DKRZ resources request 2019 for project 1026: ILModelS – 2018 report

<u>Project Title:</u> (1026) Impact of Land Model depth on climate and climate change scenario Simulations (ILModelS)

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Background

In ILModelS, we test the effects of improved subsurface layer representation in the stand-alone version of JSBACH (Hagemann et al., 2013), the atmosphere model ECHAM6.3 (including JSBACH), and the Max Planck Institute Earth System Model (MPI-ESM, including JSBACH and ECHAM6, Giorgetta et al., 2013; Jungclaus et al., 2013). There is a number of evidences (MacDougall et al. 2008; González-Rouco et al. 2009) suggesting that the simulations of subsurface thermodynamics in current GCMs might not be accurate enough since typically the thermodynamic component in a LSM makes use of an insufficient number of discretized subsurface layers and imposes a zero heat flux Bottom Boundary Condition Placement (BBCP) that is located too close to the surface. Most of the current generation of GCMs use BBCPs that are shallower than 10m depth.

Status of the first phase and scope of planned work

JSBACH stand-alone simulations

In the first project phase, we completed the implementation of a deeper Bottom Boundary Condition Placement (BBCP) into JSBACH. We extensively used the standalone JSBACH version to derive results for different radiative forcing simulations (piControl, PIC; historical, HIS; and scenario, RCP) with the modifications developed in the project. An in-depth revision of first simulation results revealed a necessity for piControl-simulations longer than previously expected because for the equilibrium temperature response to an increased soil depth to be reached, a longer than expected time span was required (Fig. 1). A revised discretization of the model structure with additional model layers up to ~1400m has been implemented in subsequent steps to accommodate for temperature signals of the order of millennia. The new soil scheme now holds 7 additional model layers, instead of the 4 that were introduced previously in 2018.



Figure 1: a) Global equilibrium temperature response of the respective subsurface layers to the PIC forcing conditions using a 9-layer LSM scheme with a depth of 274 m. b) Global subsurface temperature from our 9-layer deep BBCP LSM configuration for the historical (1850-2005) and RCP8.5 (2006-2100) JSBACH off-line simulations.

We have explored the effects of increasing the depth within the LSM in off-line control, historical and scenario simulations that have proved an impact in the ground and surface temperatures due to the extra space allowed to store energy and also water in the subsurface (Fig. 1b, Fig. 2). Differences between simulations with shallow and our extended/detached BBCP for the HIS and RCP radiative forcing revealed an overall global cooling in the upper layers below the surface (Fig. 2a). At the same time, terrestrial heat storage change has drastically increased in a deepened soil model (Fig. 2b). Both effects can be explained by the physical space made available by increasing the vertical depth of the soil that allows the temperature signal to penetrate deeper into the soil attenuating homogenously with depth (not shown), which matches well the expectations (e.g. Smerdon and Stieglitz., 2006; MacDougall et al., 2008; González-Rouco et al., 2009). A paper on this development with respect to the thermodynamic aspects is currently in preparation and it is expected to get submitted in early 2019 (González-Rouco et al., 2017a; 2017c; 2018; Steinert et al., 2018a; 2018b).

Specific efforts addressed the inclusion of permafrost-related processes (non-default exchange of latent heat processes in JSBACH) in comparison to the standard model. This allowed for sensitivity experiments considering water phase changes that have been conducted with implications for climate variability and change at the regional level in areas where freezing and thawing are of importance. In line with new development in the representation of hydrology (Hagemann and Stacke, 2015) and permafrost (Ekici et al. 2014), additional initial conditions for the new deep LSM structure were produced (Fig. 3). They include updated soil and water-table parameters that favor the simulation of hydrological aspects in JSBACH, specifically important for northern high-latitude (mostly permafrost) regions. This development doubled the number of LSM off-line experiments accomplished with respect to the initial CPU estimation.



Figure 2: a) Temperature differences between our deep JSBACH 9-layer and the original shallow 5-layer JSBACH configuration for subsurface layer 5 (9.83m) over 30 years of the RCP8.5 (RCP) off-line simulation. b) Annual heat content change in the RCP8.5 future scenario simulation using a deep JSBACH 9-layer (274m) configuration.

The first half of 2018 was used to develop these new initial conditions. The corresponding additional JSBACH off-line simulations were generated subsequently. This contributes importantly to advances in Land Surface modeling in JSBACH. A second paper on the hydrological framework is currently in preparation and is expected to be finalized in early 2019 as well (Steinert et al., 2018c)

ECHAM6+JSBACH simulations

In addition, we have launched the atmosphere-coupled version ECHAM6+JSBACH for PIC, HIS and RCP radiative forcing conditions to prepare the next project phase. This allows for a more realistic representation of energy balance at the surface and terrestrial energy storage that is not possible in the JSBACH standalone experiment. We understand that running the atmosphere-coupled simulations occupies far more computational time and storage than the stand-alone version. For this reason, we compromised our simulations by the choice of the shallowest and deepest model configurations only. However, for a more comprehensive analysis, all subsequent layer configurations would be needed. The adaptation of the model to improved hydrology representation in terms of latent heat exchange (Ekici et al. 2014) is not yet possible in ECHAM6, but the newly developed initial condition datasets will be implemented and thus require twice the number of simulations as estimated. The analysis of this set of simulations will allow a more comprehensive evaluation on the impacts of allocating more space for energy- and water-related processes when the LSM is coupled to the atmosphere in a more realistic climate.

