Effect of Surface Albedo Modification on Freshwater Pond Thawing

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Abstract

Previous approaches to modify the surface albedo of Arctic ice have been proposed to slow the rate of ice melt or to increase ice thickness. (Seitz 2011, Desch 2018, Field 2018) Sea ice, glacial ice, and ice-covered thermokarst lakes are all known to melt aided by surface albedo feedback loops. In this process, melting of snow and/or the formation of melt ponds on the surface of the ice causes a lowering of surface albedo, which causes more absorption of sunlight, further warming the ice and increasing the rate of melt. In this study on a freshwater pond, we demonstrate the real-time dynamics of melting and a reduction of ice melt rate by 26% via surface albedo modification.

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PRESENTED AT:

INTRODUCTION

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SNOW, ICE THICKNESS, AND ALBEDO MEASUREMENTS

Hollow glass microspheres (Potters 25P45) were applied to create a layer of 0.5mm thickness across half of a freshwater pond with diameter of 37 meters located in Lake Elmo, MN, on January 19, 2021. Prior to freezing, the pond had been segmented into two halves with plastic sheeting vertically applied across the midsection so that the water on each side of the pond was prevented from cross-circulating under the ice. A schematic of the measurement layout is provided in Figures 1 and 2.

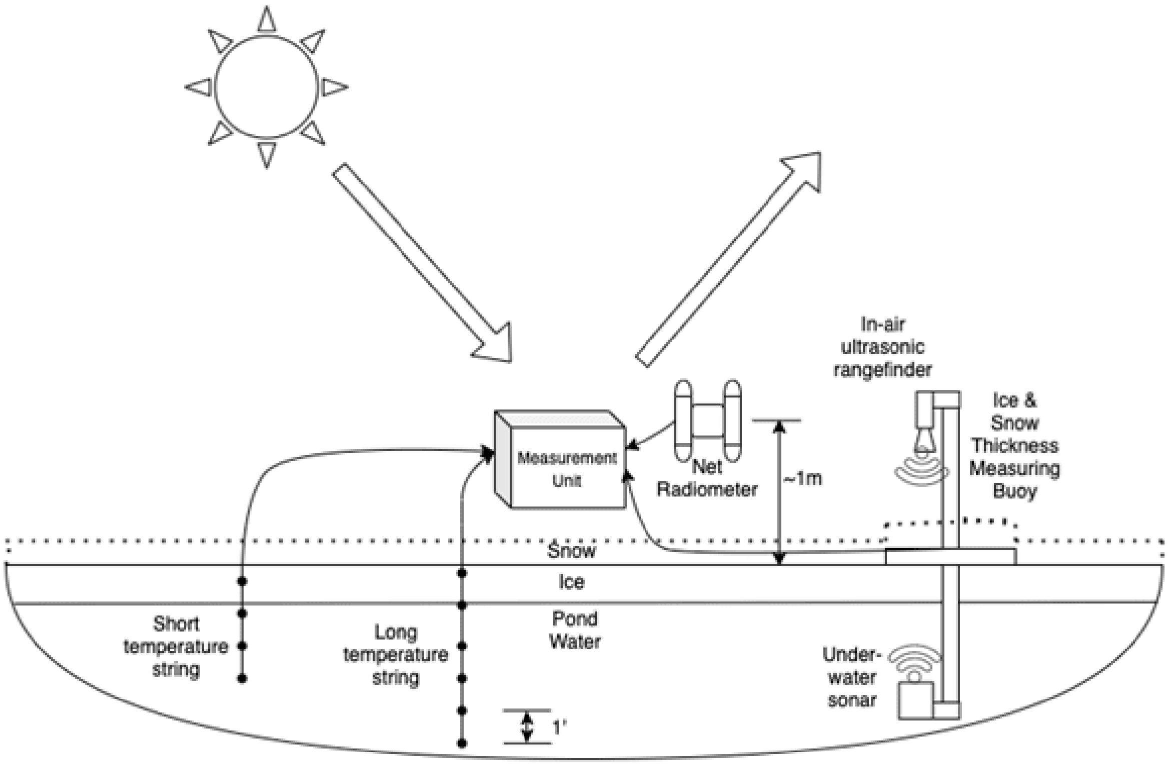

Figure 1: Side view schematic of measurement systems.

