SLIM 3D: an advanced numerical model for geophysical and environmental flows

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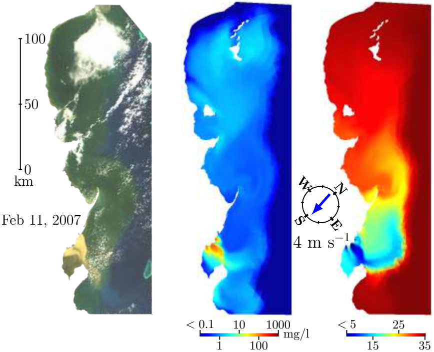

Puerto Chacabuco, Chile – October 11th, 2017

Personal background

PhD: Université catholique de Louvain, Belgium

- Numerical modelling:
  Development of SLIM 3D
- Geophysical and environmental applications

Post-doc: Utrecht University, the Netherlands

- Numerical modelling:
  Development of Parcels
- Tracking plastic litter in the ocean

Geophysical and environmental flows

www.gsfc.nasa.gov

Geophysical and environmental flows

Coastal seas

- 8% of ocean surface
- $<$ 1% ocean volume
- Very active biologically
- $\sim$ 60% of world population lives $<$ 60 km of the coast !

Numerical modelling of geophysical and environmental flows

- Sediment
- Coral larvae, turtle hatchlings, plastic debris
- Tides, storm surge
- Salmon farming

www.math.mit.edu

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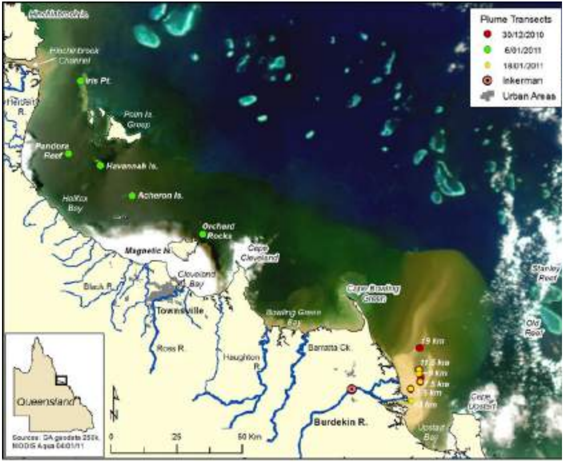

[Bainbridge et al., 2012]

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www.oceanservice.noaa.gov

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www.howtoconserve.org

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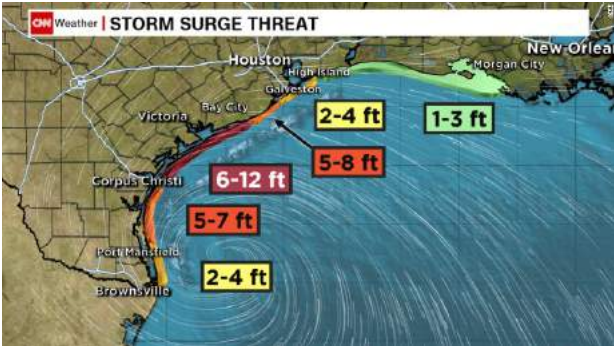

www.edition.cnn.com

Numerical modelling of geophysical and environmental flows

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www.csiro.au

Numerical modelling of geophysical and environmental flows

- Sediment
- Coral larvae, turtle hatchlings, plastic debris
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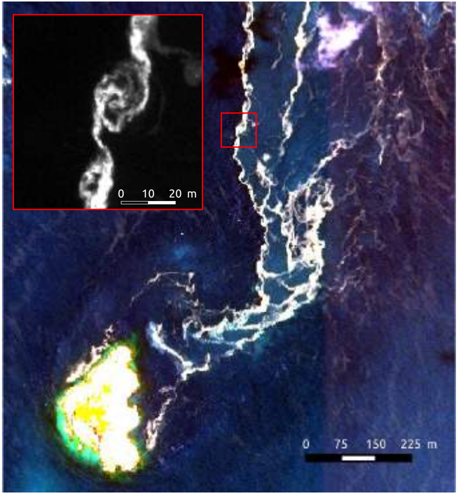
- But it's complex !



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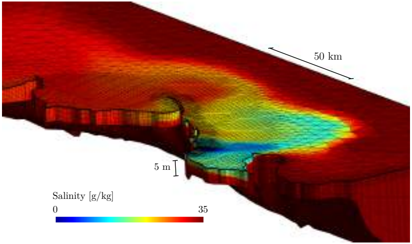
SLIM

Adaptive meshes
Lake Tanganyika

Sediment transport
Burdekin River



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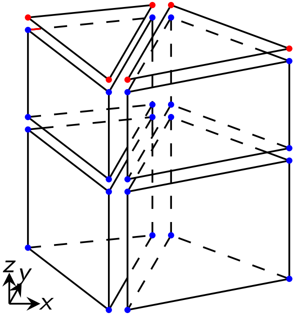
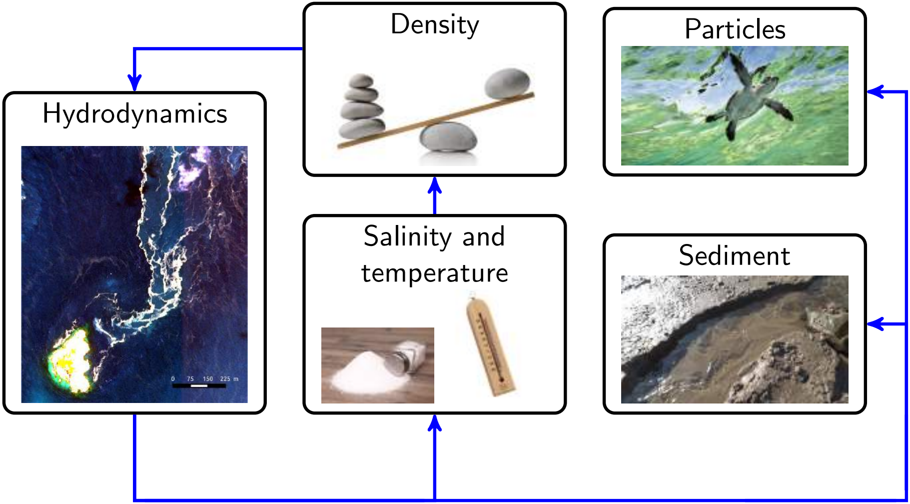
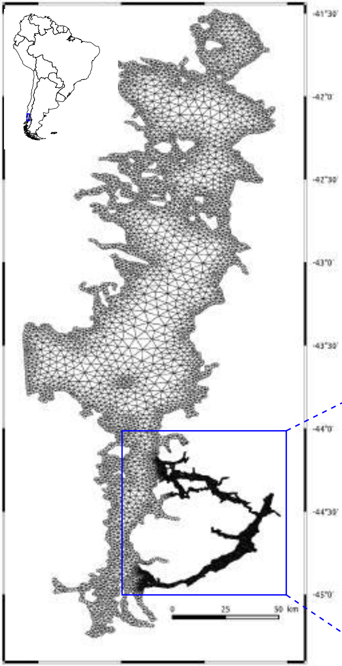


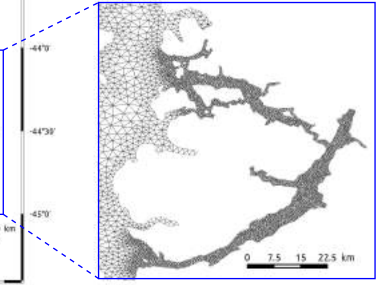
SLIM, the Second-generation Louvain-la-Neuve Ice-ocean Model



