Offshore renewable energy device impacts on seasonally stratified seas around the UK: an unstructured modelling approach

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RATIONALE

FVCOM (the Finite Volume Coastal Ocean Model, *Chen et al., 2003*) is a model based on unstructured horizontal grids. Unstructured grids are better able to model complex coastlines and increase resolution arbitrarily. These differences, compared with regularly gridded models, mean that issues which have been found in rectilinear grids (e.g. erroneous coastal boundary layers, *Davies and Jones, 1996*) can be avoided.

Figure 1 shows LANDSAT-8 imagery of turbid wakes generated by wind turbine monopiles in the Thames estuary. To model the impact of these devices across coastal and nearshore zones, the model grid must be able to resolve individual turbines. The modelling presented here shows the application of FVCOM in assessing impacts from the existing array of marine renewable energy devices in the seasonally stratified waters of Liverpool Bay.

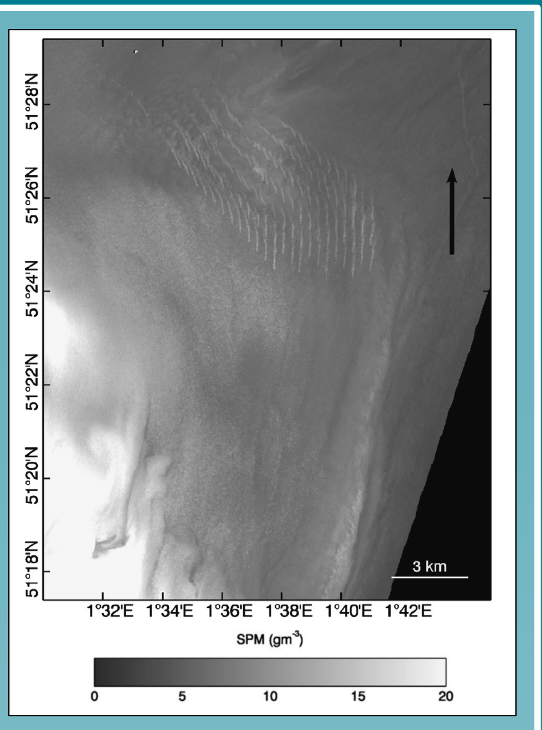

Figure 1 LANDSAT-8 imagery of turbid wakes from wind turbines in the Thames estuary (*Vanhellemont and Ruddick, 2014*).

MODEL CONFIGURATION

The model focusses on the large wind farm installations in Liverpool Bay from phases 1 and 2 of the offshore developments. Figure 2 shows the domain covering 11,300km^2, with 241 wind turbine monopiles as 5m diameter islands. Open boundary forcing is TPXO derived surface elevations (*Egbert et al., 1994*). Temperature and salinity are taken from HYCOM (www.hycom.org) and surface forcing from the NCEP Reanalysis 2 data.

