Lake Modelling

Stationary Water Quality Modelling

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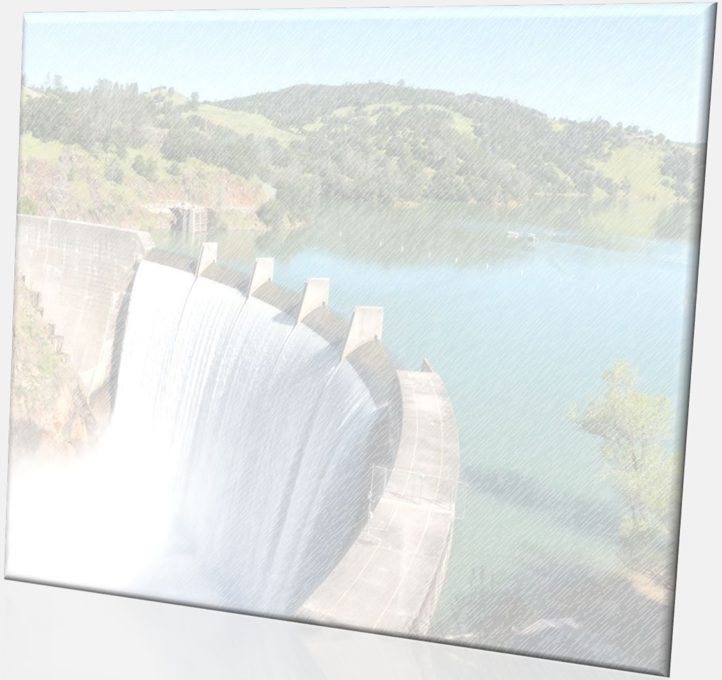
Introduction

Overview

- Key processes
- A numerical model
- Three traps
- Example



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Key processes

Key processes

What is a typical lake or reservoir?

- Deep - usually tens of metres
- Inland with no tides
- Fresh
- Receives inflows from upstream
- Delivers water downstream
    - Natural waterways
    - Offtake to treatment plant and consumers
    - Weir
    - Combination of above

Key processes

What is a typical lake or reservoir?

- Characteristics
  - Water movement
  - Water quality

  } In combination
- High level only

Key processes

Water movement: a comparison

- Floods
  - Lateral directions (x and y) matter most
  - Velocities – significant mean flows
  - Short term behaviour and impacts (weather)
  - Water temperature doesn't matter
- Lakes and reservoirs
  - Vertical direction (z) matters most
  - Turbulence and mixing – near zero mean flows (inflows aside)
  - Longer term behaviour and impacts (climate)
  - Water temperature matters most

Key processes

Water movement: what matters most to a typical lake or reservoir?

- Climate
  - Solar radiation (heat from the sun)
  - Long wave radiation (emitted from air)
  - Air temperature
  - Relative humidity
  - Wind speed (and often direction)
- Turbulence (mixing)
- Gravity
- Depth

Water temperature

Vertical distribution

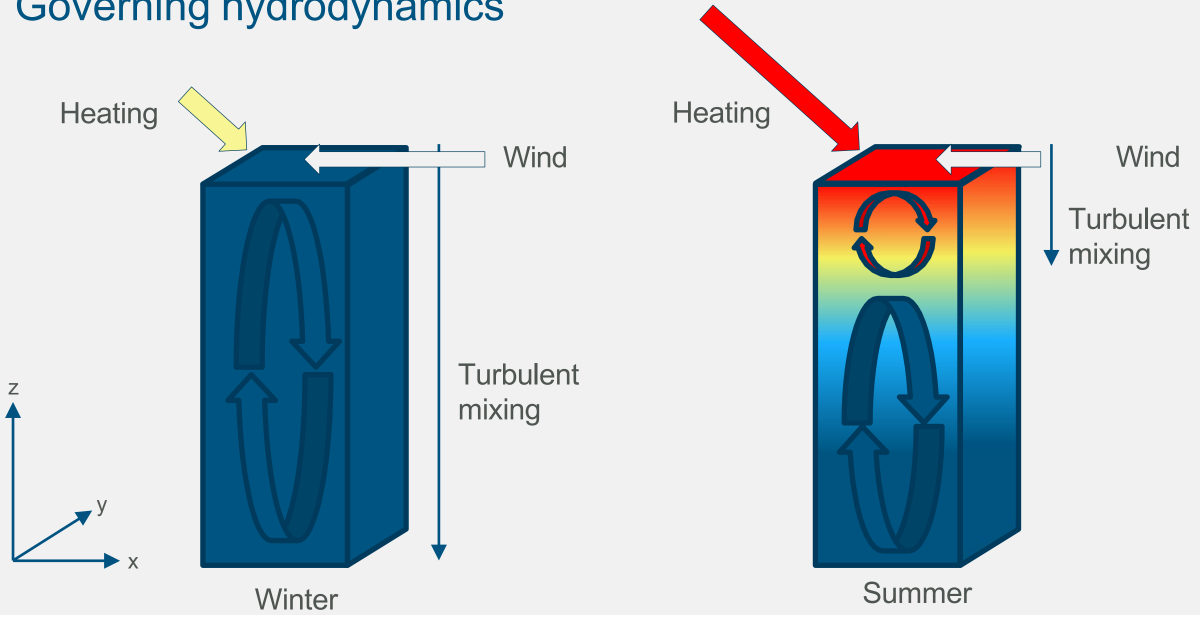
Governing hydrodynamics

Operational mode

Key processes

Water movement: what matters most to a typical lake or reservoir?

- Governing hydrodynamics



- What matters?
  - Climate
    - Heating
    - Stirring
  - Turbulence
    - Generate mixing
  - Gravity
    - Suppress mixing
  - Vertical

Thermal stratification

Key processes

Water quality: what matters most to a typical lake or reservoir?

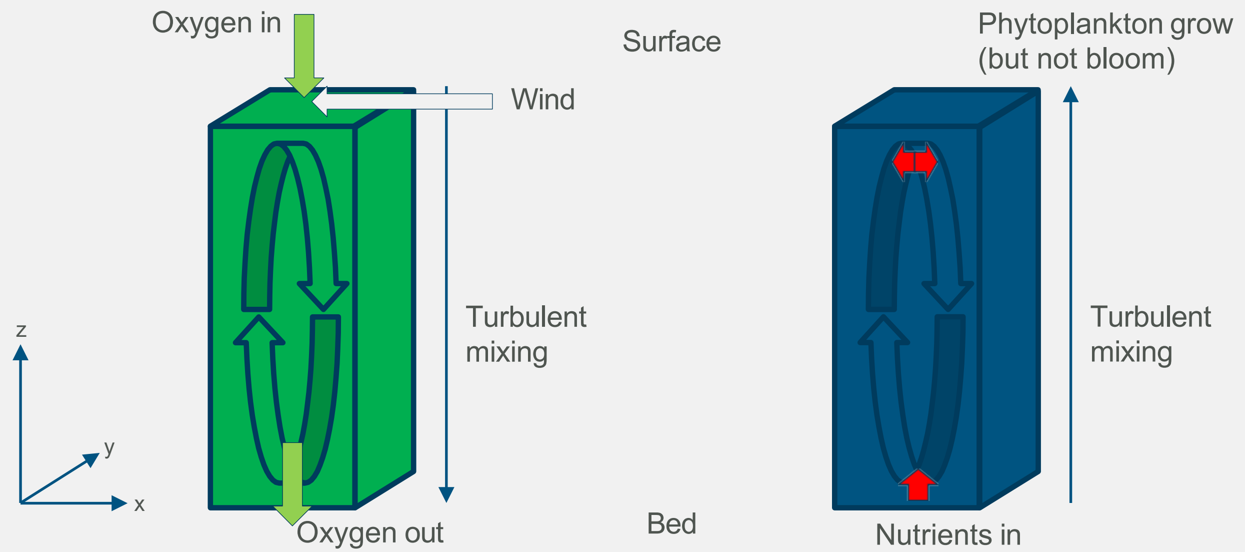
- Dissolved oxygen (surface source)
  - High oxygen concentration → good quality water
  - Low oxygen concentration → poor quality water
- Bioavailable nutrients (bed source)
  - Low nutrient concentration → good quality water
  - High nutrient concentration → poor quality water
    - Low oxygen concentration → high nutrient concentrations
- Phytoplankton (algae, surface)
  - Low concentrations → good water quality
  - High concentrations → poor water quality

Key locations: surface and bed (vertical dimension again)

Key processes

Water quality: what matters most to a typical lake or reservoir?

