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Simulation of mass and energy fluxes at a polygonal tundra site, Lena River Delta, Siberia

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A number of recent studies conducted throughout the arctic have documented a variety of hydrologic responses associated with a shifting climate and permafrost regime. However, understanding, simulation, and prediction of the associated feedbacks, due to a shifting climate and permafrost regime, of the water and energy processes remains a major challenge. Furthermore, wet tundra environments, common throughout the circumpolar arctic, represent a major contribution to the land-atmosphere exchanges of water, energy, carbon, and greenhouse gases. Simulation of the hydrologic processes in the wet tundra environment is challenging for a number of reasons. The presence of a shallow permafrost table acts as an impermeable barrier impeding drainage of surface waters, resulting in a numerous areas of surface storage. Despite the low topographical gradients typical of wet tundra environments, the surface is characterized by small scale heterogeneities such as surface (channel) flow along the polygonal crack network. In this study, we simulate the mass and energy fluxes of Samoylov Island, located in the Lena River Delta (72°22'N, 126°30'E). Samoylov Island is located the zone of continuous permafrost and with slight elevation differences (1-5 m. and 10-16 m. on the western (3.4 km2) and eastern (4.1km2) parts of the island, respectively). The surface topography is characterized by wet polygonal tundra, although differences in surface characteristics (from extremely wet to relatively dry conditions) are observed over a few meters distance.

TopoFlow, a spatially-distributed, process-based hydrologic model is used to simulate the mass and energy fluxes of Samoylov Island. The model domain is based upon a 15-meter square DEM (163 columns, 166 rows), linearly interpolated from 18200+ survey points. The vertical accuracy of the surveyed points is estimated at 95%. Five soil layers, with depths of 0.02, 0.05, 0.08, 0.10, and 0.15 meters, represent the z-component of the model domain. Hydrologically speaking, the arctic environment is unique due to the active layer - the thin soil layer above the permafrost that seasonally freezes and thaws. As the position of the freeze/thaw interface within the active layer changes, the thermal and hydraulic properties of the also soils change. Accordingly, we represent the freezing/thawing of the active layer through changes of the hydraulic conductivity and porosity (as a proxy for soil water capacity) for each soil layer. A modified two-directional freeze/thaw algorithm is used to determine the freeze/thaw interface throughout the simulation periods. For each simulation, the following hydrologic processes are simulated: precipitation (rain, input variable), evapotranspiration (both energy balance and Priestley-Taylor methods), instantaneous infiltration to the water table, groundwater flow (Darcy flow using variable hydraulic properties), and' channel/overland flow (Manning's equation). Ponded regions are represented as soils with 100% porosity.

Preliminary results indicate that evapotranspiration is the dominant water flux for Samoylov Island. Generally, we are able to represent the surface storage regions, interpreted through comparison of measured pond level and simulated groundwater level, fairly well. The simulated ground water level in the ponded areas show a rapid rise during precipitation events followed by a slow decline due to evaporative and groundwater losses. During large precipitation events, when the groundwater level (pond level) exceeds the land surface elevation, brief periods of overland flow are simulated. The simulated overland flow pattern is much more 'flashy' compared to the stream flow hydrographs during these precipitation events. The complete water and energy balance for a ponded region, a relatively dry region, and for the entire Samoylov Island will be presented for the 2006 and 2007 summer periods. The temperature and precipitation records for the summer period (1 June - 15 August) show that the 2006 summer was slightly cooler and wetter (6.1°C average and 111 mm total precipitation) than the 2007 summer (7.24°C average and 97mm total precipitation). Results from this study are being used to help guide the summer 2008 field expedition.