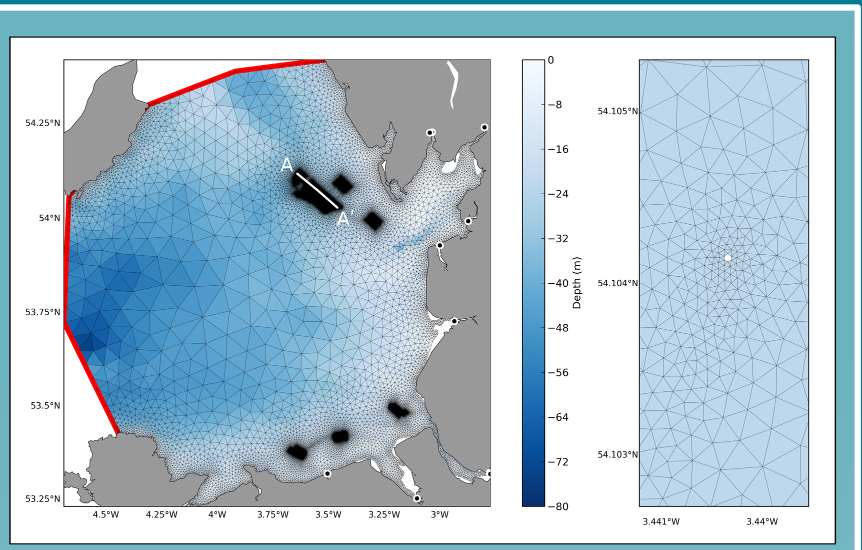

Figure 2 Liverpool Bay model domain (left) with zoomed section showing a single wind turbine monopile (right). Grid resolution varies as a function of bathymetric gradient, coastline curvature and the speed at which the gravity wave propagates across the domain. Element edge lengths vary from 2.5m at the monopiles to 10km in the centre of the model domain. Heavy red lines indicate the model open boundaries. Black dots show the river sources from the E-HYPE model. White line A-A′ indicates the location of the vertical profile in figure 4.

MODELLED WIND TURBINE IMPACTS

To verify the quality of the model results in the vicinity of individual turbines, a qualitative comparison between computational fluid dynamics (CFD) results and those from the much larger scale was performed. The left panel in figure 3 shows CFD modelled bedload sediment transport under unidirectional flow from *Solberg et al.* (2006). Since bedload transport is closely related to bed shear stress magnitude, the bed shear stress from FVCOM is shown in the right panel in figure 3.

The distribution of stress around the monopile from the FVCOM output is similar to the CFD output (lows in front of and behind the monopile with lobes of increased stress around the sides), though the spatial extent of the FVCOM distribution is larger, likely down to the relatively coarse grid (compared to the CFD grid). However, this qualitative comparison shows the turbulence parameterisation in FVCOM is able to reproduce the patterns found in models an order of magnitude smaller in scale (in both the mesh and the domain).

