Using dynamical downscaling to close the gap between global change scenarios and local permafrost dynamics

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Even though we can estimate the zonation of present-day permafrost from deep-soil temperatures obtained from global coupled atmosphere-ocean general circulation models (GCMs) by accounting for heat conduction in the frozen soil, it is impossible to explicitly resolve soil properties, vegetation cover and ice contents in great details due to the coarse resolution of contemporary GCMs that prevents a realistic description of soil characteristics, vegetation, and topography within a model grid box. On the local scale, descriptions of the heterogeneous soil structure in the Arctic exist, but only for limited areas. We propose to narrow the gap between typical GCMs on one hand and local permafrost models on the other by introducing as an intermediate step a high resolution regional climate model (RCM) to downscale surface climate characteristics to a scale comparable to that of a detailed permafrost model. This results in a considerably more realistic depiction of present-day mean annual ground temperature and active layer depth, in particular in mountainous regions (Stendel et al., 2006). By using global climate change scenarios as driving fields, one can obtain permafrost dynamics in high temporal resolution on the order of years. For the 21st century (scenarios A2 and B2), we find an increase of mean annual ground temperature by up to 6 K and of active layer depth by up to 2 m within the East Siberian transect. According to these simulations, a significant part of the transect will suffer from permafrost degradation by the end of the century.

Many permafrost models are based on the concept of a ‘surface frost index’ or ‘deep soil frost index’ (Stendel and Christensen, 2002) even though at least surface temperatures are not directly related to permafrost properties. One can circumvent complications associated with the explicit parameterisation of snow cover, but such an approach needs information about soil properties, vegetation and snow cover which hardly are realistic on a typical GCM grid. One possibility to overcome resolution-related problems is by means of downscaling to use a regional climate model (RCM). Instead of calculating a frost index from RCM data, we use the RCM to create boundary conditions for a sophisticated permafrost model. Our approach is novel in that the spatial resolution of the RCM and the permafrost model is comparable (0.5°), so that output from the RCM can be directly used to force the permafrost model. Furthermore, problems with soil, vegetation and snow properties can be overcome, as we can either pass information to the permafrost model from RCM output, or information from digitised Geographic Information Systems (GIS), where available, can be used to create forcing fields for the permafrost model. While downscaling procedures are a well established tool, no attempts have been undertaken so far to use dynamical downscaling in permafrost modelling.

As the driving AOGCM, we have chosen the state-of-the-art coupled ocean-atmosphere model ECHAM4-OPYC3. The RCM we have used is HIRHAM4 (Christensen et al., 1998), which can be thought of as a high resolution limited area version of ECHAM4. As the final step for regional permafrost modeling we have used the GIPL model (Geophysical Institute Permafrost Lab) of the University of Alaska Fairbanks (Sazonova and Romanovsky, 2003). The model is a quasi-two-dimensional, quasi-transitional, spatially distributed, physically based analytical model for the calculation of active layer thickness (ALT) and mean annual ground temperature at the permafrost table (MAGT) and uses the so-called modified Kudryavtsev's approach which is based on the theory of wave propagation in a medium with phase transitions. The input data are mean annual air temperature and its seasonal amplitude (calculated from monthly means), average winter snow depth and density, composition, water content and thermal properties of soils and characteristics of vegetation cover and geomorphologic features.

According to the GCM scenario simulations, an increase of 2m air temperature of 8 to 11 K for scenario A2 and 6 to 9 K for scenario B2 can be expected for the Russian Arctic, with a corresponding increase in mean annual ground temperature by 2 to 6 K. According to the GIPL simulations, the mean annual temperature at the bottom of the active layer will rise above the freezing point in roughly a third of the area of the East Siberian transect by the end of the 21st century. Accordingly, widespread permafrost degradation (Fig. 1) and an increase in active layer depth on the order of 0.5 to 2 m are simulated.

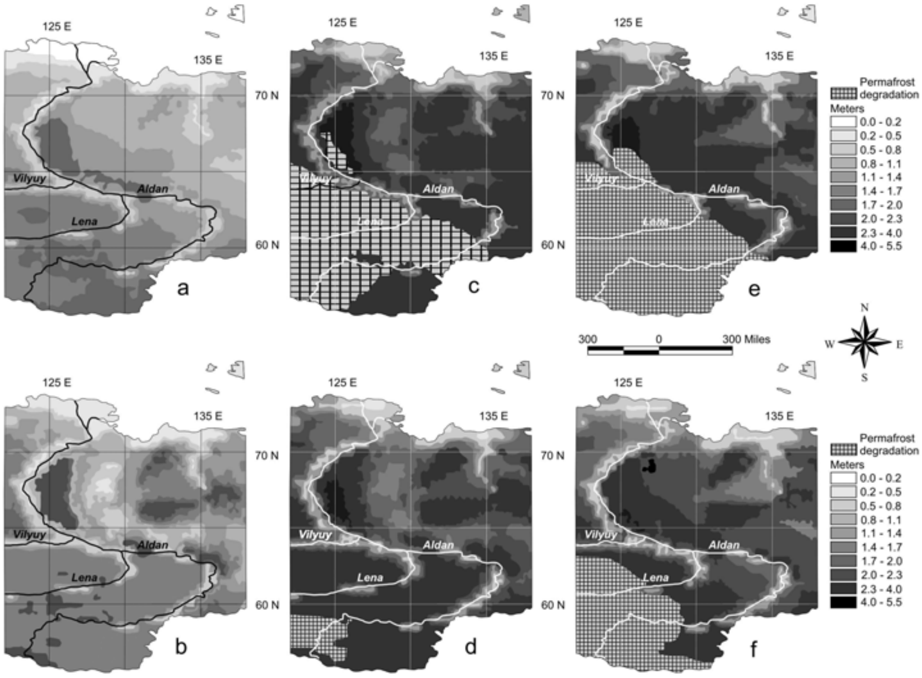

Fig. 1: Temporal evolution of ALT [m] (a) GIPL forced with observed climate data, (b) GIPL forced with HIRHAM control run, (c) GIPL forced with HIRHAM, scenario A2, average 2071-2100, (d) as (c), for scenario B2, (e) and (f) as (c) and (d), for ECHAM. Dark hatched areas denote permafrost degradation.

References
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