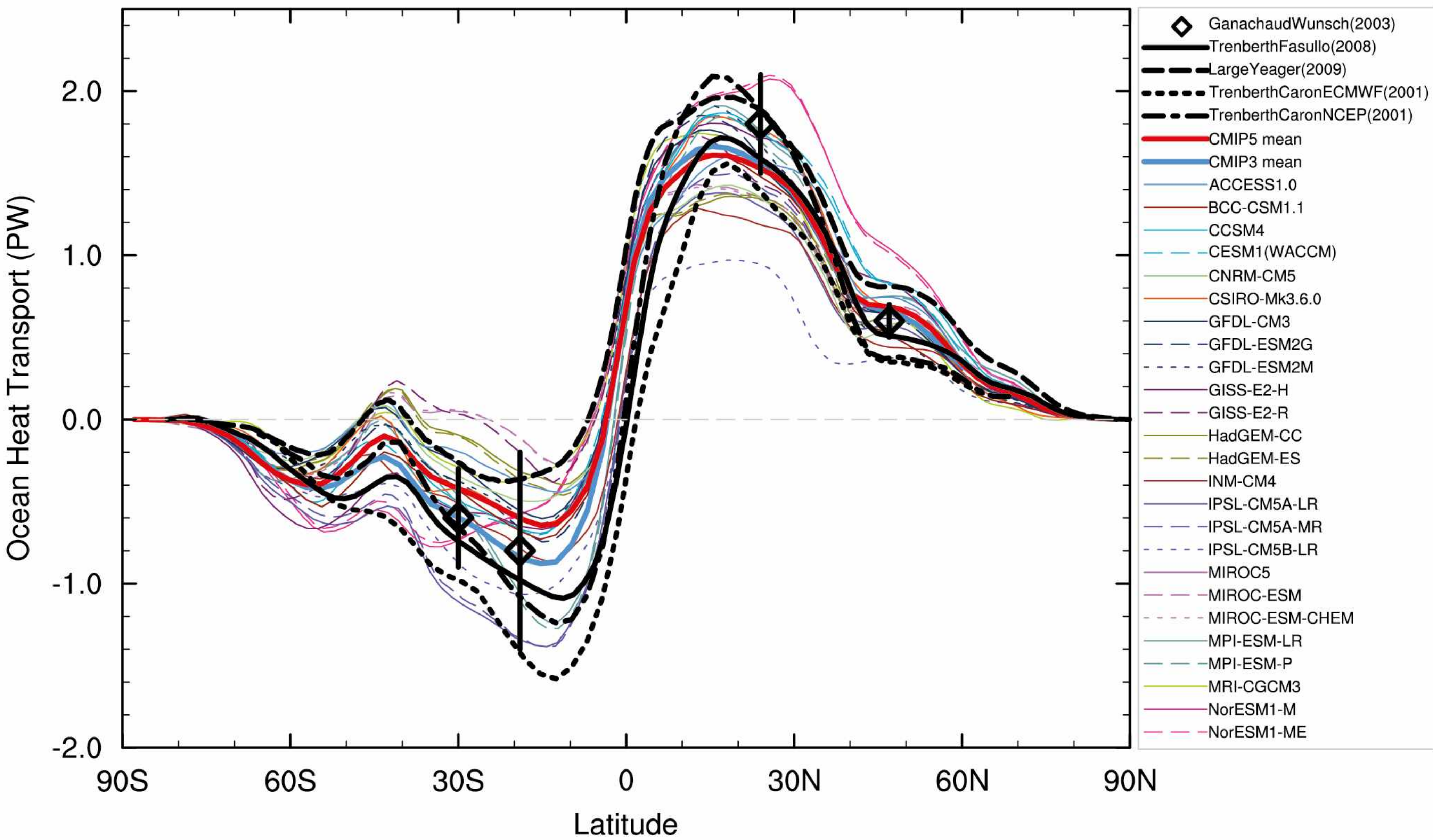
(a) Observed and CMIP5 simulated global mean surface air temperature
Temperature Anomaly (°C)
1961-1990 Mean Temperature (°C)
Year
Krakatoa
Santa Maria
Agung
El Chichon
Pinatubo
1890
1920
1950
1980
2010
HadCRUT4
GISTEMP
MLOST
CMIP5 mean
ACCESS1.0
ACCESS1.3
BCC-CSM1.1
BCC-CSM1.1(m)
BNU-ESM
CanESM2
CCSM4
CESM1(BGC)
CESM1(CAM5)
CMCC-CM
CMCC-CMS
CNRM-CM5
CSIRO-Mk3.6.0
FIO-ESM
GFDL-CM3
GFDL-ESM2G
GFDL-ESM2M
GISS-E2-H
GISS-E2-H-CC
GISS-E2-R
GISS-E2-R-CC
HadCM3
HadGEM2-AO
HadGEM2-CC
HadGEM2-ES
IPSL-CM5A-LR
IPSL-CM5A-MR
IPSL-CM5B-LR
MIROC5
MIROC-ESM
MIROC-ESM-CHEM
MPI-ESM-LR
MPI-ESM-MR
MRI-CGCM3
NorESM1-M
NorESM1-ME
(b) Observed and EMICs simulated global mean surface air temperature
Temperature Anomaly (°C)
1961-1990 Mean Temperature (°C)
Year
EMIC mean
Bern3D
CLIMBER2
CLIMBER3
DCESS
GENIE
IGSM2
IAP RAS CM
LOVECLIM1.2
MESMO
MIROC-lite
UMD
Uvic



