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Probabilistic modeling of climate change impacts in permafrost regions

O. Anisimov
Hydrological Institute, St. Petersburg, Russian Federation (oleg@oa7661.spb.edu)

The new type of climate impact models has recently come into existence. Unlike conventional models, they take into account the probabilistic nature of climatic projections and small-scale spatial variability of permafrost parameters. In this study we describe the new stochastic permafrost modeling methodology and present the predictive results obtained for the Northern Eurasia under the ensemble climatic projection for the mid-21st century.
Changes in permafrost are very illustrative of the impacts of global warming. It underlies about 22.8 million square km or 24% of the land area in the Northern Hemisphere and largely controls the state of the environment and socio-economical development in the northern lands. Observed and projected for the future warming is more pronounced in high latitudes, and there are indications that climatic change has already affected permafrost leading to deeper seasonal thawing and disappearance of the frozen ground in many locations. Particular concerns are associated with environmental and economical risks due to the damage of constructions, and with potential enhancement of the global warming through emission of greenhouse gases from thawing permafrost. Comprehensive permafrost projections are needed to predict such processes.
We developed new type of stochastic model, which operates with the probability distribution functions of the parameters characterizing the state of permafrost. Air temperature, precipitation, snow depth, as well as vegetation and soil properties contribute to the variability of these parameters in space and over time, which is taken into account in the calculations of the statistical ensemble representing potential states of permafrost under the prescribed conditions. The model requires appropriate climatic and environmental data characterizing baseline or projected for the future conditions. Four gridded sets of climatic parameters constructed through spatial interpolation of meteorological observations and model reanalysis were used to characterize the baseline climate in Northern Eurasia and evaluate regional uncertainties resulting from the differences between the databases. Additional uncertainty in predictive calculations was associated with ensemble climatic projections for the mid-21st century. Another type of uncertainty is imposed by the small-scale stochastic variations of environmental parameters that govern the response of permafrost to climate variations. We simulated the effect it may have on the state of permafrost using the following approach. In different calculations snow depth varied in the range $\pm$ 50% from the mean climatological value; lower vegetation (moss) height varied between 5 and 10 cm, and organic layer thickness – in the range 5–20 cm. The range of variation for each of the environmental parameters has been selected using observational data.
Performance of the stochastic model was evaluated using the two-step procedure. At the first step calculated for individual years statistics of the seasonal thaw depth was tested against observations at selected 1 x 1 km permafrost sites representing different bioclimatic conditions along the Russian Arctic coast. At each site the calculated ensemble was in good agreement with observations indicating that the model captures the component of small-scale variability associated with the spatial heterogeneity of environmental parameters. In the second test the model successfully reproduces the interannual variability of the ensemble-mean thaw depths at each site in the period 1990-2007.
The ultimate result of our study is the set of predictive probabilistic permafrost maps for the Northern Eurasia. Aside from portraying the "average" or "typical" active-layer thickness for the current and projected for the mid-21st century climate, such maps depict the probability of thaw depth exceeding given thresholds within specified regions. Such information has important implication in cold region engineering and risk assessment and may be used for predicting potential threats to infrastructure built upon thawing permafrost.
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