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Coupling an individual-based boreal forest model with a permafrost land-surface model to forecast biomass development in boreal larch forests at the Siberian treeline

Motivation

Boreal forest in Siberian permafrost areas (fig. 1, right) are highly sensitive to global warming. To understand possible ecosystem changes there is a need to quantify the magnitudes of feedback mechanisms (Active layer thickness, vegetation density, height, distribution and establishment). We simulate the dynamic vegetation response to changes in permafrost temperature and hydrology over large timescales and across a wide boreal regions.

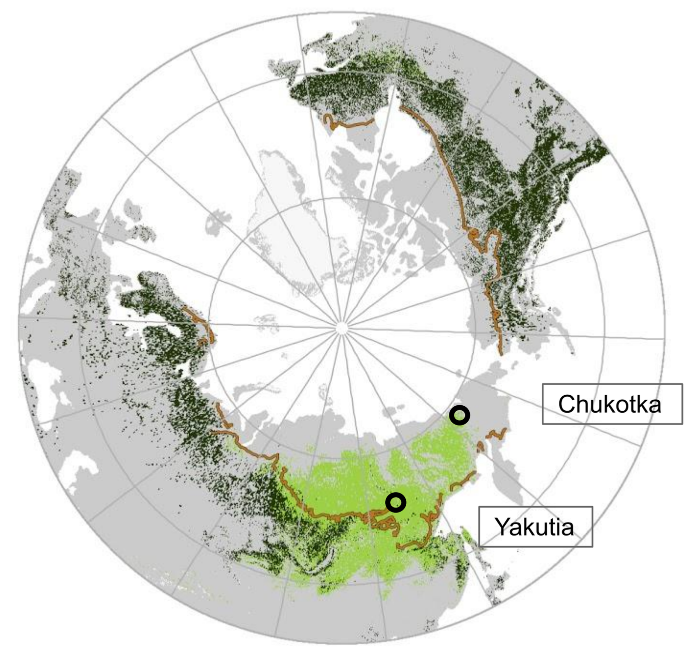

Fig 1: Map of boreal evergreen (dark green) and deciduous /light green) forest distribution and the discontinuous permafrost line (brown). Data: ESA CCI Land Cover forest classes. ESA. Land Cover CCI Product User Guide Version 2. Tech. Rep. (2017).

Develop LAVESI for coupling

We use an existing individual-based spatially explicit vegetation model that simulates *Larix* L. tree stands driven by climate forcing (Kruse et al. 2016). Based on field data from an expedition to Chukotka and Central Yakutia in 2018 we includ biomass estimations and an export function for leaf and plant area indices (in m²/m²) on 100 m² sub-grids. [See progress on Github[a]]

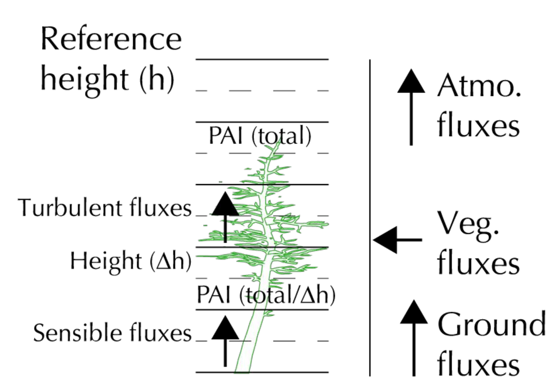

Fig. 2: Schematic illustration of the multilayer canopy module following Bonan et al. (2018).

Extending CryoGrid with a vegetation module

Further, we use a one-dimensional, numerical land surface model that simulates diverse processes in periglacial landscapes and reproduces the surface energy balance in order to represent energy transfer processes between the ground and the atmosphere (Westermann et al. 2016). We have extended this with a complex multilayer canopy model featuring a roughness sublayer turbulence parameterization (Bonan et al. 2018) to enable the use in boreal forest ecosystems (fig. 2, left).

Sensitivity analysis

In a first study we have assessed the impact of boreal forest structure and morphology on the evolution of the thermal regime of permafrost (fig. 3, right). A dense canopy has a higher insulating effect, resulting in warmer winter and summer conditions in the top ground layers.

