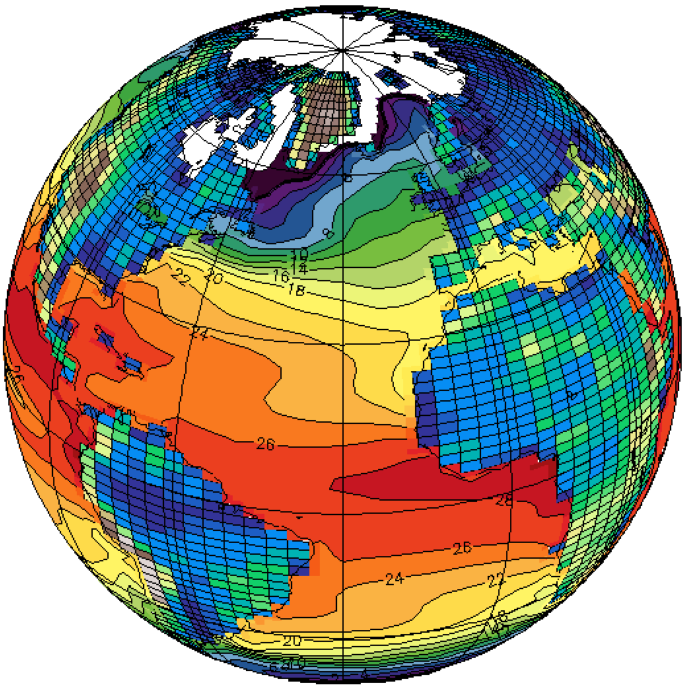
IPSL-CM5A2: Set-up, Tuning strategy & Evaluation

P. Sepulchre*[1], Arnaud Caubel[1], and friends[1]

[1]Laboratoire des Sciences du Climat et de l'Environnement, LSCE/IPSL, CEA-CNRS-UVSQ, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France

October 12, 2016



*pierre.sepulchre@lsce.ipsl.fr; Corresponding author

Contents

1 Short Context

The IPSL-CM5A model was developed and released in 2013 ”to study the long-term response of the climate system to natural and anthropogenic forcings as part of the 5th Phase of the Coupled Model Intercomparison Project (CMIP5)” [Dufresne et al., 2013]. Although this model has been used also for several paleoclimate studies (e.g. Kageyama et al. [2013], Zhuang and Giardino [2012]), a major limitation was its computation time, which averaged 10-12 model-years / day on 32 cores of Curie supercomputer. Such performances were compatible with the experimental designs of intercomparison projects (with limited number of required experiments, e.g. PMIP3, see XXX) but became limiting for modelling activities involving several multicentannal experiments, which are typical for Quaternary or ”deeptime” studies, in which a fully-equilibrated deep-ocean is mandatory.

Apart from obtaining better computing performances, one aim of setting up IPSL-CM5A2 was to overcome the cold bias depicted in global surface air temperature (t2m) in IPSL-CM5A -explained by the lack of tuning for this latter version [Dufresne et al., 2013]- while trying not to worsen the long standing biases of the model (especially the warm bias of the ocean surface over equatorial upwelling regions and the presence of a double ITCZ in the equatorial eastern Pacific). Therefore we define a tuning strategy that responds to one single target: increasing the global t2m to reach the value of 13.5°C at equilibrium with pre-industrial boundary conditions.

2 Tuning strategy

2.1 Defining a target

Our experimental design was initiated with a CM5A2 simulation forced by CMIP5 pre-industrial boundary conditions (fereafter NOTUN), the ocean component initiated by the routinely-used levitus climatologies. After 1000 years (see further sections for discussion on equilibrium), global surface air temperature gets adjusted and stabilizes at ca.11.3°C (Fig.4, red curve), that is more than 0.8°C colder than CM5A [Dufresne et al., 2013]. This cold anomaly between the 2 versions is associated with a stronger negative radiative forcing of clouds in CM5A2 at mid-latitudes and along the equator, and a negative anomaly in both surface and top of atmosphere (TOA) radiative balance between CM5A2 (-0.28 W.m^{-2}) and CM5A (+0.18 W.m^{-2}). The reason for these differences between two rather close versions of the ISPL model is still under investigation. Accounting for this difference and our goal to reduce the cold bias of IPSL-CM5A, we defined our tuning target as a 2.2°C increase of global t2m compared to CM5A. Typically this would translate into a 13.5°C annual global surface temperature in pre-industrial conditions, and a 15.5°C with present-day conditions, including the ocean heat uptake.