(a) Arctic sea ice extent in September (1900-2012)
Sea ice extent (10^6 km^2)
Year
(b) Antarctic sea ice extent in February (1900-2012)
Sea ice extent (10^6 km^2)
Year
NASA
NSIDC
Pre-satellite
CMIP5 mean
CMIP3 mean
ACCESS1.0
ACCESS1.3
BCC-CSM1.1
BCC-CSM1.1(m)
CanESM2
CCSM4
CESM1(BGC)
CESM1(CAM5)
CESM1(CAM5.1,FV2)
CMCC-CM
CMCC-CMS
CNRM-CM5
CSIRO-Mk3.6.0
FIO-ESM
GFDL-CM3
GFDL-ESM2G
GFDL-ESM2M
GISS-E2-H
GISS-E2-H-CC
GISS-E2-R
GISS-E2-R-CC
HadCM3
HadGEM2-AO
HadGEM2-CC
HadGEM2-ES
INM-CM4
IPSL-CM5A-LR
IPSL-CM5A-MR
IPSL-CM5B-LR
MIROC5
MIROC-ESM
MIROC-ESM-CHEM
MPI-ESM-LR
MPI-ESM-MR
MRI-CGCM3
NorESM1-M
NorESM1-ME
(c) CMIP5 Arctic ice extent September trends (1979 - 2010)
(10^6 km^2 per decade)
(d) CMIP5 Antarctic ice extent February trends (1979 - 2010)
(10^6 km^2 per decade)

