Estuaries are water bodies where riverine – fresh – and marine – salty – waters meet, leading to complex mixing processes depending on a wealth of parameters and forcings. Such regions are amongst the most productive natural habitats in the world. Understanding and predicting their hydrodynamics was and still is a daunting task that is crucial for the management of the land-sea continuum, where the majority of human activities take place.

The first objective of this thesis is to further develop SLIM (Second-generation Louvain-la-Neuve Ice-ocean Model, www.climate.be/slim), a multi-scale model using the discontinuous Galerkin finite element method in order to improve its ability to represent the aforementioned flows. The stability and accuracy of SLIM’s three-dimensional baroclinic module is improved, allowing the model to tackle a wide range of estuarine flow regimes. In a second phase, the improved model is applied to the estuaries and plumes of two major rivers of the world: the Columbia (Oregon, U.S.A.) and the Congo (Central Africa) Rivers. In both cases, the computational domain covers the coastal ocean and includes the tidally-influenced part of the rivers. The stratified flows inside the estuaries are dealt with, as well as the plumes, within a single unstructured mesh exhibiting a wide range of element sizes, adapted to the geometry of the domain and the key flow features.

It has been seen that cutting-edge simulation tools – going beyond the capabilities of today’s popular three-dimensional models – are needed to tackle the complex phenomena related to stratification, tides and wind stress taking place in regions of freshwater influence. For instance, the development on the continental shelf of the Columbia River plume is highly sensitive to the wind forcing, requiring relevant turbulence closure schemes, sophisticated vertical discretisation and variable horizontal resolution. As for the Congo River, the deep canyon cutting through the estuary and the continental shelf makes this region unique. Its dynamics is shown to share similarities with fjords, i.e. strong stratification and poor ventilation of deep areas, which hence exhibit almost anoxic waters.