DKRZ resources request 2024 for project: ILModelS – 2023 report

Project Title:

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

Project coordinator at DKRZ:

Johann Jungclaus (Max Planck Institute for Meteorology)

Principal Investigators:

Philipp de Vrese, Johann Jungclaus (Max Planck Institute for Meteorology),

Stefan Hagemann (Helmholtz-Zentrum Hereon),

Fidel González Rouco (Universidad Complutense de Madrid),

Participants:

Félix García Pereira (Universidad Complutense de Madrid), **Elena Garcia Bustamante** (CIEMAT), **Stephan Lorenz** (Max Planck Institute for Meteorology), **Norman Steinert** (NORCE - Norwegian Research Center)

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Background

The ILModelS (project n. 1026) consortium is an international initiative with cooperation partners from the Max Planck Institute for Meteorology (MPI-M), the Universidad Complutense de Madrid and CIEMAT (Spain), and the Helmholtz Center Geesthacht (HEREON). This initiative has been continuously funded 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of Land Model depth on climate and climate change scenario Simulations; REF: CGL2014-59644-R; 2015-2018), and then superseded by GReatModelS (Global and Regional Impacts of using more realistic Land Modelling on Historical and Climate Change scenario Simulations; REF: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 German-Spanish scientific collaboration presented herein at least until 2025.

In the ILModelS consortium we tested the effects of improved subsurface representation of the Max Planck Institute Earth System Model (MPI-ESM; Hagemann et al., 2013; 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 make use of an insufficiently deep zero-heat-flux Bottom Boundary Condition Placement (BBCP) located too close to the surface (ca. 10 m), and a poor vertical layer discretization. This constrains the land heat uptake due to global warming (Cuesta-Valero et al., 2016) and the representation of permafrost active layer and extent (Burke et al., 2020). Recent work within the ILModelS collaboration has shown that a realistic representation of subsurface temperature variability requires a BBCP depth that is virtually detached from the ground surface, both in standalone JSBACH simulations (González-Rouco et al., 2021), and from a joint analytical-numerical perspective (Steinert et al., 2021a). Later fully coupled experiments with the MPI-ESM using the deepened version of JSBACH have shown the relevance of the BBCP in the correct representation of subsurface temperature variability at multi-decadal and centennial time scales and its impacts on land heat uptake (García-Pereira et al., 2023a) and the subsequent representation of the terrestrial energy budget (Steinert et al., 2023). Moreover, a better representation of hydro-thermodynamic processes in JSBACH has proved to produce large regional responses (Steinert et al., 2021b), mostly across the Arctic region. Ongoing work with improved soil hydro-thermodynamics over permafrost affected areas (De Vrese et al., 2023; García-Pereira et al., 2023b) is also showing this in coupled simulations.

Progress of work: a summary

To adhere to the recommended two-page format, we will here provide a brief overview of the work and studies currently in development. A more detailed report including more specific information about ongoing work and a complete list of references can be found at this link: http://tifon.fis.ucm.es/fidel/downloads/dkrz/ILModelS_report_extended-DKRZ_for2024.pdf. References to articles resulting from this activity have been uploaded to the DKRZ server.

Fully-coupled MPI-ESM simulations of the industrial era (1850-2100) with a deep version of its LSM, JSBACH, were conducted. The aim was to assess surface and subsurface temperature variability and heat uptake changes due to having a deeper subsurface thermal scheme when there is active feedback from the atmospehere. Results show that deepening the BBCP induces greater land heat uptake values that align closer with observational data. Additionally, this leads to adjustments in the distribution of energy within the Earth's system, with increased energy uptake in the land and reduced, albeit relatively minor, uptake in the ocean, which better corresponds to the observed energy distribution. Land heat uptake and its role in terrestrial heat storage partitioning was a focal point in the recent IPCC AR6 (von Schuckmann et al., 2020; Cuesta-Valero et al., 2021; Forster et al., 2021), so the results may be of interest for the community. These results are presented in two publications that have been developed this year (García-Pereira et al., 2023a; Steinert et al., 2023) and are ready for submission (see extended version). The temperature variability and land heat uptake assessment has been extended to multi-centennial time scales with the conduction of a coupled fully forced MPI-ESM simulation of the last 2000 years (Past2k, 0-2014) using PMIP4 forcings (Jungclaus et al., 2017) including the deep configuration of JSBACH.

