The Influence of Consecutive ENSO Events on Lake Ice in Central Ontario

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1. BACKGROUND

- Lake ice models provide the ability to assess and understand changes occurring to ice covered lakes by incorporating data from global/regional climate models or in situ meteorological data.
- Understanding ice cover changes is important for areas likely to be impacted by changing climate conditions, as increases in air temperature are associated with decreases in ice cover duration.
- Shorter ice cover durations have been reported for the Northern Hemisphere, especially in the Arctic. However, less focus has been placed on lake ice for regions in Central Ontario.
- Snow cover can either promote ice formation through the development of slush ice or lead to reductions in ice growth due to the insulating properties reducing the thermal conductivity.
- Snow cover characteristics affect lakes in Central Ontario differently than those in the Arctic, where the snow/lake ice interactions are better understood.

2. OBJECTIVES

- In central Ontario, the presence (or absence) of snow cover leads to ice-on/off dates that differ from current model simulations, largely due to the impact of snow cover on ice composition.
- The Canadian Lake Ice Model (CLIMo) is a well tested model in northern regions, however accuracy is slightly lower for initial temperate region ice cover simulations.
- Back to back ENSO events through 2015-2017 provide the ideal variability in snow and ice cover for testing/evaluating the model for use in temperate ice conditions.
- The goal of this research is to quantify the effects of snow cover on lake ice in Central Ontario for the 2015-2017 ice seasons and identify areas of model improvement.

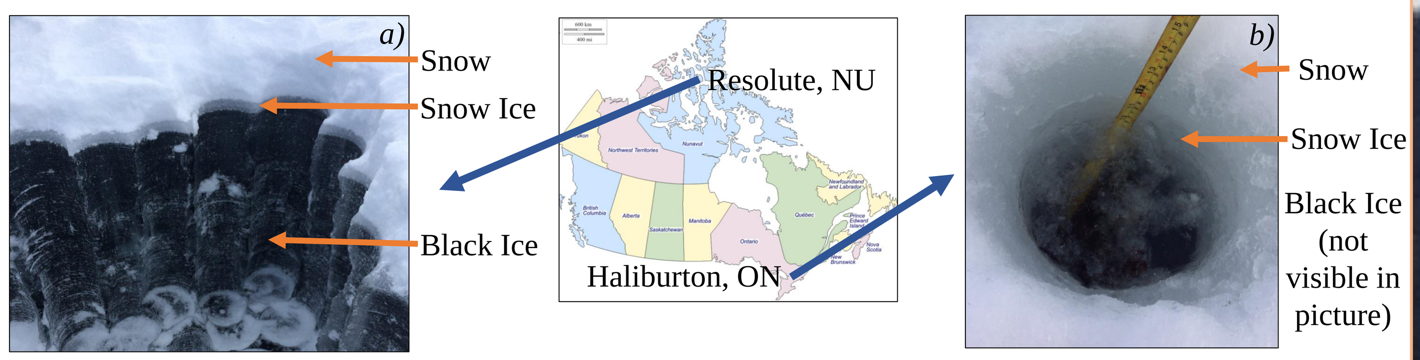

Figure 1: Comparison of lake ice composition for a) Small Lake (NU) on May 24, 2016; Ice here is predominately black, and b) MacDonald Lake (ON) on February 3, 2017; Ice here is predominately white.

3. STUDY SITE:

- MacDonald Lake and Clear Lake are located in the Haliburton Forest and Wildlife Reserve (45.101° N, 78.07° W), which is located ~250 km NE of Toronto.
- The study lakes were selected for variations in lake depth, size, orientation and accessibility for sampling.

