Modeling of a permafrost response to extreme temperature events

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Estimates of contemporary climate changes in the Arctic region are of particular importance due to developing infrastructure. Growing gas and oil exploration on the sea Arctic shelf require an implementation of the growing factor of the global climate change in building strategies for social-economic development in the region. Development of territories of the Arctic region is connected with a risk of environmental damage. Typical aspects of human activity at development of territories can lead to a risk of vegetation damage and removal of snow cover. These factors are important when accounting processes of atmosphere interaction with the underlying surface and subsurface frozen soil. An increase of air temperature in high latitudes of the Northern hemisphere is followed by a growth of cold-season temperature. According to observations on a meteorological station of Salekhard [1], the linear trend of average annual near-surface temperature for 1990-2015 is around 0.03 °C/year (see also [2]). The trends during winter and autumn seasons are 0.04 °C/year and 0.05 °C/year, respectively. The trend for this period in spring is around 0.02-0.03 °C/year. A linear trend of the surface air temperature is not significant in summer. Using these data a time series (25 model years) of the sinusoidal input monthly air temperatures has been prepared to exclude interannual fluctuations (experiment CTL) (fig. 1a).

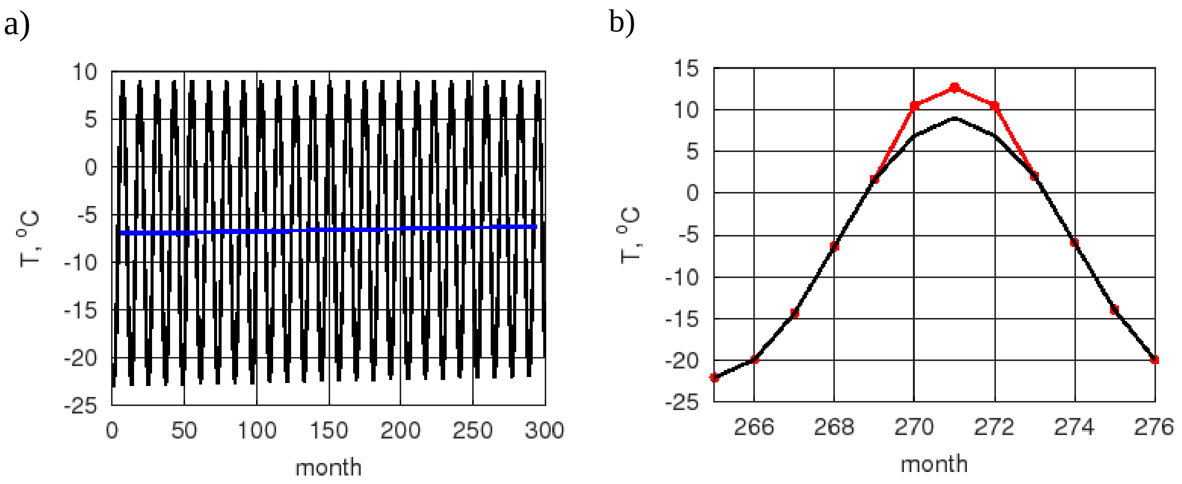

Fig. 1. Input air temperature. (a) Monthly (black) and yearly (blue) mean surface air temperatures for 25 model years (experiment CTL). (b) Monthly mean surface air temperatures in the 23rd model year in CTL (black) and EXT (red).

The increase of global and regional near-surface temperature causes an increase in the number of extreme events, including the periods of extremal high air temperatures. The response of Arctic permafrost to such events is insufficiently studied [3]. The mean summer air temperature in Salekhard was as high as 16.03 °C in 2016, some 3.6 °C above the 1990-2015 average. This is the warmest summer since 1882 when the records started, amounting to an offset of 3 standard deviations from the mean (1990-2015). To take this fact into account, we applied higher input summer temperatures in experiment EXT than those in experiment CTL for the 23rd model year (fig. 1b). For other years, the input air temperatures were the same in both experiments.

The air temperature during the summer period is the main factor of impact on the seasonal thawing of frozen soil. For modeling the impact of extreme air temperatures on the thermal regime of permafrost a heat transfer model was used [4]. To estimate the atmospheric impact on the human-changed permafrost ecosystems of the Arctic regions the vegetation- and snow-less surface were supposed. According to the model estimates for experiment CTL the soil temperature trend at a depth of 0.5 m is 0.03 °C/year for the chosen period. This trend coincides with a trend of input annual mean air temperature. The trend is about 0.02° C/year at a depth of 3 m decreasing by less then 0.02° C/year at a 10 m depth. The difference of the soil temperature in experiments of EXT and CTL is shown in fig. 2.

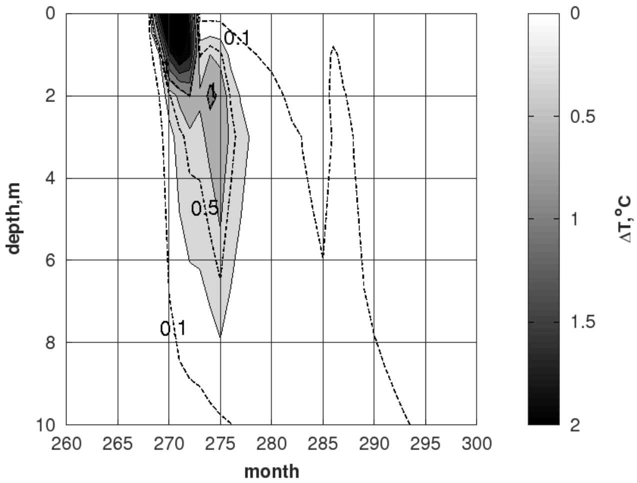

Fig. 2. Soil temperature difference between EXT and CTL experiments.

The main impact of extremal air temperature in EXT compared to CTL is noted near the surface up to 1.7-2.0 m. Though perturbation of the soil temperature field reaches approximately 10 m, at such depths it is insignificant. The largest increase in thaw depth about 6% occurs in summer and autumn. In the next years differences in thaw depth become less. Extreme temperature events can affect the soil temperature field. At the same time, the resulting perturbation is localized near the surface and disappears with time.

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