ISIMIP LAKE SECTOR 06/05/2025

Wim Thiery, Don Pierson, Daniel Mercado-Bettín, Ana Ayala & Robert Ladwig

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ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

Content of today

Introduction

ISIMIP3 Local Lake Sector:

- Hydrothermal data
- Water quality data

ISIMIP Paper Repository

Simulation Status

Project Updates

- Don Pierson – MEWS project
- Ana Ayala – Modelling the burial of organic carbon in lakes within the ISIMIP framework
- Jie Chen – Pan-Arctic lakes
- Haoran Shi – Subsurface heatwaves in lakes
- Lipa Nkwalale – Acceleration of global lake anoxia under climate change
- Jorrit Mesman - Lake model calibration

New Publications

LakeEnsemblR Push

Group Discussion

- Improving the lake sector — we aim to develop a concrete plan, including co-authorship opportunities for ISIMIP3-based papers.
- New analyses or ideas

Local Lake hydrothermal and water quality data

Hydrothermal Simulations

73 Local Lakes

- Hypsographic curve
- Measured temperature profiles for calibration

Outputs

- Water temperature
- Thermal structure

Water Quality Simulations

11 Local Lakes

- Hydrothermal parameters
- Data to support simulation of dissolved oxygen
- Data to support simulation of organic carbon
- Data to support full biogeochemical simulations
- nutrients

Outputs

- Calibrated lake models that can be evaluated in a manor similar to the hydrothermal simulations
- Basis for future climate simulations using future
  - Climate forcing
  - Watershed forcing

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Local Lakes Avaliable for Water Quality Simulations

- **Erken:** Temperature, Chlorophyll (CH), Total Phosphorus (TP), PO_4, Total Nitrogen (TN), NO_3, NH_3
- **Arendsee**: O_2
- **Bosumtwi**: Temperature, Chlorophyll (CH), Total Phosphorus (TP), PO_4, Total Nitrogen (TN), NO_3, NH_3
- **Feeagh**: Hydrothermal, Dissolved Organic Carbon (DOC), Eutrophication, Oxygen
- **Groß Glienicker**: Temperature, O_2
- **Harp**: Temperature, O_2
- **Scharmützelsee**: O_2
- **Vendyurskoe**: Chlorophyll-a (Chl-a), O_2, Photosynthetically Active Radiation (PAR), Temperature
- **Villasjön**: Temperature, CH_4 concentration, total CH_4 flux, diffusive CH_4 flux, ebullition CH_4 flux
- **Inre Harrsjön**: O_2, Temperature, CH_4 concentration, total CH_4 flux, diffusive CH_4 flux, ebullition CH_4 flux
- **Mellersta Harrsjön**: CH_4 concentration, total CH_4 flux, diffusive CH_4 flux, ebullition CH_4 flux

Data sources local and global simulations

Local lake data for ISIMIP3 hydrothermal calibration: https://github.com/icra/ISIMIP_Local_Lakes

Input water quality data local lakes:
https://drive.google.com/drive/folders/1VK6JPFfgrDAi2nmvNqbRtw9FWAEDG5ew

Input climate data local lakes:
ISIMIP3a
https://data.isimip.org/search/tree/ISIMIP3a/InputData/climate/atmosphere/
ISIMIP3b:
https://data.isimip.org/search/tree/ISIMIP3b/InputData/climate/atmosphere/

Lake morphology for ISIMIP3 global runs: https://github.com/icra/ISIMIP_Lake_Sector

Status of local and global simulations

Model name	Type	Contact person	Run	Status May 2023	Remarks
PCLake	Water quality	Annette Janssen	global	planning	Not started (yet); No coherent nutrient loading data available (to be discussed,)
CLM5	Hydrothermal	Wim Thiery	global	ongoing	Preprocessing ongoing
LAKE	Hydrothermal	Victor Stepanenko	both	ongoing	Planning to start the full-scale runs in the beginning of 2023 (last status on October 2022)
ALBM	Hydrothermal	Zeli Tan	global	completed	Available at https://data.isimip.org/search/tree/ISIMIP3b/OutputData/lakes_global/
air2water	Hydrothermal	Sebastiano Piccolroaz & Bronwyn Woodward	local	completed	Available at https://data.isimip.org/search/tree/ISIMIP3b/OutputData/lakes_local/
GOTM	Hydrothermal	Daniel Mercado-Bettin	global	completed	Available at https://data.isimip.org/search/tree/ISIMIP3b/OutputData/lakes_global/
FLake_LER	Hydrothermal	Jorrit Mesman	local	completed	Available at https://data.isimip.org/search/tree/ISIMIP3b/OutputData/lakes_local/
GLM_LER	Hydrothermal	Jorrit Mesman	local	completed	Available at https://data.isimip.org/search/tree/ISIMIP3b/OutputData/lakes_local/
GOTM_LER	Hydrothermal	Jorrit Mesman	local	completed	Available at https://data.isimip.org/search/tree/ISIMIP3b/OutputData/lakes_local/
Simstrat_LER	Hydrothermal	Jorrit Mesman	local	completed	Available at https://data.isimip.org/search/tree/ISIMIP3b/OutputData/lakes_local/
VIC-LAKE	Hydrothermal	Annette Janssen	global	ongoing	Runs 3b are almost finished and soon we start post-processing; 3a is still under discusison
Simstrat	Hydrothermal	Bo Gai	Local global	ongoing	Finishing Local and Planning Globas
GLM	Hydrothermal	Daniel Mercado-Bettin	global	planning	Waiting to finish GOTM simulations
CE-QUAL-W2	Hydrothermal	Josef Hejzlar	local	planning	Currently planned for one reservoir only
FLake	Hydrothermal	Tom Shatwell & Georgiy Kirillin	local	planning	To start in the next months

Overview ongoing/planned analyses using ISIMIP data

- Don Pierson – MEWS project, using ISIMIP to support Water4All
- Ana Ayala – Modelling the burial of organic carbon in lakes within the ISIMIP framework
- Jie Chen – Pan-Arctic lakes
- Haoran Shi – Subsurface heatwaves in lakes
- Lipa Nkwalale – Acceleration of global lake anoxia under climate change
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Managing Events and Extremes in Water Supplies (MEWS)

Water4All
Water security for the planet

Objectives

To develop a freely available comprehensive modelling tool that will allow stakeholders to evaluate the effects of extreme hydro-climatic events on drinking water quality.

To co-develop the modelling system with stakeholders from each demonstration site, including scenarios, workflows, documentation and training

To increase our understanding of the complex regulation of the effects of extreme events and antecedent conditions on water quality at the water supply withdrawal under present and future conditions.

Use of ISIMIP data

ISIMIP3 climate scenarios are being used by the project as the inputs to watershed and lake model simulations where scale is appropriate.

MEWS sites are in a sense similar to ISIMIP Local lakes, and will be added to the local lake database One (Ekoln) already is a local lake site

MEWS Illustrates how ISIMIP data can be used to support a variety of projects while still providing valuable data to the ISIMIP archive

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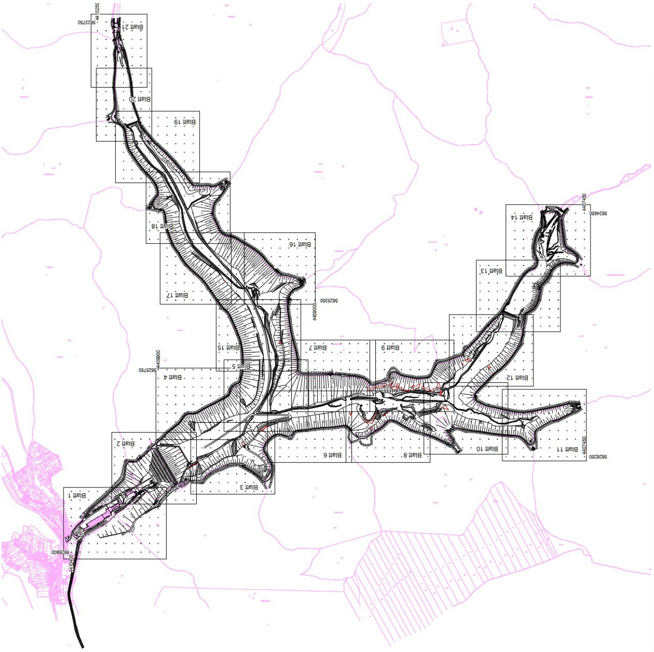
PROCLIAS

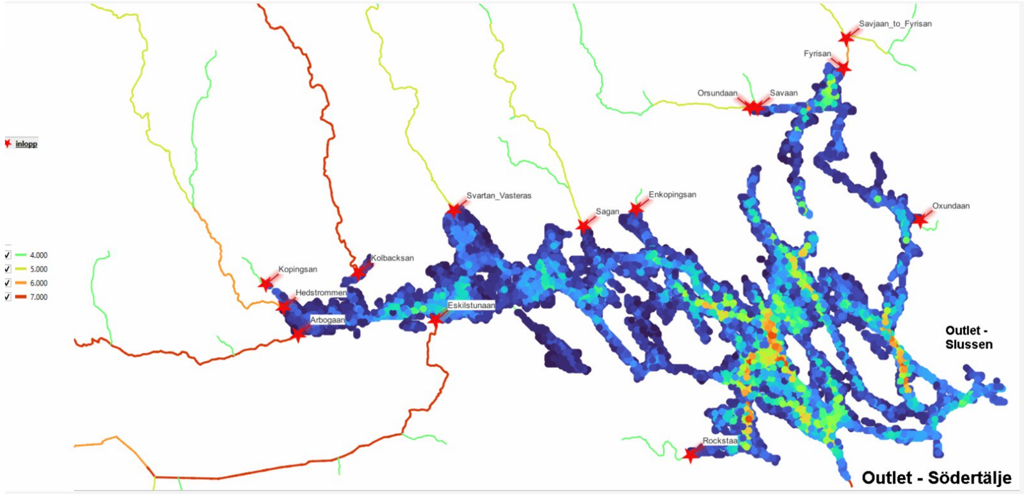
MEWS Project Sites

Ohra Reservoir Germany



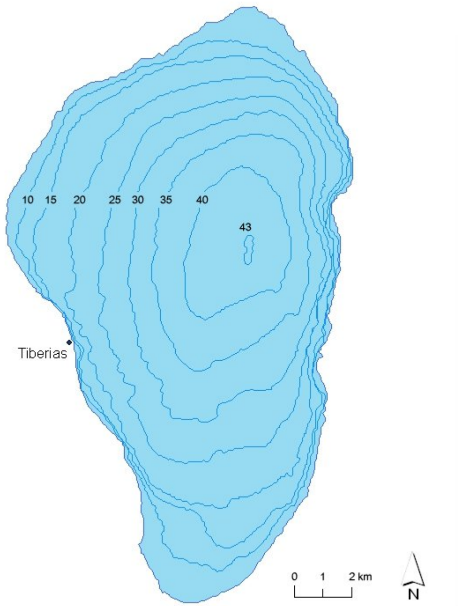
Surface Area 0.82 km^2
Residence Time ~ 1 yr
Population Served ~ 400 000

Lake Mälaren Sweden



Surface Area 1140 km^2
Residence Time 2.2 yr
Population Served ~ 2 000 000

Lake Kinneret Israel



Surface Area 166 km^2
Residence Time 4.8 yr
Population Served ~ 1 900 00 +
contributions to Jordan

OWL University of Applied Sciences and Arts

TH OWL Technische Hochschule Ostwestfalen-Lippe University of Applied Sciences and Arts

Uppsala University Sweden & Swedish University of Agricultural Sciences

Uppsala Universitet

Israel Oceanographic Limnological Research

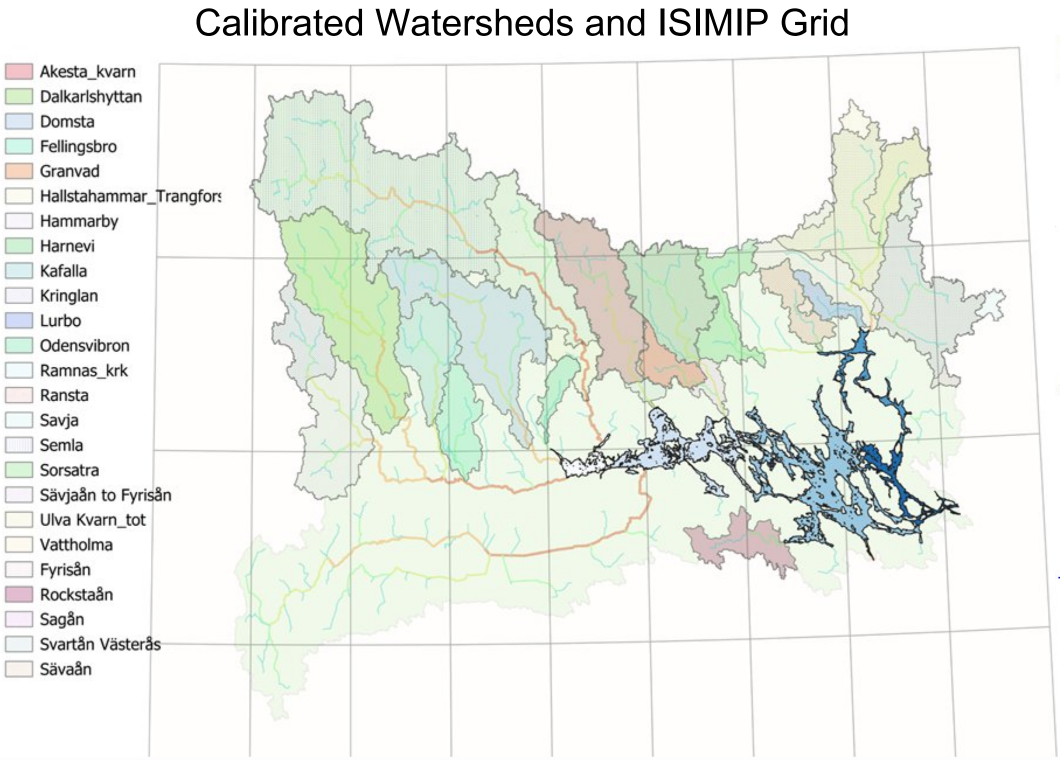
VUB Vrije Universiteit Brussel

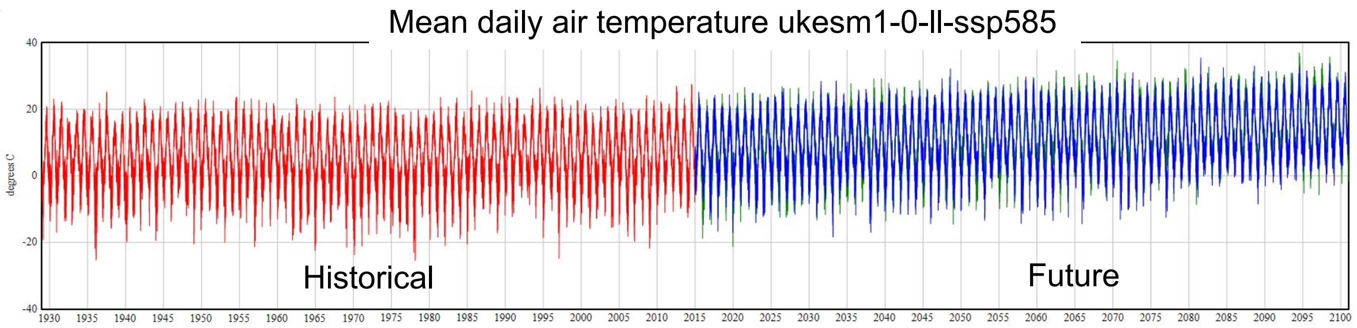
CEAB Centre d'Estudis Avançats de Blanes

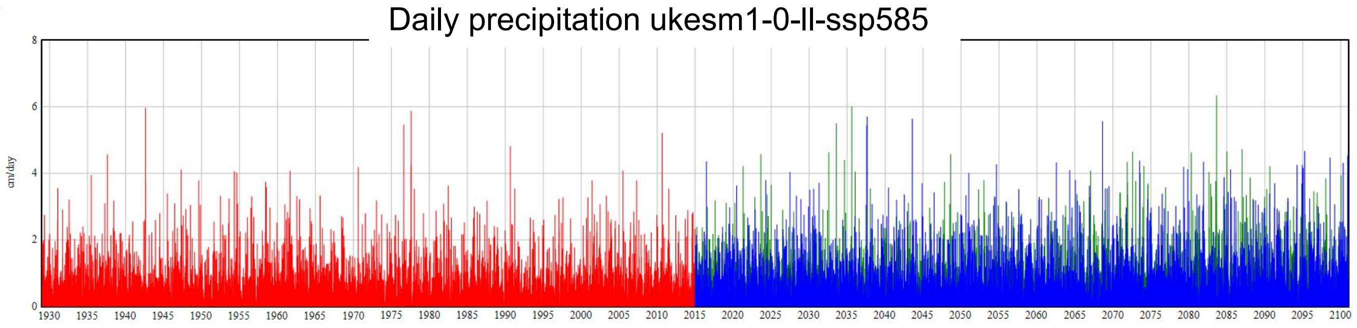
Uppsala Universitet

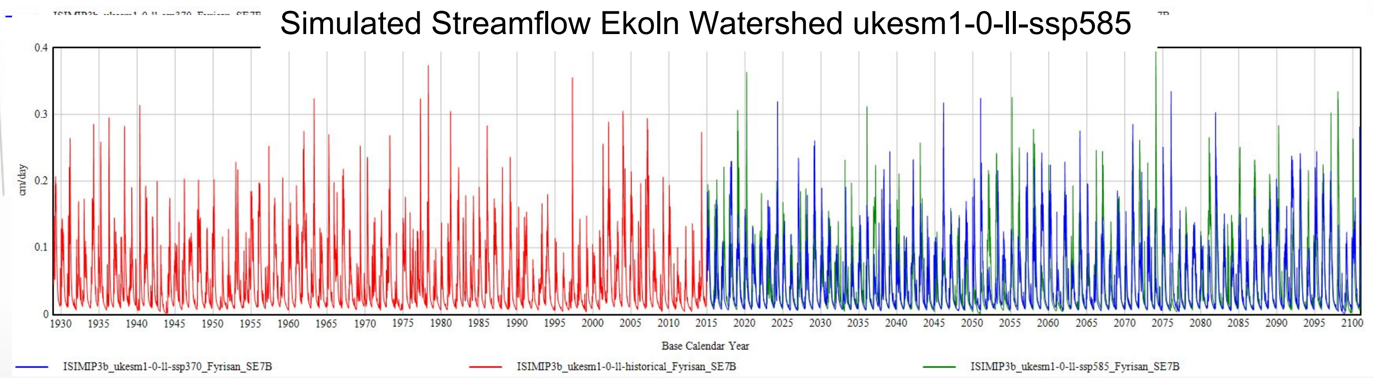
ISIMIP Inter-Sectoral Impact Model Intercomparison Project

