Using Numerical Model Diagnostic Outputs

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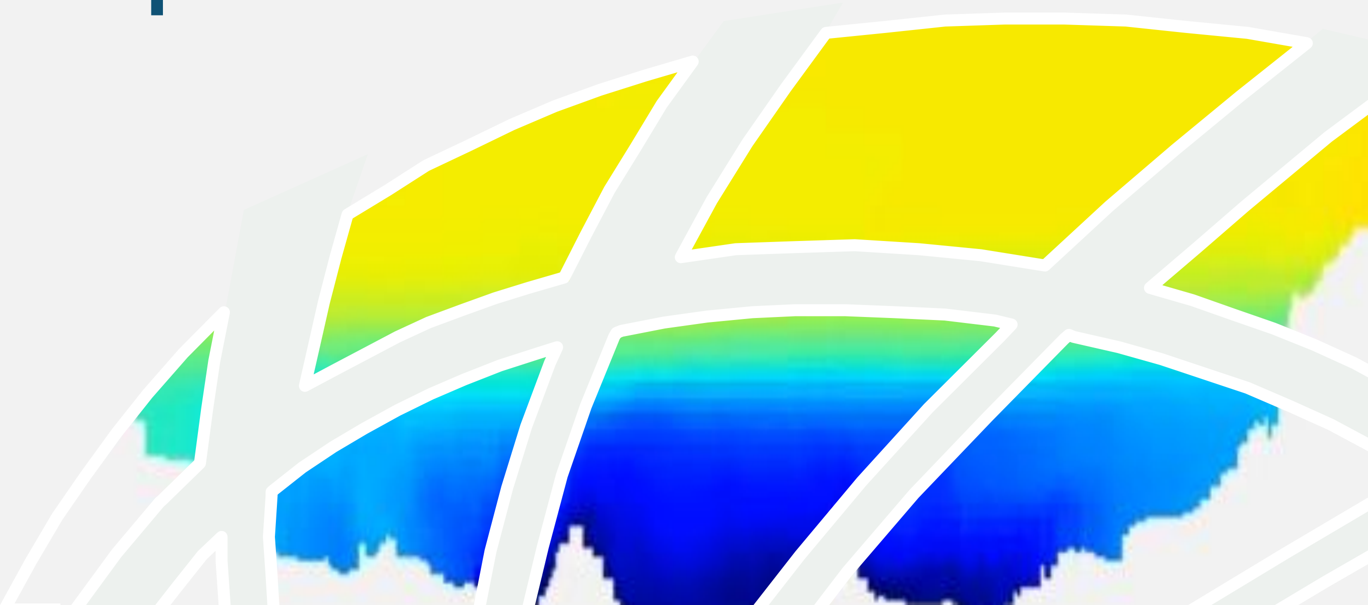
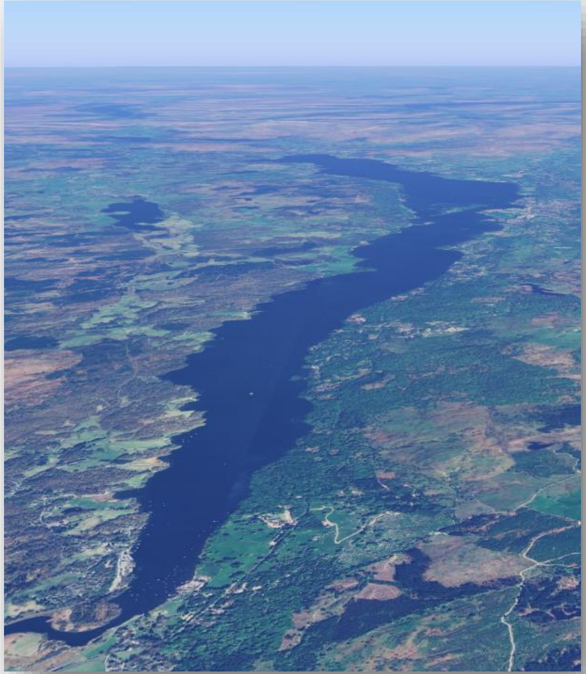


Agenda

We'll cover

- What are numerical model diagnostic outputs?
- Case study: Windermere, England
  - Model set up and outputs (existing)
  - Simulate interventions
  - Analysis of diagnostics
- Understanding the why



What are numerical model diagnostic outputs?

What are numerical model diagnostic outputs?

Concentrations

A concentration is typically a mass per unit volume of water

Dissolved oxygen concentrations are in milligrams of oxygen per litre ‘mg/L’

- Not fundamental quantities because they are the net outcome of the operation of multiple mass fluxes
  - **Can** assist with ‘the what’ – does the concentration comply with regulation/standards?
  - **Cannot** assist with ‘the why’ – why is the concentration the value it is?

What are numerical model diagnostic outputs?

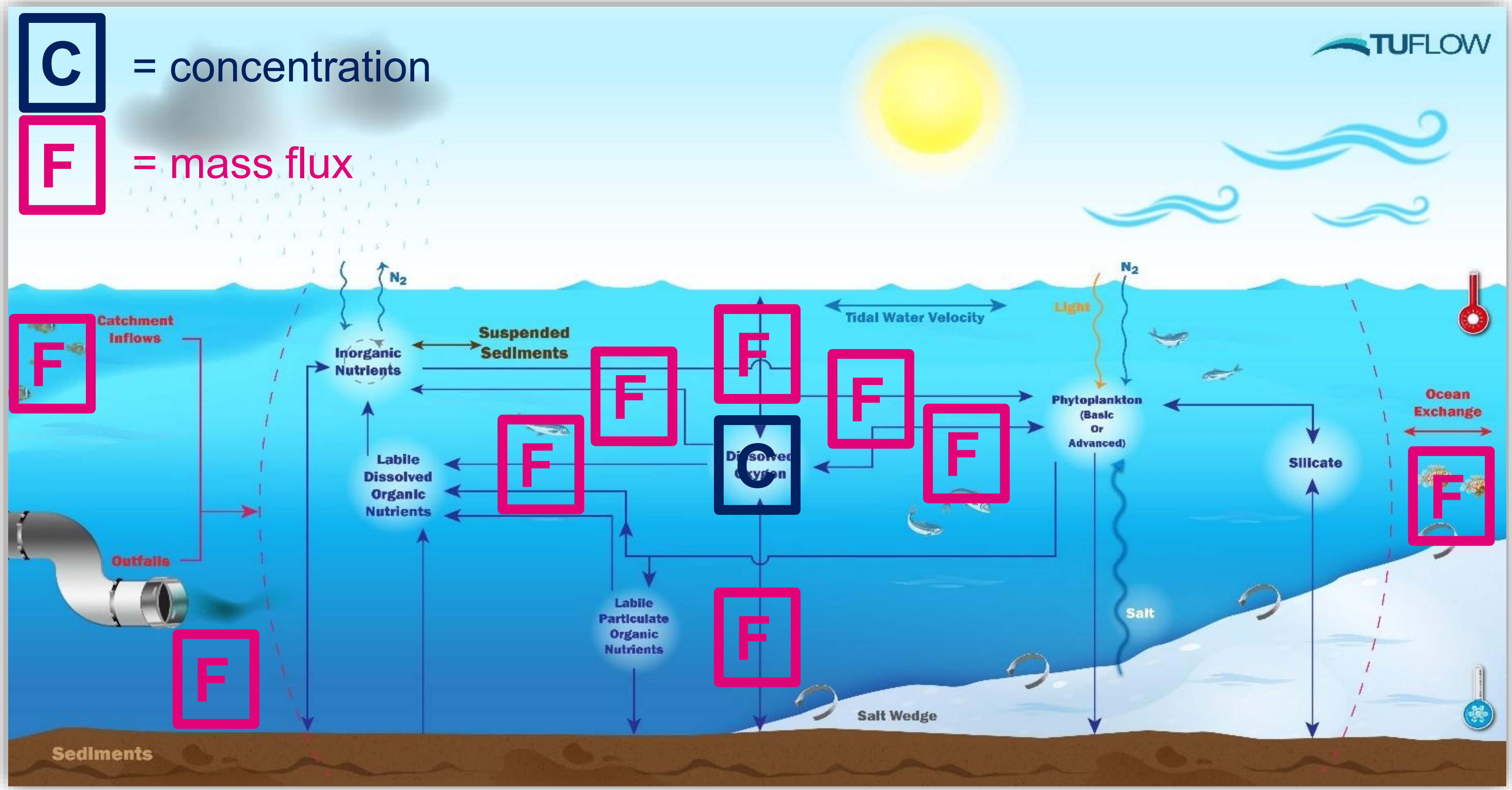
Mass fluxes

A mass flux is a transfer of mass from one form or state to another

$$CO_2 \longrightarrow C + O_2 \qquad \text{(photosynthesis)}$$

Dissolved oxygen mass fluxes are in milligrams of oxygen per vol per day ‘$mg/m^3/d$’

- Are fundamental quantities because they relate directly to the operation of environmental processes
  - **Can** assist with ‘the what’ – does the mass flux match measurements?
  - **Can** assist with ‘the why’ – they determine concentrations


C
= concentration
F
= mass flux
TUFLOW
Catchment Inflows
Outfalls
Sediments
N_2
Inorganic Nutrients
Suspended Sediments
Labile Dissolved Organic Nutrients
Labile Particulate Organic Nutrients
Tidal Water Velocity
Light
N_2
Phytoplankton (Basic Or Advanced)
Silicate
Ocean Exchange
Salt
Salt Wedge

What are numerical model diagnostic outputs?

