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An anisotropic mesh adaptation approach for regional tidal energy hydrodynamics modelling

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The construction and operation of tidal range structures has been in the spotlight recently due to the unique role they could play in the future clean energy generation mix. Tidal energy proposals must first be subject to rigorous scrutiny over their feasibility and environmental implications, e.g. water quality and sedimentary impacts. Numerical models plays a key role in such studies. Here, a novel coastal ocean finite element model has been coupled with tidal power plant operation algorithms that can simulate the hydrodynamics associated with plant different operational strategies. The method has been applied to assess and optimise performance over time to maximise electricity output over variable spring-neap tidal conditions. Informed by the design of the constituent turbines and sluice gates installed, the models can simulate the tidal power plant operation, providing insight into the energy output variability and any hydro-environmental impacts. However, this is inevitably a highly multi-scale problem spanning the metre to the 100s of kms scales, and needing to be run over at least monthly time scales. This therefore represents a significant computational challenge, which currently is somewhat tractable through the use of depth-averaged equation approximations, and variable resolution unstructured meshes. Here we consider the use of adaptive mesh methods with a view to faster, higher resolution simulations, and with an eye to future fully 3D simulations.

In this work we consider simplicial unstructured meshes, notably because they make it easier to mesh accurately complex domains. In the current fixed mesh case, the computational mesh is generated prior to the simulation, and is potentially used to model multiple different scenarios, hence the degrees of freedom are not necessarily distributed optimally. Mesh adaptation addresses this issue by generating meshes where the location of the degrees of freedom minimizes a certain error in the model. Mesh adaptation results in a gain both in terms of accuracy and CPU time that has been well documented. In this work, we consider anisotropic metric-based adaptation. The generation of the adapted meshes is driven by metric fields that prescribe the optimal size and orientation for each element, thus resulting in a better control of the distribution of the degrees of freedom.

We will detail how preliminary adaptive simulations of tidal power plants were implemented, combining several codes, notably the Firedrake-based coastal ocean modelling framework Thetis, and Pragmatic, an anisotropic remeshing library. In particular, we will focus on adapting according to the formation of large-scale vortices due to the operation of hydraulic structures within tidal range impoundments. Such patterns have previously been considered accountable for scalar entrainment that in turn impacts on water quality and sediment deposition. We will analyse the gain that can be expected from mesh adaptation in this context.