Long-Term Physical and Chemical Evolution of a Sub-Arctic Pit Lake: Observations and Modelling

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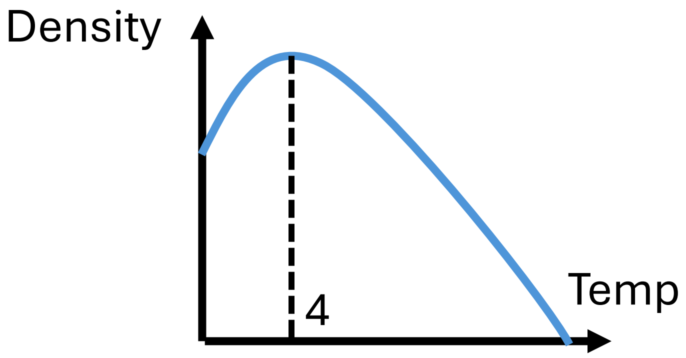
Motivation: Industry relies heavily on models to predict water quality, few opportunities to evaluate these models on long time scales.

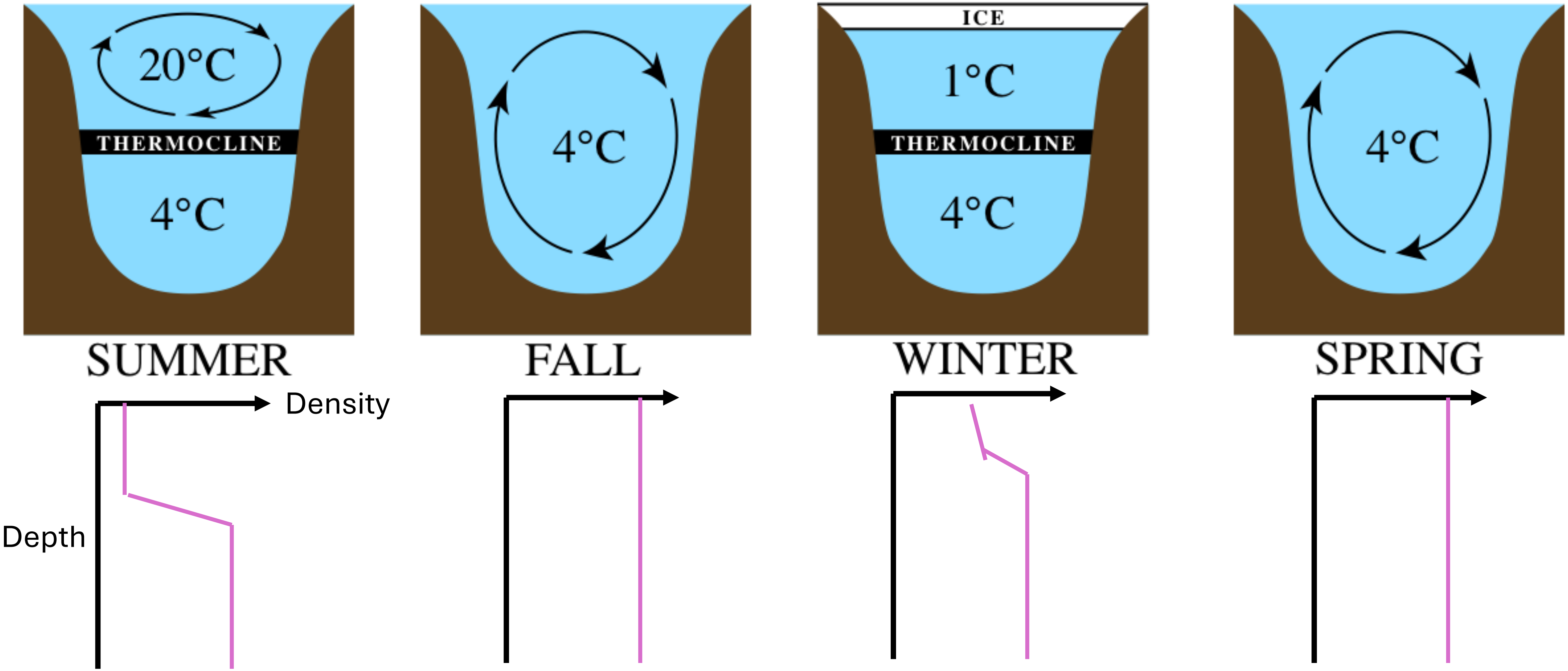
Presentation Outline

1. What is meromixis and why it can be a useful tool for mine management?
2. Background on the Colomac mine and Zone 2 Pit
3. Hydrodynamic modelling of Zone 2 Pit
4. Future improvements and considerations on pit lake modelling

1. The Usual Lake



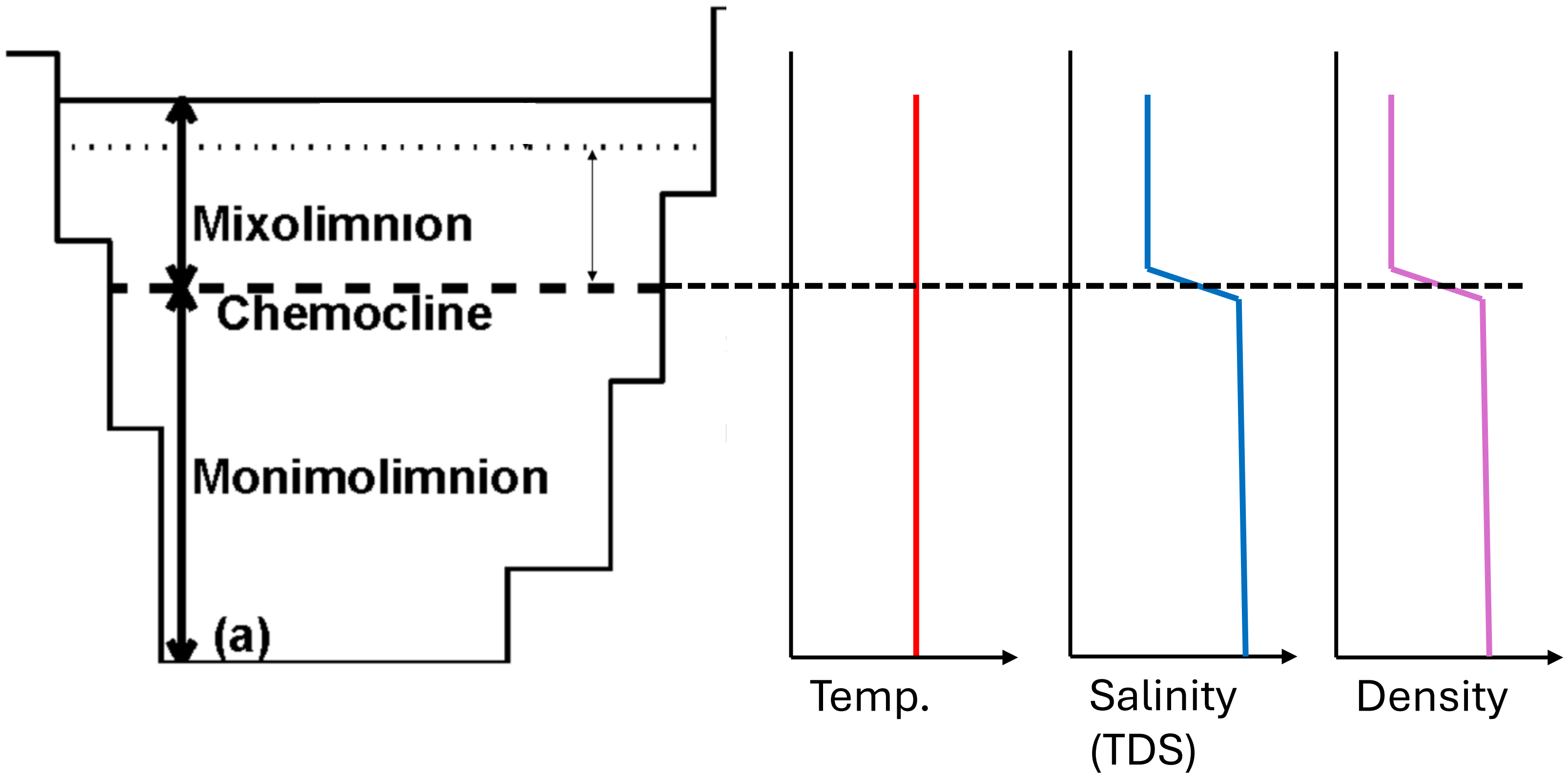
Turnover in temperate and subarctic lakes



