Dissolved Oxygen Dynamics in Arctic and Boreal Lakes in Late Winter

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Motivation and Aim

Dissolved oxygen dynamics in seasonally ice-covered lakes are critical for assessing their response to global climate change and its implications for the lake ecosystem.

Aim: Quantifying under-ice oxygen dynamics in Arctic Lake Kilpisjärvi after prolonged darkness and Boreal Lake Pääjärvi by estimating the influence of temperature, solar radiation, and mixed layer deepening with long-term high-frequency data.

Study Field

Lake Kilpisjärvi is an ultra-oligotrophic glacial tundra lake located in northwest Lapland (69°N, 20°E). Lake area is 19.8 km^2, with the average depth of 19 m and maximum depth of 45 m [3] The freezing and break up in between November and June.

Lake Pääjärvi is an oligo-mesotrophic lake located in southern Finland (61 °N, 25 °E) with 13.4 km^2 area. Mean depth is 14.4 m and maximum depth is 84 m [1] with brown water colour due to high concentration of dissolved organic matter. Freezing occurs in November and ice break up in between late April and early May.

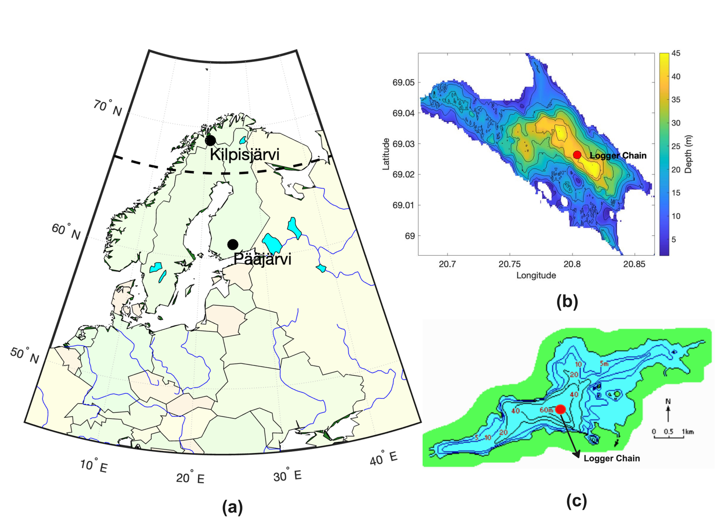

Figure 1: (a) Location of the Kilpisjärvi and Paajarvi (b) Kilpisjärvi bathymetry (c) Pääjärvi bathymetry[5].

Methods

Data Acquisition

Dissolved oxygen (DO), temperature (T) and photosynthetically active radiation (PAR) were measured during late winter (from April to ice break-up) with high frequency loggers to monitor biogeochemical and physical dynamics under the ice.

Water samples were collected in May for the phytoplankton identification, enumeration, and calculation of biomass of Lugol's iodine-preserved water samples.

Data Processing

In Kilpisjarvi, the high-frequency DO signals were influenced by physical processes, such as advection by internal motions.

A filter developed that correlates with temperature fluctuations to separate the physical and biological components within the DO signal [2].