- Key locations



- What matters?
  - Oxygen
    - Life
  - Nutrients
    - Food
  - Phytoplankton

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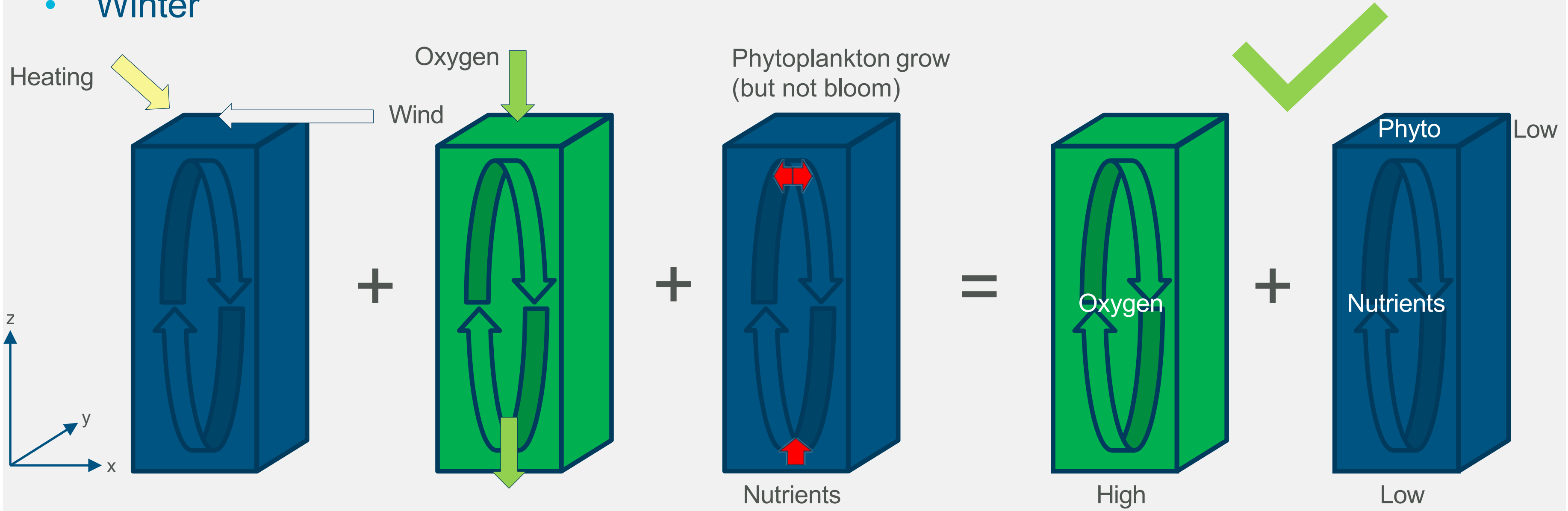
Key processes

Water movement and quality: what matters most to a typical lake or reservoir?

- Winter



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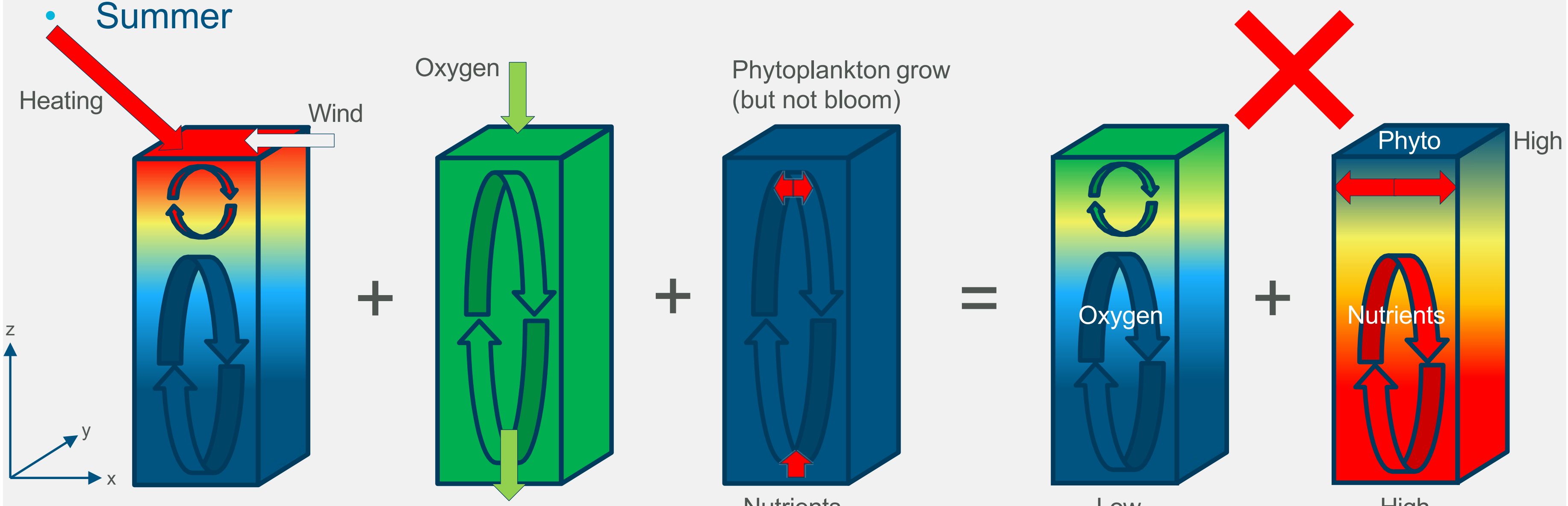
Key processes

Water movement and quality: what matters most to a typical lake or reservoir?

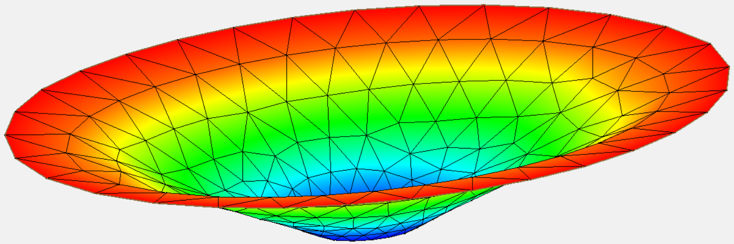
- Summer



Key processes

Water movement and quality: what matters most to a typical lake or reservoir model?

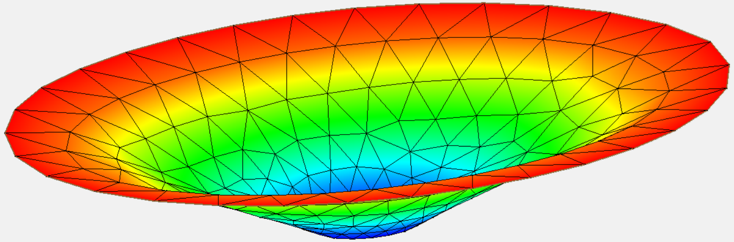
- Reproducing thermal stratification over seasons
- Calibration against measurements is critical: non-negotiable
  - Temperature with depth
  - Oxygen with depth
  - Nutrients
  - Phytoplankton
- Inflows also important



Key processes

What might a model be used for in the real world?

- Understanding and managing phytoplankton blooms
- Managing potable water offtakes
- Designing artificial mixing devices
- Informing catchment management
- Meeting water quality objectives

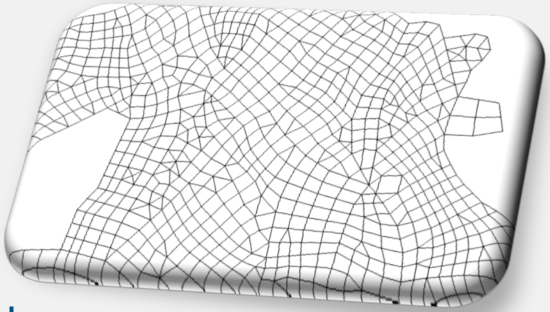


A numerical model

A numerical model

The model

- Always build a model to address well defined questions
  - How can offtake locations be managed to avoid drawing poor water?
  - What are the likely (toxic) phytoplankton dynamics in a reservoir?