What is Meromixis?

A condition where a lake does **not fully mix vertically** at least once per year

Often due to a salinity (TDS) gradient

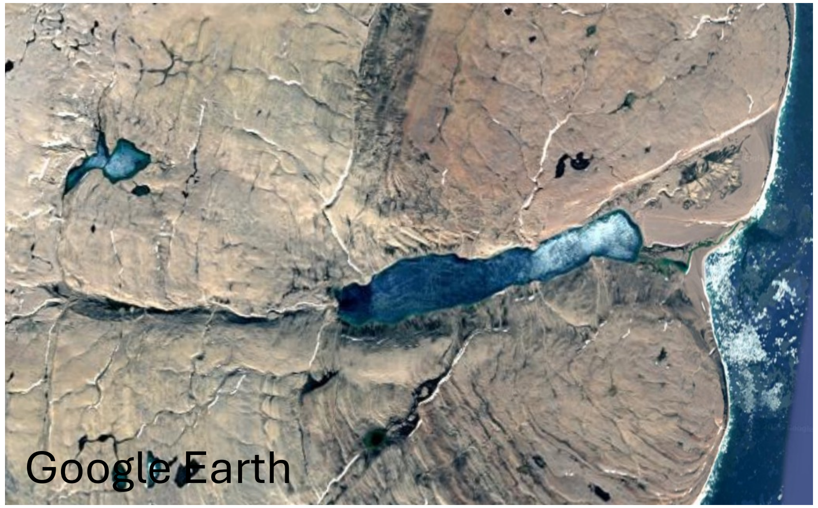


Natural Meromictic Lakes

Mahoney Lake, BC

Powell Lake, BC

Sophia Lake, NU



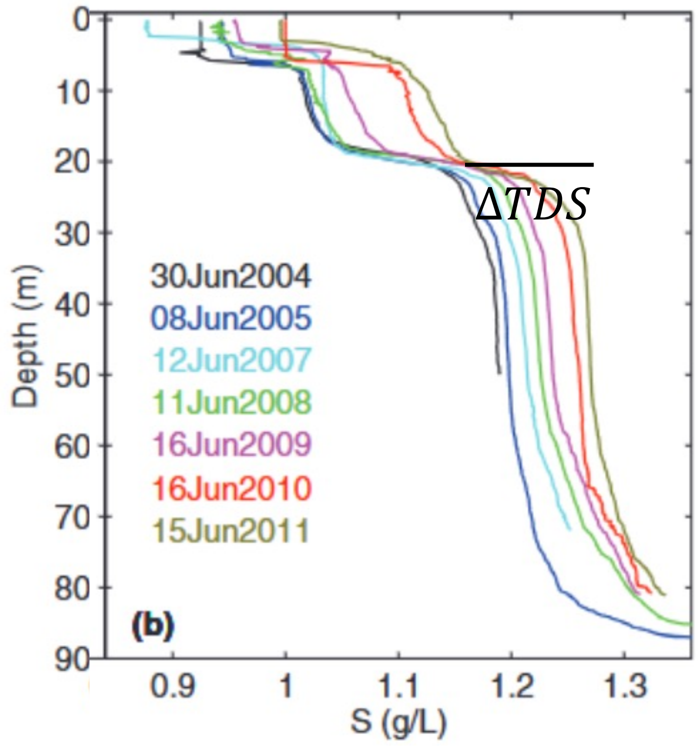
Mine Pit Lakes

Mine pit lakes are often meromictic

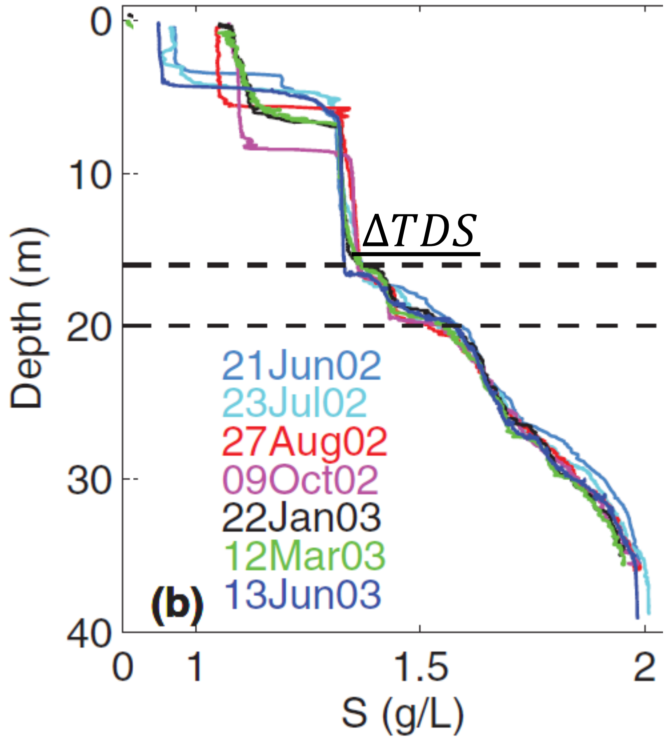
Meromixis can naturally form as the pit fills

Meromixis can be engineered by controlling the timing, amount, and the density of pit inflows