Use of ISIMIP3 Data in Sweden



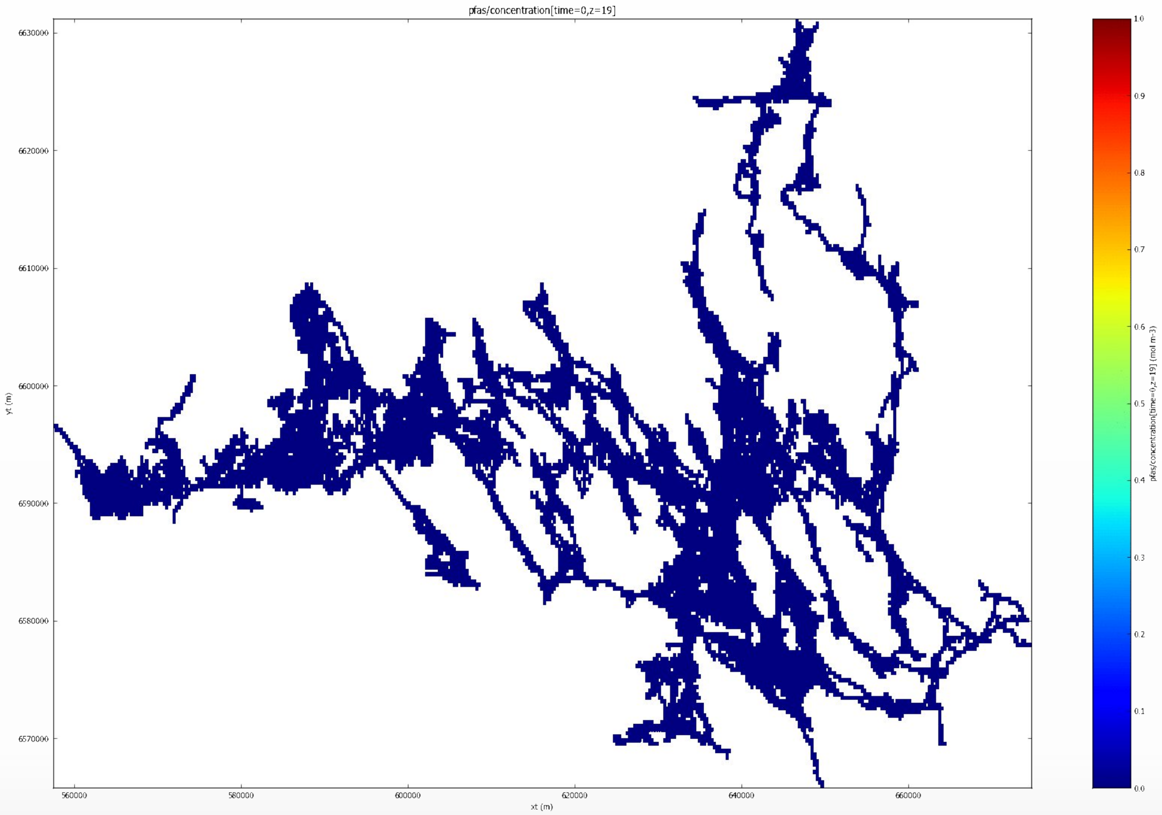






For More Information:

https://mews-water.com/



Modelling the burial of organic carbon in lakes within the ISIMIP framework

Ana I. Ayala, Donald C. Pierson and Sebastian Sobek

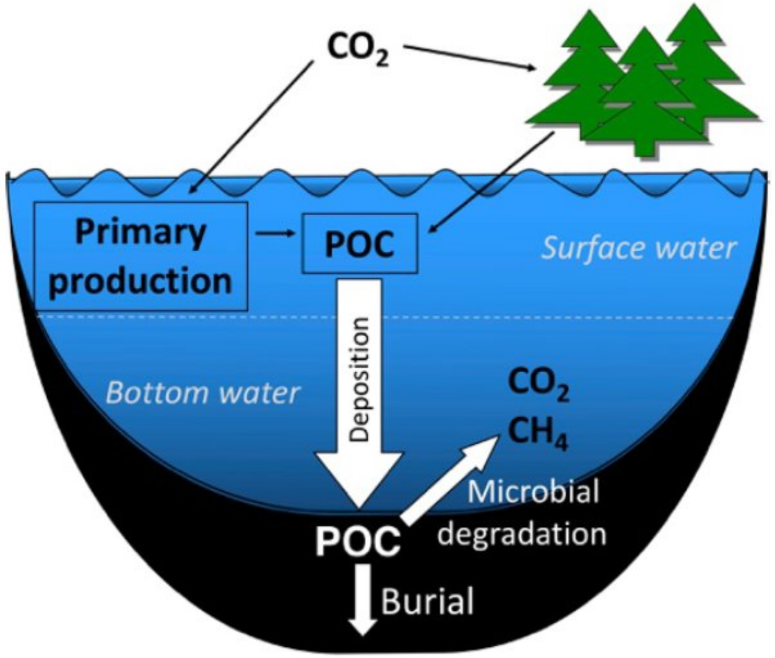
ISIMIP Lake Sector

May 6th, 2025

UPPSALA UNIVERSITY

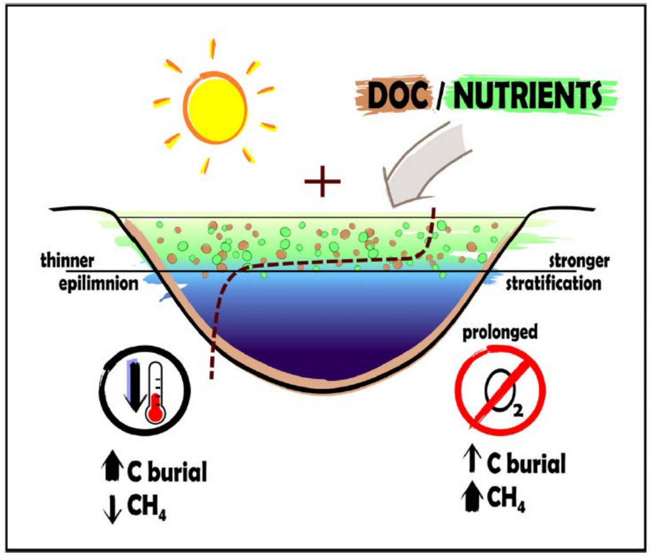
Swedish Research Council

Introduction



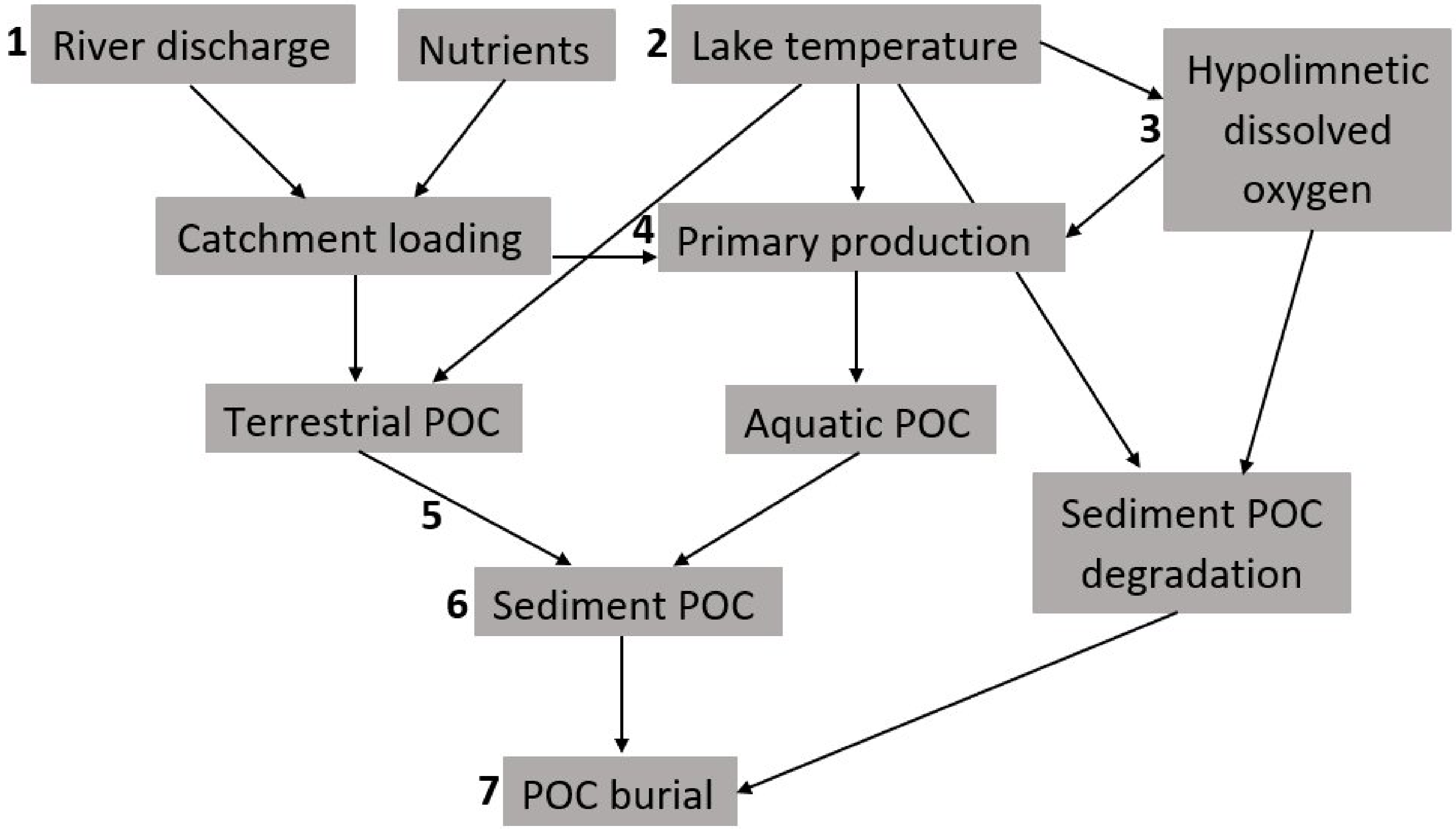
Mechanism regulation microbial degradation:

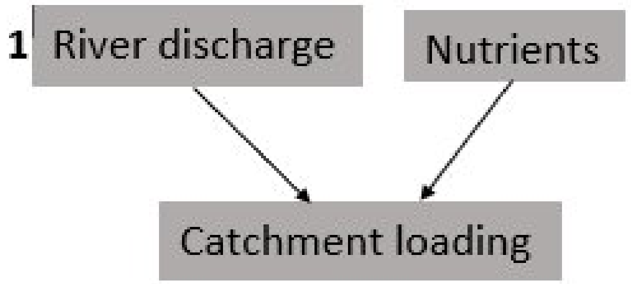
- Low temperature
- Short oxygen exposure
- Complex chemical composition of the organic matter
- Source of POC (from land or internal primary production)



Bartosiewicz et al. (2019)

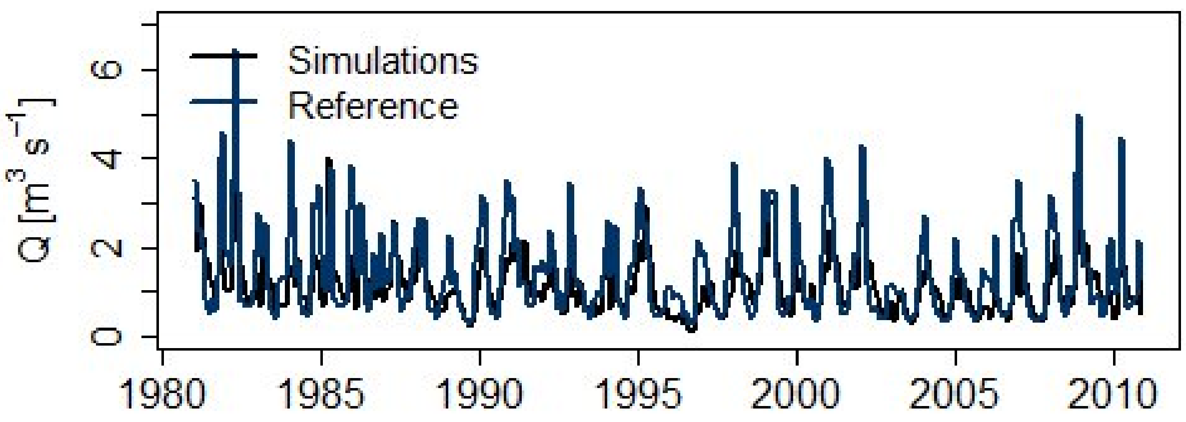
Modelling framework

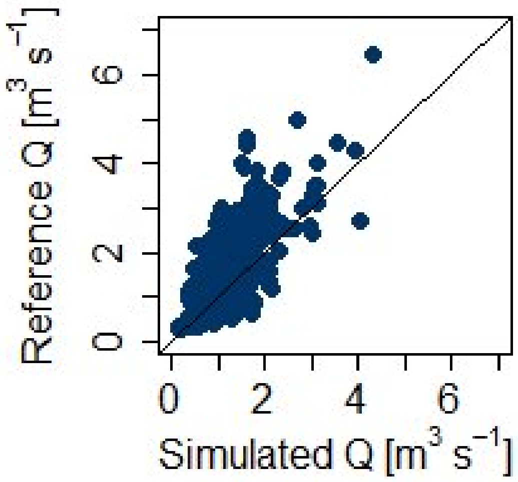




GLOBAL NEWS2: Nutrient export from land to river (Mayorga et al., 2010)

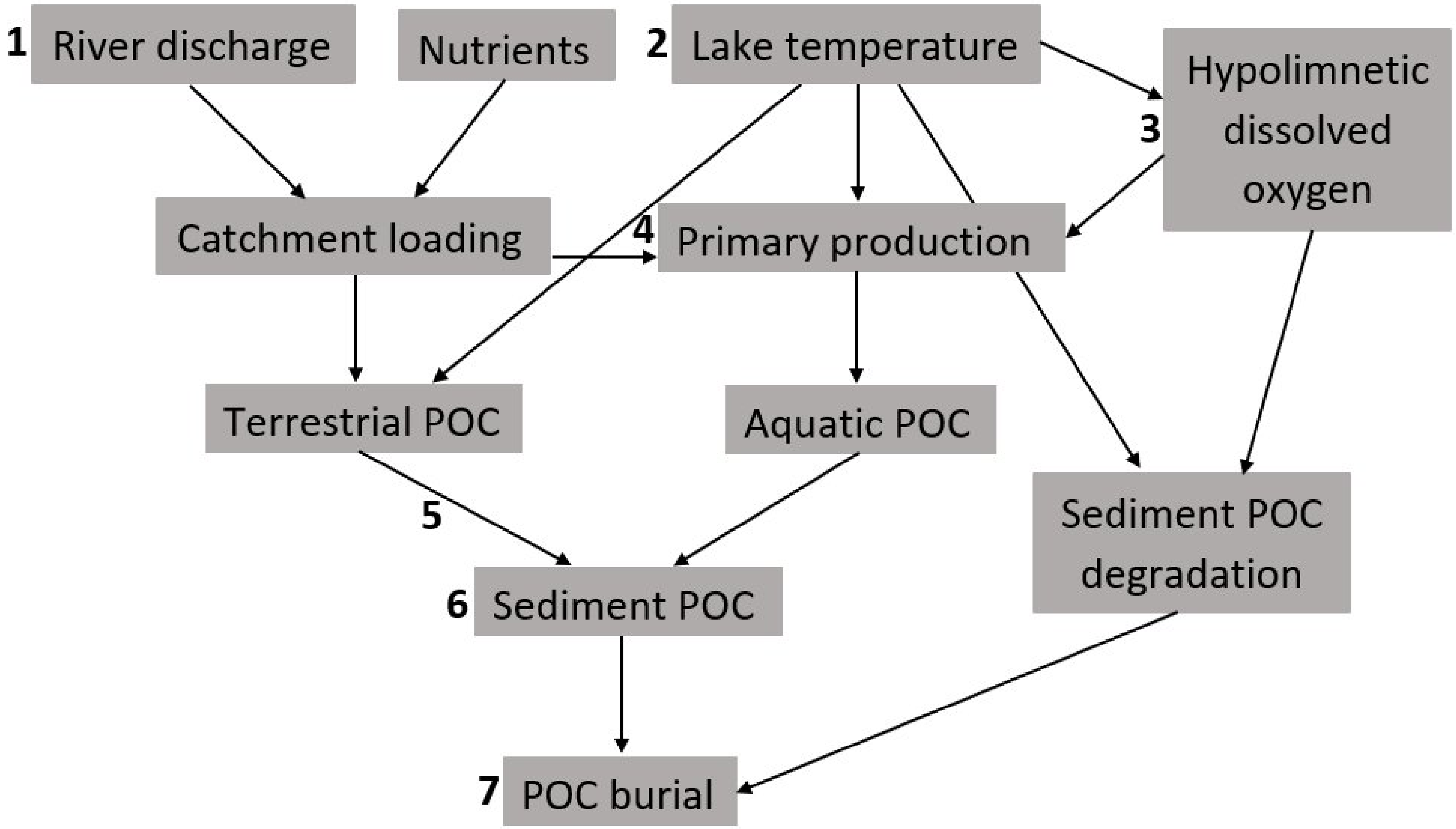
1. Scaling 0.5° grid streamflow from Global Water Sector to catchment scale using WaterGAP2.2e outputs (Ayala et al., in prep.)

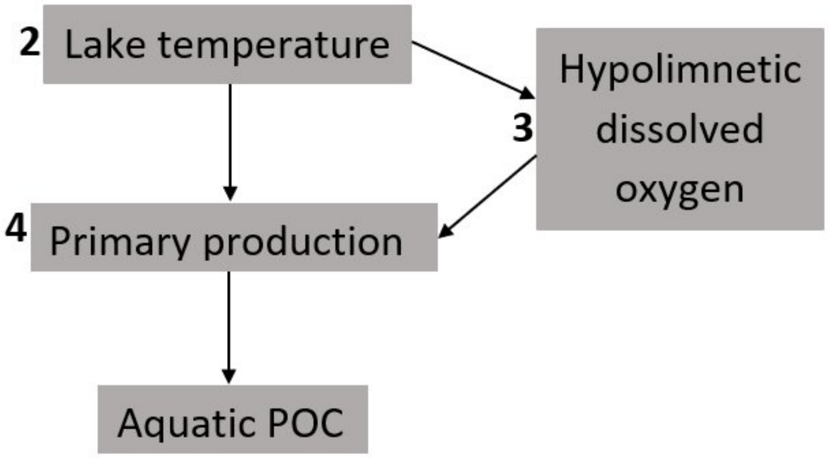




KGE=0.63
KGE_r=0.75
KGE_b=0.80
KGE_g=0.83

Modelling framework

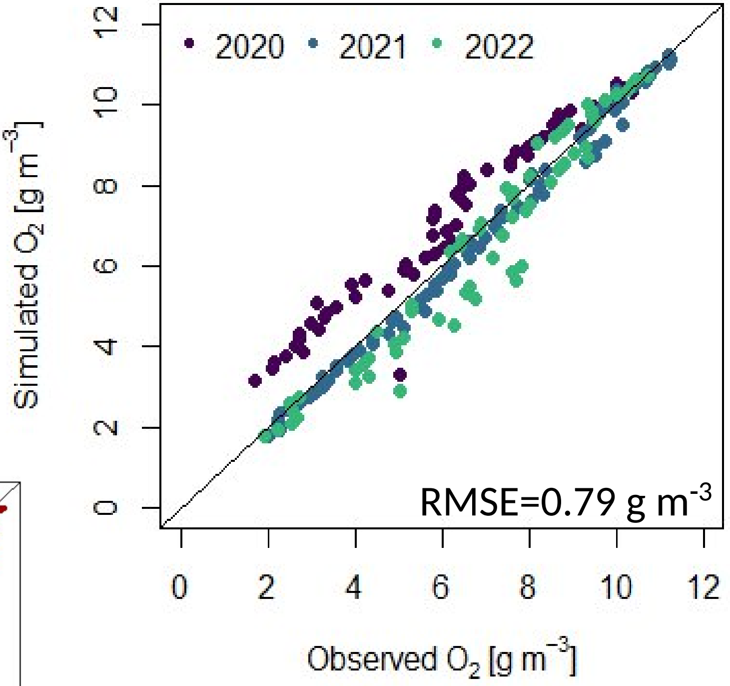




3. Hypolimnetic dissolved oxygen

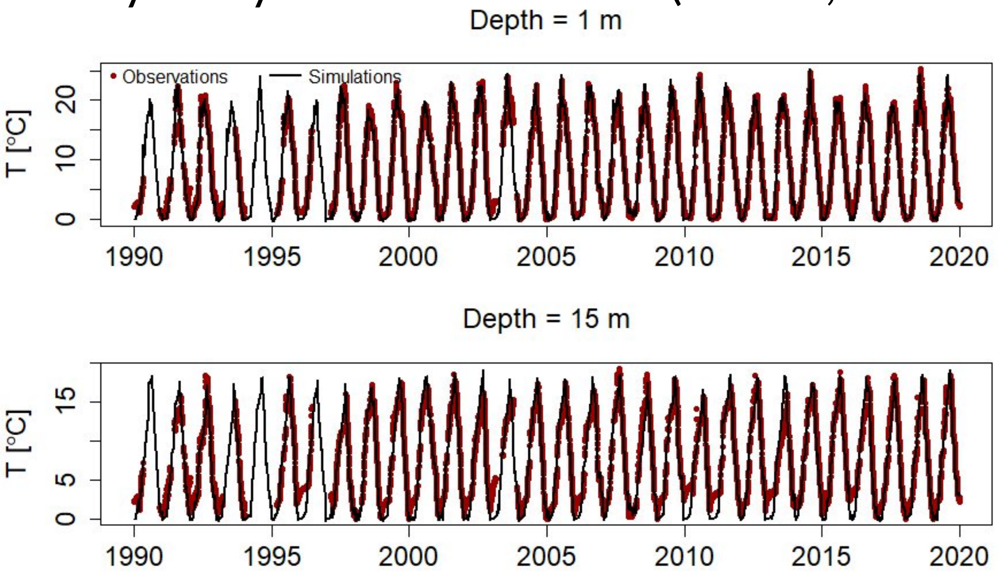
Livingstone and Imboden (1996)