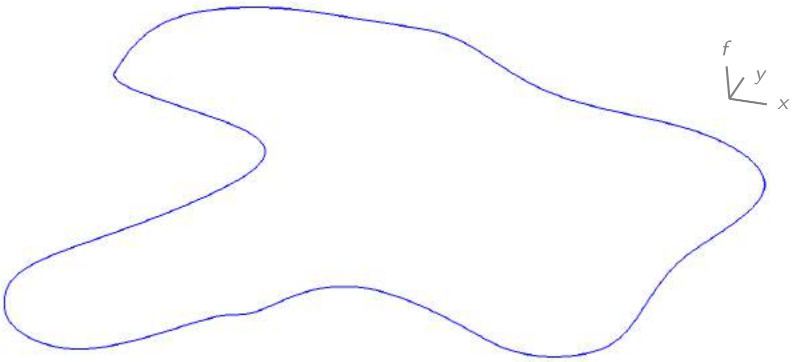


Spatial discretisation

- Unstructured meshes
- Finite element method:
  discontinuous Galerkin (DG) formulation



Approximation on unstructured meshes



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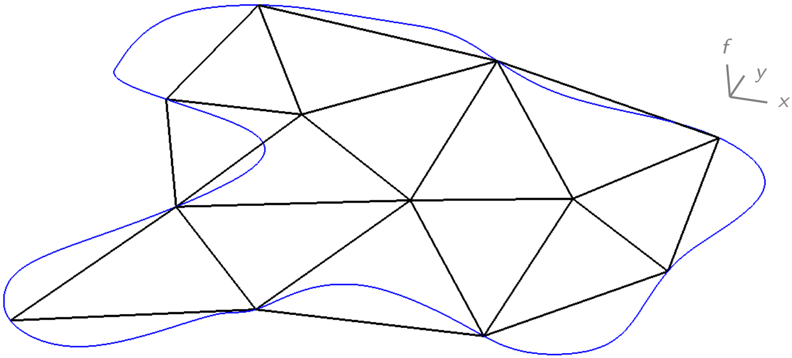

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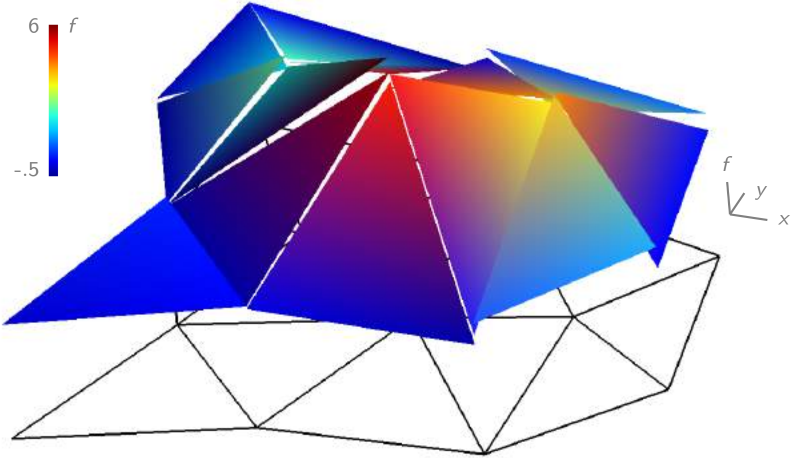
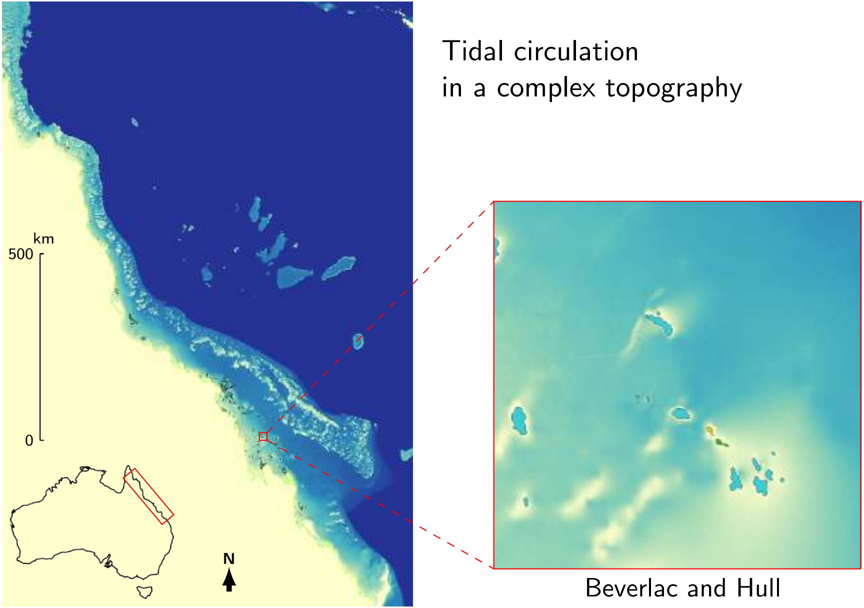


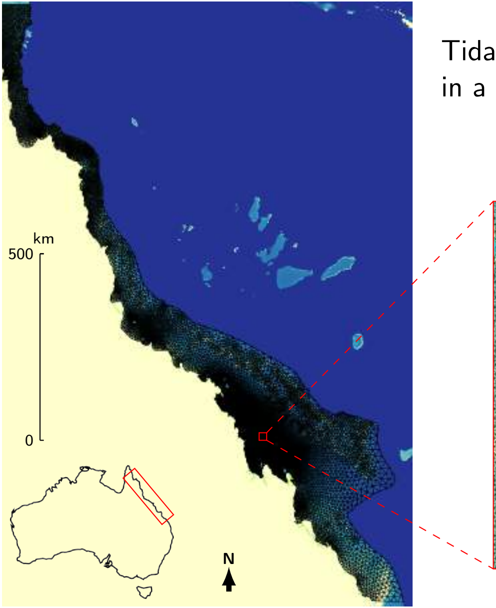
The Great Barrier Reef, Australia

Tidal circulation
in a complex topography



Beverlac and Hull

The Great Barrier Reef, Australia



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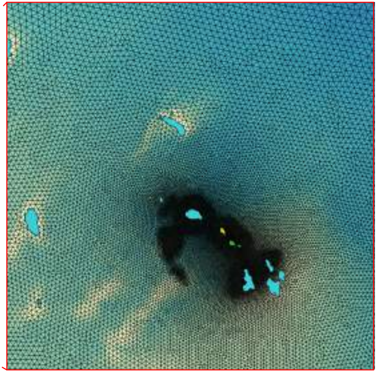
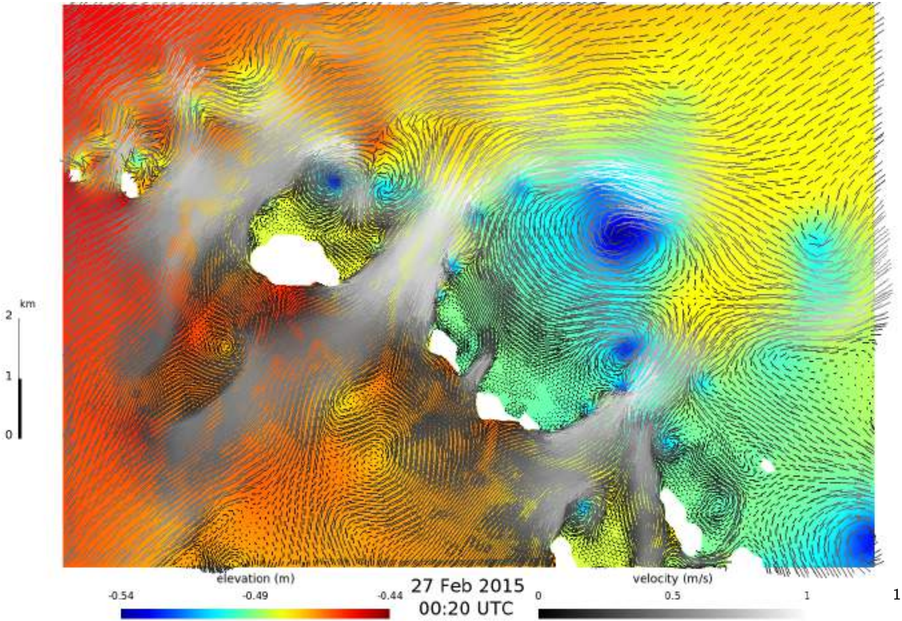