Fully coupled MPI-ESM simulations

The improvements will finally be tested in the coupled system MPI-ESM to allow for a global scale evaluation of impacts on the energy balance. In such a way, we will be able to evaluate the net effect of each one of the principal climate sub-systems on the climate variability simulated using a deeper and more realistic soil module. Such analysis grants the feedback with the simulated climate subsystems in fully coupled experiments.



Figure 3: Differences between old and new initial file datasets (also see Hagemann and Stacke, 2015) for a subset of four water-table variables that are important for the soil moisture in the hydrological regime of JSBACH (which is also influenced by changes in the thermal regime in the case of active latent heat exchanges): a) soil depth until bedrock, b) rooting depth of plants, c) maximum soil water capacity, d) soil wetness.

Additionally, to investigate the effect of the LSM depth on long-term climate variability in a GCM, a last-millennium simulation shall be carried out with the MPI-ESM in the frame of ILModelS. This will include agreed PMIP4 forcings (Jungclaus et al. 2016) and will allow for contributions to the next generation of PMIP4 runs with an MPI-ESM that incorporates a more realistic BBCP (e.g. Melo-Aguilar et al., 2017, 2018a, 2018b, 2018c). Therefore, the aim is to provide last millennium simulations based on the MPI-ESM with an improved version of the land component in the context of the CMIP6/PMIP4 community (Eyring et al., 2016; Jungclaus et al., 2016) aiming at contributing to the following IPCC assessment. Robust knowledge about multi-centennial climate variability grants understanding about the responses of the climatic system to the radiative forcings in the past.

References: (project team members in black)

- Ekici, A., C. Beer, S. Hagemann, and C. Hauck, Simulating high-latitude permafrost regions by the JSBACH terrestrial ecosystem model, *Geoscientific Model Development*, 7, 631–647, doi: 10.5194/gmd-7-631-2014, 2014.
- Eyring, V., Bony, S., Meehl, G.A., Senior, C.A., Stevens, B., Stouffer, R.J. and Taylor, K.E. "Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization". *Geoscientific Model Development*, 9(5), pp.1937-1958, 2016.
- Giorgetta, M. A., E. Roeckner, T. Mauritsen, J. Bader, T. Crueger, M. Esch, S. Rast, L. Kornblueh, H. Schmidt, S. Kinne, C. Hohenegger, B. Möbis, T. Krismer, K.-H. Wieners, and B. Stevens, "The atmospheric general circulation model ECHAM6 Model description", Berichte zur Erdsystemforschung / Max-Planck-Institut für Meteorologie, vol. 135, Max-Planck-Institut für Meteorologie, 2013.