Related to

- Thermal stratification

Focus today

- Modelling thermal stratification using a demonstration model

A numerical model

The model

- TUFLOW FV and
  TUFLOW WQM
- Three dimensional
- Bowl geometry
  - 20 metres deep
  - 7km x 4km at outer rim
  - 387 2D cells
  - 4,038 3D cells
  - Hybrid fixed and sigma layer
  - 16 vertical layers

A numerical model

The model

- TUFLOW FV and TUFLOW WQM
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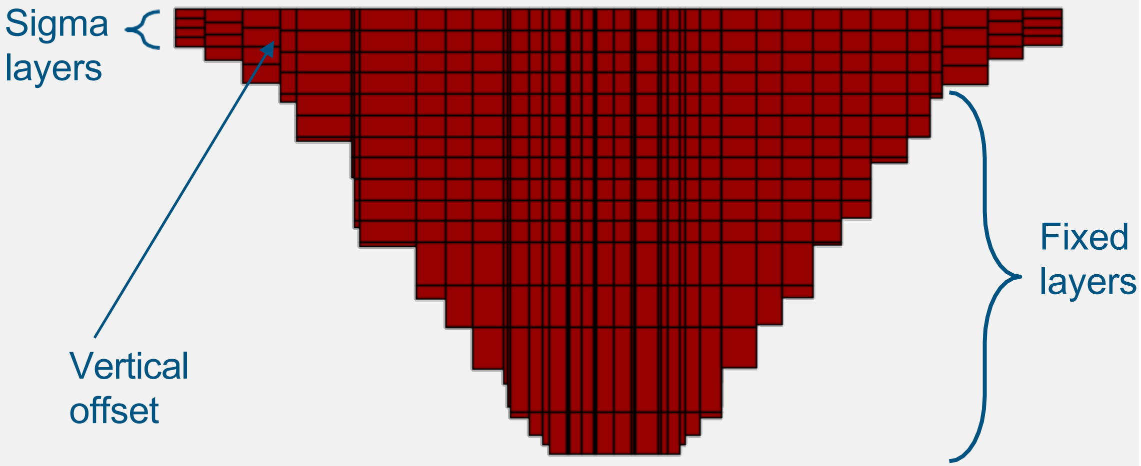

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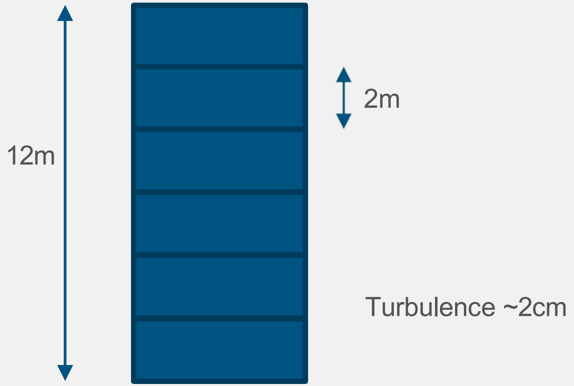
A numerical model

The model

- Applied climate
    - Typical subtropical Australian, executed over winter to autumn
- Turbulence closure
    - Second order k- ε

What is turbulence closure?

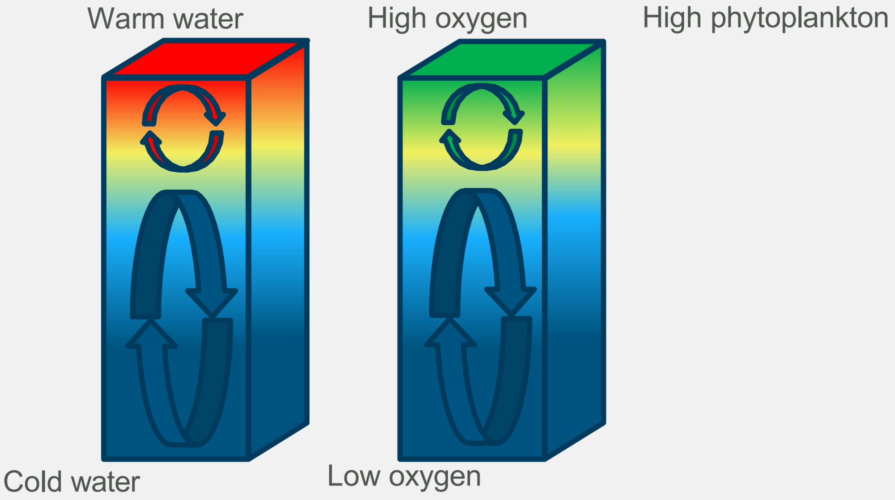
- A way to represent sub-grid scale processes
- Relate
    - Small scale (unsimulated) processes (turbulence and mixing), to
    - Larger scale (simulated) processes (density and velocity)

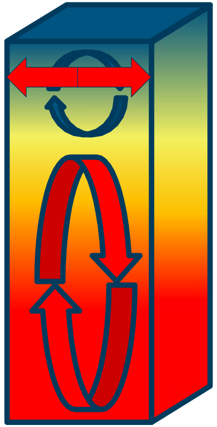


A numerical model

The model

- Simulated
  - Water level (evaporation)
  - Velocity
  - Temperature
  - Density
  - Dissolved oxygen
  - Silicate
  - Ammonium and nitrate } Nutrients
  - Free reactive phosphorus } Nutrients
  - One phytoplankton group



