SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2022
Project Title:	State- and forcing-dependence of Equilibrium Climate Sensitivity in EC-Earth
Computer Project Account:	spitfabi
Principal Investigator(s):	Federico Fabiano (S. Corti, P. Davini, J. von Hardenberg)
Affiliation:	ISAC-CNR (Bologna)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	-
Start date of the project:	01/01/2020
Expected end date:	31/12/2022

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	9,900,000	10,350,000	9,000,000	425,000
Data storage capacity	(Gbytes)	17,000	40,000	17,000	0

Summary of project objectives (10 lines max)

The aim of this project is to explore how the Equilibrium Climate Sensitivity (ECS) of a climate model (i.e. the mean global temperature increase in response to a CO_2 doubling with respect to preindustrial levels) might depend on the model tuning and mean state.
In a first part of the project we explored the tuning parameters' space to find suitable combinations that would modify the model climate feedbacks and sensitivity to CO2 forcing. Then, two coupled simulations were run both in pre-industrial and 4xCO2 conditions, with one "cold" and one "warm" parameter set respectively. The effective climate sensitivity and feedbacks of the climate system in the two configurations are finally studied.

Summary of problems encountered (10 lines max)

Nothing to report.

Summary of plans for the continuation of the project (10 lines max)

Analysis of a new set of sensitivity experiments is currently ongoing, and will hopefully produce a better tuning simulator for both the pi and 4xCO2 TOA balance, accounting for cross-parameter influences. An estimation of the impact on the Effective Radiative Forcing (ERF) will also be attempted. Depending on the results and performance of the new simulator, we will decide whether to perform a new 4xCO2 coupled simulation with a different set of "cold" parameters, or to extend the present runs to better assess the change in the climate feedbacks at longer timescales.

List of publications/reports from the project with complete references

No publication is available for this project yet.

Summary of results

1. Radiative footprint of IFS tuning parameters

The sensitivity of the radiative balance of the system to a set of tuning parameters was assessed through an ensemble of short atmosphere-only simulations with two sets of climatological SSTs corresponding to a pre-industrial and a $4xCO_2$ climate. We recall here the tuning parameters considered in the experiment: ENTRORG (organized entrainment in deep convection), RPRCON (rate of conversion of cloud water to rain), DETRPEN (detrainment rate in penetrative convection), RMFDEPS (fractional massflux for downdrafts), RVICE (fall speed of ice particles), RSNOWLIN2 (snow autoconversion constant in large scale precipitation), RCLDIFF (diffusion coefficient for evaporation by turbulent mixing), RLCRIT UPHYS (cloud to rain critical radius, autoconversion).

To better understand the impact of each parameter change, their spatial footprint on the net TOA incoming radiation is shown in Figure 1, for the pre-industrial (left panel) and 4xCO2 SSTs (right panel). It is clearly seen that, for some parameters, the footprint can differ significantly between the two climates, thus impacting the energy balance of the model and its response to warming. This is particularly evident for ENTRORG and RPRCON, that have a large impact on radiative balance of the tropical region, modifying the formation and evolution of deep convective systems.

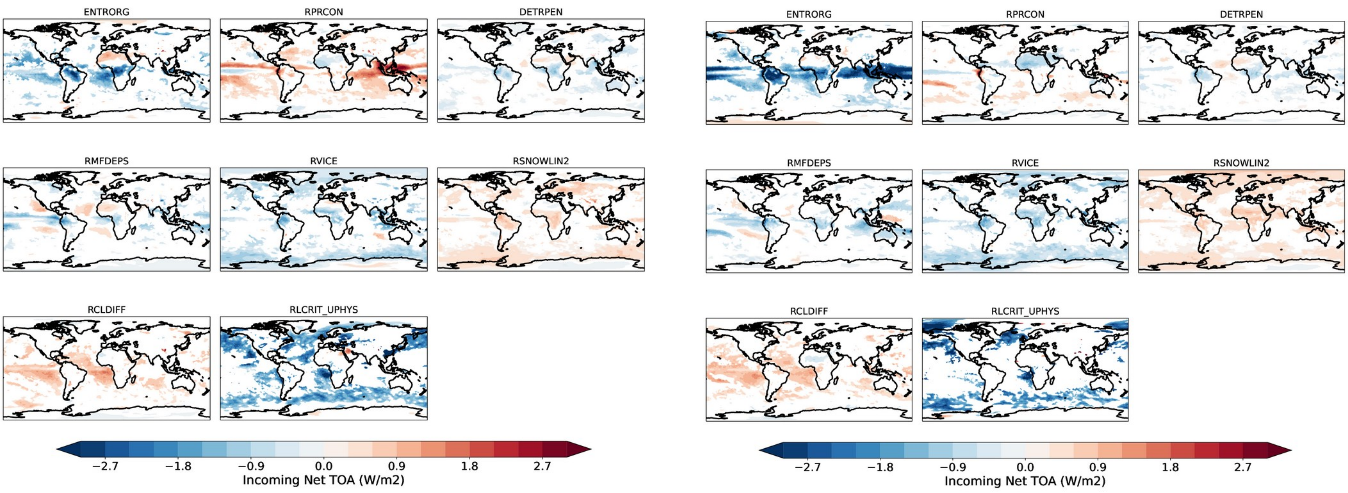

Figure 1. Net TOA footprint of the tuning parameters in a pre-industrial climate (left) and 4xCO2 climate (right).