Faro Mine pit lake



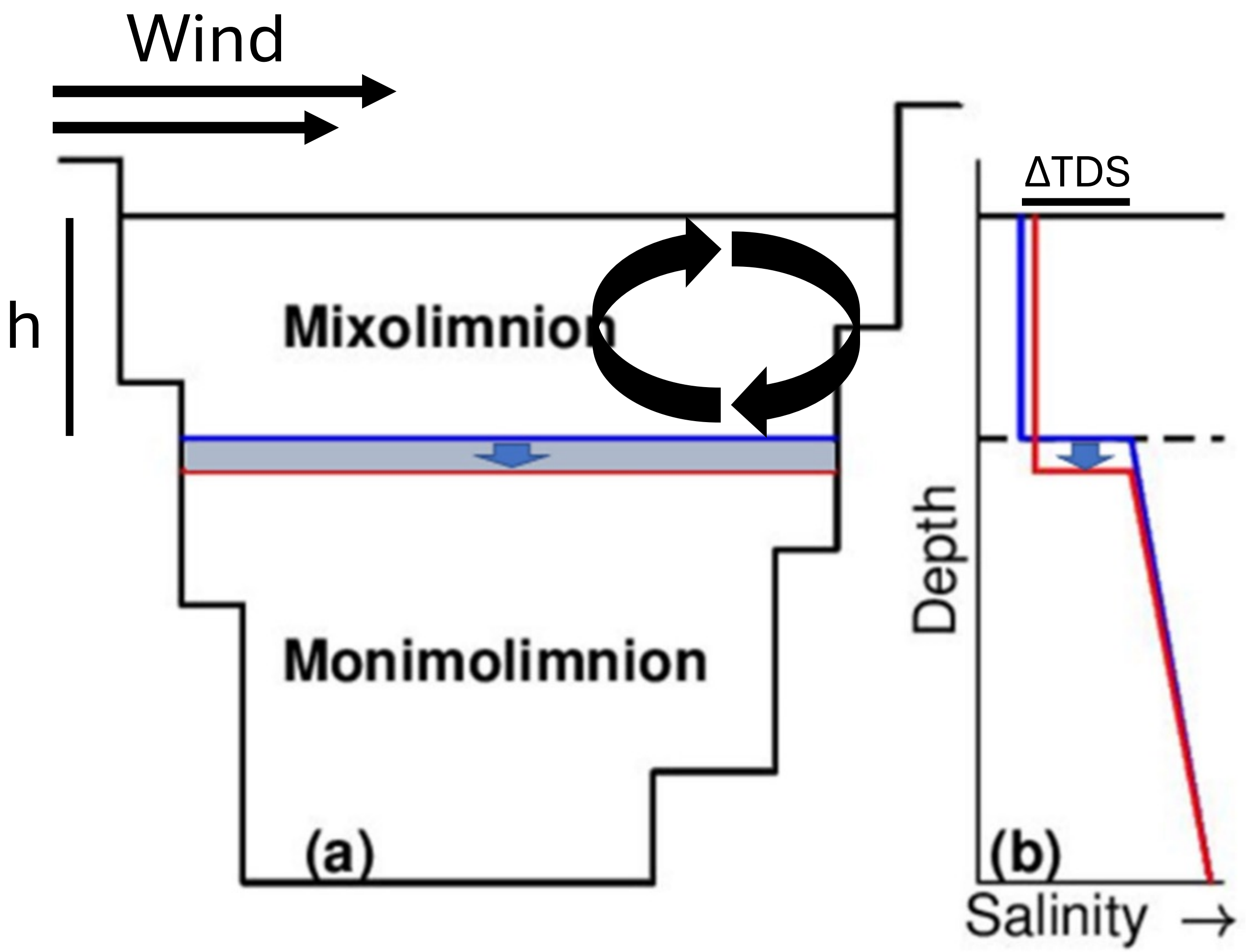
Waterline pit lake (Equity Mine)



Pieters and Lawrence, 2014

Tendency of Pit Lakes to be Meromictic

- Generally high TDS water (>1 g/L)
- Relatively low wind forcing because of sheltering and small fetch
- High depth to surface area ratio



Relevance of Meromixis to Closure Water Management

- Meromixis tends to occur naturally: Major incidence on pit lake water quality
- Meromixis can be used to permanently store contact water that would otherwise require treatment
- In-Pit bioremediation: aeration, fertilization, sub-oxic redox processes

2. Colomac Mine

- Gold mine
- Operated in the 90s
- Filed for bankruptcy
- Federal Government became owner
- Mine clean up done by the Federal Government

Zone 2 Pit

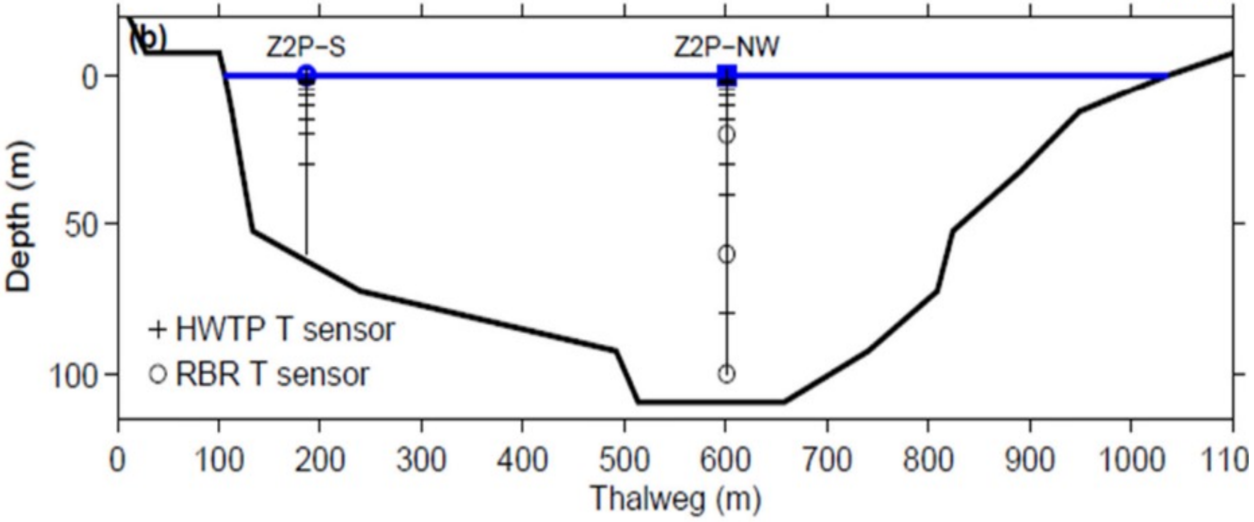
Filled with water from the TSF (50%), natural runoff and groundwater inflows

Fertilized with monoammonium phosphate, and destratified and aerated to remove thiocyanate and ammonia