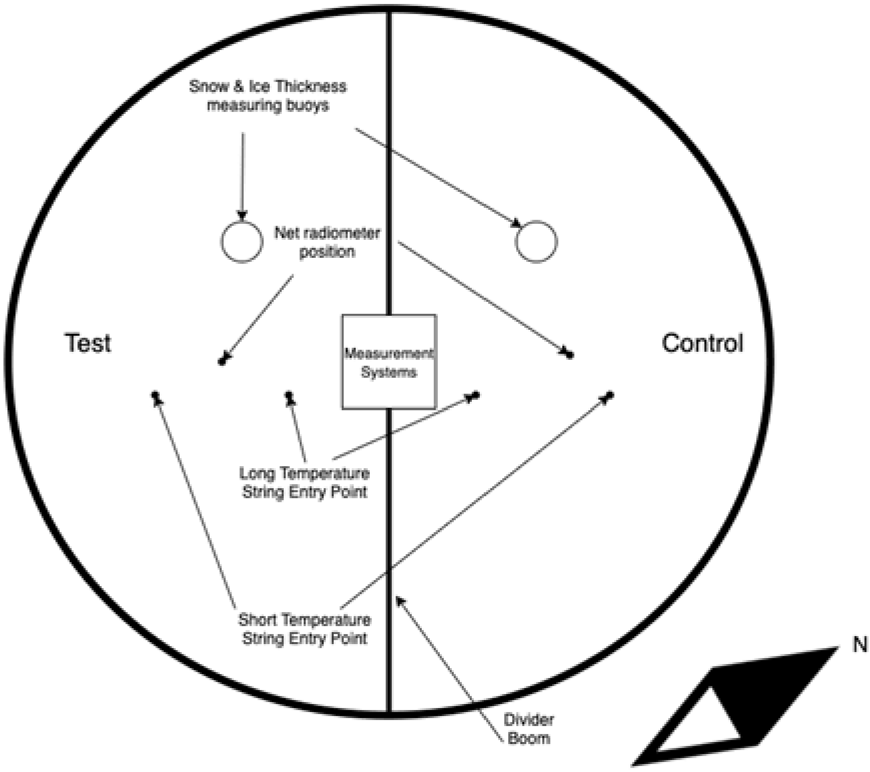

Figure 2: Top view schematic of measurement systems on test and control sides of the pond.

Laboratory UV-Vis measurements of a 0.5mm layer of the 25P45 microspheres used show a reflectivity of 30%. The reflectivity is similar when the microspheres are immersed in water or air because the interior air cavity in the hollow microspheres retains a high degree of scattering.

