HIGH FREQUENCY OBSERVATIONS OF TEMPERATURE AND DISSOLVED OXYGEN DURING UNDER-ICE CONVECTION IN LAKE SIMCOE

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Summary High-frequency observations of thermal structure under the ice of a large lake reveal the presence of large (10-20 m) overturning convection cells, driven by solar heating. Two winters observations are used to quantify the under-ice mixing and dissolved oxygen dynamics. The most vigorous convection occurred near the end of winter, as the water surface layer started warming, with a gradually deepening of the mixed layer over time. This coincided with the prediction by the Canadian Lake Ice Model of when the ice cover began to melt and decrease in thickness. During the same period the dissolved oxygen had become super-saturated from the surface to 23 m below the surface, suggesting abundant algal growth. Thorpe scale analysis revealed that very large scale mixing occurred beneath the ice; the mixed layer depth increased during the melting period, and mixing was most active during the day.

INTRODUCTION

Vigorous circulation can occur under the surface of ice-covered lakes that is driven by the penetration of solar radiation. The extent of this circulation is strongly influenced by underlying inverse stratification that typically forms under ice: near the floating ice was is close to 0°C, while water at the base of lakes is near the density maximum of 4°C water near the bottom of the lake. Due to isolation of the water in an ice covered lake from the atmosphere it has often been assumed that circulation is very small. However heat fluxes through clear ice can drive very large overturn convection near the end of winter, as reviewed by [1]. The main goal of this study is to quantitatively investigate the effect of solar radiation penetrating through the ice on the magnitude of convection and how this influences the dissolved oxygen (DO) concentrations in ice-covered lakes. Specifically, we investigate how the surface mixing layer evolves near the end of the ice-cover period; and how mixing influence dissolved oxygen concentrations in lakes.

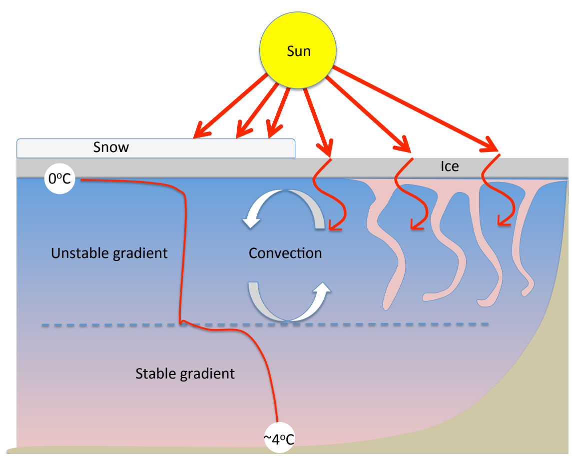

Figure 1: Schematic representation of under ice convection, showing how solar radiation penetrating through clear ice can drive heating of the water column. For water below 4°C such heating drives convective overturn of the water column (figure modified after [1]).

FIELD SITE AND METHODS

The field study was conducted in Lake Simcoe (44°25'N, 79°30'W), a large dimictic lake located in southern Ontario, Canada. A mooring with temperature and DO sensors was lowered between November 27, 2014 and April 27, 2015 into Lake Simcoe. Complete ice cover over the lake was observed between January 7 and April 25, 2015. The depth of the water column at the location of the mooring is about 42 m. The temperature loggers were configured to record at a spatial measurement interval of 2.5 m with the topmost one being at 5m deep on the rope. Each temperature logger samples at a frequency of 20 seconds. The DO loggers were configured at a spatial measurement interval of 7.5 m, with the topmost one being at 7.5 m deep. Each DO logger samples at a frequency of 30 minutes.

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We quantify the stability of the water column using two parameters, namely the buoyancy frequency and by estimations of Thorpe scales of density inversions. The buoyancy frequency N is defined by $N^2 = -(g/\rho_o)\, d\rho/dz$, where $g = 9.8\ m/s^2$ and $\rho_o = 1000\ kg/m^3$. Thorpe displacements were calculated by sorting the instantaneous density profile and tracking the distance moved by each water parcel. The minimum temperature difference we could resolve was twice the uncertainty of the accuracy of the temperature loggers. The corresponding instantaneous Thorpe scales were calculated by taking the root mean square of the Thorpe displacements. Buoyancy frequencies and Thorpe scales are calculated from the raw temperature data, and then smoothed with a 6-hour running average. The depth of the surface mixed layer beneath the ice was determined as the depth from the surface to where the buoyancy frequency first exceeds $N = 10^{-5}\ s^{-1}$

