Comparison of two hydrodynamic models for investigating energy extraction from tidal flows

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Introduction

Hydrodynamic models are important tools for predicting the environmental effects of tidal energy developments.

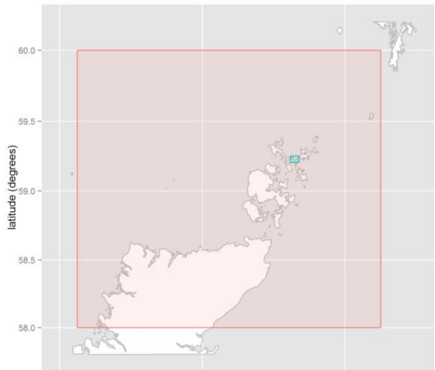


Figure 1: Map of the north of Scotland, showing the domains of the MIKE3 (red) and TideModeller (green) models.

Two commercial packages were employed to model tidal turbines in Lashy Sound – a strait in the Orkney Isles of Scotland in which Scotrenewables plans to build a 30MW tidal farm. These two models use different approaches and assumptions, and have historically been used in very different ways at very different resolutions to one another. Recently, both types of model have been used at resolutions in the range 10-100m [1, 2] to model tidal energy extraction.

A thrust curve for the tidal turbines was generated using the methodology described in [3], and then modified substantially based on advice from Scotrenewables. Turbines were defined as having twin 13m diameter rotors, centred 11m below the surface. A hypothetical array layout was used, consisting of seven devices in the centre of Lashy Sound with a total rated power of approx. 5MW.

The same bathymetry, coastlines & turbine parameters were used in both models. Beyond this, however, the approach taken was to follow best practice for each model rather than using identical inputs.

The MIKE3 model

MIKE3 by DHI solves the shallow water equations in 3D under a hydrostatic assumption. It is designed for regional-scale modelling.

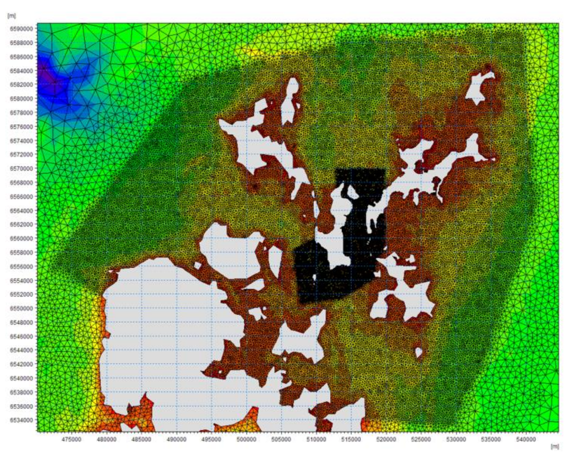


Figure 2: The inner part of the MIKE3 computational mesh. For the full extent of the model domain see Figure 1.

A flexible mesh was built over a wide domain (Fig. 1) with a maximum node spacing of ~12km at the boundaries and a minimum spacing of ~100m in the area of interest (Fig. 2). Tidal turbines are treated as sub-grid objects.

