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Assessment of the impacts of tidal stream energy through high-resolution numerical modeling

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ABSTRACT

When planning the installation of a tidal farm, the disturbances on the marine environment associated with its operation must be studied in detail. The objectives of this paper are to assess the impacts on the hydrodynamics (water level and flow velocity) and to determine how these impacts can alter the tidal resource. For this purpose, a high-resolution model of Ria de Ribadeo (NW Spain) is used to describe the potential effects resulting from the operation of two prospective tidal farms. Two different scenarios of extracted power from the flow (high and low) are analyzed. Overall, it is found that the impact on the water level is negligible, but that on the flow velocity is significant. The velocity is reduced upstream and downstream the farm, and increased beside it. These effects are enhanced in the scenario with the higher power extraction. Finally, these modifications in the flow pattern alter the available energy density at the tidal turbine, with a reduction of 21% and 12% for the high and low levels of power extraction, respectively.

1. Introduction

The aim of increasing the share of renewable energy sources to the total energy production [1–4] has brought a substantial increase in the interest in marine energies over the last years [5–9]. Within them, tidal stream energy, which taps the kinetic energy of tidal currents has been steadily gaining ground [10–14] for its advantages in terms of: (i) predictable resource derived from its astronomical dependence; (ii) nonexistence of extreme flows (unlike wind energy, for example) (iii) high load factor due to the fluid properties [15] and (iv) minimal land occupation and visual impact [16]. On the other hand, the main disadvantages are: (i) the fluctuating nature of the resource (astronomical dependence), which requires efficient control systems to optimize the power output of the converters [17–19]; (ii) the fact that the tidal turbine technology is still in its infancy [20] and (iii) the possible impacts on the marine environment. On these grounds, recent research has shown that these impacts may alter numerous environmental variables such as: tidal regime [21], hydrodynamics [22], sediment transport and water quality [23–28]. These impacts may not be restricted to the vicinity of the tidal arrays and in some cases could be noticed a few km away from the arrays (far-field impacts) [24]. In addition, the operation of a tidal stream farm modifies the tidal resource varying the power density distribution and decreasing the available energy resource [21,29]. Therefore, when planning a new tidal stream farm all these factors need to be studied in detail.

The goal of this study is to assess the potential impacts of the tidal energy extraction on the flow using as case study Ria de Ribadeo, a specific type of estuary in NW Spain. With its main axis extending 10 km along the north–south direction, Ria de Ribadeo has a mean width of 800 m and a total surface area of 8.59 km^2 (Fig. 1). The main fresh water contribution to the ria is the River Eo, with an average flow rate of 18.83 $m^3\ s^{-1}$. The tidal regime is purely semidiurnal, with a Form Factor $F = 0.068$; the maximum tidal range is 4.6 m, which produces a substantial tidal prism up to 20.6 Hm^3 in spring-neap tides. As a result of this tidal prism and the coastline shape, significant tidal flows occur in certain areas of the estuary, therefore, Ria de Ribadeo constitutes an excellent location for installing a tidal stream farm and, consequently, for studying the impacts that this plant would cause on the estuarine hydrodynamics and the available tidal energy resource. For this purpose, a numerical model of the ria, which simulates the tidal energy extraction by adding a retarding force to the local momentum