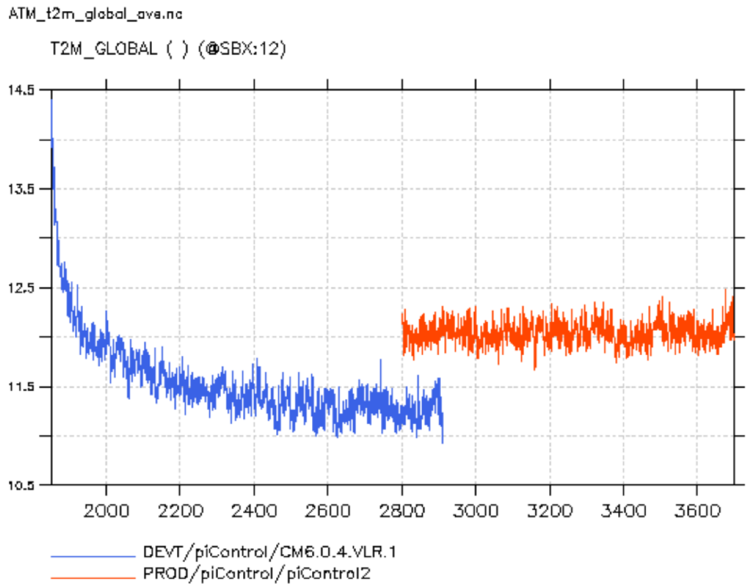


Figure 1: Evolution of t2m (°C) in IPSL-CM5A (red, after several thousand-years of spin-up) and IPSL-CM5A2 (blue, adjusting from Levitus initial state)

2.2 Changing cloud radiative effect

Choice was made to act on cloud microphysics to alter their radiative effect and eventually the global temperature, following a routine developped at LMD by F. Hourdin and

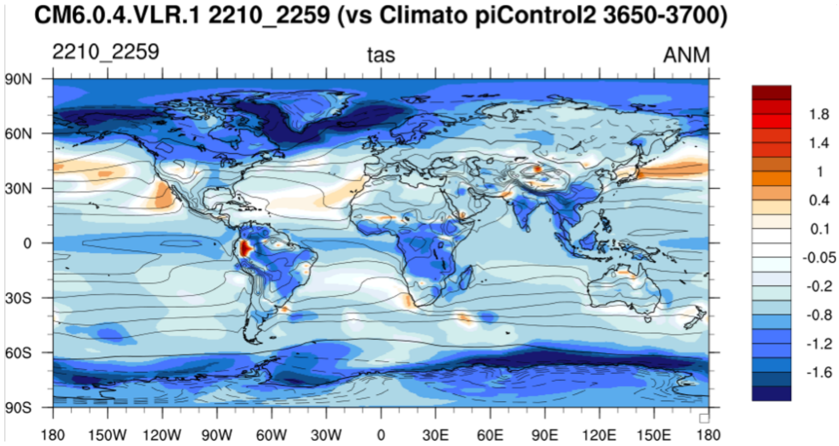


Figure 2: IPSLCM5A2 minus IPSLCM5A t2m anomaly. Averaged over the last 50 years of each experiment.

colleagues. According to Sundqvist [1978], the rate of precipitation formation is related to the amount of water in the cloud. As described in Hourdin et al. [2013], a threshold for condensed water (0.418 g.kg^{-1} before tuning) needs to be reached for rainfall to start precipitating, with a time constant τ_{conv} for auto-conversion (set at 1800 s):

$$\frac{dq_{lw}}{dt} = -\frac{q_{lw}}{\tau_{conv}} \left[1 - e^{-(qlw/\boldsymbol{clw})^2} \right]$$

where q_{lw} is the mixing ratio, clw is the in-cloud water threshold for autoconversion, τ_{conv} is a time constant for auto-conversion (here set at 1800 s).

Decreasing clw is expected to lower cloud density and reduce the net cloud radiative forcing, as depicted in sensitivity experiment CLDLC in [Hourdin et al., 2013]. Here we carried out forced-by-SSTs LMDZ simulations, keeping in mind that a change by 1 W.m^{-2} in the net radiative balance shifts global t2m by 1K. Two simulations were run with clw set at 0.316 and 0.250 g.kg^{-1}, respectively, to define the sensitivity of surface and TOA radiative budget to this parameter.

	$Control$	$Exp1$	$Exp2$
$clw(g.kg^{-1})$	0.418	0.316	0.250
$CRF(W.m^{-2})$	-21.56	-18.94	-17.10
$BILS(W.m^{-2})$	-0.176	2.737	4.544

Setting clw at 0.316 g.kg^{-1} provides a slightly too strong increase in the cloud radiative forcing (+2.61 W.m^{-2}) that echoes in surface heat budget (+2.56 W.m^{-2}) in the atmosphere-only simulation.

