Geophysical Research Abstracts,
Vol. 10, EGU2008-A-04484, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-04484
EGU General Assembly 2008

Effect of Organic Matter and Soil Water Content on Permafrost Dynamics in the Northern Hemisphere: Modeling Approach

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Climate projections for the 21st century indicate that there could be a pronounced warming and degradation of permafrost in the Arctic and sub-Arctic regions. Thawing and freezing of soils is affected by many factors, with air temperature, vegetation, snow accumulation, and soil moisture being among the most significant. In order to simulate the distribution and temperatures of permafrost and active layer thickness for the entire Northern Hemisphere permafrost domain, the equilibrium model GIPL-1.1 has been developed. It is a spatially distributed permafrost model based on an approximate analytical solution of soil freezing and thawing, which includes an estimation of thermal offset due to the difference of frozen and thawed soil thermal properties. GIPL-1.1 model also accounts efficiently for the effects of snow cover, vegetation, soil moisture, as well as soil thermal properties. The model is able to calculate snow depth, thermal conductivity, and snow density for each grid point based on known snow water equivalent (SWE) and air temperature. Comparison between calculated distribution of permafrost temperatures using GIPL-1.1 model and the International Permafrost Association (IPA) permafrost map shows a very good agreement. For this study we used three different GIPL-1.1 runs, each driven by the same boundary conditions but with different soil properties. The control run takes into account the organic layer and the thawing/freezing of soil water. For the second simulation, the presence of water was still taken into account, but the organic soil properties were replaced by the mineral soil properties throughout the entire calculated domain. The third simulation was performed for mineral soil that contains no water. All three simulations were implemented for two time intervals. For the present-day climatic conditions, the

CRU2 data set with $0.5^\circ \times 0.5^\circ$ latitude/longitude resolution was used. The future climate scenario was derived from the MIT-2D climate model output for the 21st century (averaged for 2080-2099) with the same spatial resolution.

In this research we also used GIPL-2.0 model to assess the effect of organic matter and soil water/ice content on permafrost dynamic for specific sites. This numerical model simulates soil temperature dynamics and depth of seasonal freezing and thawing by solving 1D non-linear heat equation with a phase change. In this model the process of soil freezing/thawing occurs in accordance with the unfrozen water content curve and soil thermal properties, which are specific for each soil layer and for each geographical location.

Results of permafrost modeling show significant differences between all three runs in both, spatial distribution of permafrost and in permafrost temperatures. These results show that incorrect treatment of soil properties (the lack of organic matter) may lead to a reduction of calculated present-day permafrost area by 6.8 million km^2 in comparison with the control run. In case of incorrectly prescribed soil water content, much greater discrepancies were found in evaluation of the active layer thickness. These discrepancies grew dramatically when permafrost temperatures were approaching $0^\circ C$.