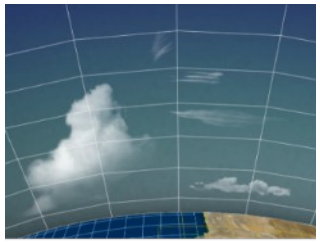
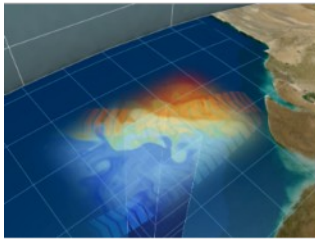
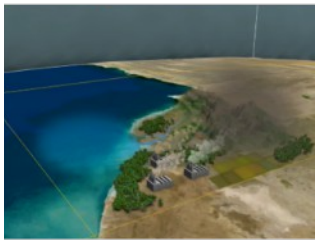
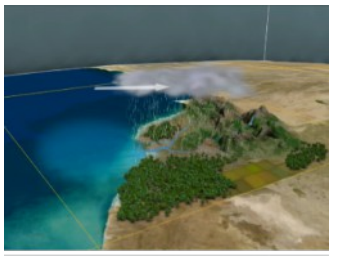
A preliminary analysis of atmosphere-only high-resolution climate simulations with IPSL-CM

T. Dubos[1], Y. Meurdesoif[3], A. Traoré[2], J. Ghattas[4], L. Fairheas[2], E. Millour[2], F. Hourdin[2], F. Lott[2], D. Cugnet[2], J. Polcher[2], A. Caubel[3], S. Fromang[5], S. Bourdin[3], M. Sicard[3], M. Kageyama[3], P. Braconnot[3], O. Marti[3], and M.-A. Foujols[4]

(1) IPSL/LMD, Ecole Polytechnique, Palaiseau, France,
(2) IPSL/LMD, CNRS, Paris, France,
(3) IPSL/LSCE, CEA,Gif-sur-Yvette, France,
(4) IPSL, CNRS, Paris, France, (5) IRFU, CEA, Gif-sur-Yvette, France

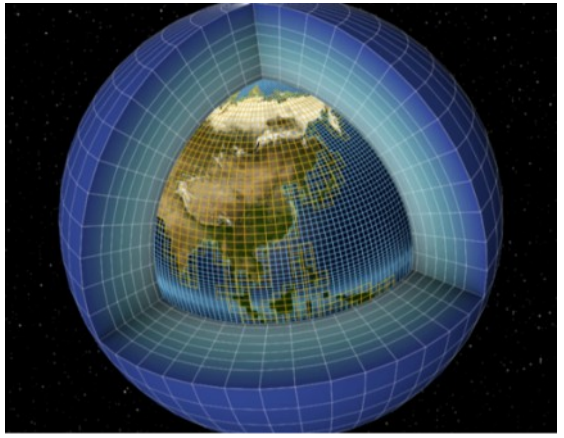
Earth System Modelling at IPSL

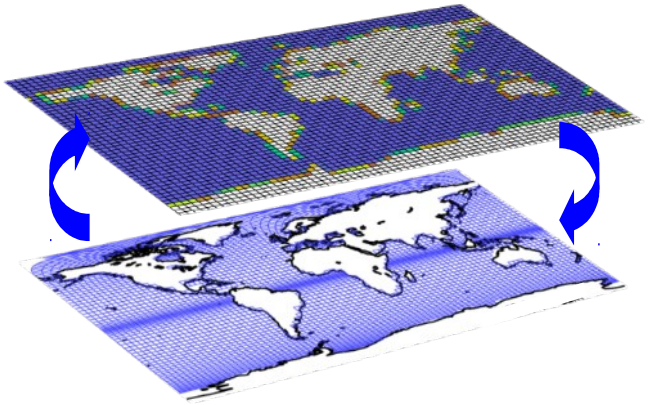
INCA/REPROBUS
Atmospheric chemistry
Aerosols