Concentrations vs mass fluxes

- The problem
  - The number 11: is it (6 + 5) or (22 ÷ 2) or …?

Concentration

Fluxes

  - A modelled concentration of 11 might match measurements, but is it matching for the right (mass flux) reasons?
  - We cannot tell by looking at concentrations
  - (But let’s hope everything is OK and just get on with our modelling project)
  - Water level is the equivalent of concentrations – what underlying flows generated it?

What are numerical model diagnostic outputs?

Concentrations vs mass fluxes

- The problem

Equifinality

A system can reach the same final state (concentration) through diverse paths (fluxes)

Beware of concentrations!

What are numerical model diagnostic outputs?

Diagnostic outputs

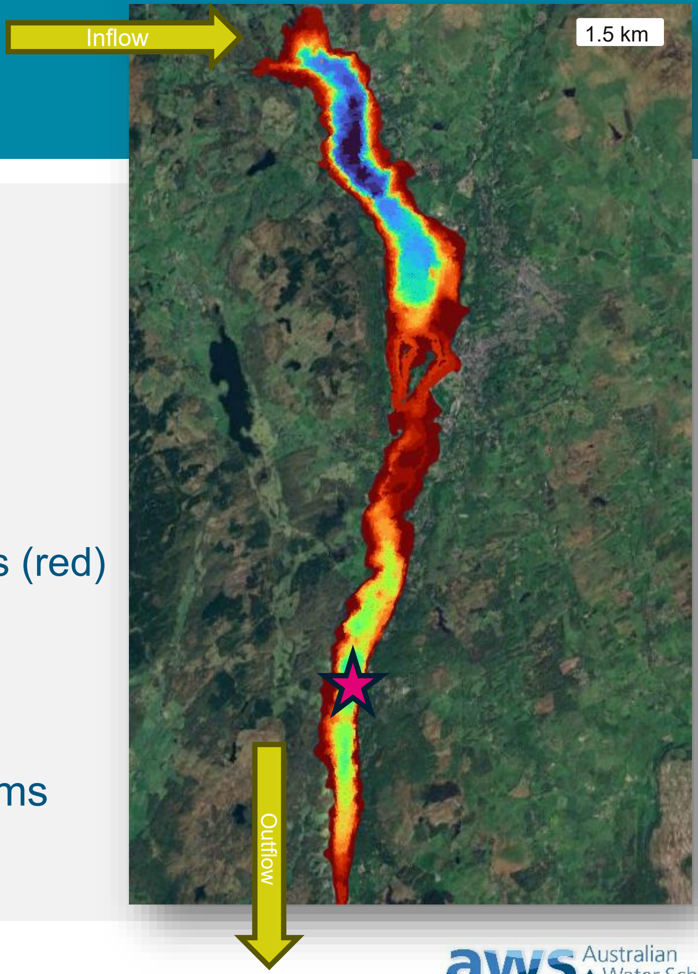
- Environmental numerical models have always output concentrations (the what) **C**
- Some environmental models output mass fluxes too (the why) **F**
  - Mass fluxes are called ‘diagnostics’ – they let us diagnose concentrations
- Today we are using TUFLOW FV and its Water Quality Module model diagnostics to understand why, not just what

Case study
Windermere, England

Case study

Windermere

- England's largest natural lake
- Post-glacial formation
  - 16 km long by 1.5 km wide
  - Two deep basins (blue/green), with extensive shallows (red)
- Sits within the Lake District
  - UNESCO World Heritage Listed area
- Hosts important ecosystems, experiences algal blooms
- Water flows from north to south



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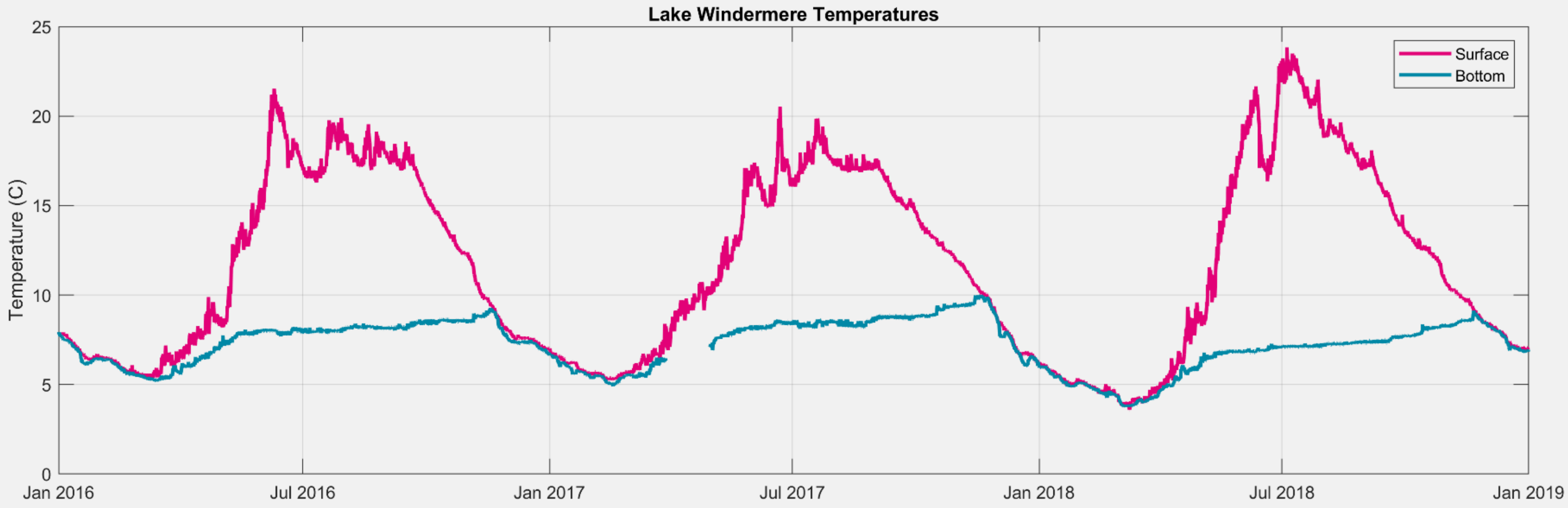
Case study

Case study

Windermere

- Strongly thermally stratified in summer (UKCEH EIDC, profiles later)

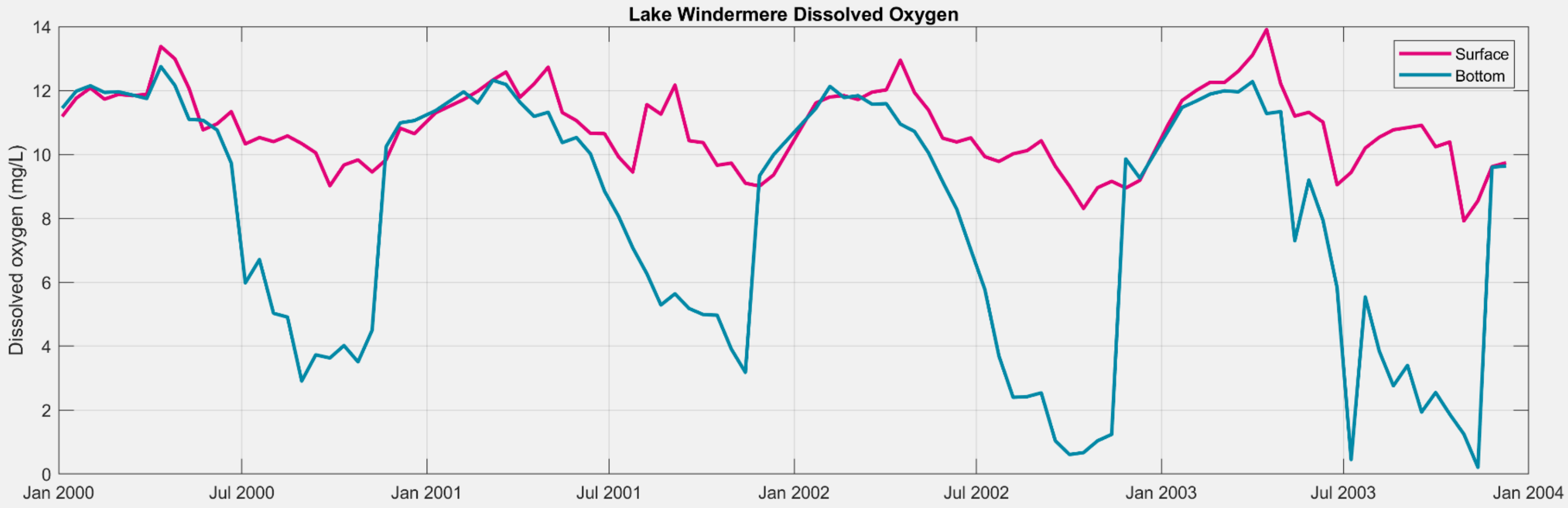


Feuchtmayr, H.; Jones, I.D.; Clarke, M.; Maberly, S.C. (2021). **Hourly data from automatic water monitoring buoy from Windermere South Basin, 2016 to 2018**. NERC EDS Environmental Information Data Centre. https://doi.org/10.5285/e1b6e387-1bd6-444a-8de9-035df0b8baec

