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SLIM: a numerical model for the land-sea continuum and beyond

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www.ericd.be

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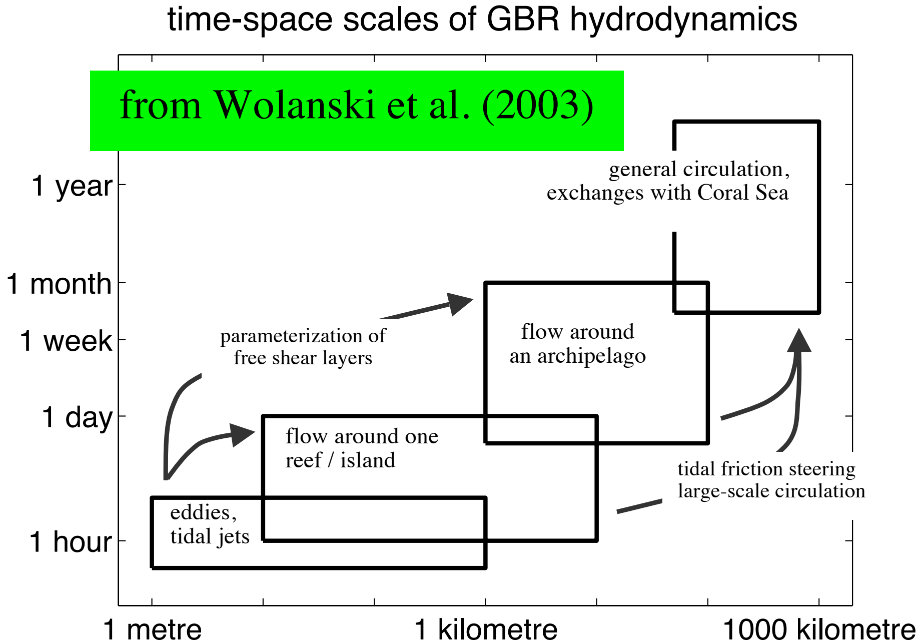
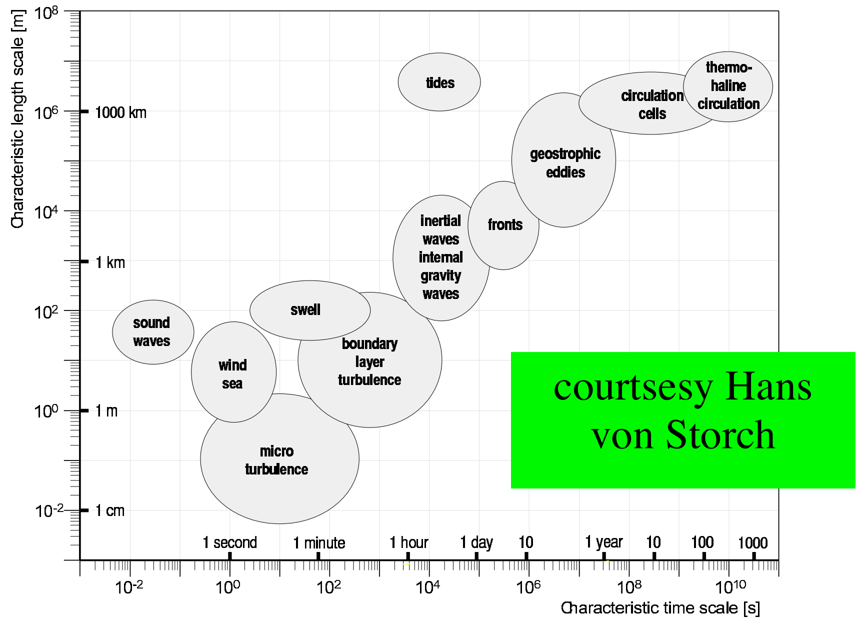
The need for multi-scale/physics models

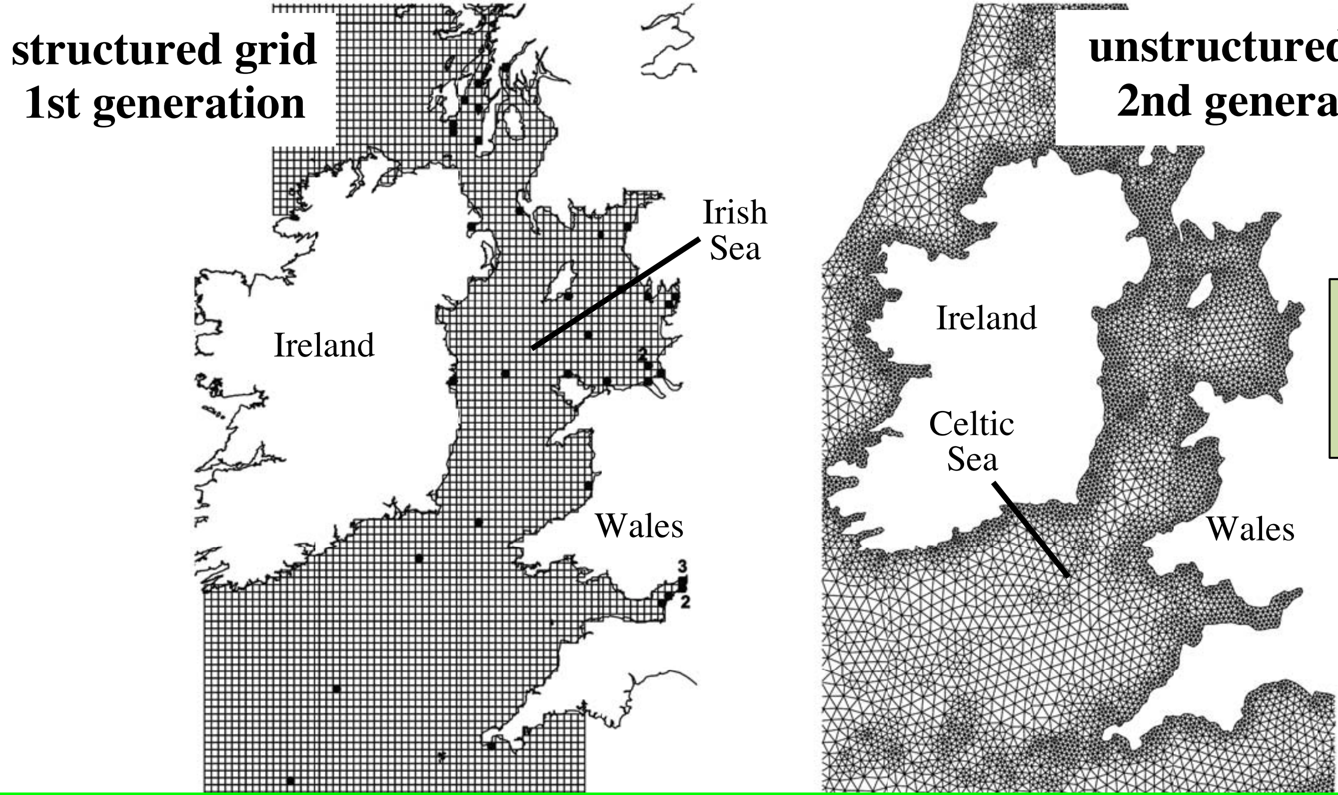
• Phenomena occurring in geophysical and environmental fluid flows span an enormous range of space and time scales.