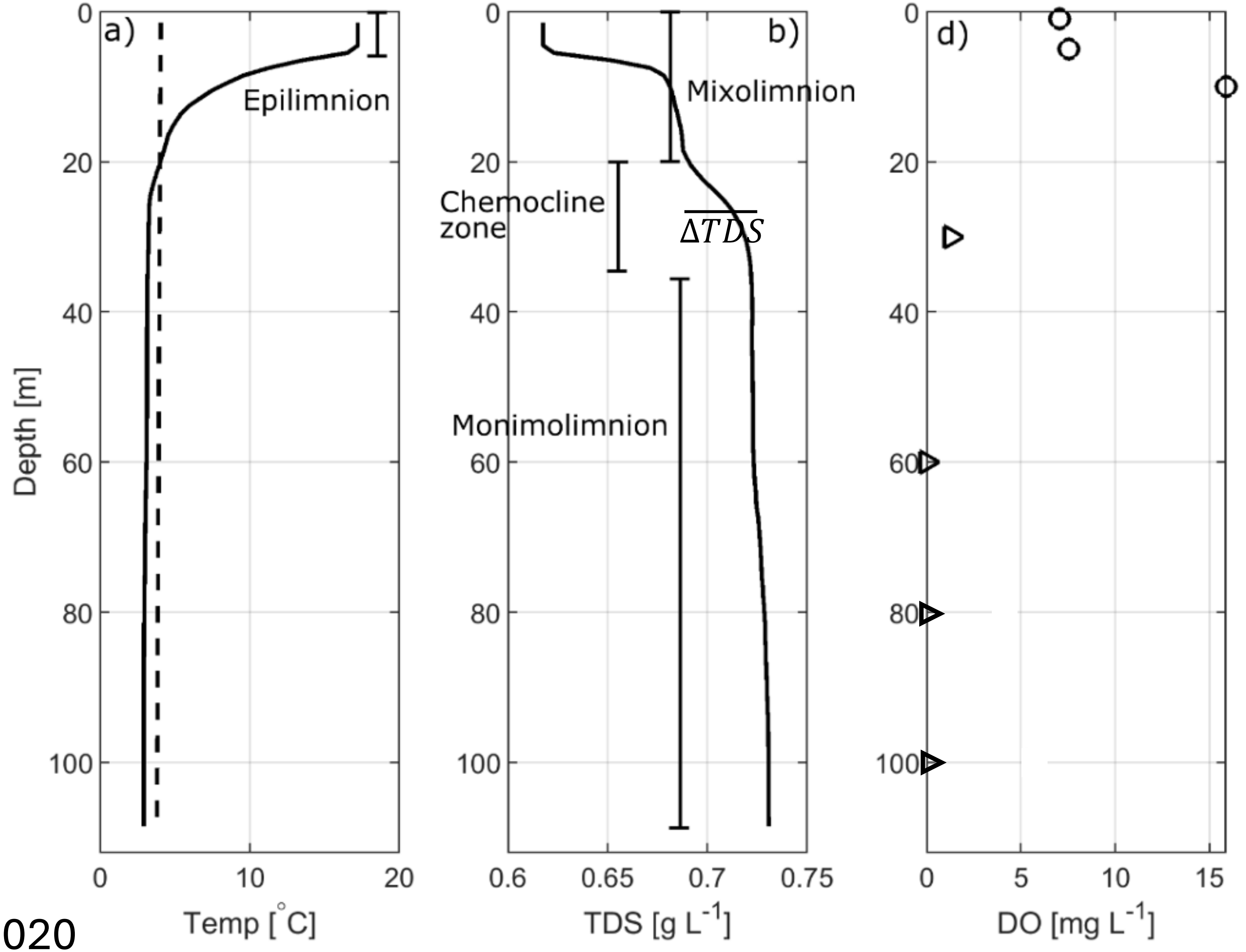
Meromixis re-developed after cessation of aeration due to continued input of low-TDS natural runoff and ice/snow melt.

1997 | Meromictic | 2006-2007 | Meromictic | 2025

Non meromictic



Photos from R. Pieters et al. 2015



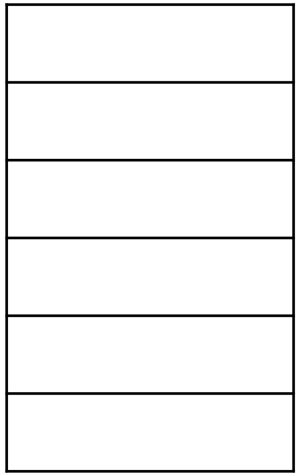
13 August 2020

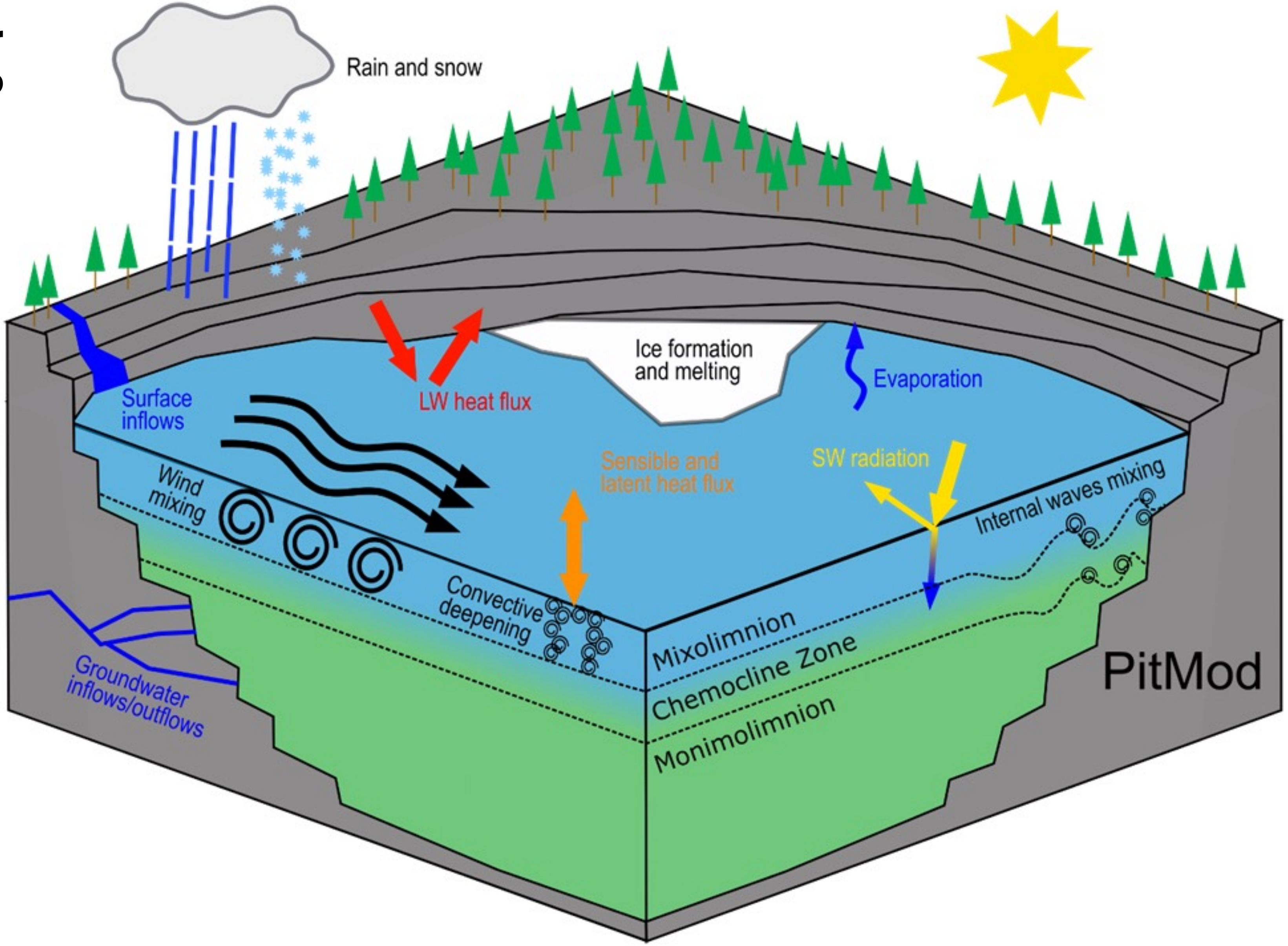
3. Modelling of Zone 2 Pit

- Observations from 2015 to 2024
- Mooring: > 20 loggers continuously recording temperature
- CTDs: Annual Conductivity (TDS), Temperature, Depth profiles
- Zone 2 Pit: limiting case for meromixis: ΔTDS = 0.04 g/L < 1g/L
- Perfect to test pit lake numerical model