LMDZ
Atmosphere

ORCHIDEE
Surface
Vegetation



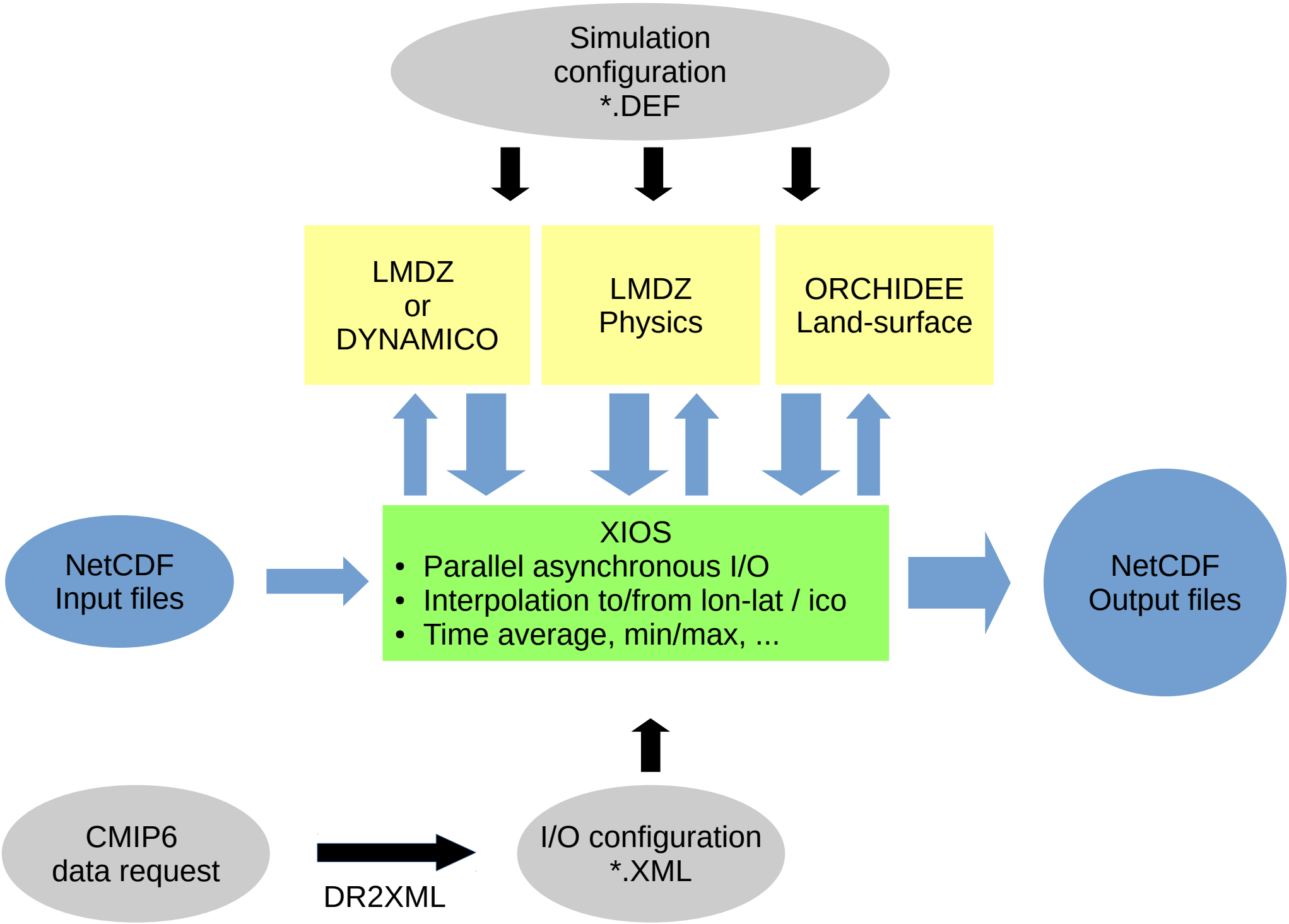
OASIS
Coupler



NEMO-PISCES
Biogeochemistry

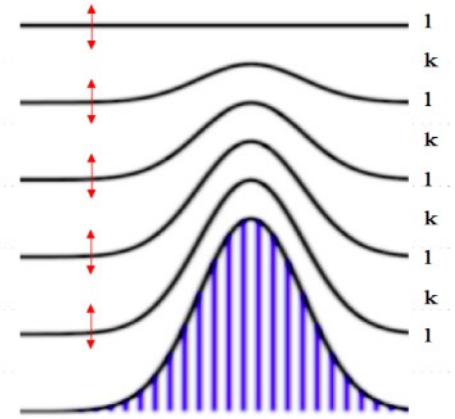
NEMO-OPA
Ocean

NEMO-LIM
Sea ice


Simulation
configuration
*.DEF
LMDZ
or
DYNAMICO
LMDZ
Physics
ORCHIDEE
Land-surface
NetCDF
Input files
XIOS
• Parallel asynchronous I/O
• Interpolation to/from lon-lat / ico
• Time average, min/max, ...
NetCDF
Output files
CMIP6
data request
DR2XML
I/O configuration
*.XML

	Vertical grid	Horizontal grid	Physical parameterizations	Name
CMIP3	19 levels	96x71	Emanuel convection scheme Subgrid scale orography	IPSL-CM3 LMDZ4
CMIP5	39 levels stratosphere	LR = 96x95 MR = 144x143	2 versions **Standard Physics (SP)** same as CMIP3	IPSL-CMX LMDZX 5A-LR/MR
			New physics (NPv3) with thermal plumes and cold pools	**5B-LR**
CMIP6	79 levels **dZ/Z < 0.1** **up to 3 km** **(PBL clouds)** **For QBO** **dZ=1km** **up to 50km**	LR = 144x143 (200km at mid-lat) HR=512x360 (50km at mid-lat)	**NPv3 +** **- New radiation (RRTM)** **- Stochastic closure** **- stratocumulus from thermals** **- Ice thermodynamics[3]** **- Surface couplings (continents&ocean)[2,4]** **- gravity waves** (including non orogr., QBO)[1]	**6A-LR**

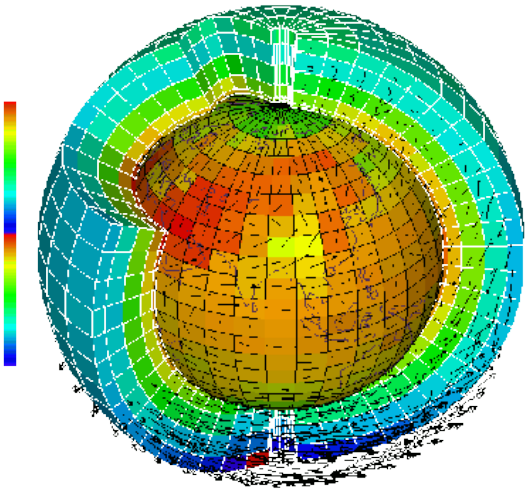
[1]François Lott, [2]Frédérique Cheruy, [3]Jean-Baptiste Madeleine, [4]Jean-Louis Dufresne



79 vertical levels

$4 - 12$ OpenMP threads

LMDZ

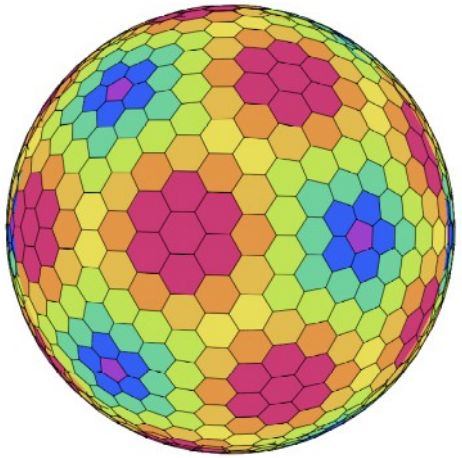


$N_{lon} \times N_{lat}$ points

$\leq N_{lat}/2$ MPI processes

$\geq 2N_{lon}$ atmospheric columns / MPI pro.

