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## Modeling the influence of the gravitational circulation on estuarine sand dunes

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Estuaries are hydrodynamically complex regions where a river meets saline water. In many estuaries, sand dunes can be found; these are large-scale rhythmic bedforms. Observational studies have revealed several estuarine processes that affect sand dune dimensions and dynamics. These are for instance sand-mud interactions and tidal amplification. Here, we build upon an observational study in the Gironde Estuary, France, which indicated that the gravitational circulation – present in many estuaries due to the interaction between (heavy) seawater and (light) freshwater – is significant enough to affect sand dunes (Berne et al., 1993). Our aim is to understand the effect of this circulation on bedform dimensions and dynamics, and to explain the underlying mechanisms.

To this end, we develop an idealized process-based model which contains descriptions for the motion of water and non-cohesive sediment transport within a local section of a generic estuary. On this geometry, we impose a steady river discharge, superimposed on an oscillatory tidal flow. Furthermore, we include the effect of salinity-induced density differences by following the model as presented by MacCready (2004). In here, we adopt a diagnostic approach, meaning that the along-estuarine salinity gradient is imposed on the domain instead of being an unknown which interacts with the flow. The alternative, a so-called prognostic approach, is also explored.

This model is analyzed using a so-called linear stability analysis, as applied earlier to e.g. marine sand waves (Hulscher, 1996) but not yet to estuarine dunes. Within this analysis, the reference state with a flat bed is slightly perturbed, and the model shows whether these perturbations decay (the flat bed is stable) or grow (it is unstable). The model results provide a generic insight into the role of the gravitational circulation on bedform dimensions and dynamics, particularly growth and migration; the latter possibly directed opposite to the river discharge. To test our model, it is then applied to the specific settings of the Gironde. Furthermore, a systematic sensitivity analysis shows the effect of environmental parameters on bedform development when subject to the gravitational circulation. Including this estuarine-specific process is a novel and first step in obtaining a solid understanding of the behavior of estuarine sand dunes.

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