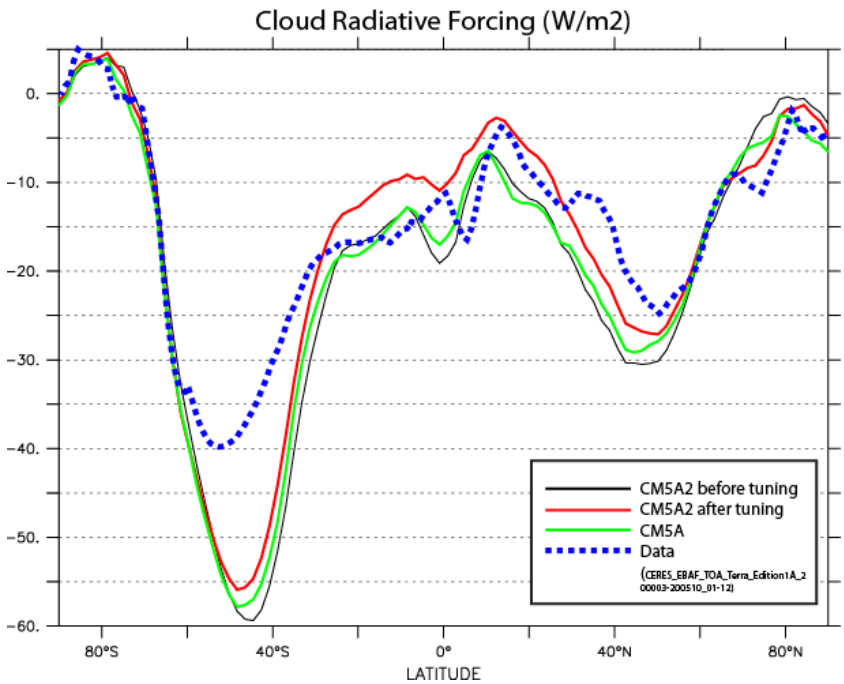


Figure 3: blabla

On the 500th year of CTL-Notun, we branched a second IPSL-CM5A2 simulation (CTL-tun00) prescribed with *clw* set to 0.316 $g.kg^{-1}$. After 500 years CTL-tun00 depicted an annual t2m reaching 13.75°C (Fig.4, green curve) with surface radiative balance stabilizing at +0.19 $W.m^{-2}$.

From these experiments we linearized the *clw*-bils relationship and obtained that setting *clw* at 3.25 $g.kg^{-1}$ would be the right choice to reach the +2.2°C target. We branched a new IPSL-CM5A2 experiment CTL-tun01 on the 400th year of CTL-tun00 and let the model run for 1000 years, for all the slow components to reach equilibrium. Comparing zonally-averaged cloud radiative forcing of CTL and CTL-tun00 confirms that decreasing *clw* strongly reduces cloud-related cooling between 50°S and 50°N. Comparison with the CERES Energy Balanced and Filled (EBAF) dataset shows that our tuning improves total CRF between 10°N and 60°N, but also leads to an overestimation between the Equator and 30°S. The tuning also slightly improves CRF in the Southern hemisphere mid-latitudes although the absolute values are still largely overestimated. We obtain a net surface heat flux of 0.11 $W.m^{-2}$ and a global air temperature at surface of 13.56°C, when averaged over the last 100 years of simulation.