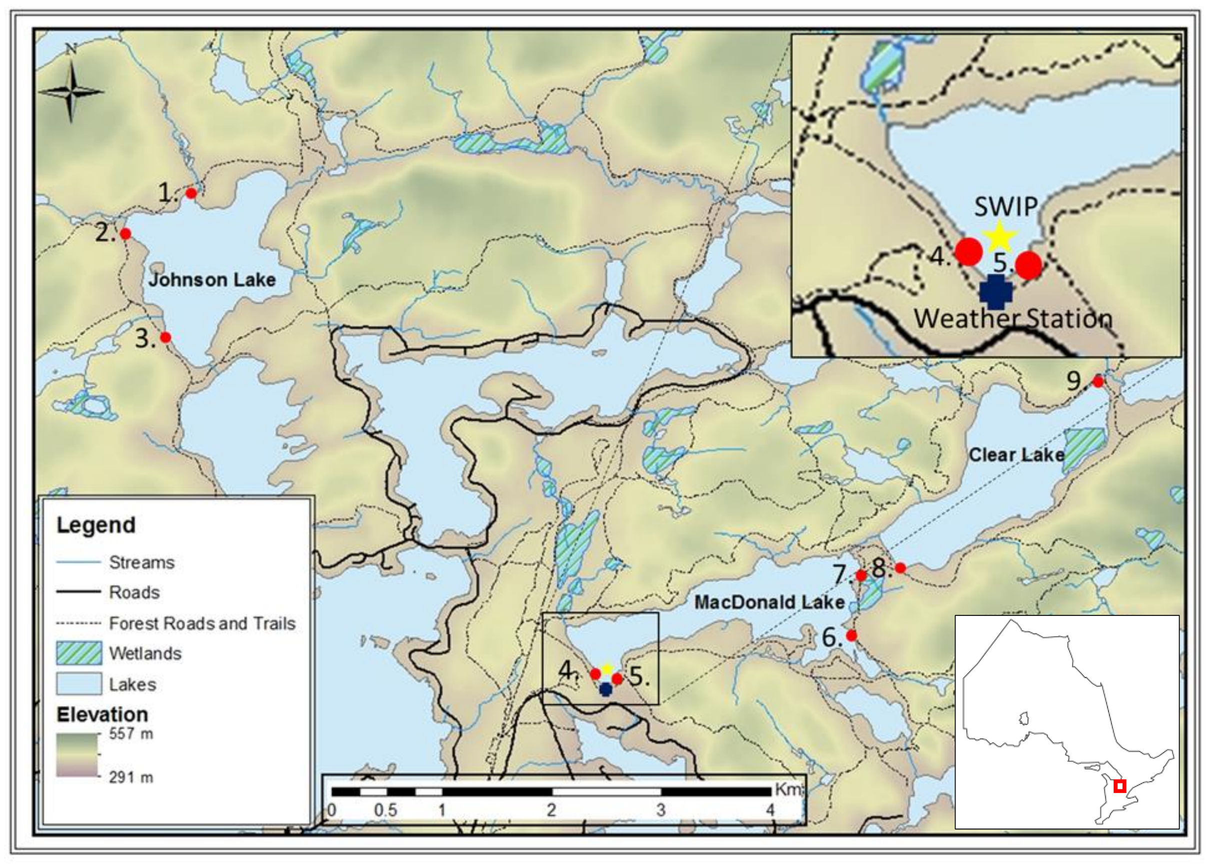

Figure 2: Study site map and camera locations depicted by the red dots. The upper right figure displays the location of the Shallow Water Ice Profiler (yellow star) and the automated weather station (blue cross).

4. METHODS

Meteorological Data Collected:

- Air temperature
- Wind speed and direction
- Net radiation
- Barometric pressure
- Snow depth
- Temperature of the snowpack

Canadian Lake Ice Model (CLIMo):

- Comparison of lake ice simulations with in-situ field data

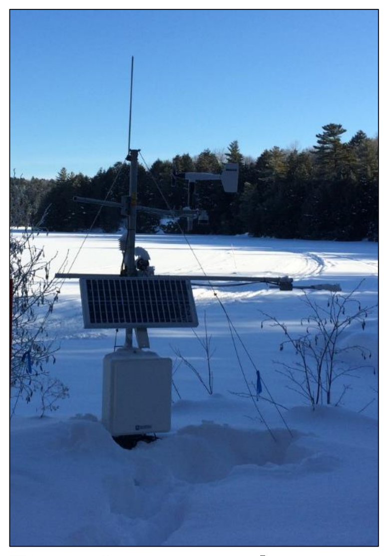

Figure 3: Automated weather station located on MacDonald Lake

Field Observations:

- Nine digital cameras
- Snow depth, snow density and snow water equivalent
- Ice thickness and composition

Shallow Water Ice Profiler

- Captures the full season of ice evolution

Figure 4: Shallow Water Ice Profiler

5. RESULTS

5.1 Climate Data: Temperature

2015-2016

- Temperatures from November to April were 2.5°C > than normal.
- A strong El Niño event occurred from spring 2015 to spring 2016, and peaked in August-September with a Multivariate ENSO index (MEI) of +2.53 .
- The MEI remained above +2 until February-March, when the strength of the El Niño began to decline.

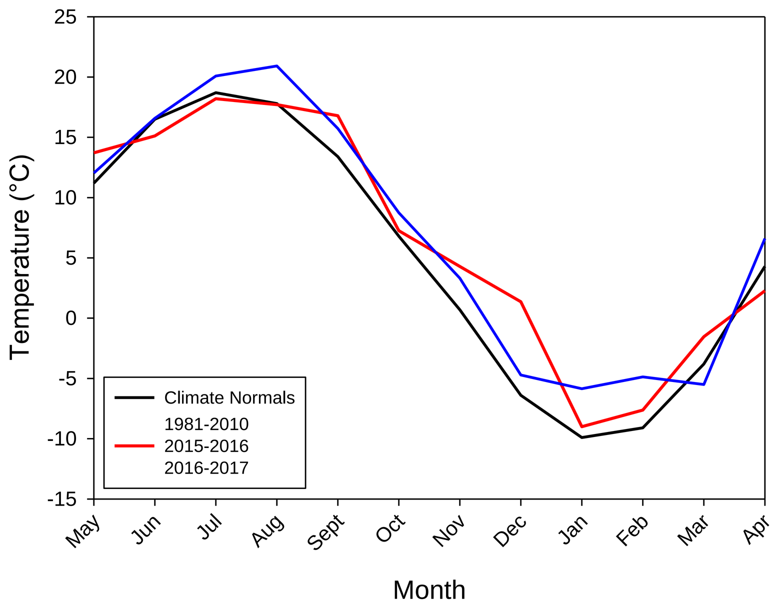

Figure 5: Monthly temperature averages from the Haliburton (ON) weather station, climate normal (black line) to 2015-2016 study year (red line) and 2016-2017 study year (blue line).

2016-2017

- Temperatures from November to April were 2.2°C > normal.
- A weak La Niña occurred in September (MEI,-0.379), followed by ENSO neutral.
- However, a cold period dominated from June through January, where sea surface temperatures remained below the -0.5°C anomaly threshold for La Niña using the Ocean Niño Index (ONI).

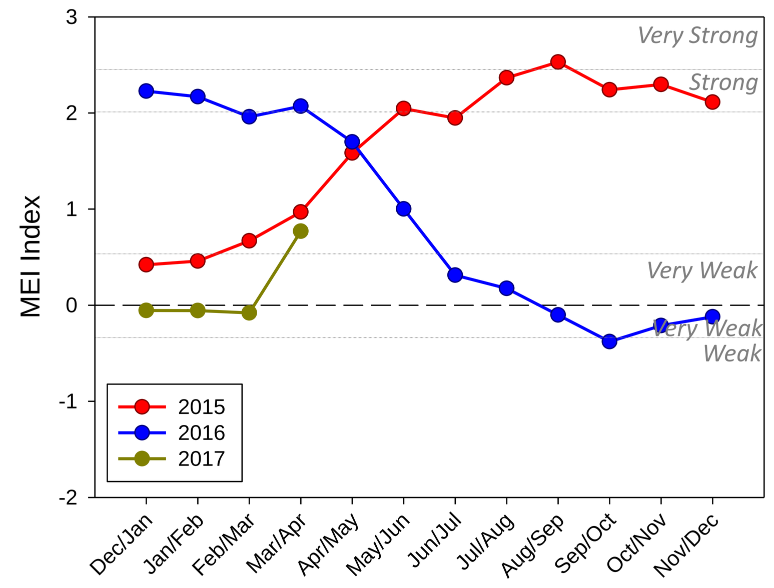

Figure 6: Multivariate ENSO Index (MEI) for 2015-February 2017.