3. Modelling

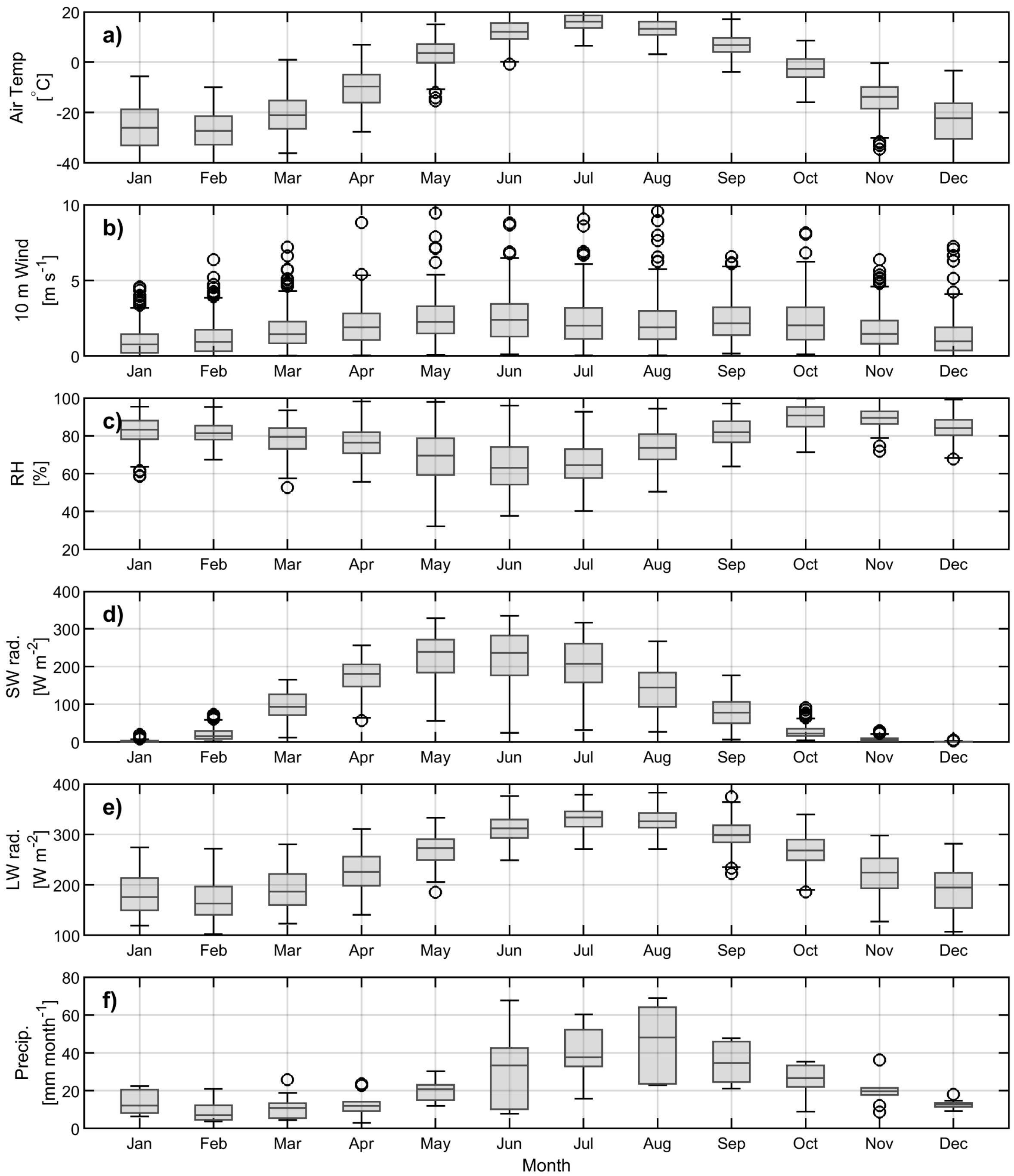
1D Model



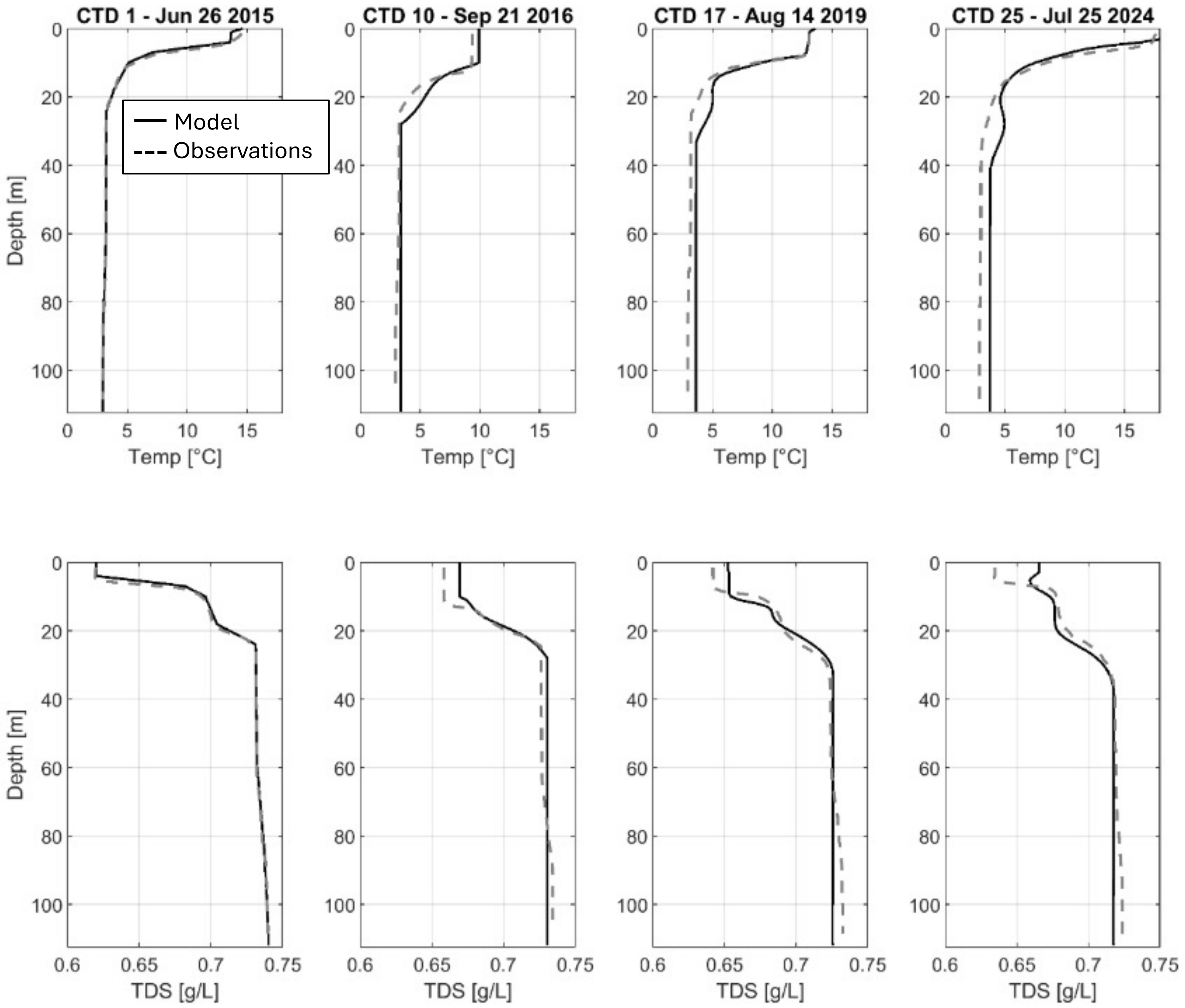


Model Inputs