DYNAMICO

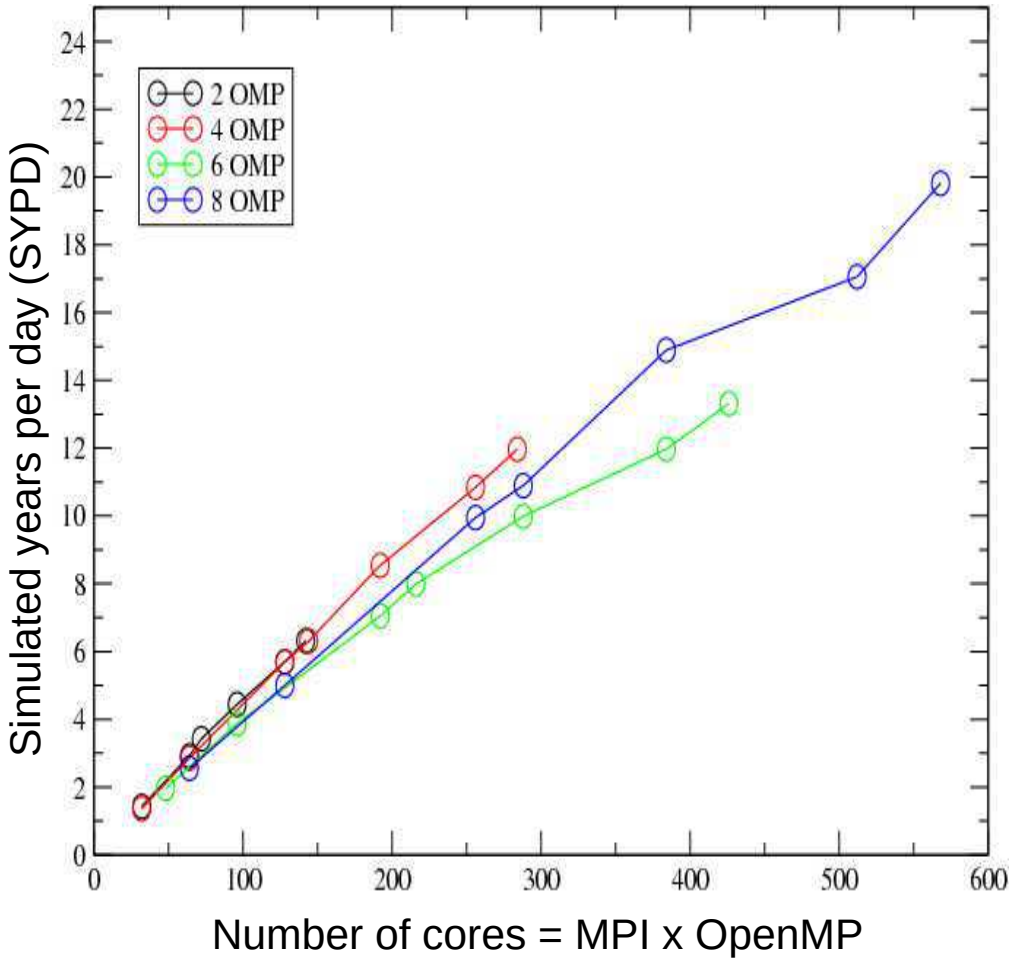


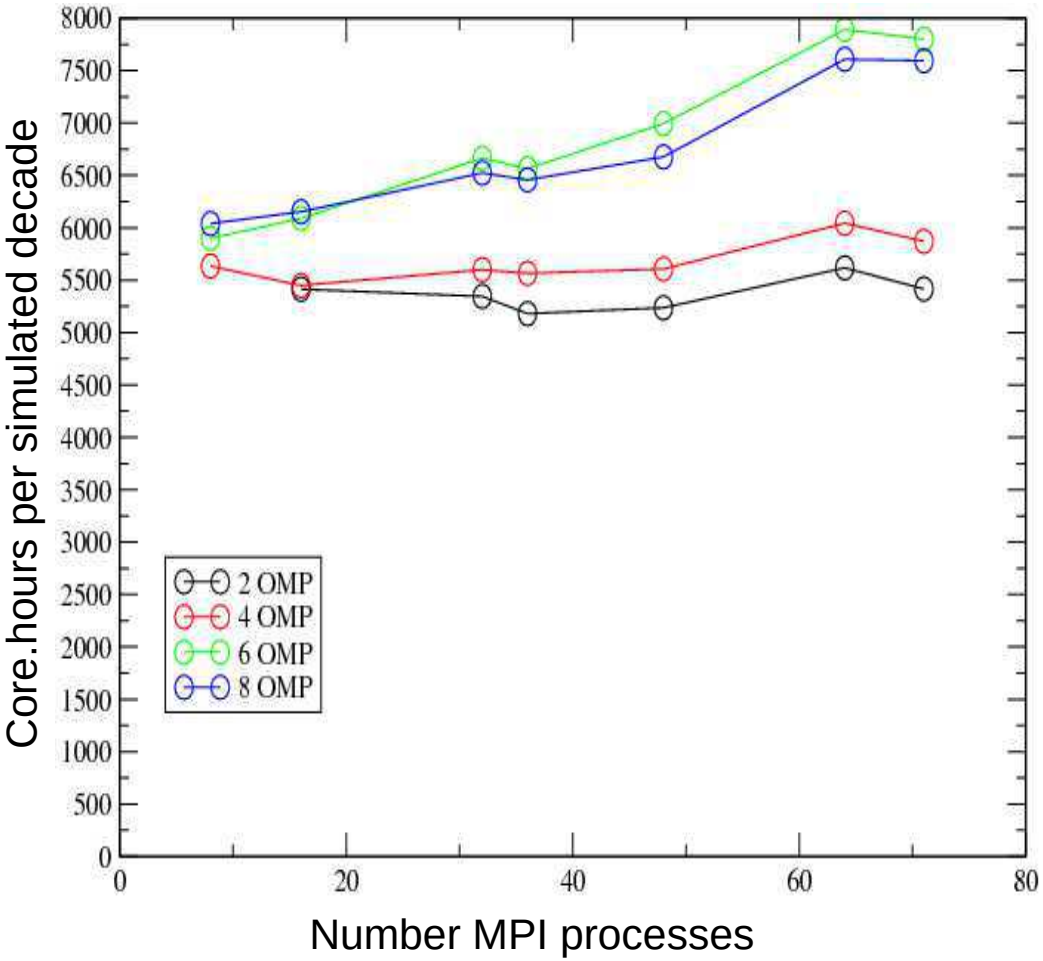
$10 \times N^2$ points

$\sim N^2/10$ MPI processes

~ 100 atmospheric columns / MPI pro.

