Project: **1026**
Project title: **Impact of Land Model depth on climate and climate change scenario Simulations (ILModelS)**
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ILModelS focuses on the idea that state-of-the-art General Circulation Models (GCMs) or Earth System Models (ESMs) use Land Surface Models (LSMs) that are too shallow. 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. It has been analytically demonstrated that too shallow sub-surfaces distort the amplitude and phase of the heat propagation in the subsurface with implications for energy storage and land-air interactions (Smerdon and Stieglitz, 2006). Most of the current generation of GCMs use BBCPs that are shallower than 10m depth.

In the first phase of the ILModelS project we could successfully incorporate modifications for a deeper BBCP into the source code of a the JSBACH land model component in MPI-ESM (Giorgetta et al. 2013). Four additional subsurface layers have been added, thus extending the depth of the BBCP from 10m to 275m depth.
We have run simulations for “piControl”,”historical” and “RCP8.5” radiative forcing scenarios for JSBACH standalone with the standard five layers and BBCP at 10m depth. We made additional experiments while progressively adding subsurface layers to the deepest layer ay 275m depth. Early results show a strong sensitivity of subsurface temperature distribution to the BBCP deepening. The extended soil model depth to 275m occurs to be sufficient and necessary for the centennial scenario simulations performed. This indicates that there is a corruption of subsurface thermodynamics in shallow LSMs. Its representation appears to be more realistic in our modified model setup and matches the results of previous investigations (Stevens et al. 2007). Furthermore, we can see an amplification on the regional subsurface mean energy storage by factor of up to 10 in the RCP8.5-scenario simulation (Fig1. c,d).

It has to be noted that, before proper simulations could be started, the development and code implementation into JSBACH consumed an unexpected large share of computing time, due to the uniqueness and novelty of the approach. Additionally, new development in terms of JSBACH’s representation of hydrology has been made (Hagemann and Stacke, 2014), going from the single-layer “bucket” scheme to a 5 layer hydrology module. Implementation of this scheme required redoing some simulations with the JSBACH standalone version. More importantly, there has also been development in the permafrost representation in JSBACH (Ekici et al. 2014). First simulations show that running JSBACH with permafrost might have non-negligible effects on the model results (Fig.1 a,b). Climate-sensitive region where permafrost exists, strongly depend on a proper subsurface representation and have the potential to massively impact the terrestrial heat, water- and carbon balance. Considering the freezing/thawing cycle for permafrost (permafrost-on experiments hereafter) shows a much larger impact in terms of subsurface temperatures than experiments where these processes are included (permafrost-off hereafter). Additional impact on the subsurface hydrology is expected, but needs further investigation in detail. The standard version of JSBACH used in CMIP6 still does not include the implementation of active permafrost. Thus, investigating active layer dynamics in the context of a LSM deepening adds additional value to the activities focussing on evaluating the impact of including a proper representation of permafrost in JSBACH. Therefore, permafrost-on and permafrost-off simulations for all configurations, depths and forcings are being performed.

