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Toward multi-scale modelling of the whole hydrosphere: concepts, applications and diagnoses

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Are adaptive- and unstructured-mesh models coming of age?

- Classical structured-mesh eco-hydrodynamic models with (almost) constant resolution may be getting obsolete.

- Time may be ripe for developing models in which resolution may be enhanced **where** and **when** needed.

- Encouraging example: reduced-gravity simulation of a baroclinic eddy* in the Gulf of Mexico by means of a Discontinuous Galerkin (DG), finite-element, adaptive-mesh model (Bernard et al., *Ocean Dynamics*, 2007). **⇒ movie1**

This simulation is one order of magnitude cheaper than a constant-resolution one of the same accuracy!

* Features of the eddy inspired by Lewis and Kirwan (*JGR*, 1987).

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The Second-generation, Louvain-la-Neuve, Ice-ocean Model (SLIM)

http://www.climate.be/SLIM
htp://www.climate.be/timothy

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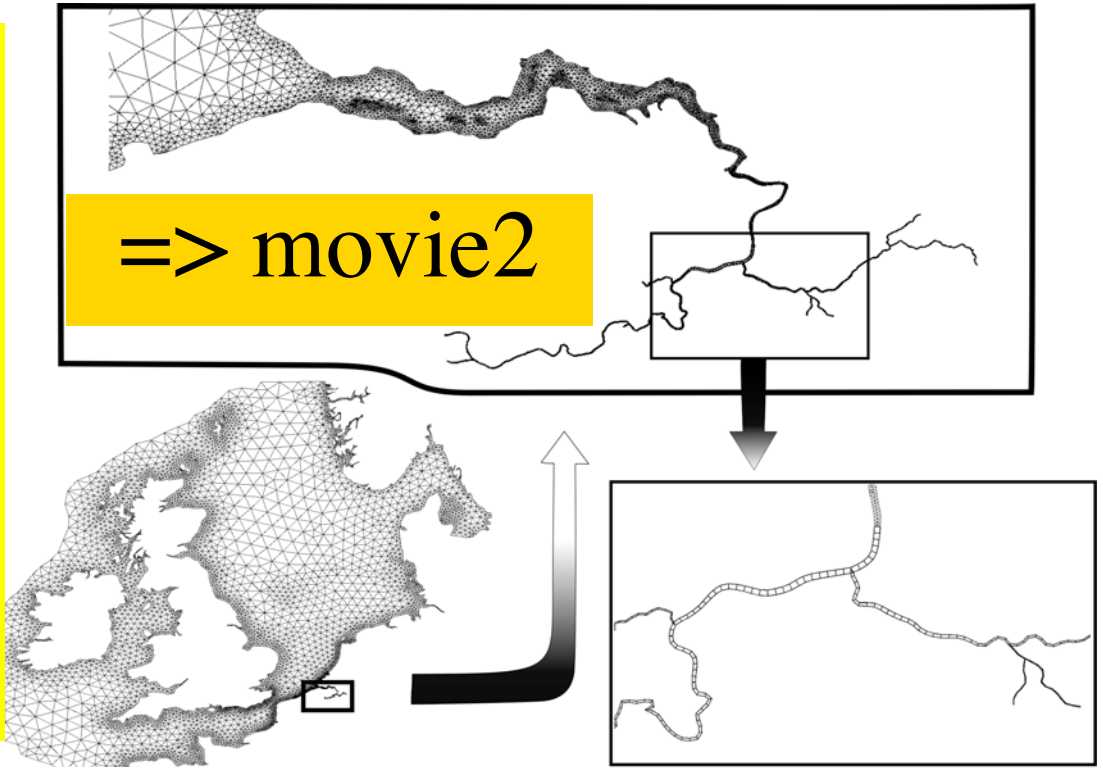
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Multi-scale modelling: the Scheldt basin (I)

The main advantage of unstructured meshes probably is that multi-scale modelling is rendered easier. Example: the Scheldt tributaries, River, Estuary and ROFI (www.climate.be/timothy).

- 40% of the meshes in the estuary, which represents 0.3% of the computational domain.
- No major problem with open boundary conditions (for tides, storms, river discharge).