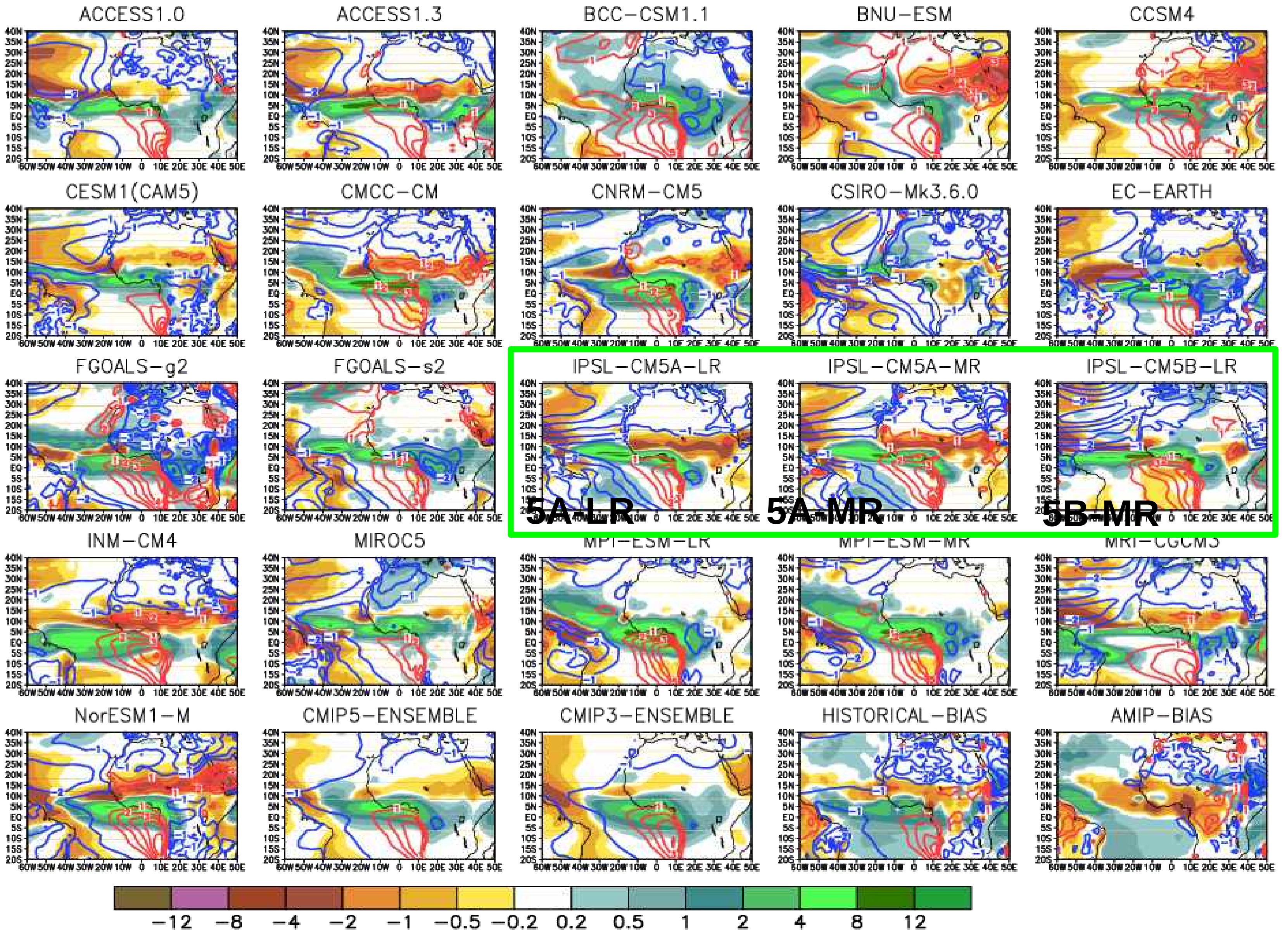


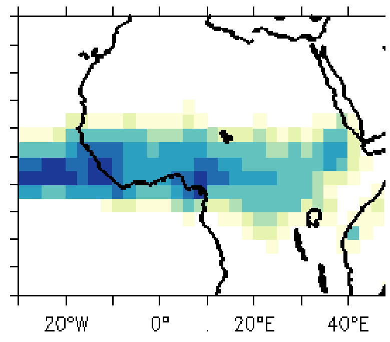
LW CRE
SW CRE
RSUT
RLUT
PR
TAS
ZG (500hPa)
VA (200hPa)
VA (850hPa)
UA (200hPa)
UA (850hPa)
TA (200hPa)
TA (850hPa)
MMM
ACCESS1-0
ACCESS1-3
BCC-CSM1.1
BCC-CSM1.1(m)
BNU-ESM
CCSM4
CESM1(BGC)
CESM1(CAM5)
CESM1(FASTCHEM)
CESM1(WACCM)
CMCC-CESM
CMCC-CM
CMCC-CMS
CNRM-CM5
CSIRO-Mk3-6-0
CanCM4
CanESM2
EC-EARTH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



Ocean Heat Transport (PW)
2.0
1.0
0.0
-1.0
-2.0
90S
60S
30S
0
30N
60N
90N
Latitude
GanachaudWunsch(2003)
TrenberthFasullo(2008)
LargeYeager(2009)
TrenberthCaronECMWF(2001)
TrenberthCaronNCEP(2001)
CMIP5 mean
CMIP3 mean
ACCESS1.0
BCC-CSM1.1
CCSM4
CESM1(WACCM)
CNRM-CM5
CSIRO-Mk3.6.0
GFDL-CM3
GFDL-ESM2G
GFDL-ESM2M
GISS-E2-H
GISS-E2-R
HadGEM-CC
HadGEM-ES
INM-CM4
IPSL-CM5A-LR
IPSL-CM5A-MR
IPSL-CM5B-LR
MIROC5
MIROC-ESM
MIROC-ESM-CHEM
MPI-ESM-LR
MPI-ESM-P
MRI-CGCM3
NorESM1-M
NorESM1-ME

