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The use of adaptive meshes in ocean modelling: considerations from simulations of the lock-exchange flow

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Ocean dynamics occur at scales that vary over many orders of magnitude, the representation of which presents a major challenge for numerical ocean models. Adaptive meshes aim to model a range of scales in an efficient manner through refining or coarsening the mesh depending on the evolution of the flow which offers a promising approach for ocean modelling. Using an adaptive mesh adds another layer of numerical complexity to the model configuration. Therefore, the performance of such meshes in numerical models and the implications for the flow dynamics require careful consideration.

Here simulations of the two-dimensional lock-exchange flow are used to investigate the potential of adaptive meshes. The lock-exchange is a widely studied laboratory-scale set up that produces two horizontally propagating gravity currents. The physical processes encountered occur in gravity currents over many scales, for example ocean overflows, sediment-laden density currents and atmospheric dust storms. This makes the lock-exchange an excellent test-case for assessment of adaptive meshes and their applicability to ocean flows. Simulations are performed with the finite-element model, Fluidity-ICOM[1], using a non-hydrostatic, Boussinesq formulation of the Navier-Stokes equations. The performance of fixed and adaptive unstructured meshes are compared through evaluation of the Froude number (non-dimensional front speed) and quantification of the mixing.

The mesh adapt is guided by a metric-tensor (metric) which is key to the ability of the adaptive mesh to represent the flow. The metric employed in Fluidity-ICOM is simple, based on the curvature of the solution fields and user-defined solution field weights. Changing the metric settings, for example by reducing the horizontal velocity field weight near the boundaries, allows for interactions of the flow features and their importance to the diagnostics to be distinguished. Good representation of the density interface and the region at the gravity current front are both found to be crucial. With configurations that enable this, the adaptive meshes are seen to perform as well as high-resolution fixed meshes whilst using at least one order of magnitude fewer nodes. The Froude numbers also compare well with previously published values.

Adaptive meshes with a simple metric are employed successfully here as both the diagnostics of interest are clear and an understanding of the metric and physics are used to guide the settings. In the ocean, as the complexity of the scenario increases, these factors will remain key to appropriate use of such meshes. The efficiency gains suggested by the reduction in the number of nodes used by the adaptive meshes are encouraging. Adaptive meshes that employ simple metrics have the potential for effective use in ocean modelling, in particular, for regional or basin scale applications, process studies and idealised geophysical fluid dynamics problems.

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[1] http://amcg.ese.ic.ac.uk/FLUIDITY