The TideModeller model

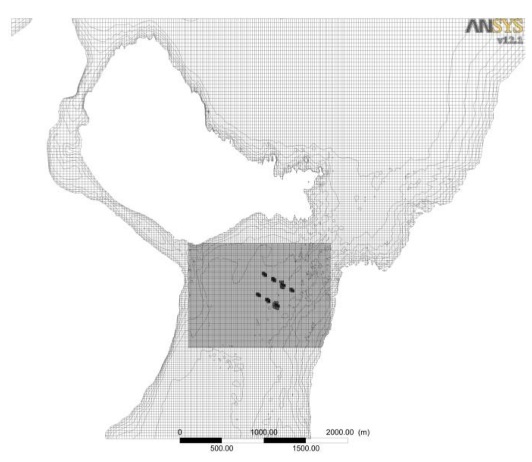


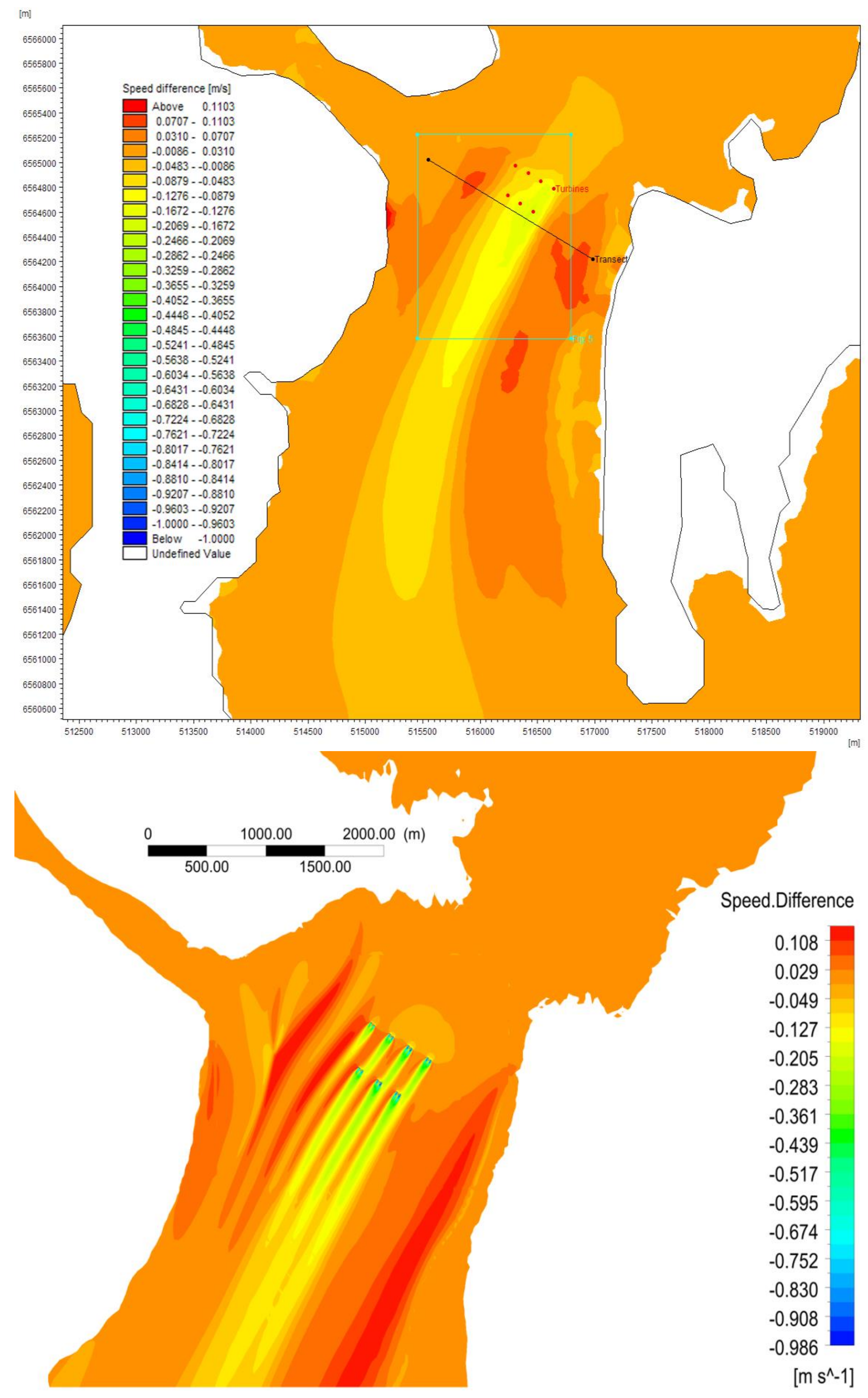
Figure 3: The full TideModeller computational mesh. Note that this entire model domain covers only a part of the densest region in Figure 2.

TideModeller is a simplified front end to the CFX package by Ansys, designed for simulating tidal arrays. CFX solves the full 3D Reynolds-averaged Navier-Stokes equations, without the shallow water or hydrostatic assumptions employed by MIKE3. It has historically been used for a wide range of CFD problems in industry.

A rectilinear mesh was used, covering only the immediate area of Lashy Sound, with a ~8m resolution in the area of interest. Adaptive meshing was used to refine the regions around the turbines to give 5-7 cells across a rotor diameter of 13m.

TideModeller operates in a steady-state mode. One time step in the MIKE3 model, at the peak of a springs flood tide, was used to provide a constant upstream boundary, and the CFX model was stepped forward until the domain settled to a steady state.

Results



Figures 4a & 4b: Changes in current speed at turbine hub height resulting from energy extraction in MIKE3 (top) and TideModeller (bottom), with matching colour scales. In Fig. 4a the red dots, represent turbine locations, the cyan box shows the area covered by Fig. 5, and the black line shows the transect displayed in Fig. 6.