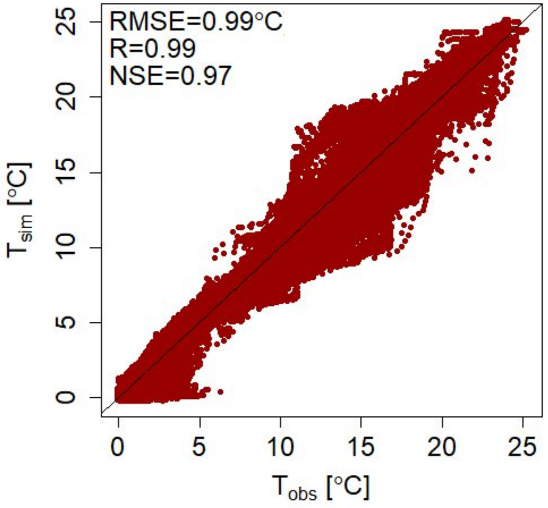
$$\frac{\partial O_2(z,t)}{\partial t} = -\left(J_v + J_A \cdot \alpha(z)\right) \cdot \theta^{T_{hyp}(z,t)-20}$$

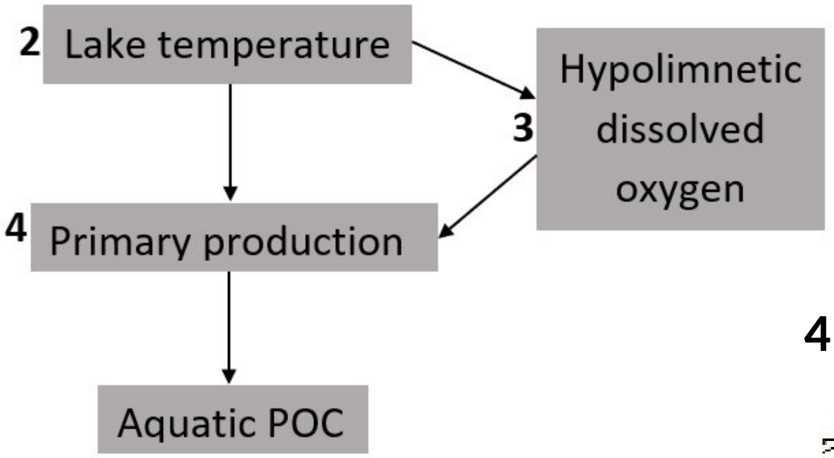


2. Water temperature, stratification and mixing dynamics

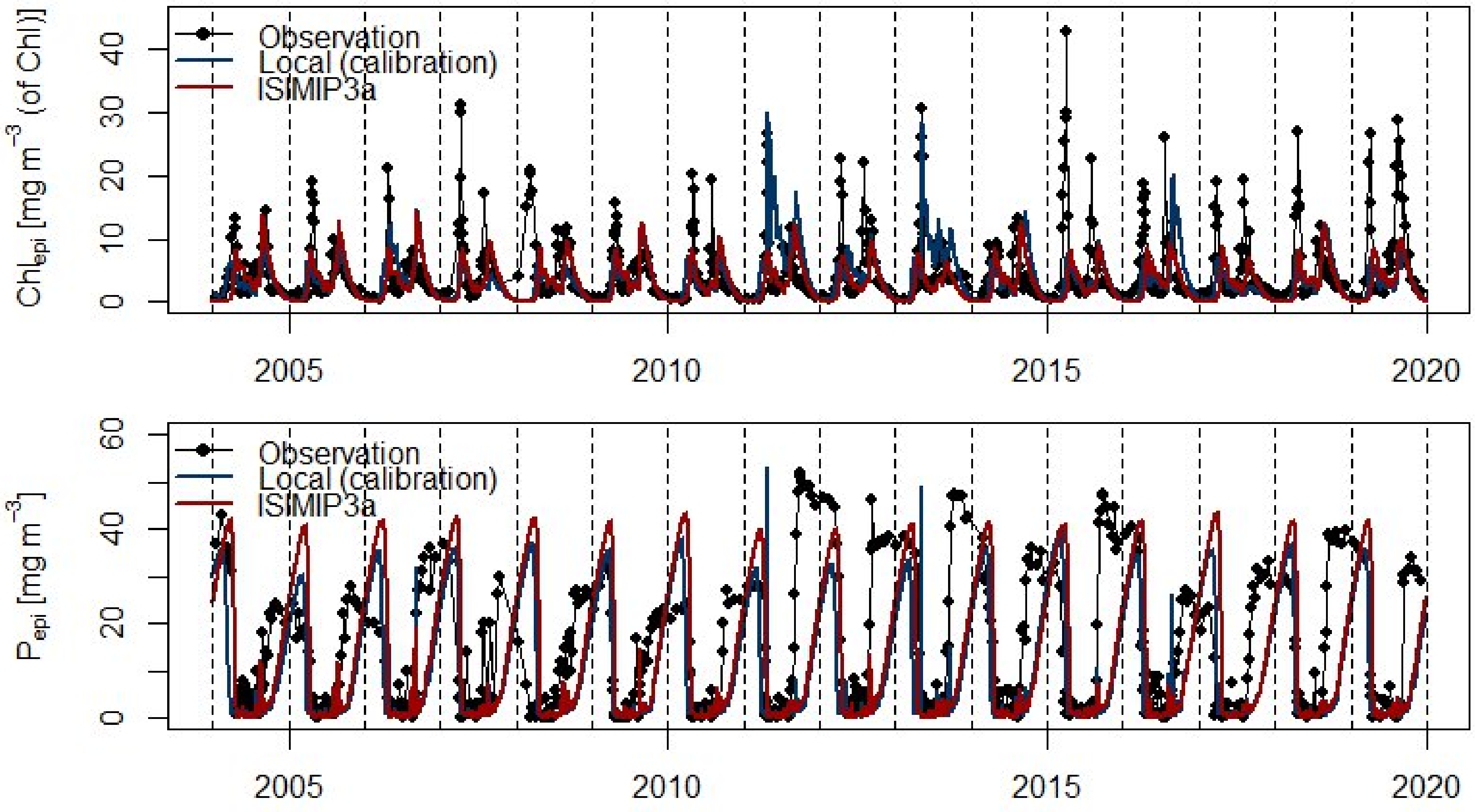
1D hydrodynamic lake model (GOTM; Burchard et al., 1999)





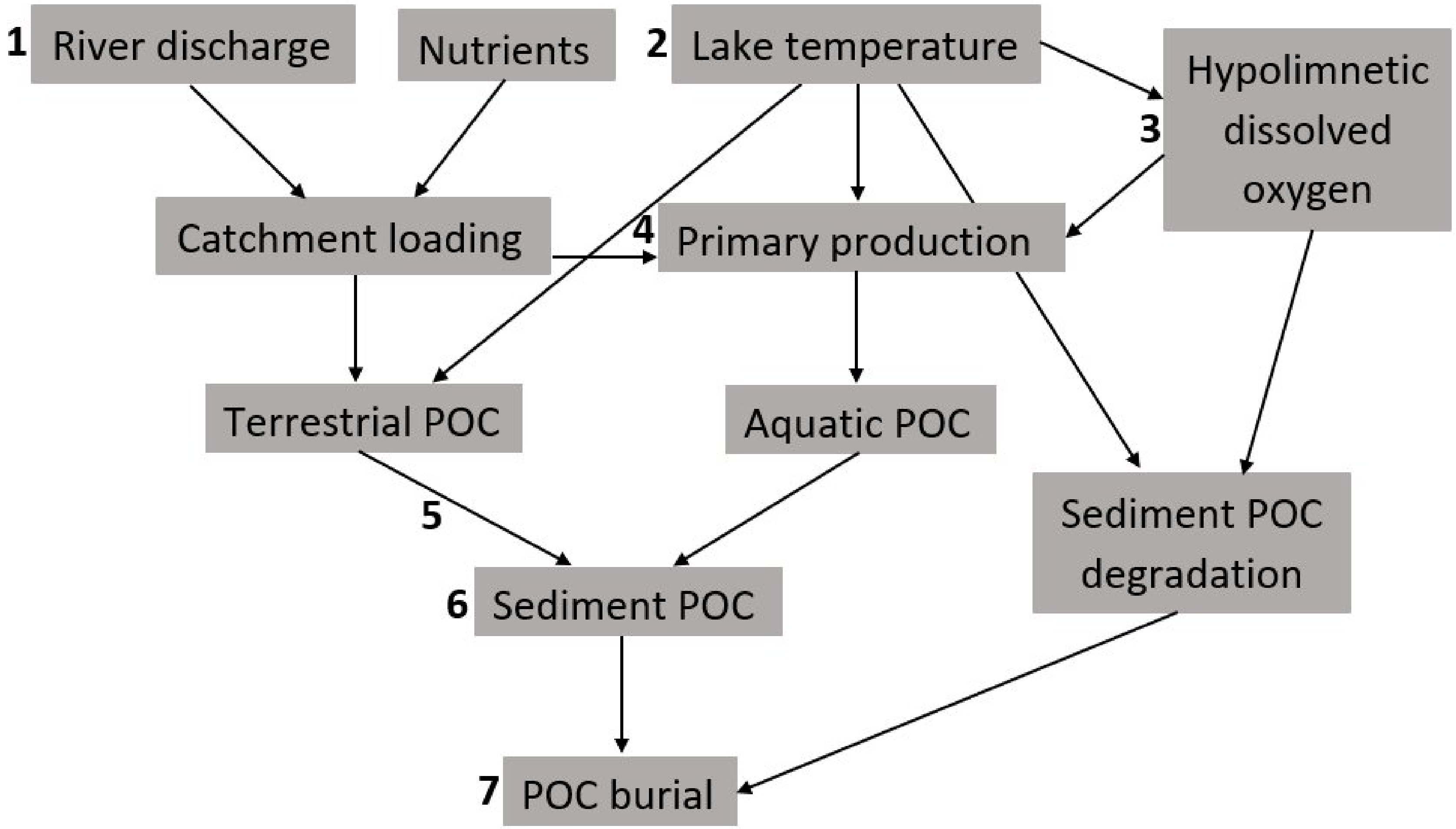


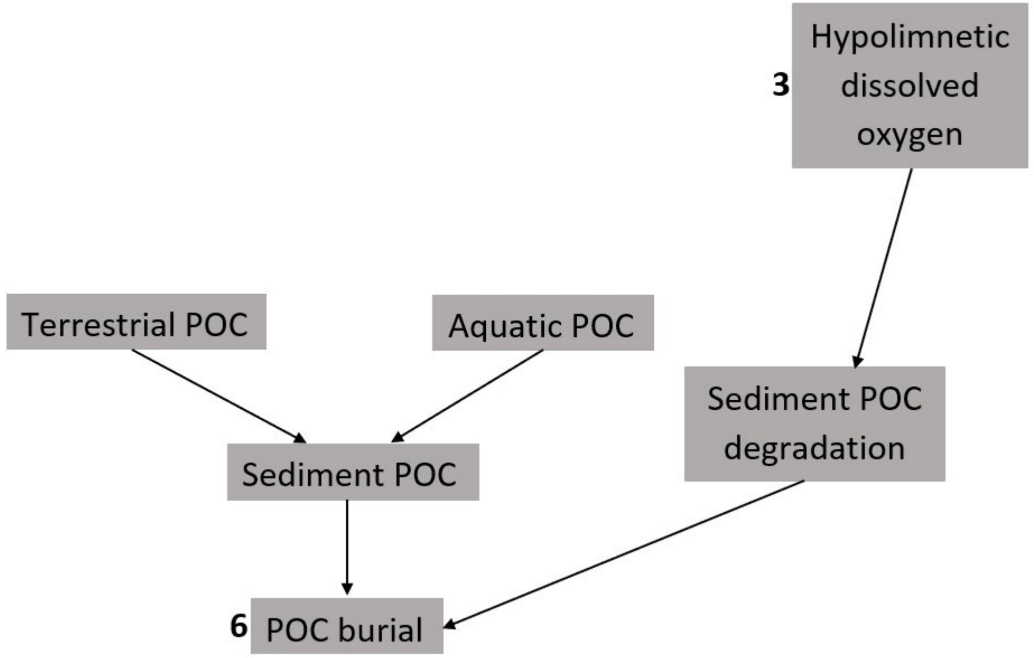
4. Lake primary production



	Local (calibration)		ISIMIP3a	
	NRMSE	RMSE	NRMSE	RMSE
Chl_{epi}	0.16	6.64 mg m^{-3}	0.15	6.36 mg m^{-3}
P_{epi}	0.28	14.37 mg m^{-3}	0.28	14.56 mg m^{-3}

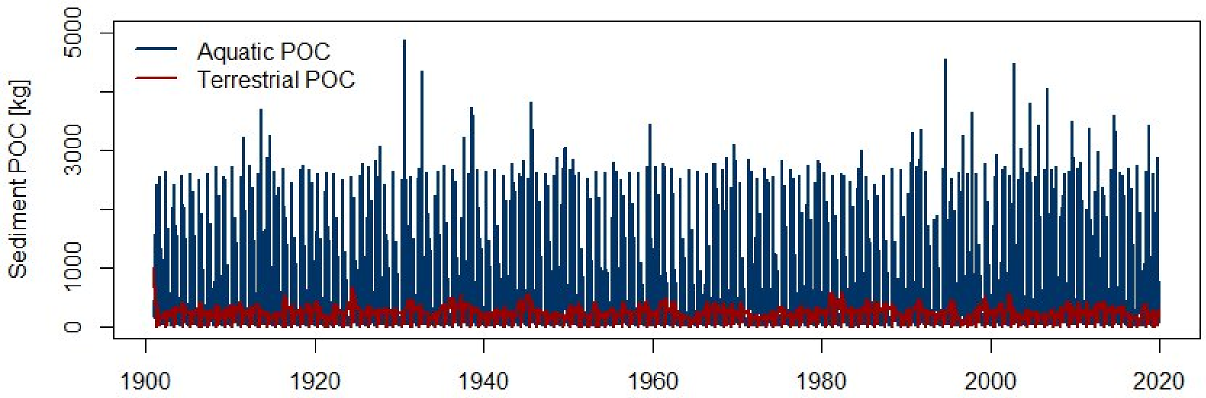
Modelling framework



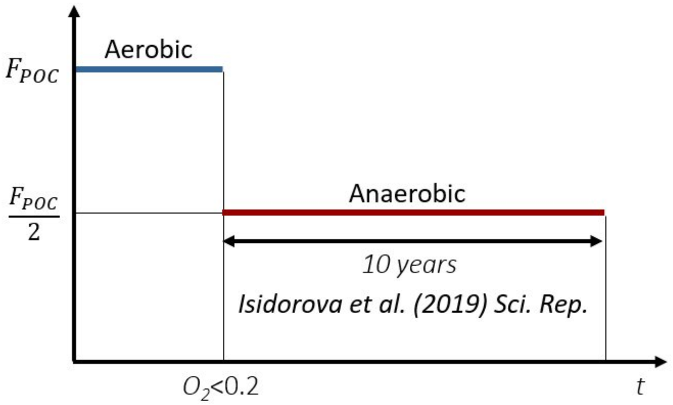


Sediment POC

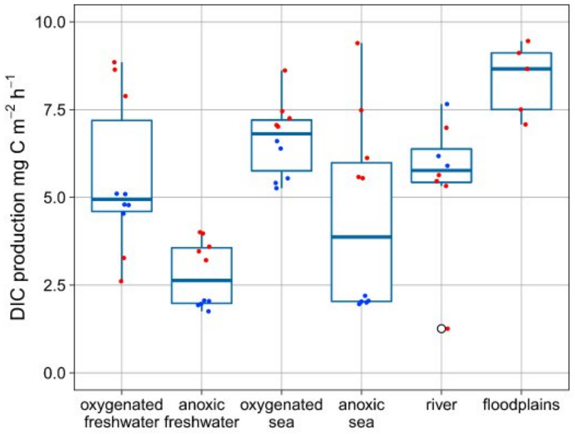
POC_{auto} = 72.3 % of total POC
POC_{allo} = 27.7 % of total POC



6. Sediment diagenesis



$$F_{POC} = f\ (J_A)$$



Isidorova et al. (2019) JGR Biogeo

School of Ocean Sciences,
Bangor University,
Menai Bridge, Wales, UK

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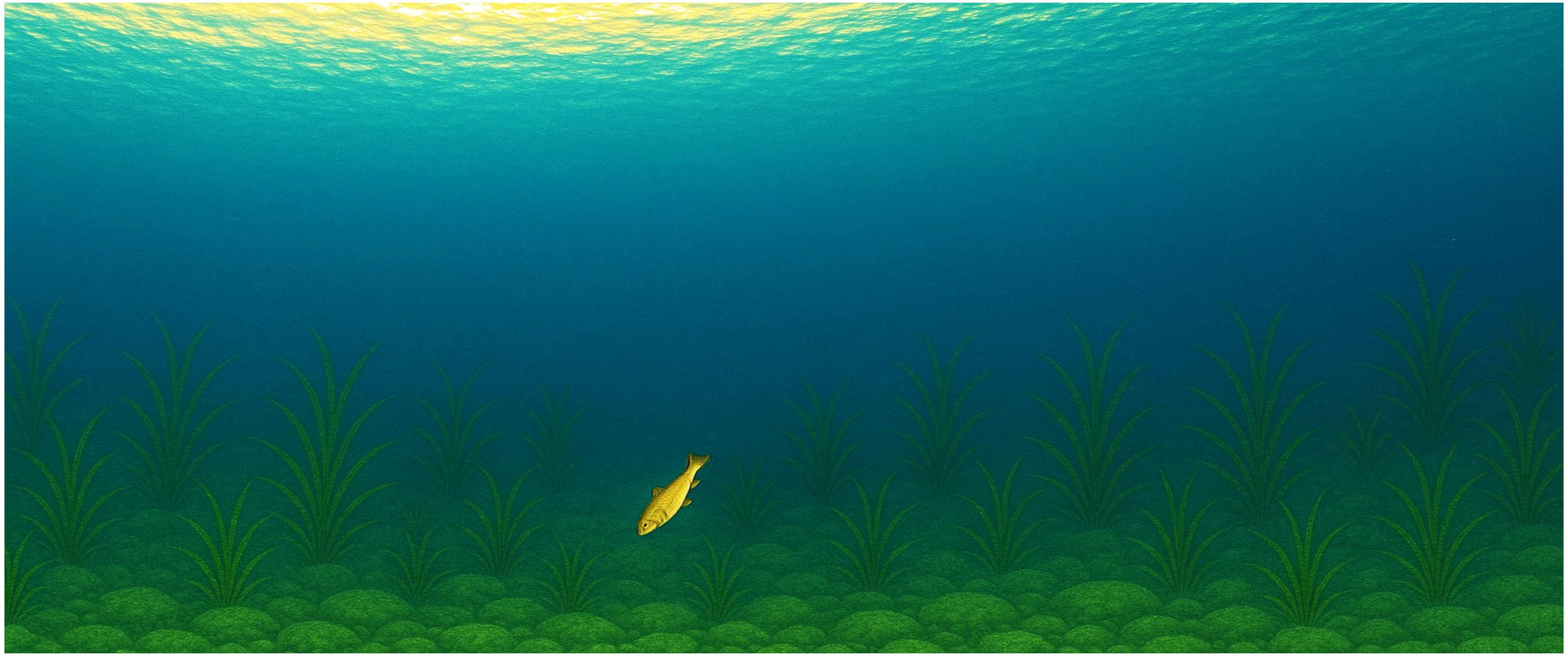
Subsurface heatwaves in lakes

ISIMIP Lake Sector Meeting

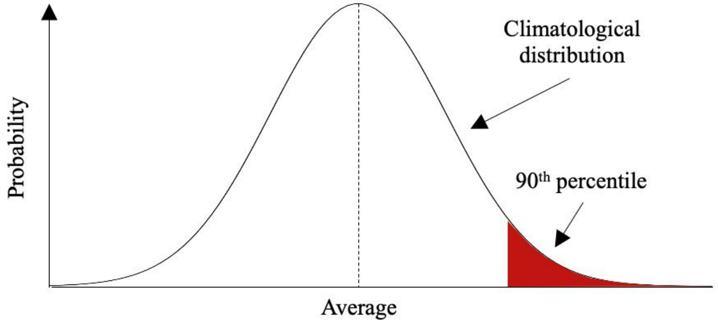
May 6th, 2025

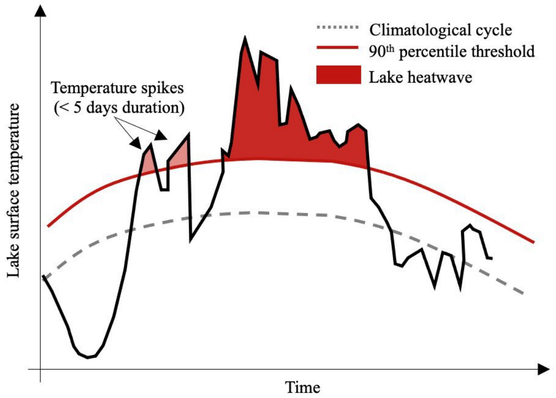


Reporter: **Haoran Shi** on behalf of **Dr. Iestyn Woolway**

Background

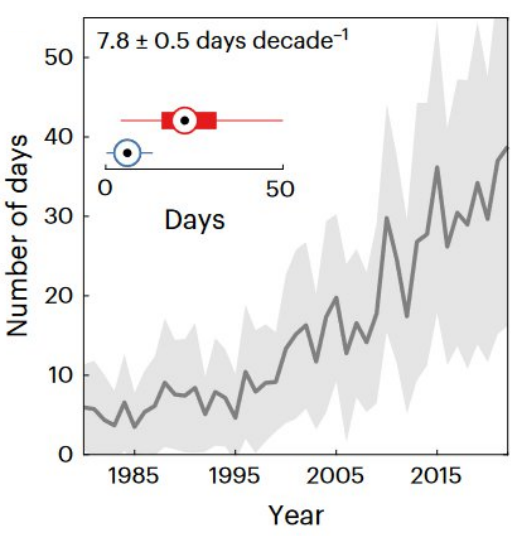
Lake Surface Heatwaves



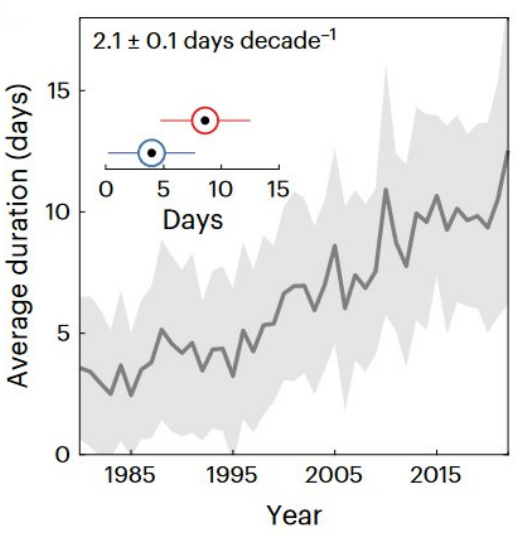


Some species can migrate downwards to escape from the heatwaves while the others cannot.