Case study

Windermere

- Dissolved oxygen drops at depth (EA)

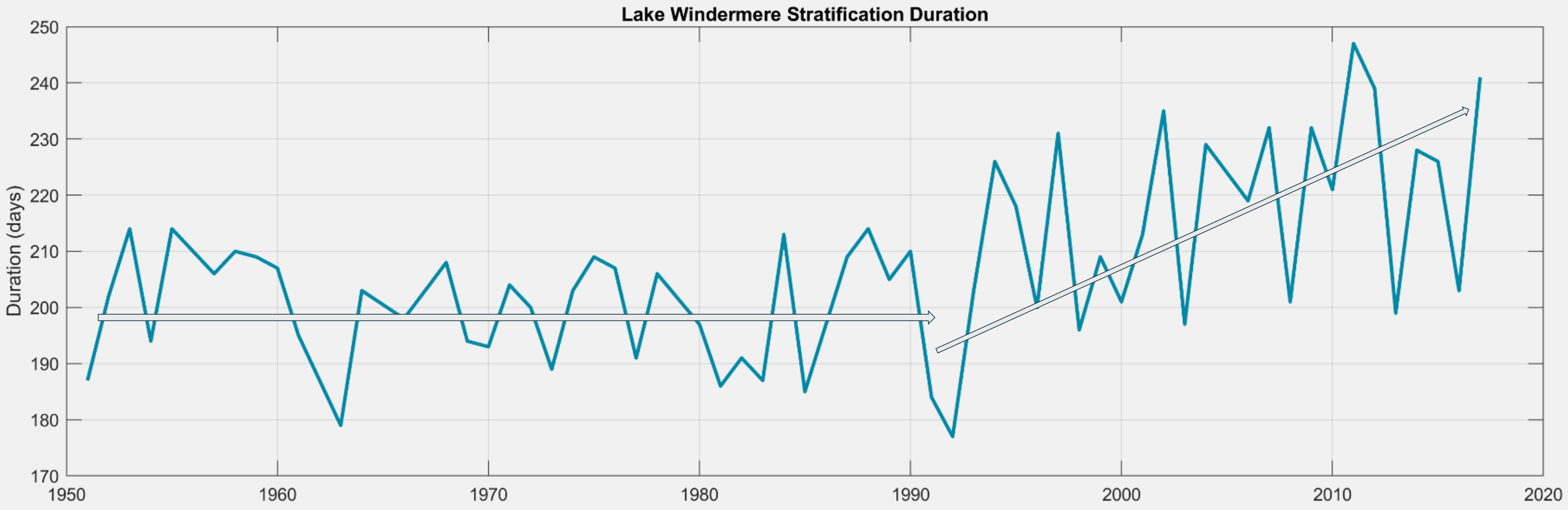


https://environment.data.gov.uk/water-quality/sampling-point/NW-88016096

Case study

Windermere

- Number of days stratified per year is potentially changing (UKCEH EIDC)



Mackay, E.B.; Clarke, M.A.; Dodd, B.A.; Feuchtmayr, H.; Fletcher, J.M.; James, J.B.; Maberly, S.C.; Rhodes, G.; Thackeray, S.J. (2021). **Cumbrian Lakes Monitoring thermal stratification timing 1951-2017** NERC Environmental Information Data Centre. https://doi.org/10.5285/d029bb43-5722-4932-9c14-be316a2e7144

Case study

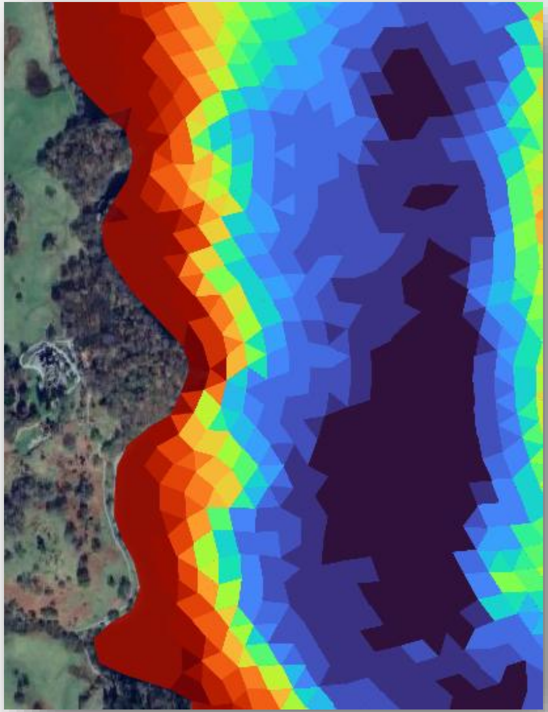
Windermere

- Reasonable to construct a numerical model to
  - Understand lake operation now and future
  - Assess / investigate management options
- Model is qualitative and for demonstration only
- No suggestion that the management options investigated are under consideration

Case study

Windermere

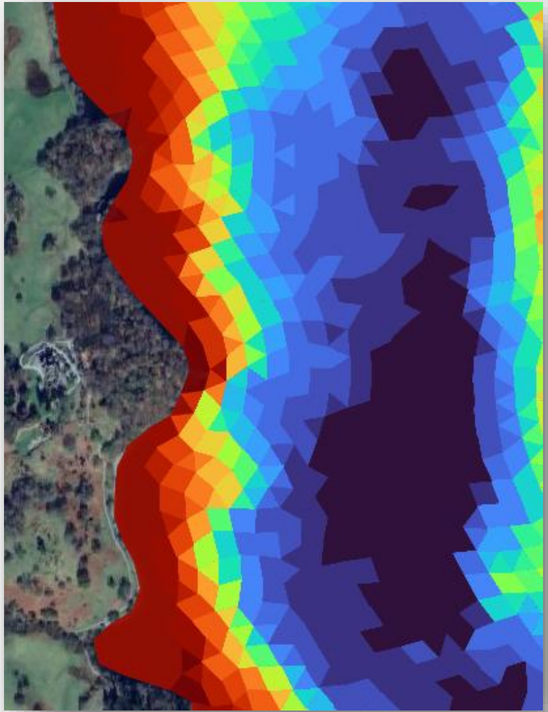
- 3D TUFLOW FV model, with Water Quality Module
- GPU accelerated
- 10,041 (245,772) 2D (3D) cells
- ~ 70 x 1m thick layers (depending on bathymetry)
- 3 inflows (River Brathay, Trout Beck and Cunsey Beck)
- One outlet (Newby Bridge, River Leven)
  - Constrained outlet



