Doctoral thesis at the P' (UPR 3346, CNRS – Université de Poitiers – ENSMA) and I2M (UMR CNRS 5295, CNRS – Université de Bordeaux) Institutes

NUMERICAL AND PHYSICAL STUDY OF PROPAGATION AND EVOLUTION CHARACTERISTICS OF TIDAL BORES OVER ERODABLE BATHYMETRIES

Work context

BABA (BArre de flot et Bathymétrie Augmentée in French) is a research project that aims to understand the hydro-sedimentary dynamics related to the propagation of a (TB) Tidal Bore in internal estuaries by addressing unresolved issues in previous ANR MASCARET project. A TB is a phenomenon occurring in macrotidal estuaries when the tidal wave front propagates against a river current. It has different geometries, ranging from a very long wavelength wave perceptible only with pressure sensors [*Bonneton et al., 2012*], to a 2*m* high breaking wave propagating on the whole river width and at velocities reaching up to 4m/s during spring tides [*Chanson, 2005*] (see Fig. 1).

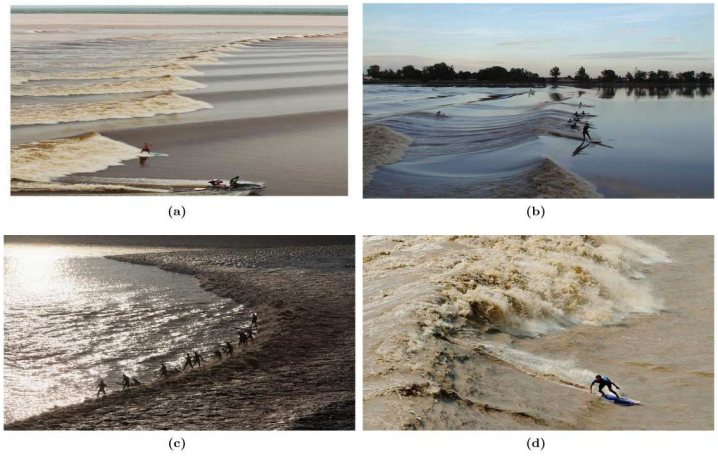


Figure 1 *– Several tidal bores in the world: (a) Bono on Kampar river Indonesia, (b) Mascaret on Dordogne river France, (c) Tidal bore on River Severn United Kingdom and (d) Porooca on Amazon river Brazil [Putra, 2018].*

The macrotidal conditions alone do not explain the development of this front. Its formation and dynamics are also sensitive to the general morphology of funnel-shaped estuaries [*Jouy et al., 2024*]. Its development and characteristics would also be sensitive to the spatial evolution of tidal range in estuaries, the shape of the tidal wave, the intensity of river flow, anthropization and particularly to local bathymetric variations. Observation of different shapes depending on depth, bank slope, sand banks development or meander sinuosity. Short term, bathymetric variations are mainly induced by erosion/deposition cycles partly controlled by the tidal bore itself, or periods of high or low water. The estuaries are morphological systems in constant evolution adapting to variations of controlling factors such as the location of base level, long term tidal cycles, river flow, sediment supply and anthropization [*Grasso et al., 2021*]. Although the factors of TJ and TB formation and dynamics are identified, they are

not yet fully understood due to their spatial and temporal variability. In a context of global change, modifications of estuarine systems are expected in the future [*Elliott et al., 2019*] Sensitive to modifications, TJ and TB could disappear or conversely, strongly intensify in areas where it has currently no impacts [*Chanson, 2005; Bonneton et al., 2012*].

Investigations are needed to characterize the factors controlling TJ/TB development in internal estuaries whose bathymetry changes due to the TJ/TB induced erosion. BABA will study the dynamic interactions between bathymetry, sediment transport and TJ/TB. The physical processes will be studied at the scales of laboratory channels (cm) and estuaries (km). The time scale will vary from a few seconds to several years. BABA is based on 4 complementary approaches: history, in situ measurements, laboratory experiments, numerical modelling and simulations. The thesis topic is on the numerical modelling and simulations.

Proposed work

There have been many works addressing the development of numerical models for the study of water flow and erodible in rivers. Most of existing numerical models are based on the solving of Shallow-Water-Exner equations [*Kazhyken et al., 2021*]. When dispersive wave propagation is predominant, the hydrostatic shallow water equations are not anymore, a relevant model, and non-hydrostatic variants must be considered. The propagation of tidal bores is rich in flow regimes with different characteristics. A transition appears between undular tidal bores dominated by non-hydrostatic effects, and dispersive-like undular tidal bores associated to a hydrostatic wave refraction process due to the variations of the bathymetry within each section [*Bonneton et al., 2012*]. A numerical and theoretical study of this transition has been performed in [*Chassagne et al., 2019*]. In this paper, the authors underline the dynamic process of development and stabilization of finite wavelength undular bores, in which the equilibrium between nonlinearity, dispersion and dissipation is established. In [*Jouy et al., 2024*], a modified version of section-averaged Boussinesq equations has recently been proposed in 1D. The main features of the wave train's free surface have been reproduced using channel Favre waves cases with a fixed and linear geometry, different in the natural environment. The absence of explicit dissipation terms in propagation, such as the nonlinear shallow water, Boussinesq and Serre-Green-Naghdi equations usually assuming irrotational ideal flow, requires some implicit or explicit closure for these effects [*Lannes, 2020*]. The interaction between modelling and numerics becomes relevant. Numerical dissipation can be a surrogate for the lack of physical dissipation, and indeed it does allow to obtain a qualitatively correct description of the underlying processes, as the results of [*Chassagne et al., 2019*] show. However, the dependence on mesh size makes this approach less reliable when a robust quantitative prediction of bore dynamics is necessary.

