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COMPARISON OF TWO TYPES OF HYDRODYNAMIC MODEL FOR INVESTIGATING THE ENVIRONMENTAL IMPACTS OF ENERGY EXTRACTION FROM TIDAL FLOWS

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ABSTRACT

Two commercial suites, MIKE3 by DHI and TideModeller by Ansys, are used to simulate energy extraction by an array of tidal turbines in Lashy Sound, Orkney. We compare the predictions of the two models for the effects of energy extraction on flow speed and water level, and consider the advantages and disadvantages of the two modelling approaches for various environmental impact applications.

INTRODUCTION

Numerical hydrodynamic modelling of flow is a key tool in predicting the environmental effects of energy extraction from tides. Two types of model are considered for this work:

- High resolution systems using the full Reynolds-averaged Navier-Stokes equations (hereafter referred to as "CFD") are typically used for studying small-scale flow patterns at the scale of individual turbines.

- Shallow water equation solvers, which use simplifications of these equations and usually run at lower spatial resolutions. Historically, these have been used for regional-scale models covering tens to hundreds of km.

Recently, in representing the effects of turbines on the surrounding area, users of both types of model have converged towards grid resolutions of 10-100m ([1], [2]). This is a higher resolution than was common for shallow water solvers in the past, and a lower resolution than was common for CFD.

In this work we apply both approaches to Lashy Sound, a channel between the isles of Eday and Sanday in northern Orkney, Scotland. We insert tidal turbines into both models and qualitatively compare the form of the results produced and the advantages and disadvantages of each for predicting environmental impacts. Quantitative comparisons of the models' predictions are intended in the future.

The software used for this study was MIKE3 FM HD (2012 version) from DHI, and TideModeller, which is an application-specific front end to the CFX (version 12.1) CFD modelling package from Ansys.

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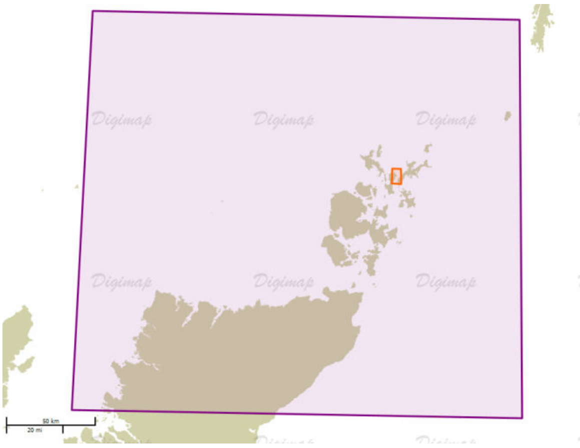

Figure 1: Map of the north of Scotland, showing the extents of the domains of both models: MIKE3 model in purple and TideModeller model in orange. Base map © Crown Copyright / SeaZone Solutions Ltd 2013

Previous work [2] has applied a similar approach to a different location, but used the MIKE21 2D solver rather than the MIKE3 3D one, and was focussed on resource assessment rather than environmental impacts.

MIKE3 MODEL

MIKE3 solves the shallow water equations under the Boussinesq and hydrostatic assumptions, using a cell-centred finite volume method with explicit time stepping. Horizontally it uses a triangular unstructured mesh, while vertically a structured grid is used with sigma-coordinate layers [3].

The mesh was built with a number of concentric zones of increasing horizontal density, cumulating in node spacings of approximately 100m in Lashy Sound and the Fall of Warness. Ten equally spaced vertical layers were used. Bathymetry was used from three sources: a) For Lashy Sound itself, data from Scotrenewables to match that used in TideModeller; b) For the remainder of the Pentland Firth & Orkney Waters (PFOW) area a 20m gridded bathymetry, produced by ABPMer for The Crown Estate; c) For outer areas not covered by this dataset, the commercial SeaZone product. Datum corrections, necessary to merge these three datasets, were obtained from the VORF model [4].