• One of the greatest challenges the modellers are currently faced with is to widen the range of explicitly resolved phenomena.

Structured *vs* unstructured grids in geophysical and environmental fluid dynamics (GEFD) models



Geophysical and Environmental Fluid Dynamics (GEFD)

Impossible to transform step by step a first generation dynamical core into a second generation one.
A tough choice is to be made!

The Second-generation Louvain-la-Neuve Ice-ocean Model (SLIM, www.climate.be/slim)

• SLIM's development started about 15 years ago, aiming at the **multi-scale/physics** modelling of (some of the components) of the **hydrosphere**.

• Key steps:

- Collaboration of mechanical engineers and GEFD specialists;
- Programming in C++;
- Adopting the finite element (FE) method, then switching to Discontinuous Galerkin FE (DG FE ≈ hybrid of FE and FV);
- Proximity of SLIM and the mesh generation software Gmsh (www.geuz.org/gmsh)

What SLIM can and cannot do (I)

• SLIM solves **partial differential equations** in 1, 2 or 3 space dimensions for unknowns of the form $\psi(t,\mathbf{x})$. The generic form of (most of) these equations is:

$$\underbrace{\frac{\partial\psi}{\partial t} + \nabla\bullet(\overbrace{\mathbf{v}\psi - \mathbf{K}\bullet\nabla\psi}^{\text{advect.+diff. flux}})} = \underbrace{\overbrace{P - D}^{\text{"reactions"}}}$$

Dealt with by SLIM on an unstructured mesh by means of the discontinuous Galerkin finite element method in a C++ code

Dealt with by SLIM or by external modules interfaced with SLIM

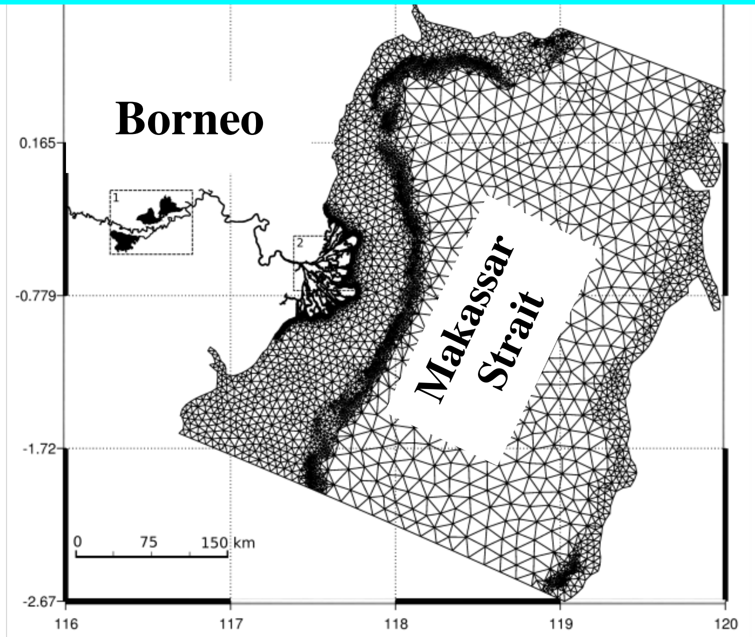
We are not (always) reinventing the wheel...

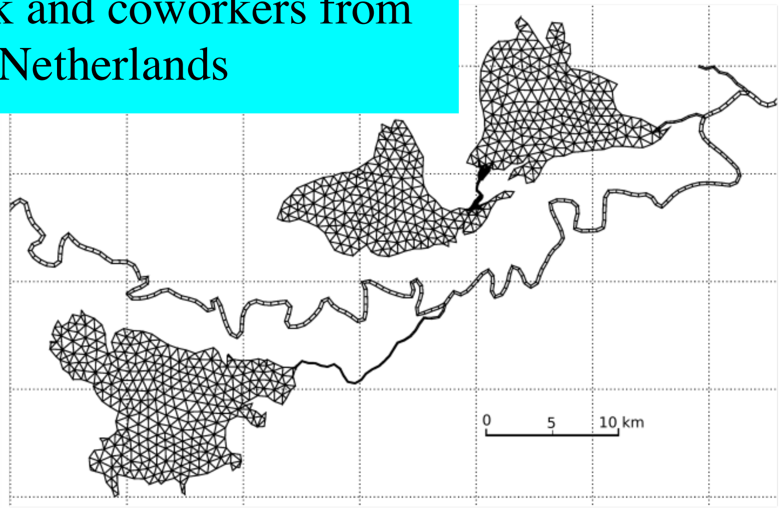
What SLIM can and cannot do (II)

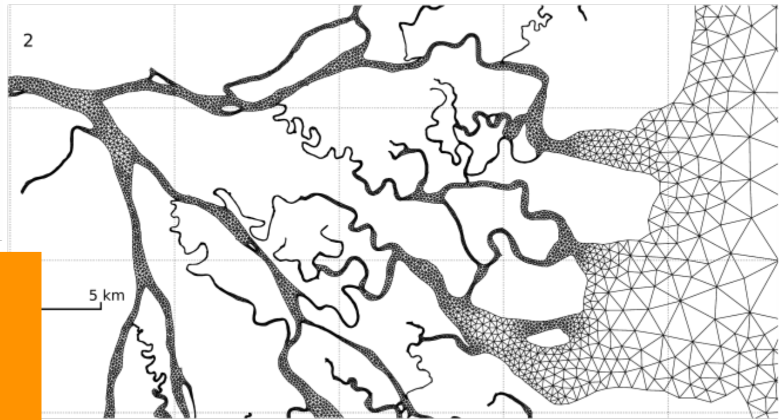
- SLIM is capable of being **interfaced** with well-established models/modules often based on (radically) **different numerical methods** (e.g. finite differences) and **programming languages** (e.g. FORTRAN):
  - in SLIM's hydrodynamic module, the turbulence closure is GOTM (General Ocean Turbulence Model, www.gotm.net);
  - the sea ice thermodynamics is now that of LIM3 (Louvain-la-Neuve Sea Ice Model, version #3, www.climate.be/lim);
- SLIM solves CART's equations (www.climate.be/cart), to obtain diagnostic timescales (age, residence time, exposure time, etc.).
- Most in- and out-put files are to be dealt with by means of specific routines, owing to the unstructured nature of the mesh.