Is it possible to simulate the propagation of different types of tidal bores in real rivers by means of actual models based on the nonlinear shallow water, Boussinesq and Serre-Green-Naghdi equations? Does solving the system of shallow water equations, the Exner equation, and the advection-dispersion equation allow to study the interaction between river bathymetry and tidal bores?

In the thesis, the proposed work will attempt to address numerically the question of characterizing the hydrodynamic processes and regimes having the largest potential impact on morphological modifications. As already said, the work by [*Chassagne et al., 2019*] has highlighted the existence of two modes of propagation of a bore, of which one is essentially hydrostatic, the other fully non-hydrostatic. The second mode involving vertical kinematics of much larger magnitudes is clearly more prone to produce particle suspensions and may be more interesting for morphodynamical chances. Note that these modes have been not only produced in numerical models but observed in

measurements in artificial and natural environments [*Jouy et al., 2024*]. In addition, one needs to account for the dynamics of vorticity and the interaction with the boundary layers, which for sure play a crucial role in the actual morphological modifications due to the bore. To address these issues, the numerical modelling adds more levels of depth to the hierarchy of investigation tools used in BABA. More specifically, to complement laboratory and in situ measurements in BABA, it will consider three family of models of increasing fidelity. The lowest level of fidelity is represented by depth integrated models for which we will make use of the solver TELEMAC2D [*Almoghayer et al., 2024*]. This model has the advantage of having a reduced computational cost which should allow its use for all the cases, including the in situ ones studied in BABA. To include a richer description of the vertical dynamics, it will consider using the multilayer model implemented in TELEMAC3D (EDF) [*Almoghayer et al., 2024*]. This model provides an intermediate fidelity prediction at moderate computational costs, which on one hand may allow to also include realistic simulations, but more importantly allows to exploit TELEMAC3D's functionalities in terms of sediment modelling to go beyond purely hydrodynamic predictions and have some estimates for morphodynamical chances. The three-dimensional Navier-Stokes solver NOTUS allows to perform numerical simulations tackling processes with length scales range from several meters to the submillimetre scale, as well as all physical processes going from the propagation of the waves generated by the tidal bore to the secondary waves propagating upstream the river channel, including vorticity dynamics, and boundary layers development and separation [*Simon et al., 2023*].

In order for the thesis to be a success, it is first necessary to define benchmarks based on simple geometries and in situ cases (task 1). The simple geometries will be taken from scientific literature (for example, the rigid trapezoidal channel configurations used by Chassagne *et al.* (2019) and Jouy *et al.* (2024)) and the project with the laboratory data obtained in BABA. The in situ cases will be given by BABA. These benchmarks, defined in this way, will be used to perform code-to-code benchmarking and a comparison with fields measurements and laboratory experiments. Each model will be applied to all the benchmarks. This will correspond to one task per model, task 2 NOTUS, task 3 TELEMAC2D and task 4 NOTUS.

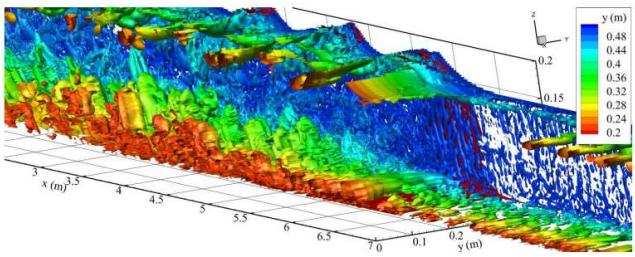


Figure 2 *– Tidal bore simulated with NOTUS [Simon et al., 2023].*

Reference

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Themes Field

Applied Mathematics, Fluid Mechanics, Scientific Computing and Modelling

Profile and skills sought

Candidates motivated by collaborative work in an academic context bringing together physicists, numerical scientists, applied mathematicians and computer scientists within the framework of a national collaborative project.

A Master's degree in applied mathematics, mechanics or physics with a strong focus on simulation is preferred.

The following characteristics are required:

- A strong scientific curiosity is essential;

- Numerical simulation analysis skills are very important;

- Programming skills are appreciated, as well as initial experience in projects involving numerical simulations;

- A solid knowledge of transfer physics is essential;

- Short and long-term travel to national partners and participation in national and international conferences and workshops are envisaged;

- Communication skills are required.

General information

Contract type: scientific fixed-term contract (36 months)
Planned start date: 1st October 2026
Working time: complet time
Salary = 1,800 euros (gross salary)
Desired level of education: master and/or engineering degree
Supervisors: Pierre Lubin (pierre.lubin@bordeaux-inp.fr, Institute I2M) and Anthony Beaudoin (anthony.beaudoin@univ-poitiers.fr, Institute P')
Location : Institut P', Département Fluides, Thermique, Combustion, SP2MI Bât. H2, 11 Boulevard Marie et Pierre Curie, TSA 41123, 86073 Poitiers Cedex 9, France