A 3D baroclinic model of the Burdekin River Plume, Australia

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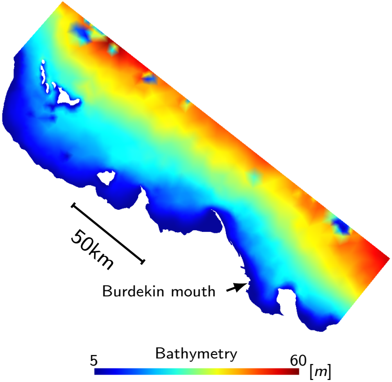
The problem

Goal : Understanding the key proccesses controlling the fate of sediment exported by the Burdekin River to the Great Barrier Reef [Lewis et al., 2014]



⇒ 3D modelling

SLIM 3D : a baroclinic dg-finite element model

Second-generation Louvain-la-Neuve Ice-ocean Model[1]

- Spatial features
  - P_1 dg-finite element discretisation
  - prismatic elements
  - ALE formulation on a moving mesh

- Time discretisation
  - split-explicit approach
  - implicit vertical diffusion on every column

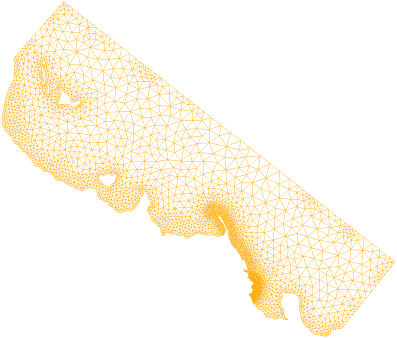
[Kärnä et al., 2013]

[1] www.climate.be/slim

Applying SLIM 3D to the Burdekin River Plume dynamics

- Until now:
  - Square boxes geometry
  - flat or linear bathymetry

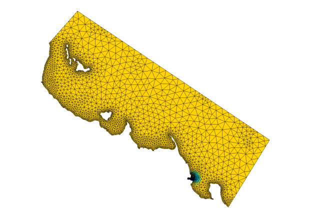
- The Challenge:
  - Complex geometry
  - Complex bathymetry
  - Actual forcings

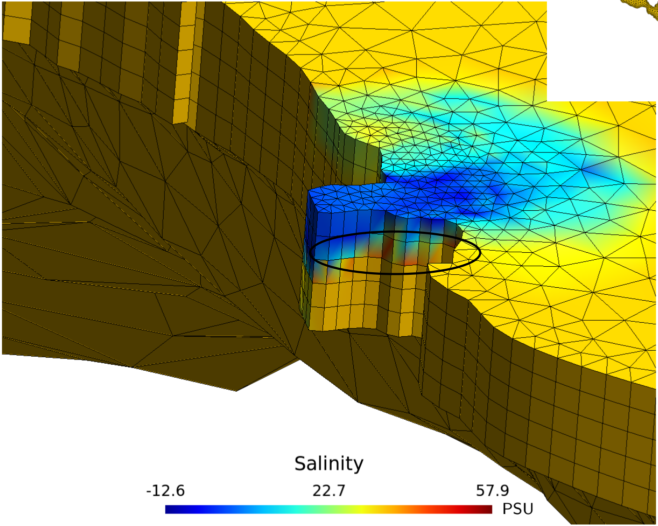


Mesh generated with Gmsh Software[2]

[2] www.geuz.org/gmsh

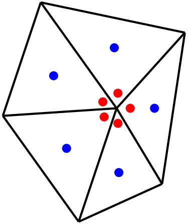
Overshoot problems





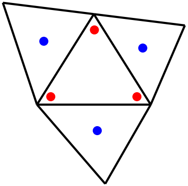
Limiters are necessary !

- Kuzmin [2010], Aizinger [2011]



- dg nodes
- P_0 values

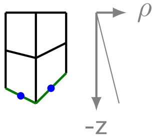
- Cockburn and Shu [1998]



Limiter issues

No more overshoots, but it has a cost:

- Invalid lake at rest for a stratified water column.
  ⇒ Choose boundary condition for limiter



- Constant fields on an element where strong gradients appear
  ⇒ Loss of precision. ⇒ Adaptive mesh
- This can lead to non-physical behaviour for σ-layers.
  ⇒ Constant depth for upper layers

Moving mesh difficulties

- ALE formulation:

$$\frac{\partial T}{\partial t} + T\frac{\partial w_m}{\partial z} + \boldsymbol{\nabla}_h \cdot (\mathbf{u}T) + \frac{\partial\big((w - w_m)T\big)}{\partial z} = \mathbf{D}$$

- Moving mesh algorithm:

$$z = -h + \big(h + \eta\big)\frac{z_0 + h}{h}, \qquad z_0 \in [-h, 0]\,, z \in [-h, \eta]$$

$$\Rightarrow \begin{cases} w_m & = w_{m,\text{surf}}\frac{z_0+h}{h} \\ \frac{\partial w_m}{\partial z} & = \frac{w_{m,\text{surf}}}{h+\eta} \end{cases}$$

- w_m and $\partial w_m/\partial z$ must match perfectly !