5.2 Climate Data: Anomalies

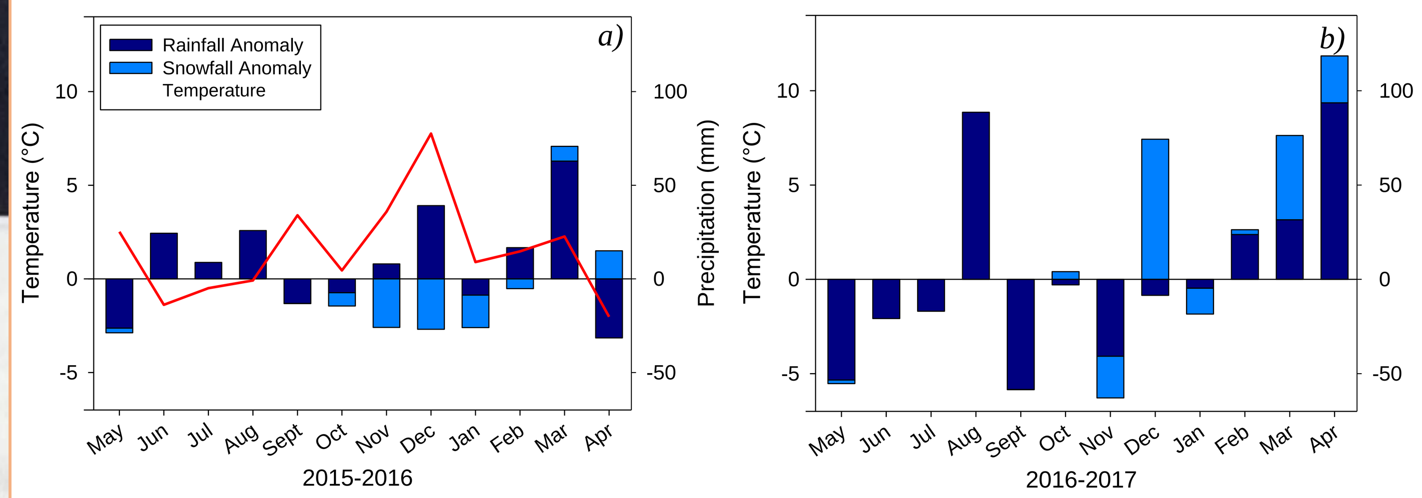

Figure 7: Temperature and precipitation anomalies for a) 2015-2016 and b) 2016-2017 were compared to the climate normal to assess the annual variability.

2015-2016

- Total precipitation was 51.4mm less than normal and had 8.2% more precipitation fall as rain than snow.
- December deviated +7.8°C from the mean and received +58.5% more rainfall.
- This delayed ice cover formation until January 5, 2016.
- Cooler April air temperature (-2.02°C), and 45.5% less rainfall, allowed the ice cover to persist until April 24, 2016.

2016-2017

- Total precipitation was 71.9mm less than normal and had 4.6% more precipitation fall as snow.
- December was 1.7°C warmer, and had 55.3% more snowfall than normal.
- Ice formation occurred December 14, 2016; 3.5 weeks earlier than 2015-2016.
- Ice off occurred April 21 2017, two days earlier than 2016.