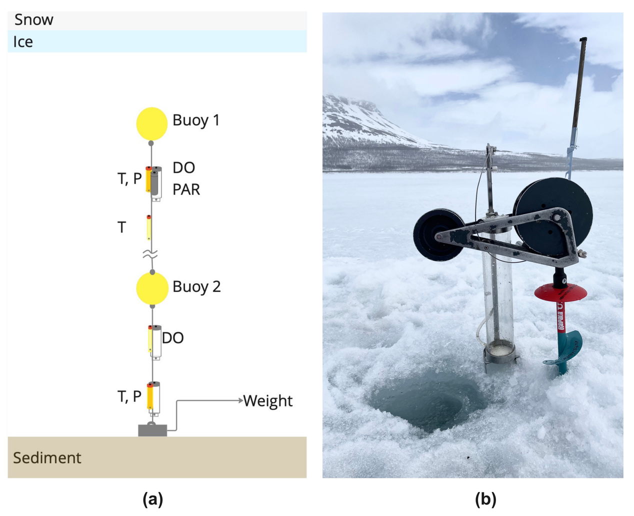

Figure 2: (a) Logger chain illustration (b) Limnos sampler

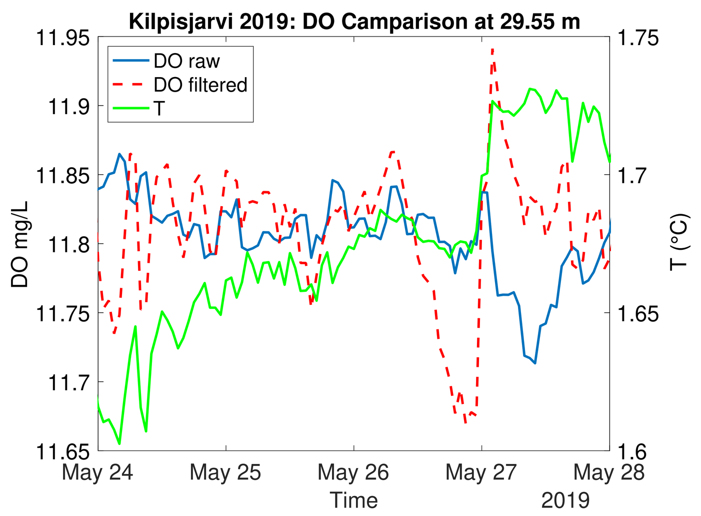

Figure 3: Temperature based DO filter

Mixed Layer Deepening

High-resolution temperature data is used to identify the convective mixed layer in the water column. The rate of the mixed layer deepening is estimated by analyzing daily-averaged temperature profiles.

Lake Metabolism

Variations in dissolved oxygen (DO) during late winter are influenced by the interplay between net ecosystem productivity (NEP) and diffusion within the mixed layer.

$$\frac{dDO^n}{dt} = GPP - R - F^n_{\text{diff}} \quad (1)$$

$\frac{dDO}{dt}$ presents the change of DO over time where GPP and R denote to the gross primary production and respiration which are calculated based on the dayfraction obtained from the PAR data. The diffusive flux between the mixed layer and below expressed as:

$$F^n_{\text{diff}} = -K_z \frac{DO_{n-1} - DO_{n+1}}{z_{n-1} - z_{n+1}} \quad (2)$$

Eq. (2) describes the DO diffusion at the bottom of mixed layer. F^n_{diff} is oxygen flux (mg/L $\cdot$ m^2/s), K_z is the thermal diffusivity coefficient (m^2/s), DO_{n-1} and DO_{n+1} are DO concentrations (mg/L) below and above the mixed layer at n^{th}logger depth, and Δz is the vertical distance (m) between layers.

Results

Mixed Layer Deepening

The initiation of solar-driven convection demonstrates annual variability in Kilpisjärvi, influencing the rate (dh/dt) and duration of mixed layer deepening.

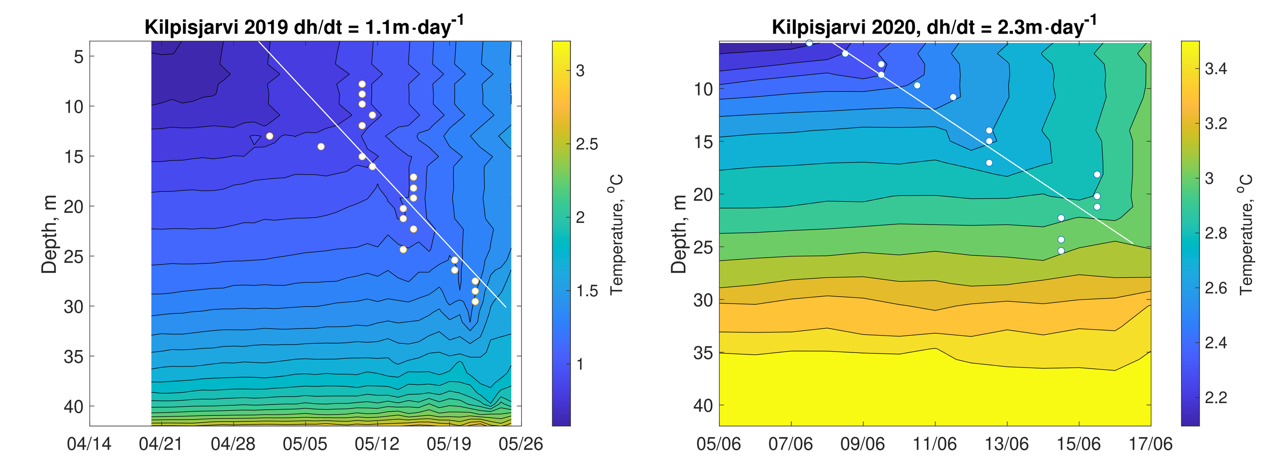

Figure 4: Temperature profile in Lake Kilpisjärvi for 2019 (left) and 2020 (right). Mixed layer deepening calculated by linear approximation presented with white line.