RESULTS

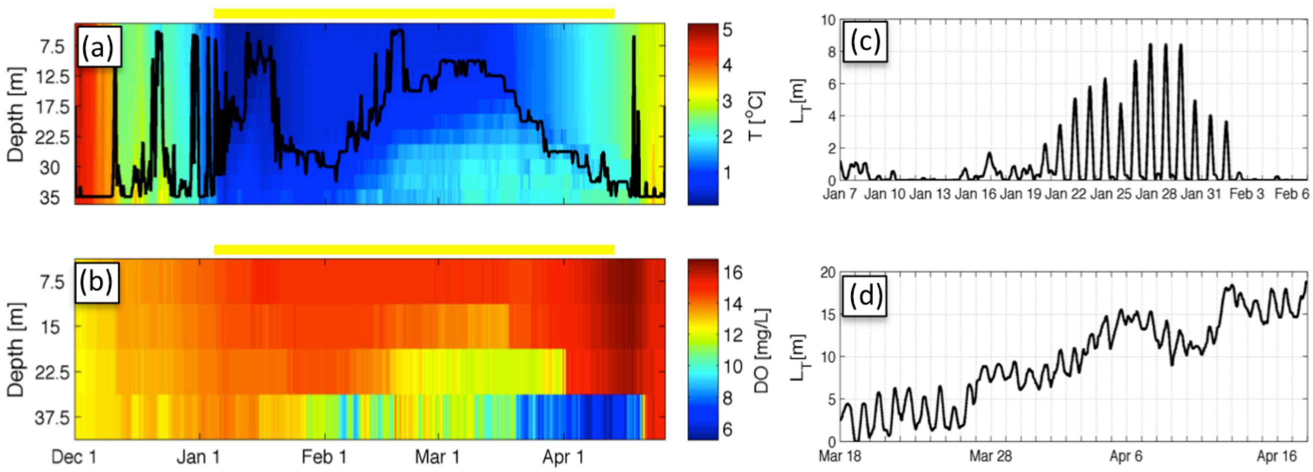

Figure 2: Water column temperature time series, black line indicates estimated mixed layer depth (a), DO concentration time series (b). Yellow bar on top of graph indicates ice cover. Calculated Thorpe scales between the periods January 7 to February 7 (c) and March 18 to April 18 (d).

Figure 2 shows that before the ice-cover period, the mixing layer spans the entire water column with overturns as large as 15-20 m occurring. Ice covered the lake on January 7, and there was a vigorous period of mixing from Jan 16 to 31st, after which the snow cover was sufficient to block any light. Calculations of Thorpe scales show that the water column is highly unstable in this period of time. From the time series of the Thorpe scales in this period of time, it is clear that there is a periodic behaviour of convection. In particular, the maximum Thorpe scales occur around noon, suggesting that the main driving mechanism of mixing is solar radiation. Between February 3 and March 18, the water column stratifies with warm water at the bottom and cold water at the top. The mixing layer shallows and DO concentrations decrease in the water column. The bottom levels of the water column gradually increase in temperature over this period, suggesting positive surface heat flux from the bottom. After March 18, steady increase in mixed layer depth and Thorpe scales are observed. The calculated Thorpe scales once again exhibit a periodic behaviour. DO concentrations in the water column homogenize as the mixed layer extends deeper. There is a clear increasing trend of DO in the mixing layer while the bottom stratified region still shows a decreasing trend of DO. This suggests algal growth in the water column. Algae then produce oxygen by photosynthesis. The maximum DO concentration observed in the water column is about 17 mg/L, which is supersaturated relative to the surface.

A new field deployment in the winter 2015/2016 includes a velocity meter, light sensor and faster response DO and T sensors. We use this new data to discuss the energetics of under-ice convective mixing in more detail in our presentation.

References

[1] Kirillin, G., Leppäranta, M., Terzhevik, A., Granin, N., Bernhardt, J., Engelhardt, C., Tatyana Efremova, T., Golosov, S., Palshin, N., Sherstyankin, P. , Zdorovennov, R. (2012). Physics of seasonally ice-covered lakes: a review. Aquatic sciences, 74(4), 659-682.