Case study

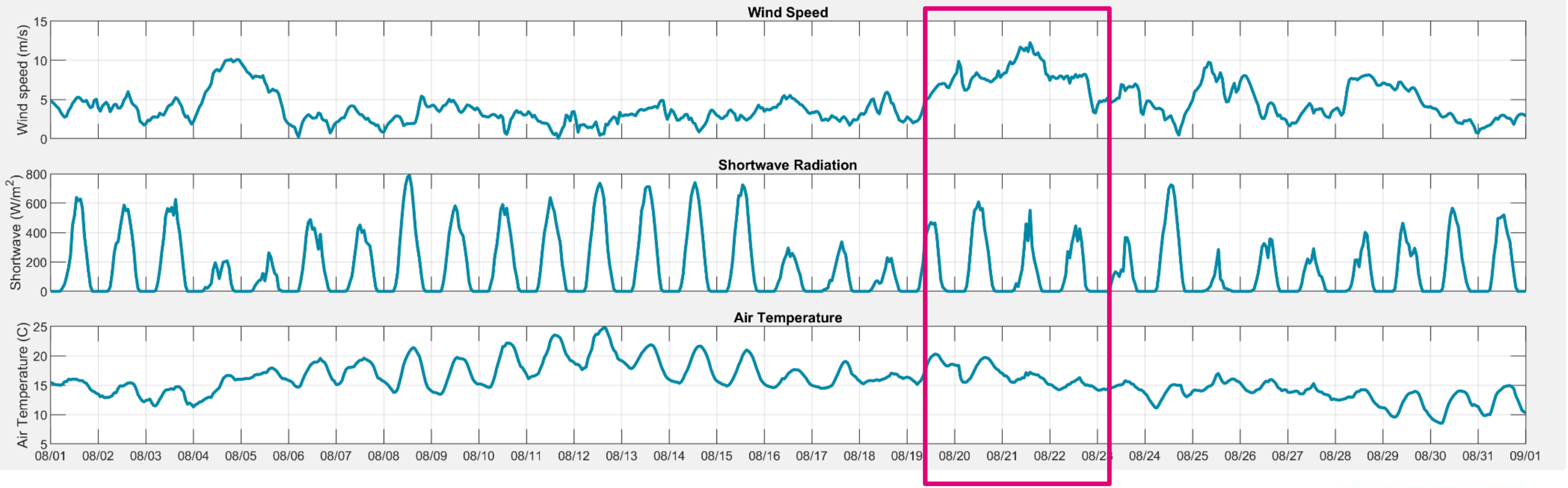
Windermere

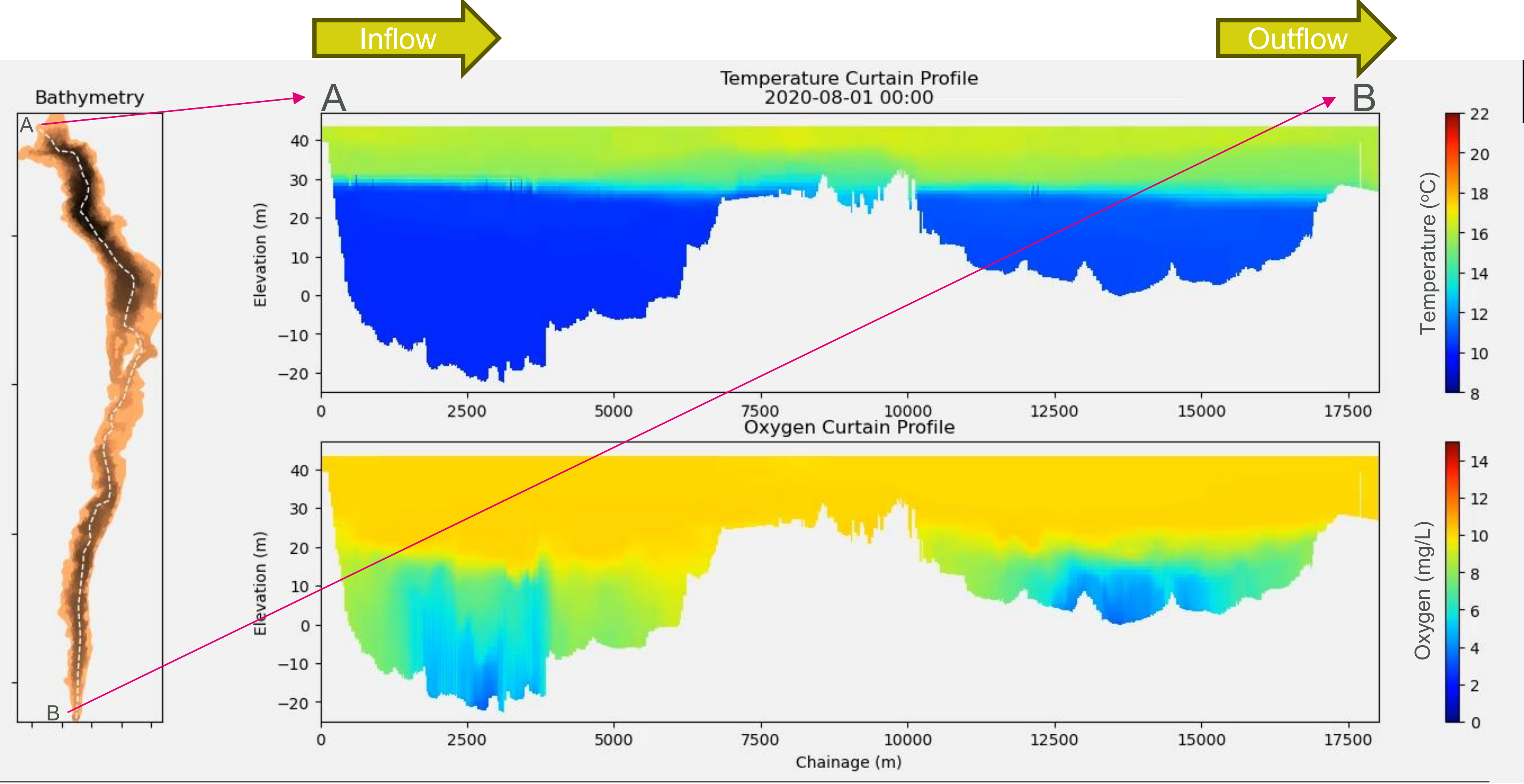
- Bathymetry: British Geological Survey
- Inflows: Environment Agency Hydrology Data Explorer
- Atmospheric forcing: Copernicus Climate Data Store (ERA5)
- Period of simulation: August 2020 (summer)
- Three dimensional, simulating
  - Hydrodynamics (with one passive tracer)
  - Temperature
  - Dissolved oxygen



Case study

Windermere




Inflow
Outflow
Bathymetry
A
B
Temperature Curtain Profile
2020-08-01 00:00
Elevation (m)
Temperature (ºC)
Oxygen Curtain Profile
Oxygen (mg/L)
Chainage (m)

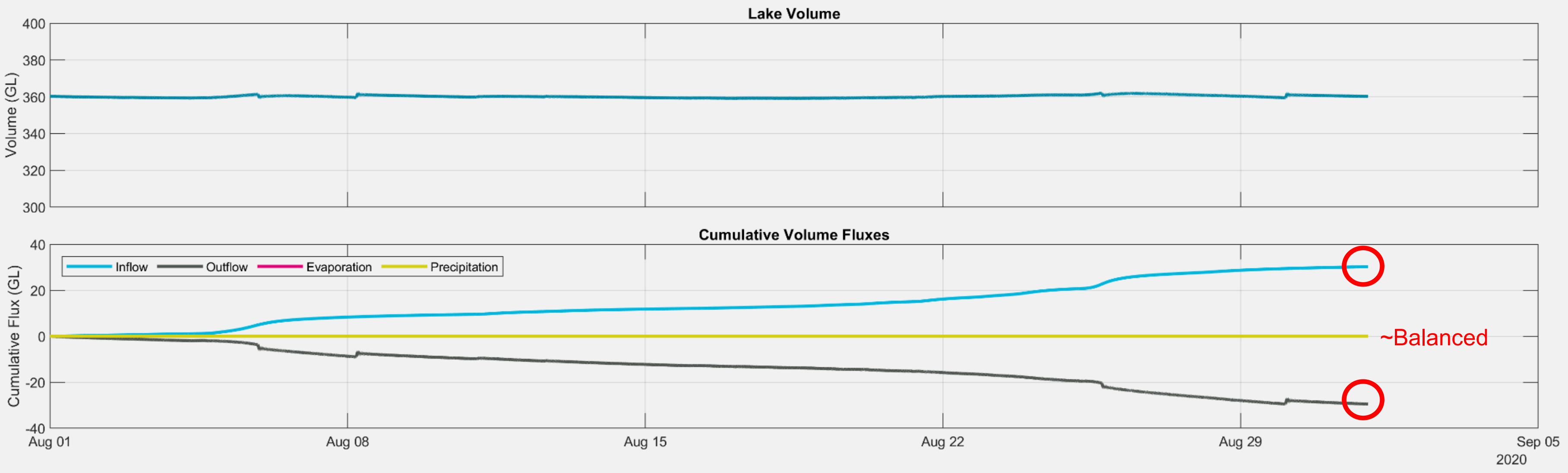
Case study

Windermere

- These are concentrations
  - Water level is the net result of volume fluxes (a proxy concentration) C
  - Temperature is the net result of heat fluxes (the concentration of heat) C
  - Dissolved oxygen is the net result of oxygen fluxes C
- What about the diagnostics? F