The Mahakam river-sea continuum (Indonesia) (I)

Work carried out with Prof Ton Hoitink and coworkers from
Wageningen University, The Netherlands



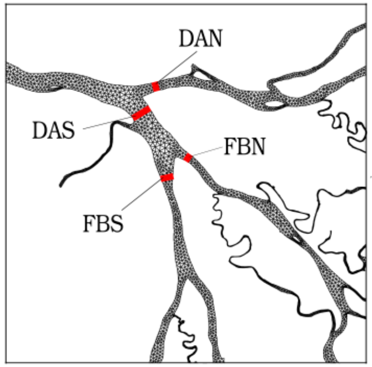


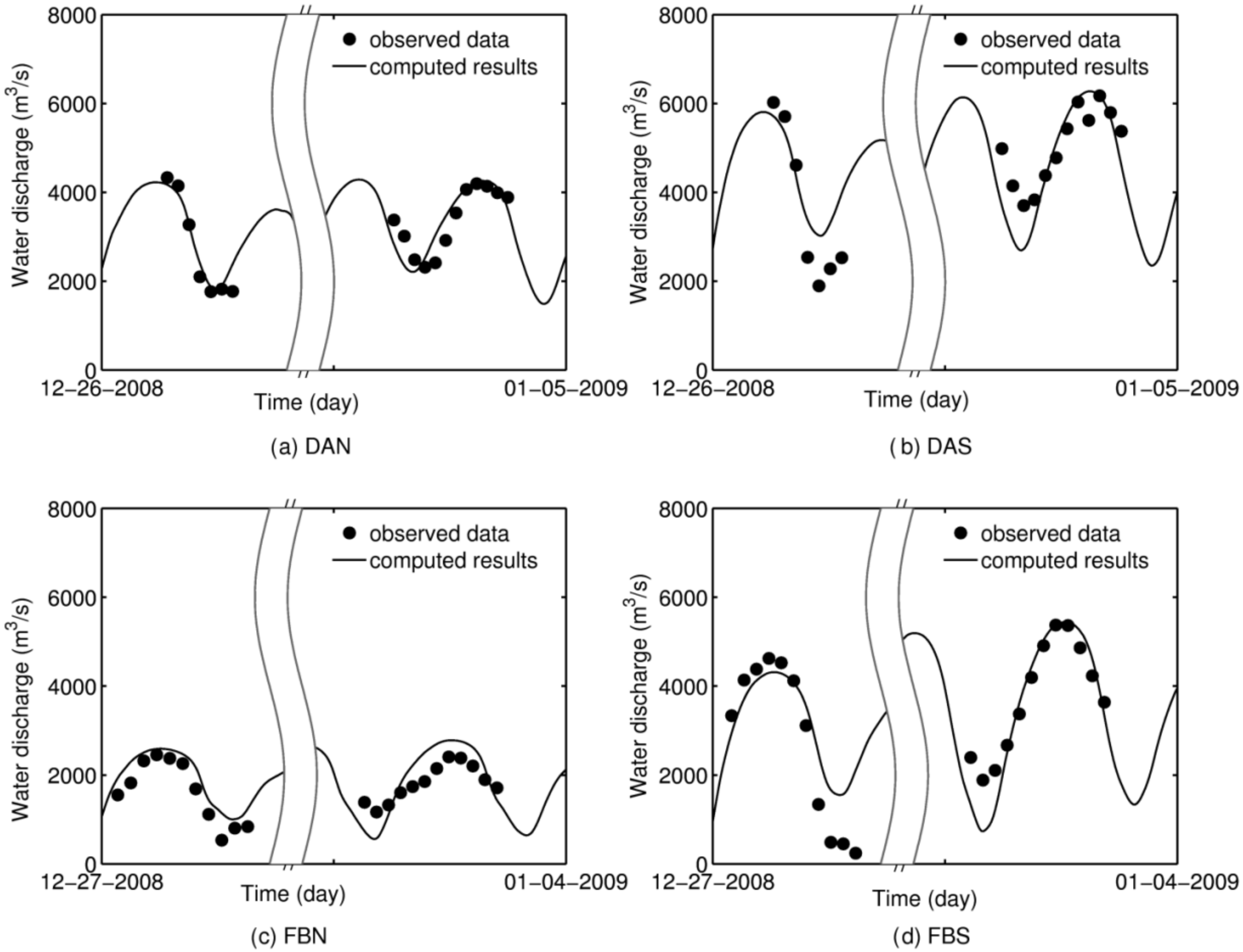


de Brye et al. (*Ocean Dynamics*, 2011)
Sassi et al. (*Ocean Dynamics*, 2011)
Sassi et al. (*JGR - Earh Surface*, 2012)
Pham Van et al. (*JHeR*., accepted)

Hydrodynamics in 1D + 2D (tides, river discharge)
Tidal impact on the division of river discharge over distributary channels
Modelling sediment transport in the rivers and the delta

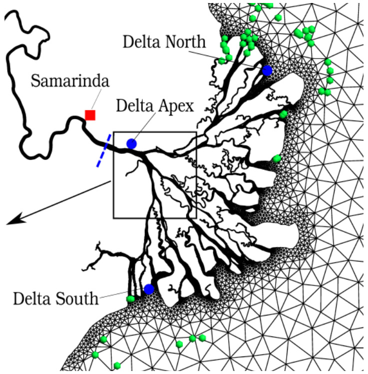
The Mahakam river-sea continuum (Indonesia) (II)