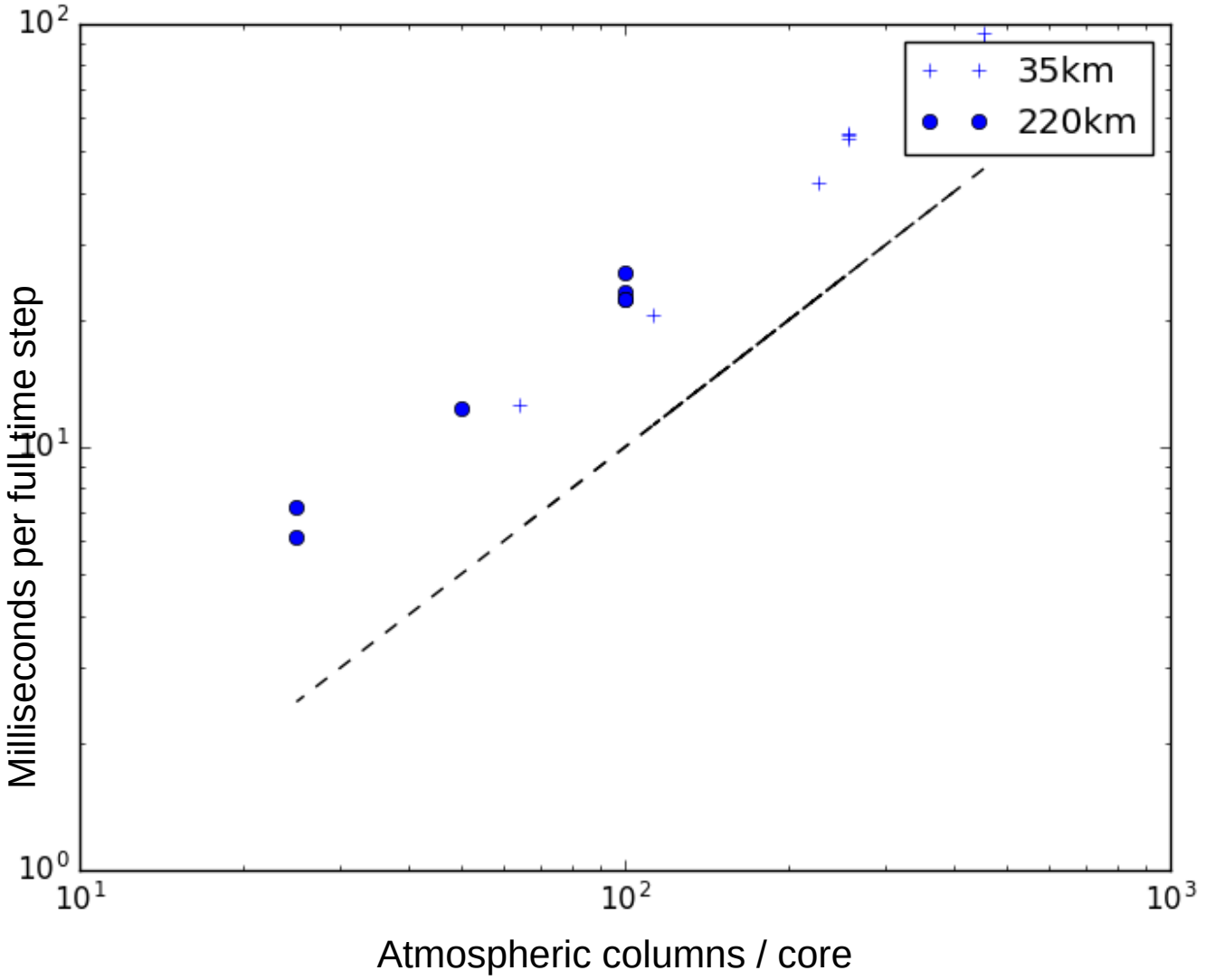
Scaling of LMDZ (dynamics + physics + CMIP6 I/O)
at resolution 144x143 (LR) on ADA (Intel Sandy Bridge ES4650)





- 4 threads fast and efficient
- 8 threads faster at higher total cost

Scaling of DYNAMICO (dynamics + 4 tracers only)
on Curie (Intel Sandy Bridge EX X7560)



- Weak and strong scaling, down to ~10ms/step for 50 columns/core

HighResMIP Protocol

Haarsma et al., (2016) Geosci. Model Dev.

Table 1. Forcings and initialization for the Historic simulations (pre-2015).

Input	CMIP6 AMIPII	HighResMIP Tier 1 highresSST-present
Period	1979–2014	1950–2014
SST, sea-ice forcing	Monthly 1° PCMDI dataset (merge of HadISST2 and NOAA OI-v2)	Daily $\frac{1}{4}$° HadISST2-based dataset (Rayner et al., 2016)
Anthropogenic aerosol forcing	Concentrations or emissions, as used in Historic CMIP6 simulations (Eyring et al., 2016)	Recommended: specified aerosol optical depth and effective radius deltas from the MACv2.0-SP model (Stevens et al., 2016)
Imposed boundary conditions – land sea mask, orography, land surface types, soil properties, leaf area index/canopy height, river paths	Based on observations, documented. LAI to evolve consistently with land use change.	Land use fixed in time, LAI repeat (monthly or otherwise) cycle representative of the present-day period around 2000