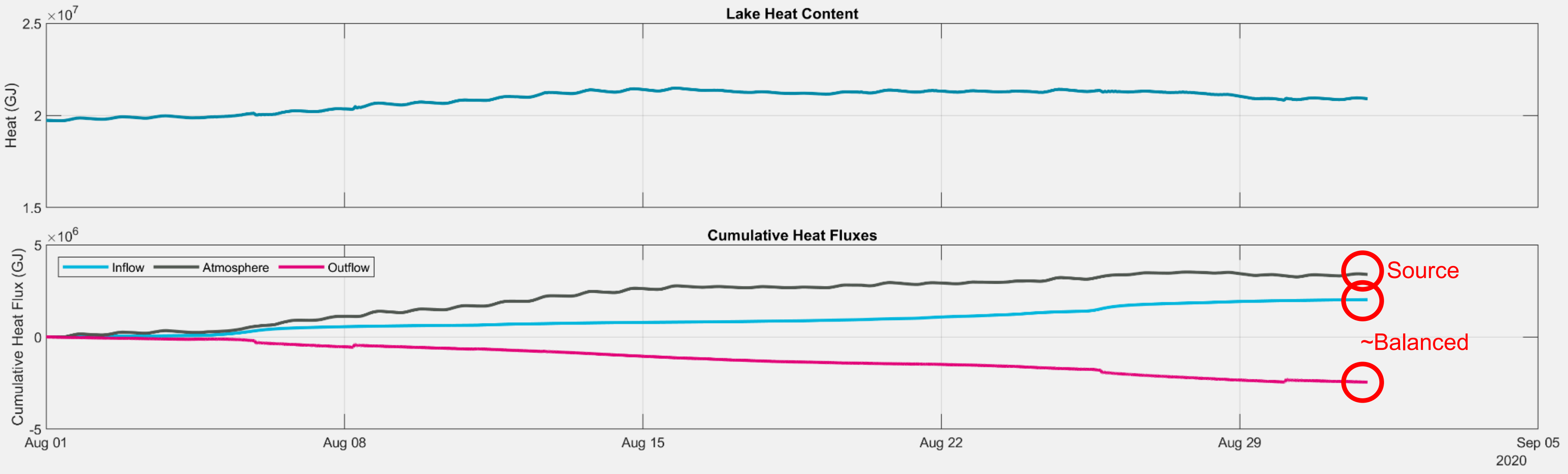
Case study

Windermere – volume diagnostics (1GL = 1 million cubic metres)



Case study

Windermere – heat diagnostics (note different vertical axes)



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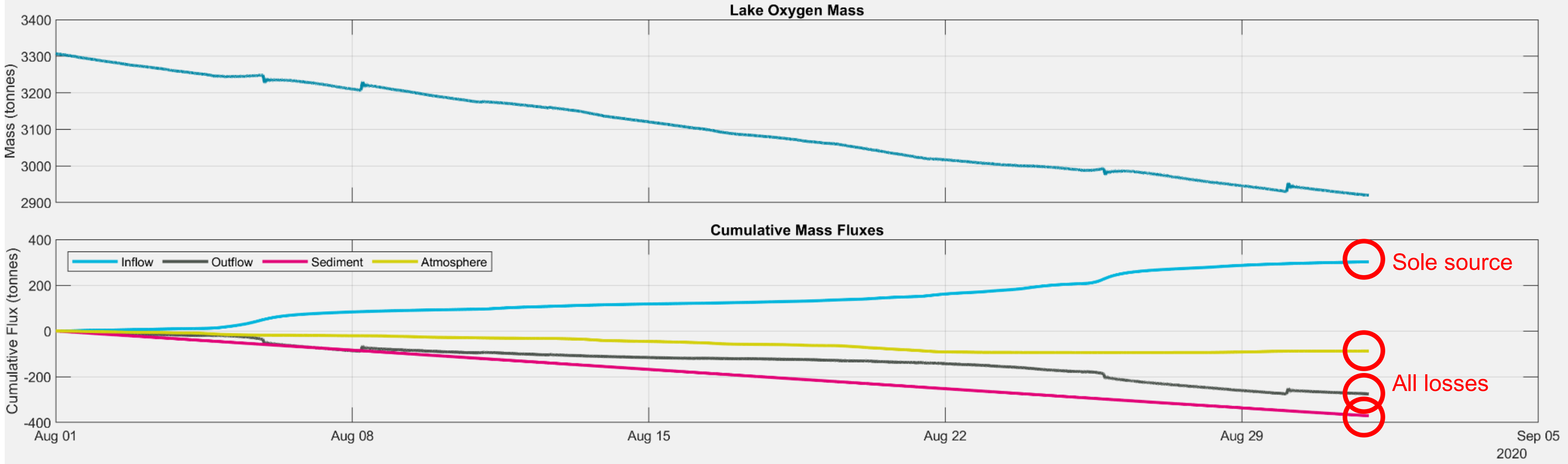
Case study

Windermere – oxygen diagnostics



Case study

Windermere

- Diagnostics tell us that inflows are important to
  - Volumetric turnover - dominates evaporation and direct rainfall
  - Heat delivery - but that atmospheric heating dominates
  - Oxygen delivery – especially since atmospheric oxygen delivery is negative
- Diagnostics tell us that Windermere is losing oxygen – more than 10% / month
  - Surface fluxes of oxygen are outwards due to very warm surface waters
  - Negative bottom fluxes of oxygen are critical to overall mass balance – enhanced by low DO conditions, which are in turn related to stratification

Case study

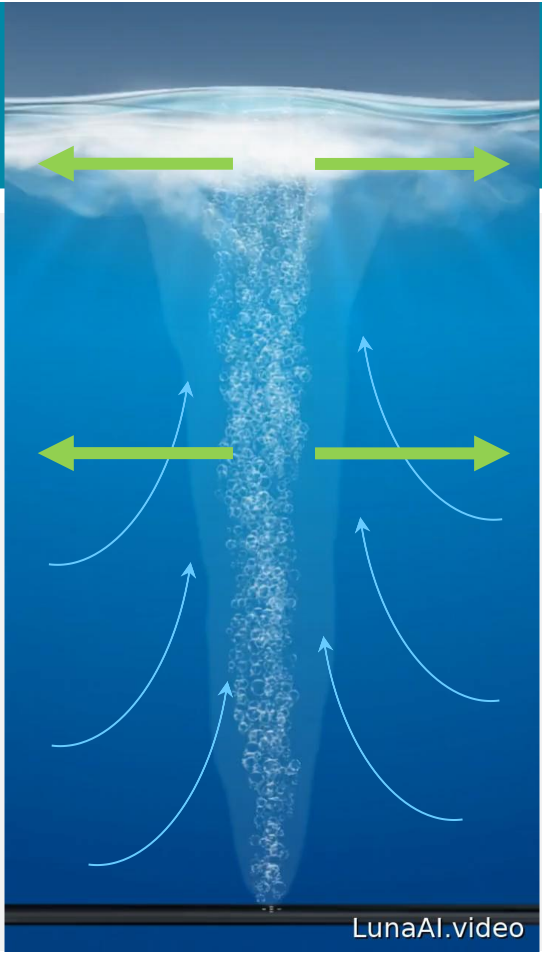
Windermere

- Controlling inflows is difficult
- Altering surface fluxes is within reach by dismantling the thermocline
  - Destratification
- Use the model to
  - Examine how fluxes (diagnostics) change, and therefore
  - Optimise destratification design (and cost)

Case study

Windermere

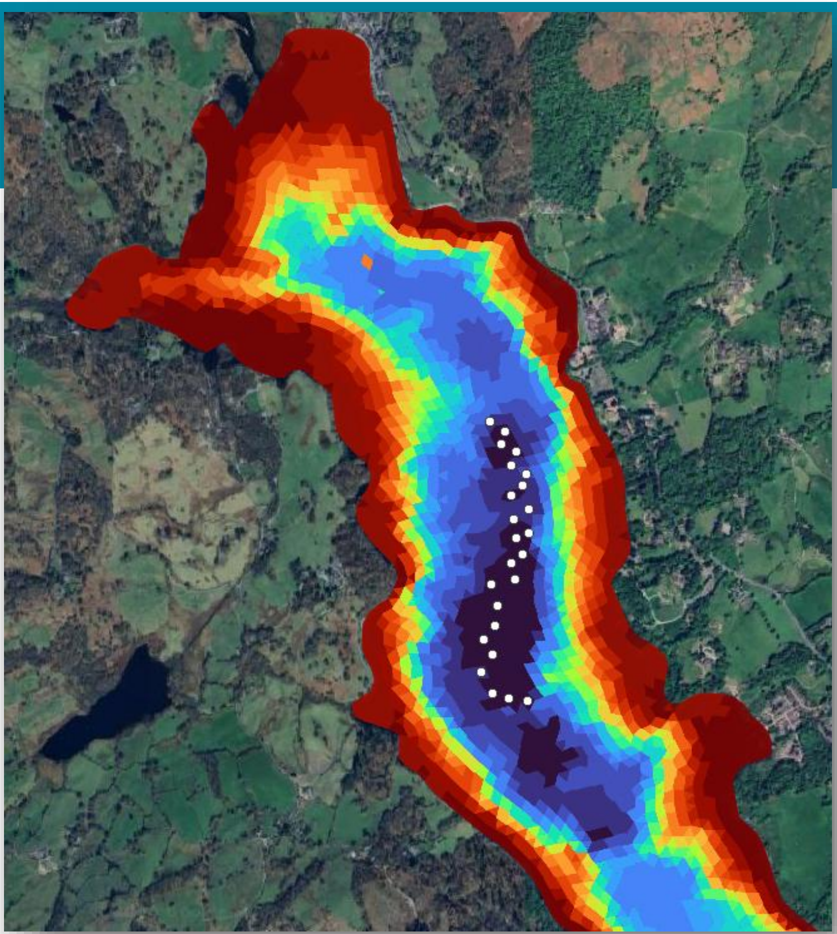
- Destratification via bubble plumes
  - Land based air compressor delivers air to depth
  - Bottom mounted perforated pipe
  - Upwards moving bubble plumes entrain and detrain as they rise
  - Mix bottom waters upwards and destratify
- But…
  - How much air (and how much cost)?
  - Diagnostics will help!