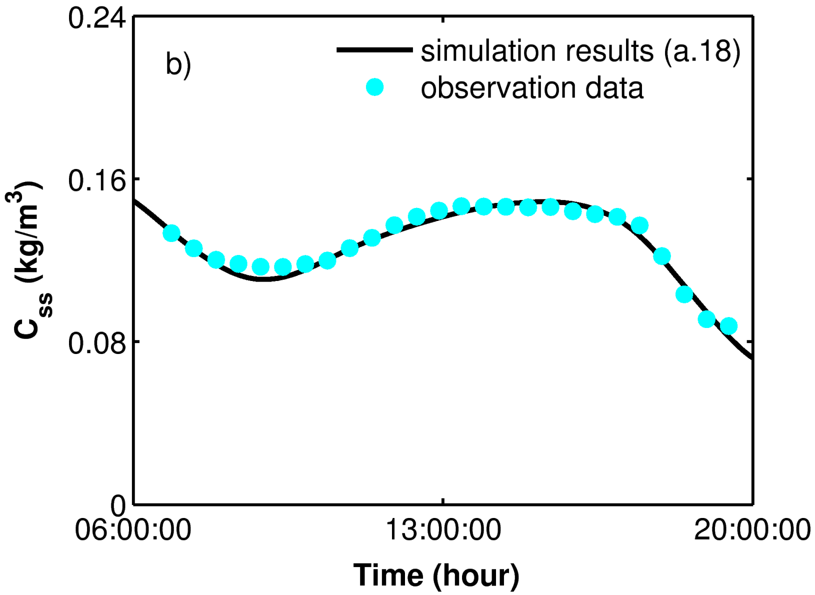


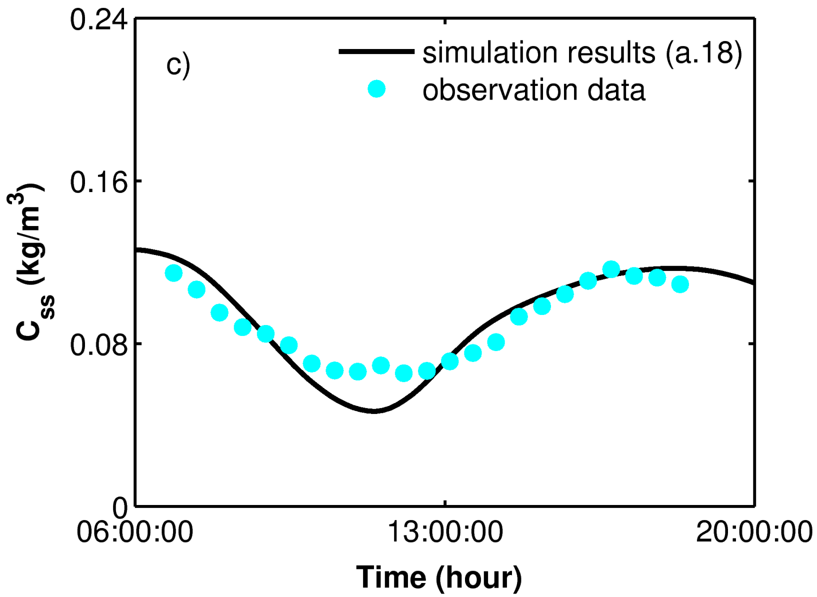
Water discharge in the delta

The Mahakam river-sea continuum (Indonesia) (III)

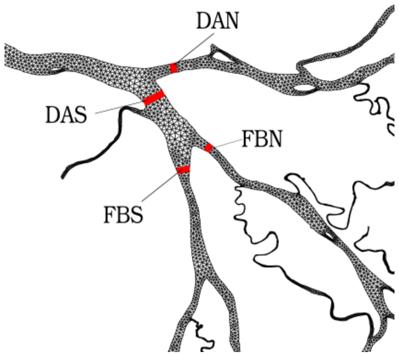


Suspended sediment concentration (SSC) at Samarinda (a little upstream of the delta apex)

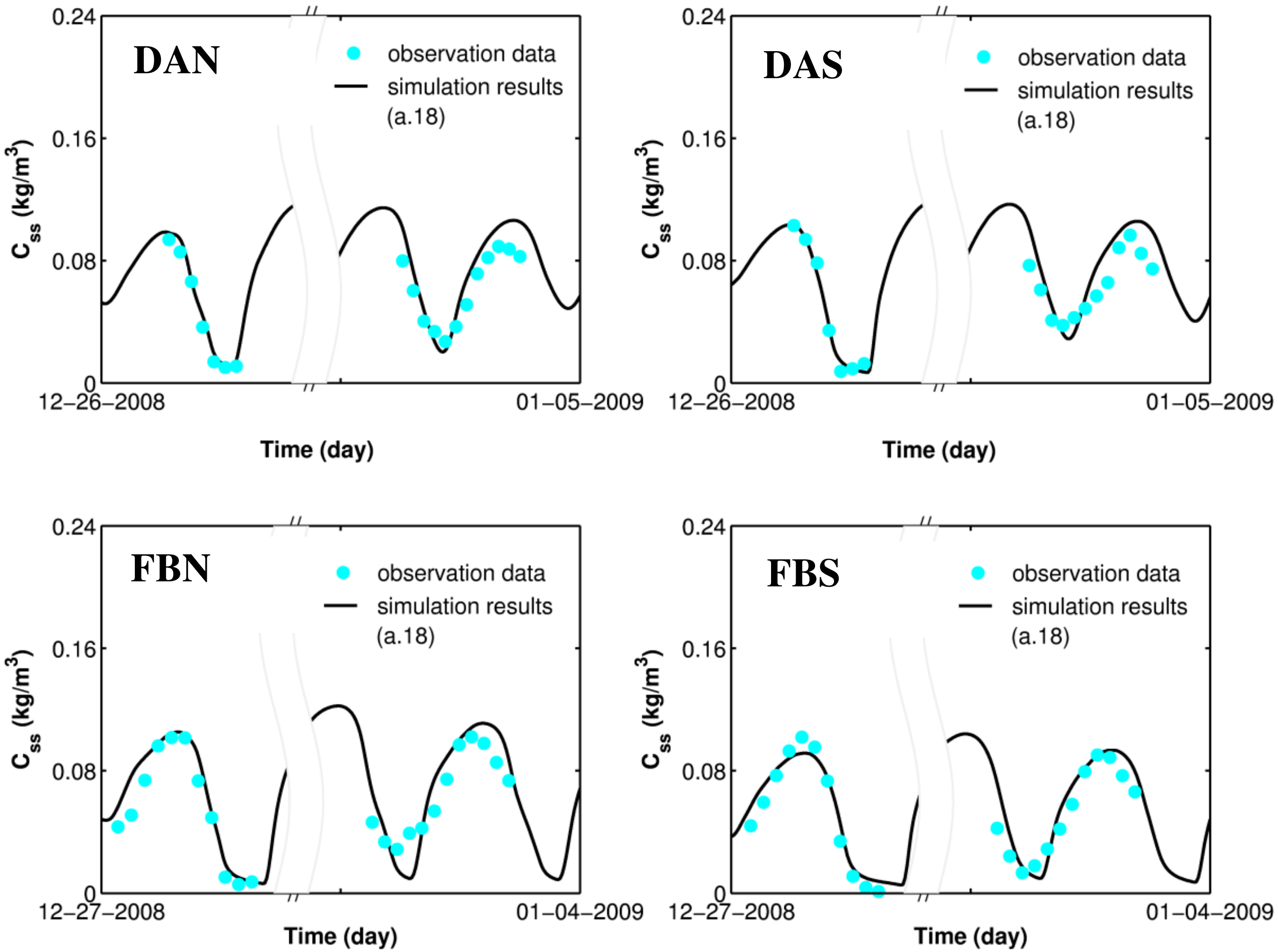




The Mahakam river-sea continuum (Indonesia) (IV)