(de Brye et al., *Coastal Engineering*, in press)

Multi-scale modelling: the Scheldt basin (II)

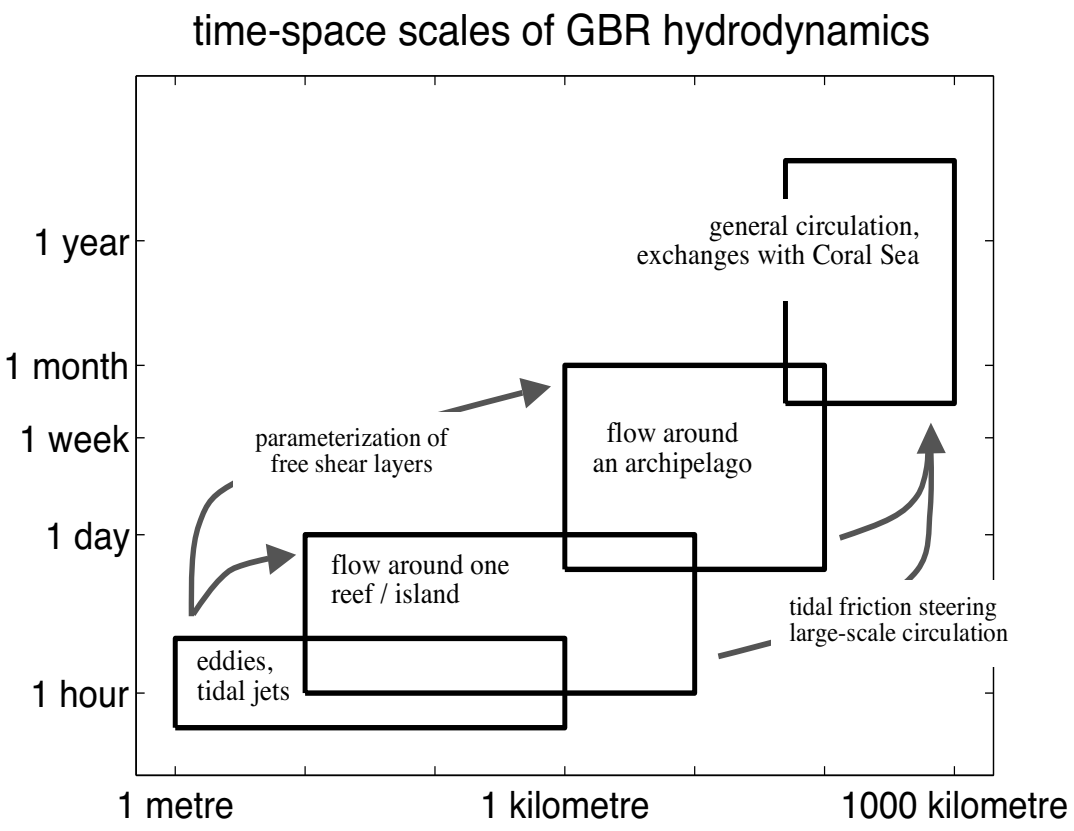
- Validation of hydrodynamics: water height & salinity (de Brye et al. *Coastal Engineering*, in press)