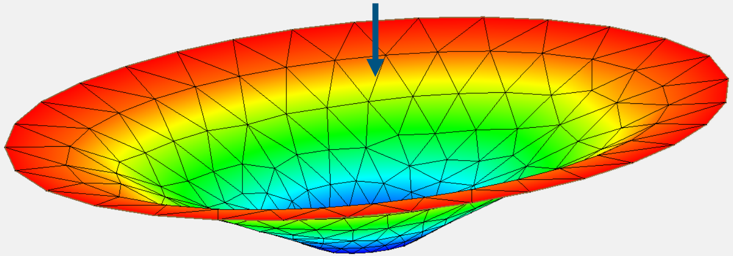


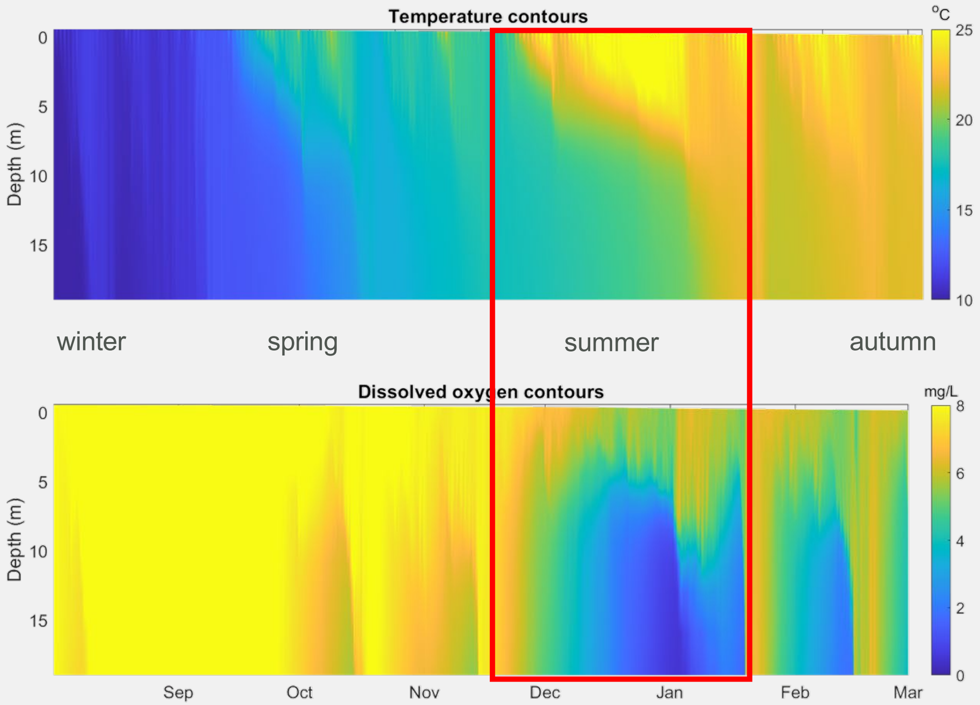
High nutrients

A numerical model

The model

- Presentation of results





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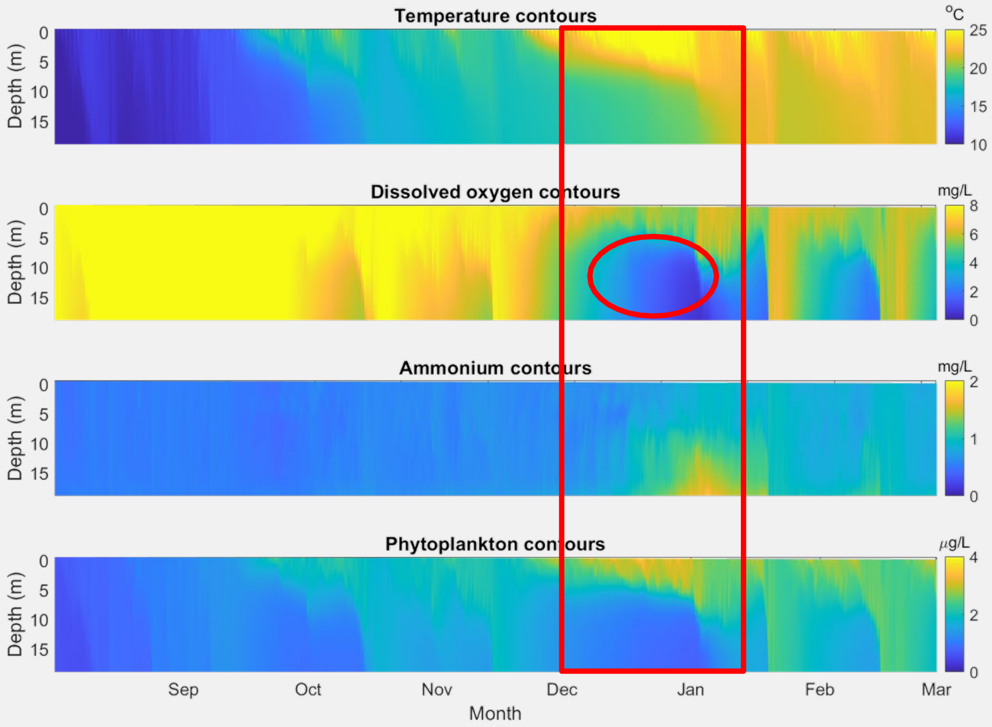
A numerical model

Predictions

- Will be repeating these as a baseline



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Three traps

Three traps

What lakes care about (recap)

- Climate
- Turbulence
- Oxygen
- Nutrients
- Phytoplankton

Modelling thermal stratification traps

- Trap 1: Climate
- Trap 2: Turbulence closure scheme
- Trap 3: Vertical solution scheme

Thermal stratification

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Three traps

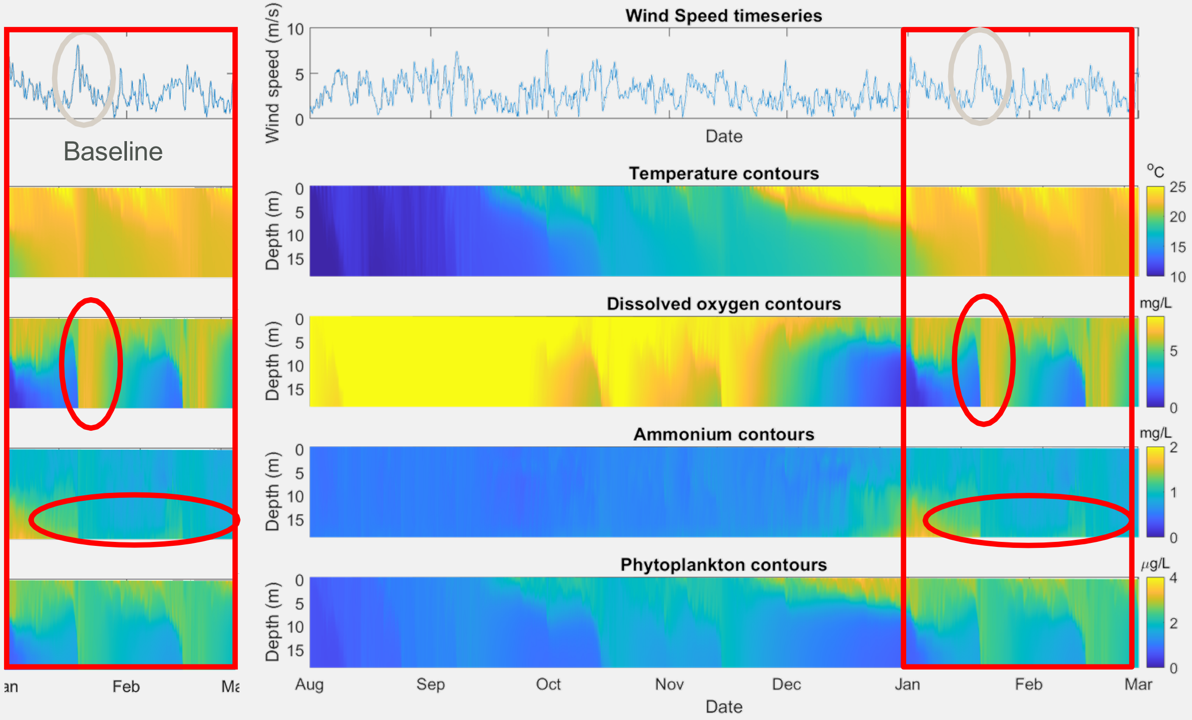
Trap 1: Climate

- On lake data
  - Can be great meteorology
  - But still need to understand data
    - Sheltering
    - Maintenance / calibration
- Look at wind
  - Event being knocked out and replaced
  - Using daily (instead of six hourly) values