Beverlac and Hull

Tidal generated eddies



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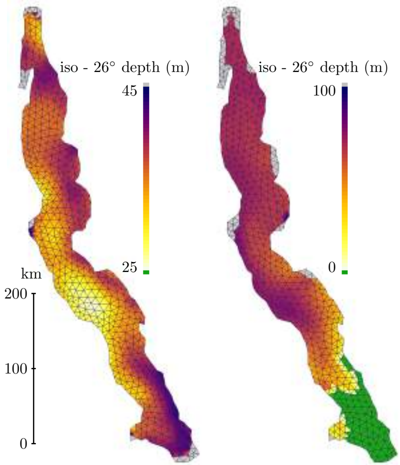
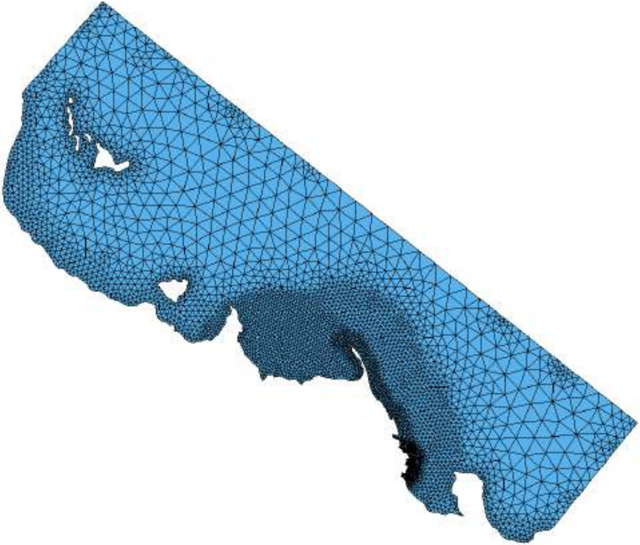


Delandmeter et al., 2017, A fully consistent and conservative vertically adaptive coordinate system for SLIM 3D, a DG finite element hydrodynamic model, with an application to the thermocline oscillations of Lake Tanganyika, *Geoscientific Model Development*, (submitted)

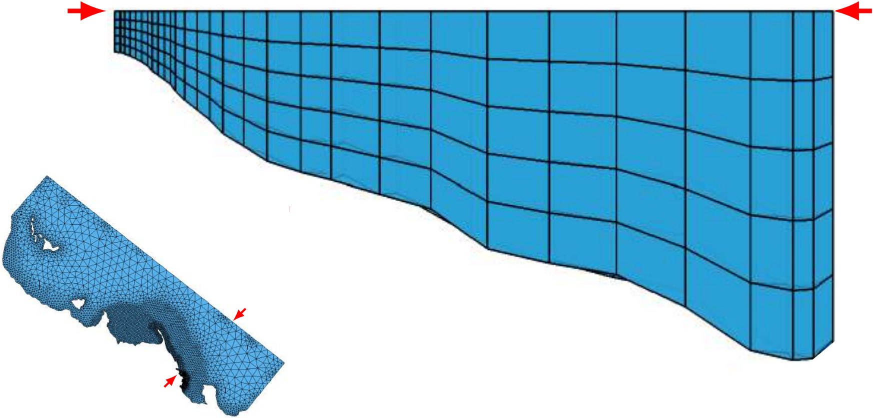
Vertical discretisation

- Unstructured horizontally



Vertical discretisation

- Unstructured horizontally
- Structured vertically



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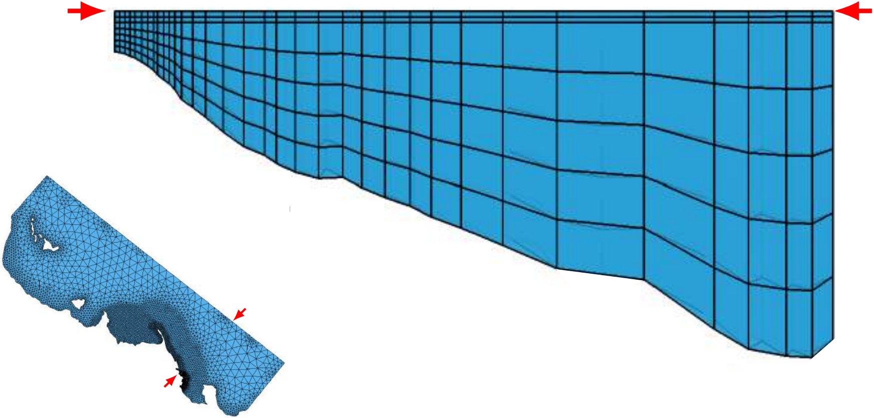
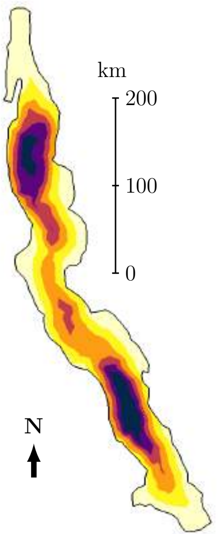
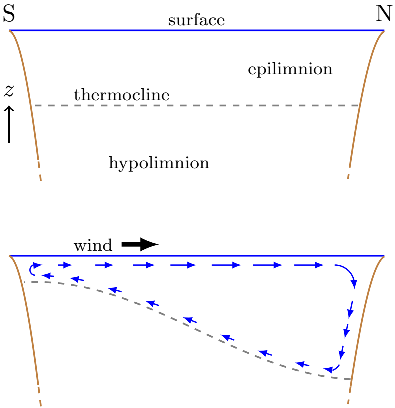


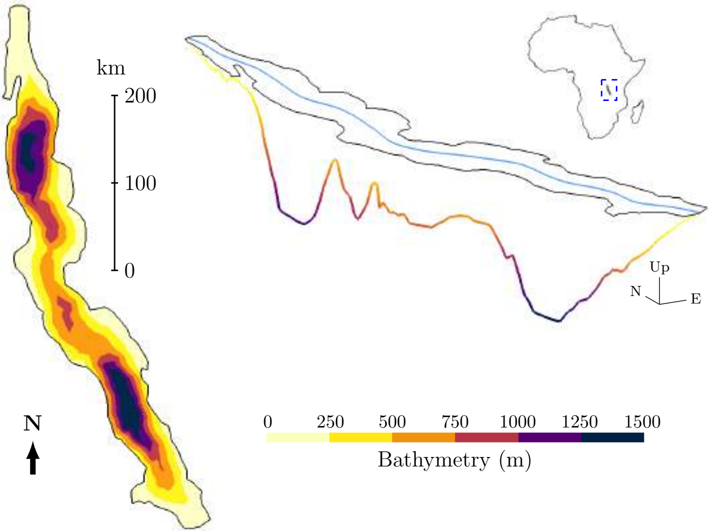
Lake Tanganyika: thermocline oscillations