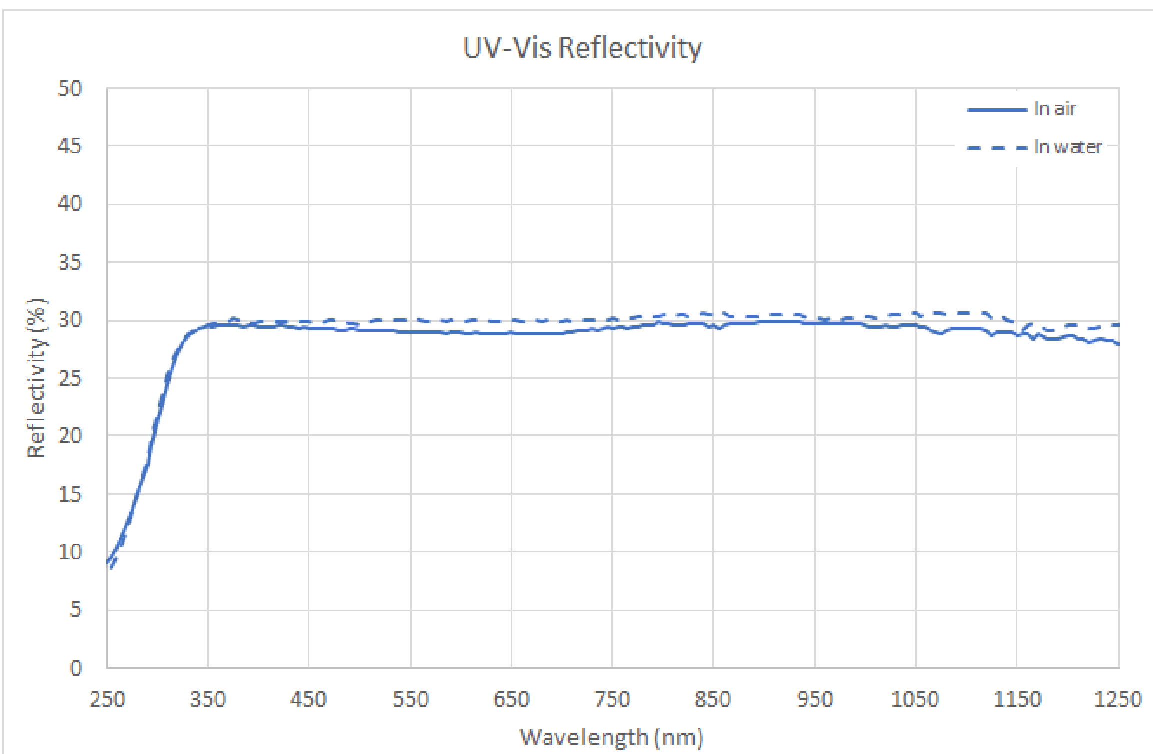

Figure 3: UV-Vis Reflectivity of 0.5mm thick layer of 25P45 material. Reflectivity was measured as in (Chamberlin, 2020).

Real-time snow thickness and ice thickness measurements were made from January through the melt period in March, as shown below:

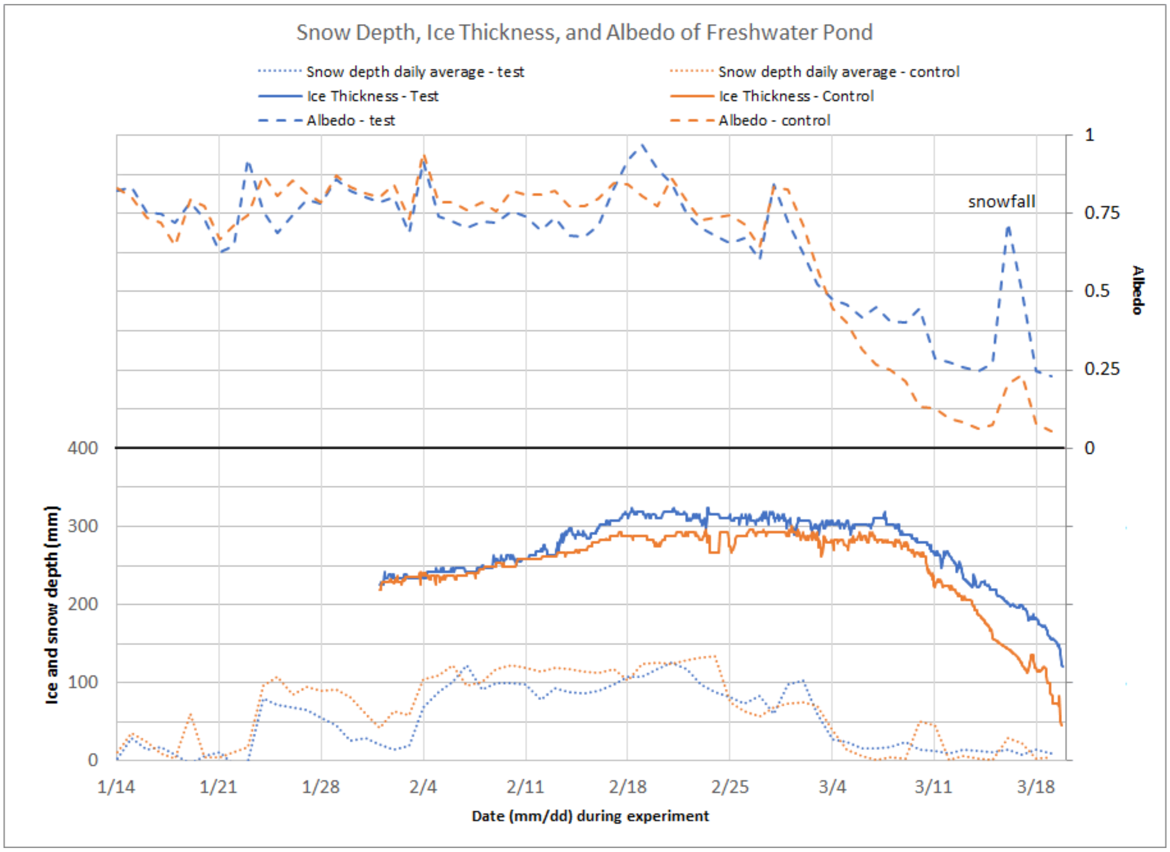

Figure 4: Snow and ice thickness and albedo through the test period of January 14 through March 20.

Incoming and outgoing short-wave and long-wave radiation were measured with Apogee SN-500 Net Radiometers on the test and control sides of the pond. The average daytime albedo from 8AM to 4PM was calculated from the incoming and outgoing short-wave radiation measurements and is presented below:

As seen in Figure 4, at the time of application of hollow glass microspheres on the test side of the pond on January 19, only a thin layer of snow covered the ice. Subsequently, ~10 centimeters of snow fell, covering both test and control sides in a layer of high-albedo snow. Snow and ice thickness were comparable on both sides of the pond through the end of February, when the snow started to melt. Around March 5, the snow has melted from the surface, and a difference in albedo between the test and control sides is apparent. The test side of the pond remains at higher albedo through the period of ice melt, and the ice melts at a slower rate on the test side of the pond.

SURFACE ALBEDO MODIFICATION INFLUENCE ON MELT RATE

Aerial views of the progression of the ice melt through March on the test and control sides of the pond are shown in the video below. The test side clearly shows a larger area with ice coverage as the melt progresses.

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1638408054/agu-fm2021/F5-64-13-97-1B-32-71-91-7F-DA-F8-75-C1-F7-7D-C7/Video/drone_footage_sequence_dy3pgt.mp4

Figure 5: Aerial drone footage of the freshwater pond through the melt period. The left side of the pond is the test side where a 0.5 mm thick layer of hollow glass microspheres is applied.

The ice thickness as measured by ultrasonic sensors is plotted in Figure 6 over the period of ice melt. The volume of pond ice during the period of melt was calculated from the areal coverage of ice in the aerial photos shown in figure 5, with an assumption of a flat disk of ice of the area measured in the photos.

A linear regression of the rate of thickness loss finds a melt rate of 11.4 mm/day for the test side vs a loss of 15.7 mm/day on the control side, a reduction in melt rate of 27%. A linear regression of the volumetric melt rate finds a loss of 7.3 m^3/day for test and 11.2 m^3/day for control, a reduction in melt rate of 34%.