- González-Rouco, J. F., H. Beltrami, E. Zorita and M. B. Stevens. "Borehole climatology: a discussion based on contributions from climate modelling". Climate of the Past., 5, 97-127, (CPD.4, 1-80, 2008), 2009.
- González-Rouco, J.F., E. García-Bustamante, N. Steinert, S. Hagemann, S. Lorentz, J. Jungclaus, P. de Vrese, C. Melo-Aguilar, J. Navarro. "Impact of land model depth on long-term climate variability and change" presented (oral) at the Fourth International Conference on Earth System Modelling (4ICESM), Hamburg, Germany, 2017a.
- González-Rouco, J.F., E. García-Bustamante, N. Steinert, S. Hagemann, S. Lorentz, J. Jungclaus, P. de Vrese, C. Melo-Aguilar, J. Navarro. "Impact of land model depth on long-term climate variability and change" presented at (poster) at the 1st PMIP4 Conference, Stockholm, Sweden, 2017b.
- González-Rouco, J.F., E. García-Bustamante, S.Hagemann, S. Lorentz, J. Jungclaus, P. de Vrese, C. Melo-Aguilar, J. Navarro, N. Steinert. "Impact of Land Model Depth on Long Term Climate Variability and Change" presented (poster) at 2017 Fall Meeting, AGU, New Orleans, LA, 11-15 Dec. 2017c.
- González-Rouco J. F., N. Steinert, S. Hagemann, E. García-Bustamante, P. de Vrese, J. Jungclaus, S. Lorenz and C. Melo-Aguilar. "Increasing the depth of a Land Surface Model I: Implications for the subsurface thermal and hydrological regimes" In preparation to be submitted to Geoscientific Model Developments. 2018.
- Hagemann, S., A. Loew, and A. Andersson. "Combined evaluation of MPI-ESM land surface water and energy fluxes", J. Adv. Model. Earth Syst., 5, 259-286, 10.1029/2012MS20008, 2013.
- Hagemann, S., and T. Stacke, Impact of the soil hydrology scheme on simulated soil moisture memory, Clim Dyn, 44(7-8), 1731{1750, doi:10.1007/s00382-014-2221-6, 2015.
- Jungclaus, J.H., N. Fischer, H. Haak, K. Lohmann, J. Marotzke, D. Matei, U. Mikolajewicz, D. Notz, and J.S. vonStorch. "Characteristics of the ocean simulations in MPIOM, the ocean component of the MPI-Earth system model", J. Adv. Model. Earth Syst., 5, 422–446, doi: 10.1002/jame.20023., 2013.
- Jungclaus, J.H., Bard, E., Baroni, M., Braconnot, P., Cao, J., Chini, L.P., Egorova, T., Evans, M., González-Rouco, J.F., Goosse, H., Hurtt, G.C., Joos, F., Kaplan, J.O., Khodri, M., Klein Goldewijk, K., Krivova, N., LeGrande, A.N., Lorenz, S.J., Luterbacher, J., Man, W., Maycock, A.C., Meinshausen, M., Moberg, A., Muscheler, R., Nehrbass-Ahles, C., Otto-Bliesner, B.I., Phipps, S. J., Pongratz, J., Rozanov, E., Schmidt, G.A., Schmidt, H., Schmutz, W., Schurer, A., Shapiro, A.I., Sigl, M., Smerdon, J.E., Solanki, S.K., Timmreck, C., Toohey, M., Usoskin, I.G., Wagner, S., Wu, C.-J., Yeo, K.L., Zanchettin, D., Zhang, Q., and Zorita, E. "The PMIP4 contribution to CMIP6 – Part 3: The last millennium, scientific objective, and experimental design for the PMIP4 past1000 simulations", *Geoscientific Model Development*, 10, 4005-4033, https://doi.org/10.5194/gmd-10-4005-2017, 2017.
- MacDougall, A. H., J. F. González-Rouco, M. B. Stevens, and H. Beltrami. "Quantification of subsurface heat storage in a GCM simulation", Geophys. Res. Lett., 35(13), L13,702, doi: 10.1029/2008GL034639, 2008.
- Melo-Aguilar, C., J.F. González-Rouco, E. García-Bustamante, J. Navarro and N. Steinert. "Influence of radiative forcing factors on ground-air temperature coupling during the last millennium: implications for borehole climatology". Climate of the Past Discussions, 1- 44, doi: 10.5194/cp-2018-72, 2018a.

Melo-Aguilar, C., J.F. González-Rouco, E. García-Bustamante, J. Navarro and N. Steinert.

"Impacts of long-term land use land cover changes on borehole temperature reconstructions" presented at (poster) 2018 EGU General Assembly, Vienna, Austria, 2018b.

- Melo-Aguilar, C., J.F. González-Rouco, N. Steinert, E. García-Bustamante and J. Navarro. "From methodological to physical bias in borehole temperature reconstruction: a new assessment from a pseudo-proxy perspective" (In prep.), 2018c.
- Melo-Aguilar, C., J.F. González-Rouco, E. García-Bustamante and J. Navarro. "Last Millennium atmosphere and soil temperature coupling in surrogate climates: implications for borehole temperature reconstructions" presented at (oral) 2017 EMS Annual Meeting, Dublin, Ireland, 2017.
- Smerdon, J. E., and M. Stieglitz, Simulating heat transport of harmonic temperature signals in the Earth's shallow subsurface: Lower-boundary sensitivities, Geophys. Res. Lett., 33(14), L14,402, doi:10.1029/2006GL026816, 2006.
- Steinert, N., J.F. González-Rouco, S. Hagemann, E. García-Bustamante, P. de Vrese, J. Jungclaus, S. Lorenz and C. Melo-Aguilar. "Increasing the depth of a Land Surface Model: Implications for the subsurface thermal and hydrological regimes" presented (oral) at the 2018 EGU General Assembly, Vienna, Austria, 2018a.
- Steinert, N., J.F. González-Rouco, S. Hagemann, E. García-Bustamante, P. de Vrese, J. Jungclaus, S. Lorenz and C. Melo-Aguilar. "Increasing the depth of a Land Surface Model: Implications for the subsurface thermal and hydrological regimes" presented (oral) at the International Conference on Terrestrial System Research: Monitoring, Prediction and High Performance Computing, Bonn, Germany, 2018b.
- Steinert, N., J.F. González-Rouco, S. Hagemann, E. García-Bustamante, P. de Vrese, J. Jungclaus, S. Lorenz and C. Melo-Aguilar. "Increasing the depth of a Land Surface Model II: Evaluation of improved permafrost representation" In preparation to be submitted to Geoscientific Model Developments. 2018c