5.3 Lake Ice Freeze up and Break up

2015-2016: January 5, 2016 – April 24, 2016, 107 days of ice cover

2016-2017: December 13, 2016 – April 21 2017, 129 days of ice cover

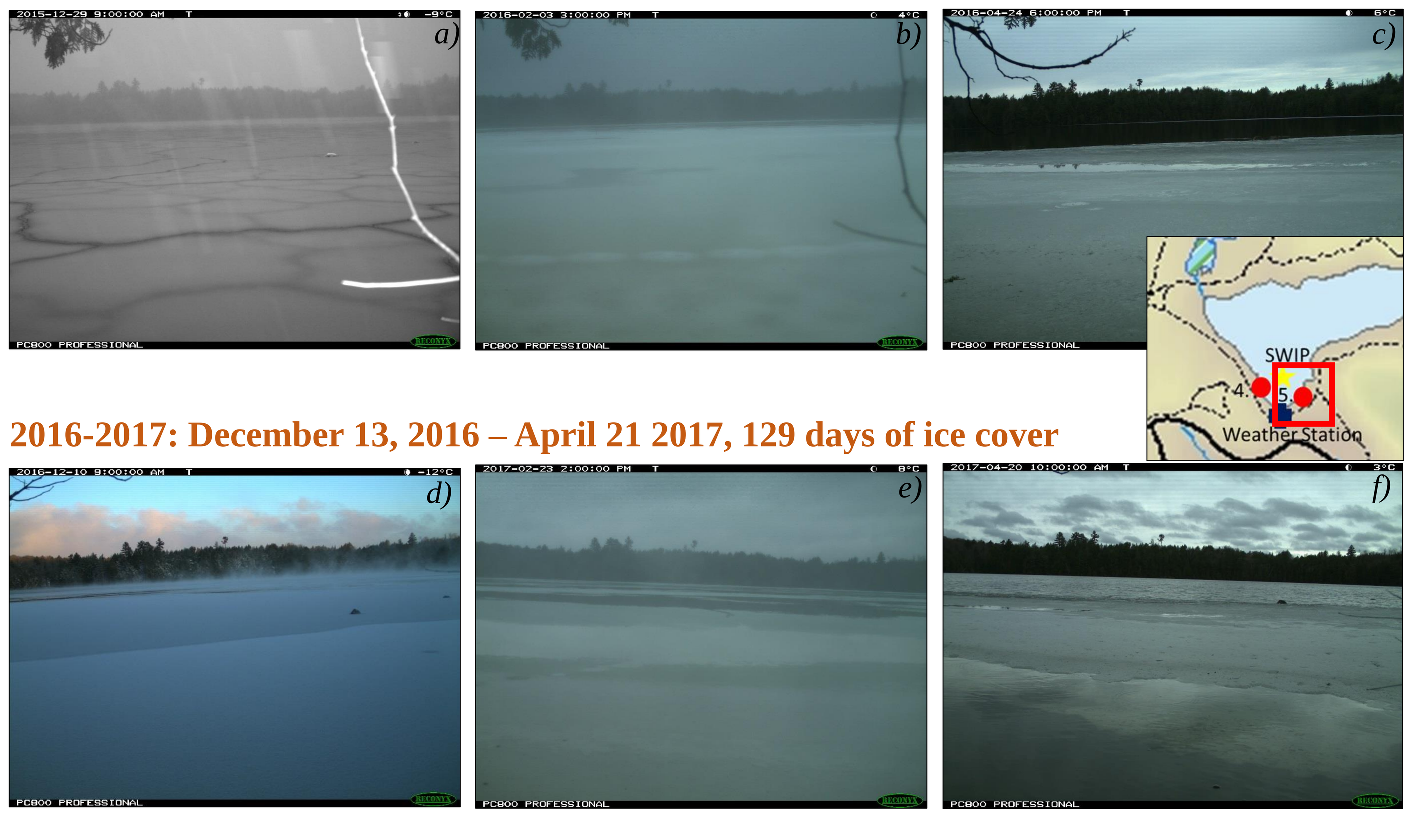

Figure 8: Pictures are all from Camera 5 located on MacDonald Lake (a) ice cover formation on December 29, 2015, which became ice free the following day, (b) February 3, 2016 slushing event, (c) April 24, 2016 ice break-up, (d) December 10, 2016 initial ice formation, (e) February 23 2017, slushing event, and (f) April 20, 2017 ice break-up.