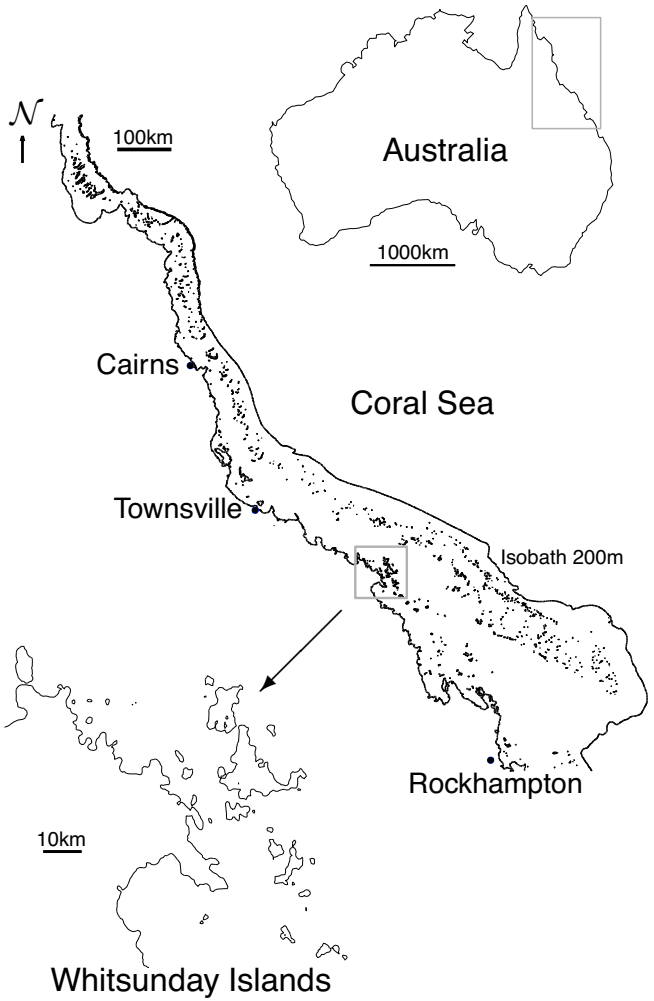
- Modelling of scalar variables:
  - water renewal timescales (de Brauwere et al., *Journal of Marine Systems*, submitted)
  - Fecal bacteria + experimental design (de Brauwere et al., *Environmental Modelling and Software*, 2009)
  - Radioactive tracers (Doel nuclear power station);
  - Sediment and heavy metals (Gourgue et al., in preparation)

=> movie3

Multi-scale modelling: the Great Barrier Reef (I)

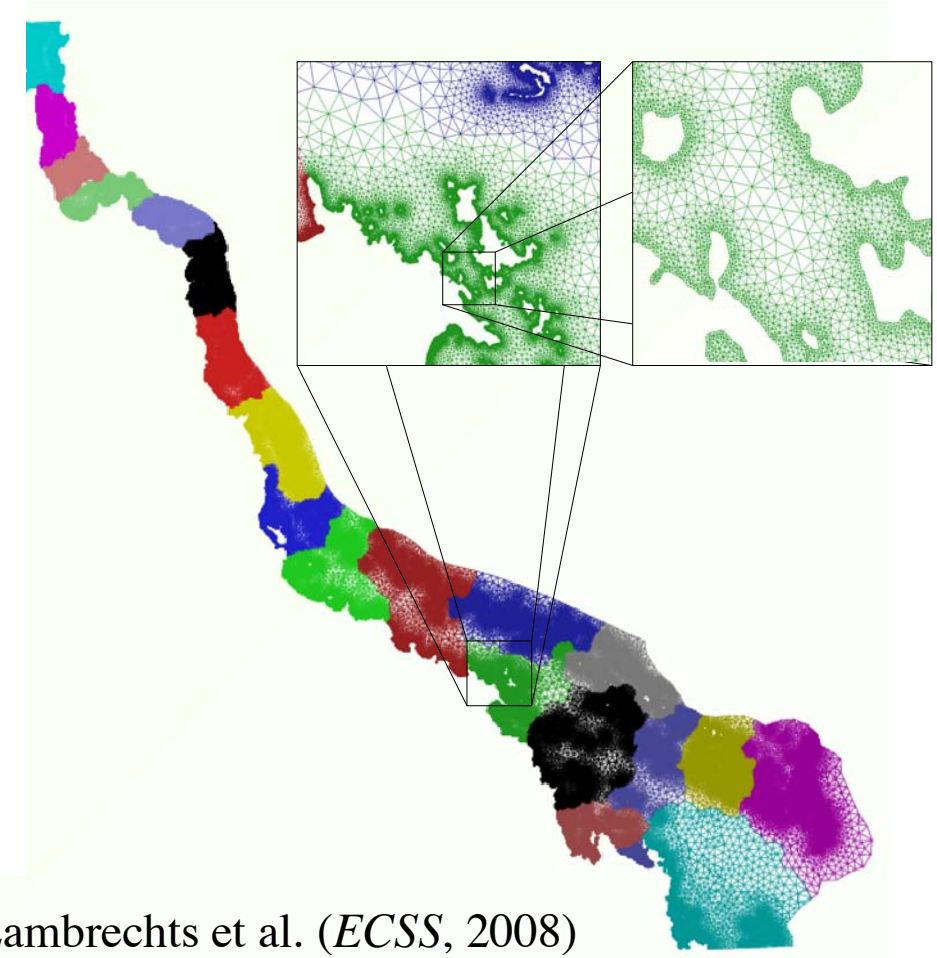
See Wolanski et al. (2003, in: *Advances in Coastal Modeling*, V.C. Lakhan (Ed.))