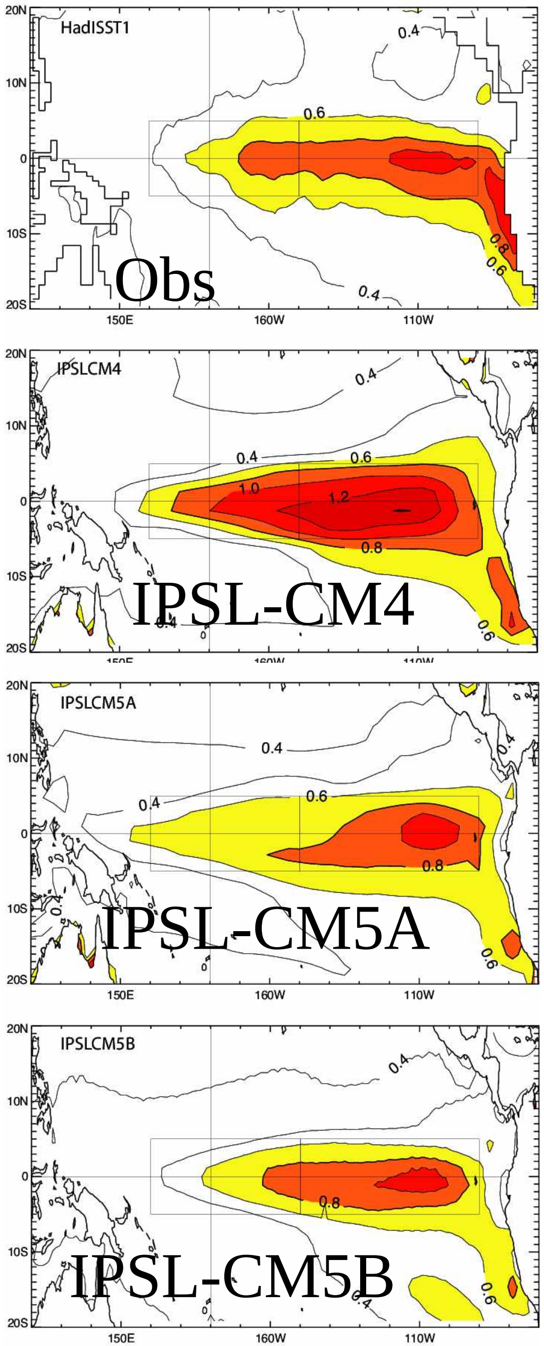
Biais de température (quasi systématique) et leur effet sur la précipitation
Différence historical-Amip : T2m (contours, K) et Précip (à plat de couleur, mm/j)