Three traps

Trap 1: Climate

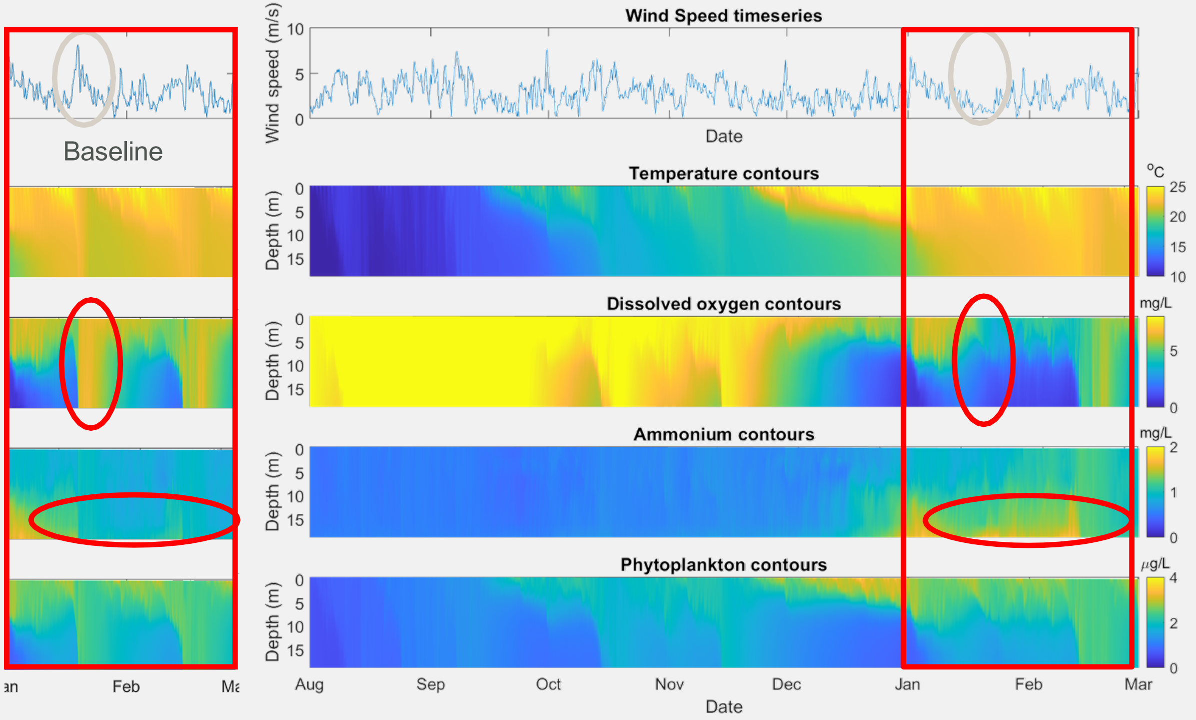
- Baseline



Three traps

Trap 1: Climate

- Event missed
  - Mixing absent
  - Oxygen remains low
  - Nutrients higher



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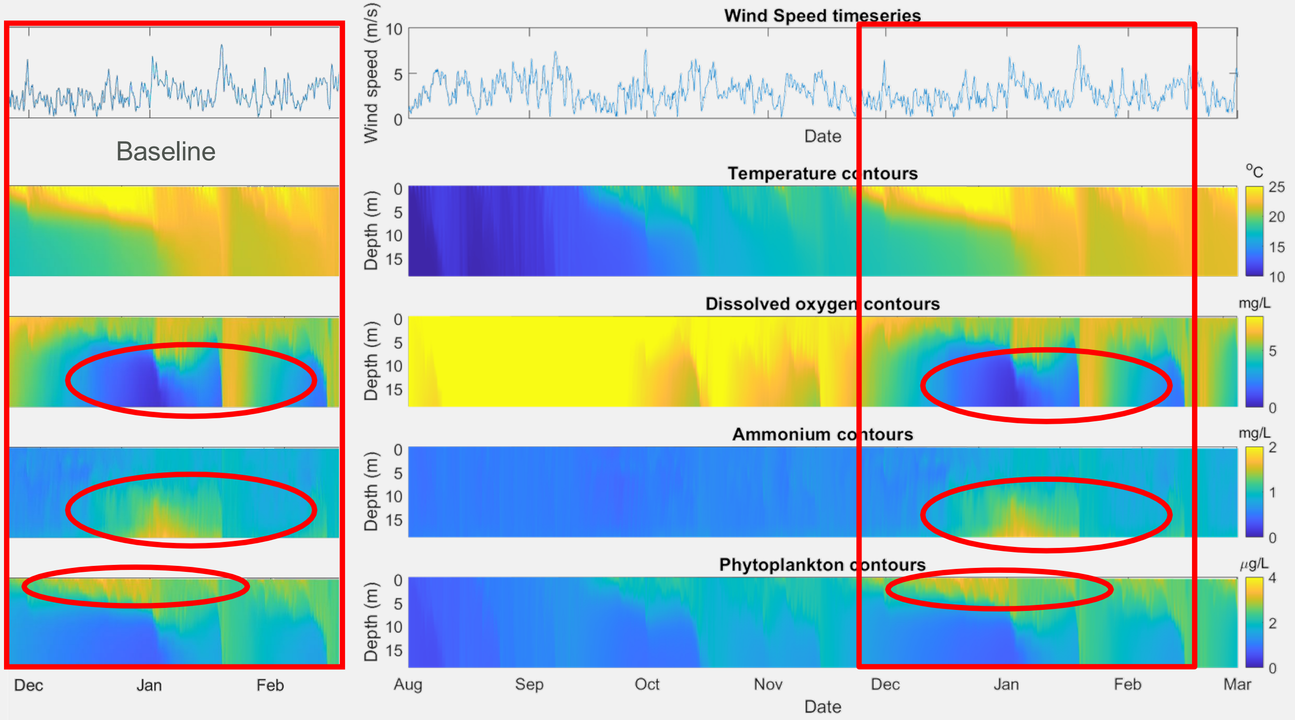
Three traps

Trap 1: Climate

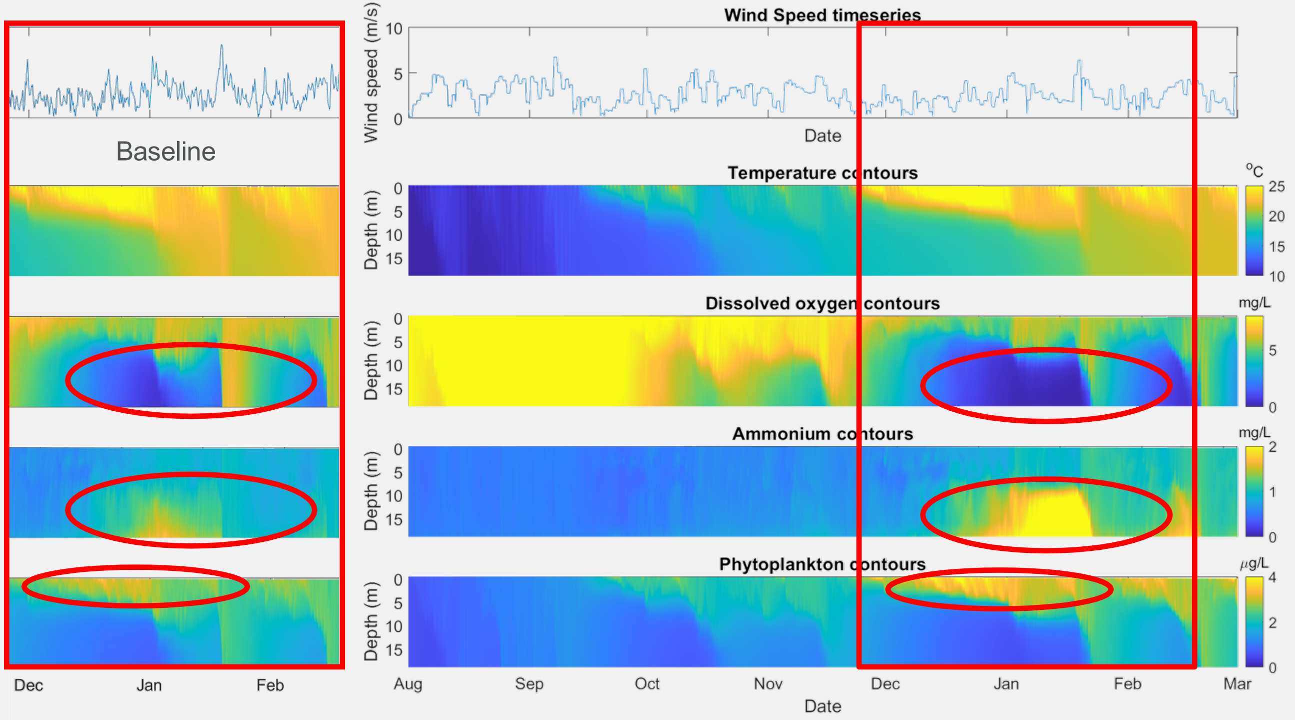
- Baseline



Three traps

Trap 1: Climate

- Daily wind
  - Mixing less
  - Oxygen lower
  - Nutrients very much higher
  - Phytoplankton very much higher



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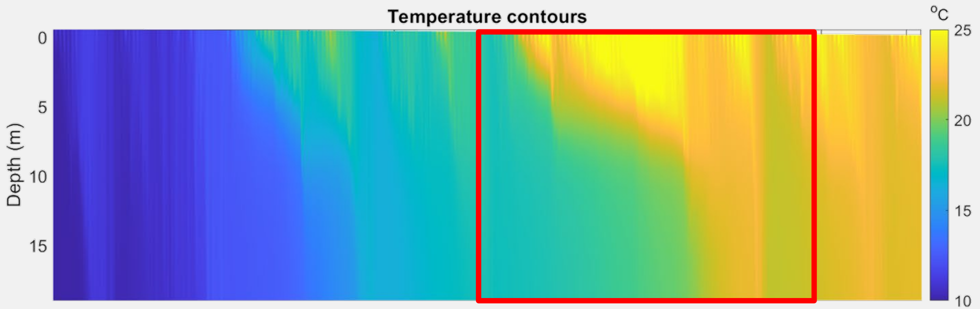
Three traps

