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Recent warm events in Scandinavia driving development of a proglacial lake thermal regime model

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In a warming climate in which many glaciers lose mass and contribute to sea-level rise (AR5 IPCC, 2013), it is imperative to be able to predict rates of glacier retreat and freshwater flux into the oceans. Proglacial lakes form in topographic basins created by retreating glaciers and have been shown to accelerate mass loss rates through thermo-mechanical processes (Carrivick and Tweed, 2013). Consequently proglacial lakes have increased in number and extent across many mountain areas, as glaciers have retreated back from their Little Ice Age maximum positions (Carrivick and Tweed, 2013). Despite an increasing number of warm air temperature events in Arctic areas (e.g. July 2018 in Scandinavia), a common assumption persists that smaller proglacial lakes remain at a uniform 1 °C. With future predicted increases in air temperatures (IPCC AR5, 2013) it is increasingly important to challenge this assumption through direct and indirect quantification of changes in proglacial lake thermal regime. Additionally, lake and stream thermal fluxes will also have an ecological impact, particularly on temperature vulnerable species, such as Salmonids.

We have used field and remote sensing data (ASTER spanning 2010-2018) to conduct an inventory of proglacial lakes and detailed measurements from key sites in Arctic Sweden. We report an increase in number of proglacial lakes of 8% between 2010 to 2014. During August 2014 33% of glaciers had a proglacial lake in their fore-field, with 47% of these being in contact with the glacier. Analysis of ASTER AST08 data demonstrates that 11 out of the 12 largest proglacial lakes had daytime surface skin temperatures of > 6°C in July 2018, with maximum temperatures of 18 °C for a non-ice contact proglacial lake. We present thermistor data of lake surface temperatures that shows a strong validation ($R^2 = 0.9365$) of the surface skin temperatures from the AST08 temperature product.

For one of these sites, we present the first recorded proglacial lake temperatures from the front of an actively calving glacier (July 2017), which had rapidly lost 10,523 m^2 of ice (0.67% of area) between 2014 to 2018. From this site we report: (a) warmer than expected night time temperatures of 3 °C, and rapid formation of a thermally eroded notch, (b) diurnal temperature cycles from the distal section of the proglacial lake, with maximums of 8 °C and minimums of 5 °C, (c) short ($\sim$24 hour) periods of cooling following the arrival of icebergs near the glacier outlet, (d) spatial boundaries between iceberg meltwater (2 °C) and ambient lake water (5 °C) (validated by remote controlled boat thermistors), which also revealed the development of iceberg meltwater forming a thin surface layer following a reduction in wind driven mixing, (e) weak correlations ($R^2 = 0.58$) between incoming solar radiation and near surface water temperature ($\sim$5 cm depth) but no significant correlation with air temperature ($R^2 = 0.12$).

Using these data, we propose a conceptual model for proglacial lake thermal regime through different stages of deglaciation, and work towards incorporating water circulation and entrainment of warmer distal water; a factor likely to drive high subaqueous melt rates at the terminus (Roehl, 2006).