SSC in the delta

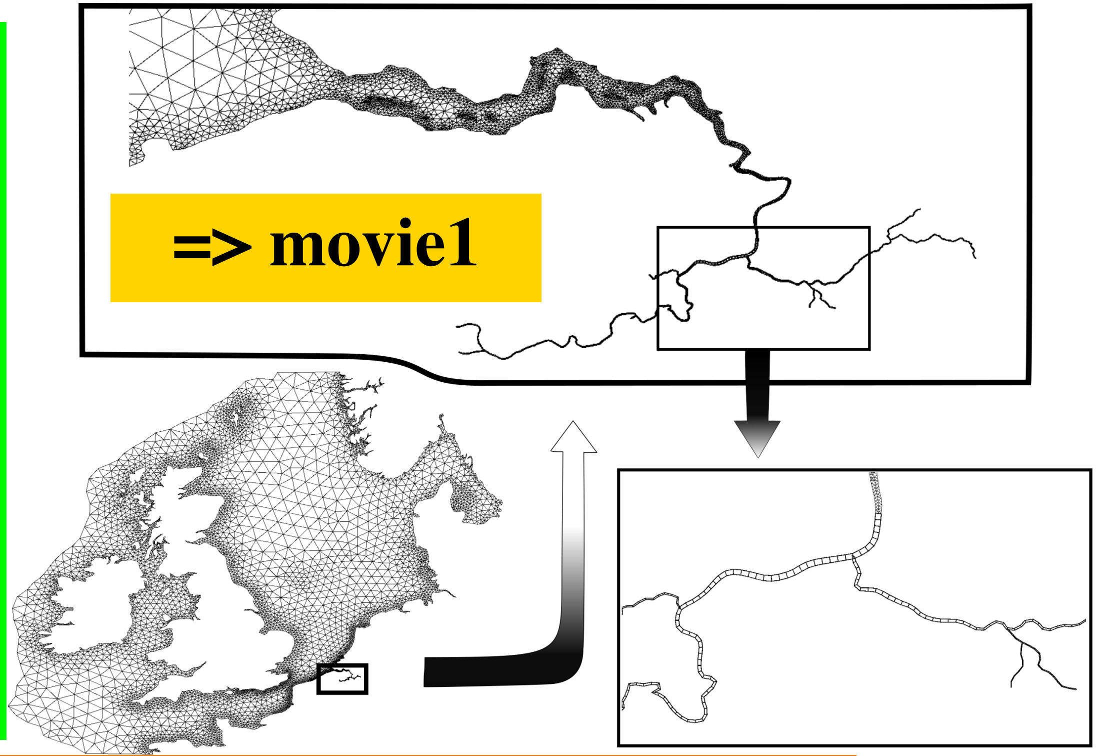


The Scheldt river-sea continuum (I)

The main advantage of unstructured meshes probably is that multi-scale modelling is rendered easier. Example: the Scheldt tributaries, River, Estuary and the adjacent coastal zone.

- 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).



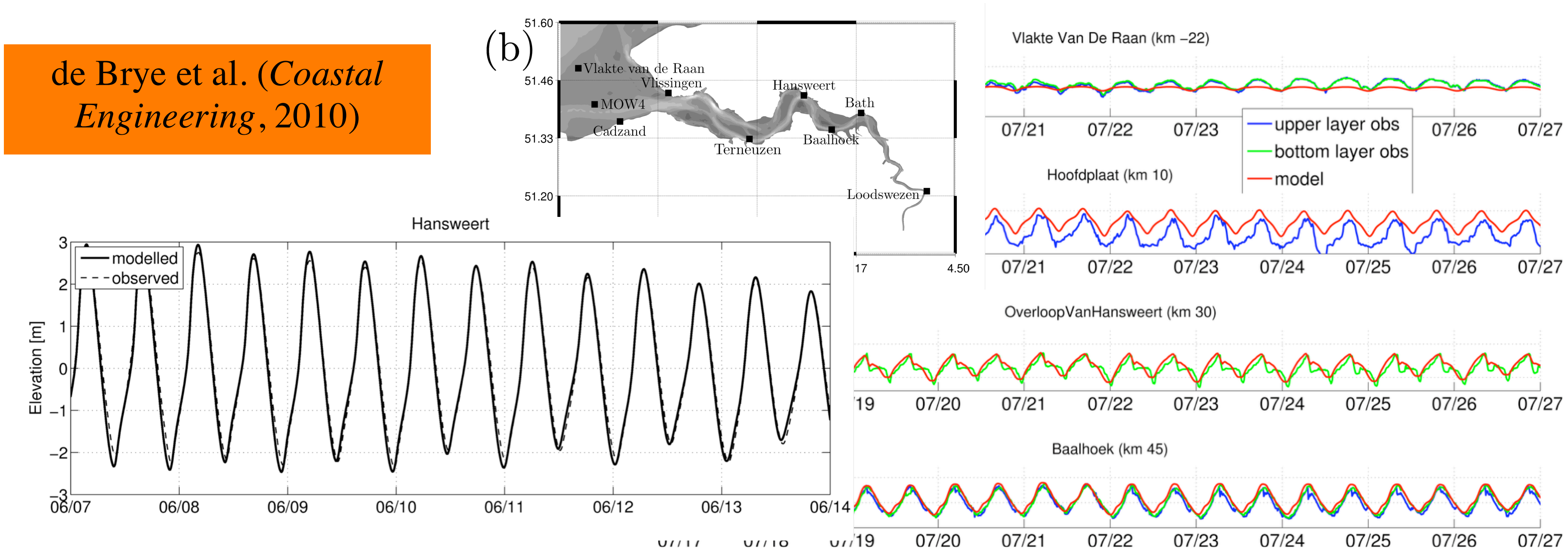
SLIM's DG FEM wetting-drying schemes:
Gourgue et al. (*Advances in Water Research*, 2009)
Kärnä et al. (*Computer Methods in Applied Mechanics and Engineering*, 2011)

The Scheldt river-sea continuum (II)

- Hydrodynamics is forced by tides (prescribed at the shelf break) and wind stress.