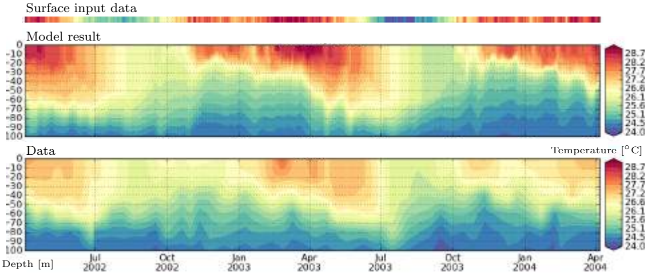


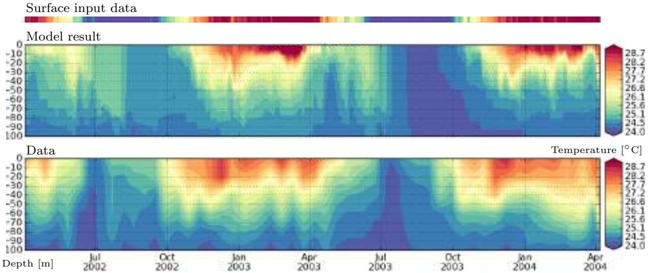
[adapted from Mortimer, 1961]

Lake Tanganyika: thermocline oscillations



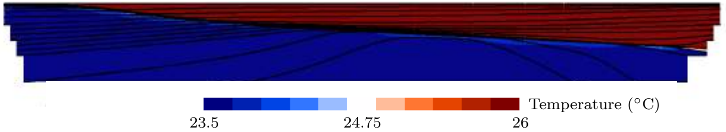
Temperature vertical profile





Modelling lake thermocline oscillations using adaptive meshes

- Main processes of Tanganyika dynamics reproduced by the model
- Surface heat fluxes
- Reduced computational cost



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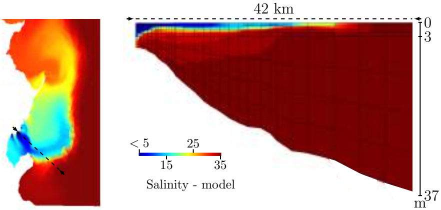
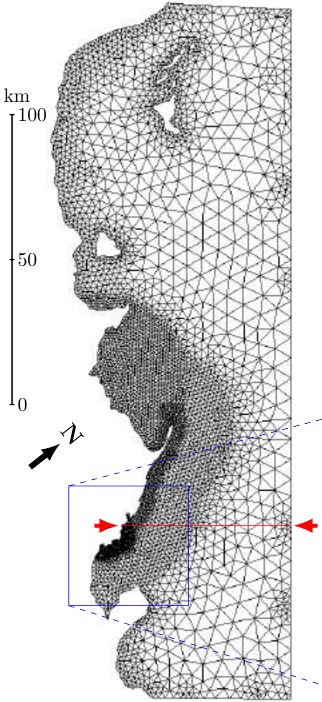


Delandmeter et al., 2015, The transport and fate of riverine fine sediment exported to a semi-open system, *Estuarine, Coastal and Shelf Science*, 67, 897 – 913

Modelling

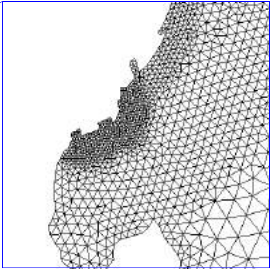


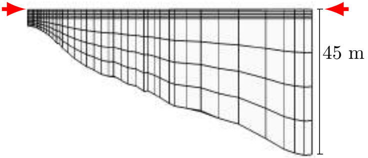
Numerics

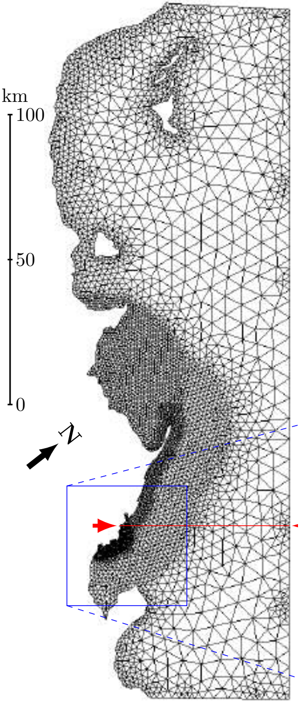
- ∼ 65,000 3D elements
- Simulation on 128 CPUs

Forcings

- Boundary conditions
- Surface wind stress
- River flow and concentrations







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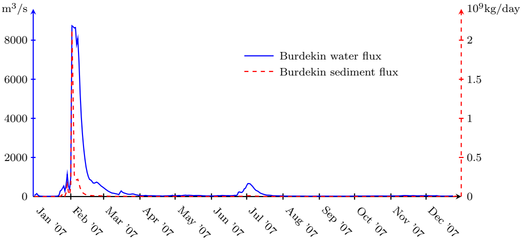
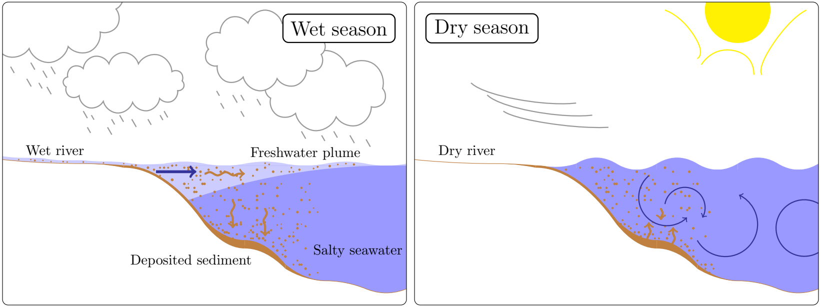


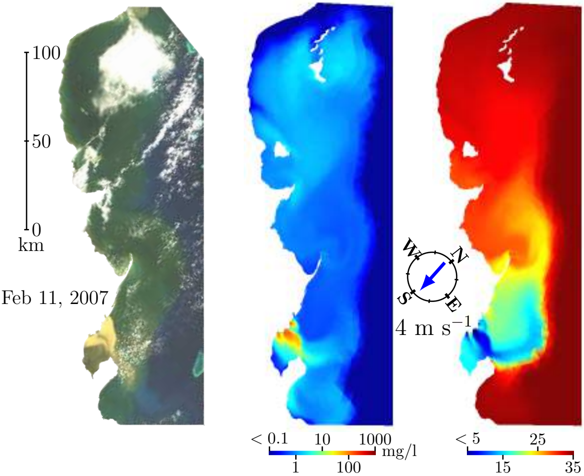
Sediment transport



- Sediment is a passive tracer
- Settling velocity is proportionnal to sediment concentration
- Resuspension due to entrainment
- Resuspension due to turbulent mixing

Model validation

- Satellite data (flood and dry seasons)
- Sea surface concentrations (flood season)



