DKRZ resources request 2025 for project: ILModelS - 2024 report

Project title:
Impact of Land Model depth on climate and climate change scenario Simulations (ILModelS)

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Link to the full report:
http://ucmfgr.es/downloads/inandout/20241029_ILModelS_report2024-DKRZ_for2025_v5.pdf

1. Background

The ILModelS (project n. 1026) consortium is an international initiative with cooperation partners from the Max Planck Institute for Meteorology (MPI-M, Germany), the Instituto de Geociencias, IGEO (CSIC-UCM; Spain), a joint research center of the Spanish council for research (CSIC) and the Complutense University (UCM), the CIEMAT (Spain), and the Helmholtz-Zentrum Hereon (Germany). This initiative has been continuously founded by the Spanish Ministry of Science since 2015, first by the homonymous project ILModelS (Impact of Land Model depth on climate and climate change scenario Simulations; REF: CGL2014-59644-R; 2015-2018), and then superseded by GReatModelS (Global and Regional Impacts of using more realistic Land Modelling on Historical and Climate Change scenario Simulations; REF: RTI2018- 102305-B-C21; 2019-2022), and SMILEME (Sensitivity of climate Models to Improved soil hydro-thermodynamics and Land-air interactions: impacts over the European-MEditerranean domain; REF: PID2021-126696OB-C21; 2023-2025). SMILEME ensures the continuation of the scientific collaboration presented herein at least until the end of 2025. Due to the funding provided by the Spanish Ministry of Science, it is very likely that the execution of SMILEME is extended until the end of the third term of 2026.

In the ILModelS consortium we tested the effects of improving the subsurface representation of the thermodynamics of the Max Planck Institute Earth System Model (MPI-ESM; Mauritsen et al., 2019) Land Surface Model (LSM), JSBACH (Reick et al., 2021). The motivation was that most of the state-of the-art LSMs within ESMs incorporate a shallow zero-heat-flux Bottom Boundary Condition Placement (BBCP) and a poor vertical layer discretization when resolving underground thermal transfer, which constrains land heat uptake (Cuesta-Valero et al., 2016) and permafrost representation (Burke et al., 2020). Results derived from the work within ILmodelS have shown that to realistically represent the subsurface temperature variability and global warming trends, the BBCP depth should be virtually detached from the ground surface. This has been shown first for standalone JSBACH simulations (González-Rouco et al., 2021) and using a mixed analytical-numerical perspective (Steinert et al., 2021a). Additionally, fully coupled experiments with the MPI-ESM using the deepened version of JSBACH have shown the relevance of the BBCP in improving the representation of subsurface temperature variability at multi-decadal and centennial time scales and its impacts on land heat uptake (García-Pereira et al., 2024), which subsequently modifies the representation of the terrestrial energy partition (Steinert et al., 2024). In the frame of ILModelS, we have also assessed the relevance of incorporating a more realistic representation of the soil hydrology in JSBACH, both in standalone and fully coupled simulations. A more exhaustive representation of soil hydro-thermodynamic processes in JSBACH has proved to produce large regional responses (Steinert et al., 2021b). The impacts are especially relevant in the Arctic, which comprehends vast extensions of permafrost soils. Permafrost hydro-thermodynamics has been studied in fully coupled MPI-ESM simulations with a modified version of JSBACH under two different hydrological configurations (WET/DRY, de Vrese et al. 2023), showing remarkable differences in permafrost temperatures, active layer thickness and extent (García-Pereira et al., 2024b), and Arctic amplification of global warming (Meabe-Yanguas et al., 2024).

2. Progress of the work: a summary and contributions of the collaboration

As a result of the activity of ILModelS, four articles have been published this year (Roldán-Gómez et al., 2023; Steinert et al., 2024; García-Pereira et al., 2024a; García-Pereira et al., 2024c). Three more publications are in preparation (García-Pereira et al. 2024b, Meabe-Yanguas et al. 2024; García-Pereira et al., 2024d) and their submission is expected in the next months. Additionally, the activity of ILModelS led this year to the defense of a PhD dissertation (Roldán-Gómez, 2024) at Universidad Complutense de Madrid. It also was the focus of a six-month grade student research contract for Álex Martínez-Vila, under the Spanish program JAE-Intro. The collaboration also enabled a PhD short stay for Félix García-Pereira at the MPI-M in Hamburg (September-December 2023). The Spanish members of ILModelS also had the chance to enjoy two short stays in Hamburg (July 2022, July 2023) thanks to the "iLESM" project (i-LINK B 2021 call), an initiative promoting international collaboration funded by the Spanish Council for Research (CSIC). Additionally, in the context of iLESM, a workshop was held in Madrid in October 2023. The cross-stays and scientific workshops are intended to continue next year with funding from SMILEME. Moreover, the group results have been disseminated in various national and international conferences (see Section Outreach activity in the frame of ILModelS).