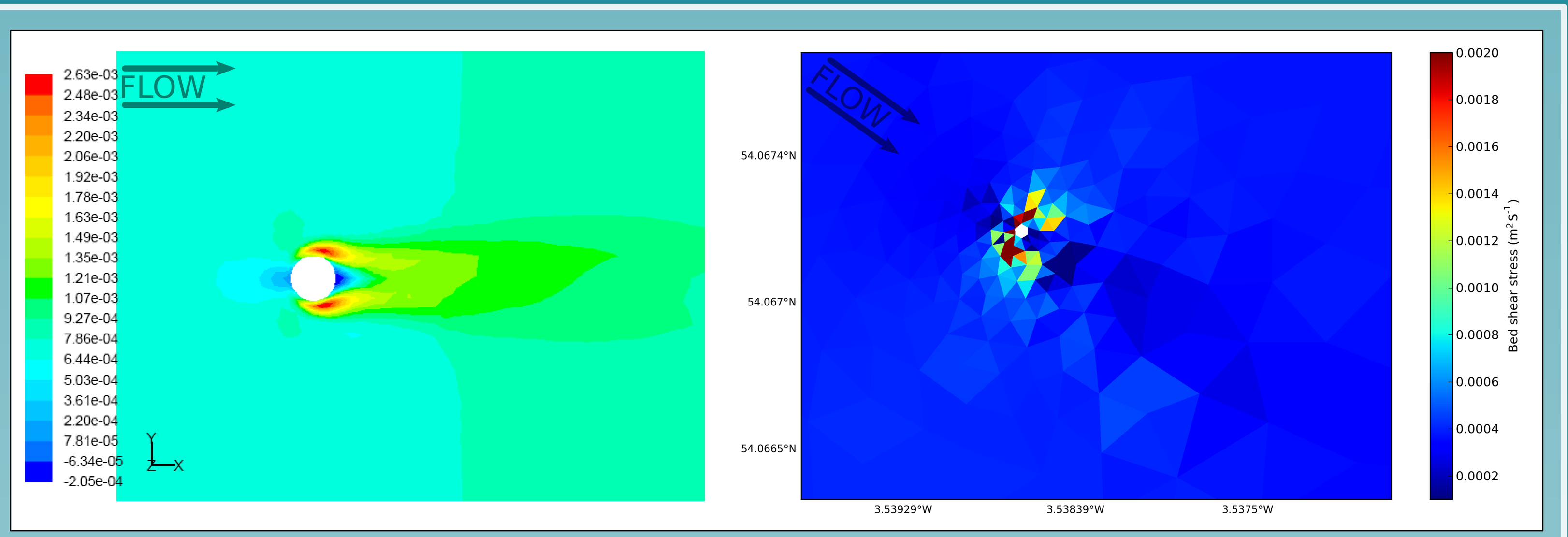

Figure 3 Left: Computational Fluid Dynamics (CFD) model output of bedload transport around a wind turbine monopile (*Solberg et al., 2006*). Right: FVCOM bed shear stress magnitude during a flood tidal cycle. Evident is a similar pattern of increased stress at the sides of the monopile (relative to the flow) with lows in front of and behind the obstacle. The flow is from the north-west and the region of lower stress extends away from the monopile in the direction of flow.

Figure 4 Impact from wind turbine monopiles on the vertical distribution of turbulent kinetic energy during peak spring tides. Clearly visible are regions of decreased turbulence adjacent to the wind turbine monopiles with localised increases nearer the surface in certain areas (indicated in the figure). Turbulent energy is greatest in shallow areas and decreases with depth, although the impacts are seen throughout the full range of depths in this profile. The range in turbulent energy is strongly affected by the state of the tide, with lower turbulence occurring as the tide turns. The increase in turbulence with the changing tide propagates from the seabed to the surface.