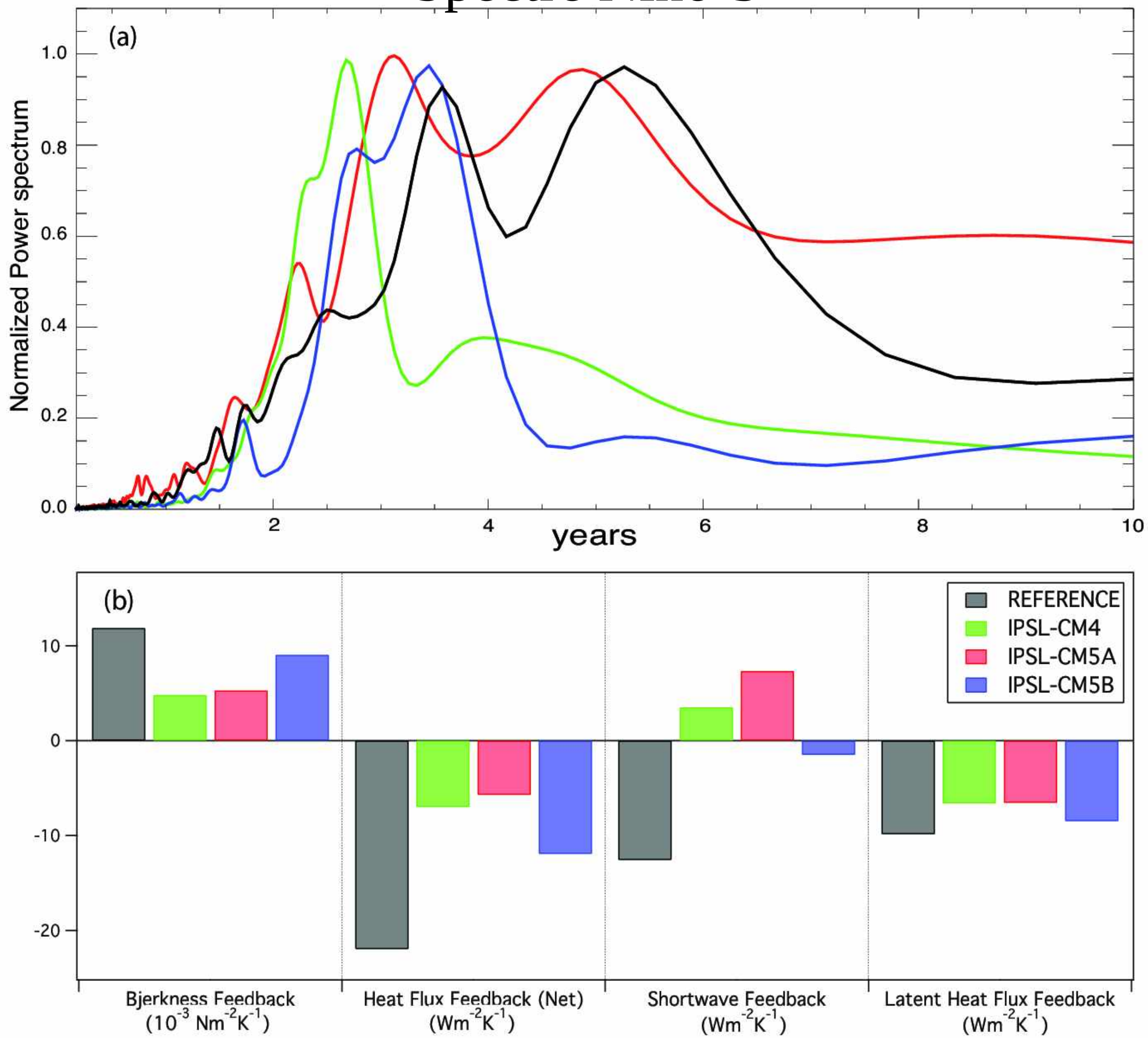


Pluie moy climato

El Nino dans les versions successives de IPSL-CM

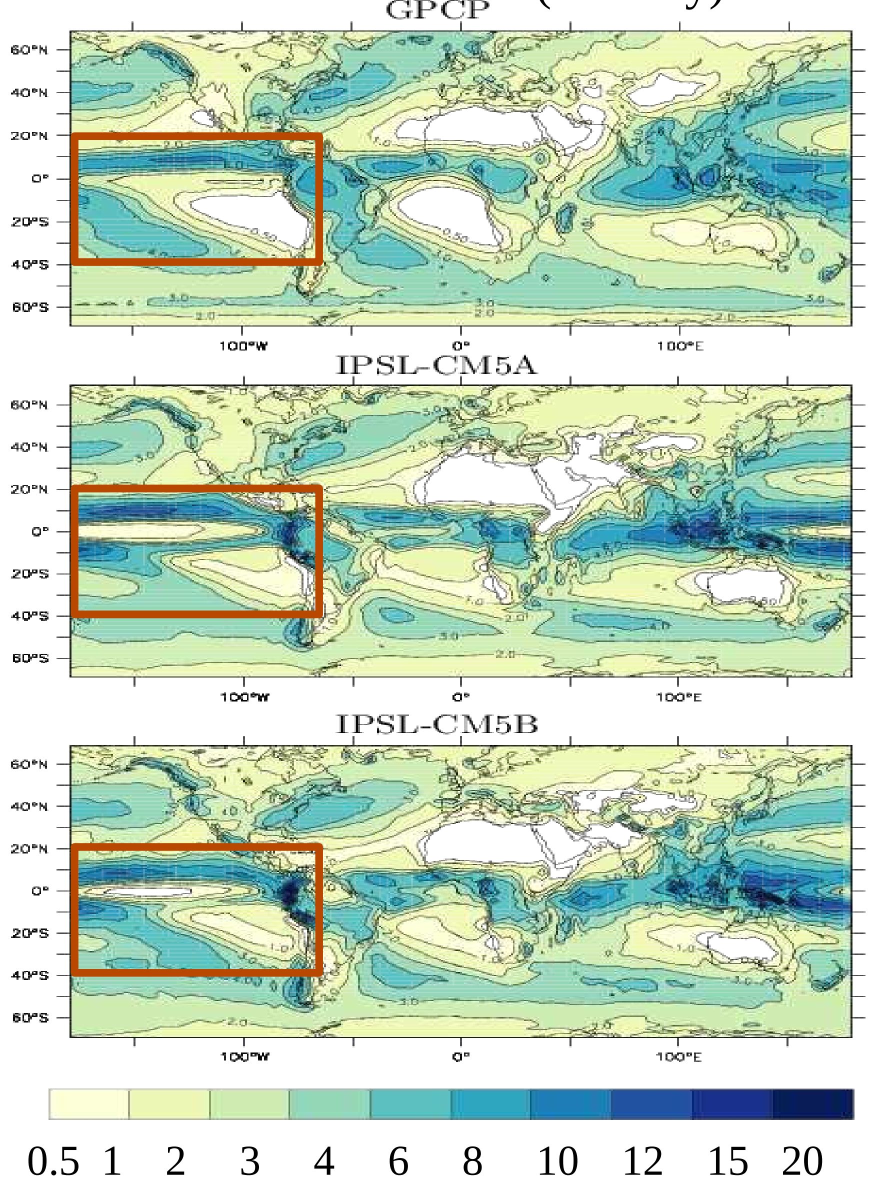


Spectre Nino-3

