

Effects of a tidal farm on the transient and residual circulation of an estuary

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Summary: This work is concerned with the impact of the extraction of energy from the flow by means of a tidal farm on the transient and residual flow in an estuary. The investigation is conducted through a case study. A 3D, high-resolution hydrodynamics model is implemented and successfully validated based on field data. The model is then applied to investigate the effects of the tidal farm in winter and summer scenarios. After analysing the impacts on the transient flow, the residual flow is considered; it is found that the farm does not alter the two-layer estuarine circulation drastically, but it does weaken the residual velocities over a large area, which could have consequences in terms of water quality and biological productivity.

Introduction

Estuaries are particularly complex and sensitive systems; they are also some of the areas with the largest tidal resource worldwide. Prior to exploiting this resource by means of a tidal stream farm it is fundamental to understand its impacts on the system – with all its complexity. This requires taking into account the effects of the energy extraction not only on the transient circulation (the instantaneous flow velocities) but also on the residual circulation (the net flow over one or a number of tidal cycles). The latter is often disregarded in spite of its importance for water quality and biological productivity, among other aspects.

This work examines the effects of a tidal farm on the 3D transient and residual circulation of an estuary through a case study: Ria de Ortigueira (NW Spain). An estuary of the ria type characterised by a positive estuarine circulation, a pronounced tidal asymmetry in its inner section (with flood dominance) and a high biological productivity, Ria de Ortigueira presents areas with potential for tidal stream exploitation [1].

Methods

The investigation of the impacts of a prospective tidal farm was carried out by means of a 3D hydrodynamics model solving the baroclinic Navier-Stokes equations [2]. The vertical column was discretised into 12 boundary-fitted σ -layers. The horizontal spacing was 50 m \times 50 m in the area of interest. The tidal forcing was prescribed through the main nine harmonics (including M4) at the outer grid boundary, and the river inflow was considered with two cases, representative of winter and summer conditions. Using field data from an Acoustic Doppler Current Profiler (ADCP) and a tidal gauge deployed in the inner and middle ria, the model was successfully validated, with values of the correlation coefficients close to unity. The extraction of power from the flow was modelled for the farm using the momentum sink approach. In another investigation into the effects of a tidal farm on the flow in an estuary east of Ria de Ortigueira [3], a high-resolution, 2DH model was implemented, which enabled to represent the extraction of energy by each individual turbine in the farm.

Results

With respect to the transient circulation, it was found that the flow is strengthened by up to 15% (0.3 ms^{-1}) beside the farm, and weakened in front of it and in its lee (Fig. 1). Differences between the winter and summer cases were negligible. The largest impacts occur during the ebb.

As regards the residual flow, its general 3D pattern, and in particular the two-layer, positive circulation in the inner and middle rias, is not altered in any fundamental way by the operation of the tidal farm, but it is weakened by up to 0.03 ms^{-1} (approx. 10-15%); importantly, this reduction in the residual flow extends over a large area (some 2 km away from the farm), much larger than that affected in terms of transient flow

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Conclusions

The consequences of the modifications to the transient and, in particular, residual flow in an estuary caused by a tidal stream farm are far from being fully understood. In light of the previous results, in which it emerged that the residual circulation was affected over a large area, and taking into account the high sensitivity of estuarine systems, it may be concluded that the investigation of the impacts of a tidal farm on the hydrodynamics of an estuary should attend not only to tidal levels or velocities but also to residual flow.

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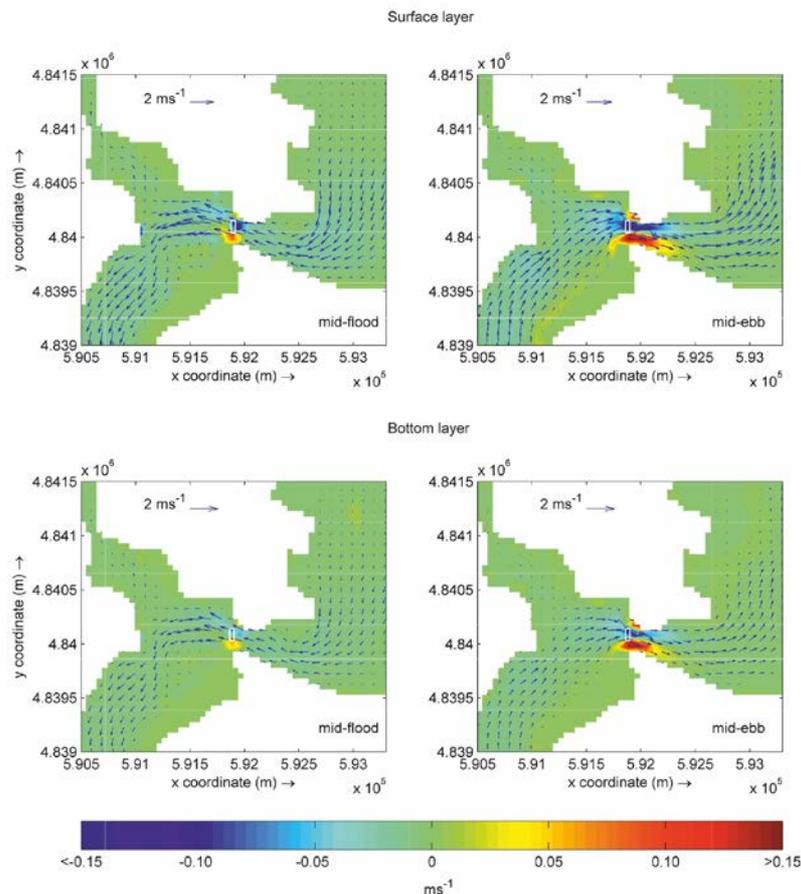


Fig. 1. Modification of the transient circulation caused by the tidal farm in the surface and bottom layers at mid-flood and mid-ebb (winter case).