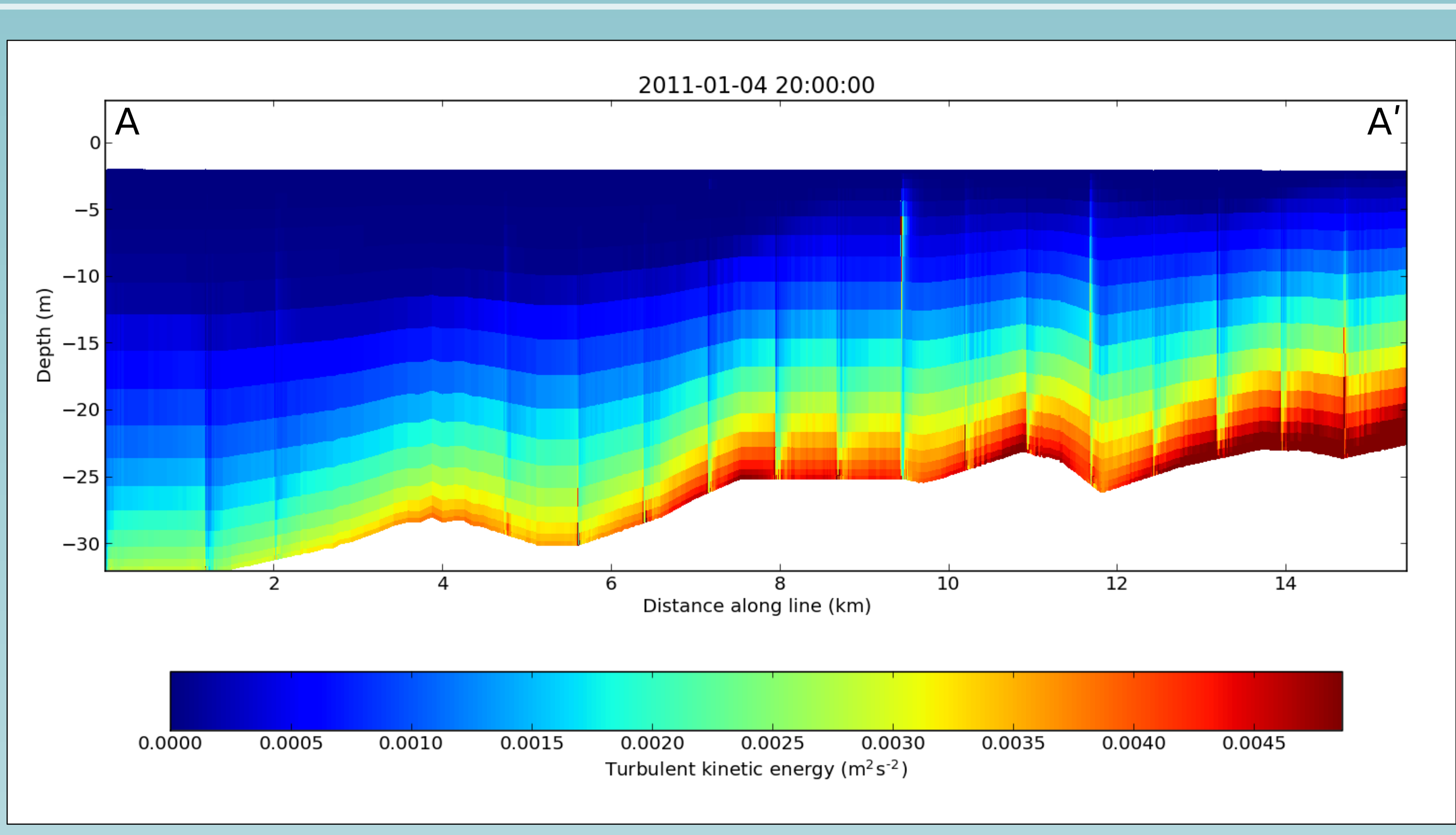

Figure 4 shows the turbulent kinetic energy (TKE) and the vertical impact from the monopiles. In particular, the monopiles decrease turbulent energy up to 500m downstream (100x the monopile diameter). The largest (spatial) changes occur 5-10m above the seabed whilst the greatest decrease in energy is found < 5m from the bed. TKE is heavily dependent on the water depth and is higher in the shallowest parts of the domain.

Figure 5 shows the potential energy anomalies in Liverpool Bay before and after the onset of spring stratification. The structure in this area is a combination of freshwater input from the large English and Welsh rivers (e.g. Mersey, Ribble and Dee) and the influence of the Irish Sea. In winter, strong tidal forces mix the water column throughout the domain yielding low potential energy anomalies (the system would require little energy to fully mix the water column). By the onset of spring, the surface insolation has increased to the point where a buoyant warm surface layer has formed which is strong enough to survive the effects of tidal mixing.

The introduction of wind turbine monopiles into a seasonally stratified sea could alter the timing, spatial distribution and magnitude of stratification which could have knock on effects for the development of the spring bloom.