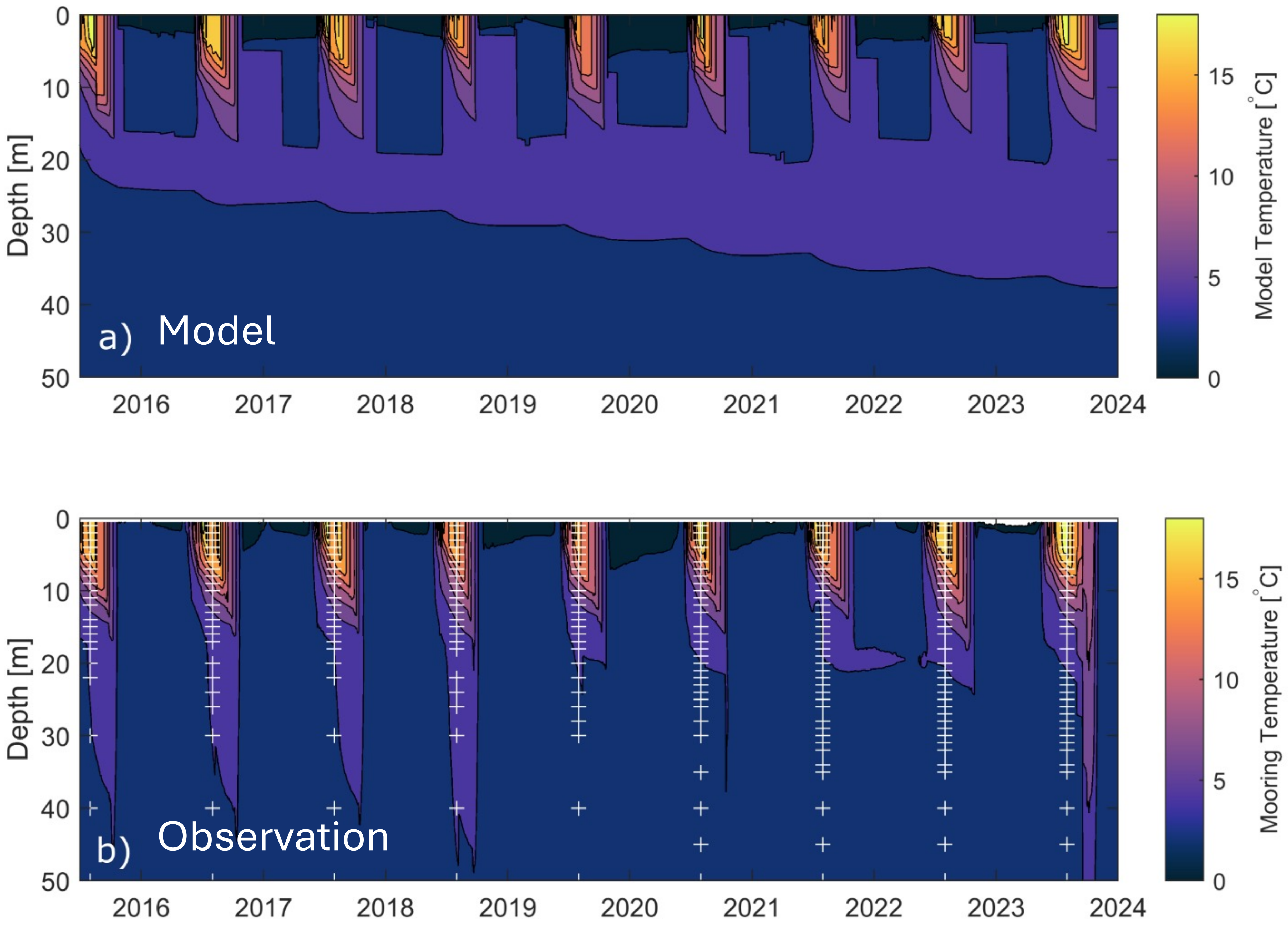
- Inputs from onsite weather station
- Except longwave radiation (in) and precipitation (ERA5)