HighResMIP Protocol

Tier 1 : Atmosphere-only historical 1950-2016

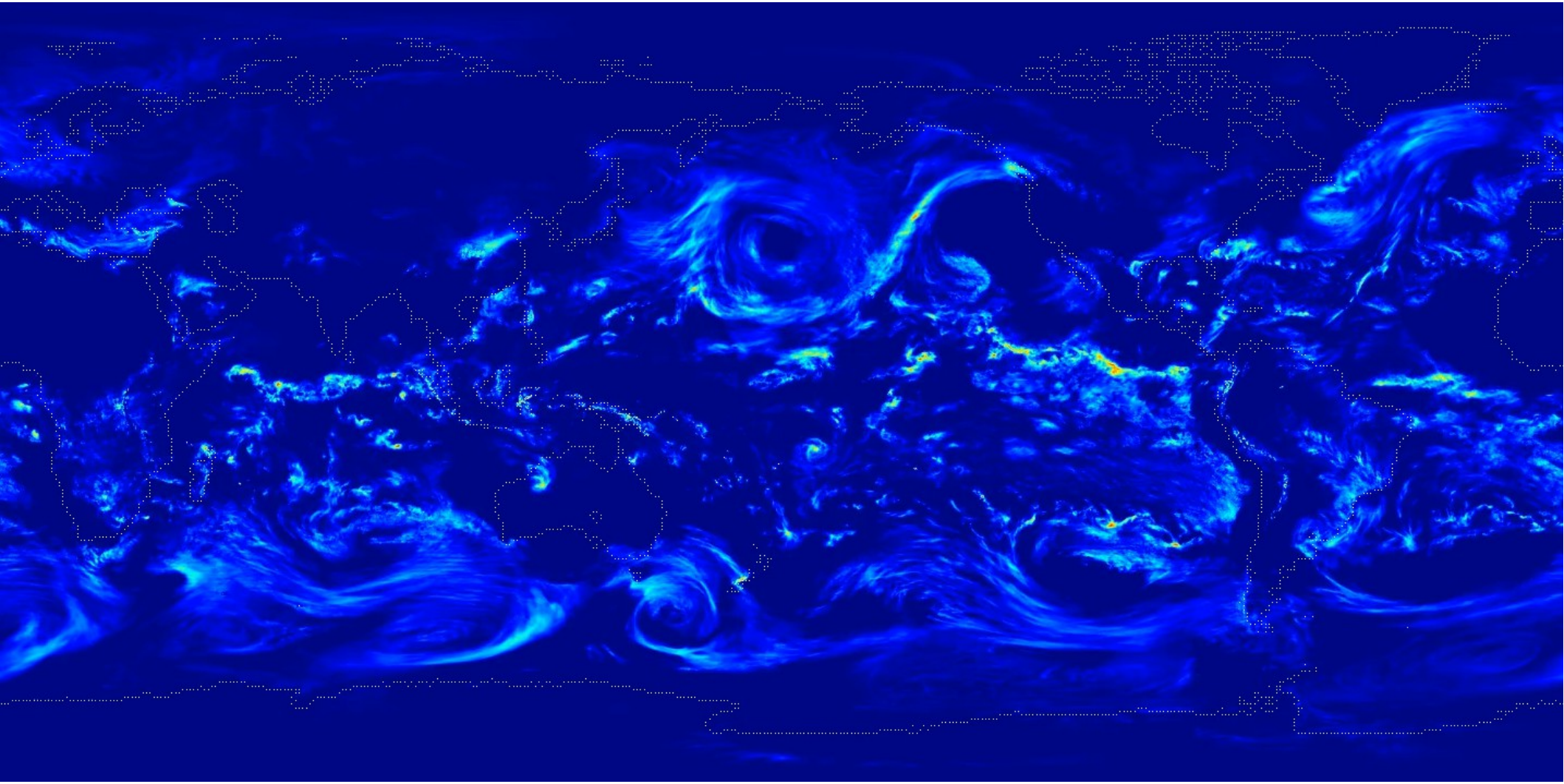
- IPSL-CM6-LR 144x142 (~200 km at mid-lat)
- IPSL-CM7A-LR $10x40^2$ (~200 km)
- IPSL-CM6-HR 512x360 (~50 km at mid-lat)
- IPSL-CM7A-HR $10x160^2$ (~50 km)
- IPSL-CM7A-VHR $10x320^2$ (~25 km)

Tier 2 : Ocean-Atmosphere historical 1950-2016 + future 2015-2050

Tier 3 : Atmosphere-only future 2015-2050-2100

IPSL-CM7A-HR :

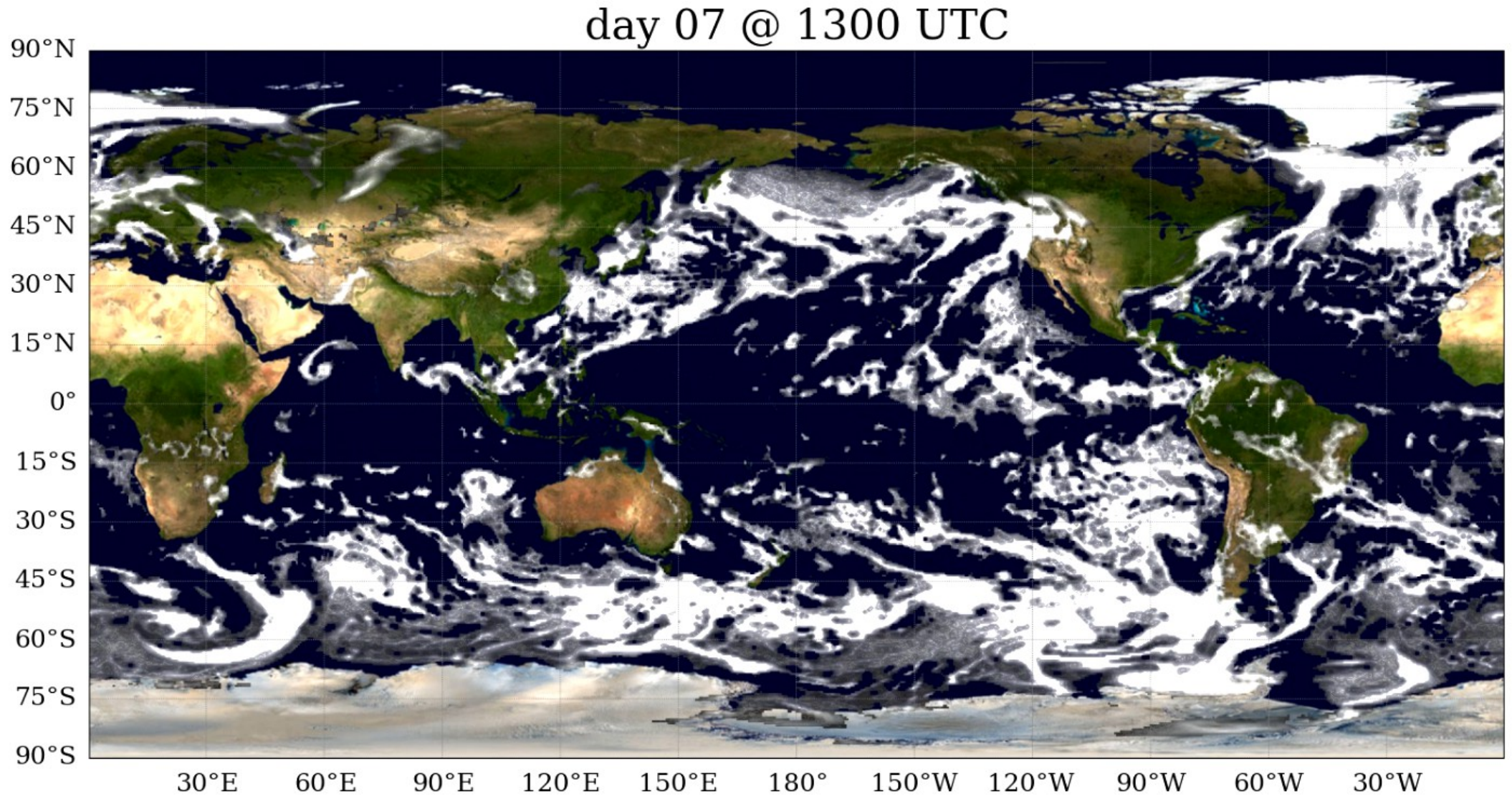
DYNAMICO-LMDZ, 25km (1 024 000 atmospheric columns)