5.3 Snow Cover Variability and Lake Ice Thickness

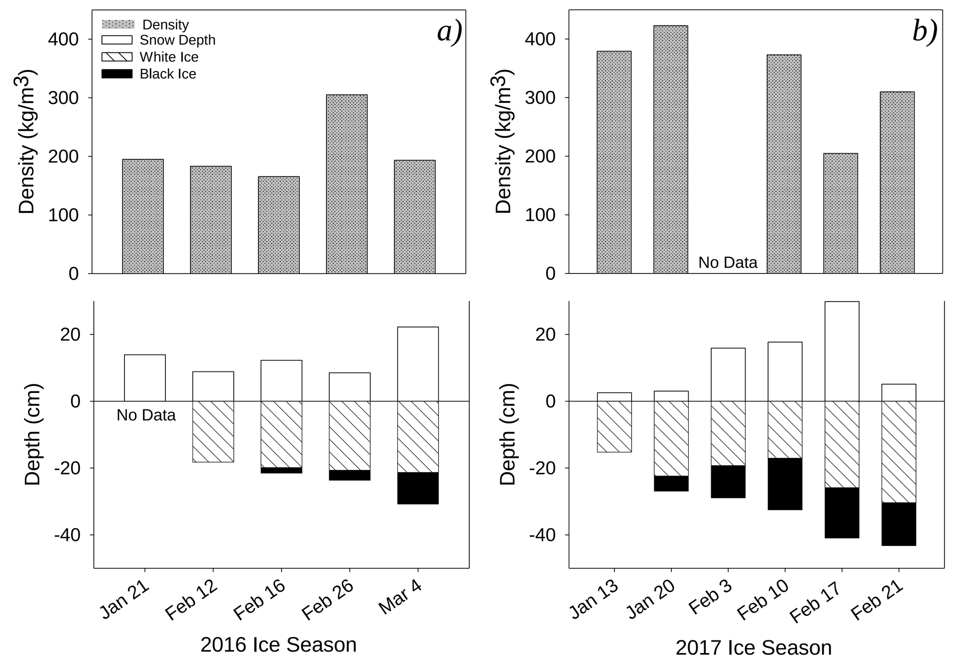

Figure 9: average snow density (kg/m³), depth (cm), and ice thickness (cm) from transects on MacDonald and Clear Lake for a) 2016 and b) 2017.

- The inclusion of snow during initial ice formation and early slushing events created initial white ice.
- Snow/slush ice events were indistinguishable in the ice profile as the initial ice was white ice.

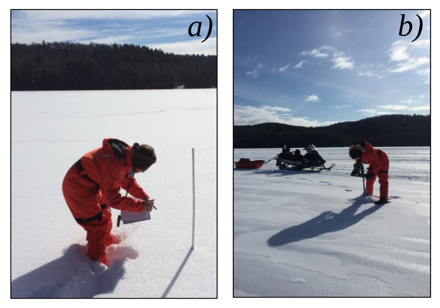

Figure 10: sampling (a) snow depth, (b) ice thickness.

5.4 Observed vs. Simulated Ice Thickness

- Currently, the (un-adjusted) model simulations are over-simulating black and under-simulating white/slush ice thickness due to the initial formation, however, overall thickness is simulated well with maximum ice thickness being slightly overestimated by 5.6 cm for 2016, and slightly underestimated by 3.2 cm for 2017.
- Adjustments were made to the model output to account for the initial white ice formation. This adjustment indicates a better fit for both ice types after the initial discrepancy, with the exception of black ice in 2017, which was under-represented.
- Current model simulations for ice break up predict earlier ice off dates than field observations, likely due to discrepancies in the ice thickness composition and albedo driven melt feedbacks.

