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Direction de l'Enseignement Supérieur et de la Recherche

Centre National de Recherches Météorologiques

Title: Long-term adjustment of the ocean-atmosphere system: process analysis and consequences for climate hindcasts and projections.

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Topic:

The observed climate system never reaches equilibrium due to the continuous evolution of external natural forcings such as the solar irradiance or the volcanic sulfate aerosols emissions. From a theoretical point of view in which external forcings would be constant, it is not obvious whether the climate system has one or several equilibrium and stable states. Several studies suggest that their could exist several stable states (Rose, 2015). However, the time needed to reach such stable states is of at least several thousands of years due to the long time-scale needed by the ocean to reach equilibrium. Therefore, such questions have been addressed using reduced complexity climate models or in simplified configurations of more complex climate models such as aquaplanets (Ferreira et al., 2011; Ragon et al., 2022). The mechanisms at play when the ocean drifts towards a stable state in more complex state-of-the-art climate models as those used for producing future climate simulation in the ScenarioMIP intercomparison project (Tebaldi et al., 2021) thus remain elusive. In such realistic atmosphere-land-ocean coupled models, we could expect that the long term evolution of the ocean component towards an equilibrated state would be like a slow monotonous evolution and concerns mainly the deep ocean. However, a recent study (Ridley et al., 2022) suggests that tipping points could occur along this slow evolution through interactions between the deep and surface ocean following convective events. The main objective of the PhD is to assess if the climate system as simulated by a state-of-the-art climate model can reach a stable state if integrated long enough and thereby shed light on the long-term processes occurring in the ocean in its drift towards equilibrium. This will allow to better quantify the time-scales needed to reach an equilibrium in realistic Earth model configurations.

These long time-scale adjustments have implications on the way climate models simulations are interpreted. Indeed, CMIP class climate models are supposed to be integrated long enough to reach a steady state before running historical and future simulations. However, the amount of CPU time needed to perform simulations with such models covering several thousands of years stays prohibitive and it is often not possible possible to attain such a state within (computational and human) time constraints. The residual drift in CMIP models has been shown to vary among the models and can be substantially large (Gupta et al., 2013). These drifts are taken into account in CMIP community, by analyzing trends in historical simulations in anomaly to trends obtained under constant preindustrial forcing simulations. The assumption is thus made that the residual drift in the control simulation evolves "at a fairly constant rate that presumably decreases slowly as equilibrium is approached". The recent study by (Ridley et al., 2022) highlights that this hypothesis may not hold. A second objective of this PhD work is to develop a method to assess the degree of convergence and estimate the acceptable level of convergence required in CMIP class models to study the climate evolution over century time-scales.

Analysing these long time-scale processes in a state-of-the-art complex climate model will be possible through the use of a recently developed low resolution version of the CNRM-CM model (Voldoire et al., 2019) which is able to integrate about 100 years per day at reduced CPU cost. Using this model, it will be possible to integrate the model over several centuries at reasonable CPU cost in a few weeks or months and reach a stable state. However, the objective remains to be able to attain reasonable levels of convergence with standard resolution climate models, which will probably remain unaffordable given their computational cost. Acceleration methods have been proposed (Bryan, 1984, Cooper, 2017) but rarely tested in complex climate models. With the low cost version of CNRM-CM, we can take advantage of knowing the effective stable state of the model to test and evaluate such acceleration methods. The analysis of long-term adjustments processes may also provide some directions to develop alternative methods either based on physical or statistical methods. We will also evaluate the possibility to reach equilibrium through the use of uncoupled configurations. The traditional OMIP (Griffies et al., 2016) ocean forced protocol is probably not adequate since the ocean is strongly constrained by the forcing and the final state not representative of the characteristics obtained in coupled mode (Silvy et al., 2022). The recently developed simplified atmospheric boundary layer scheme (ABL1D, Lemarié et al., 2021) appears as a promising tool to get an ocean state similar to the one obtained in coupled mode at lower cost than a fully coupled model.

This PhD will be part of the OpimESM EU project and will benefit from interactions with other partners of the project. This activity will also benefit from the French Program PEPR TRACCS. In this program, a specific project (PC6-QUINTET "QUantifying uncertaINties, Tuning and Equilibrating climaTe models") will foster innovation and interactions within the French community on the climate model equilibration challenge. The PhD is funded for a 3 years period with a gross salary of 2044€.

About the CNRM:

The French Centre National de Recherches Météorologiques (CNRM, http://www.umr-cnrm.fr/) is a joint research unit (UMR 3589) affiliated to Météo-France and the CNRS. It brings together 80 researchers and 150 engineers, technicians and administrative staff. Each year, the CNRM welcomes between 15 and 20 new doctoral candidates.

Candidate expected skills:

- a Master of Science degree or an equivalent qualification in oceanography, atmospheric physics, environmental physics or climate before starting the Ph. D. project
- knowledge of oceanography
- good written and oral English skills to present scientific results
- good programming and data processing skills (Fortran, Shell, Python or similar)
- experience in numerical modelling

Application:

For full consideration, the application must include a curriculum vitae, a short letter (two pages maximum) stating qualifications, research interests, relevant experience and motivation for the application. It must also include copies of undergraduate certificates (or a letter from the master supervisor stating when the master degree or equivalent is expected) and names and contact information for two relevant referees to whom we may ask for recommendation. Applications must be sent by email to aurore.voldoire@meteo.fr before 16 July 2023.

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