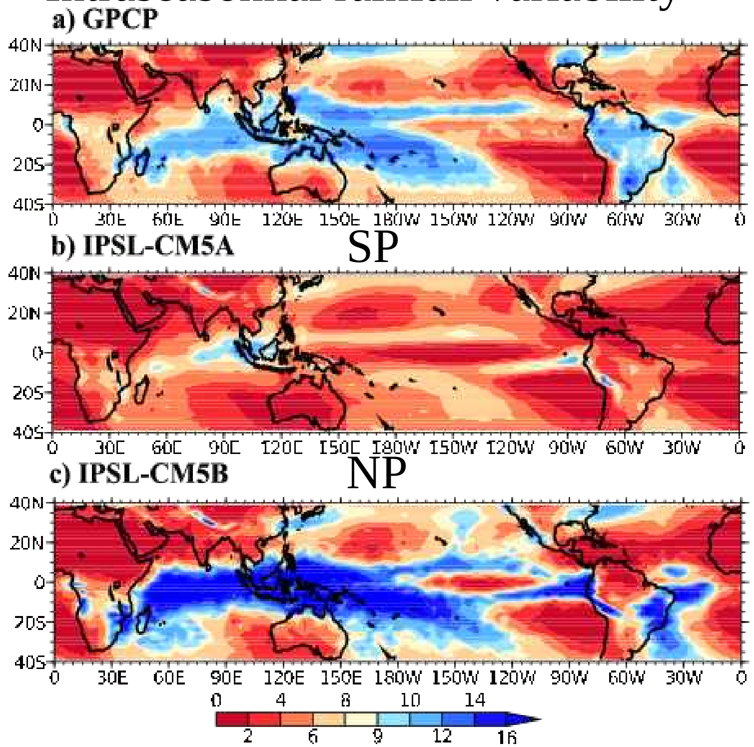


3. La convection profonde

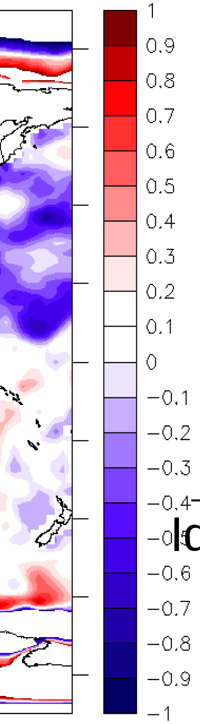
Slight bias reduction for
Annual mean rainfall (mm/day)