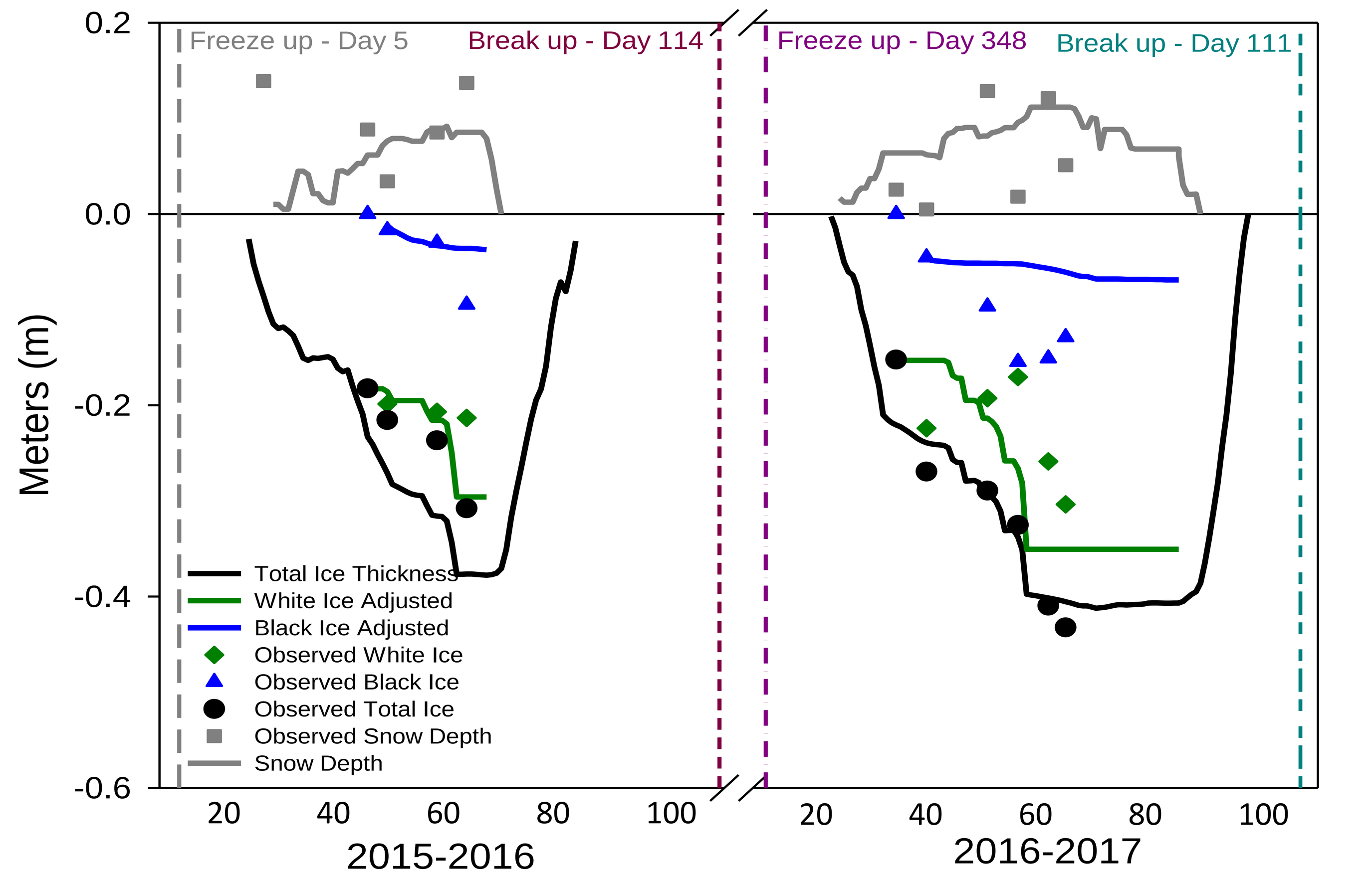

Figure 11: 2016 and 2017 ice season model results compared to in situ field observations.

6. CONCLUSIONS & FUTURE WORK

- The 2015-2016 El Niño resulted in delayed ice formation as seasonal temperatures were well above the mean, in contrast to the 2016-2017 study year.
- As a result of snowfall events and freeze-thaw cycles, initial ice formation was white, therefore true slush ice (formed from re-frozen flooded snow) cannot be distinguished from more general white ice. Later in the season, a smaller amount of black ice formed thermodynamically.
- The type of initial ice formation and percent ice composition of white and black ice differs from Arctic lakes.
- Ongoing work will address the initial ice formation issues and investigate possible refinements for albedo values during decay for the white ice dominated, temperate lake ice.
- Further research is needed to determine the impact of snow cover and snow ice on a landscape-climate scale and to more accurately predict changes in ice phenology with changing climate conditions for central and southern lakes.

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