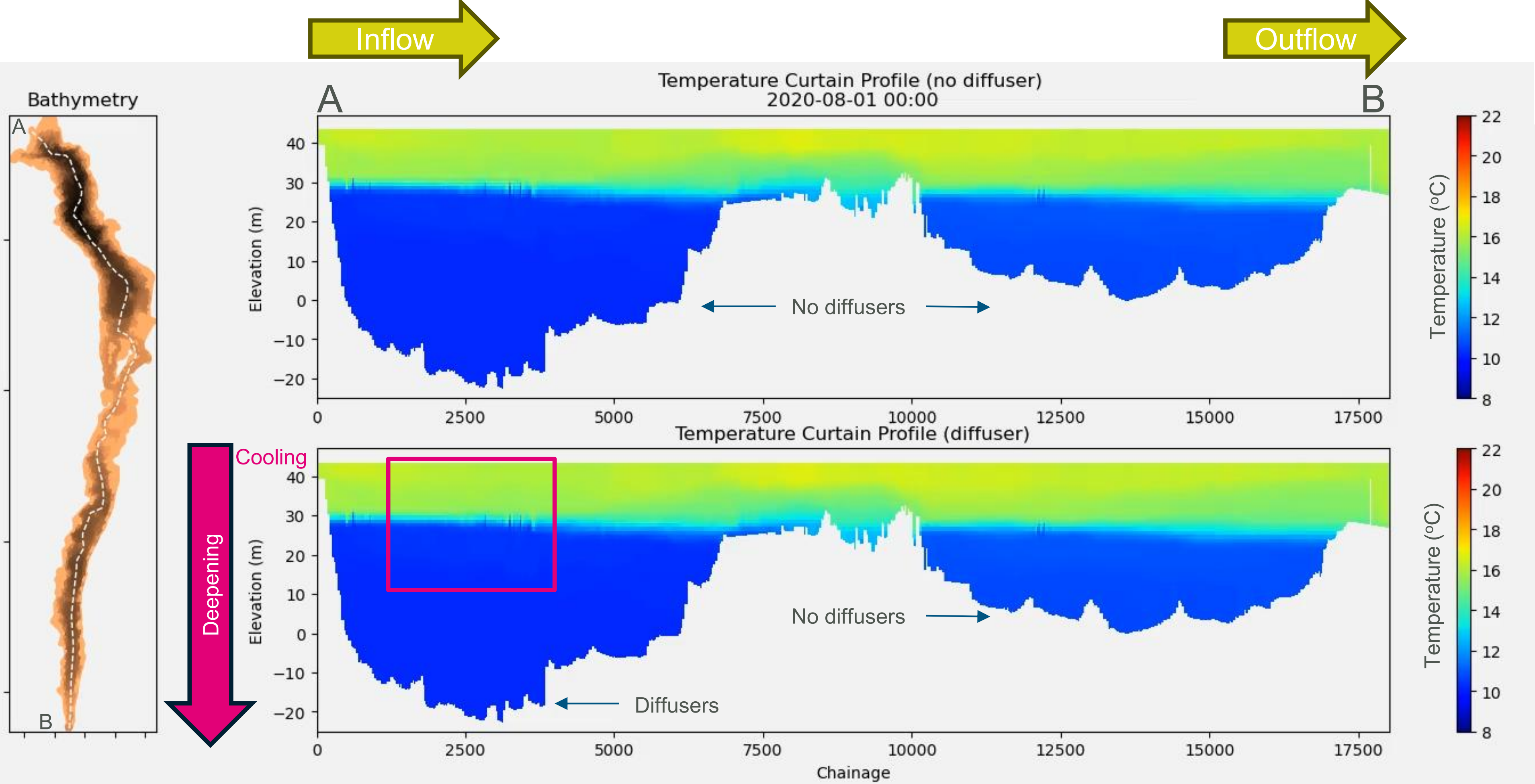


Case study

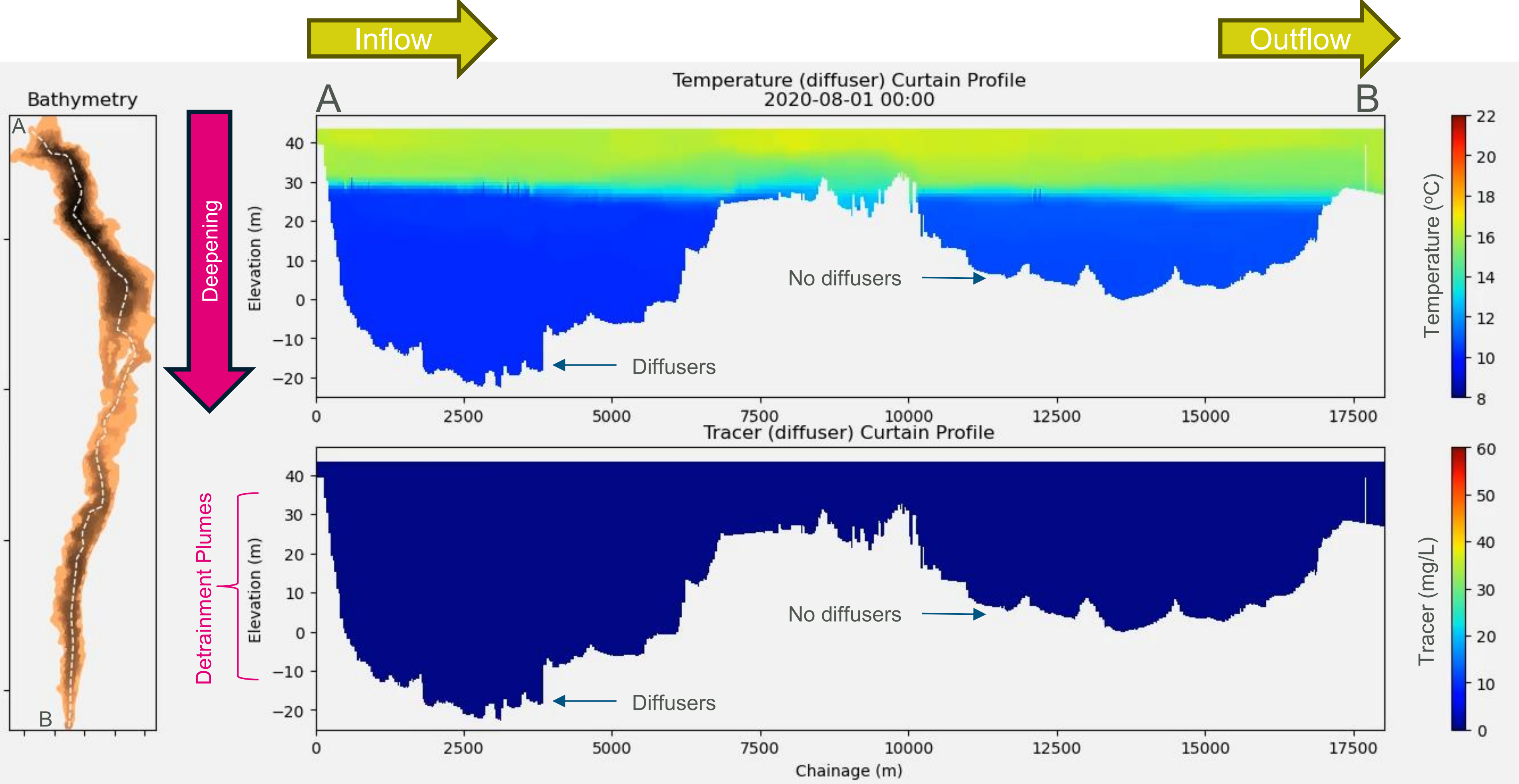
Windermere

- Destratification via bubble plumes
  - Added 192 ports
  - 1 L/s per port (at depth – 6 L/s at surface)
- Rerun model