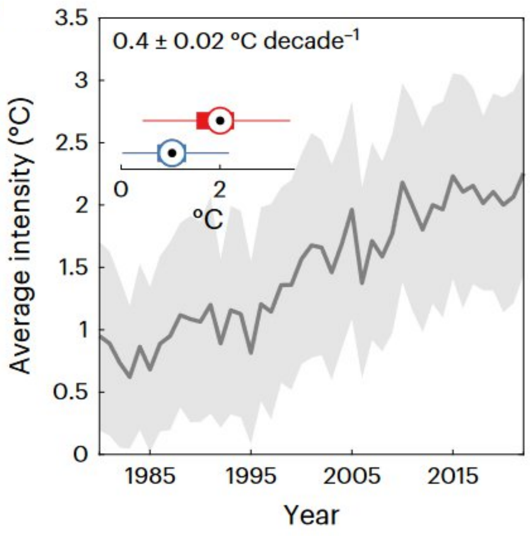
Surface heatwaves are increasing !



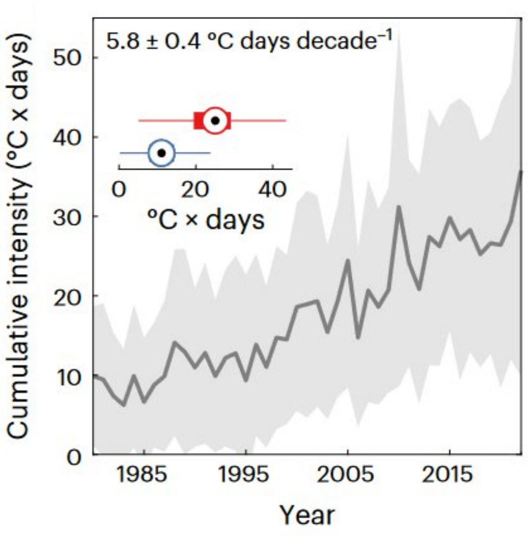
occurrence



duration



intensity



cumulative intensity

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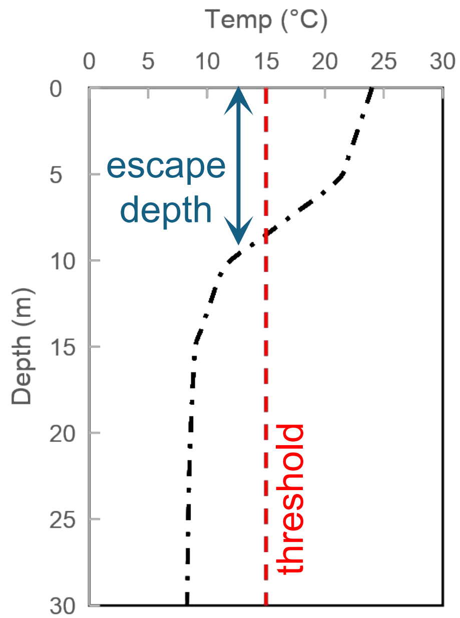
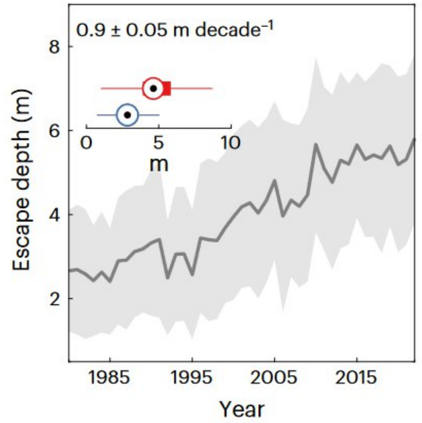
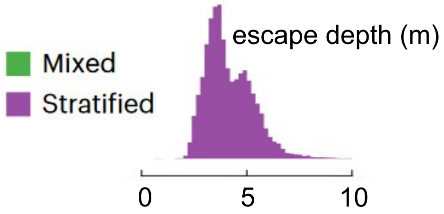
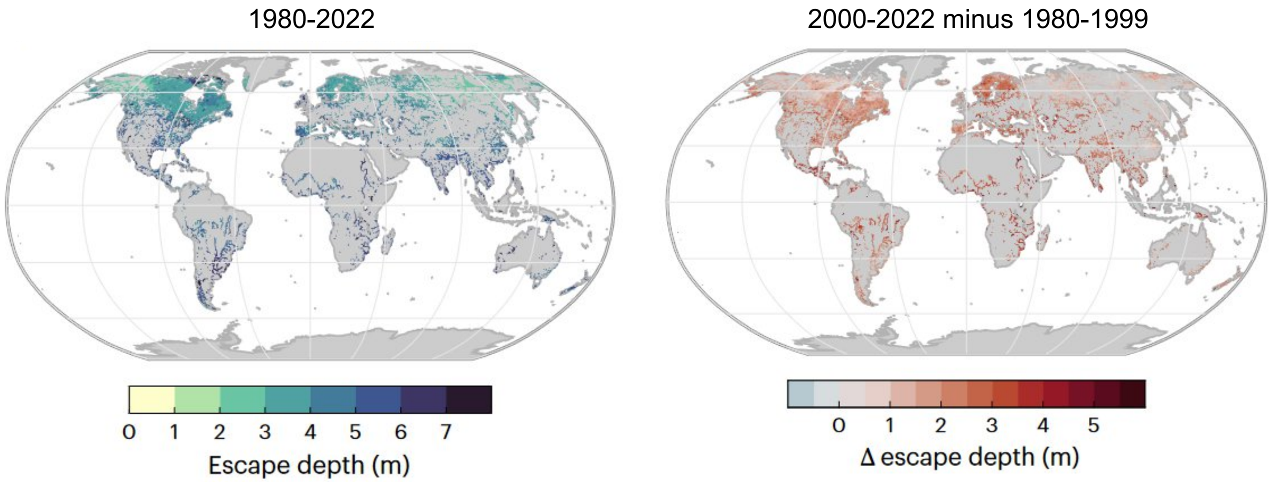
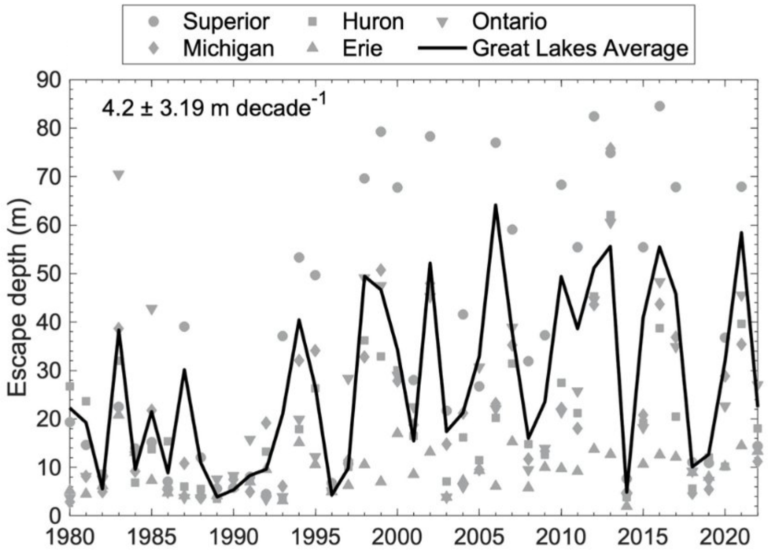
Vertical escape depth