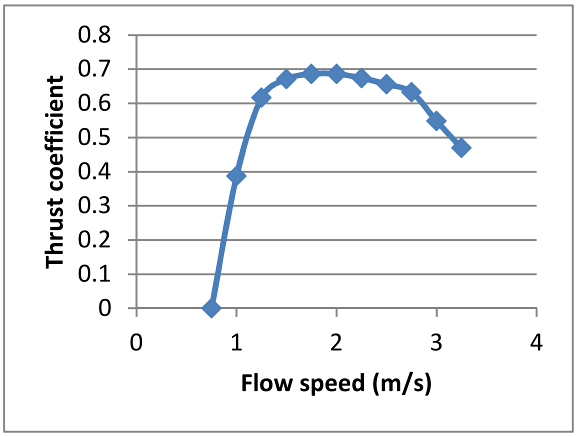

Figure 2: Thrust curve used in the MIKE3 model

Eddy viscosity, representing sub-grid turbulence, was modelled horizontally using the Smagorinsky formulation and vertically with a log law. Open boundaries were forced with water level information from the DTU10 ocean tide model [5], which provides 12 tidal constituents at 0.125° resolution. A Nikuradse equivalent bed roughness of $k_s = 2.0$m was adopted following calibration against ADCP data at the Falls of Warness test site.

The turbine diameter was specified as 10m, in order to leave a minimum of 5m clearance above and below the rotor, and a thrust curve, shown in Figure 2, was derived from information presented in [6]. The turbines were assumed to be of a "weathervaning" type that would always face directly into the direction of the flow.

TIDEMODELLER MODEL

CFX solves the full Reynolds-averaged Navier-Stokes equations, without the shallow water or hydrostatic assumptions employed by MIKE3. The model for Lashy Sound covers a relatively small area (see Figure 1), but does so at a high resolution. It uses a rectilinear grid with a 24m base resolution, which is further refined in the area around the turbines. Ten vertical layers are used. The solver is used in a steady-state mode. As such it ignores the cyclic nature of tidal flow, and simulates specific instants in time.

Open boundary forcing is by flow velocities, extracted from the wider MIKE model. The bed roughness parameter was set to $k_s = 0.1$m, based on prior experience with the model. This is lower by an order of magnitude to the value used in MIKE. Because bed roughness is used as a calibration parameter, it implicitly embodies not only the actual bed roughness but also other processes that are not included in the model [7]. As such, it is not surprising that a different value is needed in a different model that makes different assumptions. In particular, some bedforms that are of sub-grid scale in MIKE, and are thus included in the bed roughness parameter in that model, will be explicitly modelled as bathymetry on the finer grid used in TideModeller.

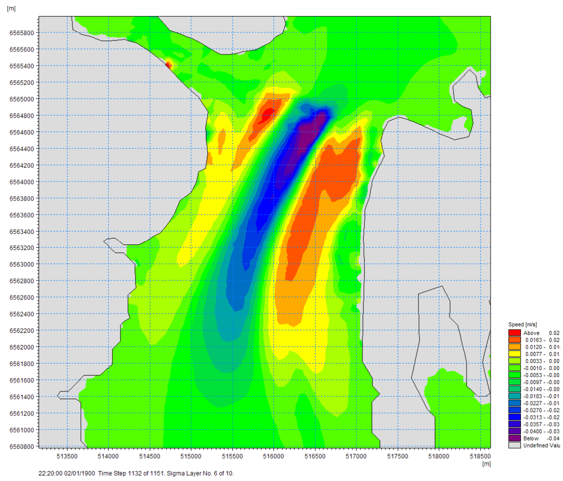

Figure 3: Example output from MIKE3, showing differences in current speeds in a mid-layer resulting from the introduction of turbines.

The turbine parameters used for this illustrative run are not available due to commercial confidentiality. It is intended to develop parameters for a generic turbine that are acceptable to a range of developers and use this for future study.

EXAMPLE RESULTS

Initial testing with MIKE3 used a relatively low level of energy extraction, and as such the effects of turbines on the flow are very minor (in the order of 0.5%). Nevertheless, they can be clearly seen by running the same simulation with and without turbines, and plotting the differences in predicted current speed, as shown in Figure 3.

Figure 4 shows a sample output from TideModeller, in which absolute current speed is plotted, and the effects of individual turbines on the tidal flow are clearly visible.