Multi-scale modelling: the Great Barrier Reef (II)

- $O(10^6)$ triangles, with $\Delta x_{\max} / \Delta x_{\min} \approx 10^2$
- Forcings: wind, tides, Coral Sea inflow
- A wide spectrum of hydrodynamic processes simulated (eddies, tidal jets, "sticky waters", general circulation)

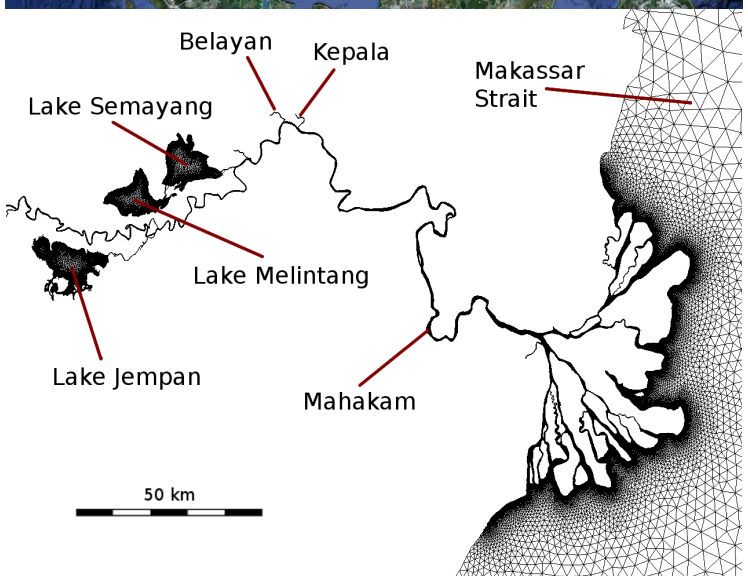


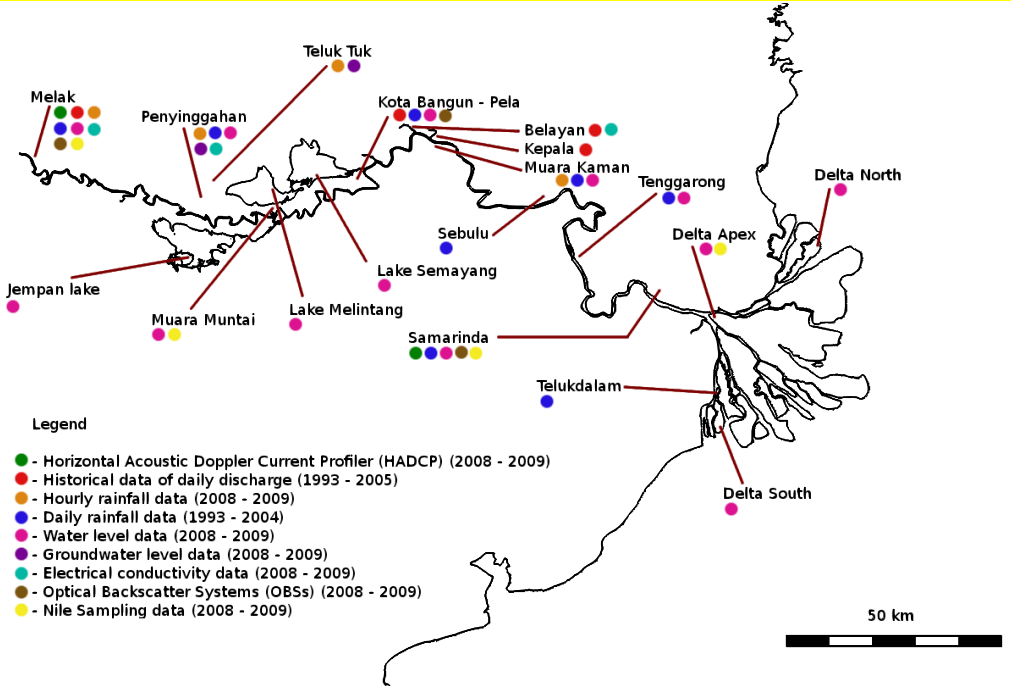
See Legrand et al. (*ECSS*, 2006) and Lambrechts et al. (*ECSS*, 2008)