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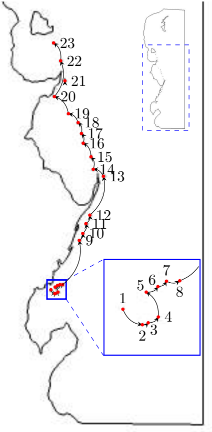
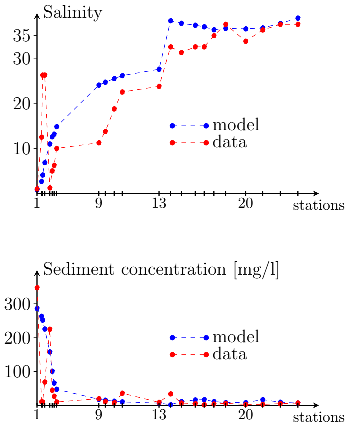
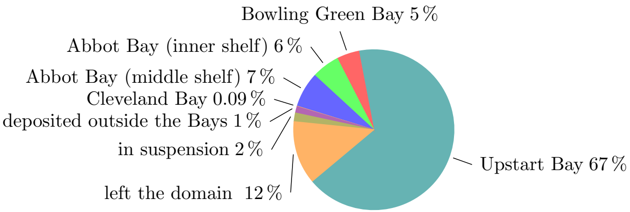
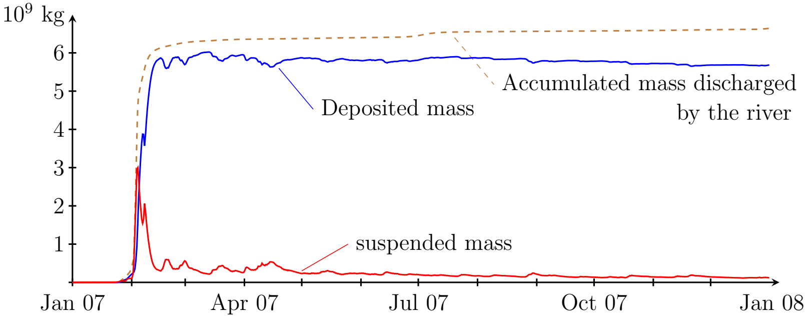


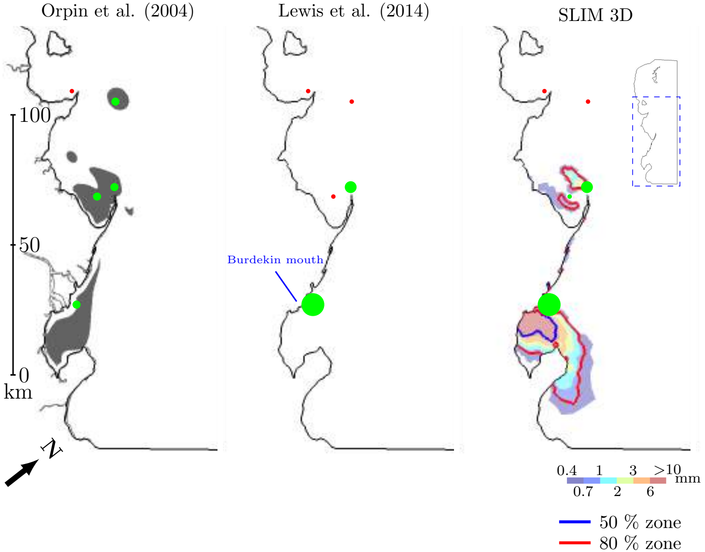


Results: Predicted annual budget



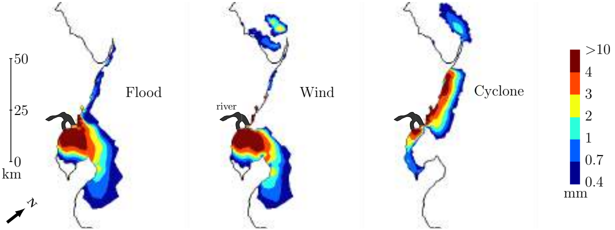


Results: sedimentation areas



Sediment transport into semi-open systems

- Semi-open systems trap most of the riverine sediment. ($\sim$ 67% for Burdekin River)
- Wind-driven resuspension events redistribute the sediment within an embayment.
- Fate of sediment is strongly related to wind conditions during flood event.



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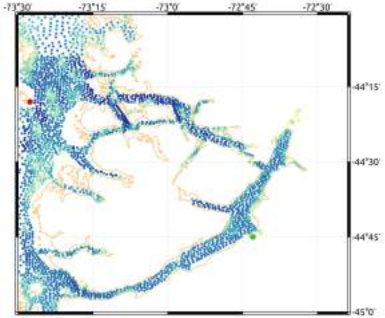
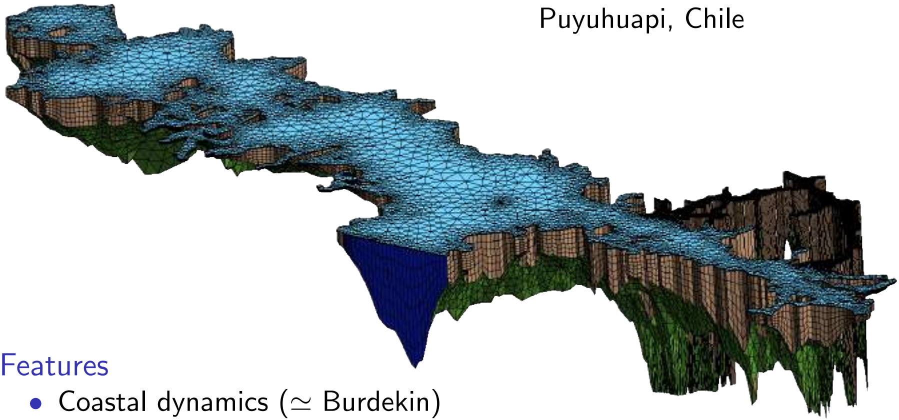


Puyuhuapi Channel

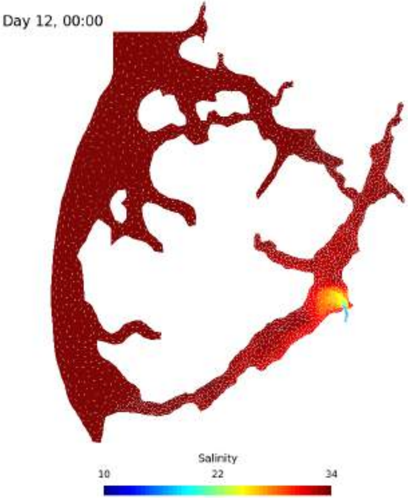


Puyuhuapi, Chile

Features

- Coastal dynamics ($\simeq$ Burdekin)
- Surface heat fluxes ($\simeq$ Tanganyika)
- Sharp bathymetry ($\simeq$ Tanganyika)

Modelling fjord and channel dynamics with SLIM 3D



- Unstructured mesh ideal for complex topography
- SLIM 3D used in river plume dynamics
- Easy plugin of ecological modules
- Open access – open source

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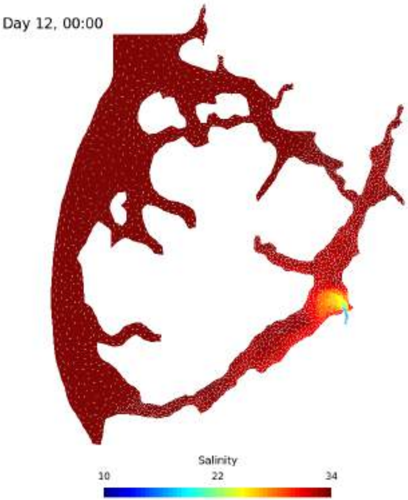

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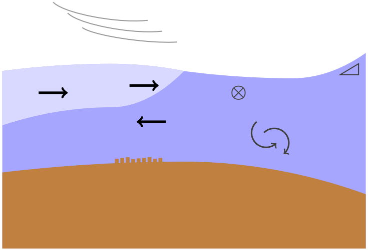
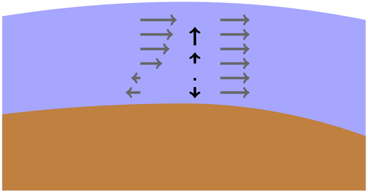
Thank you for your attention !