Liquid water

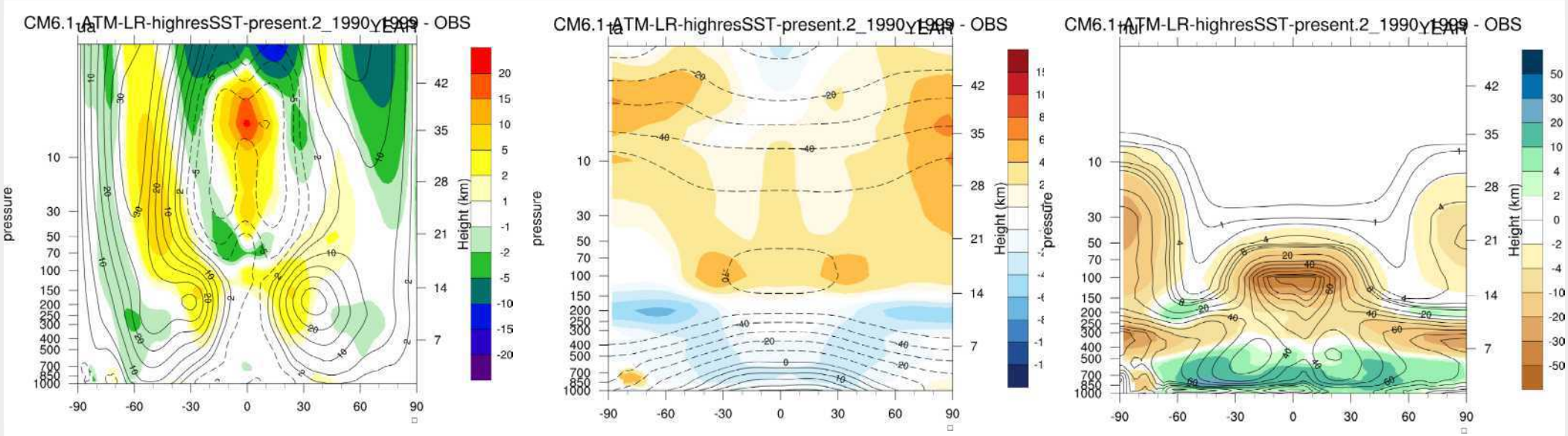
IPSL-CM7A-HR :

DYNAMICO-LMDZ, 50km (256 000 atmospheric columns)