Mahakam River (Indonesia) land-sea continuum



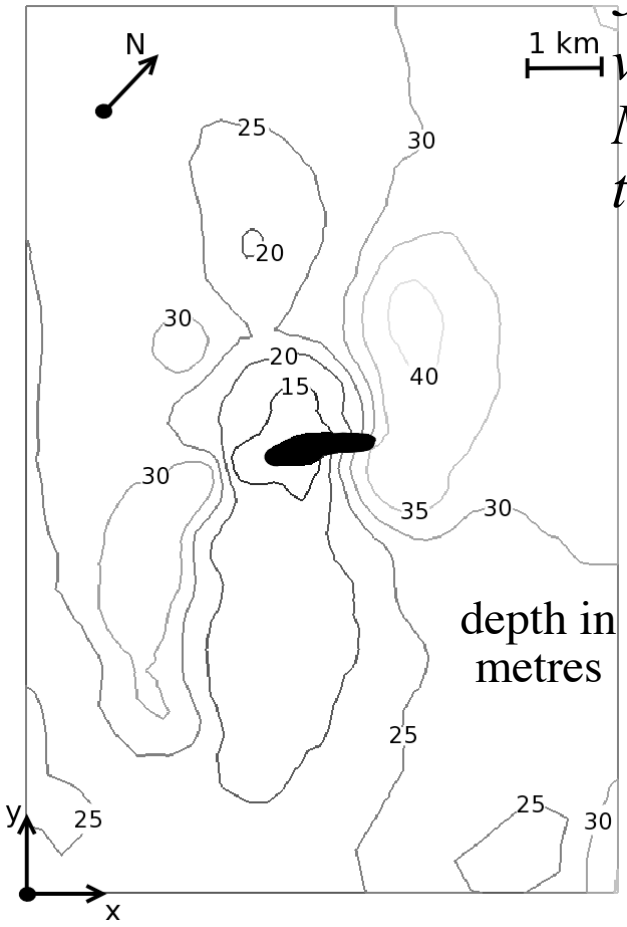
New project,
to be conducted in collaboration with
Prof Ton Hoitink (Univ. Wageningen)
http://www.eastkalimantan.org