Moving mesh difficulties (2)

$$z = -h + \left(h + \eta\right)\frac{z_0 + h}{h}$$

- σ-layers mesh:

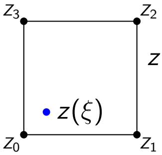
$$z_0 = -\alpha h, \qquad\qquad \alpha \in [0, 1]$$

$$\Rightarrow \begin{cases} w_m & = w_{m,\text{surf}}\frac{z_0+h}{h} = w_{m,\text{surf}}(1-\alpha) \\ \frac{\partial w_m}{\partial z} & = \frac{w_{m,\text{surf}}}{h+\eta} \end{cases}$$

- Constant depth for upper layers:

$$\Rightarrow \begin{cases} w_m & = w_{m,\text{surf}}\frac{z_0+h}{h} \quad = w_{m,\text{surf}}\frac{z+h}{h+\eta} \\ \frac{\partial w_m}{\partial z} & = \frac{w_{m,\text{surf}}}{h+\eta} \end{cases}$$

$$\frac{\partial}{\partial z}\left(w_m\right) = w_{m,\text{surf}}\frac{1}{h}\frac{\partial z_0}{\partial z} \neq \frac{w_{m,\text{surf}}}{h+\eta}$$



$$z(\xi) = \sum_i Z_i \phi_i(\xi)$$

Upper layers at constant depth

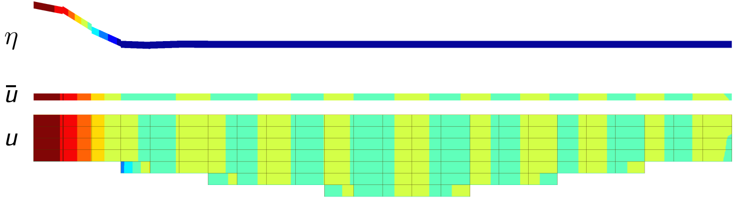
Salinity Profile

- 5 σ-layers mesh

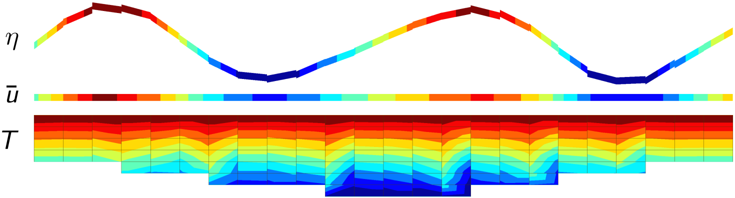
- 7 layers mesh: first two at constant depth, next 5 σ-layers

When z layers are needed..