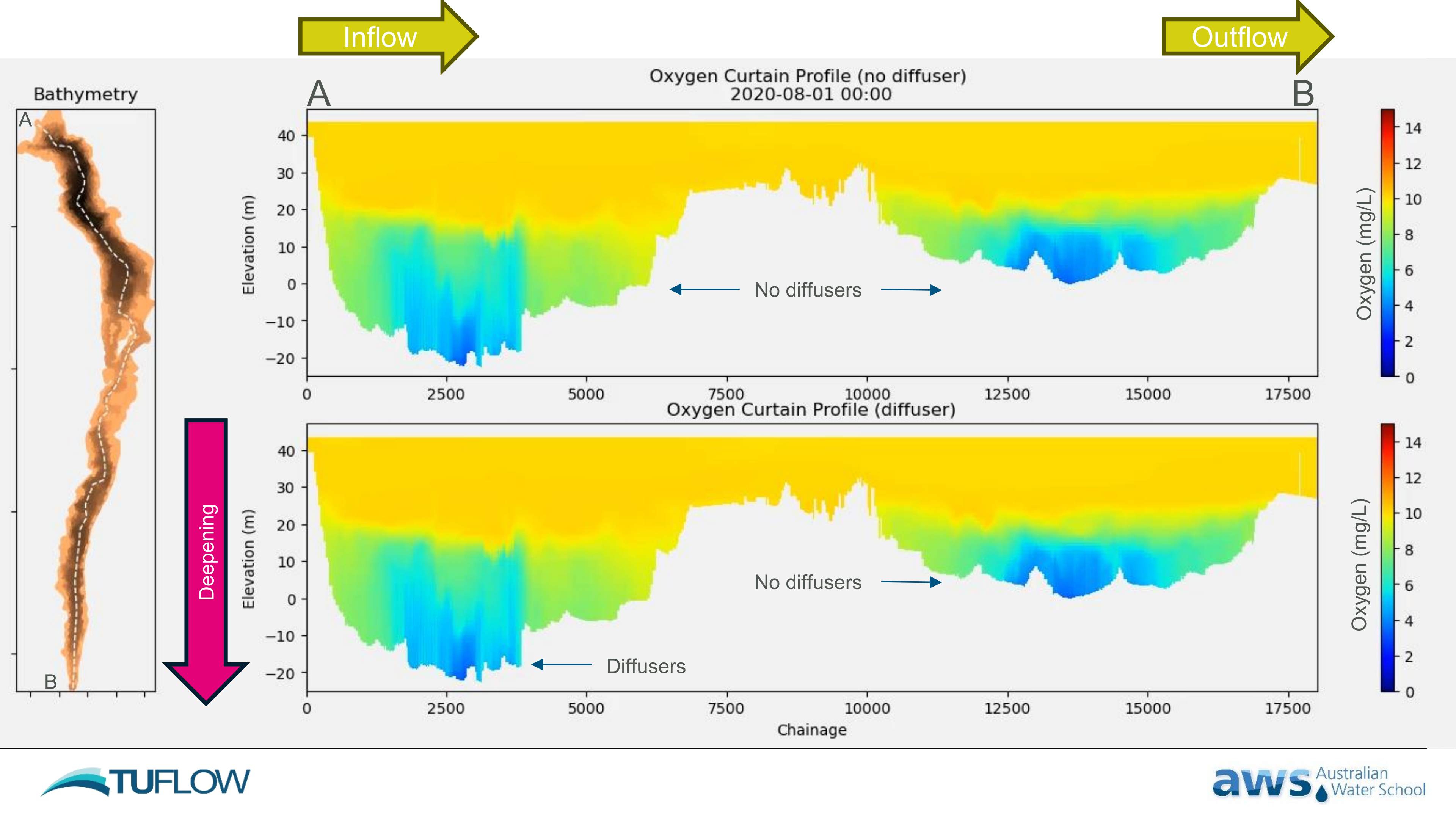




Inflow
Outflow
Bathymetry
A
B
Temperature Curtain Profile (no diffuser)
2020-08-01 00:00
Elevation (m)
No diffusers
Temperature (°C)
Temperature Curtain Profile (diffuser)
Cooling
Deepening
No diffusers
Diffusers
Chainage



Inflow
Outflow
Bathymetry
A
B
Deepening
Detrainment Plumes
Temperature (diffuser) Curtain Profile
2020-08-01 00:00
A
B
Elevation (m)
No diffusers
Diffusers
Temperature (°C)
Tracer (diffuser) Curtain Profile
Elevation (m)
No diffusers
Diffusers
Chainage (m)
Tracer (mg/L)


Inflow
Outflow
Bathymetry
A
B
Deepening
Oxygen Curtain Profile (no diffuser)
2020-08-01 00:00
Elevation (m)
No diffusers
Oxygen (mg/L)
Oxygen Curtain Profile (diffuser)
No diffusers
Diffusers
Chainage
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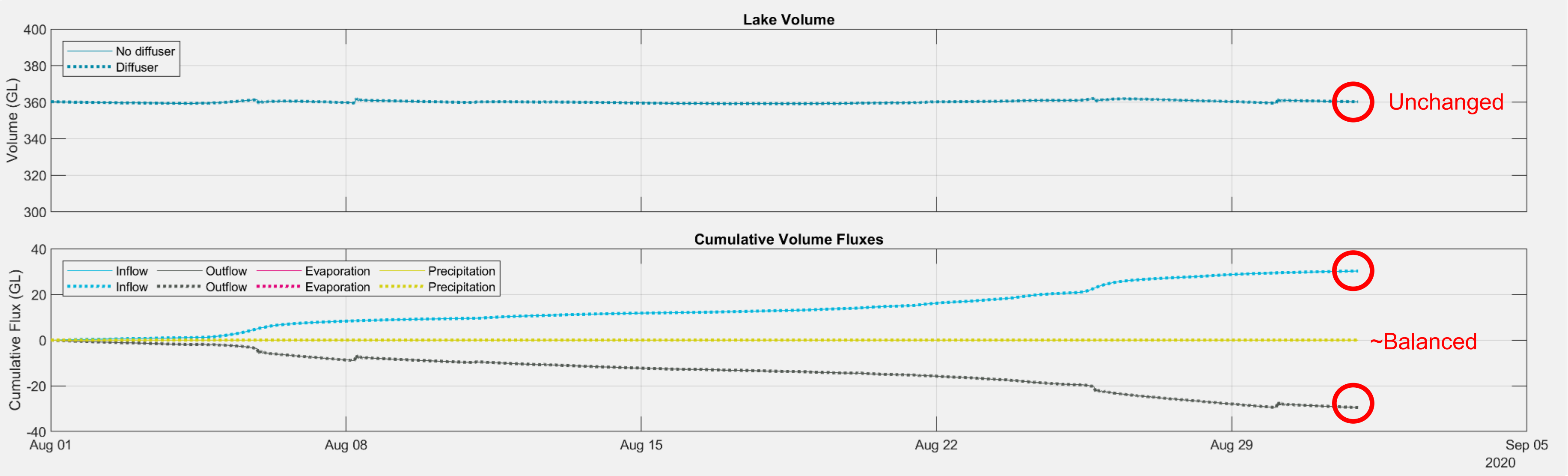
Case study

Windermere – volume diagnostics



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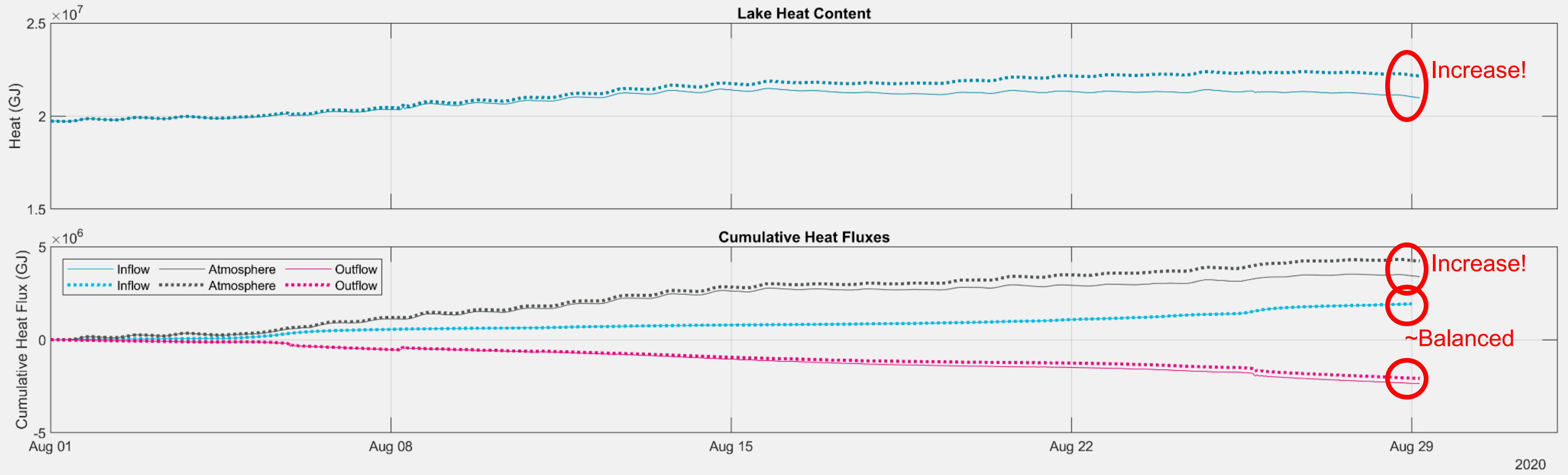
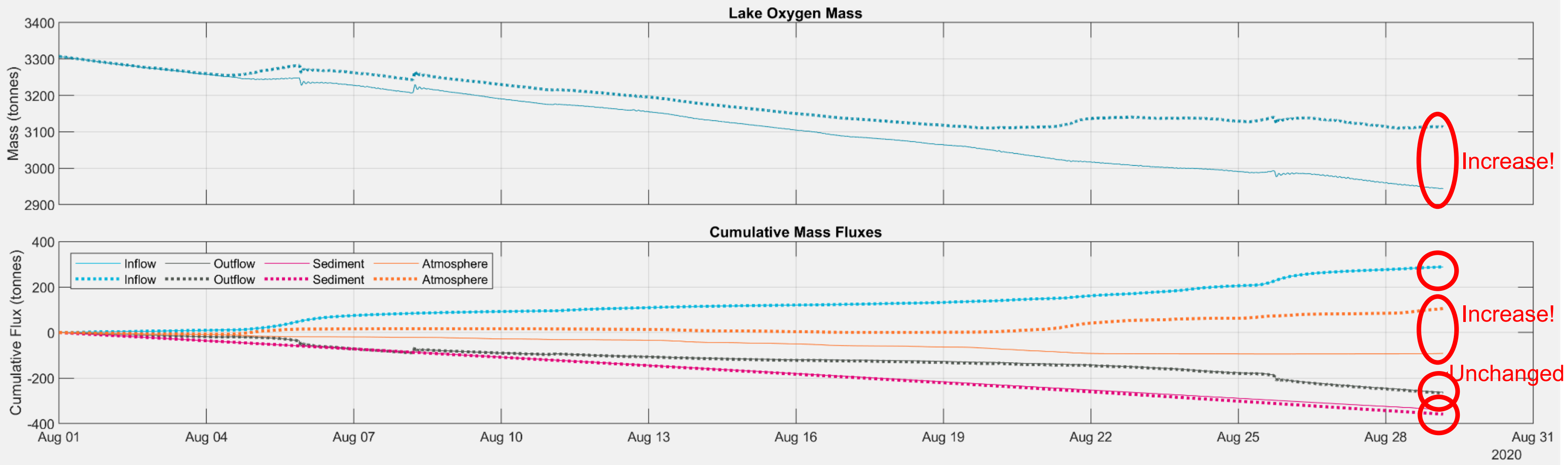
Case study