Trap 2: Turbulence closure scheme

- Many schemes available: relate large scale simulated quantities to small scale unsimulated quantities
- Selected four schemes
  - Second order k- ε
  - Lengthscale method 1
  - Lengthscale method 2
  - Constant diffusivity

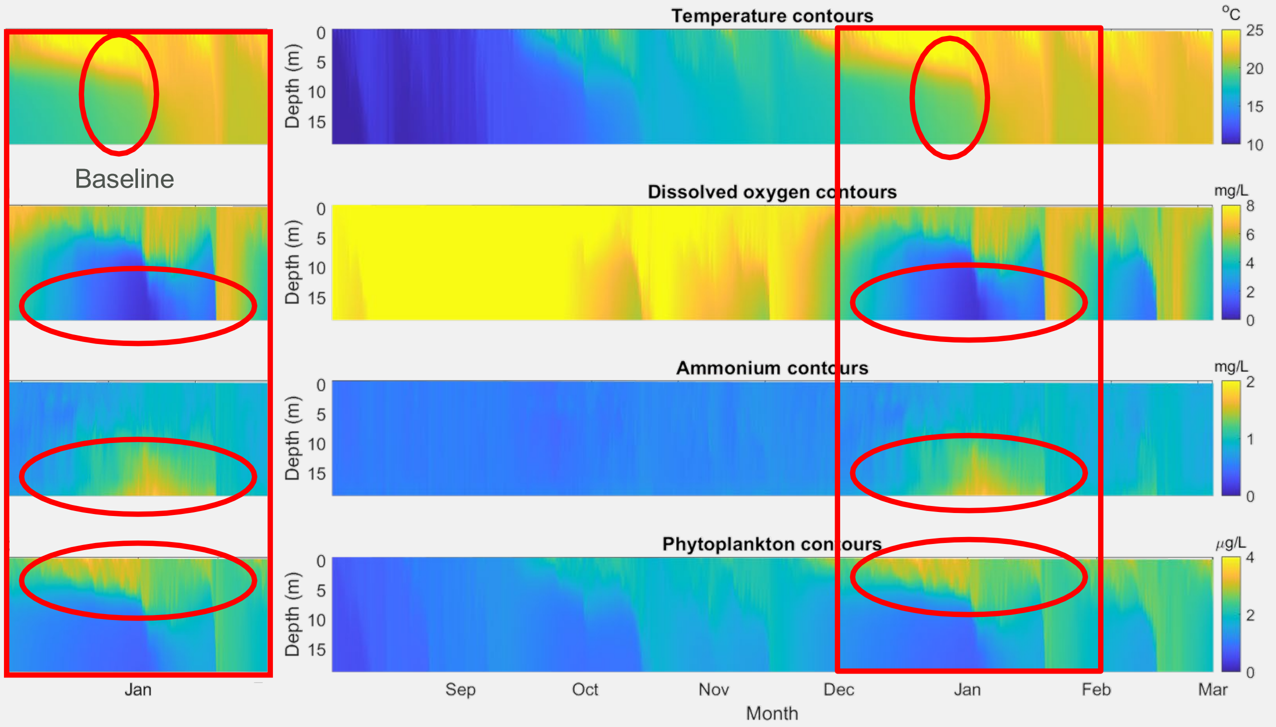


Warner, J. et al. (2013). Performance of four turbulence closure methods implemented using a Generic Length Scale Method. Ocean Modelling. 8. 81-113.