- Shift on the entire column

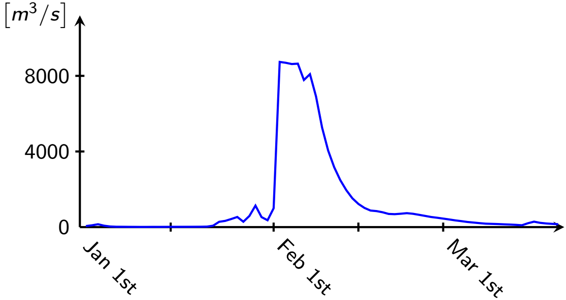


- No shift where vertical bottom boundary



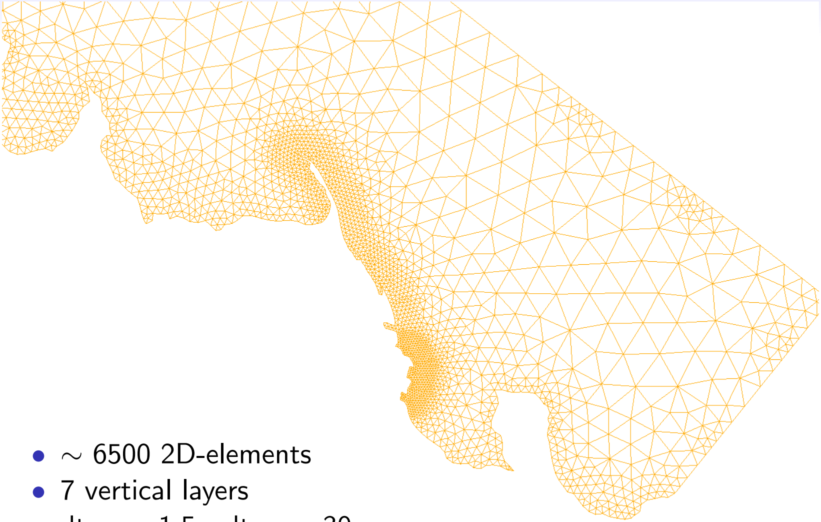
Burdekin River Plume dynamics

- Burdekin river discharge for 2007 flood season



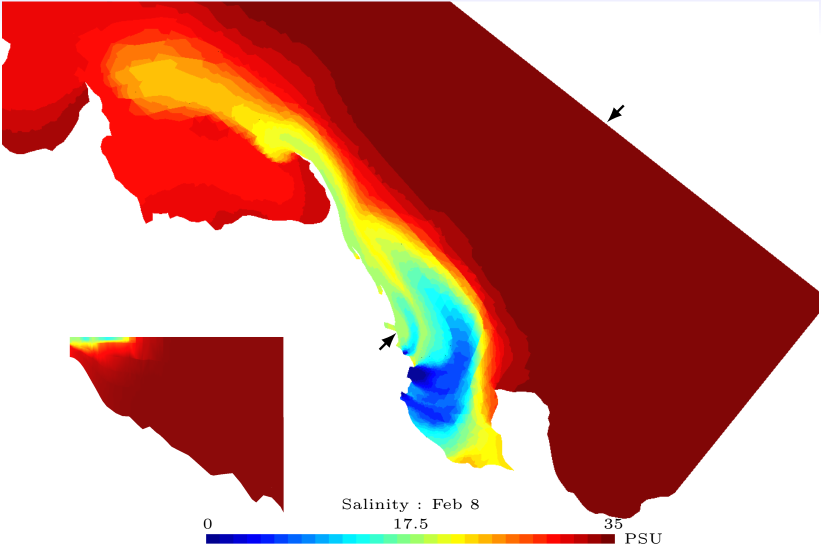
- Wind forcing
- Tidal forcing
- Varying sediment concentration discharge

Salinity dynamics



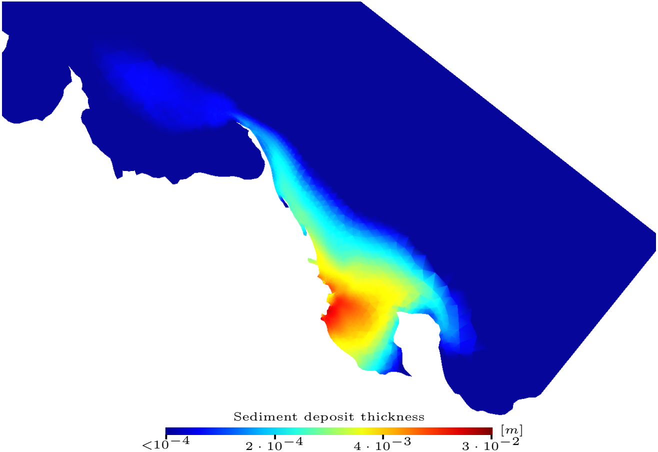
- $\sim$ 6500 2D-elements
- 7 vertical layers
- $dt_{2D} = 1.5s$, $dt_{3D} = 30s$
- 20 times faster than physical time on 12 CPUs

Salinity dynamics



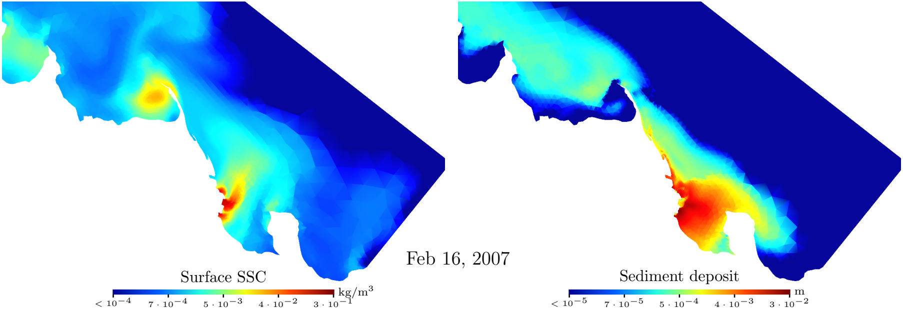
Results

- Only with settling effect :
  $>$50km region : deposit thickness $<$ 0.1mm
  $\Rightarrow$ accordance with Lewis et al. [2014]



Results (2)

- Full sediment model :
  $>$50km region : deposit thickness $<$ 0.1mm
  $\Rightarrow$ accordance with Lewis et al. [2014]



Conclusions and Perspective

- Burdekin River model
  - During a flood event, the sediments do stay in the region defined by Lewis et al. [2014].
  - Calibration of sediment model needs to be done.

- SLIM 3D model
  - SLIM 3D is ready to model actual coastal applications for a small ratio max(bath)/min(bath).
  - More flexibility for vertical layers should be developed.

Thank you for your attention !

References

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