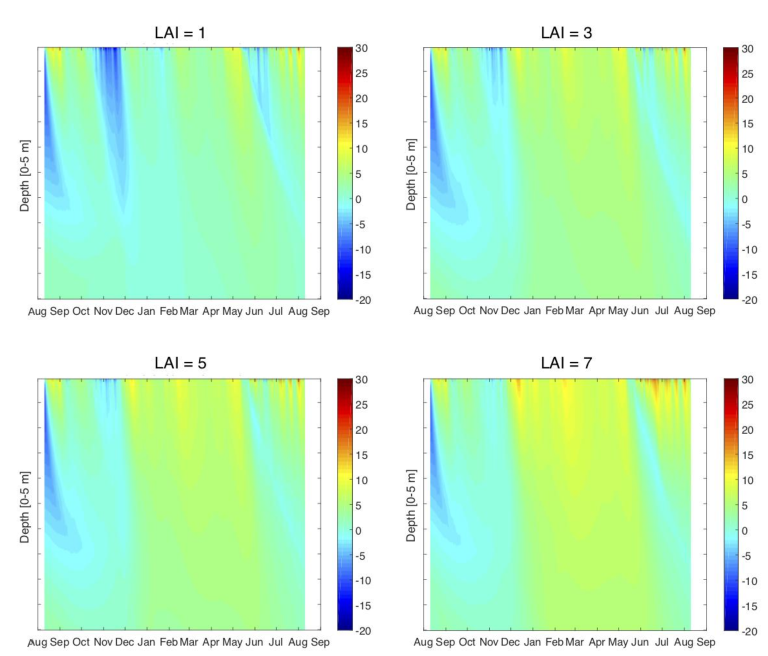

Fig 3: Permafrost sensitivity to different forest densities for a one year period. Shown is the ground temperature difference (°C) between leaf area index 1, 3, 5, 7 and grassland from the surface to a depth of 5 m.

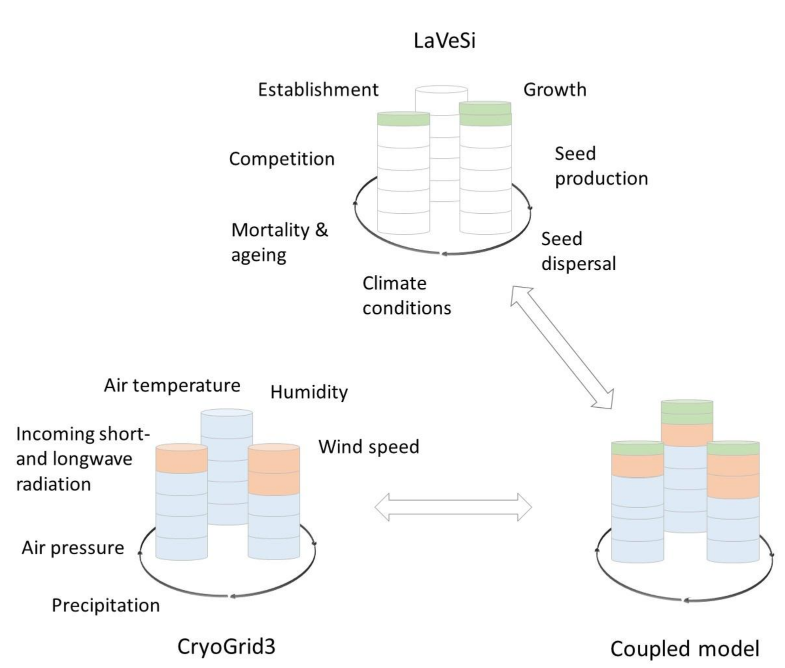

Fig 4: Schematic illustration of the coupling of LAVESI and CryoGrid.

Coupling vegetation and ALT dynamics in LAVESI-CryoGrid

Combining the strength of both model approaches, we can simulate the turnover of heat, water, and snow between atmosphere, forest canopy and ground based on the exchange of key parameters such as the forest structure and the ALT (fig. 4, left).

Preliminary results

While LAVESI runs are fast, the coupled version needs higher computational power. To be able to quickly test the impact of ALT on vegetation dynamics, we implement an abstracted ALT estimation based on coupled LAVESI-CryoGrid runs.

Accurate ALT estimation is crucial for forecasts

We evaluated the impact of ALT on realized tree growth and ultimately on the development of biomass. A stronger impact forces larger population sizes but population dynamics are delayed (fig 5, right).