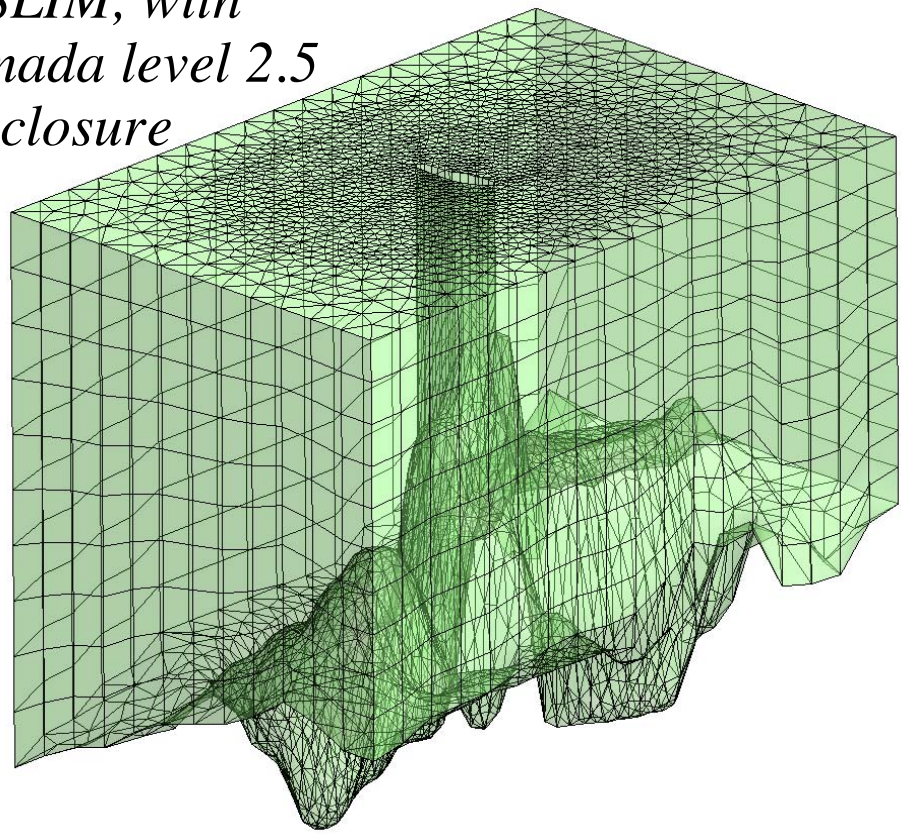




Rattray Island eddies and associated upwelling

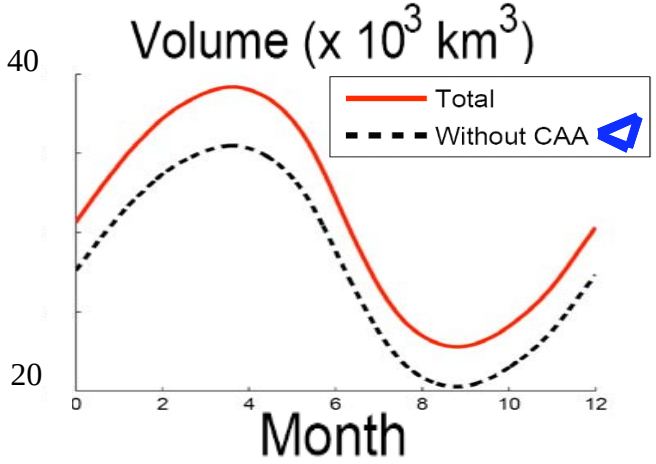
3D, σ-coordinate, barotropic version of SLIM, with Mellor-Yamada level 2.5 turbulence closure





See Blaise et al. (*CSR*, 2007) , White et al. (*ECSS*, 2007), and White and Wolanski (*ECSS*, 2008)

Sea ice in the Arctic



=> movie4

- Finite element formulation of Hibler's rheology
- Semtner's zero-layer thermodynamics
- Slab ocean (no ocean current)

(Lietaer et al., *Ocean Modelling*, 2008)

Current developments

- A underground flow module (Richards equation).
- 3D baroclinic flow module is being tested, and coupled to the sea ice module (Blaise et al. & Comblen et al., *Ocean Dynamics*, to be submitted).
- Wetting-drying algorithm: speed up of $O(200)$ (Kärnä et al., *Computer Methods in Applied Mechanics and Engineering*, 2010, submitted).

- Speeding up the model by at least one order of magnitude:

- Higher-order implicit schemes (appropriate for a few processors);
- Multi-rate RK (explicit) time steppings (appropriate for a large number of processors) (Constantinescu and Sandu, *Journal of Scientific Computing*, 2007; Schlegel et al., *Computational and Applied Mathematics*, 2009).

Conclusion

- SLIM already has some of the building blocks of a multi-scale hydrospheric model.
- The (relative lack of) availability of multi-scale data is a key problem.
- Will multi-scale reactive transport models prove superior to those focused on long time and space scales (which often do not represent the most energetic processes, such as floods, tides, etc.)?
- Will pursuing the dream of a model of the whole hydrosphere lead to useful results (even if such a model never comes true)?



www.climate.be/slim www.climate.be/cart www.climate.be/timothy

You may say I'm a dreamer / But I'm not the only one
I hope some day you'll join us

(John Lennon, Imagine, 1971)