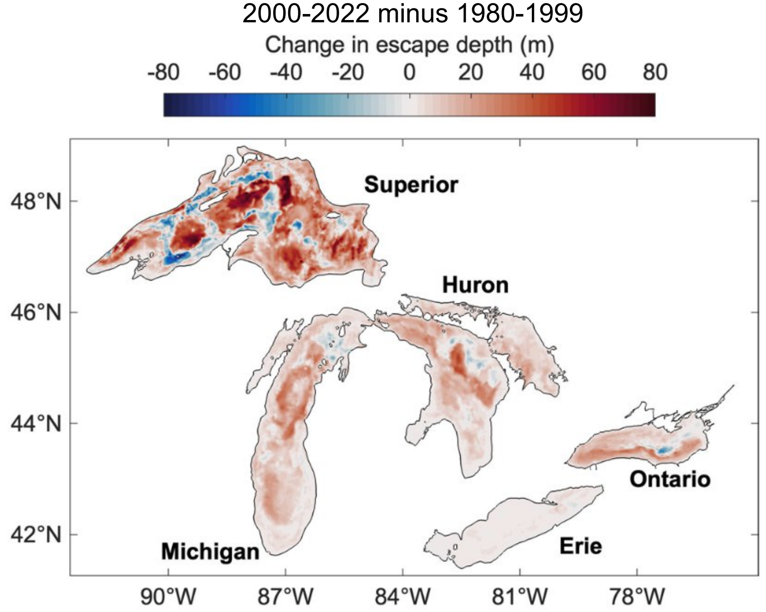






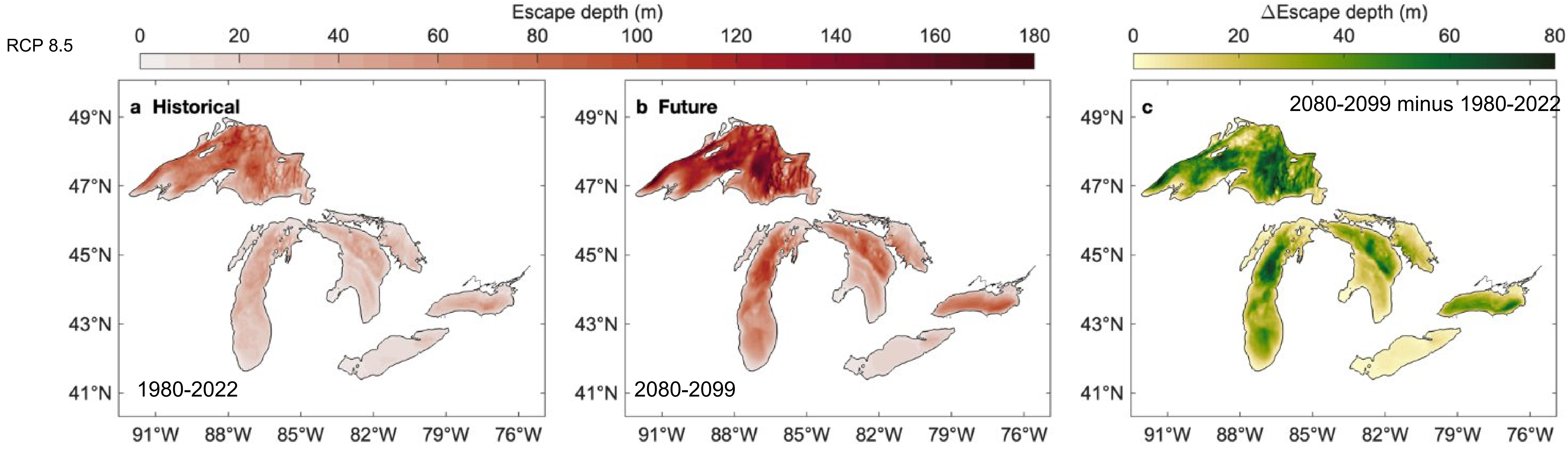


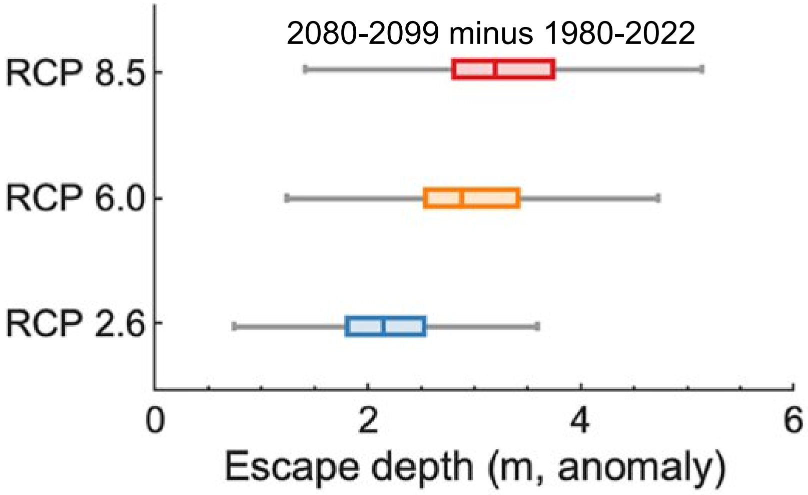




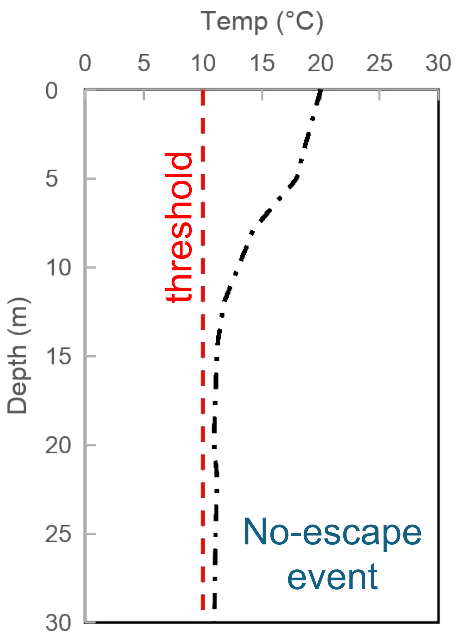
2000-2022 minus 1980-1999

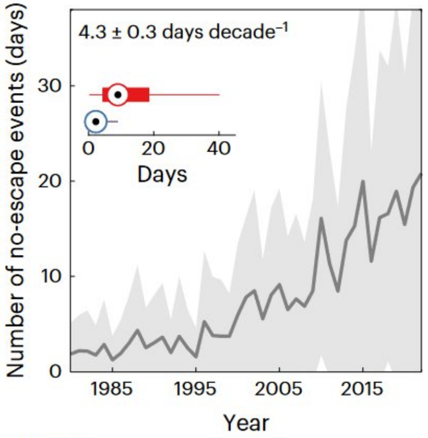
Vertical escape depth

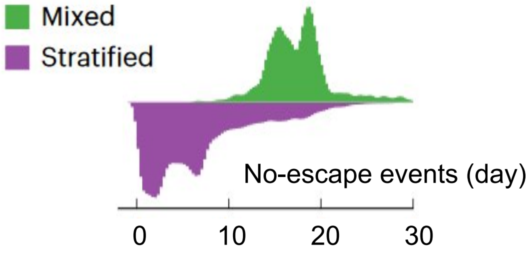


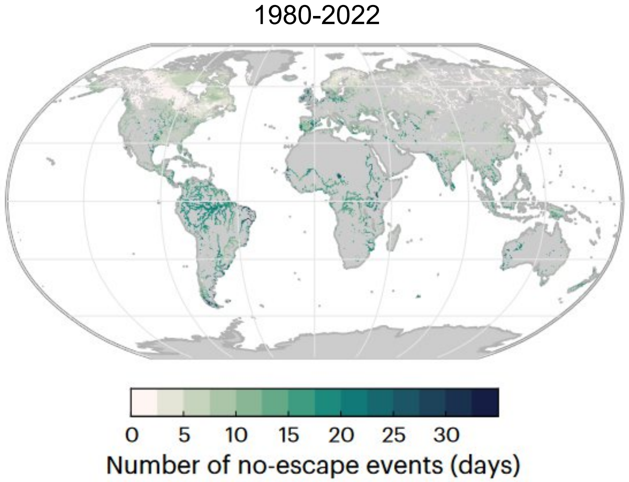


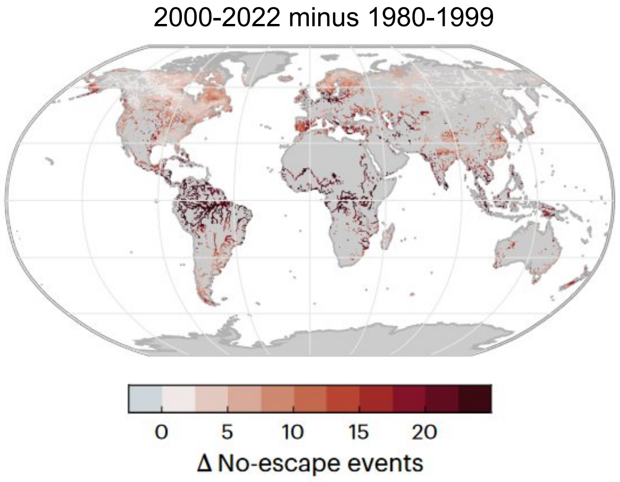
No-escape events

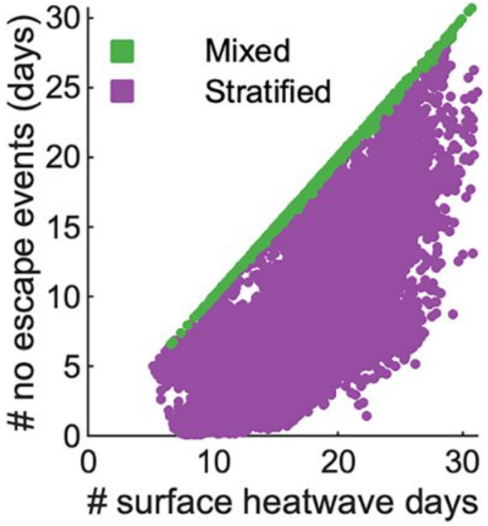


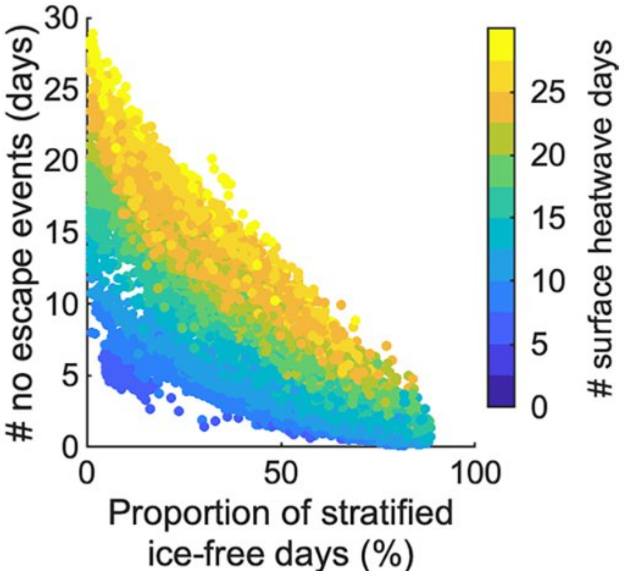


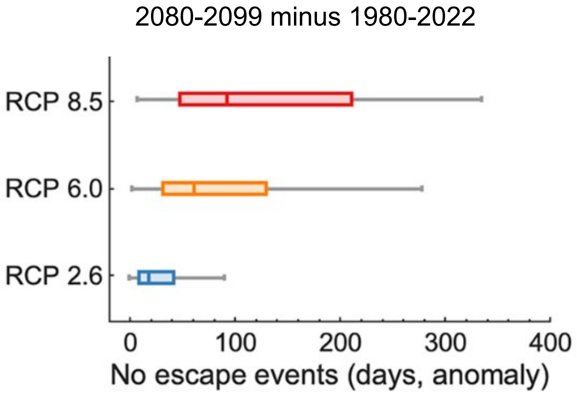




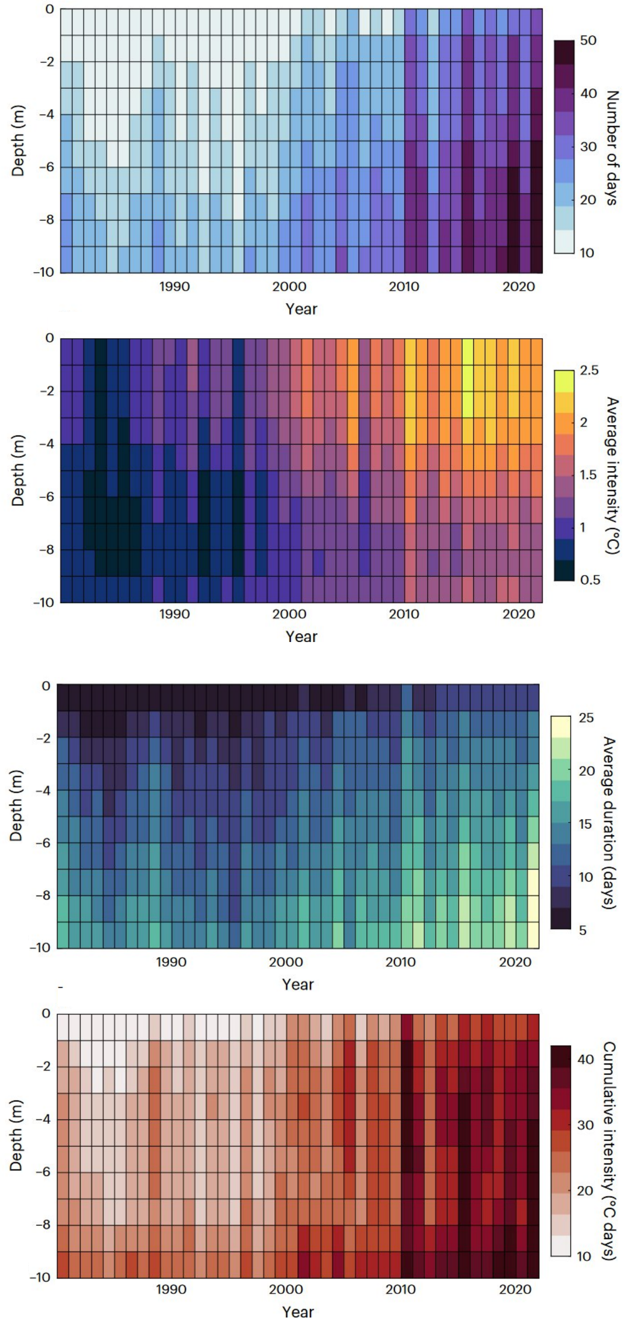




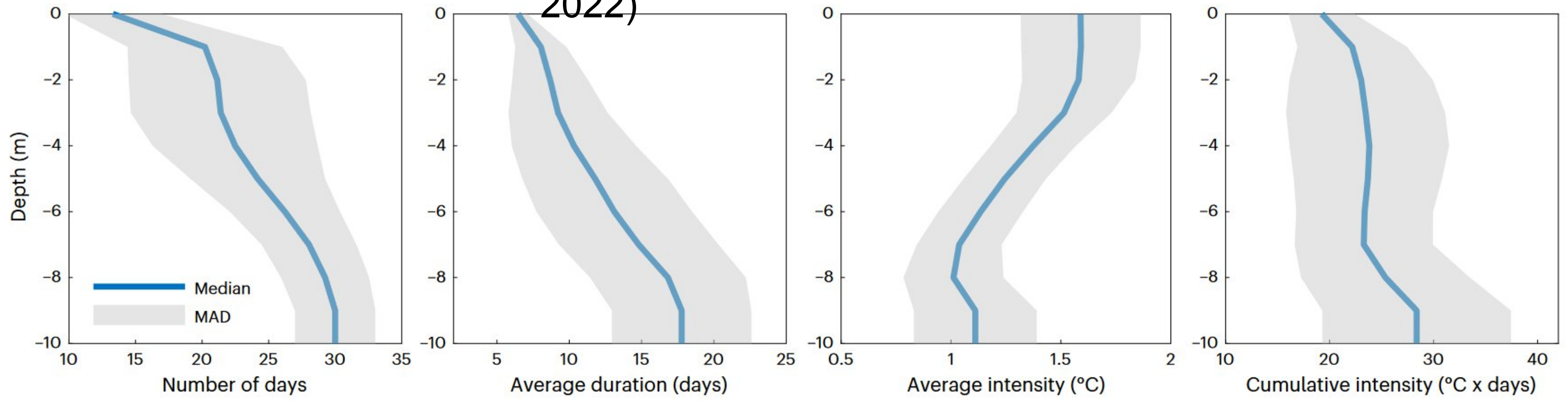




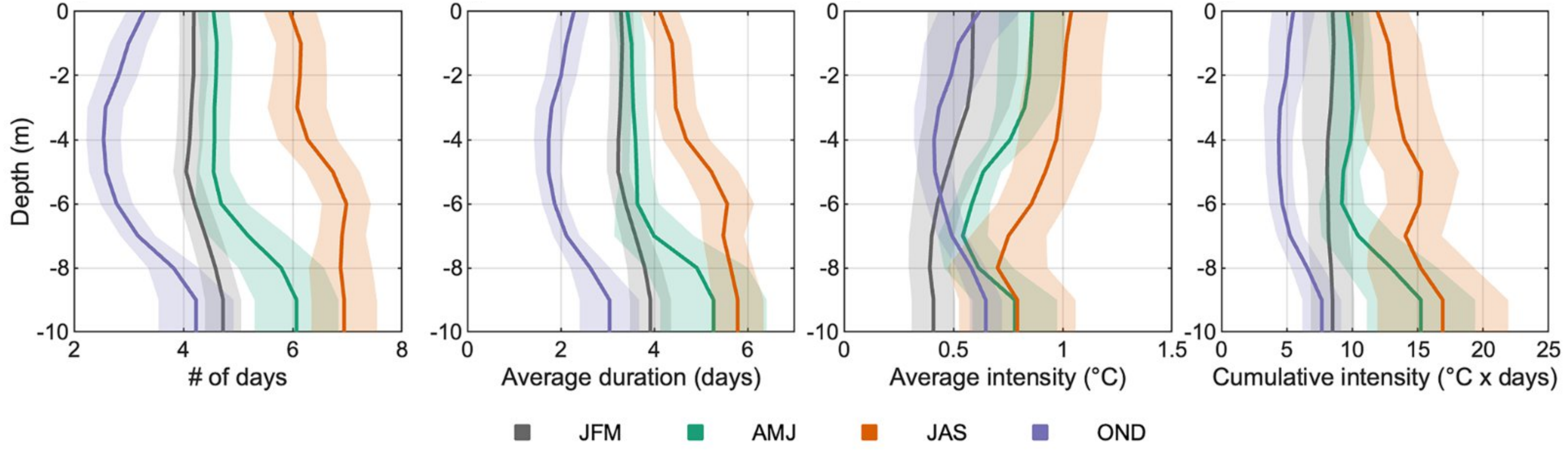
Subsurface heatwaves



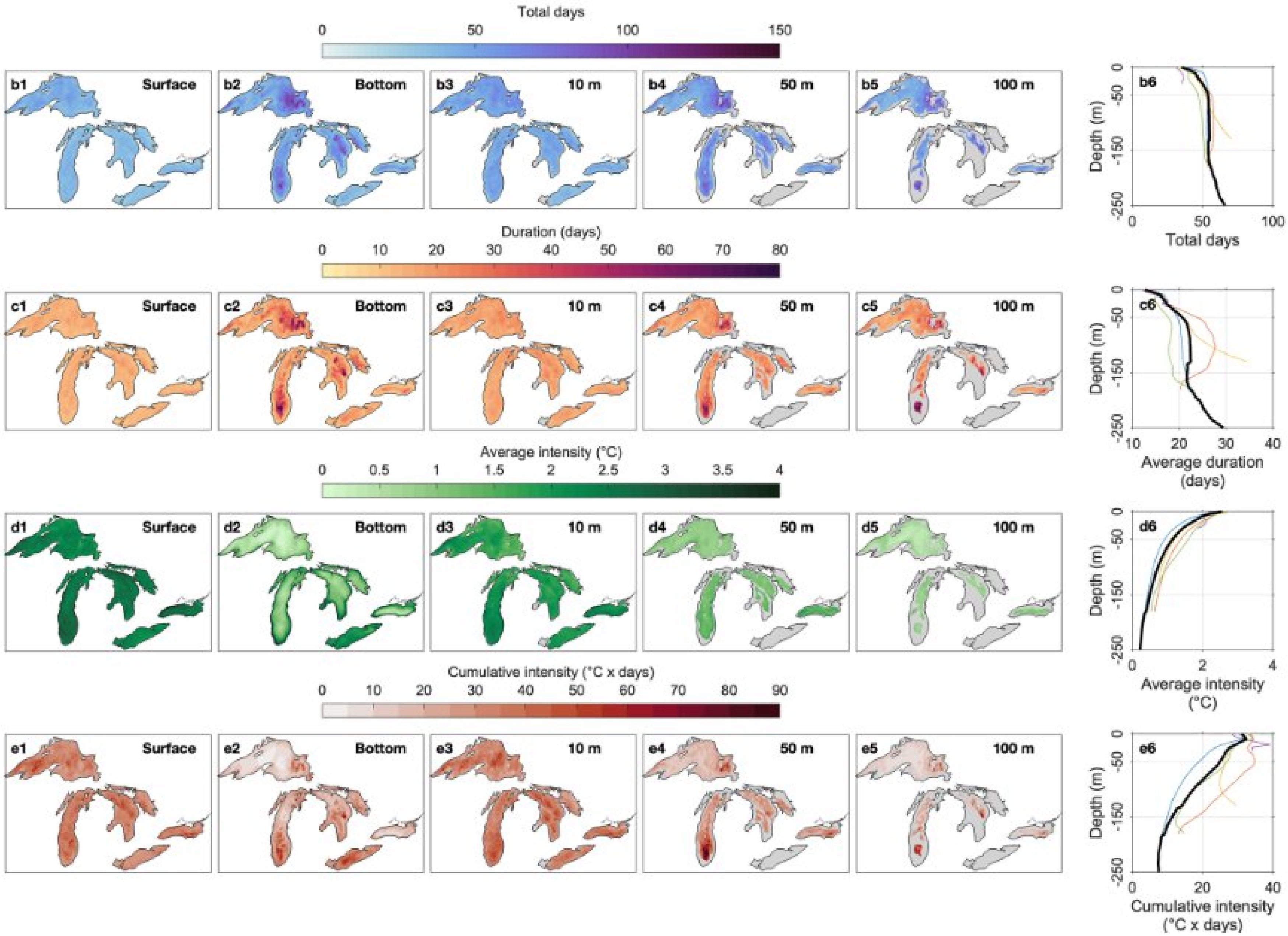
Heatwave metrics (1980-2022)



Seasonality (1980-2022)

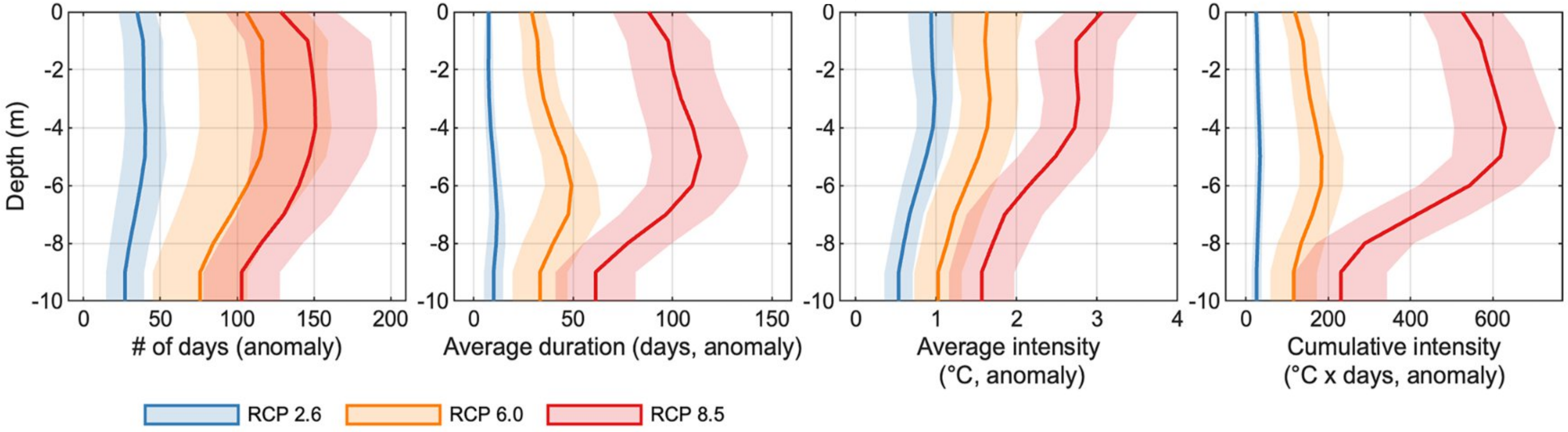


Subsurface heatwaves

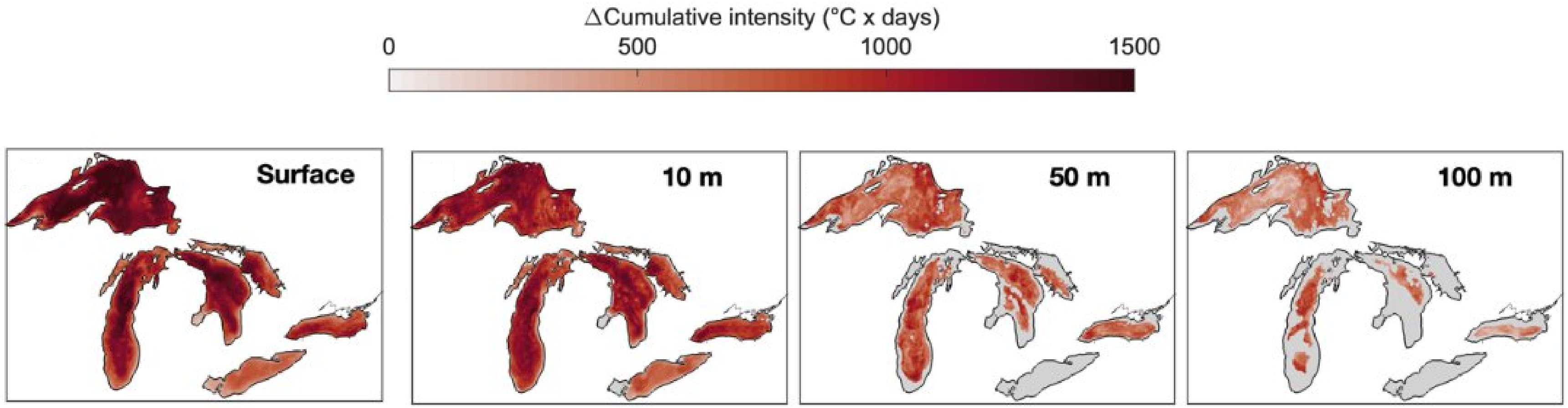


Subsurface heatwaves

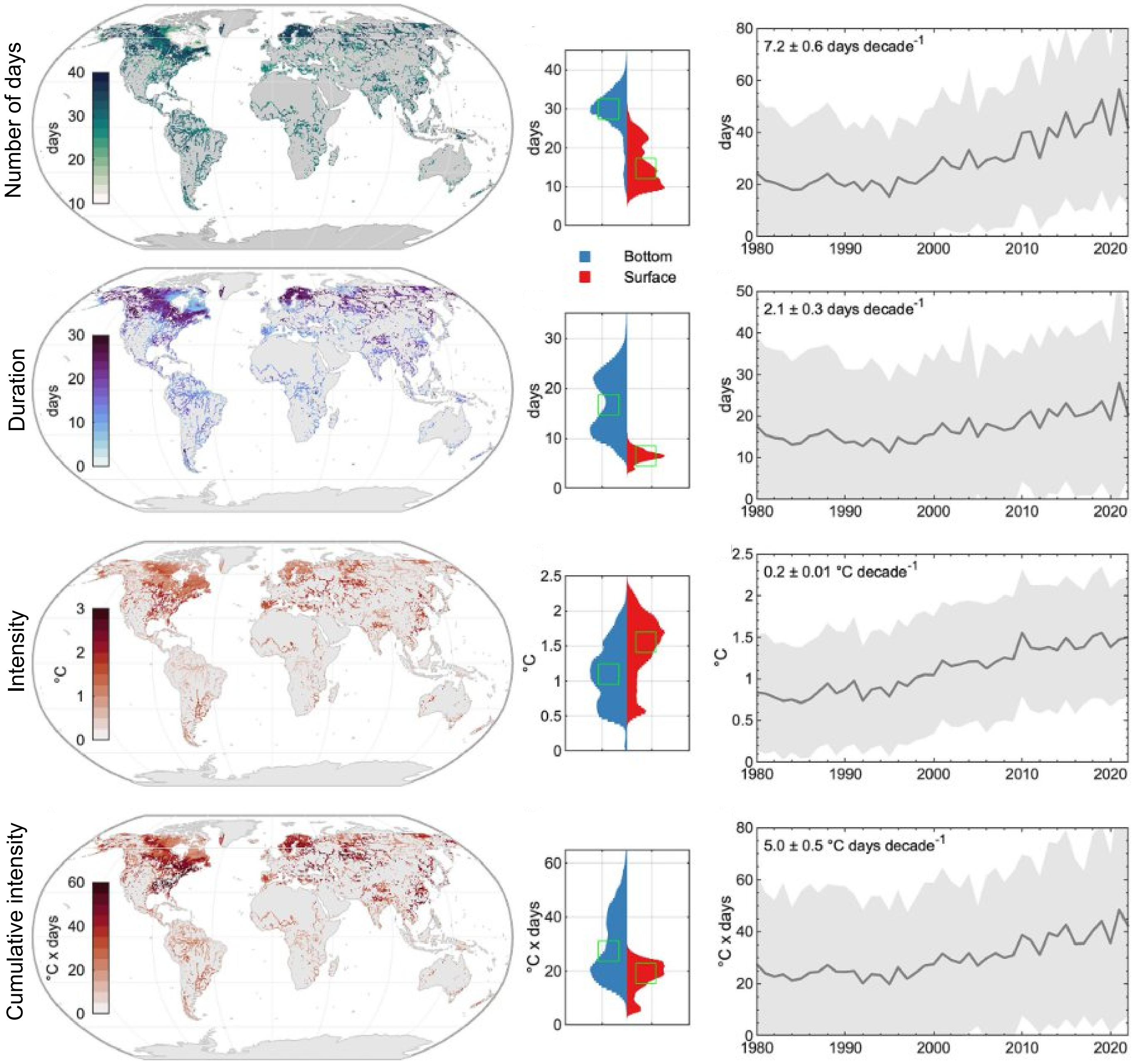
Heatwave metrics (2080-2099 minus 1980-2022)