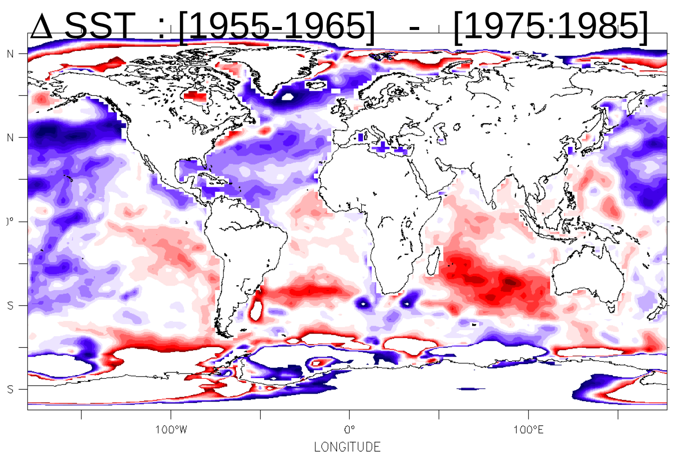


Large positive impact on the
Intraseasonnal rainfall variability

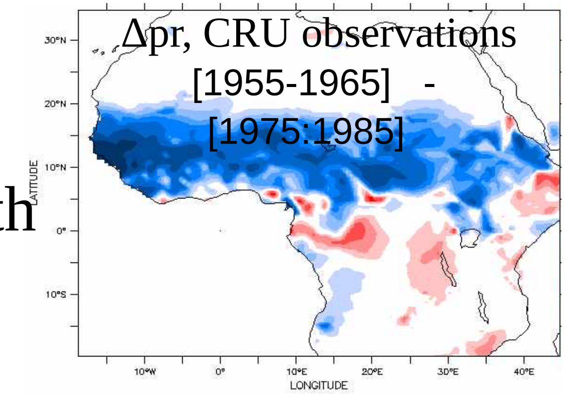


Standard deviation of daily rainfall anomalies (mm/day) of the a) GPCP dataset (1996-2009), b) IPSL-CM5A and c) IPSL-CM5B preindustrial simulations, for the winter season (November to April - NDJFMA)





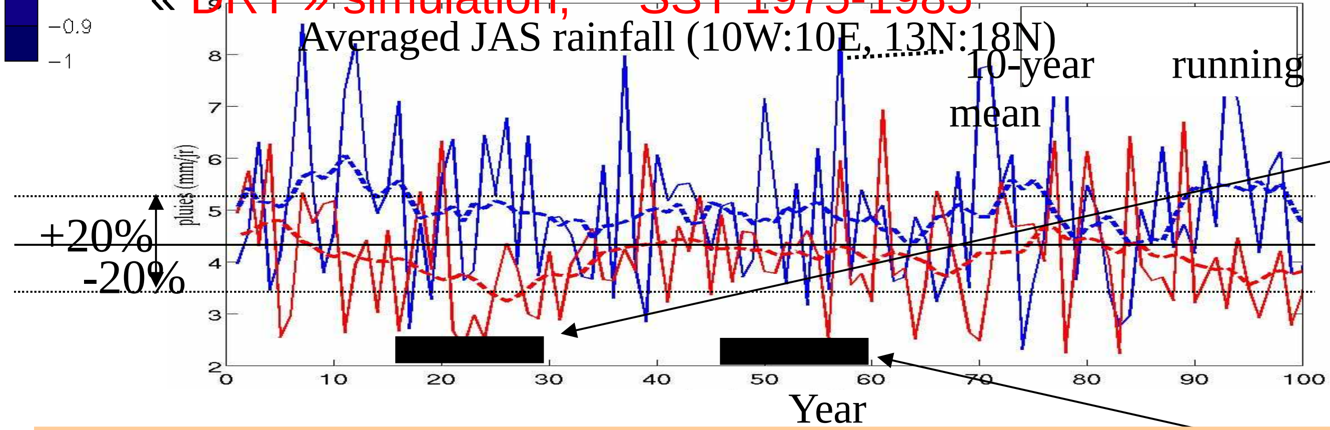
1975-1985 :
Warm SSTs in the south
Drought over Sahel