Lake Metabolism

After six months of darkness in Kilpisjärvi, photosynthetic activity increases triggered by light intensities measured at the ice-water interface. The threshold for light limitation is 20 μmol m^{-2} s^{-1} [4].

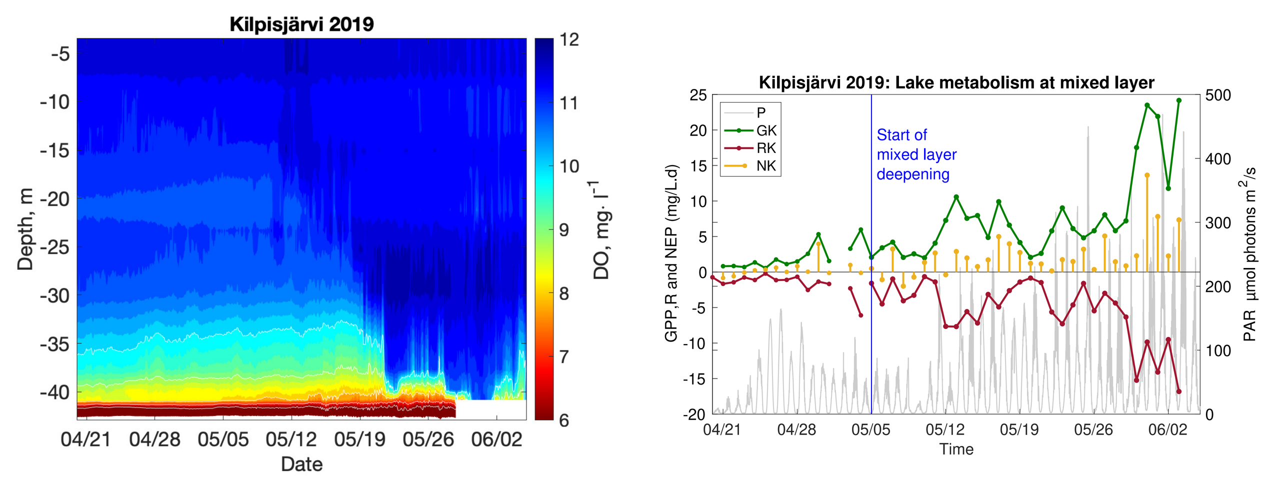

Figure 5: Vertical profile of dissolved oxygen (mg/L) (right) and lake metabolism with solar radiation (left) in Lake Kilpisjärvi for 2019 during late winter in ice-covered period.