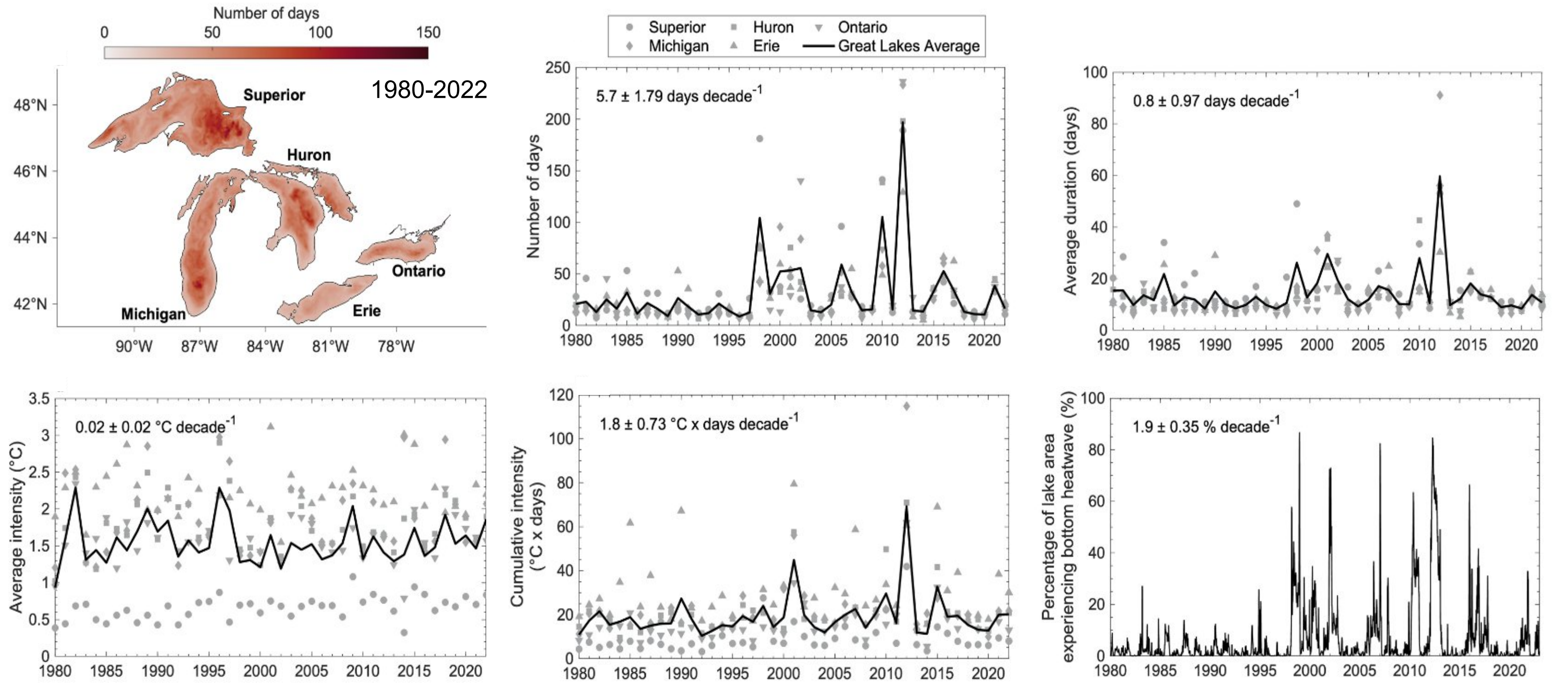
RCP 8.5

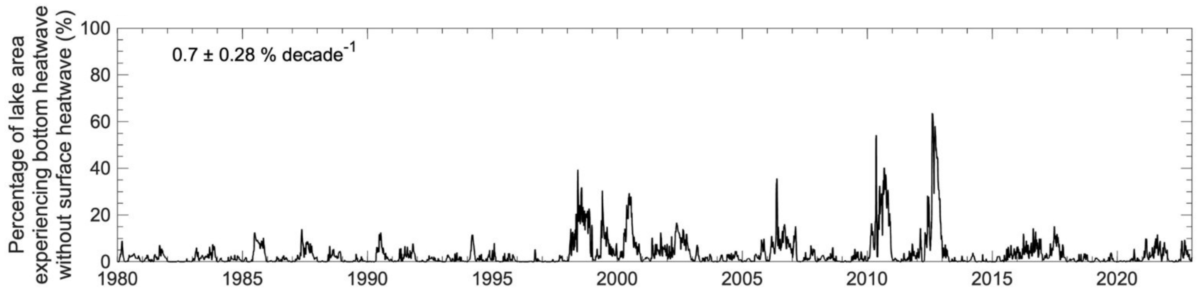


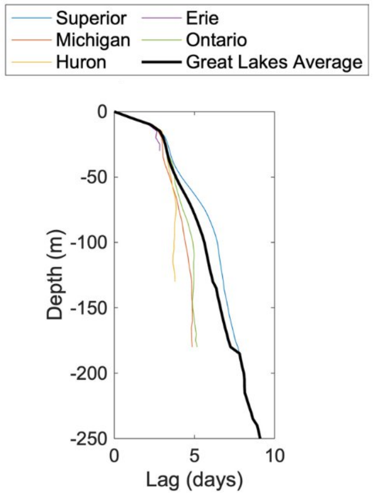
Bottom heatwaves



Bottom heatwaves

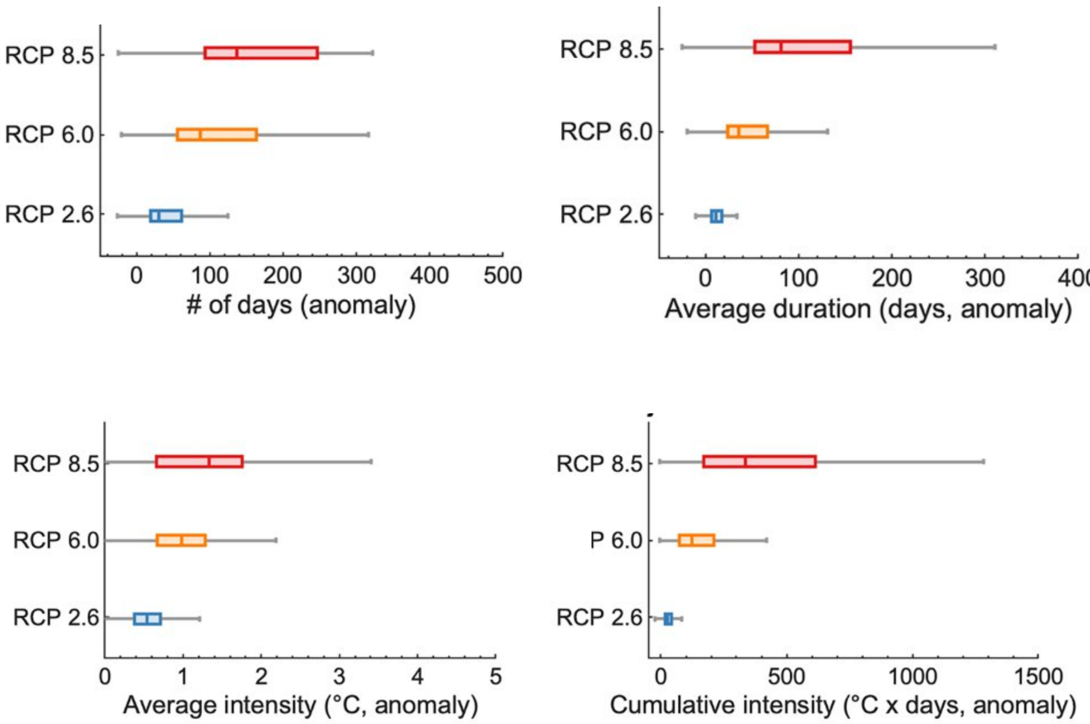


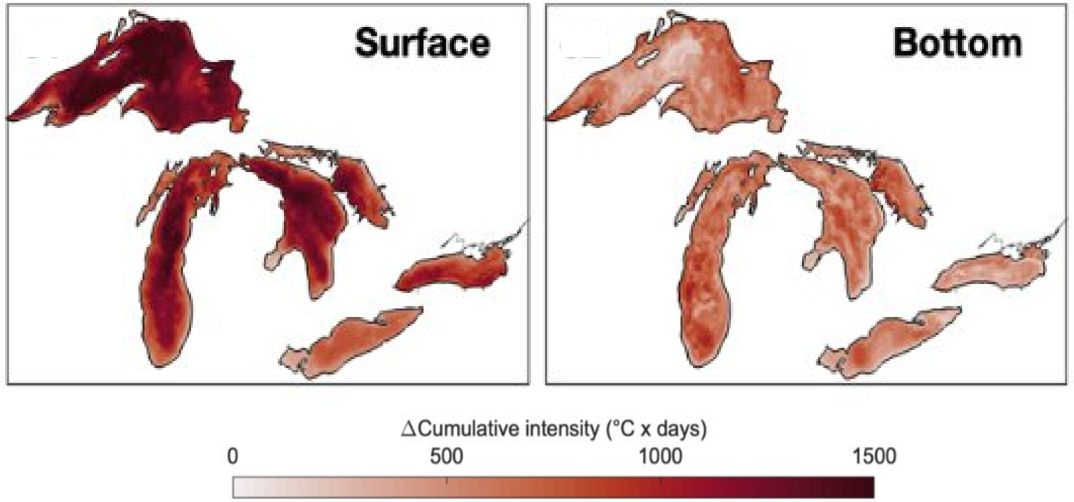




Bottom heatwaves

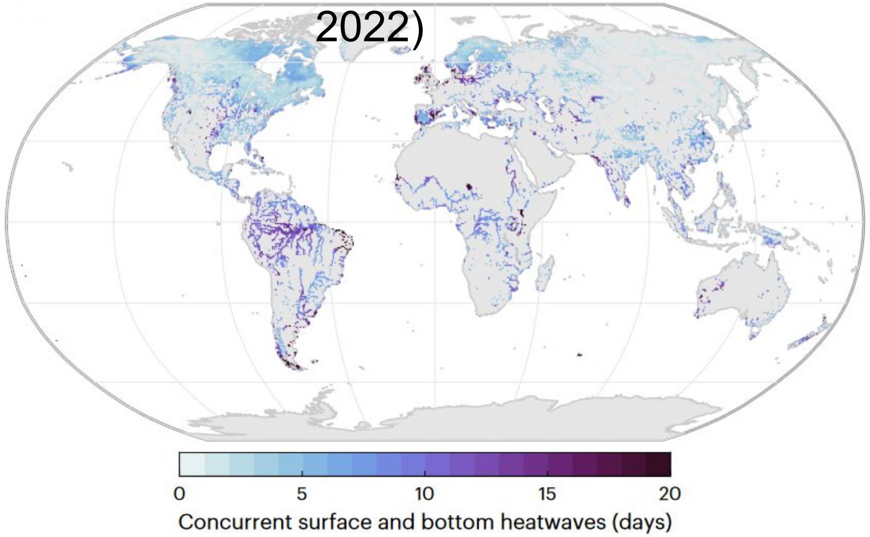
Heatwave metrics (2080-2099 minus 1980-2022)

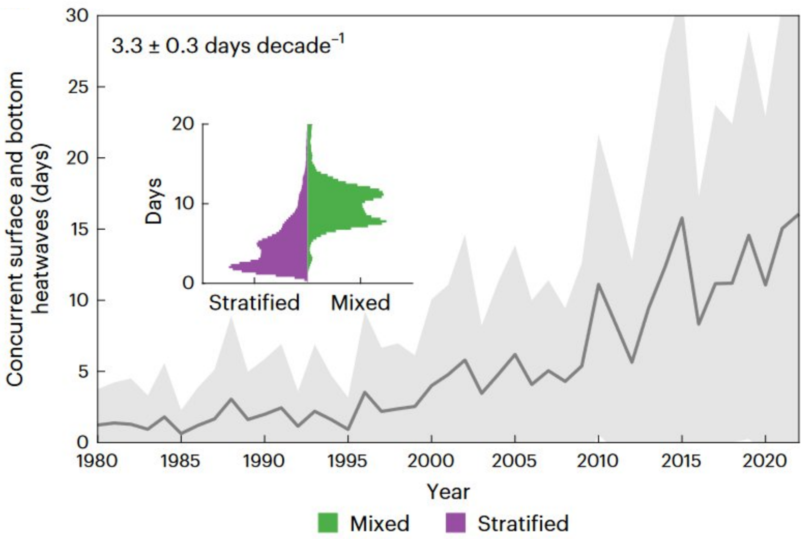




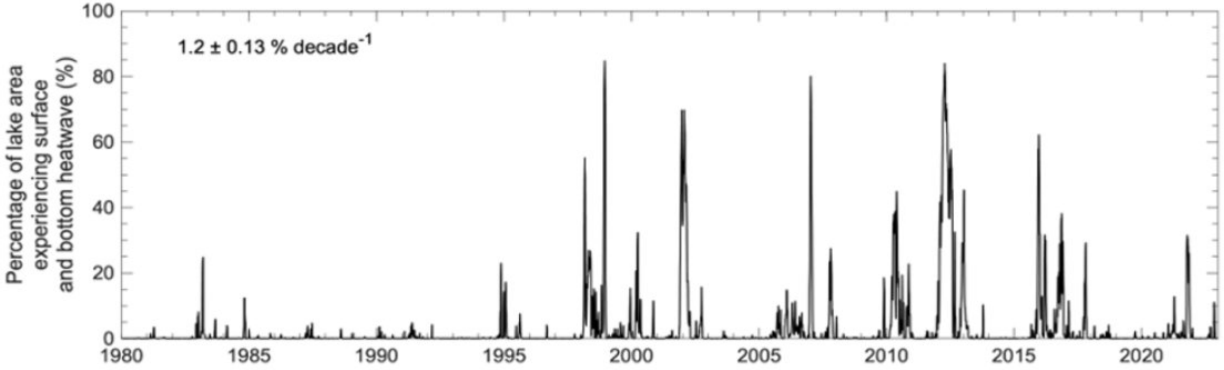
Concurrent surface and bottom heatwaves

(1980-
2022)



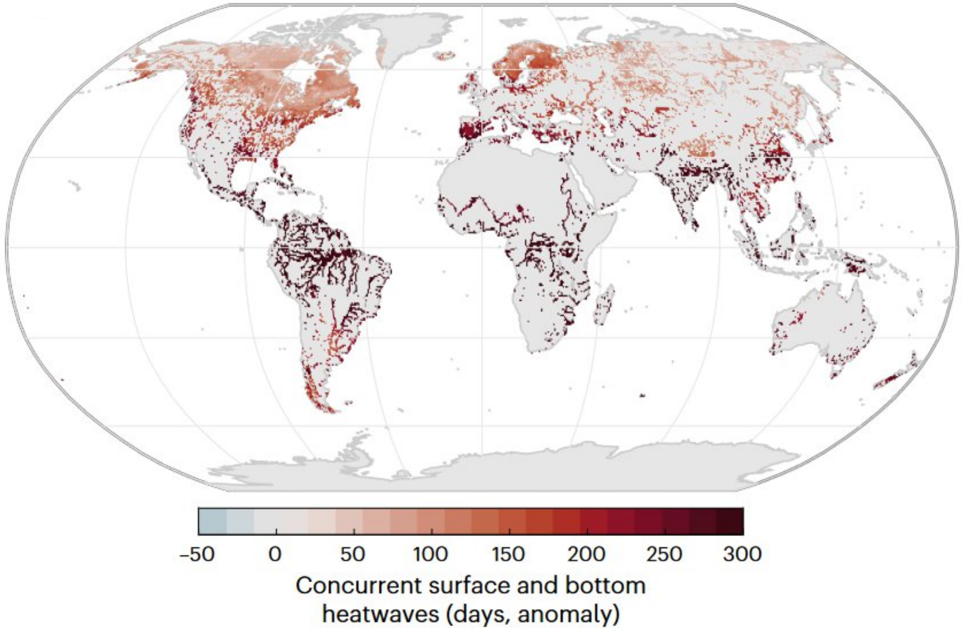


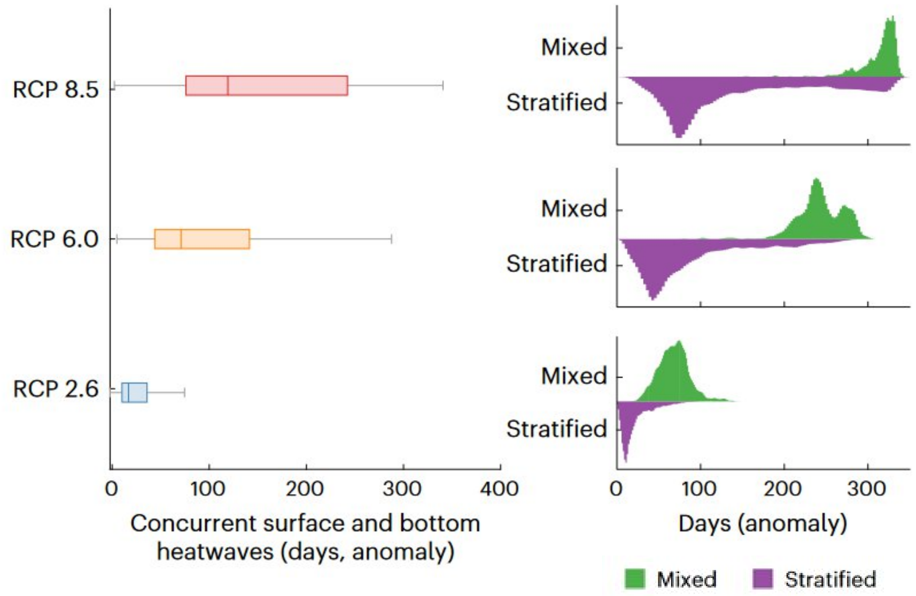
Great



Concurrent surface and bottom heatwaves

2080-2099 minus 1980-2022





Summary

- Escape depth is increasing due to climate warming.
- No-escape events occur in large amounts of lakes, especially in mixed lakes.
- No-escape events are increasing due to climate warming.
- The intensity of subsurface/bottom heatwaves is usually smaller than the surface, but the duration is usually longer, resulting into larger cumulative intensity.
- Subsurface heatwaves can occur without surface heatwave, which might because of the time lag between surface and subsurface heatwave

nature climate change

Article https://doi.org/10.1038/s41558-025-02314-0

Subsurface heatwaves in lakes

Received: 14 May 2024

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Published online: 10 April 2025

R. Iestyn Woolway[1], Miraj B. Kayastha[2,3], Yan Tong[4], Lian Feng[4], Haoran Shi[1] & Pengfei Xue[2,3,5]

ACCELERATION OF GLOBAL LAKE ANOXIA UNDER CLIMATE CHANGE

L. Nkwalale, *K. Rinke, J. Feldbauer, J. Mesman, T. Bucak, T. Shatwell, D. Mercado-Bettin, R. Ladwig*

This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska Curie grant agreement No. 956623