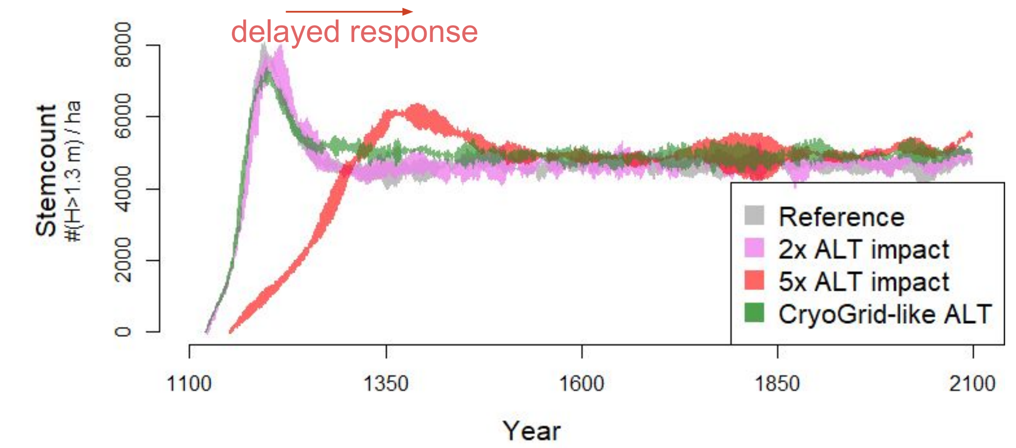

Fig. 5: Population dynamics are delayed when ALT impact is stronger in simulation runs. These start on bare ground at year 1100 with randomized weather until 1900, and thereafter ERA-Interim reanalysis data that was extended to 2100 (RCP8.5).

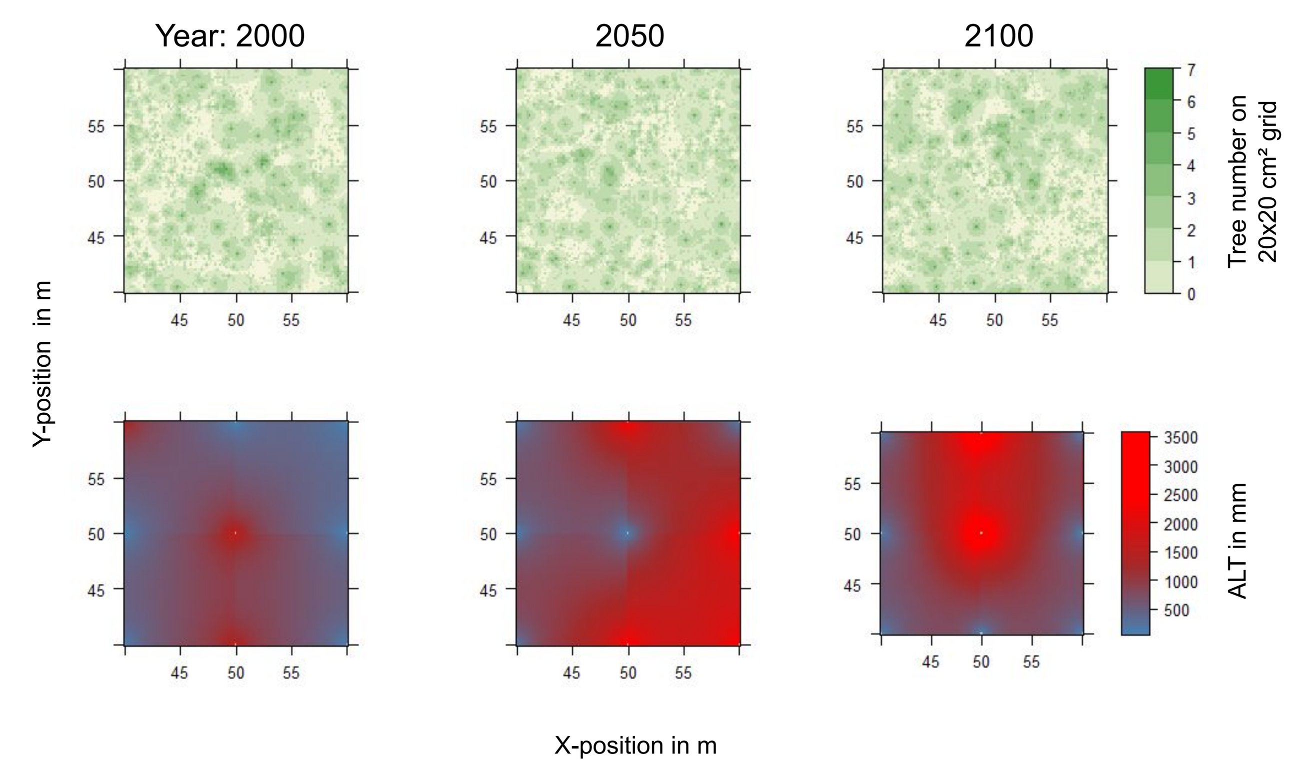

Fig. 6: 2D-view on the centre of simulated tree stands for 2000, 2050 and 2100. Top: Tree density values. Bottom: Resulting ALT based on the forest structure above.