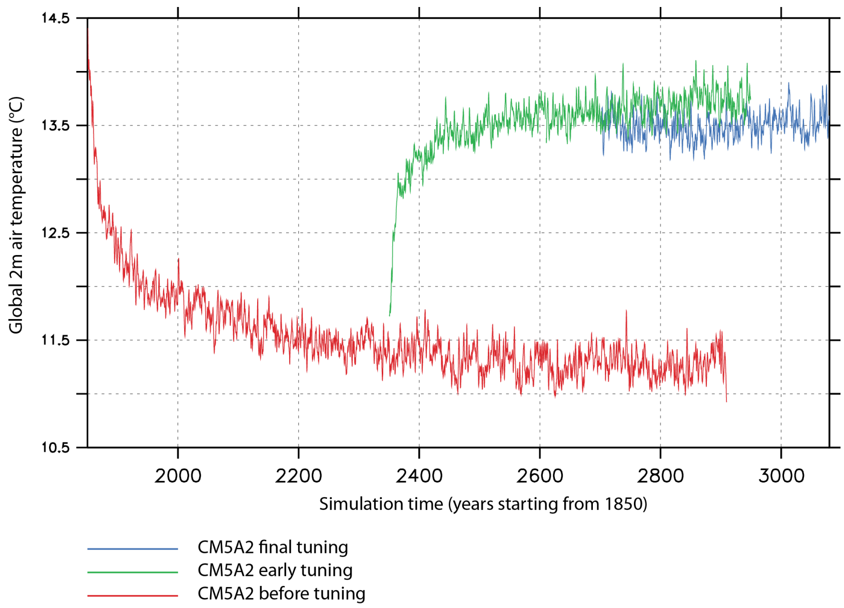


Figure 4: Evolution of t2m (°C) and branching of IPSL-CM5A2 simulations.

3 Model performances

3.1 Ocean equilibrium

The discrepancy between the initial state of the ocean, set at present-day, and the forcings, set at pre-industrial values, results in an initial unbalanced radiative budget (-2.3 W.m^{-2}) and an associated global cooling from inital t2m at 14.4°C that stabilizes at 11.3°C. The long-term global surface temperature timeseries of NOTUN experiment indeed shows that 1,000 years are required to have a negligeable deviation in surface temperature. At that time the surface heat flux stabilizes at -0.28 W.m^{-2}.

References

J.-L. Dufresne, M.-A. Foujols, S. Denvil, A. Caubel, O. Marti, O. Aumont, Y. Balkanski, S. Bekki, H. Bellenger, R. Benshila, S. Bony, L. Bopp, P. Braconnot, P. Brockmann, P. Cadule, F. Cheruy, F. Codron, A. Cozic, D. Cugnet, N. de Noblet, J.-P. Duvel, C. Ethé, L. Fairhead, T. Fichefet, S. Flavoni, P. Friedlingstein, J.-Y. Grandpeix, L. Guez, E. Guilyardi, D. Hauglustaine, F. Hourdin, A. Idelkadi, J. Ghattas, S. Joussaume, M. Kageyama, G. Krinner, S. Labetoulle, A. Lahellec, M.-P. Lefebvre, F. Lefevre, C. Levy, Z. X. Li, J. Lloyd, F. Lott, G. Madec, M. Mancip, M. Marchand, S. Masson, Y. Meurdesoif, J. Mignot, I. Musat, S. Parouty, J. Polcher, C. Rio, M. Schulz, D. Swingedouw, S. Szopa, C. Talandier, P. Terray, N. Viovy, and N. Vuichard. Climate change projections using the IPSL-CM5 Earth System Model: From CMIP3 to CMIP5. *Climate Dynamics*, 40(9-10):2123–2165, May 2013. ISSN 0930-7575, 1432-0894. doi: 10.1007/s00382-012-1636-1.

Frédéric Hourdin, Jean-Yves Grandpeix, Catherine Rio, Sandrine Bony, Arnaud Jam, Frédérique Cheruy, Nicolas Rochetin, Laurent Fairhead, Abderrahmane Idelkadi, Ionela Musat, Jean-Louis Dufresne, Alain Lahellec, Marie-Pierre Lefebvre, and Romain Roehrig. LMDZ5B: The atmospheric component of the IPSL climate model with revisited parameterizations for clouds and convection. *Climate Dynamics*, 40(9-10): 2193–2222, May 2013. ISSN 0930-7575, 1432-0894. doi: 10.1007/s00382-012-1343-y.

Masa Kageyama, Pascale Braconnot, Laurent Bopp, Arnaud Caubel, Marie-Alice Foujols, Eric Guilyardi, Myriam Khodri, James Lloyd, Fabien Lombard, Véronique Mariotti, Olivier Marti, Tilla Roy, and Marie-Noëlle Woillez. Mid-Holocene and Last Glacial Maximum climate simulations with the IPSL model—part I: Comparing IPSL_CM5A to IPSL_CM4. *Clim Dyn*, 40(9-10):2447–2468, 2013. ISSN 0930-7575, 1432-0894. doi: 10.1007/s00382-012-1488-8.

Hilding Sundqvist. A parameterization scheme for non-convective condensation including prediction of cloud water content. *Q.J.R. Meteorol. Soc.*, 104(441):677–690, July 1978. ISSN 1477-870X. doi: 10.1002/qj.49710444110.

Kelin Zhuang and John R. Giardino. Ocean Cooling Pattern at the Last Glacial Maximum. *Advances in Meteorology*, 2012:e213743, December 2012. ISSN 1687-9309. doi: 10.1155/2012/213743.