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Thermal processes of thermokarst lakes in the continuous permafrost zone of northern Siberia - observations and modeling (Lena River Delta, Siberia)

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Abstract

 Thermokarst lakes are typical features of the northern permafrost ecosystems, and play an important role in the thermal exchange between atmosphere and subsurface. The objective of this study is to describe the main thermal processes of the lakes and to quantify the heat exchange with the underlying sediments. The thermal regimes of five lakes located within the continuous permafrost zone of northern Siberia (Lena River Delta) were investigated using hourly water temperature and water level records covering a 3-year period (2009-2012), together with bathymetric survey data. The lakes included thermokarst lakes located on Holocene river terraces that may be connected to Lena River water during spring flooding, and a thermokarst lake located on deposits of the Pleistocene Ice Complex. Lakes were covered by ice up to 2 m thick that persisted for more than 7 months of the year, from October until about mid-June. Lake-bottom temperatures increased at the start of the ice-covered period due to upward-directed heat flux from the underlying thawed sediment. Prior to ice break-up, solar radiation effectively warmed the water beneath the ice cover and induced convective mixing. Ice break-up started at the beginning of June and lasted until the middle or end of June. Mixing occurred within the entire water column from the start of ice break-up and continued during the ice-free periods, as confirmed by the Wedderburn numbers, a quantitative measure of the balance between wind mixing and stratification that is important for describing the biogeochemical cycles of lakes. The lake thermal regime was modeled numerically using the FLake model. The model demonstrated good agreement with observations with regard to the mean lake temperature, with a good reproduction of the summer stratification during the ice-free period, but poor agreement during the ice-covered period. Modeled sensitivity to lake depth demonstrated that lakes in this climatic zone with mean depths > 5 m develop continuous stratification in summer for at least 1 month. The modeled vertical heat flux across the bottom sediment tends towards an annual mean of zero, with maximum downward fluxes of about 5 W m-2 in summer and with heat released back into the water column at a rate of less than 1 W m-2 during the ice-covered period. The lakes are shown to be efficient heat absorbers and effectively distribute the heat through mixing. Monthly bottom water temperatures during the ice-free period range up to 15 °C and are therefore higher than the associated monthly air or ground temperatures in the surrounding frozen permafrost landscape. The investigated lakes remain unfrozen at depth, with mean annual lake-bottom temperatures of between 2.7 and 4 °C.

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