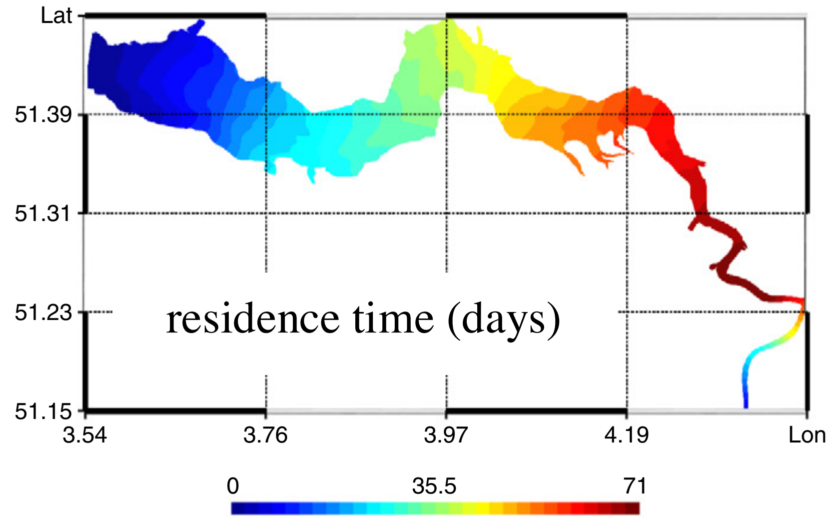
- Tidal components (amplitude and phase) are well represented, as well as salinity (treated as a passive tracer).

de Brye et al. (*Coastal Engineering*, 2010)

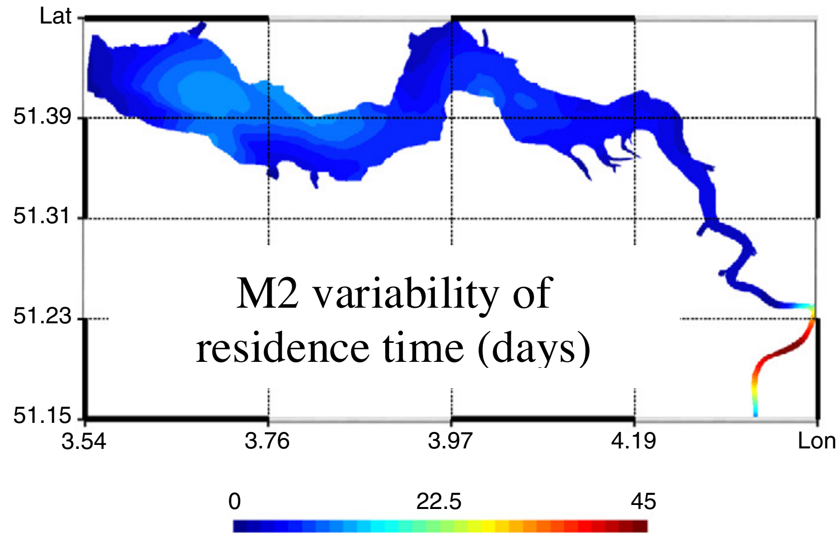


The Scheldt river-sea continuum (III)

• CART's water renewal timescales (age, residence time, exposure time) and return coefficient for the estuary have been simulated at any time and position.



www.climate.be/cart

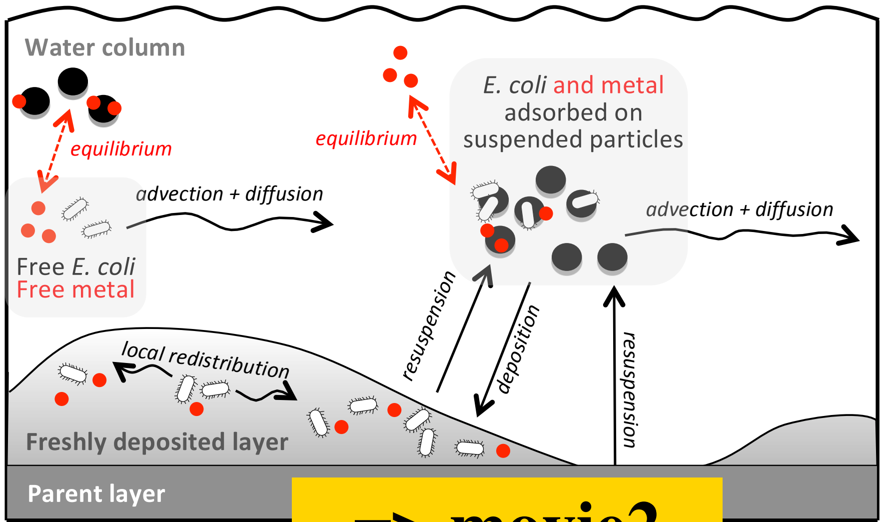


• Surprising result: the large time variability of the residence time.

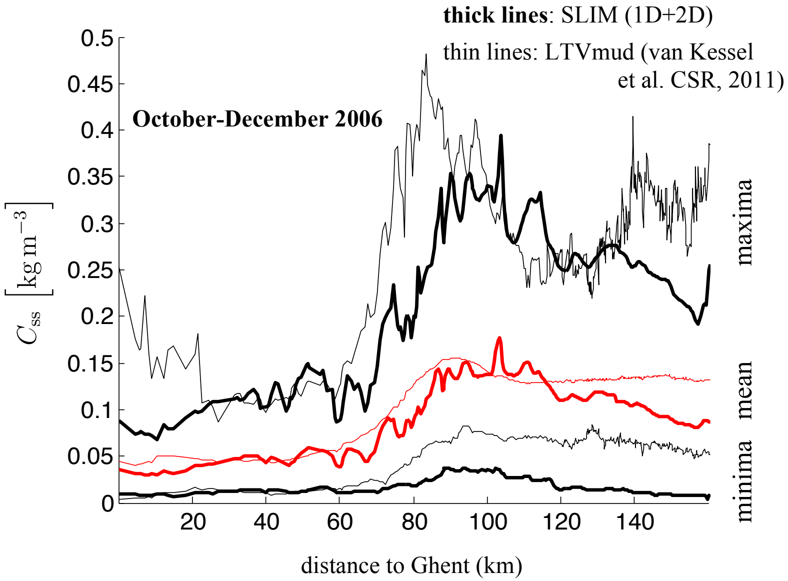
Blaise et al. (*Ocean Dynamics*, 2010), de Brauwere et al. (*Journal of Marine Systems*, 2011)
de Brye et al. (*Journal of Marine Systems*, 2012)

The Scheldt river-sea continuum (IV)

- We developed a simple sediment module, which is a prerequisite for simulating the fate of several classes of contaminants (e.g. fecal bacteria, trace metals).