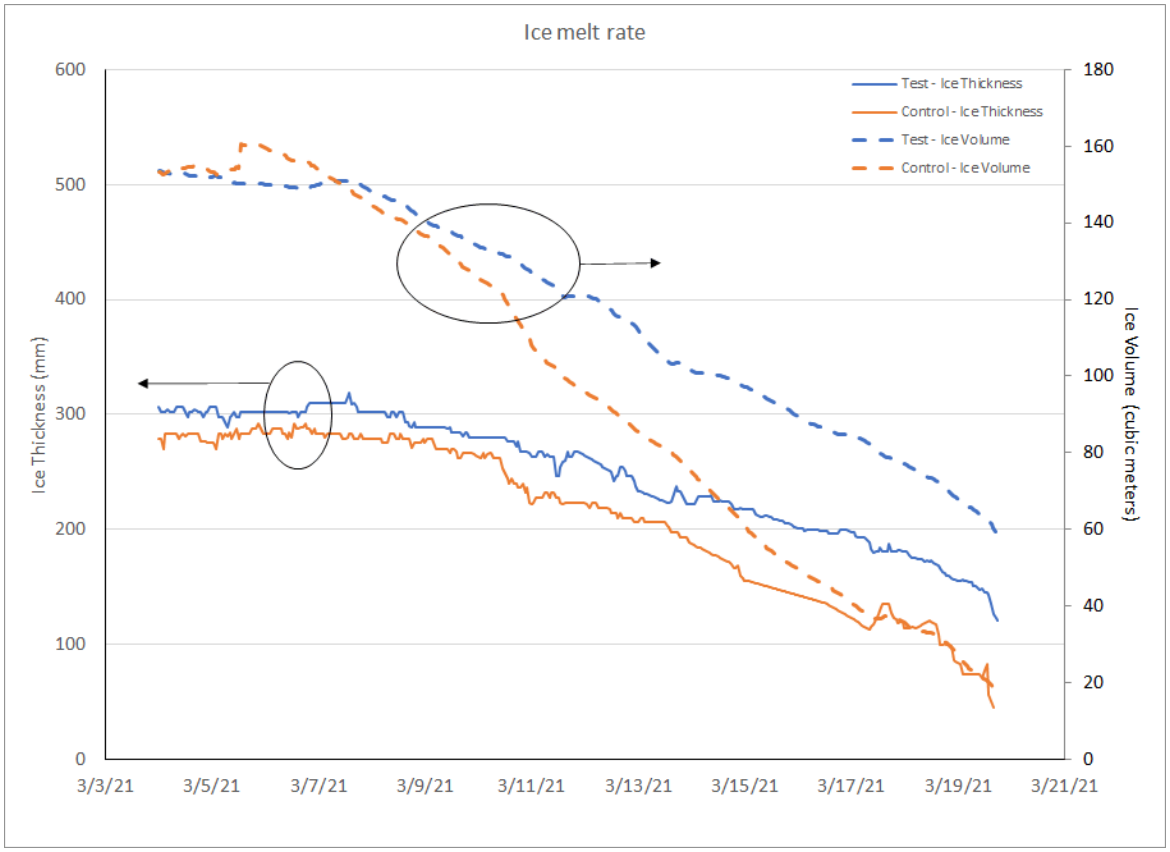

Figure 6: Ice thickness and ice volume for test and control sides of the pond through the melt season of March 7 to 20.

MECHANISM OF MELTING

The temperature of the water was measured at 1 foot intervals below the surface of the pond, as shown in Figure 7:

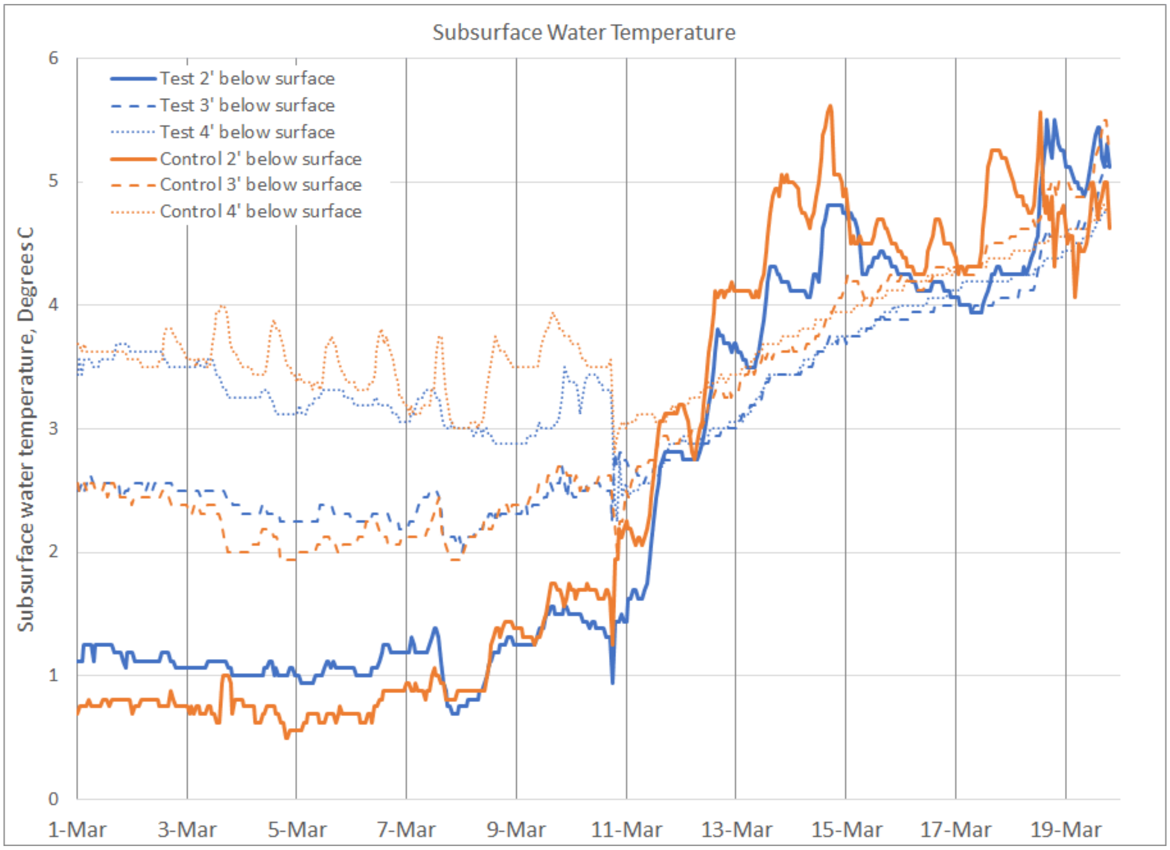

Figure 7: Subsurface temperature on test and contol sides of the pond.

In the period before the ice starts to melt, the expected stratification is observed. (Leppäranta, 2015) As the ice begins to melt around March 7, the water closest to the surface warms most rapidly. At each level the water on the control side of the pond warms more than the water on the test side, and larger daytime rises in temperature are observed on the control side.

In contrast to the difference in temperature rise of the water between day and night, we do not see a similar difference between daytime and nighttime ice melt rates. The rate of ice melting during daytime (solid) and nighttime (dashed) is shown for the test and control sides of the pond in Figure 8. There is a trend towards higher melt rate with time, and the control side of the pond melts at a higher rate towards the middle and end of the melt cycle. However, there is no significant difference in melt rate between day and night for either control or test. This indicates that the effect of the albedo increase is to lower the temperature rise in the subsurface water, which in turn melts the ice, rather than the sunlight melting the ice directly.