At this stage Figures 3 & 4 are not directly comparable, but the expected outcome of this work is to quantify of the effect of the turbines on the flow in both models and to use this comparison to explore advantages and drawbacks of both approaches according to the application. Example applications are: a) Predicting changes in water level as a result of a development; b) Predicting changes in velocities and flow patterns resulting from a development, which could then be applied in predicting sediment movement, larval dispersion, or other environmental effects.

OBSERVATIONS & DISCUSSION

MIKE3 shows a speed reduction behind the farm as a whole, and shows increases in speed to either side as water is diverted by the blockage, but it is not possible to pick out individual turbines, nor to see the individual wakes from them. TideModeller, benefiting from its higher mesh resolution, clearly shows an individual speed deficit downstream of each turbine. It is not practical to increase MIKE's resolution to that used by TideModeller due to the computational effort involved.

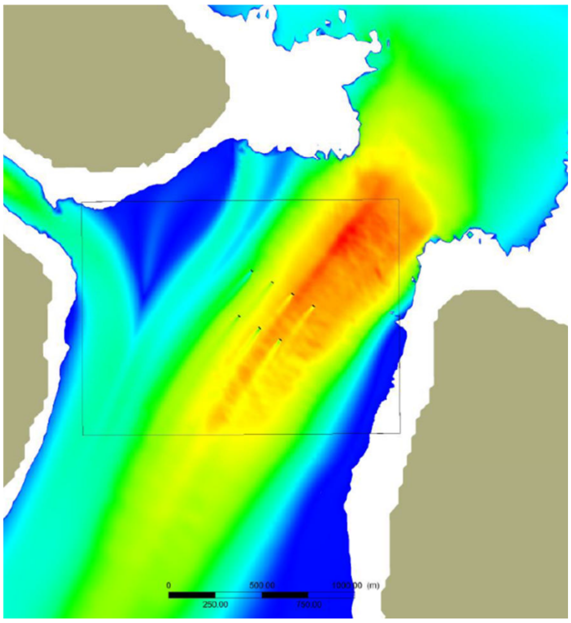

Figure 4: Example output for an illustrative farm layout from TideModeller, clearly showing wakes from individual turbines in a mid-layer. Image courtesy of Ansys. Colour scale deleted to protect commercial confidentiality.

TideModeller's steady state approach means that it is not able to take inertial effects into account. This approximation is likely to be better for a short channel – where the timescale for water to travel along the channel is much less than the timescale of the tidal cycle – than a longer one. This is because with the short channel it is more reasonable to assume that the effects of the boundary conditions propagate throughout the domain before those boundaries change significantly.

The small domain – necessary both to limit computation time and because of the steady state approximation – means that the effect of the turbines may potentially be constrained by the proximity of pre-determined boundary conditions [8]. Additionally, the small domain precludes the use of this model to study any far-field effects of energy extraction. It is planned to investigate the effects of the boundaries and the steady state approximation in the future, once quantitative comparisons can be made between the models.

It is worth noting that while MIKE3 can predict the overall effect of an array as a whole, the accuracy of this prediction may be reduced by its lesser ability to accurately model interactions within the array. One solution to this would be to couple a regional-scale shallow water model and a local CFD model, as demonstrated in [9]. However, this requires an iterative method that is extremely computationally demanding. Another approach may be to use a CFD package to parameterise array effects, and then use this parameterisation to take account of them in regional-scale models. This is a suggested area for future research.

CONCLUSIONS

So far in this work we have presented observations on the forms of the output from each model, and discussed the advantages and disadvantages for specific environmental applications.

MIKE3 is primarily limited by resolution, being unable to resolve the effects of individual devices within our example array. TideModeller is likely to be a better tool for examining detailed array layouts, interactions between turbines, or highly localised environmental effects such as scour.

Conversely, TideModeller is 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.

To continue this work it is intended to run both models with the same turbine parameters and extract the same data for moments of interest. From the resulting data we plan a quantitative comparison of their predictions, which will allow us to refine our comments on the capabilities and limitations of each modelling approach.

ACKNOWLEDGEMENTS

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