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Principal investigator:	**Victor Brovkin**
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Representation of vertically stratified carbon pools in ICON-Land (JSB)

The standard JSBACH soil carbon module (Yasso) is very limited with respect to the representation of below ground carbon pools—particularly in high-latitude regions where permafrost dynamics and active layer depth variations strongly influence carbon accumulation and decomposition. To address this, we have implemented a vertically stratified soil carbon scheme in ICON-Land, aligning the carbon pool distribution with the existing multi-layer structure used for hydrology and soil energy balance. Together with realistic vertical transport mechanisms such as bioturbation and cryoturbation, which facilitate the downward mixing of organic matter from surface litter into deeper soil horizons. Furthermore, soil hydrological and thermal properties are now computed interactively based on the dynamically evolving soil organic matter content, replacing the static input fields.

Using the vertically stratified carbon representation, combined with an implementation of shrub PFTs for permafrost regions, we investigated the influence of vegetation dynamics on permafrost region carbon balance, in review as Kleinen et al. (2026). In this study, we determined permafrost region changes under historical and future conditions, RCPs 2.6, 4.5, and 8.5. We could show, that the strong loss of soil carbon under conditions of permafrost thaw is significantly reduced by increased litter inputs from vegetation growth, especially if changes in vegetation distribution are considered. In the warmest scenario, this effect reduces the loss of C from the permafrost region from 349 to 68 PgC, while lower warming scenarios may even become carbon-neutral.

Laterally coupled land-surface elements in ICON-Land (JSB)

Additionally, our experimental Q-Arctic model version using the new T-Rex scheme (deVrese et al., 2026) was updated to incorporate the multi-layer Yasso framework. By integrating the vertically stratified soil carbon scheme with a physically based lateral exchange framework for subgrid-scale tiles, ICON-Land now enables a fully coupled representation of carbon dynamics across topographically heterogeneous landscapes. Carbon pools are distributed across multiple soil layers, enabling realistic vertical transport via bioturbation and cryoturbation, while the lateral exchange framework captures horizontal gradients in soil moisture and temperature across distinct microtopographic units. This dual representation—vertical stratification within the soil column and spatial heterogeneity across tiles—allows for a quasi-spatially resolved carbon cycle: carbon turnover is enhanced in dry, warm ridges, near the surface, while cold, wet depressions promote carbon preservation, particularly at greater depths. Consequently, the model captures critical feedbacks between microscale topography, soil moisture and temperature dynamics, and carbon cycling—particularly in permafrost regions where subgrid-scale heterogeneity governs large-scale carbon stability.

General improvements and bugfixes for ICON-LAND

In parallel with the core model development, this year's efforts included a series of general enhancements and critical bug fixes to improve model robustness and usability. A key correction addressed an error in the phase change latent heat implementation within the surface

energy balance, which had occasionally led to unphysically low soil temperatures. This fix ensures more stable and realistic energy partitioning at the land surface. Furthermore, the soil boundary data input routine was upgraded to support tile-specific soil property definitions, enabling greater flexibility in representing heterogeneous land surface conditions. Complementary to these technical upgrades, comprehensive code cleanup was performed—including the removal of outdated components such as the legacy ECHAM snow scheme—alongside significant improvements to inline documentation. These changes collectively enhance model maintainability, transparency, and user accessibility.

Shrubs in ICON-LAND/QUINCY

As preparation for the global scale the two new shrub plant functional types were applied in a site-level study (Emmerichs et al., preprint) which investigated the impacts of shrub coverage for Arctic ecosystem carbon uptake and storage. Based on this, we contribute with QUINCY to a model intercomparison which aims at assessing uncertainties of land surface models representing carbon in the Arctic across ecotones. For this, ICON-LAND/QUINCY (offline) simulations (carbon-only and nitrogen dynamics) and scenarios (following 2.45 pathway) were performed at Levante forced by site-specific meteorological forcing and land boundary data (identical for all models). The respective manuscript is in preparation.

Permafrost C release during the deglaciation

To better understand contributions from the permafrost region to deglacial CO_2 changes, we performed a set of deglaciation simulations, initialised from an LGM obtained from the Palmod project. Our experiments show a period of special interst around 14 ka BP, where extremely rapid changes occur, thawing several tens of PgC of C in central Europe. We consider this a prototype of events that might have occurred more often during the deglaciation. A publication is forthcoming.

Large Eddy Simulations

We performed high-resolution simulations with the EULAG LES model to study the turbulence properties in the stratified atmosphere typical for the Arctic nights or very cloudy days. The goal is to develop improved tools for the flux processing of eddy covariance towers deployed in the Arctic region. These towers measuring the surface-atmosphere-exchange fluxes are technically restricted to well-mixed turbulent conditions during daytime. During stable nighttime conditions, the accuracy vastly diminishes. By means of LES simulations we were able to corroborate promising approaches to increase the accuracy.

Furthermore, the causal link chain for the permafrost cloud feedback was studied with cloud-resolving high-resolution Large Eddy Simulations. We were able to show how soil moisture influences the cloud cover that governs, in turn, how much of the incoming short wave solar radiation is reflected into space and absorbed. The key result is that wetter soil leads to denser cloud cover which causes less short wave incoming radiation to reach the surface. This result demonstrates the mechanism behind the permafrost cloud feedback.

Finally, we used the EULAG LES model to link concentration measurements in the Arctic from unmanned areal vehicles to patch-specific fluxes on the land surface by inversion (Yazbeck et al., 2025).