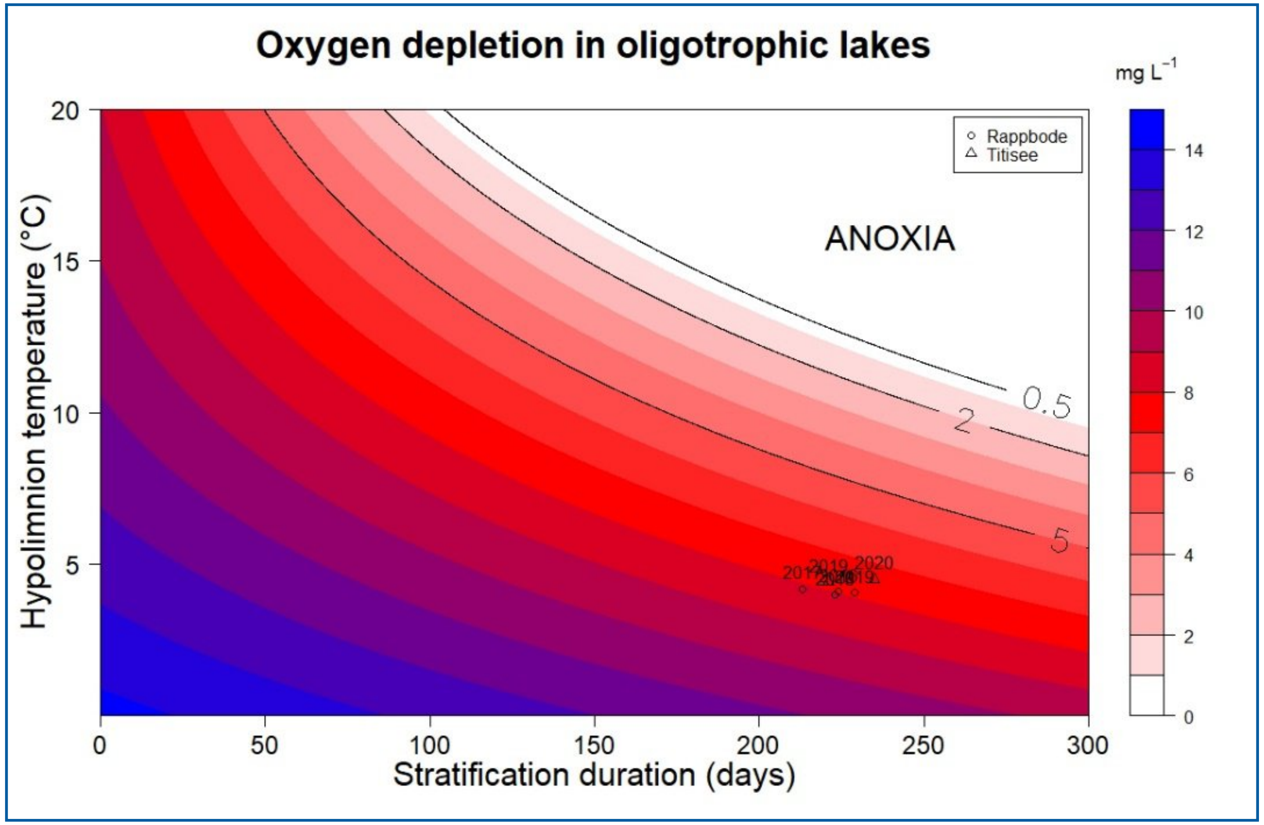
Research Article

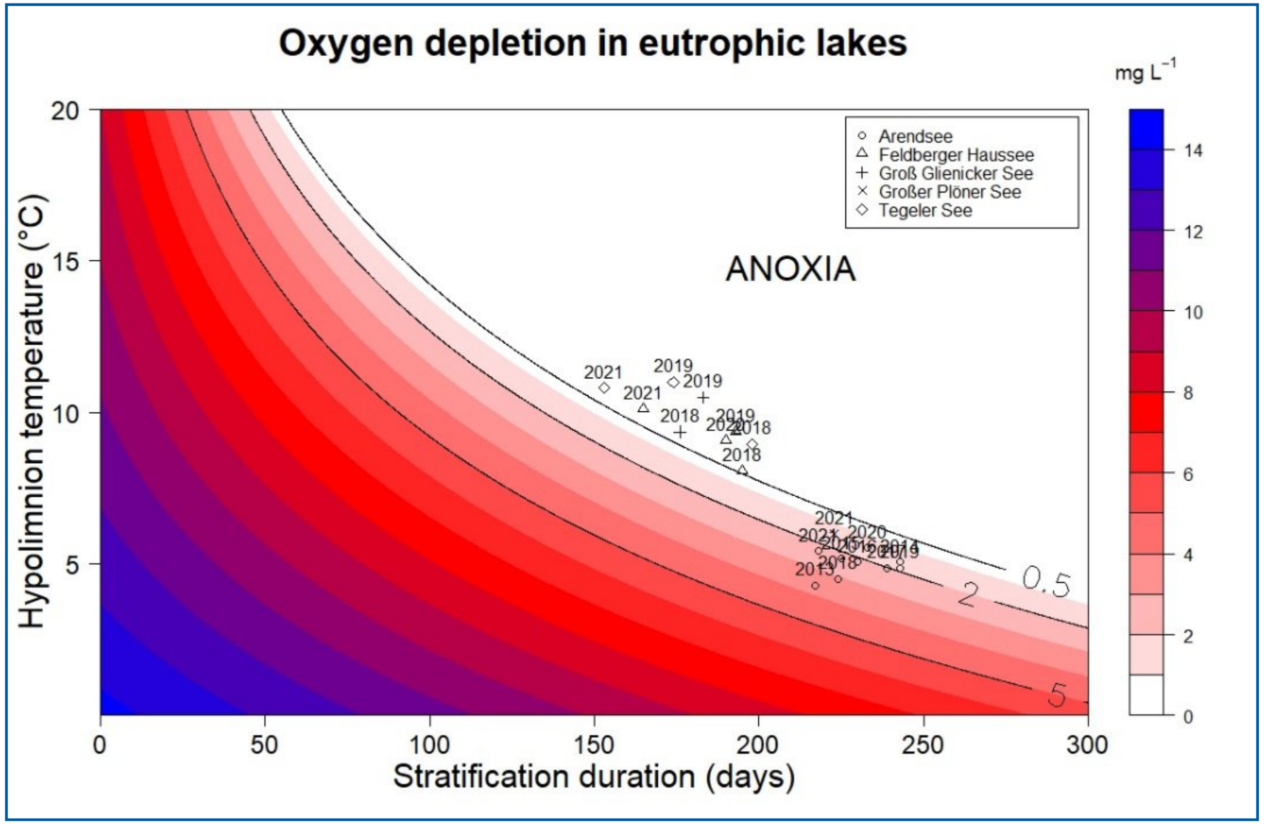
A simple model for predicting oxygen depletion of lakes under climate change

Lipa Nkwalale, Robert Schwefel, Mahtab Yaghouti & Karsten Rinke

Received 04 Jul 2023, Accepted 04 Jan 2024, Accepted author version posted online: 19 Jan 2024

Cite this article https://doi.org/10.1080/20442041.2024.2306113 Check for updates





$$O_2(t) = O_2(t_0) - t_{stratification} * VHOD_T$$

Temperatures and hypolimnetic oxygen in German lakes: Observations, future trends and adaptation potential

Climate Adaptation of Inland Waters | Open access | Published: 05 July 2024

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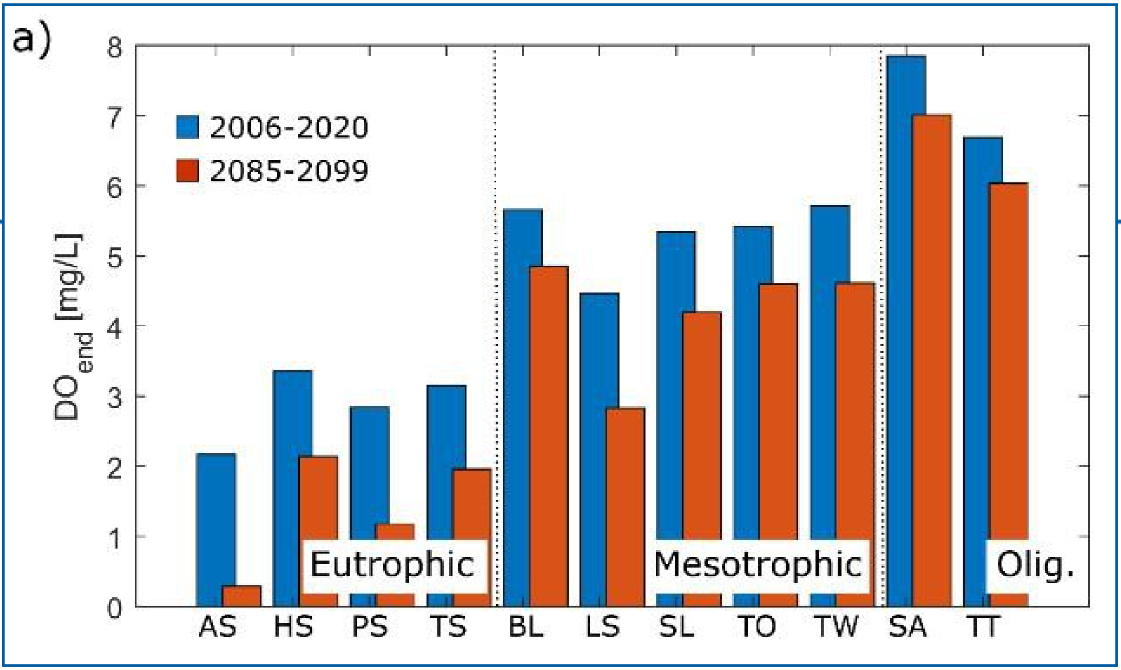
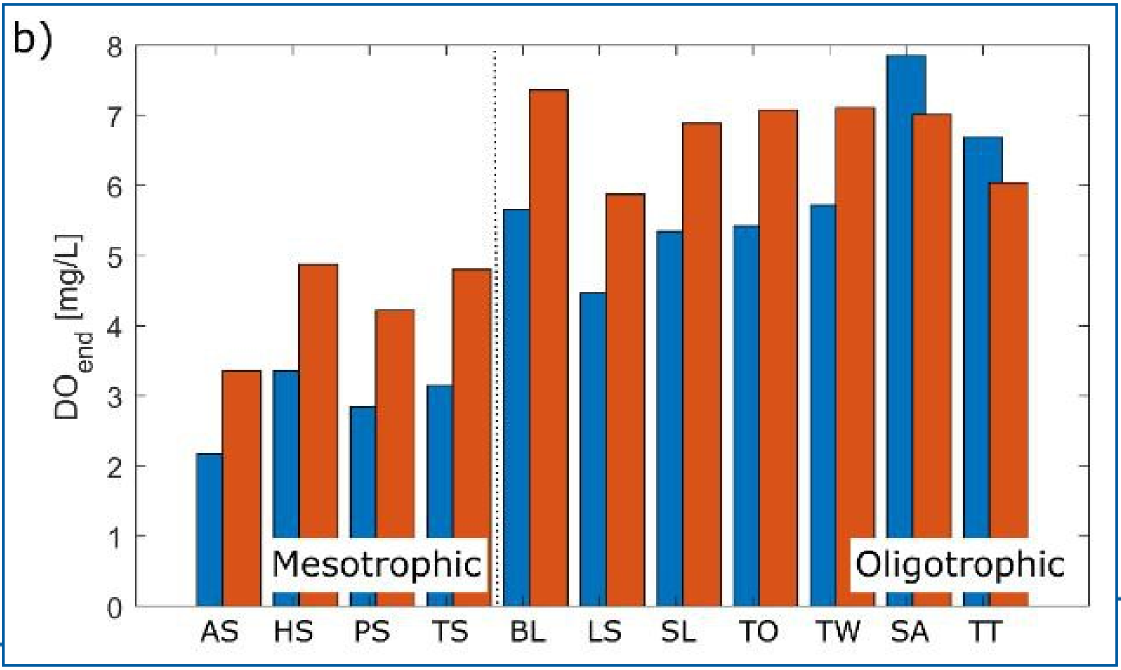
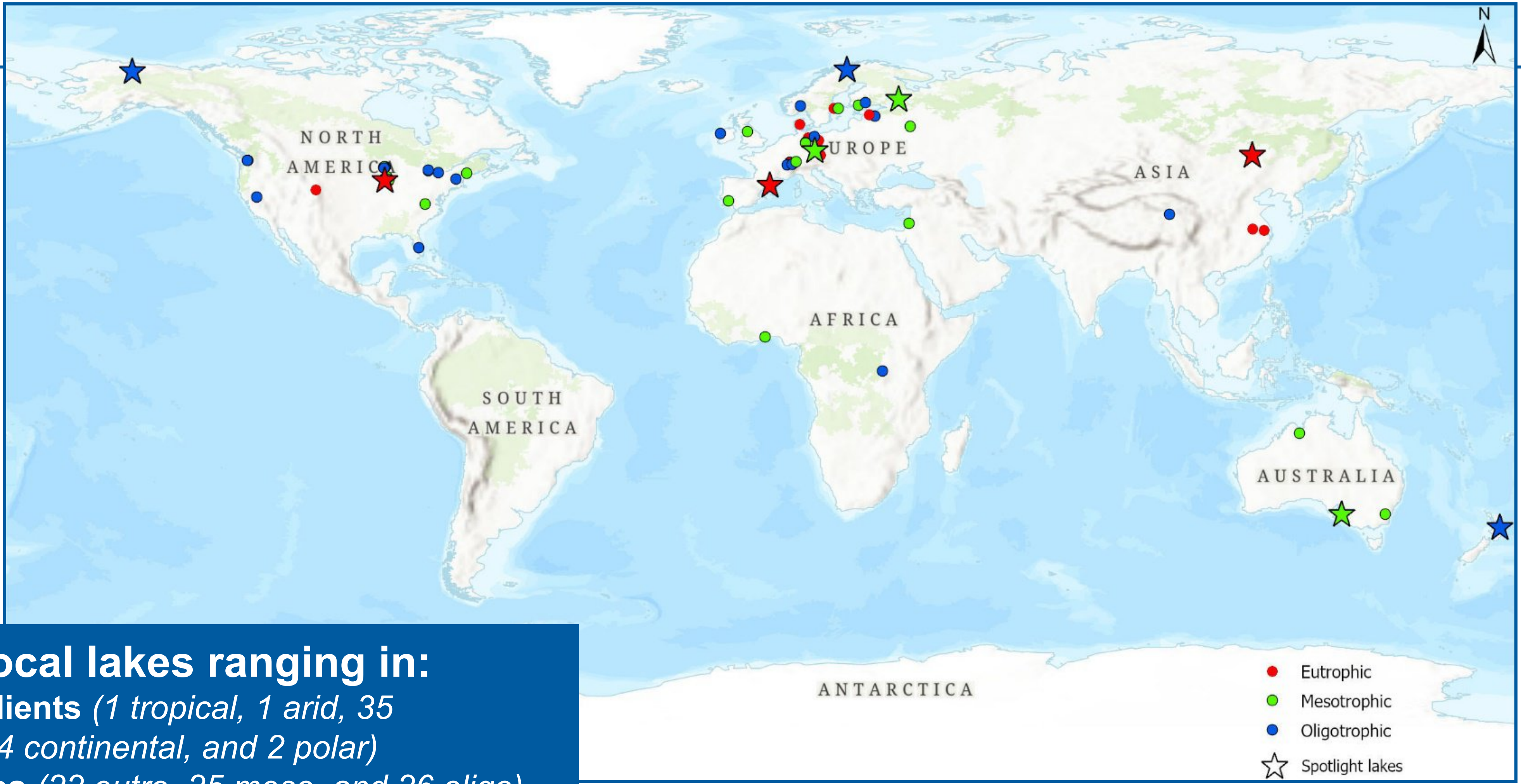
Robert Schwefel, Lipa G. T. Nkwalale, Sylvia Jordan, Karsten Rinke & Michael Hupfer

- O_2 projection for 11 dimictic German lakes
- IPCC scenarios RCP 8.5
- Constant trophic state in scenario A
- adaptation intervention scenario B.





How about we apply it globally?



73 ISIMIP local lakes ranging in:

- **climate gradients** *(1 tropical, 1 arid, 35 temperate, 34 continental, and 2 polar)*
- **trophic states** *(22 eutro, 25 meso, and 26 oligo)*
- **mean depths** *(i.e. 1.7m – 304.8m)*
- **elevation** *(i.e. -210m – 4300m)*
- **area** *(i.e. 0.01km^2 – 2700km^2)*

Step 1: Processing O_2 model inputs

5 GLOBAL CLIMATE MODELS

4 CLIMATE SCENARIOS

3 LAKE MODELS

73 LAKES

372,300 observations

Yearly lake data (2015 – 2100):

1. **Stratification duration**
   - density difference greater than 0.1 $kg\ m^{-}$
   - longest period of continuous **summer** stratification
   - Northern hemisphere year = Jan – Dec
   - Southern hemisphere year = Jun – Jul
2. **Hypolimnion temperature**
   - volumetrically weighted average hypolimnetic temperature (rlakeAnalyzer)
   - used to calculating $O_{2,initial}$
3. **VHOD rate**
   - temperature corrected using hypolimnion temperature
   - rate based on Carlson's Trophic State index