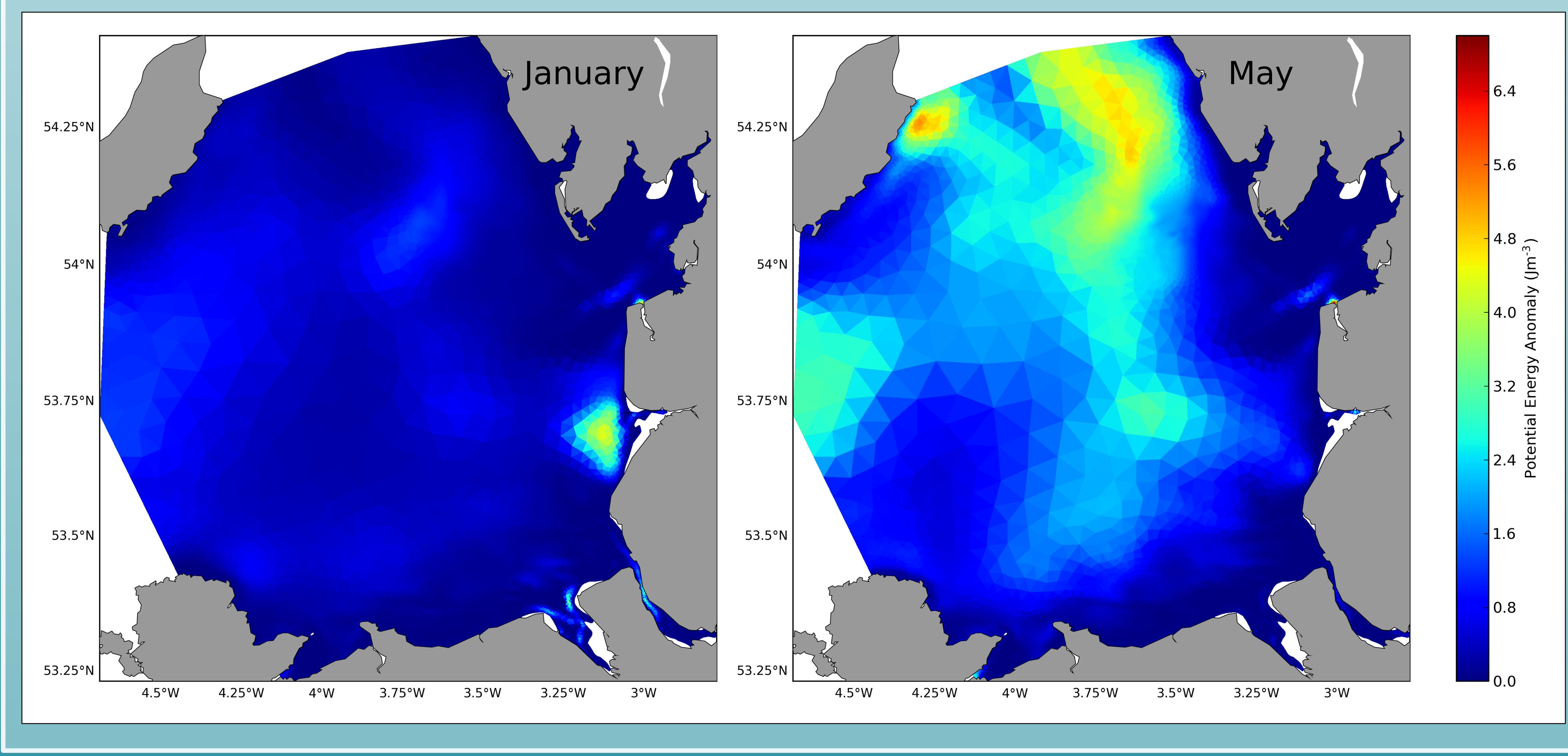

Figure 5 The potential energy anomalies (PEA) in Liverpool Bay for January (left) and May (right). The PEA shows the amount of energy required to fully mix the water column. It indicates the amount of water column stratification. Areas with high values are stratified, with a warm and/or fresh surface layer, whilst those with low values indicate areas in which the water column is well mixed.

The Liverpool Bay domain clearly shows the presence of a front dominated by the large rivers on the English and Welsh coastlines. The Simpson-Hunter parameter (u^3) can be used to predict the location of these fronts. The results shows in the right hand panel are in agreement with both the Simpson-Hunter parameter and previously published locations of the Liverpool Bay front.