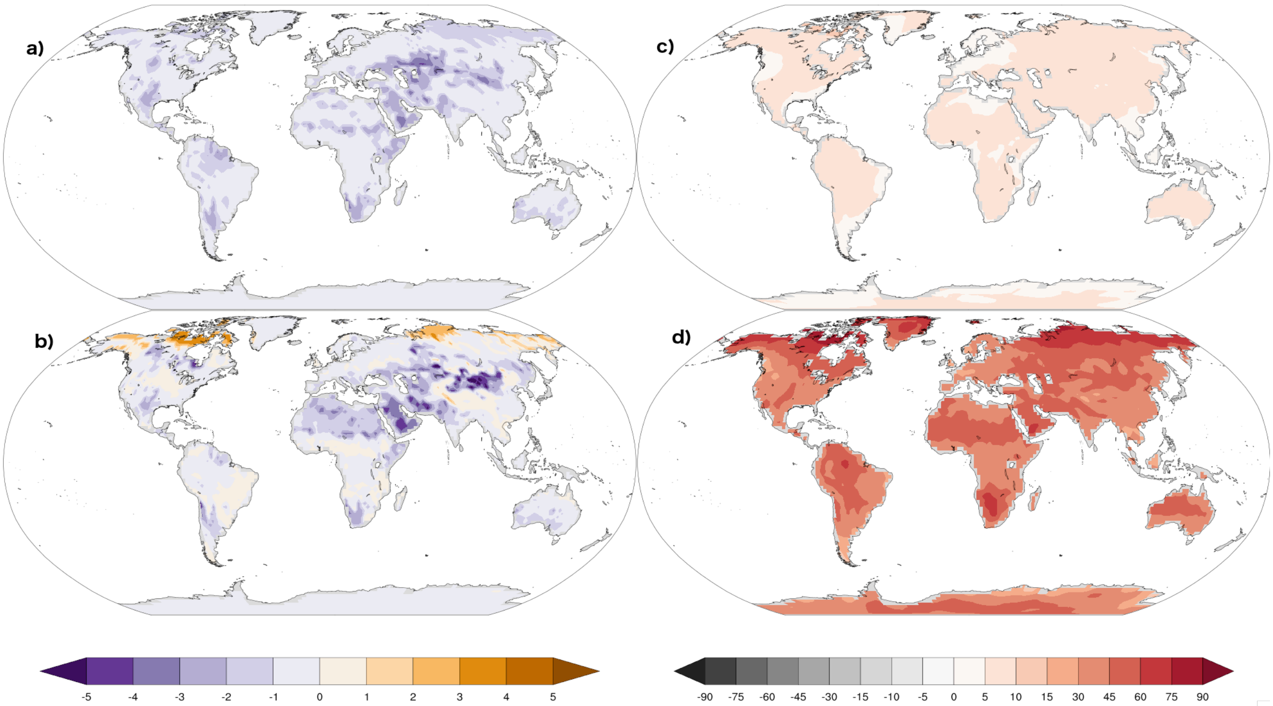

Figure. 1: Left: Temperature differences (K) for subsurface layer 5 and between the last 30 years of the RCP8.5 scenario simulation and the 5-layer permafrost-off piControl run in a) between shallow and deep BBCP in permafrost-off and in b) between permafrost-off and permafrost-on in deep BBCP. Right: Terrestrial heat storage change ($10^5 Jm^{-2}a^{-1}$) over the period (2005-2100) of the RCP8.5 scenario simulation in c) shallow BBCP permafrost-off and in d) deep BBCP permafrost-off.

Based on the first results, the conceptual structure for the initial work phase of the ILModelS project has been decided to be split up into two branches. According to the findings we want to focus on: 1) the effect of a deep BBCP depth under permafrost-off conditions and 2) the effect of considering permafrost-on in the JSBACH stand-alone. This concept incorporates the idea to contrast the state-of-the-art model version used in CMIP6 in part 1 with a more sophisticated model scheme used in part 2. Furthermore, it gives the opportunity to exclude the net effect of both proposed adaptations by investigating their influence on energy distribution and hydrological properties, respectively. For the model simulations including permafrost, some new modifications in snow modelling will be included to further investigate their effect on intensified hydrology modulation. Additionally, we want to test the uncertainty related to using two different datasets of water depth (Hagemann 2002; Hagemann and Stacke, 2014). This extends our concept of land model depth to both, BBCP and water depth. Currently two papers are in development in terms of the strategy split up to permafrost-off and permafrost-on.

Following work should reveal the importance of the deep BBCP on the soil thermodynamics in a atmosphere-coupled model configuration (ECHAM6+JSBACH), and subsequently a fully coupled model configuration (MPI-ESM). This allows us to verify the first results in the context of a connected and interacting climate system. It represents the BBCP sensitivity on climate variation and climate change simulations with state-of-the-art General Circulation Models as used in CMIP6.

Tab. 1: Roadmap for ILModelS. In green: the part that has been accomplished already.

Modification of JSBACH source code		
	Permafrost on	Permafrost off
Phase 1: JSBACH standalone	✓☐	✓
Phase 2: ECHAM6 incl. JSBACH	✓☐	✓☐
Phase 3: MPI-ESM	✗☐	✓☐

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