Simulations were completed with and without turbines, and the differences in speed at turbine hub height were plotted in both packages (Figs 4a & 4b).

The MIKE3 model is unable to resolve the effects of individual turbines, and shows a region of reduced speed covering the width of the array. This region has a velocity deficit of up to 0.15ms^{-1}, or 6% of the undisturbed speed. The area of reduced speed starts from slightly upstream of the turbines and remains discernable for over 3km downstream. To either side of the farm is a region of increased speed (by up to 0.07ms^{-1}), predicting that water will be channelled to either side of the array by the impedance that the turbines represent. The magnitude of the effect, and hence of the speed differences, is low because the simulated array only removes a small fraction (~3%) of the kinetic energy passing through the channel.

TideModeller shows a similar overall pattern of regions of raised and lowered current speed. Its higher resolution allows it to resolve individual turbines' wakes, which have velocity deficits of up to 0.8ms^{-1} (30% of the undisturbed speed) within a few rotor diameters. A broader effect from the array as a whole is visible to the edge of the domain, approx. 2km away. Speed increases of up to 0.05ms^{-1} are predicted immediately downstream of the gaps between turbines, showing channelling of flow through these spaces, in addition to larger-scale diversion of flow around the outside of the array.

Outputs from a central area of both models were interpolated onto a regular 200m square grid — coarser than either model's computational mesh — in order to remove the visual effects of the resolution difference. Plotting the results side by side (Fig. 5) shows great similarity.

Transects taken across the flow approx. 6 rotor diameters downstream of the array show broadly similar patterns in each model but, as with the horizontal planes, TideModeller's higher resolution shows larger changes in current speed in smaller regions than MIKE.

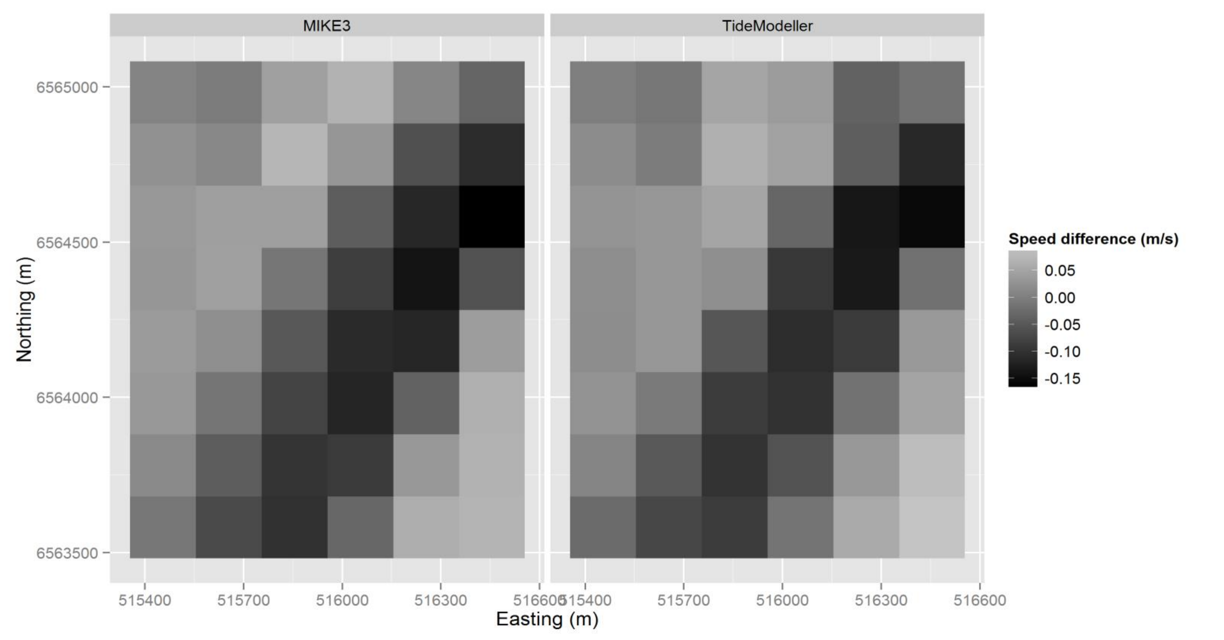
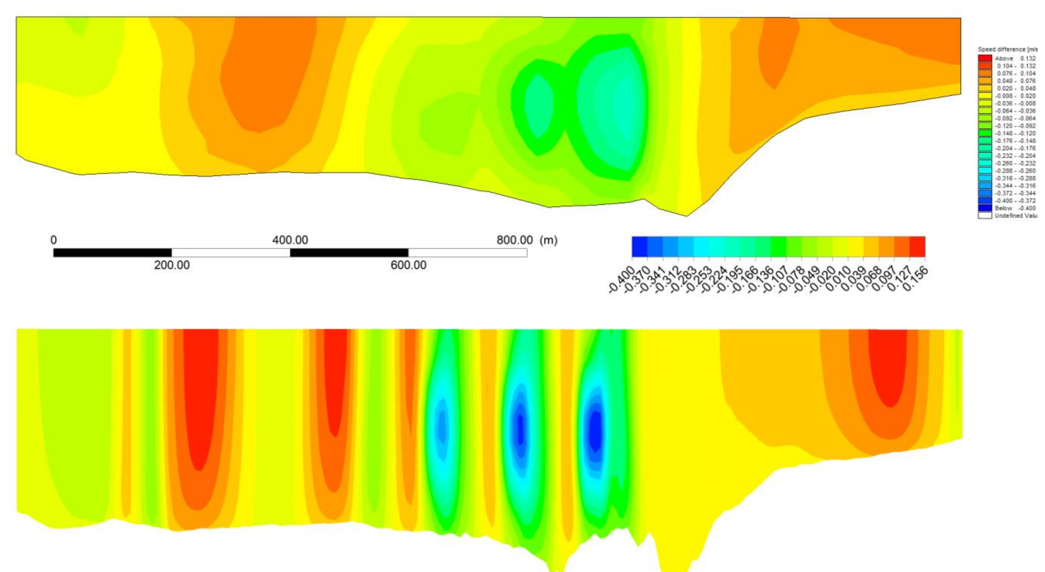