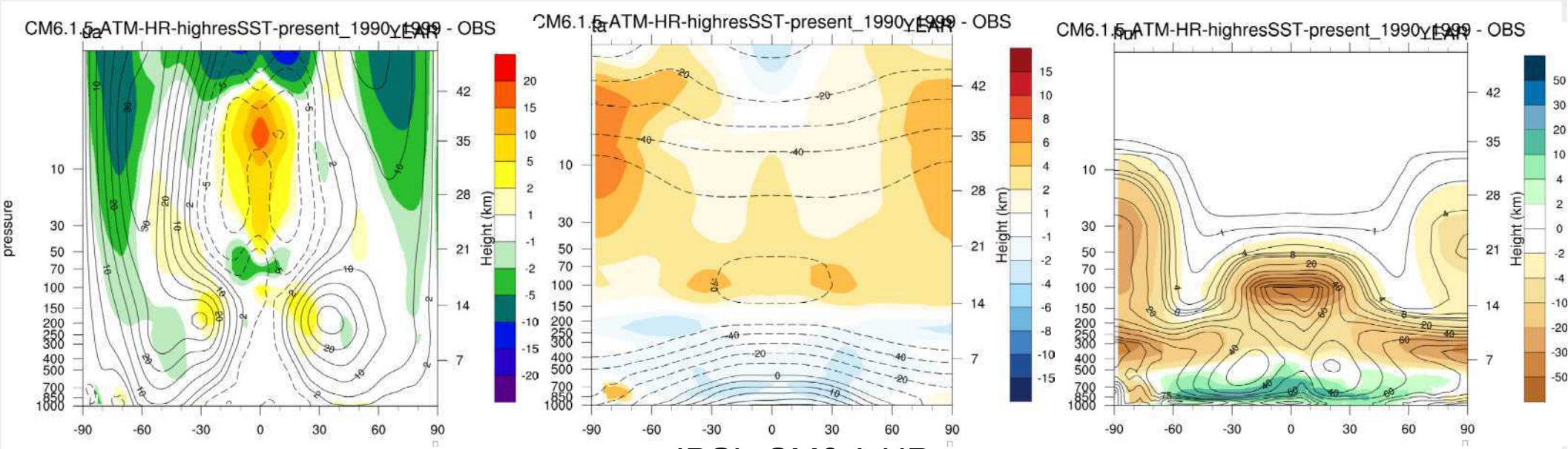
Low-level cloudiness

Zonal wind *Temperature* *Relative humidity*



IPSL-CM6.1-LR

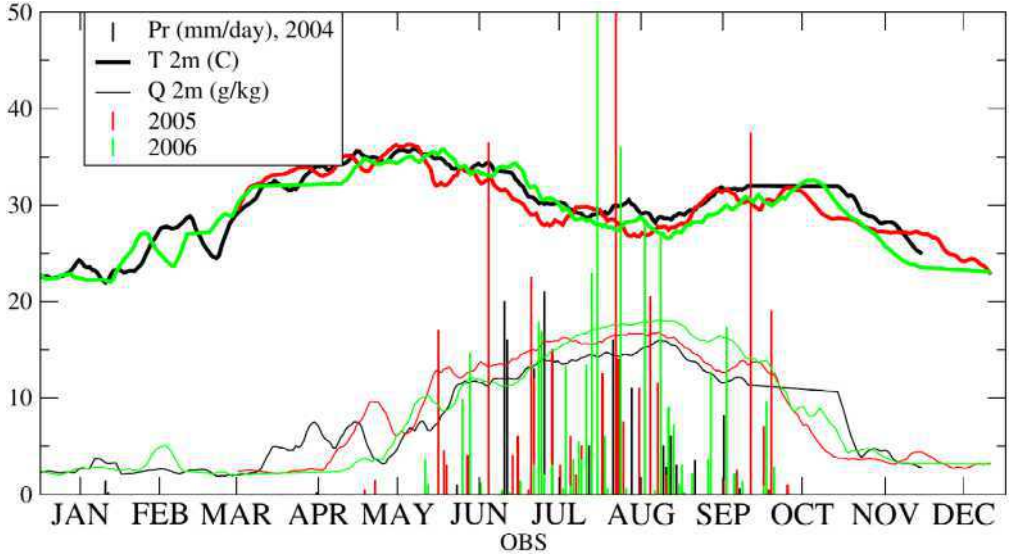
Contours : OBS (ERA) *Colors : bias = model-OBS*

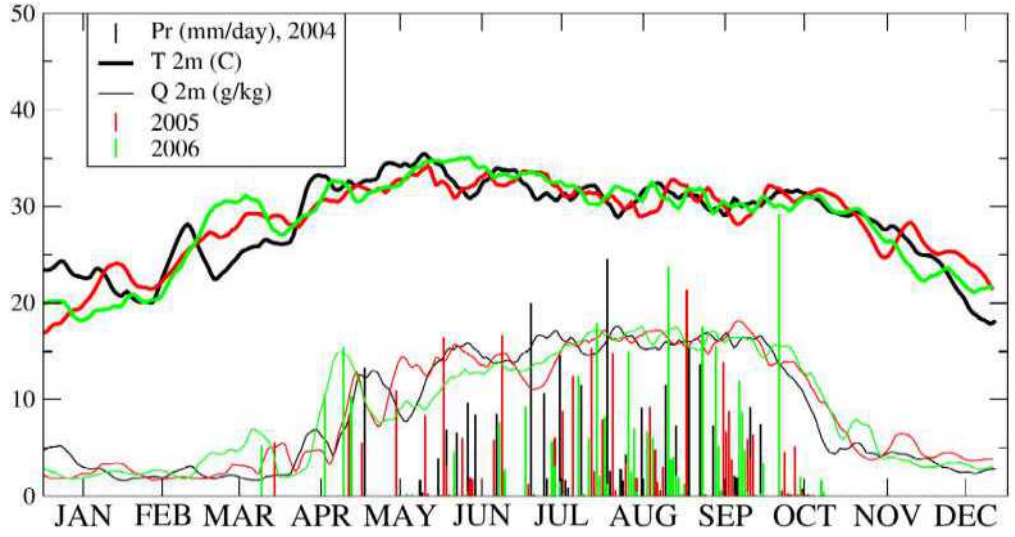


IPSL-CM6.1-HR

=> some reduction of mean biases at higher resolution

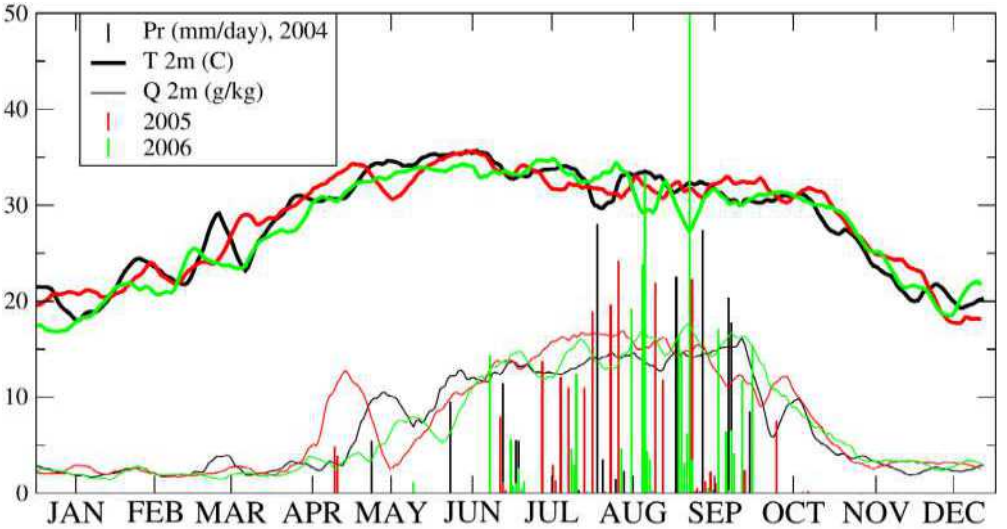
Distribution of precipitation at the Agoufou weather station, Mali : observed and modelled in 2004, 2005, 2006