2. Coupled simulations for the cold and warm worlds - update

After choosing a "cold" and a "warm" set of tuning parameters, two 150-year long 4xCO2 abrupt simulations were performed. The feedback parameter and equilibrium climate sensitivity in the two configurations has been estimated with the usual method based on linear feedback theory (Gregory et al., 2004; Andrews et al., 2012). As can be seen in Figure 2 below, the difference between the ECS of the two setups is not large but still significant at about 0.5 K. In particular, the cold set has a similar ECS to the nominal configuration. At a closer look however, the change in the feedback parameter λ for the three simulations is significant and goes in the expected direction, being more negative for the cold set (-0.91 W/m2/K) and less for the warm set (-0.75 W/m2/K). As hypothesized in the previous report, the corresponding change in ECS is indeed masked by the concomitant change of the effective radiative forcing (ERF), which varies from 3.3 W/m2 in the warm set to 3.7 W/m2 in the cold set.

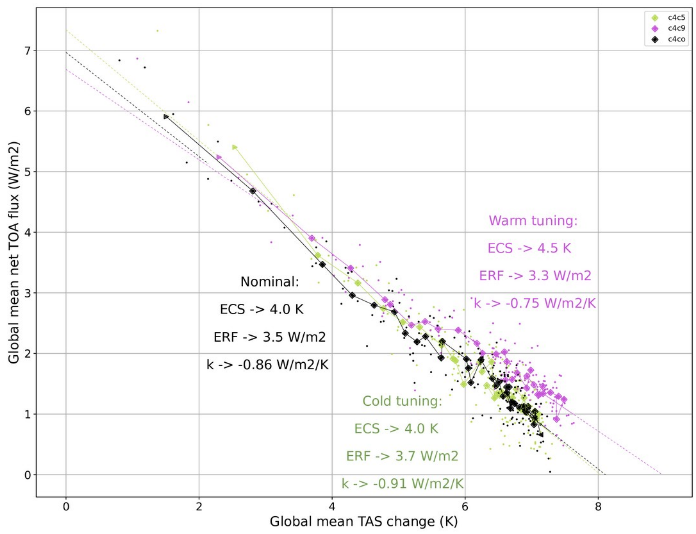

Figure 2. Fit of the feedback parameter and ERF for the "cold" set, "warm" set and the nominal configuration.

3. Sobol mapping of the tuning parameter space

In the previous report, some evidence had emerged that the original assumption of linear independency of the tuning parameters may not always hold, as the change in the TOA radiative fluxes predicted from the linear framework differed consistently from the actual values calculated in test atmosphere-only runs. To solve this issue and build a proper simulator of the impact of the tuning parameters on the TOA radiative balance, we revisited our linear assumption to calculate the parameter sensitivity. Instead of just perturbing one parameter at a time, we mapped the full 8-dimensional parameter space using a Sobol sequence (a quasi-random low-discrepancy sequence in Sobol, 1967). Sobol sequences allow to optimally sampling a n_{th} dimensional space using just n^2 points. A projection of the Sobol sequence used for the new sampling is shown in Figure 3. An ensemble of 64 different tuning parameter sets has been generated in this way, and for each set an atmosphere-only sensitivity run has been performed both for the pre-industrial and the 4xCO2 climate. Due to computational limits, the 128 simulations only lasted 3 years, which however should be enough for assessing at least the global and zonal mean impact on the radiative balance. The analysis of the new sensitivity runs is currently under-way. Also, strategies to estimate the impact of the parameters on the ERF will be explored.

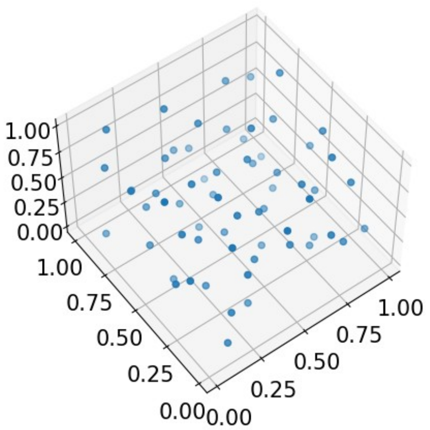

Figure 3. Example of the Sobol mapping projected on the first 3 parameters' space.

References

Andrews, T., Gregory, J. M., Webb, M. J., & Taylor, K. E. (2012). Forcing, feedbacks and climate sensitivity in CMIP5 coupled atmosphere-ocean climate models. Geophysical Research Letters, 39(9).

Gregory, J. M., Ingram, W. J., Palmer, M. A., Jones, G. S., Stott, P. A., Thorpe, R. B., ... & Williams, K. D. (2004). A new method for diagnosing radiative forcing and climate sensitivity. Geophysical research letters, 31(3).

Sobol, I.M. (1967), "Distribution of points in a cube and approximate evaluation of integrals", *Zh. Vych. Mat. Mat. Fiz.* **7**: 784–802