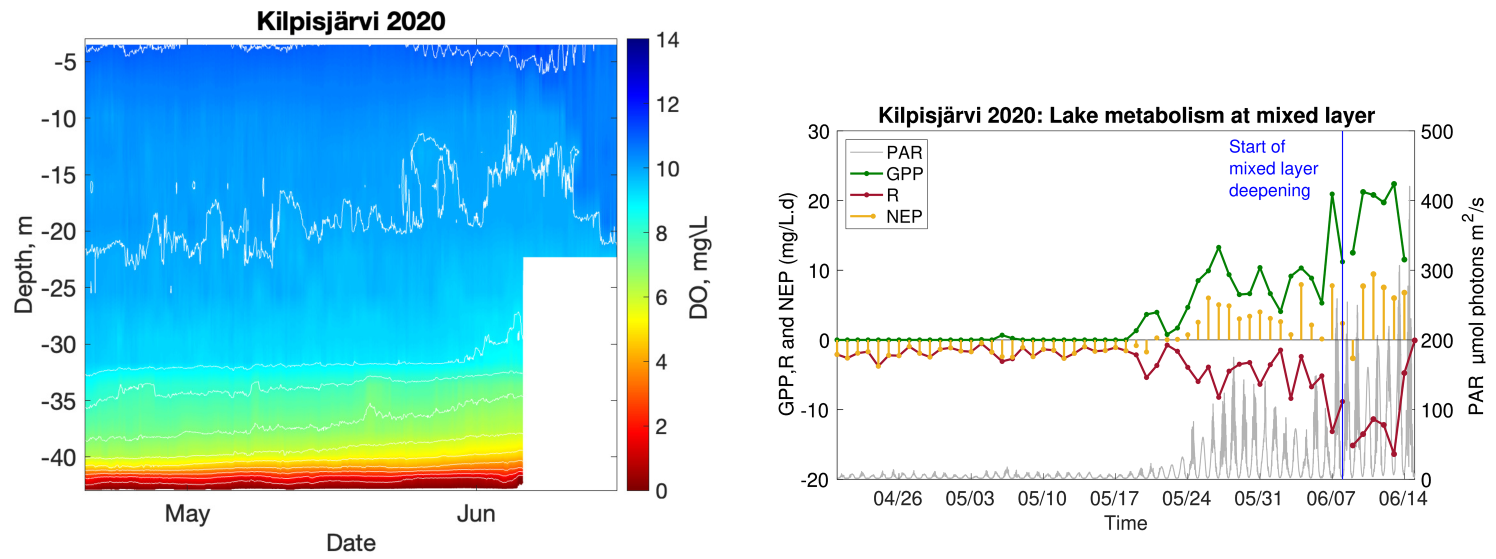

Figure 6: Vertical profile of dissolved oxygen (mg/L) (right) and lake metabolism with solar radiation (left) in Lake Kilpisjärvi for 2020 during late winter in ice-covered period.

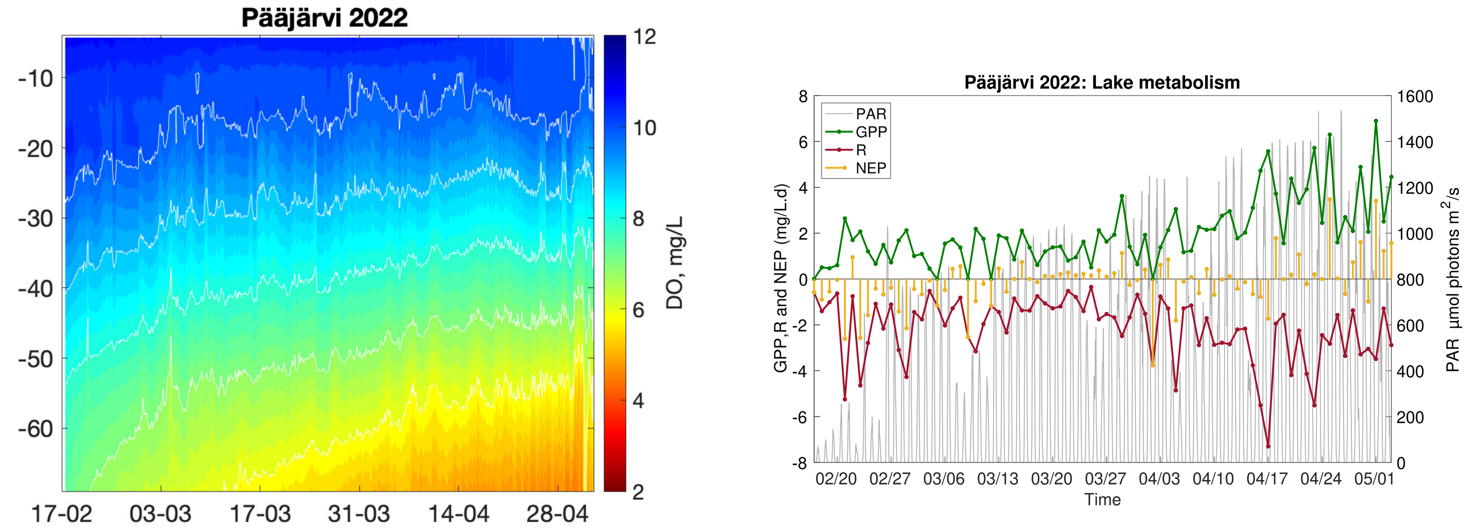

Figure 7: Vertical profile of dissolved oxygen (mg/L) (right) and lake metabolism with solar radiation (left) in Lake Pä"ajärvi for 2022 during late winter in ice-covered period.

Phytoplankton Diversity

Phytoplankton diversity in Kilpisjärvi differentiates in the following groups: Cyanobacteria, Chlorophyta, Haptophyta, Heterokontophyta, Cryptista, and Dinoflagellata. Heterokontophyta and Cryptista were observed most frequently, followed by Cyanobacteria.

Conclusion

- The interplay of physical parameters such as solar radiation, water temperature, and the timing of ice formation exerts a profound influence on the hydrodynamic conditions within arctic and boreal lakes during late winter.
- These variations play a key role in shaping the oxygen levels in deeper layers, thereby significantly impacting the overall health and dynamics of the lake ecosystem.

References

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