Hydrodynamics: the equations

Momentum conservation



Continuity



Hydrodynamics: the equations

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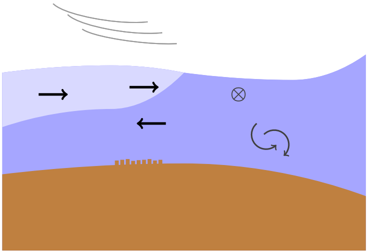

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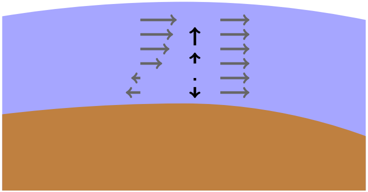
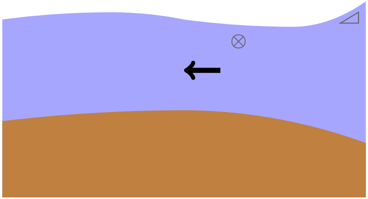
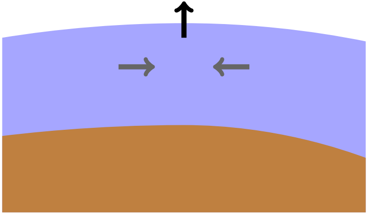


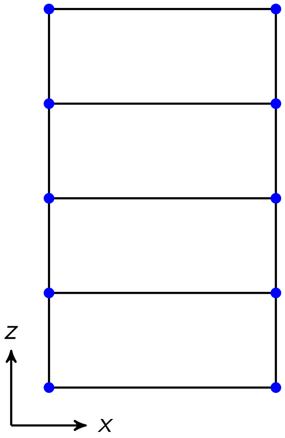
Momentum conservation 2D



Continuity 2D



Vertically adaptive meshes



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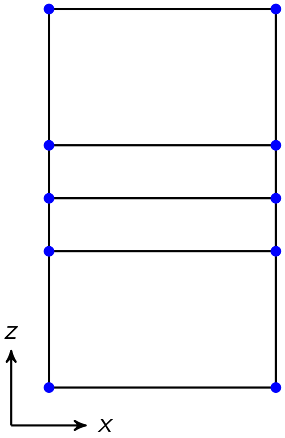

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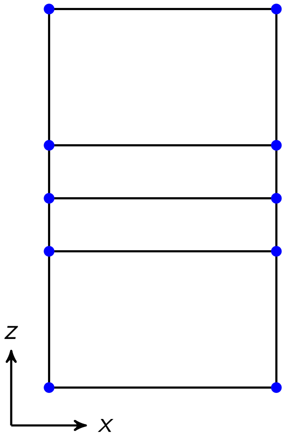
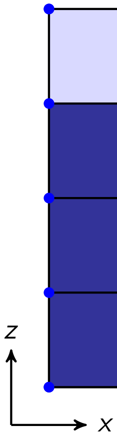


- Conservativity: Tracer total mass is conserved
- Consistency: Constant tracer is conserved

Vertically adaptive meshes



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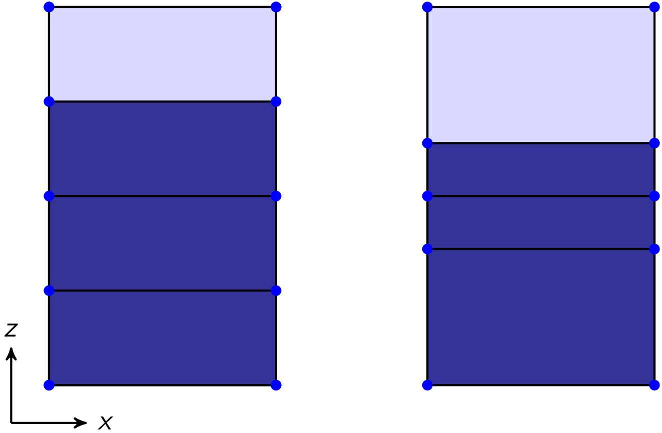

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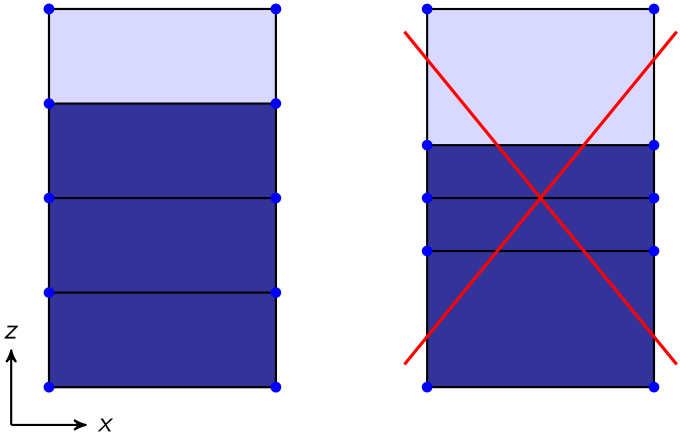

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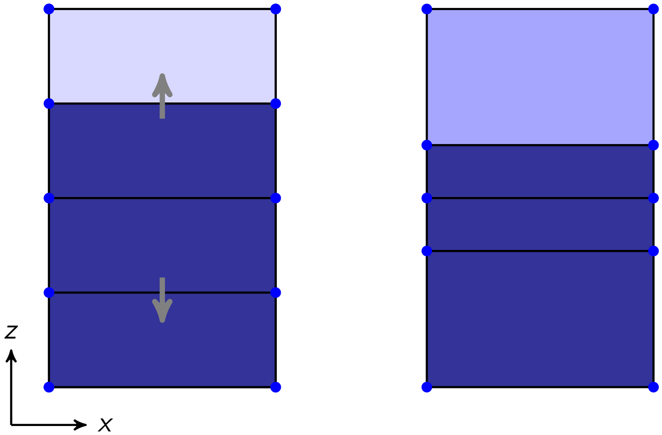

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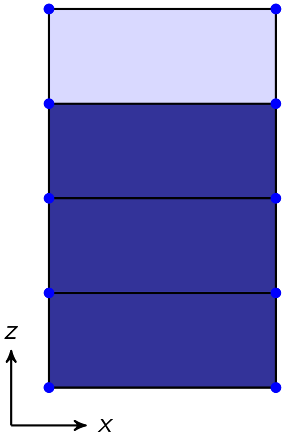
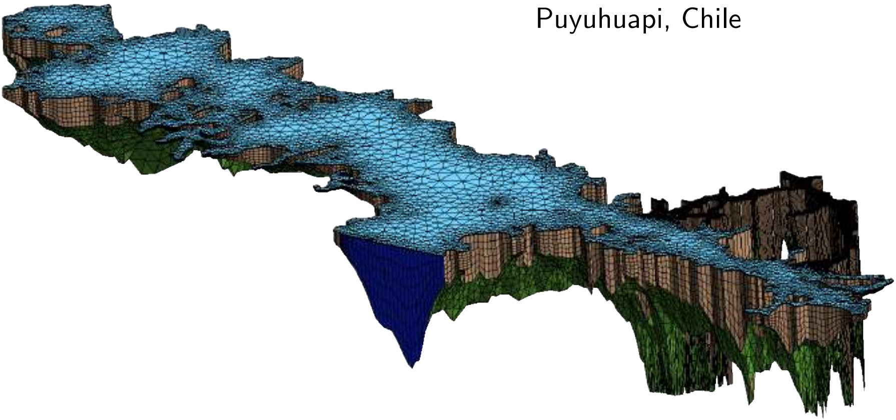