Moreover, the team has completed an ensemble of simulations conducted with a version of MPI-ESM incorporating an improved representation of hydrological features in the permafrost regions that allows hydro-thermodynamical coupling (HTCp). This version of the MPI-ESM model was developed within the MPI-M "The Land in the Earth System" department (de Vrese et al., 2021; de Vrese & Brovkin; 2021). We ran a set of 9 HTCp CMIP + ScenarioMIP (preindustrial control, historical and SSP126/SSP534os/SSP585; scenarios yet unfinished) simulations as part of this ensemble, combining a different representation of the subsurface vertical layering (5/11/18 layers) and different configurations of Arctic soil hydrological features. These features can be inactive, which makes the HTCp version of the model identical to the standard JSBACH (OFF configuration), or be active and generate diverging states of the Arctic land hydrology (WET and DRY configurations; de Vrese et al., 2023). Results stemming from the ensemble show the relevance in deepening the BBCP on the permafrost thawing in the 21st century, in terms of permafrost extent reduction and active layer thickness deepening (García-Pereira et al., 2023b) for the three configurations. Moreover, WET (DRY) representation of the Arctic generates a colder (warmer) global climate, with temperature differences that can be up to 3 °C in northern high latitudes. These greater differences in the Arctic are linked to the ice-snow-albedo feedback (Meabe-Yanguas et al., 2023).

Lastly, this year we started to conduct a couple of deep simulations with the WET and DRY versions of the HTCp model. The intention is to evaluate the operation of the changes in temperature variability and hydrology in the Arctic at centennial and multi-centennial time scales. A couple of 0 CE 500-yr control runs were already completed, and both all-forcing Past2k simulations are running now on ca. 600 CE.

Contributions of the collaboration

Apart from the aforementioned publications (Melo-Aguilar et al., 2020; González-Rouco et al., 2021; Steinert et al., 2021a,b; García-Pereira et al., 2023a,b; Steinert et al., 2023), the collaboration between the German and Spanish teams in ILModelS has brought relevant scientific outcomes in the past years. It made possible a PhD dissertation (Steinert, 2021) that was defended in Universidad Complutense de Madrid and co-supervised by Dr. Johann H. Jungclaus, from MPI-M, and a MSc Thesis (Pérez-Pérez, 2021) that was fully constructed from JSBACH standalone simulations data. An extension of the work in González-Rouco et al. (2021) and Steintert et al. (2021b) was granted two prizes in both the "PhDay Físicas UCM 2019" and the "PhDay Físicas UCM 2021". Furthermore, the collaboration has facilitated the pre-doctoral stays at MPI-M in Hamburg for Camilo Melo-Aguilar (September-November 2019), Norman Steinert (October-December 2020), and presently Félix García-Pereira (September-December 2023), which have fostered the collaboration between the UCM and the MPI-M and clearly contribute to the development of their PhD projects. The group members also had the chance to enjoy some short stays either at Hamburg or Madrid thanks to "iLESM" (i-LINK B 2021 call) project, an international collaboration initiative funded by CSIC (Spanish Council for Research). These cross-stays are intended to continue soon within the frame of the Spanish team project SMILEME. A workshop in Madrid has been also taken place in October 2023 within iLESM, where the group will have the chance to discuss the latest results derived from the simulations and think of potential mid-term strategies. Further, the group has also participated in multiple conferences (listed in "References", "Outreach activity" in the extended version of this document) which has made it possible to disseminate the joint activity carried out under ILModelS.

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 also like to thank the last year's reviewers for the revision process and their constructive feedback on the report. We attempted to include all the suggestions we were provided with to improve this report.