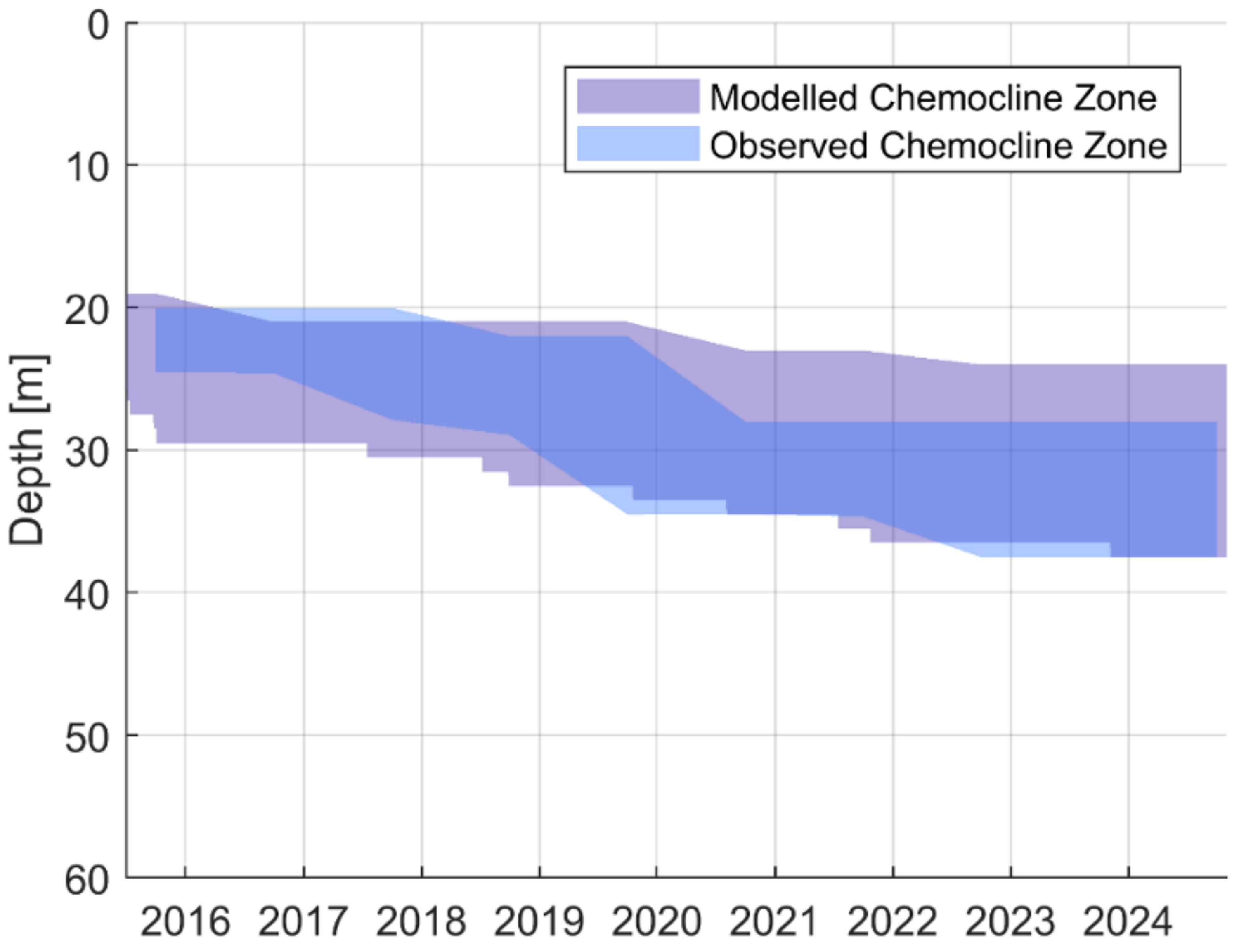
Comparison of model to profiles



Comparison of model to mooring temperature



Comparison between observed and modelled chemocline zone

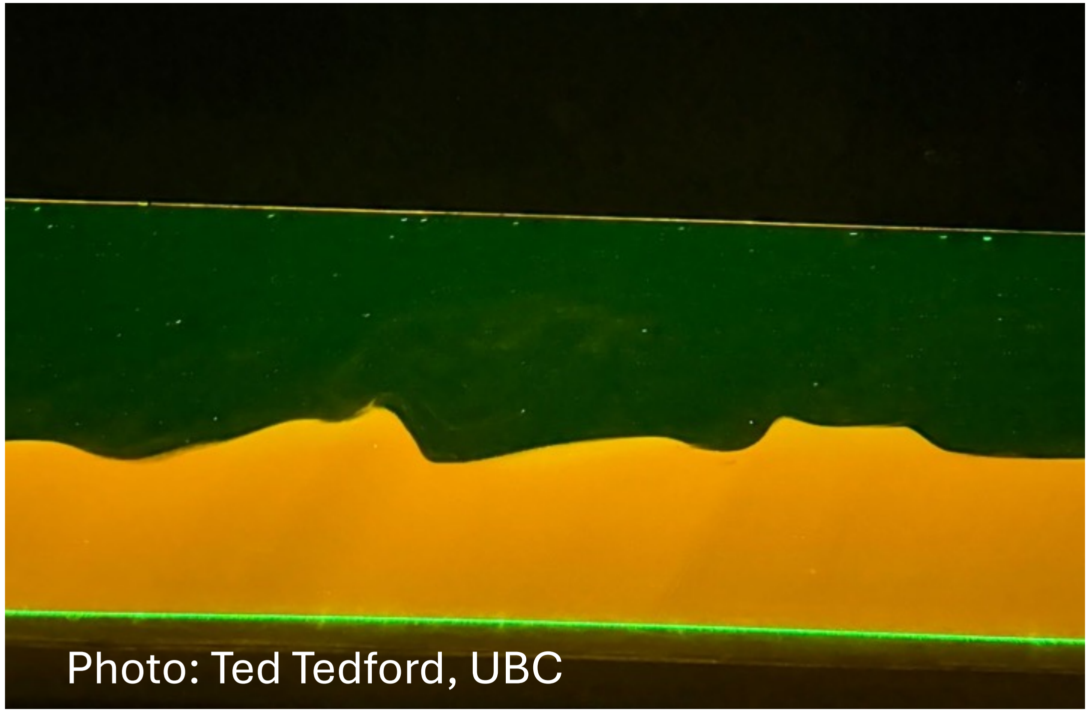


Modelled vs observed results: comparison to other studies

Lake	Type of Observation	Metric	Value or Range	Present Study	Reference
32 different lakes around the world	Temperature from CTD profiles	RMSE	0.7 to 2.2°C	0.72°C	Bruce et al., 2018
32 different lakes around the world	Epilimnion temperature	RMSE	0.5 to 3.5°C	1.1°C	Bruce et al., 2018
32 different lakes around the world	Thermocline depth	% difference	14% to 78%	8% (mean depth)	Bruce et al., 2018
Lake Beyşehir, Turkey	Temperature from profiles	RMSE	0.87°C	0.72°C	Bucak et al., 2018
Lake Ammersee, Germany	Temperature profiles	RMSE Bias	0.65°C 0.08°C	0.72°C 0.40°C	Bueche et al., 2017
72 different lakes around the world	All temperature data available	RMSE	Avg. 1.2°C	0.72°C (CTD)	Feldbauer et al., 2025

4. Future improvements in pit lake modelling

- Internal wave-driven turbulent diffusion at the chemocline
  Added to PitMod for better results



4.Considerations for improvement of pit lake management

- Collection of site specific data
  - Climate
  - Water balance
  - Geochemical source terms for all inflows

- Effect of warming climate on hydrogeology
- Ability to predict behaviour of redox-related processes as they relate to contaminant fate and pit bioremediation.
- Share observations?

Conclusion

- Meromixis can occur naturally or be engineered
- Meromixis can be exploited in the context of mine closure:
  - Permanent storage of contact water that would otherwise require treatment
  - Creation of suboxic conditions to promote in-situ bioremediation
- Modelling is required to confirm stability and predict surface water quality over time
- The results of this study show that mixing behaviour can be accurately modelled over decadal time scales
- Opportunities exist for further improvement (as always)

Thank you!