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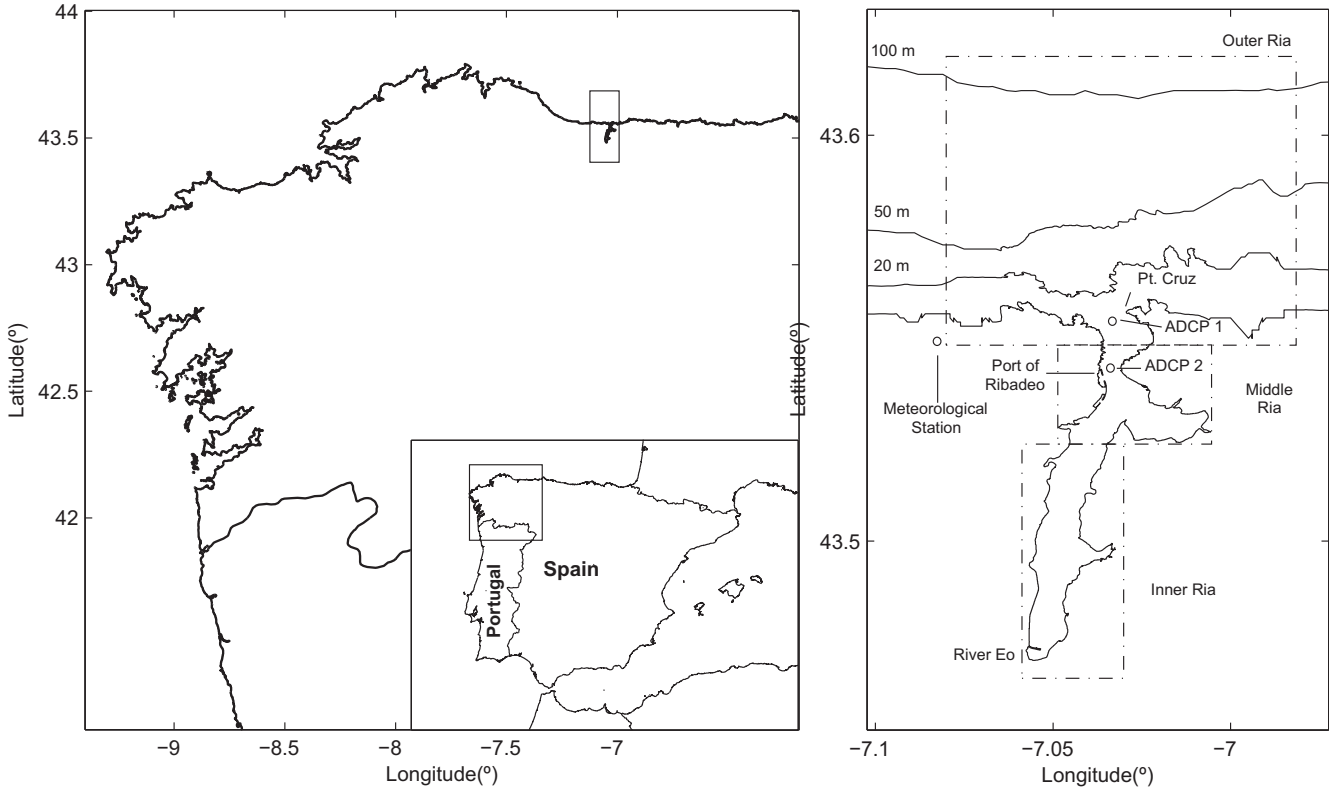

Fig. 1. Ria de Ribadeo (right) in Galicia, NW Spain (left).

equations, is implemented and successfully validated based on field data. After validation, the model is used to illustrate the effects associated with the operation of two tidal farms on the flow velocities and water levels; and to determine how the modifications on the flow can alter the power density distribution and, therefore, modify the available tidal energy resource.

2. Materials and methods

2.1. Numerical model

The model, Delft 3D FLOW, is a finite difference code that solves the Navier–Stokes equations along with the transport equation.

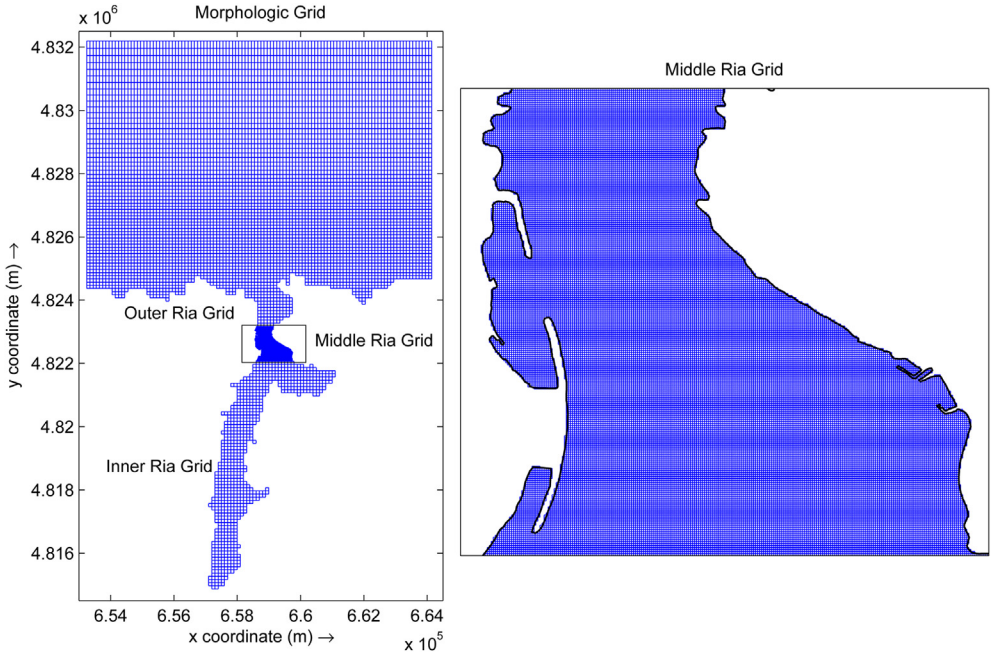

Fig. 2. Computational grid.