Three traps

Trap 2: Turbulence

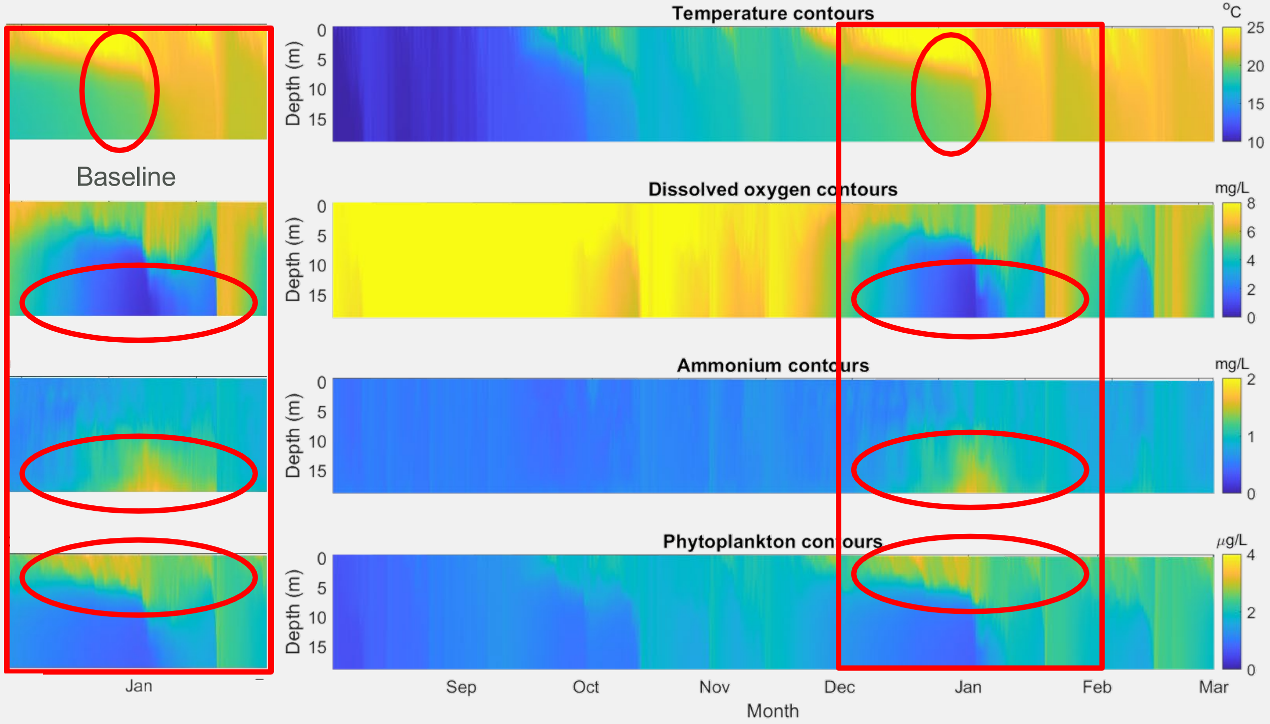
- Baseline



Three traps

Trap 2: Turbulence

- Lengthscale method 1
  - More mixing
  - Lower nutrients



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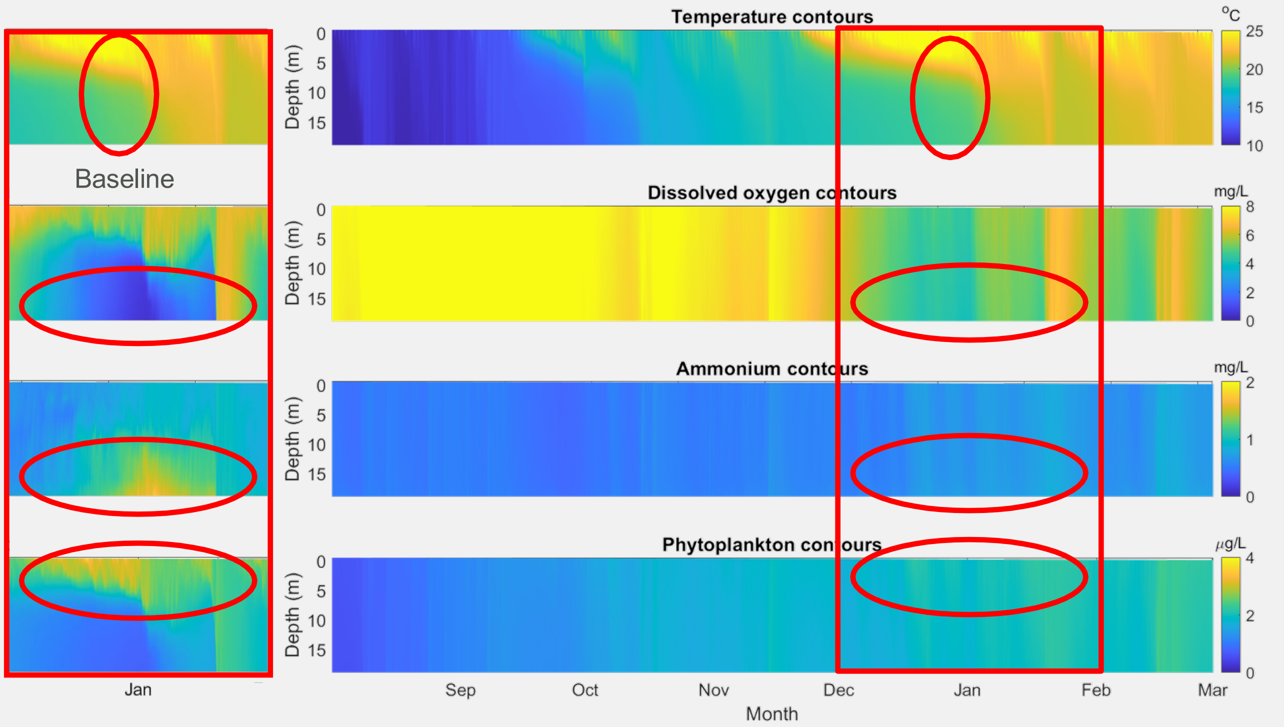
Three traps

Trap 2: Turbulence

- Lengthscale method 2
  - More mixing
  - Less nutrients
  - Less phytoplankton



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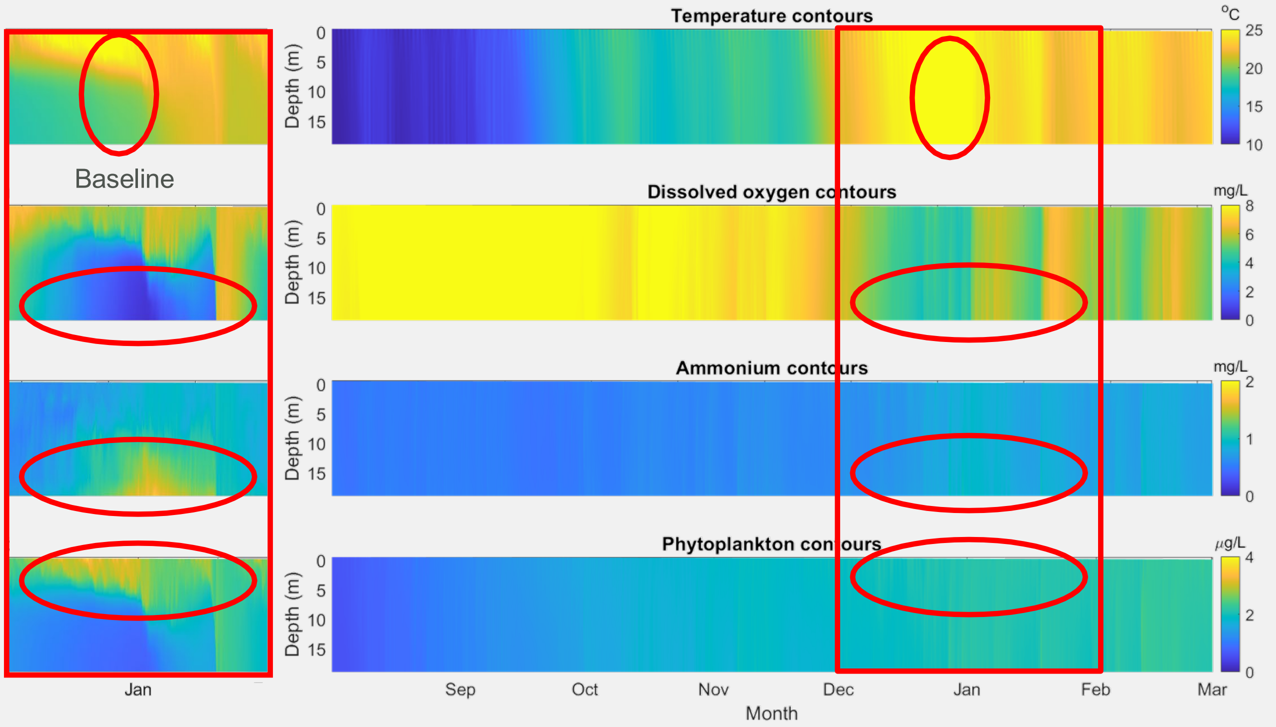
Three traps

Trap 2: Turbulence

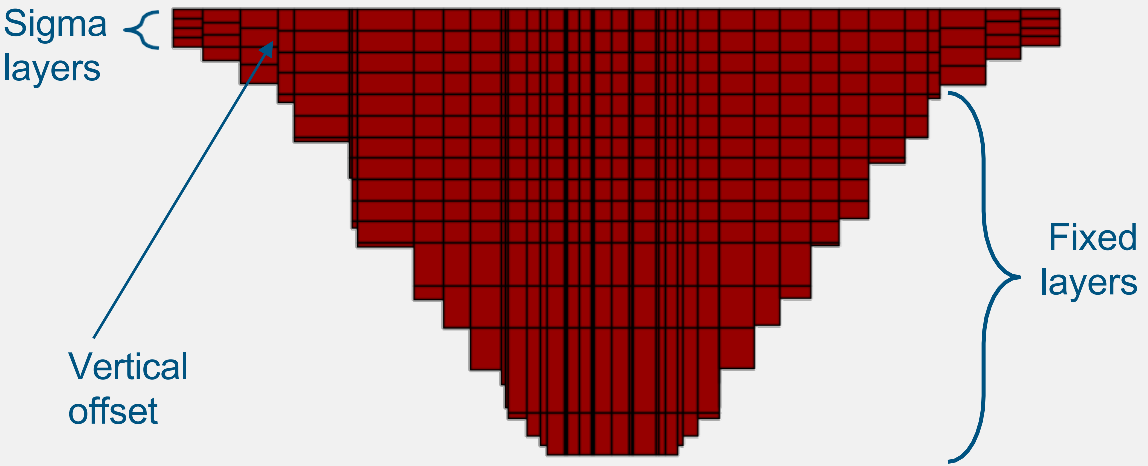
- Constant diffusivity
  - Well mixed



Three traps

Trap 3: Vertical solution scheme

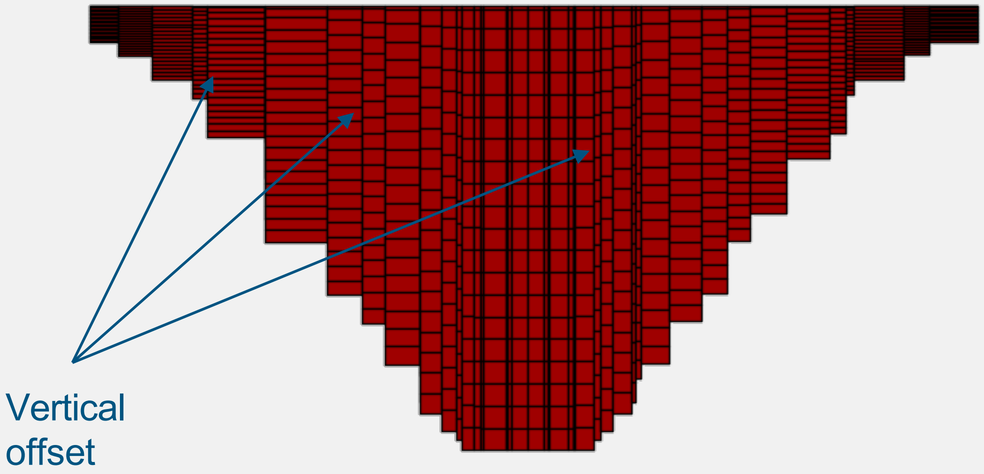
- Two primary schemes
  - Fixed/sigma hybrid