Figure 5: Comparison of speed differences from a portion of both models, interpolated onto a common 200m grid, which is coarser than the resolution of either, using a common colour scale. The area covered is shown by the cyan box in Fig. 4a.



Figures 6a & 6b: Cross-section through the channel approx. 6 rotor diameters downstream of the turbine array, from MIKE3 (top) and TideModeller (bottom). Colours represent changes in speed when turbines are included in the model. The position of the transect is marked by the black line in Figure 4a.

Discussion & Conclusions

We have compared two different types of hydrodynamic model and established that, when spatially averaged on a 200m grid, both produce similar predictions (Fig. 5). Both predict a reduction in current speed of approx. 0.1ms^{-1} at 1km downstream of the array. Without this averaging, TideModeller shows much greater effects over much smaller areas than MIKE3, due to its higher resolution.

The similarity in overall predictions can provide some confidence in the accuracy of both models, but the two approaches have advantages and disadvantages for different applications:

- MIKE3 is limited by resolution, this mesh being unable to resolve the effects of individual turbines within our example array. TideModeller is therefore likely to be a better tool for examining detailed array layouts, changes to turbine design parameters, interactions between turbines, or highly localised environmental effects such as scour.
- TideModeller is primarily limited by the small domains that it must use. It is not possible to use TideModeller to study far field effects such as large-scale changes to current patterns, sediment movement or ecology. When arrays with very high blockages are simulated, the proximity of the upstream boundary may introduce unnatural constraints, but this has not been a problem in the relatively low-blockage simulations conducted here.Other restrictions on TideModeller's utility may come from its steady state approach, which means that only specific instants can be simulated rather than effects over time. However, using TideModeller in conjunction with a lower-resolution time-stepping model may be an acceptable solution for many applications.

Inspection of Figure 6 suggests a benefit of using a 3D model when looking at environmental effects: where turbines are present, the flow is not uniform with depth and does not follow a standard log-law vertical shear profile. A 2D model may therefore be inaccurate in predicting the effects of energy extraction on sediment and benthic habitats, at least in the near field.

References

[1] V. Ramos, R. Carballo, M. Álvarez, M. Sánchez, and G. Iglesias, "Assessment of the impacts of tidal stream energy through high-resolution numerical modeling," Energy, Sep. 2013.

[2] S. Crammond, R. Caljouw, I. Jones, A. Wells, I. Hamill, and O. Petersen, "MeyGen Tidal Energy Project: Numerical Modelling of Tidal Turbine Wake Interactions," presented at EWTEC 2013, Aalborg, 2013.

[3] M. C. Easton and D. K. Woolf, "The influence of non-linear turbine dynamics on the environmental stress of tidal stream arrays," presented at the EWTEC 2013, Aalborg, 2013.

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