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Heat and salt flow in subsea permafrost modelled with CryoGRID2

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Degradation of sub-aquatic permafrost can impact offshore infrastructure, affect coastal erosion and release large quantities of methane, which may reach the atmosphere and function as a positive feedback to climate warming. The degradation rate depends on the duration of inundation, warming rate, sediment characteristics, the coupling of the bottom to the atmosphere through bottom-fast ice, and brine injections into the sediment. We apply the CryoGRID2 model, coupled to a salt diffusion model, to near-shore subsea permafrost thawing offshore of the Bykovsky Peninsula in Siberia. We model permafrost through multiple settings, including 1) terrestrial permafrost, 2) shallow sea with ice grounding, and 3) shallow offshore sea (<= 5.3m depth) without ice grounding. The model uses a terrestrial permafrost temperature of -10 °C at the depth of zero annual amplitude, based on borehole observations, and a coastal erosion rate of 0.5 m/year, based on historical remote sensing imagery dating back to 1951. The seawater salinity prior to ice formation is based on a series of conductivity, temperature, and depth (CTD) measurements from summer 2017, as well as from Soil Moisture and Ocean Salinity (SMOS) satellite data. Water depth is available from echo-sounding surveys made in parallel with floating electrode electrical resistivity surveys in summer 2017. The model outputs are compared to the depth of the ice-bearing permafrost table (IBPT) determined from an electrical resistivity survey perpendicular to the shoreline. The floating electrode survey was combined with a terrestrial resistivity survey to show the transition from undisturbed terrestrial permafrost to submerged permafrost. The geoelectric surveys show a gently inclining IBPT table perpendicular to the coastline, which can be explained by a decreasing rate of degradation with increasing period of inundation. As the inundation period increases, the diffusive (heat and salt) gradients become less steep. The IBPT is located 20 m below the seabed 300 m offshore, which corresponds to 600 years of coastal erosion and an average IBPT degradation rate of 0.33 m per decade. The modelling results show an IBPT 18 m below the seabed and salty sediment up to 14 m below the seabed 300 m offshore. Therefore, the modelling results agree, at least qualitatively, with the sediment state inferred from the geoelectric data. Coupled heat and salt diffusion produces profiles of temperature and salt concentration in sediment as a function of time. The inclusion of salt flow in thermal models is particularly important in shallow waters where cryotic sediments form due to negative benthic water temperatures or ice grounding, because the depressed freezing point produced by salt diffusion can delay or prevent ice formation in the sediments and enhance the IBPT degradation rate.