# SLIM: a numerical model for the land-sea continuum and beyond[1]

The hydrosphere is made up of a number media, such as groundwater, oceans, shelf seas, estuaries, rivers, sea ice. The processes taking place in these domains are vastly different in nature and are characterised by a wide range of space- and time-scales. The components of the hydrosphere interact with each other. For instance, the shallow marine and estuarine regions, though accounting for less than 1% of the volume of the oceans, have a biomass far from negligible as compared to that of the oceans, suggesting that they play a significant role in global biogeochemical cycles. This is one of the reasons why models are now needed that deal with most, if not all, of the components of the hydrospheric system.
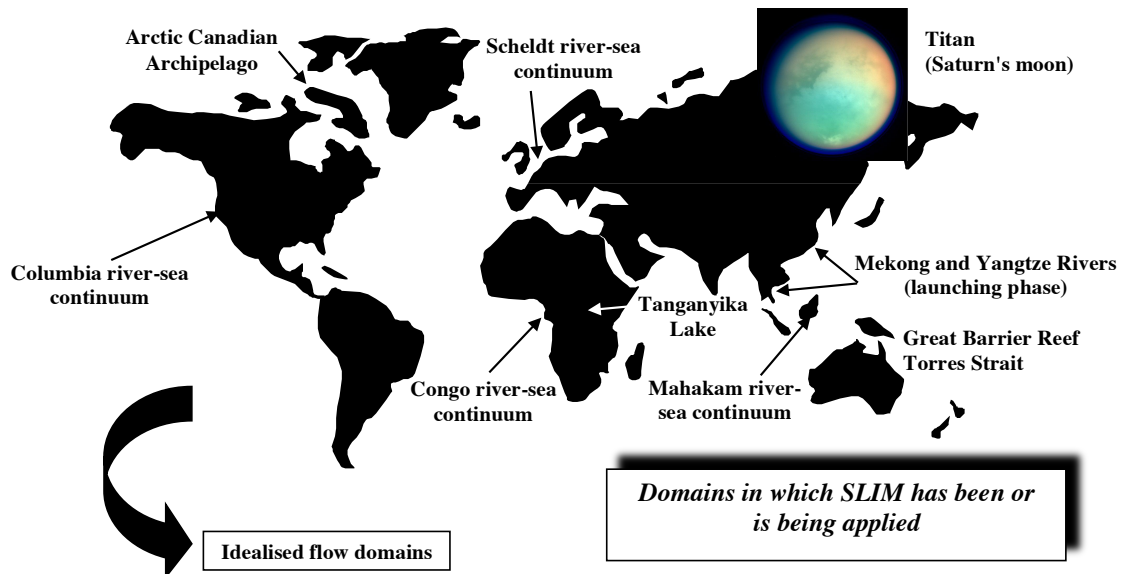
Numerical models of each of the components of the hydrosphere already exist. However, an integrated model of the whole hydrosphere has yet to be developed. Building such a model is a daunting task, requiring the development of multi-scale/physics simulation tools.
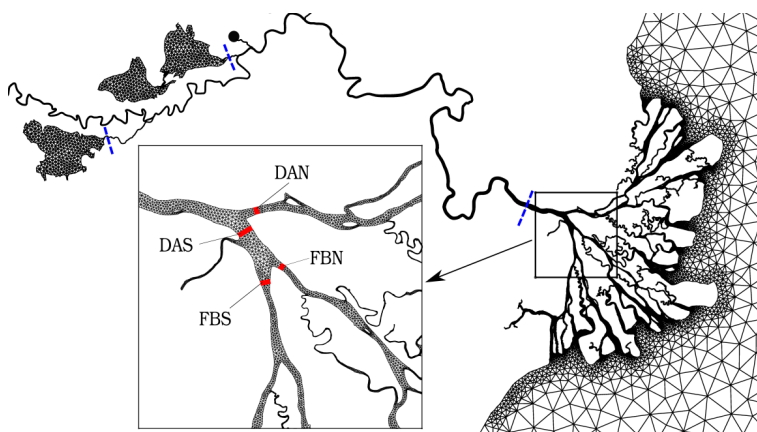
Numerical methods for dealing with multi-scale problems are developing rapidly. Unstructured meshes (see figure opposite[2]) offer an almost infinite geometrical flexibility, allowing the space resolution to be increased when and where necessary. In addition, time steppings for dealing with a wide spectrum of timescales while retaining a high order of accuracy have been developed over recent years (e.g. multi-rate schemes).

Taking advantage of the abovementioned progress in numerical methods, various teams over the world have started developing models for simulating in an integrated manner a significant number of components of the hydrosphere. One of these groups is building the Second-generation Louvain-la-Neuve Ice-ocean Model (SLIM, www.climate.be/slim), the main focus of which has been thus far the land-sea continuum. SLIM solves the equations governing geophysical, environmental and groundwater phenomena by means of the (discontinuous Galerkin) finite element method on 1D, 2D or 3D unstructured meshes. To take advantage of state-of-the-art developments, SLIM is also

