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

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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
ORCHIDEE Land-surface

● Parallel asynchronous I/O
● Interpolation to/from lon-lat / ico
● Time average, min/max, ...

NetCDF Output files

NetCDF Input files

Simulation configuration *.DEF

LMDZ or DYNAMICO

LMDZ Physics

ORCHIDEE Land-surface

CMIP6 data request

DR2XML

I/O configuration *.XML

XIOS

- Parallel asynchronous I/O
- Interpolation to/from lon-lat / ico
- Time average, min/max, ...
<table>
<thead>
<tr>
<th>Name</th>
<th>Vertical grid</th>
<th>Horizontal grid</th>
<th>Physical parameterizations</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMIP3</td>
<td>19 levels</td>
<td>96x71</td>
<td>Emanuel convection scheme Subgrid scale orography</td>
<td>IPSL-CM3 LMDZ4</td>
</tr>
<tr>
<td>CMIP5</td>
<td>39 levels stratosphere</td>
<td>LR = 96x95 MR = 144x143</td>
<td>2 versions <strong>Standard Physics (SP)</strong> same as CMIP3</td>
<td>IPSL-CMX LMDZX 5A-LR/MR</td>
</tr>
<tr>
<td>CMIP6</td>
<td>79 levels</td>
<td>LR = 144x143 (200km at mid-lat) HR=512x360 (50km at mid-lat)</td>
<td><strong>New physics (NPv3) with thermal plumes and cold pools</strong></td>
<td>5B-LR</td>
</tr>
<tr>
<td></td>
<td>dZ/Z &lt; 0.1 up to 3 km (PBL clouds) For QBO dZ=1km up to 50km</td>
<td></td>
<td><strong>NPv3 +</strong></td>
<td>6A-LR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- New radiation (RRTM) - Stochastic closure - stratocumulus from thermals - Ice thermodynamics$^3$ - Surface couplings (continents&amp;ocean)$^2,4$ - gravity waves (including non oro.gr., QBO)$^1$</td>
<td></td>
</tr>
</tbody>
</table>

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79 vertical levels
4 – 12 OpenMP threads

\[ N_{\text{lon}} \times N_{\text{lat}} \text{ points} \]
\[ \leq N_{\text{lat}}/2 \text{ MPI processes} \]
\[ \geq 2N_{\text{lon}} \text{ atmospheric columns / MPI pro.} \]

10 \times N^2 \text{ points}
\sim N^2/10 \text{ MPI processes}
\sim 100 \text{ 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 \(~10\text{ms/step}\) for 50 columns/core
### Table 1. Forcings and initialization for the Historic simulations (pre-2015).

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

Published on ESGF


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

Trial runs => coming soon
IPSLS-CM7A-HR:
DYNAMICO-LMDZ, 25km (1 024 000 atmospheric columns)

Liquid water
IPSL-CM7A-HR:
DYNAMICO-LMDZ, 50km (256 000 atmospheric columns)
day 07 @ 1300 UTC

Low-level cloudiness
Relative humidity

Zonal wind

Temperature

Relative humidity

=> some reduction of mean biases at higher resolution
Distribution of precipitation at the Agoufou weather station, Mali: observed and modelled in 2004, 2005, 2006

Suggests better ability to produce high-intensity rainfall at higher resolution
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)
  
  \[ \Rightarrow \text{ms/time step required to reach 3SYPD} : \]
  
  - 25km \quad 60 \text{ ms per full time step}
  - 8km \quad 20 \text{ ms per full time step}
  - 1km \quad 2.5 \text{ 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 \quad \Rightarrow \quad 20+\left(100\times\frac{2}{5}\right)=60 \text{ ms} \quad \Rightarrow \quad 3 \text{ SYPD at 25 km with 10 000 cores}
- 30 columns/core \quad \Rightarrow \quad 10+\left(30\times\frac{2}{5}\right)=22 \text{ ms} \quad \Rightarrow \quad 3 \text{ SYPD at 8 km with 300 000 cores}
- 10 columns/core \quad \Rightarrow \quad 3+\left(10\times\frac{2}{5}\right)=7 \text{ ms} \quad \Rightarrow \quad 1 \text{ SYPD at 1 km with 50 million cores}