$$O_2(t) = O_2(t_0) - t_{stratification} * VHOD_T$$

Step 2: Recalibrating O_2 model

Research Article

A simple model for predicting oxygen depletion of lakes under climate change

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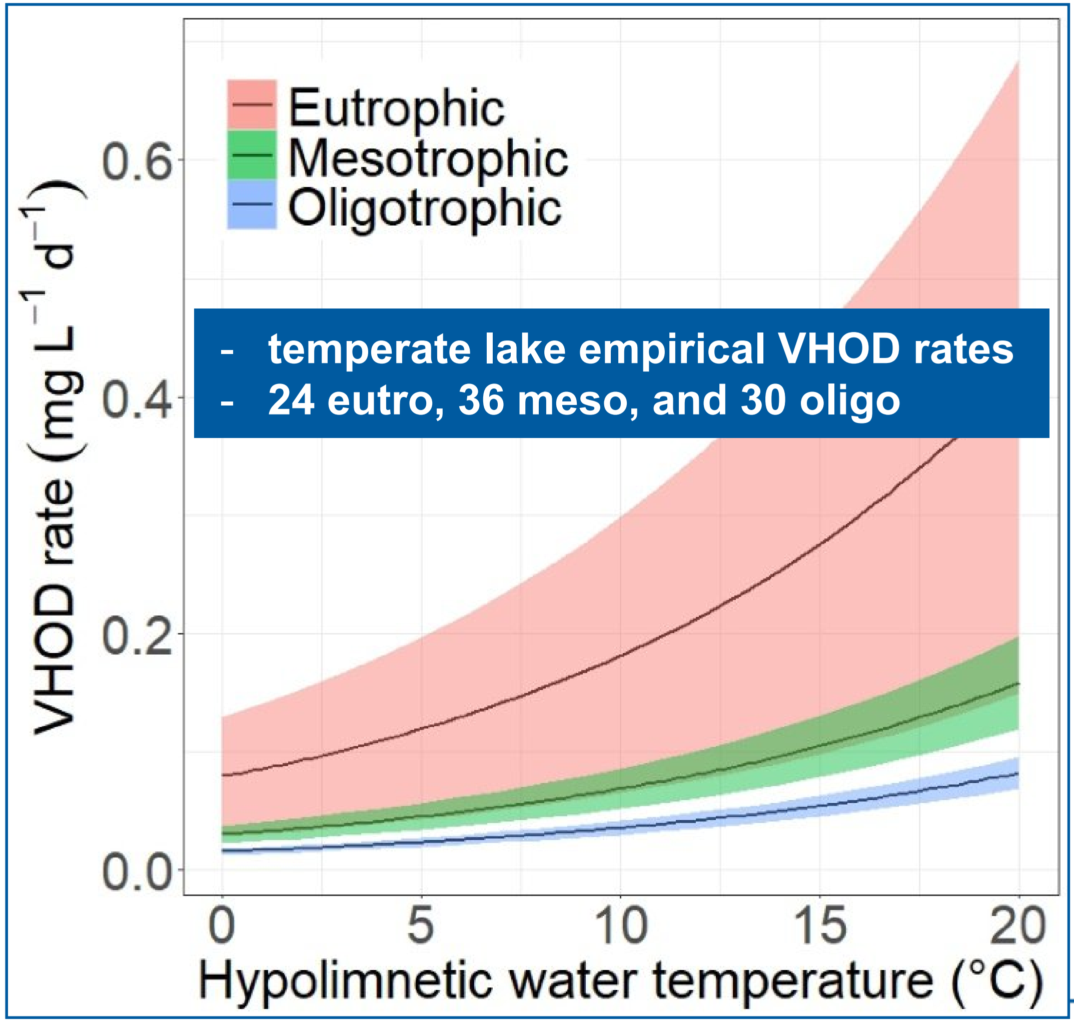
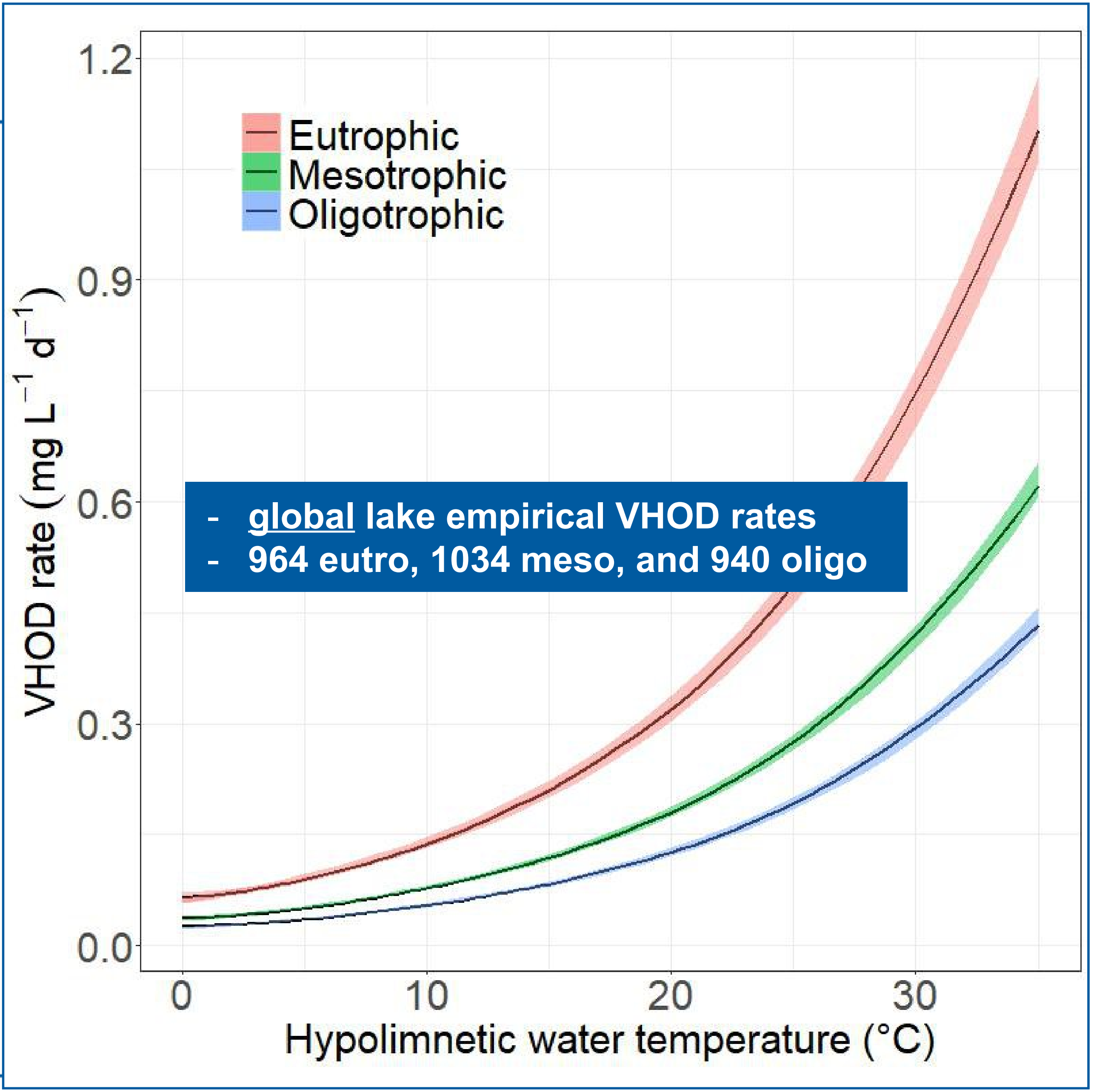
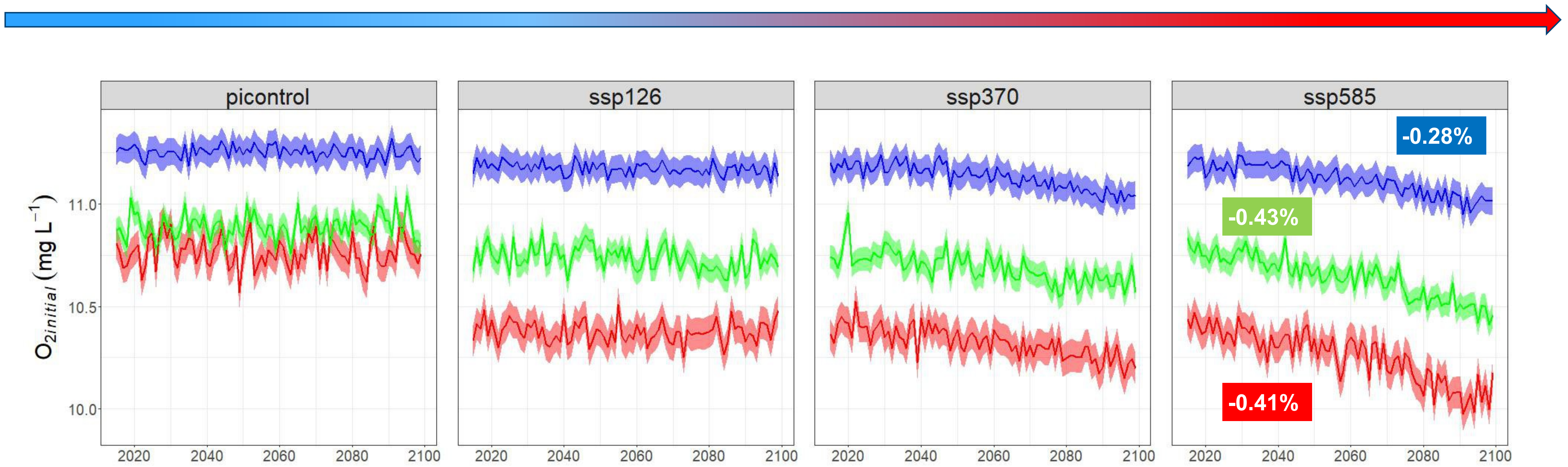
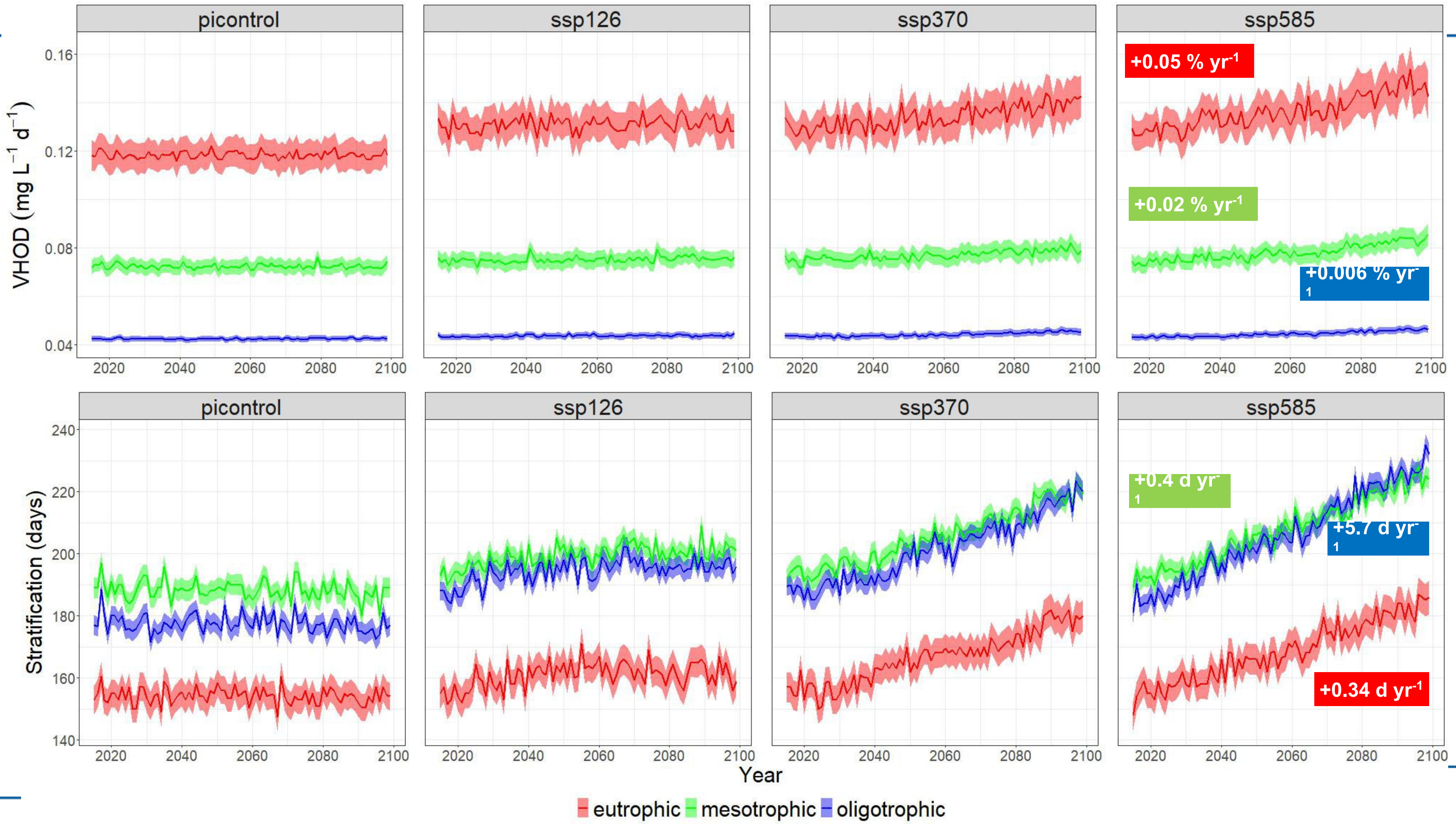




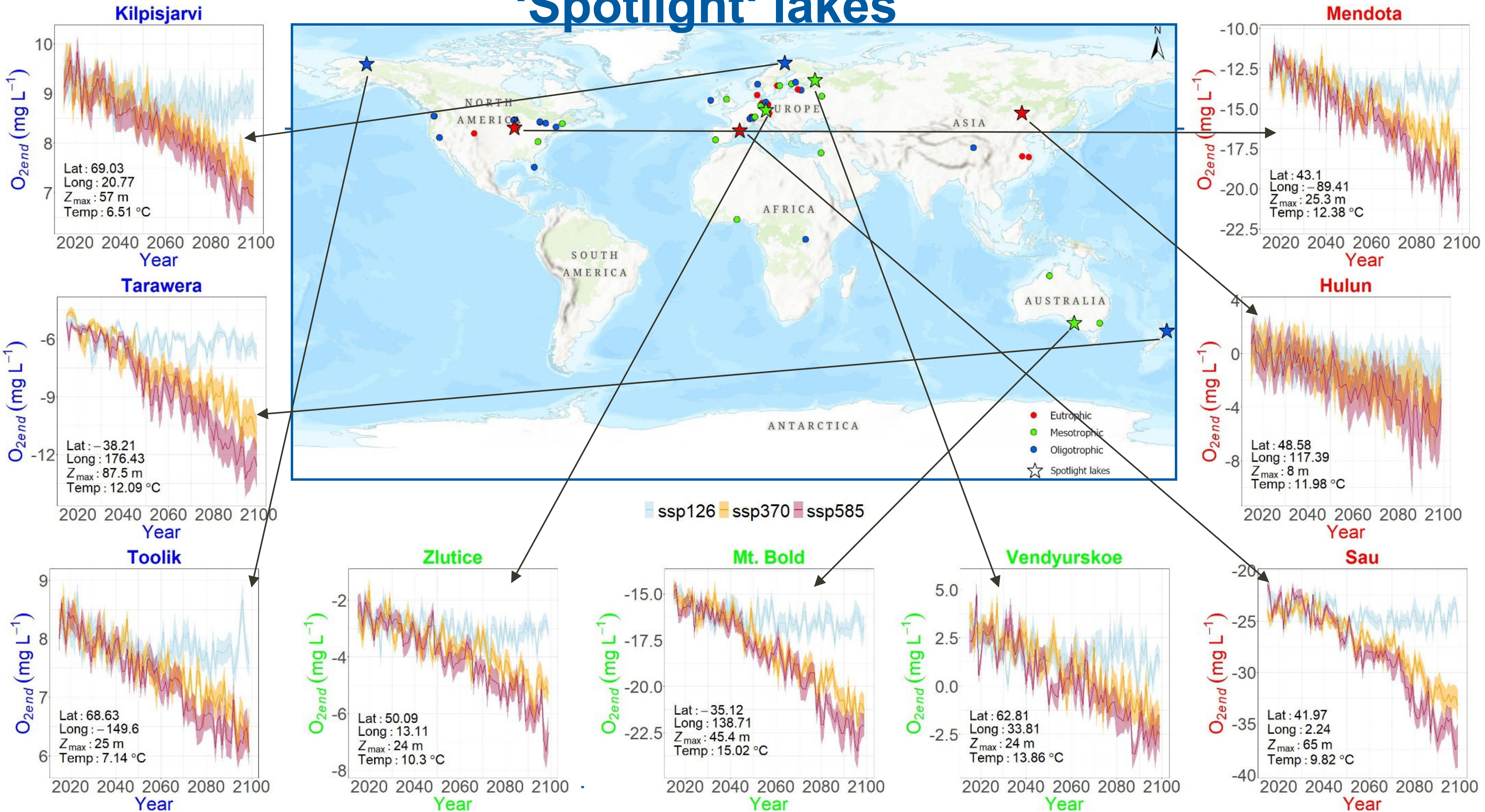
O_2 model inputs‘ future projections



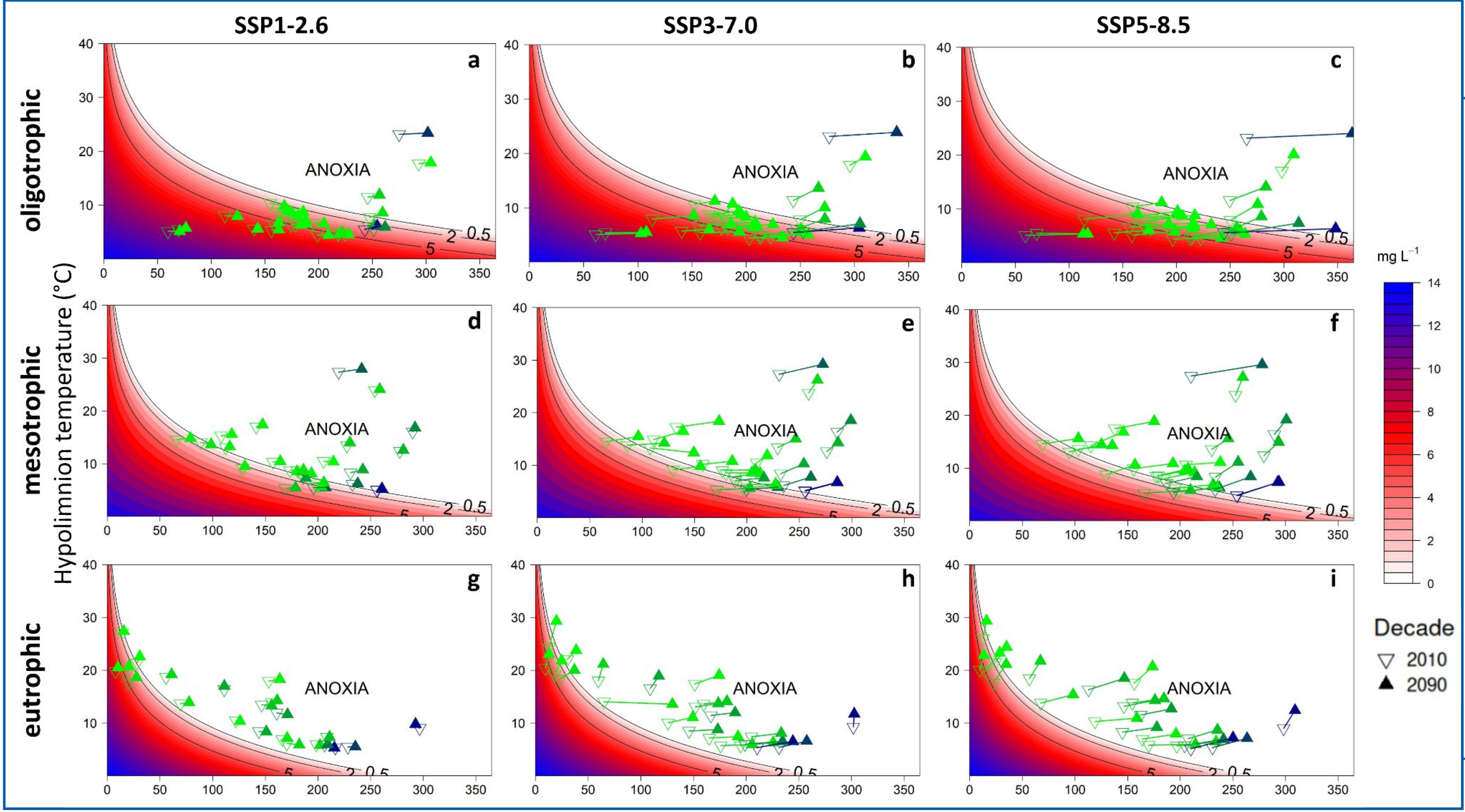
O_2 model inputs‘ future projections



‘Spotlight‘ lakes



Future O_2 trajectory of lakes



Key takeaways

- Elongated stratification period critical for O_2 concentrations.
- Hypolimnion temperature affects both initial O_2 concentrations and O_2 depletion rates.
- Longer stratification and rising temperatures increase O_2 depletion.
- Focus on lowering trophic states to counter climate change impacts on O_2 concentration dynamics.

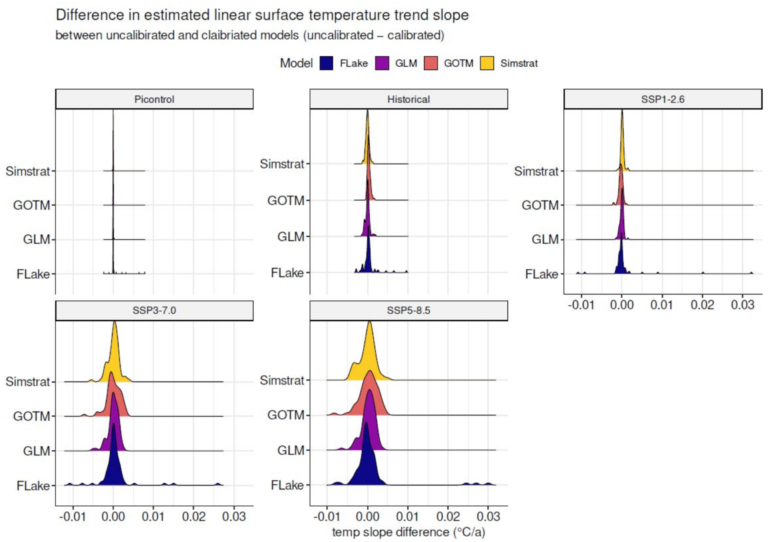
Thank you!

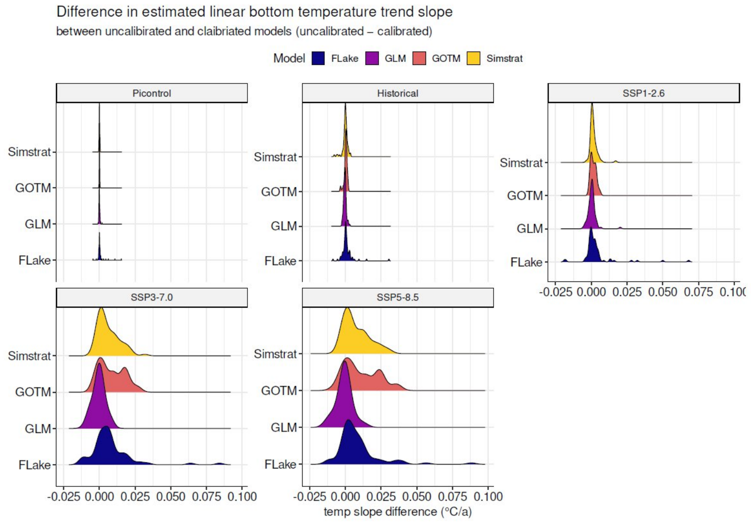
lipa.nkwalale@ufz.de

ISIMIP lake model calibration project

Feldbauer, Mesman, Mercado-Bettín, Piccolroaz, Schmid, Gai, Bärenbold, Lorimer, Marcé, Donini, Shikhani, Shatwell

- Impact of calibrating lake models on climate impact simulations
  - Initial project lead: Tom Lorimer
- Local lakes
  - But important for global lakes
- Current models
  - FLake, GLM, GOTM, Simstrat, air2water
  - Modellers already working on local lakes are welcome to join





Contact: johannes.feldbauer@tu-dresden.de

Initiative to run LER on HTC

Currently working on integrating the LakeEnsemblR framework on HTC in Brussels

Would allow the configuration and parallel simulations using GLM, Simstrat, FLake, MyLake, and GOTM → potential for future water quality simulations

Still in early steps

Anyone interested, please email Robert, rladwig@ecos.au.dk

(we also plan to host a joint MSc thesis project between Aarhus and Trento to integrate additional models, i.e., air2water)

New Papers

Woolway, R. I., M. B. Kayastha, Y. Tong, L. Feng, H. Shi, and P. Xue. 2025. Subsurface heatwaves in lakes. Nature Climate Change. https://www.nature.com/articles/s41558-025-02314-0

Feldbauer, J., J. P. Mesman, T. K. Andersen, and R. Ladwig. 2025. Learning from a large-scale calibration effort of multiple lake temperature models. Hydrol. Earth Syst. Sci. **29**:1183-1199. https://hess.copernicus.org/articles/29/1183/2025/

Qiu, Y., Chen, J., Chen, D. *et al.* Enhanced heating effect of lakes under global warming. *Nat Commun* 16, 3954 (2025). https://doi.org/10.1038/s41467-025-59291-3

Open questions: discussion and comments from the audience.

1. Which scientific aspect of the lake sector you think needs improvements?
2. Co-authorship for ISIMIP3 papers
3. How can we boost the simulations of water quality variables in the lake sector?
4. How can we establish connections between the lake sector and other sectors of ISIMIP (water quality, water global, water regional)?
5. New Analysis or Ideas

THANK YOU!

VUB VRIJE UNIVERSITEIT BRUSSEL

CEAB Centre d'Estudis Avançats de Blanes

UPPSALA UNIVERSITET

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ISIMIP Inter-Sectoral Impact Model Intercomparison Project