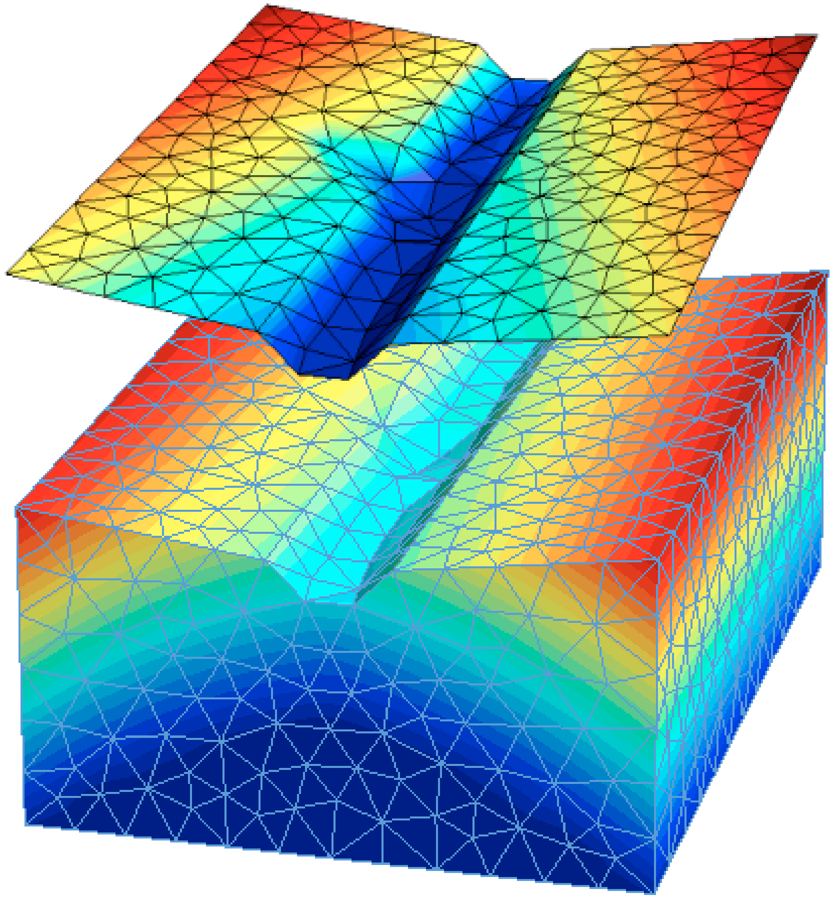
=> movie2



de Brauwere et al. (*Env. Model. & Soft.*, 2009)
de Brauwere et al. (*Water Research*, 2011)
Gourgue et al. (*J. Marine Systems*, 2013)
de Brauwere et al. (*STOTEN*, 2014)
Elskens et al. (*STOTEN*, 2014)

Suspended sediment concentration:
results of SLIM (1D+2D) are not that different from those of the 3D, much more complex LTVmud model

Groundwater and surface water



Surface flows:
diffusive wave approximation of the shallow-water equations
(solved with DG FEM)

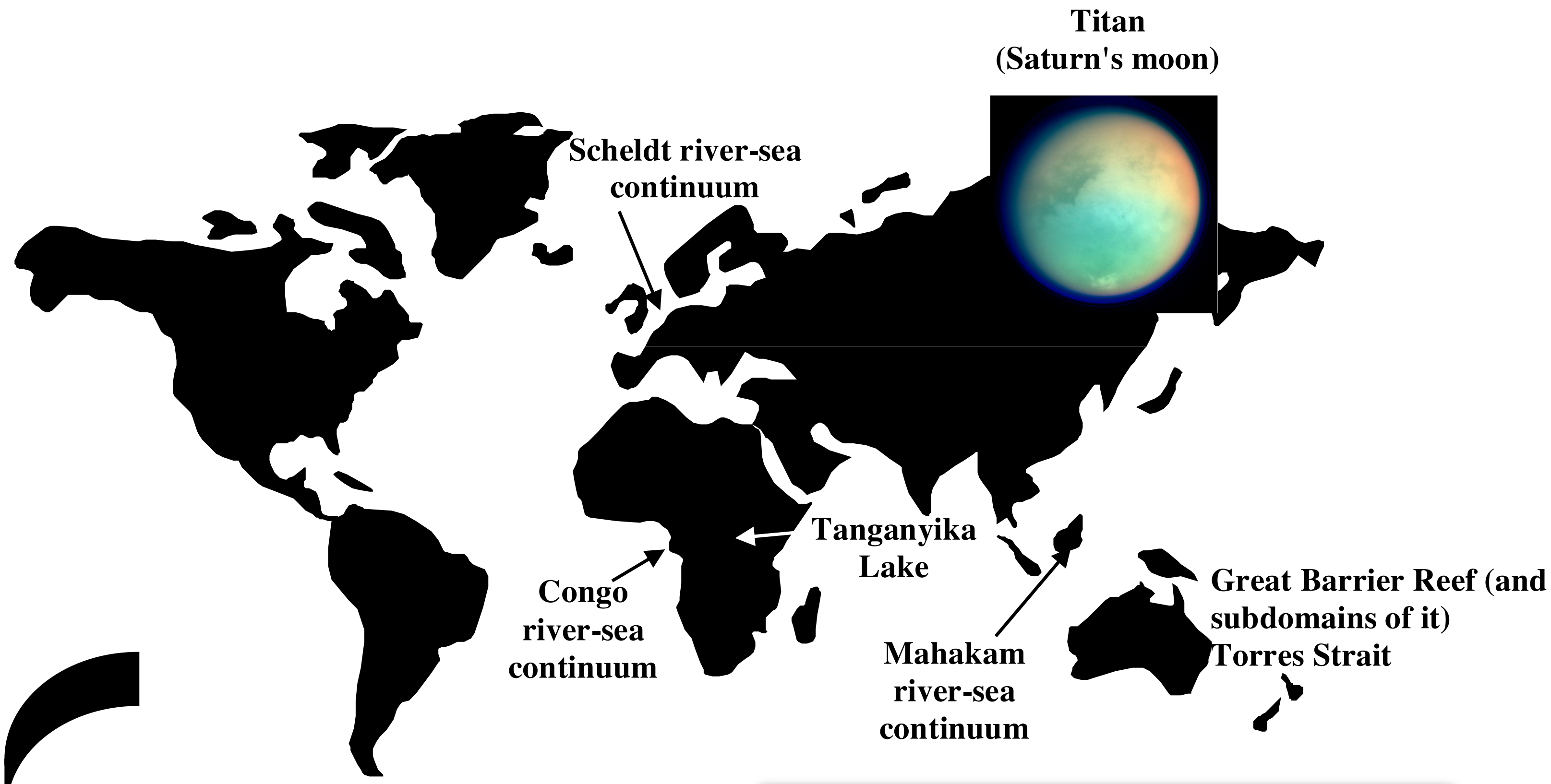
Outline:

1. 3D subsurface flows
2. 2D runoff
3. coupling between surface/subsurface

Subsurface flows:
Richards equation
(soved with DG FEM)

de Maet et al. (*Journal of Hydrodynamics*, 2014)
de Maet et al. (*Computers & Fluids*, 2015)

Domains of applications



Idealised flow domains

Domains in which SLIM
has been or is being applied

Main achievements

- SLIM already has some of the building blocks of a multi-scale/physics hydrospheric model, which are progressively coupled with eachother with a focus on the land-sea continuum.

- SLIM has been applied successfully to a number of domains.

- We believe that the choice of DG on unstructured meshes was a good one.

- There are almost 100 peer-reviewed publications related to the development and applications of SLIM.

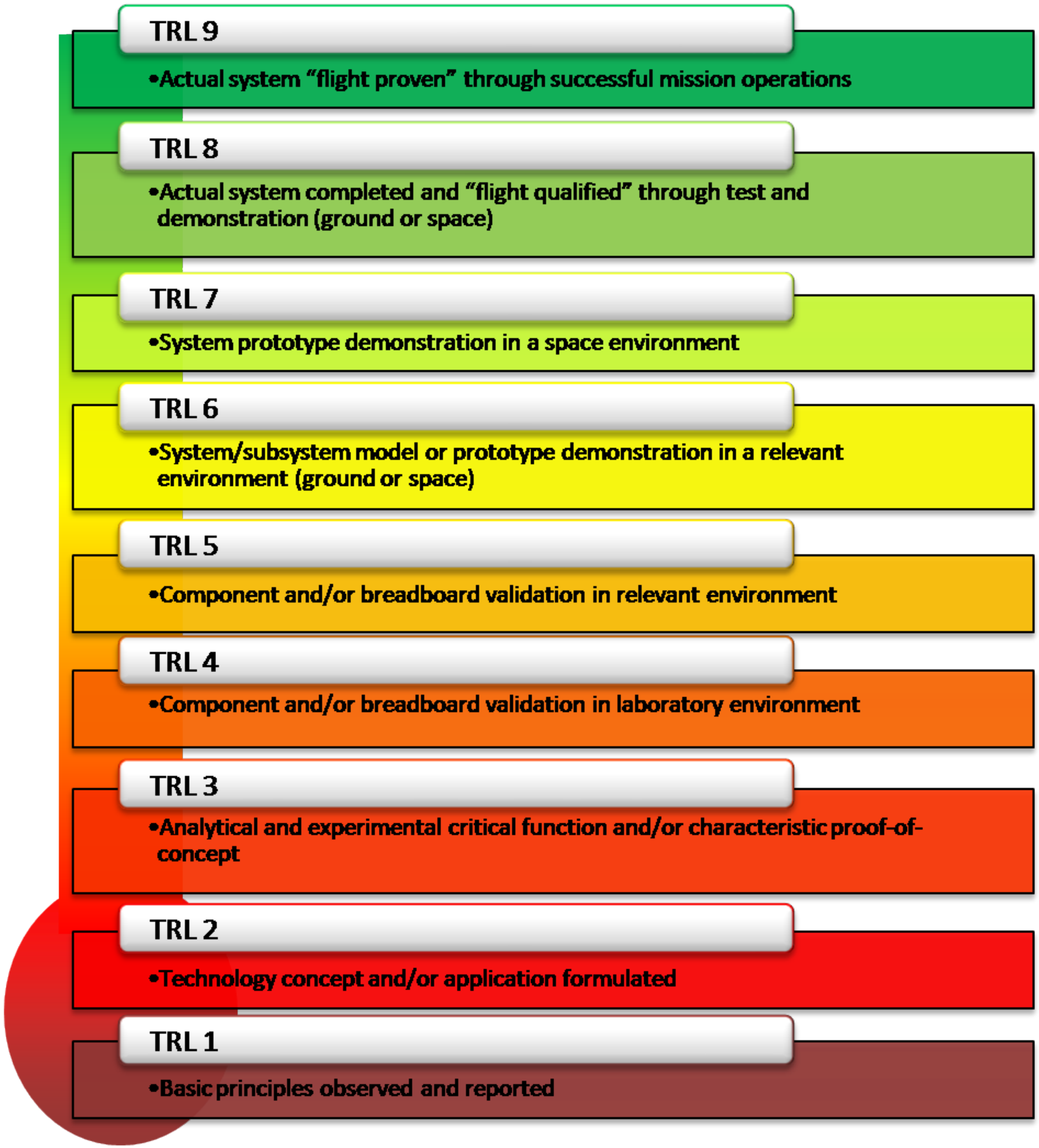
Outlook

- We want to further develop SLIM with a focus on the land-sea continuum.

- Which existing models/modules should be interfaced with SLIM (rather than developed by ourselves within SLIM's framework)?

- We need a surface wave model (e.g. www.swan.tudelft.nl), a GUI, data assimilation package (e.g. www.openda.org), and, above all, much more investment in water quality modelling.

- Within the next few years, SLIM should rise from TRL1-2 to TRL5-6 (https://www.nasa.gov/sites/default/files/trl.png).


TRL 9
•Actual system "flight proven" through successful mission operations
TRL 8
•Actual system completed and "flight qualified" through test and demonstration (ground or space)
TRL 7
•System prototype demonstration in a space environment
TRL 6
•System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 5
•Component and/or breadboard validation in relevant environment
TRL 4
•Component and/or breadboard validation in laboratory environment
TRL 3
•Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 2
•Technology concept and/or application formulated
TRL 1
•Basic principles observed and reported

www.climate.be/slim