Regarding the ongoing scientific activity linked to last year's allocation request, our efforts have been focused on studying the influence of a more realistic representation of permafrost thermo-hydrodynamics in reshaping the Arctic's response to the current climate change in fully coupled MPI-ESM simulations. Using the modified version of JSBACH allowing hydro-thermodynamical coupling in permafrost areas (HTCp) by de Vrese et al. (2023), we performed an ensemble of nine MPI-ESM fully-coupled experiments (MPI-ESM HTCp) varying the subsurface vertical discretization and BBCP depth (5-, 11-layers, BBCP at 10 m; and 18-layers, BBCP at 1400 m), and the hydrologic configuration (OFF or standard JSBACH, WET, DRY). These experiments were run in 2023 for the historical period (1850-2014) and four different Shared Socioeconomic Pathways (SSPs, 2015-2100). In 2024, the 18-layer experiments were continued until 2300. An analysis of the response of permafrost to these changes in terms of surface and subsurface temperature variability, active layer thickness, and permafrost extent will be soon submitted (García-Pereira et al., 2024b). Additionally, the atmospheric response to the WET/DRY changes has been explored. A work assessing the behavior of the Arctic amplification and analyzing the feedback mechanisms involved is currently in preparation (Meabe-Yanguas et al., 2024). The impacts of the WET/DRY changes in the large-scale circulation are also being investigated (Martínez-Vila et al., 2024). Furthermore, a PhD student at the MPI-M, Zhijun Liu, is intended to start exploring the response of the AMOC in this ensemble of simulations next year.

Apart from the already mentioned MPI-ESM HTCp ensemble, the impact of the representation of the Arctic hydrology at multi-centennial and millennial time scales is studied in the Common Era. A couple of 18-layer WET and DRY of the past2k (0-2014) were started in 2023. They were meant to be finished this year with computational time requested in the last year's allocation request call. However, these simulations only ran until the sixth. The simulations crash upon consulting lookup tables to resolve the convection in the ocean. We are intensively working on finding and solving the bug and expecting to complete both simulations in 2025.

Despite the past2k WET and DRY experiments could not be completed, the node hours were successfully used for other alternative purposes of interest for ILModelS. An ensemble of 5-layer DRY and WET simulations of the historical + SSP585 periods departing from different initial conditions in 1850 was conducted. A total number of 20 simulations was performed. This ensemble will be useful to disentangle the role of internal variability in Arctic amplification in Meabe-Yanguas et al. (2024). Additionally, we executed an ensemble of standard historical + SSP585 MPI-ESM experiments with different number of subsurface layers (8 to 18 layers, 11 simulations in total). The aim of this ensemble is exploring the dependency of the ground heat with the BBCP depth in fully coupled simulations and elucidate whether it can be behind changes in the land heat uptake (García-Pereira et al., 2024d). Lastly, a proportion of the time requested last year has been devoted to get started and familiarizing ourselves with the ICON Seamless MR R2B5 atmosphere/R2B6 ocean setup, conducting some control test experiments in the process.

3. Acknowledgements

The Spanish team would like to highlight the great importance of DKRZ/MPI in supporting this project with its resources. The deeper insight in understanding the role played by the LSM in fully coupled climate models provided by ILModelS would not have materialized without the computational hours and storage capacity granted by DKRZ/MPI. We are aware of our commitment to manage these resources responsibly. We are managing HSM space and keeping track of our resource occupation comprehensively.

Last, we would like to thank the previous year's reviewers for the revision process and their constructive feedback on the report. We attempted to include all the suggestions we were provided to improve this report and limit its extension to two pages. For an extended version of this document, please click on the link in the previous page.

4. References

Find the references to the cited papers, the papers of ILModelS and the outreach activity in the extended report.