Windermere – heat diagnostics (note different vertical axes)



Case study

Windermere – oxygen fluxes



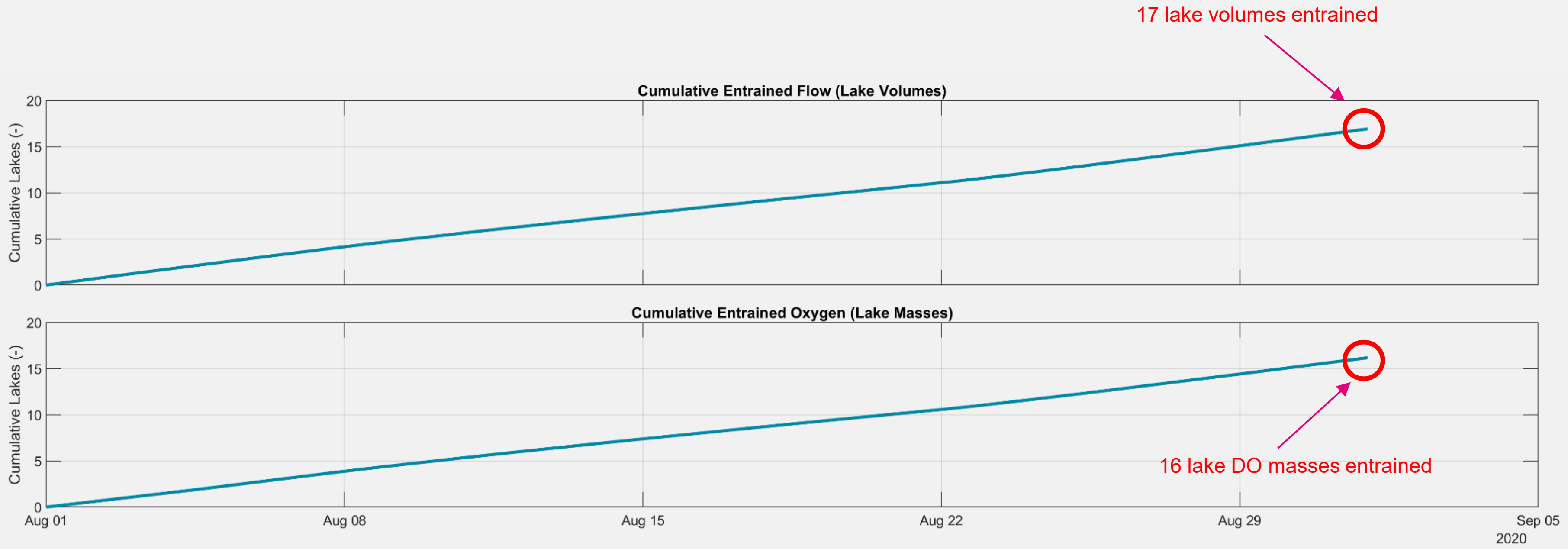
Case study

Windermere

- Destratification works, but are we over-blowing?
- Look at a new suite of diagnostics: bubble plume entrainment rates
  - Water
  - Oxygen

Case study

Windermere – bubble plume diagnostics



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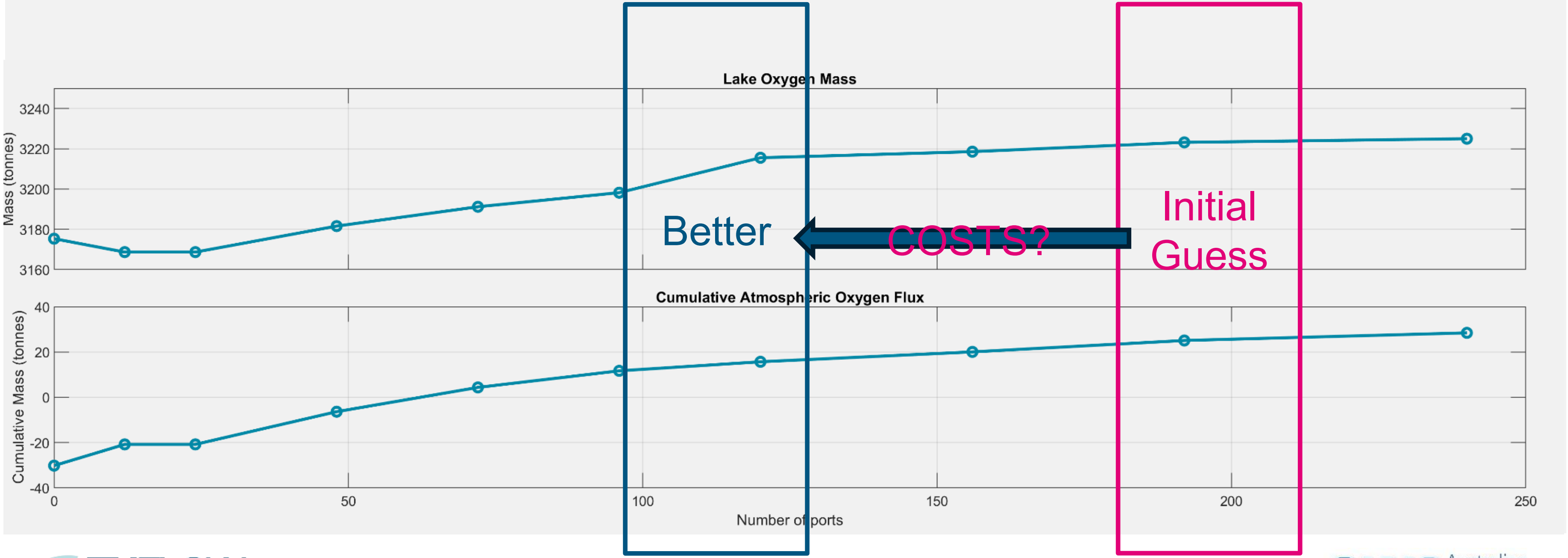
Case study

Windermere

- Seems like a large volume / mass?
- Ran several simulations with different bubble plume port numbers
  - 12 to 240 (initial guess was 192)
  - Same flow rate per port
- Examined lake oxygen masses and cumulative atmospheric mass fluxes

Case study

Windermere – oxygen diagnostics vs diffuser port



Understanding the why

Understanding the why

Windermere

- Diagnostics helped us understand
  - Inflows are a key source of oxygen in the current conditions (what might happen to the lake under extended drought conditions?)
  - How surface fluxes and oxygen masses changed with number of ports
  - That we were overcapitalising (by a lot)
- Simply looking at water levels, temperatures and dissolved oxygen concentrations is of limited use in this case
- Seek to understand ‘why’ can save a lot of time and money!

Questions?