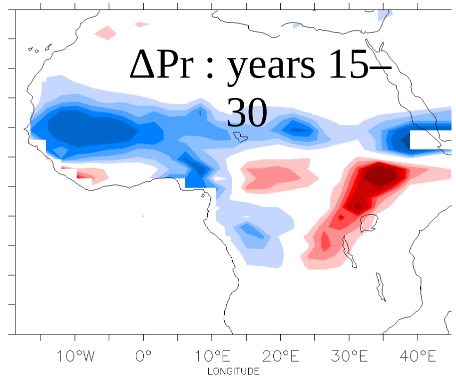


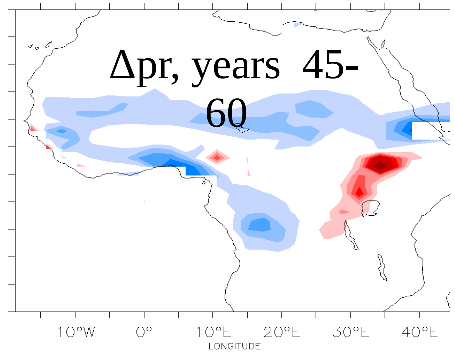
Idealized experiments with IPSL-CM5A-MR, Imposed SSTs, mean seasonal cycle

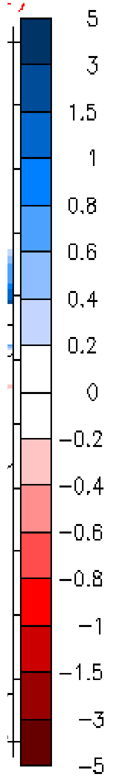
« MOIST » simulation, SST 1955-1965

« DRY » simulation, SST 1975-1985









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

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

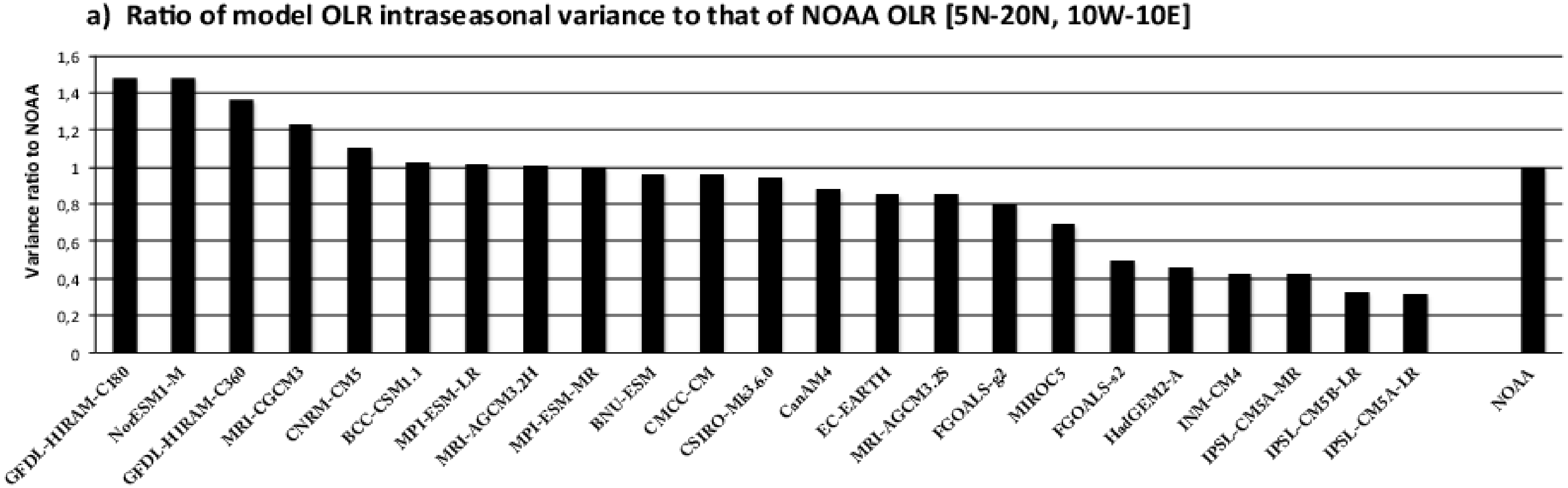


Fig : précipitation journalière en mm/j sur 3 été (JAS) successif. Point 0W-13N