- Coherence between the discrete formulation of moving mesh, continuity and tracer equations

Vertical discretisation (2)



Puyuhuapi, Chile

Number of levels: constant

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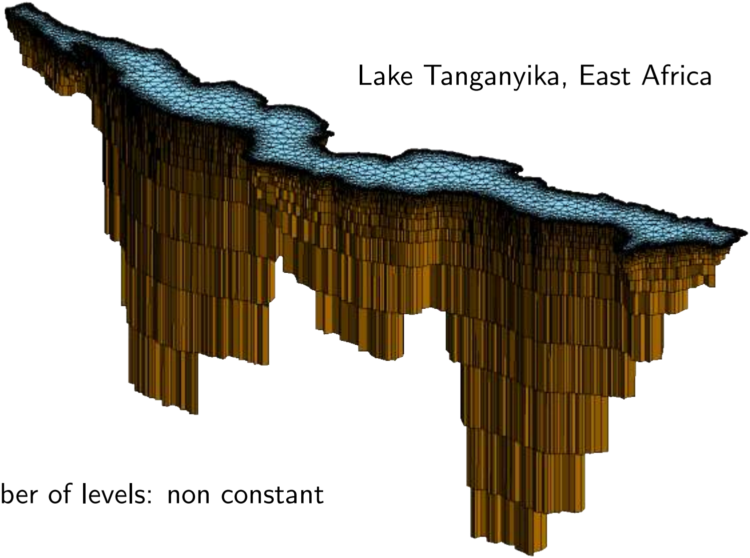
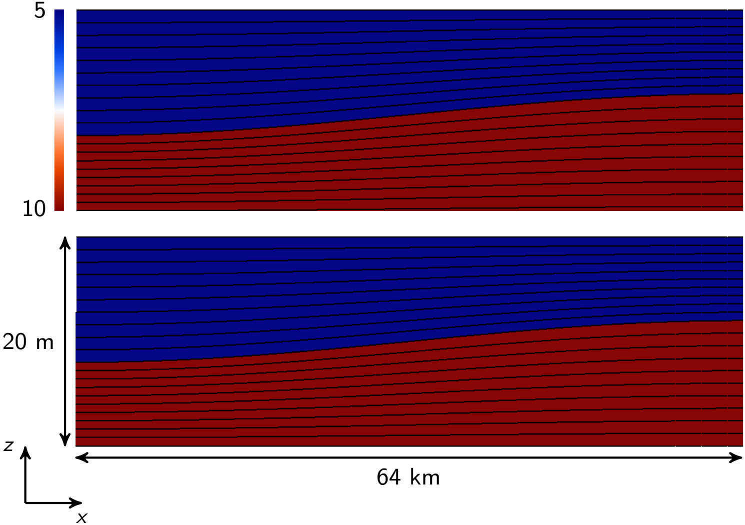


Lake Tanganyika, East Africa

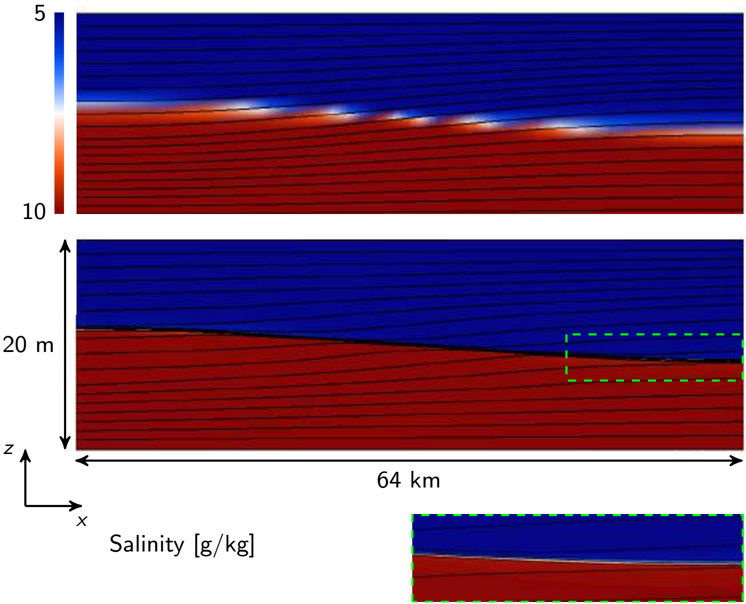
Number of levels: non constant

Internal seiche (initial condition)



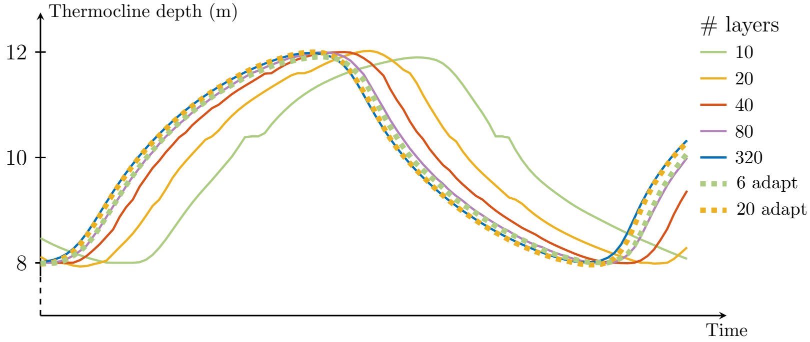
Salinity [g/kg]

Internal seiche (after half an oscillation)



Salinity [g/kg]

Convergence analysis



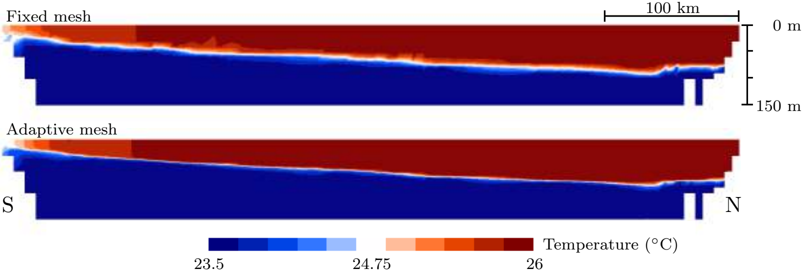
Adaptive mesh efficiency

- Speed-up of 16 for similar accuracy
- Minimal number of levels: 6

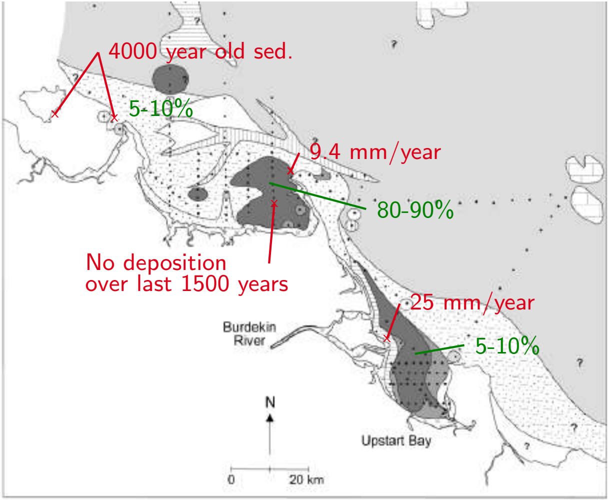
Lake Tanganyika: thermocline oscillations