ALT increases with warming

While ALT generally increases with warming (fig. 6, left), the tree density simulated by LAVESI is patchy. Therefore the warming leads to higher within-stand variety of LAI values (extremes of 2000 and 2100 at 43-1527 and 97-3584 mm).

Biomass increases linearly in coupled version

In reference and coupled simulations biomass increases over the course of the 21st century (fig. 7, below).

However, in the enhanced ALT computation it can be observed that biomass increases linearly whereas it did not change in the reference run in the first half of the 21st century.

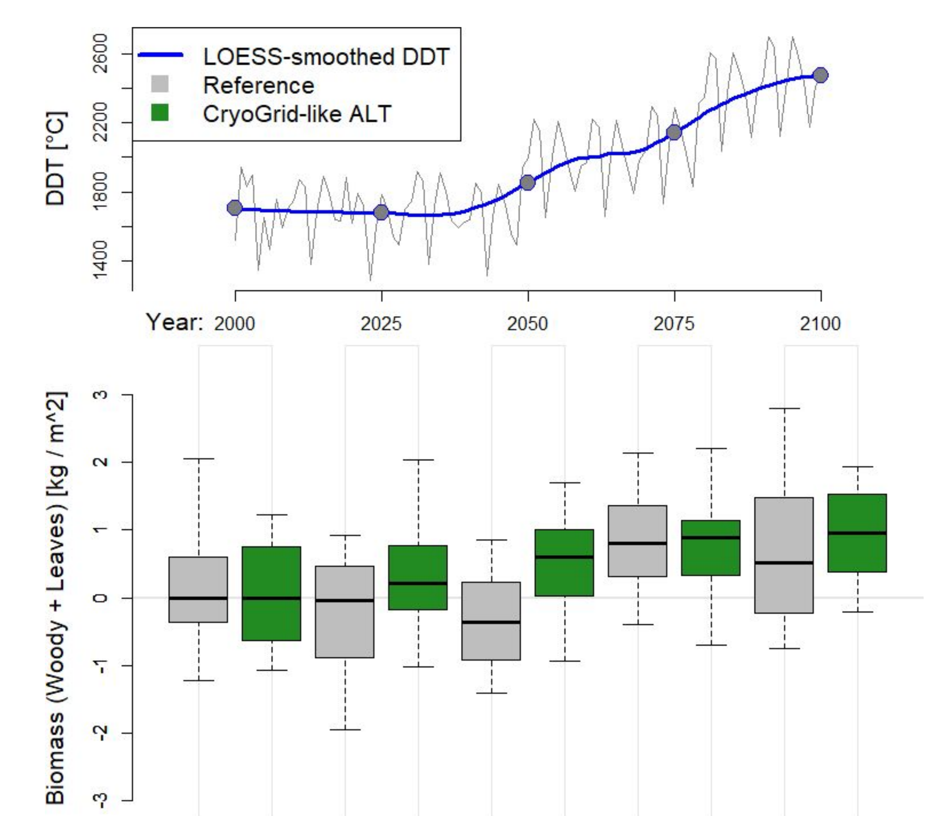

Fig. 7: Top: Degree day temperatures for 2000-2100. Bottom: Biomass development in decadal steps for 2000-2100 simulations for a reference run (grey) and for the coupled run with ALT as a dynamic input based on CryoGrid (pink).

Preliminary conclusions

The coupled ground module has some difficulties in reproducing the very low ALT typically found in pure larch stands of Eastern Siberia. Nevertheless, and as shown by the first model simulations, the coupled models more accurate ALT estimation has a high impact on larch growth and is crucial for future projections of ecosystem dynamics. As shown, biomass and ALT increase under the warming scenario RCP 8.5.

Outlook

- Integration of fire / disturbance
- Use of a fast CG/Forest model (coupled to LAVESI) for pan-siberian larch forest simulations

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Stay in touch
a) Github repository: https://github.com/StefanKruse/LAVESI/tree/LAVESI-CRYOGRID

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