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Investigations of Topographic Control on Thermokarst Development and the Ground Thermal Regime in Ice Wedge Polygons using the Advanced Terrestrial Simulator

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Permafrost degradation in ice wedge polygon terrain has accelerated in the last three decades, resulting in drastic changes to tundra hydrology which may impact rates of soil organic carbon mobilization. The goal of this research is to determine to what extent the near surface thermal regime, and hence the vulnerability of the upper permafrost, may be controlled by surface topography in ice wedge polygons. The central hypothesis is that energy is preferentially transferred into the polygon subsurface in summer at low, wet zones (such as low-centered polygon centers and troughs), then released to the atmosphere in winter through elevated zones (such as rims) that are less insulated by snowpack. Disturbance to the approximate balance between these seasonal energy fluxes may help explain the onset and development of thermokarst. In this work, we present a numerical model of thermal hydrology in a low-centered polygon near Prudhoe Bay, Alaska, constructed within the Advanced Terrestrial Simulator, a state of the art code that couples a meteorologically driven surface energy balance with equations for surface and subsurface conservation of mass and energy. The model is calibrated against a year of daily ground temperature observations throughout the polygon and used to quantify meter-scale zonation in the subsurface thermal budget. The amount of relief in the rims and the trough of the simulated polygon is then manipulated, and simulations are repeated including a pulse of one warm year, to explore the extent to which topography may influence the response of permafrost to increased air temperatures. Results suggest that nearly 80% of energy entering the ground at the trough during summer may be released back to the atmosphere through the rims in winter, substantially enhancing cooling in the ice wedge, and implying that cracking may be impeded as polygon rims erode. Active layer thickness is modestly impacted by rim size, because the subsurface in polygons with larger rims is colder at the start of the thaw season. As troughs deepen, ice wedge degradation may be accelerated by positive feedbacks, because inundated troughs sustain thicker active layers. The results expand upon current conceptual understanding thermokarst development in polygonal terrain and shed light on nonlinear changes to Arctic hydrology driven by a warming climate.