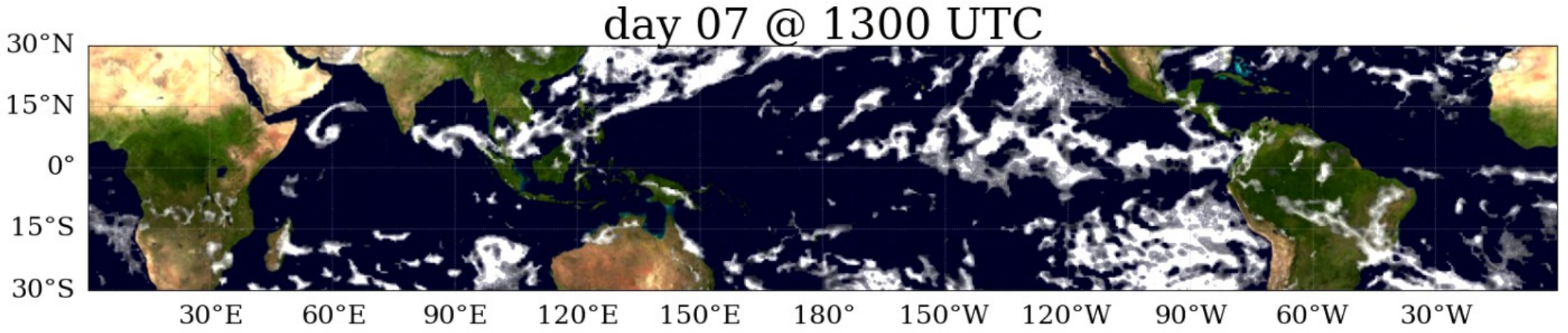
Agoufou au Mali, IPSL-CM6.1-LR

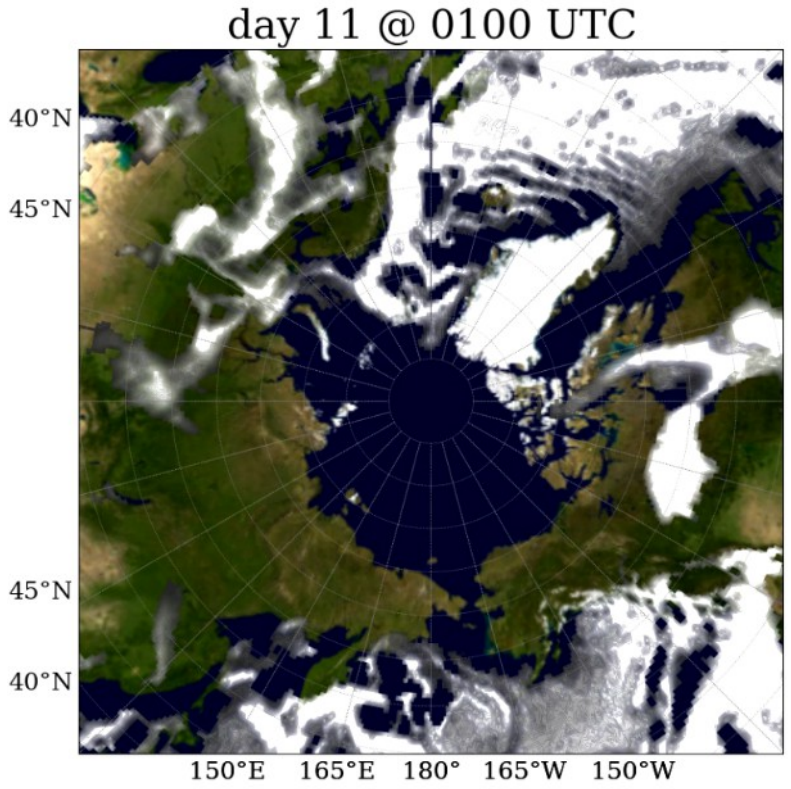
Suggests better ability to produce high-intensity rainfall at higher resolution

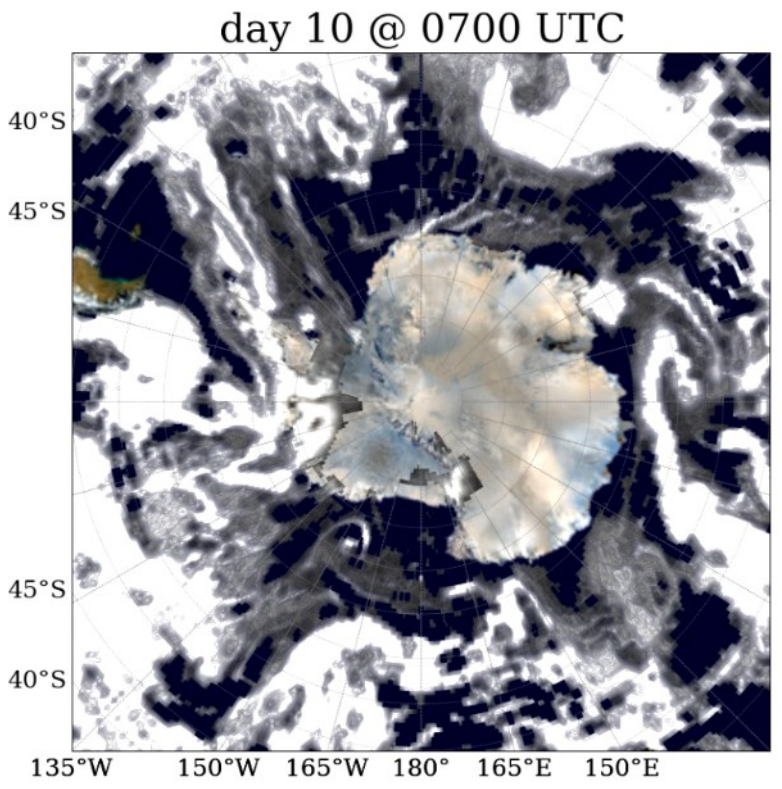


IPSL-CM6.1-HR

Thank you for your attention







Prospects for higher-resolution *climate* modelling

- CMIP requires a throughput of x10000 (30SYPD)
- Some climate modelling still doable with x1000 (3SYPD)
- Ability to attain x1000 depends on maximum stable time step (numerics) and walltime needed to perform one time step (implementation)
- Assuming a large enough machine, reducing walltime is a **strong scaling problem**
- For DYNAMICO, dt (in sec) is about 2.5*dx (in km)

  => ms/time step required to reach 3SYPD :
  - 25km 60 ms per full time step
  - 8km 20 ms per full time step
  - 1km 2.5 ms per full time step

CMIP6 physics (79 vertical levels) cost 2-3 ms per column per call
(24 SYPD with 96 calls per day, 36 columns per core)

If physics are called every 5 dynamics time steps :

100 columns/core	=> 20+(100*2/5)=60 ms	=>	3 SYPD at 25 km with 10 000 cores
30 columns/core	=> 10+(30*2/5)=22 ms	=>	3 SYPD at 8 km with 300 000 cores ?
10 columns/core	=> 3+(10*2/5)=7 ms	=>	1 SYPD at 1 km with 50 million cores ??