Three traps

Trap 3: Vertical solution scheme

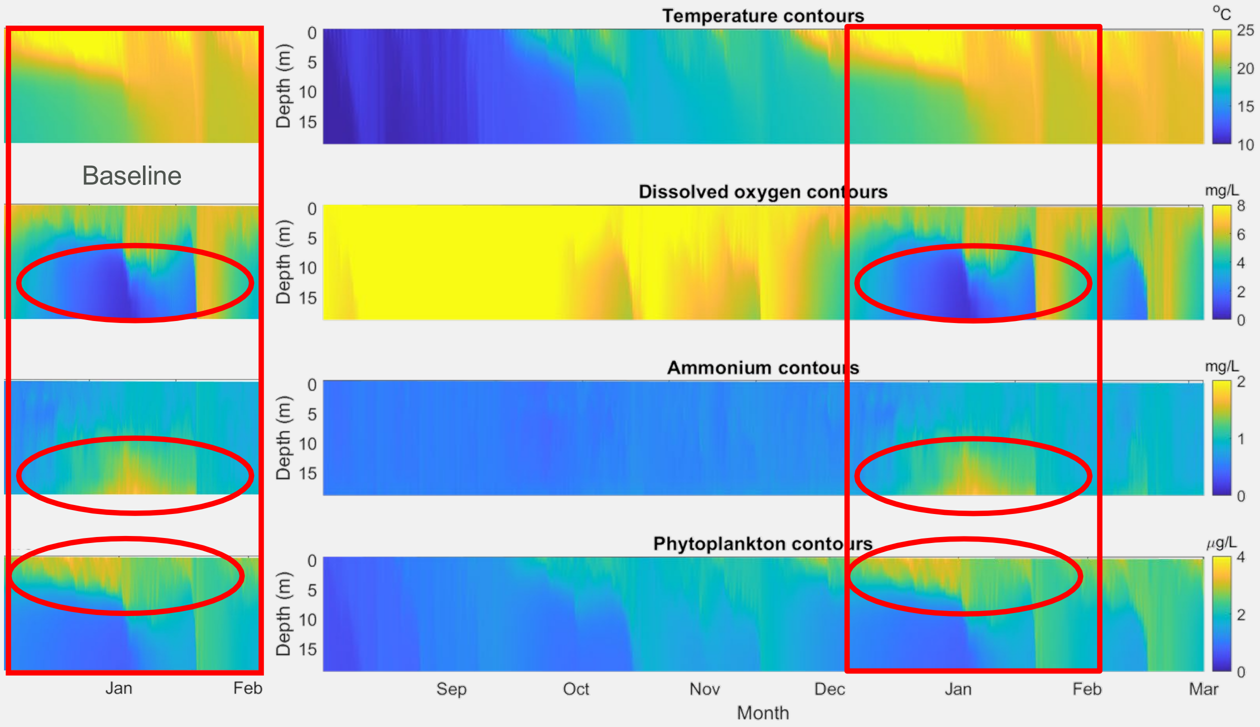
- Two primary schemes
  - Sigma



Three traps

Trap 3: Vertical solution scheme

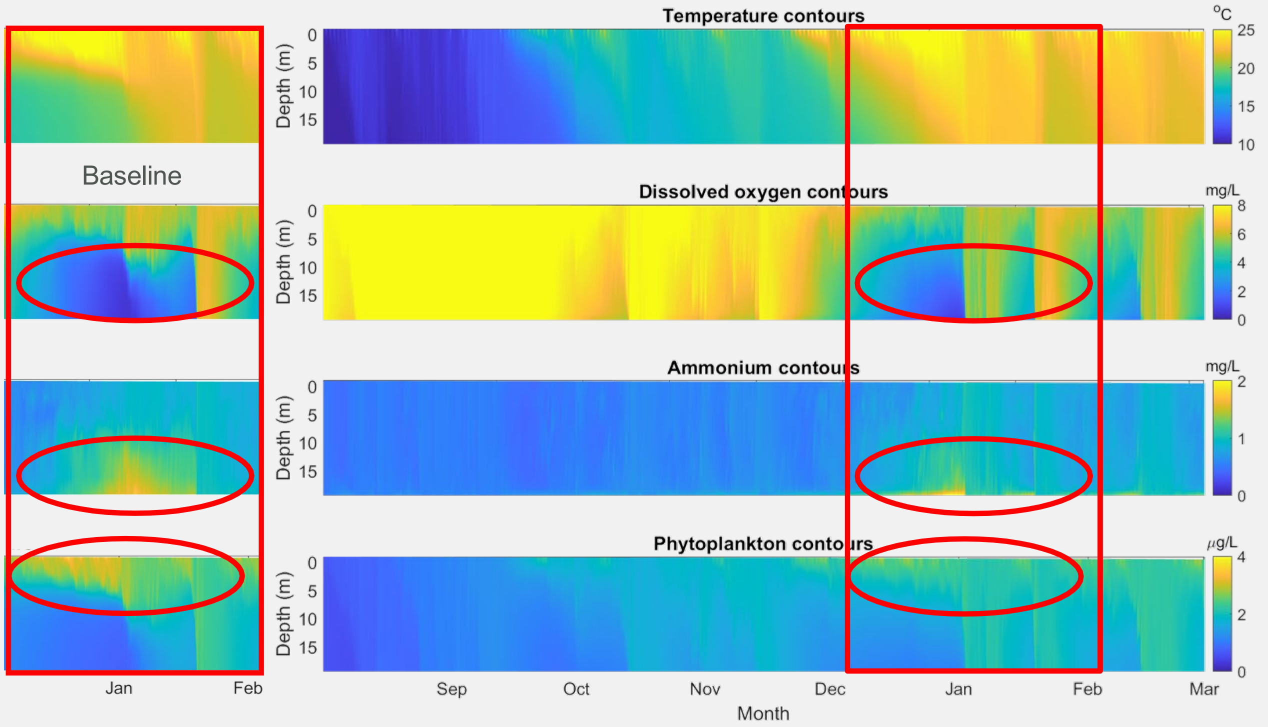
- Baseline



Three traps

Trap 3: Vertical solution scheme

- Sigma



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Three traps

It all about thermal stratification

- Physical (and biological)
- Lessons:
  - Climate is critical
  - Turbulence and mixing are critical
  - Solution schemes matter
  - Calibration is non-optional
    - With the right information and expertise this can be done
    - TUFLOW FV has a long track record of doing so

Example

Example

Real world water supply reservoir

- TUFLOW FV and TUFLOW WQM
- Early summer inflow into stratified system
  - Different predictions for stratification in receiving reservoir
- Inflow
  - Same inflow but contains pollutants to be avoided
- Where should an offtake be placed vertically?
  - Impacts on water supply quality

Example

Real world water supply reservoir

- The same inflow behaves differently in the reservoir depending on the predicted thermal stratification
- Different mixing and pollutant concentrations at different depths
- Very different predictions of offtake quality
- Underscores importance of getting stratification right in numerical models
- What to do?

Example

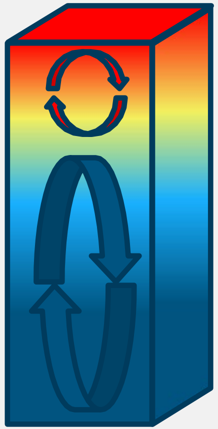
Real world water supply reservoir

- Consider variable height offtake
- Consider the influence of mechanical destratification on offtake quality
- A bubble plume diffuser
  - Bed mounted HDPE pipe with drilled holes
  - Connected to a land based air compressor
  - Plumes entrain water as they rise and dismantle stratification
  - What happens to the inflow?

Summary

Reservoir and lake modelling

- Climate
- Turbulence and mixing
- Oxygen
- Nutrients
- Phytoplankton



Thermal stratification: get it right (it can be done)!

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Q &A