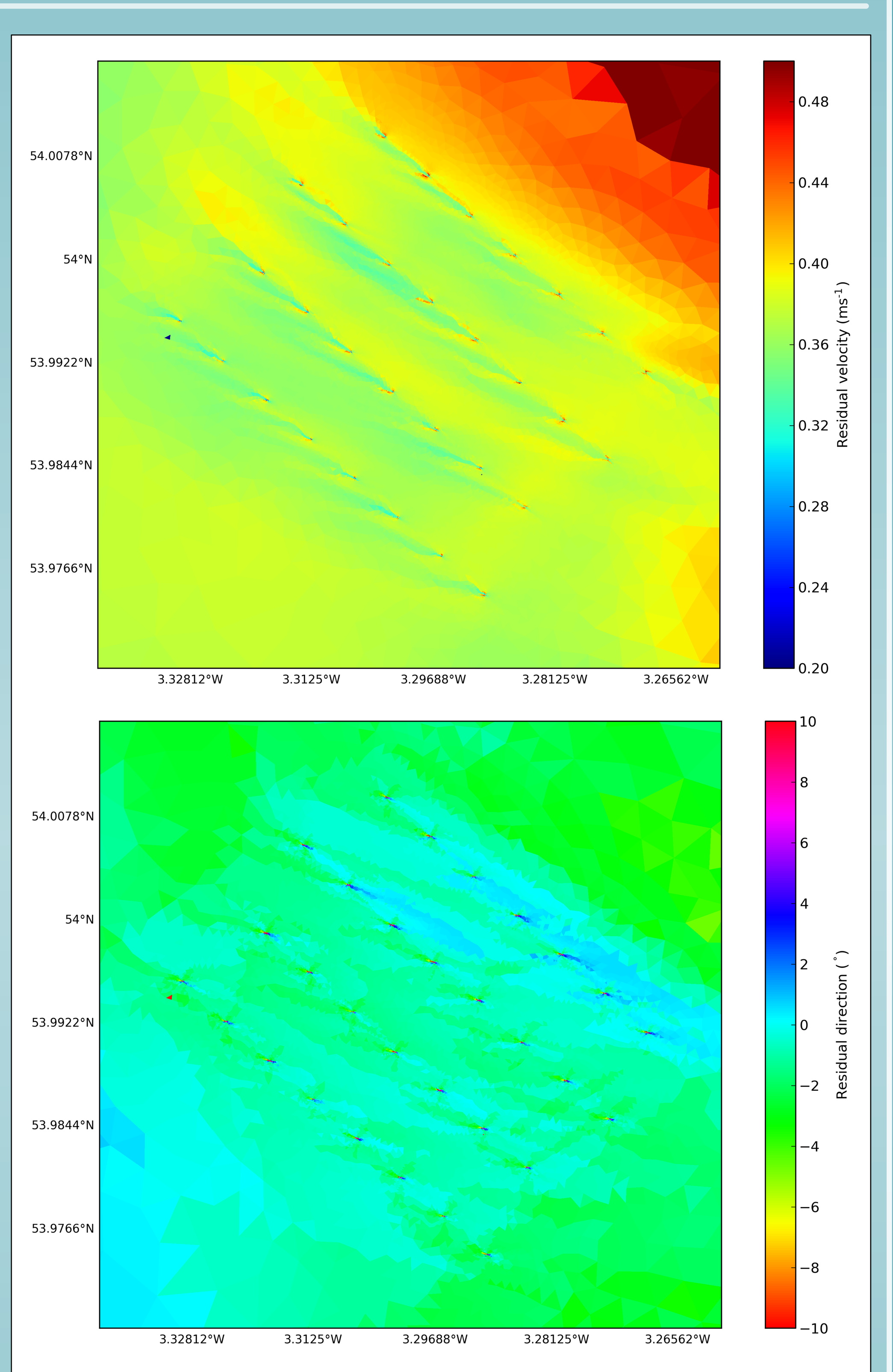

Figure 6 Monthly maximum depth-averaged residual current speed (top) and direction (bottom) in a wind farm region. Evident are large wake regions extending several kilometres from the wind turbine monopiles.

Figure 6 shows the impact from the monopiles on the long term residual circulation. Clearly visible in the speed plot is the impact from the wind turbine monopiles as wakes of decreased velocity (8cms^{-1}) extending in the direction of the residual circulation up to 2km from the source monopile. The direction plot shows changes in residual direction of ±3° within the wind farm compared with the values outside the wind farm region. The introduction of the wind turbine monopiles has noticeably impacted the long term circulation within the farm but those changes also extend beyond its limits.

CONCLUSIONS AND FUTURE APPROACHES

- Modelling marine renewable energy device impacts is critical if the energy needs to the future are to be provided with the smallest number of downsides.
- Therefore, models which can accommodate the range of scales necessary to model these environments are critical.
- Unstructured grid modelling provides a powerful way to increase model performance in complex coastal and shelf areas to describe changes from energy devices.
- This modelling is the first attempt at modelling realistic environments in full 3D over such large areas.
- The qualitative similarity between the FVCOM results and those from large-scale remotely sensed suspended particulate matter data and the small-scale CFD is encouraging.
- As such, the approach taken here has the potential to provide meaningful estimates of the spatial and temporal impacts from marine renewable devices on shelf seas.
- The flexible nature of the model means that additional proposed wind farms can be included with relative ease.
- Further modelling will assess the impacts from tidal renewable energy devices through mid-water column obstructions.

References

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Acknowledgements

This work is funded by UKERC and the NERC project FLOWBEC. Thanks to Yuri Artioli and Bob Brewin for their help and thoughts with regards the modelling.