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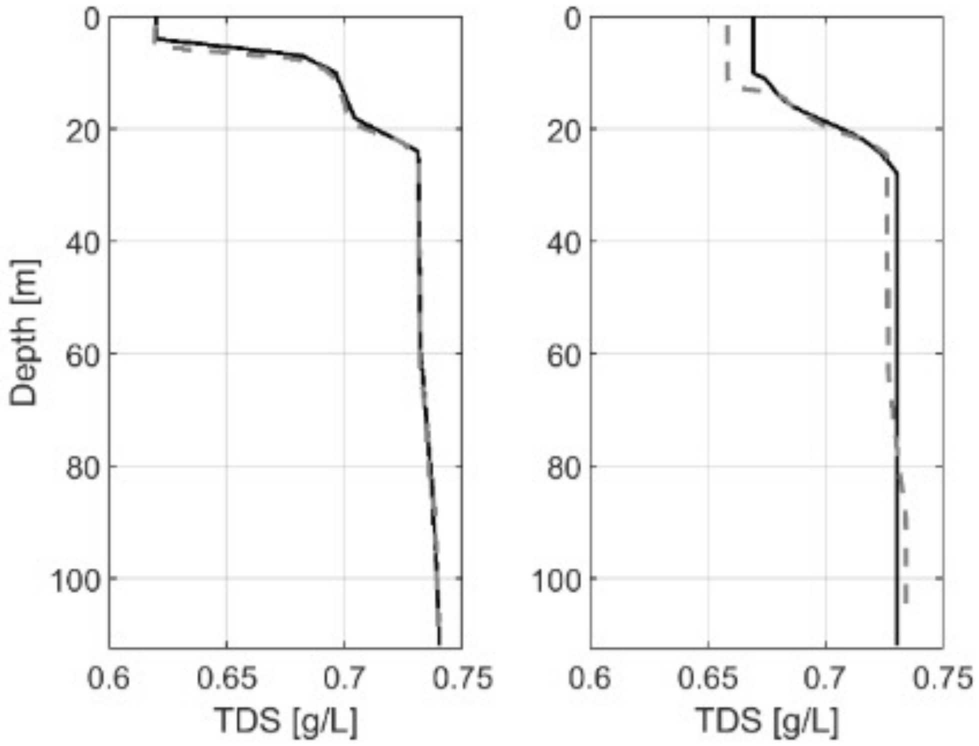
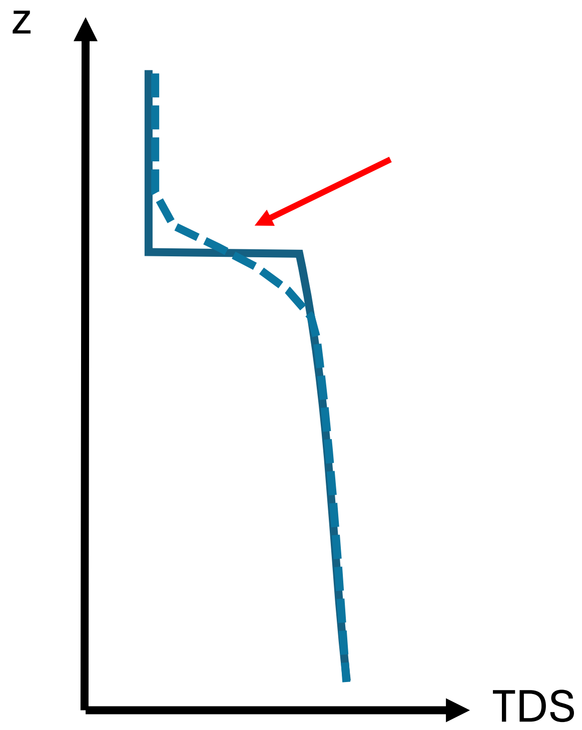
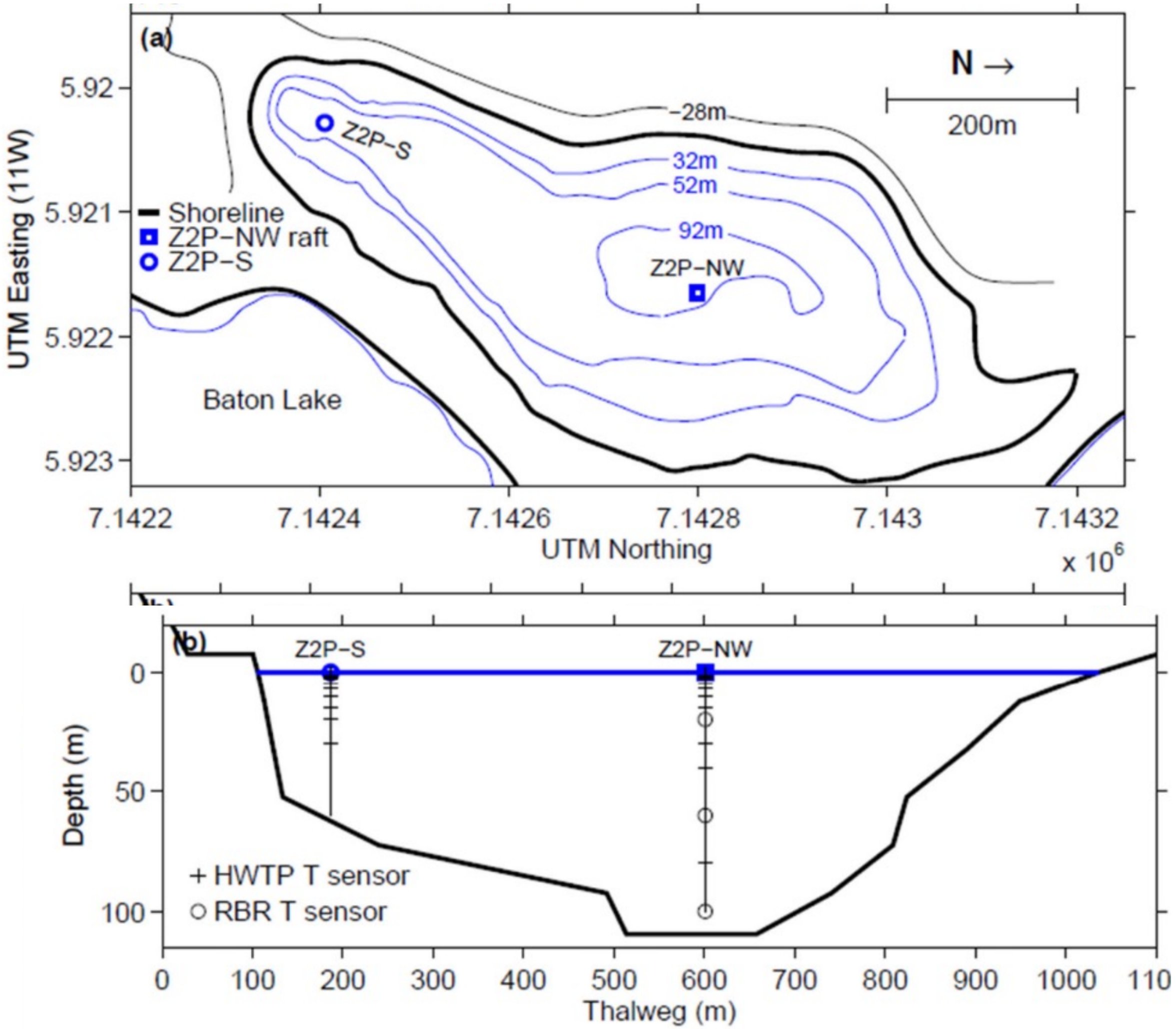


0
20
40
60
80
100
Depth [m]
0.6
0.65
0.7
0.75
TDS [g/L]
0
20
40
60
80
100
0.6
0.65
0.7
0.75
TDS [g/L]



z
TDS

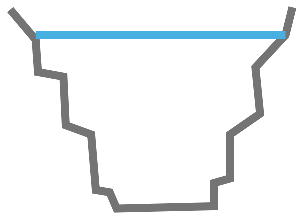

(a)
N →
200m
-28m
32m
52m
92m
Z2P−S
Z2P−NW
Shoreline
Z2P−NW raft
Z2P−S
Baton Lake
UTM Easting (11W)
5.92
5.921
5.922
5.923
7.1422
7.1424
7.1426
7.1428
7.143
7.1432
UTM Northing
x 10^6
(b)
Z2P−S
Z2P−NW
Depth (m)
0
50
100
+ HWTP T sensor
○ RBR T sensor
0
100
200
300
400
500
600
700
800
900
1000
110
Thalweg (m)

Tendency of mine pit lakes to become meromictic

- Relatively low wind (U) forcing because of sheltering and small fetch

$$\Delta h \propto \frac{U^3}{h \Delta TDS}$$

- Generally high ΔTDS (>1 g/L)



- High relative depth (depth/surface area)