Computational efficiency and better understanding of river deltas using Lattice Boltzmann method

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Project introduction:

River deltas are home to half a billion of people, are among the most productive ecosystem on earth, and constitute the main food source for many nations thanks to their fertile soils, and fisheries activities. Deltas form when sediments carried by rivers enter the sea, and form fans of sand or mud which give rise to complex depositional environments. Understanding the evolution of river deltas has become a pressing issue due to climate change, and considering challenges connected to food security, land reclamation, and overpopulation of coastal environments (e.g. Fagherazzi et al., 2015; Leonardi et al.,2016).

Turbulent jet theory, and numerical simulations have been extensively used to investigate the hydrodynamic and sediment transport processes of river deltas, because when rivers enter the ocean they behave as turbulent jets (Figure 1; e.g. Leonardi et al., 2013, 2014; Rowland et al., 2009).

Coastal engineers and oceanographer classically use Navier-Stokes solvers, coupled with sediment transport modules to numerically investigate the sediment paths and morphological evolution of river deltas. Turbulence characteristics, eddies generation, and jets meandering are especially relevant for the morphological evolution of deltas as they regulate the spreading of sediments out of the jet centre, the rapidity of deltas development, the formation of natural levees, as well as the shape of the depositional environment.
However, the detailed modelling of turbulent eddies, and jet meandering features requires high spatial and temporal model resolution and, similarly to what happen in many other geophysical problems, the computational efforts become a limiting factor even when using parallel computing. This is especially true considering that the majority of solvers used by Oceanographer and coastal engineers follow partially implicit numerical schemes which are not optimized for parallel computing. Differently, Lattice Boltzmann method (LBM) as an explicit numerical scheme, requires only neighbour operations which are very suitable for parallel, and GPU computations, and can therefore be much more efficient (e.g. Lin et al., 2010). Unlike traditional computational methods which solve conservation equations, LBM models the fluid as particles subject to collisions and propagations processes over a discrete lattice mesh. Due to its discrete nature, the method has several advantages, especially when dealing with

parallelization algorithms.
While the use of lattice Boltzmann has been extensively tested and is widely diffused in other engineering applications, its use for the modelling of coastal environments is still limited even when the problems to be analysed follow identical physical dynamics such as the ones of a turbulent jet, which, for example, is a classic test case in mechanical engineering. This can be mostly attributed to the lack of communication, and collaboration between experts working in different research fields.

Research questions

This project aims at investigating the following research questions:
The first two research questions are:

- How turbulence, and meandering characteristics of turbulent jets influence the morphological features and the planar configuration of river deltas?
-Which are the environmental factors mostly responsible for the generation of stable or unstable meandering jets?
To answer these questions we will execute a combination of numerical tests using Navier-Stokes solvers commonly used in ocean and earth science. Analysis in relation to these first research questions will help to identify: i) the main morphologies arising from different jet meandering and turbulence features; ii) the main external factors regulating turbulence generation; iii) limitations connected to the use of standard Navier Stokes solvers. After concluding this first part of the analysis, the same numerical tests will be executed using LBM solvers and a comparison between the two methodologies will be made having in mind a third research question, i.e.:
- Can LBM methods be used to realistically model the hydrodynamic of coastal environments?
- Can the use of LBM improve the computational efficiency of hydrodynamic models? To answer this question we will use riverine deltas as test cases and compare the computational efficiency of LBM and Navier-Stokes solvers. The suitability of the different tools for the modelling of coastal settings will be then evaluated.

Work plan

- Formulation of key questions based on literature review, and available data.
- Familiarization with the numerical models, and model runs.
- Execution of numerical experiments aimed at exploring the specified research questions.
- Evaluation of models performance and predictions
- Data analysis, and results interpretation: Results will be critically analysed and discussed to provide useful indicators and parametrizations aimed at identifying the role of climate change and different external forcing on soil salinization and salt intrusion.
- Results dissemination: research outcomes will be disseminated through presentations at international conferences, workshops, as well as the publications of scientific papers and a final report.

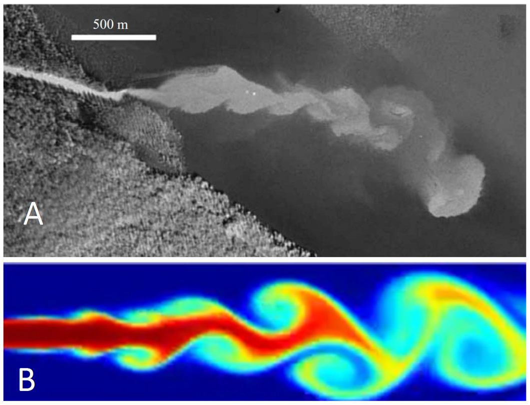

Figure 1. a) Aerial photograph of a channel outlet discharging as a turbulent jet near the Lower Mississippi River near Baton Rouge, LA (from Rowland et al., 2009). b) Numerical simulation of a turbulent jet modelled using Navier-Stokes solvers (adapted from Mariotti et al., 2013).

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