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[1] This flyer may be found on the web at the following address: www.climate.be/slim_flyer
[2] This is Figure 4b of Pham Van C., B. de Brye, E. Deleersnijder, A.J.F. Hoitink, M. Sassi, B. Spinewine, H. Hidayat and S. Soares-Frazao, 2016, Simulations of the flow in the Mahakam rive-lake-delta system, Indonesia, *Environmental Fluid Mechanics*, 16, 603-633

being interfaced with existing tools (often based on radically different numerical methods), such as the well-known and widely used General Ocean Turbulence Model (GOTM, www.gotm.net). The post-processing of the results is achieved with the help of usual statistical and computer graphics methods. Other techniques are also resorted to, such as tracer and timescale methods derived from CART (Constituent-oriented Age and Residence time Theory, www.climate.be/cart_flyer) or network science tools (sites.uclouvain.be/networks). The hydrodynamics simulated by the aforementioned finite element model can be introduced into a number of SLIM-based environmental modules, which are capable of representing sediment transport, as well as the fate of some classes of contaminants, namely microbiological pollutants, endocrine disrupting compounds, heavy metals or radionuclides. A simple ecological model is being developed, whose aim is to simulate the evolution of various species of phyto- and zoo-plankton. SLIM results are also employed in theoretical investigations of the design of marine protected areas.

SLIM has been applied successfully to a wide variety of standard, idealised test cases for geophysical an environmental fluid flows — including atmospheric ones. It was seen that space-time mesh adaptivity pays off. Realistic problems were or are also dealt with, in particular the application of SLIM to the Great Barrier Reef, Australia, and the land-sea continua of several rivers, namely the Scheldt (France, Belgium, The Netherlands), the Mahakam (Indonesia) and the Congo (Democratic Republic of the Congo). Finally, seas or lakes on some of the Jupiter and Saturn icy moons are being modelled. See figure above.

Nowadays, most efforts are focusing on the three-dimensional, baroclinic version of SLIM and the accompanying sediment and contaminant modules. The figure opposite, which is taken from Delandmeter et al. (2015 [3]), displays snapshots of sea surface sediment concentration and salinity as simulated in the region of freshwater influence of the Burdekin River, Great Barrier Reef, Australia.

SLIM's sea-ice module is being re-examined and, hopefully, a full-fledged solid and liquid water simulation tool will be available in the near future, which will be based on up-to-date sea-ice's thermodynamics and rheology.
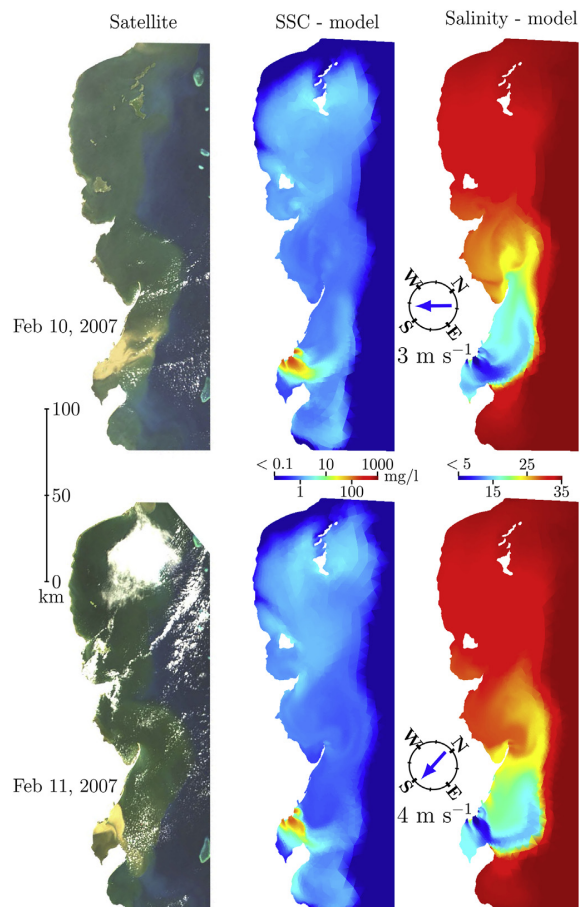
The development and use of SLIM has been or is being performed by many researchers, including Paul-Emile Bernard, Sébastien Blaise, Sylvain Bouillon, Kay Critchell, Hans Burchard, Richard Comblen, Anouk de Brauwere, Benjamin de Brye, Thomas De Maet, Véronique Dehant, Philippe Delandmeter, Eric Deleersnijder (coordinator), Eric Delhez, Marc Elskens, Thierry Fichefet, Fabricio Fiengo Perez, Olivier Gourgue, Emmanuel Hanert, Hidayat Hidayat, Anh Hoang Le, Ton Hoitink, Ozgur Karatekin, Tuomas Kärnä, Jonathan Lambrechts, Yoann Le Bars, Vincent Legat (founding father), Sébastien Legrand, Olivier Lietaer, Samuel Mechior, Jaya Naithani, Alice Pestiaux, Chien Pham Van, Fernando Pinheiro Andutta, Jean-François Remacle, Maximiliano Sassi, Bruno Seny, Sandra Soares Frazao, Benoît Spinewine, Christopher Thomas, Martin Vancoppenolle, Valentin Vallaeys, David Vincent, Laurent White, Eric Wolanski.

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[3] Delandmeter P., S.E. Lewis, J. Lambrechts, E. Deleersnijder, V. Legat and E. Wolanski, 2015, The transport of riverine fine sediment exported to a semi-open system, *Estuarine, Coastal and Shelf Science*, 167, 336-346

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