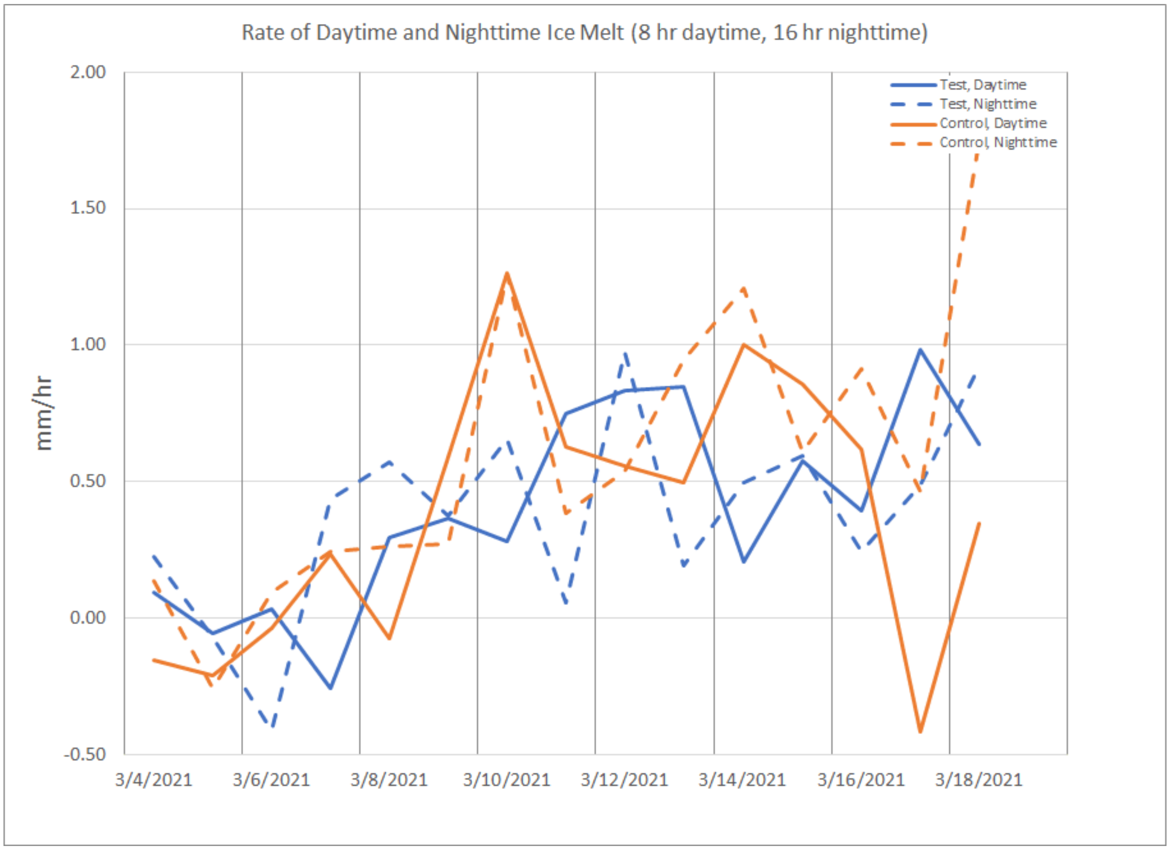

Figure 8: Rate of melting (mm/hr) over 8 hour daytime and 16 hour nighttime cycles, per day, for test and control sides of the pond.

CONCLUSIONS

- Hollow glass microspheres reflecting about 30% of visible light can increase the albedo of ice on a freshwater pond from ~0.1 to 0.3 during the period of melt
- This results in ~30% reduction in the rate of ice thickness loss.
- The reduced rate of melt is due to decreased themal heating of the water beneath the ice.
- Hollow glass microspheres applied early in the season can withstand typical weathering of a northern climate for two months and remain fixed as an intact layer beneath the snow, reemerging after snowmelt to brighten the ice surface during the period of ice thawing.
- This technique may have applications to slow positive albedo feedback loops leading to ice melt, including Arctic sea ice, glacial ice, and Arctic lake ice.

ABSTRACT

Various methods of albedo modification have been proposed to slow the melting of Arctic ice, including high-altitude, tropospheric, and surface albedo modification. In this study, we have evaluated the efficacy of applying a reflective hollow glass microsphere layer on the ice surface to slow the melting of ice in a freshwater pond over the 2020/2021 winter/spring melt season. This layer reflected ~30% of shortwave radiation from entering the ice. Ice thickness, snow depth, temperature profile, weather, and incoming and outgoing longwave and shortwave radiation were continuously monitored over the winter months and through the melt. The hollow glass microsphere layer was retained at the surface of the ice throughout the winter season and had a significant effect in maintaining ice thickness, increasing albedo and reducing energy input into the pond, ultimately reducing the rate of ice melt during the melt season by ~30%.

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