Preliminary simulation

- Uniform wind
- No vertical diffusivity



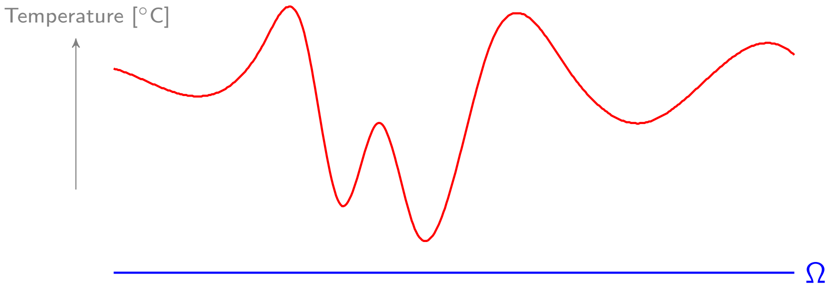
Burdekin River sediment



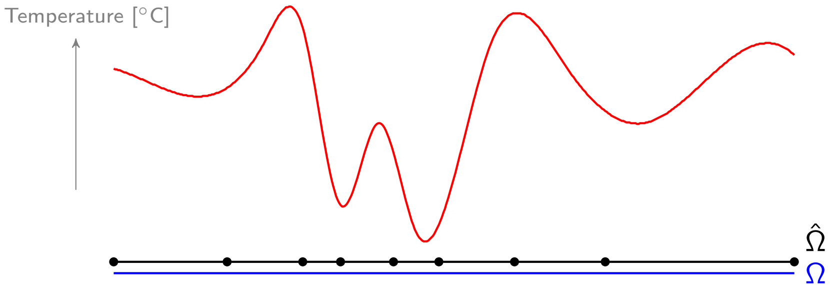
[Orpin et al., 2004] [Lewis et al., 2014]

Where does the sediment end up ?

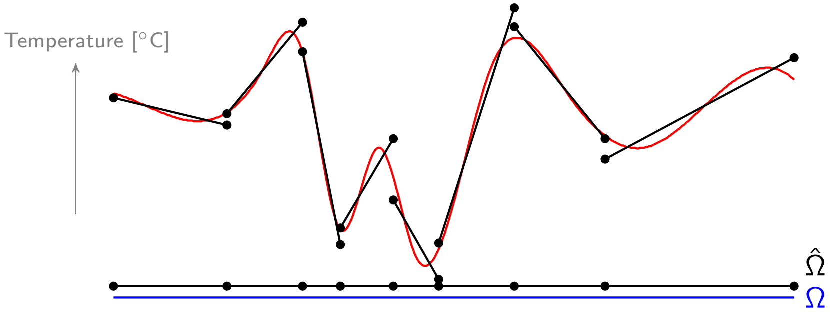
Unstructured meshes: 1D example



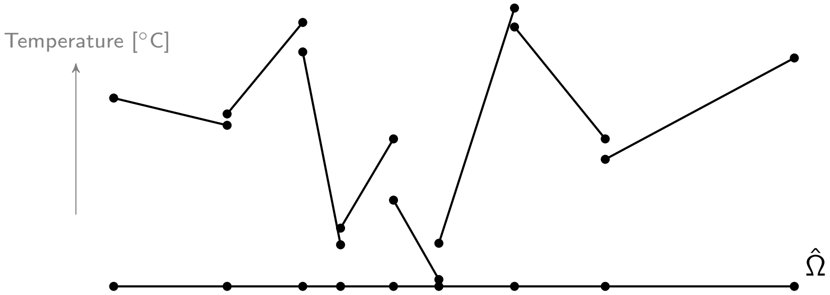
Unstructured meshes: 1D example



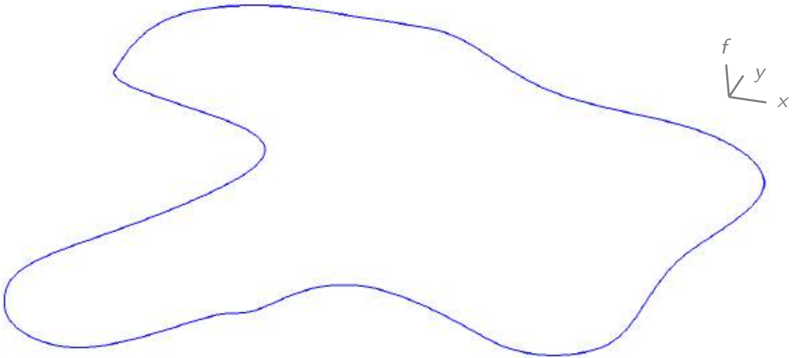
Unstructured meshes: 1D example



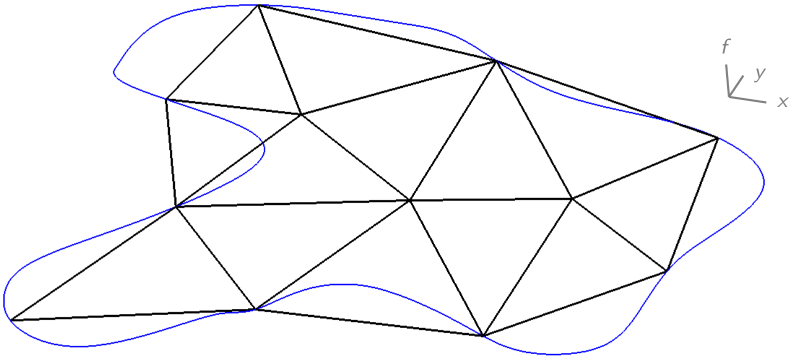
Unstructured meshes: 1D example



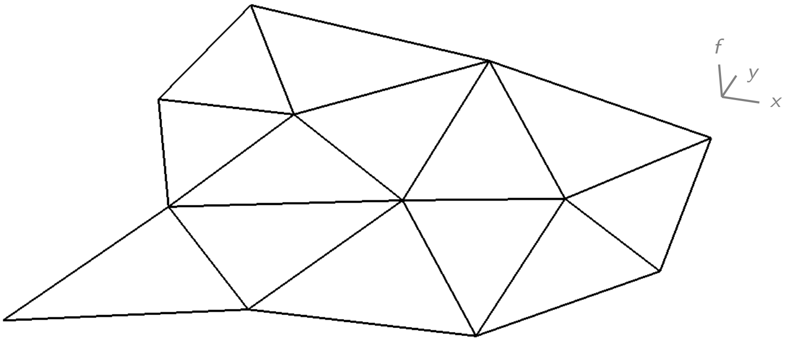
Unstructured meshes: 2D example



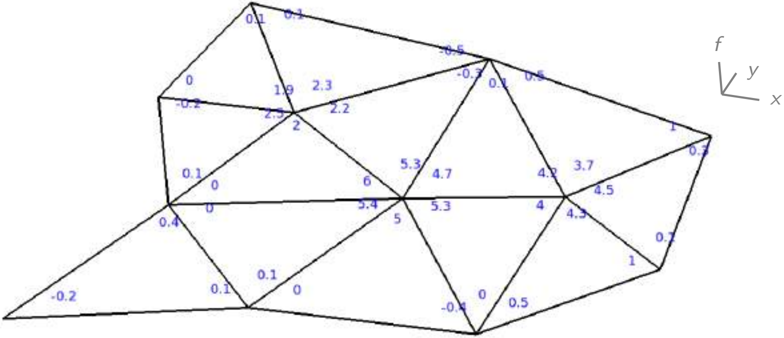
Unstructured meshes: 2D example



Unstructured meshes: 2D example



Unstructured meshes: 2D example



Unstructured meshes: 2D example