DKRZ resources request 2026 for project: ILModelS - 2025 report

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

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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), 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of Land Model depth on climate and climate change scenario Simulations; REF: CGL2014-59644-R; 2015-2018), and then superseded by GReatModelS (Global and Regional Impacts of using more realistic Land Modelling on Historical and Climate Change scenario Simulations; REF: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 was granted an extension of the continuation of the collaboration presented herein during 2026. The group is applying for a new project in the RTI 2025 call from Spanish Ministry of Science (expected in November 2025) to keep the collaboration active beyond 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. Results derived within ILModelS have proved that an insufficient BBCP depth constrains the land heat uptake because of global warming (García-Pereira et al., 2024a), biasing the terrestrial energy partition (Steinert et al., 2024), and the representation of the permafrost active layer and extent (García-Pereira et al., 2025a). 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). 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), especially in the Arctic, which comprehends vast extensions of permafrost soils (see Section 2).

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

As a result of the activity of ILModelS in 2025, one article has been submitted and is now under revision (García-Pereira et al., 2025a). Another article demonstrating that shallow BBCPs bias the representation of the long-term surface energy balance is very close to submission (García-Pereira et al., 2025b). Two more publications are in preparation (Meabe-Yanguas et al. 2025; Martinez-Vila et al., 2025) and their submission is expected in the next months. Additionally, the activity of ILModelS led to one PhD defense last year (Roldán-Gómez, 2024) and one expected in November this year (García-Pereira et al., 2025), both at Universidad Complutense de Madrid. The Spanish members of ILModelS also had the chance to enjoy a short stay in Hamburg (July 2025), where all the members of ILModelS discussed the latest outcome and future work within the framework of the project. Additionally, 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 hydro-thermodynamics in reshaping the Arctic's response to climate change. We performed an ensemble of nine MPI-ESM fully-coupled experiments (MPIESM-PePE) 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, Fig. 1). In 2024-2025, all the 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., 2025a). 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., 2025). The impacts of the WET/DRY changes in the large-scale circulation are also being investigated (Martínez-Vila et al., 2025). On the other hand, the impact of the representation of the Arctic hydrology at multi-centennial and millennial time scales was intended to be studied in the Common Era. Three 18-layer simulations of the past2k (WET, DRY, and REF) were started in 2023. However, in 2024, the simulations crashed upon consulting lookup tables to resolve atmospheric convection over the ocean. After deep research that implied many simulation tests and intensive collaboration between the members of the ILModels consortium, the problem was solved in the summer visit of the Spanish team to the MPI-M in 2025. An error in the indexing when computing evaporation minus precipitation over glaciers in mo_surface.f90 routine was triggering a water leakage in the model that forced sea level to drop, which produced the fatal crash. The three simulations had to start again from the first year of the 0 CE control and are currently in production (Fig. 2). We expect them to finish before the end of 2025. Having an ensemble of three past2k experiments exploring permafrost sensitivity to changes in the hydro-thermodynamics of the LSM is extraordinary in the context of climate modeling of the Common Era. Therefore, it will contribute to disentangle the mechanisms that condition climate response to changes in external forcing in the Arctic, with teleconnections globally.

3. Acknowledgements
The Spanish team would like to highlight the great importance of DKRZ/MPI in supporting this project with its resources. 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.

An extended version of this report including figures and a list of references is included here:
http://ucmfgr.es/downloads/inandout/20251021_ILModelS_report2025-DKRZ_for2026.pdf