Enhanced bed shear stress and mixing in the tidal wake of an offshore wind turbine monopile

ECOWind ACCELERATE

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Background

Tidal flow past offshore windfarm (OWF) infrastructure generates a turbulent vortex wake. Foundations add barotropic drag to the tidal flow that causes a mean flow velocity deficit and forms a vortex wake that generates additional turbulence at the scale of the monopile.

The wake is hypothesised to impact the environment through:

- enhanced seabed stress,
- increased water column vertical mixing,
- and by affecting the transport of nutrients and oxygen.

These factors will change seabed heterogeneity and at the array scale may affect seasonal stratification in deeper waters, resulting in cumulative ecological impact.

Aims and Objectives

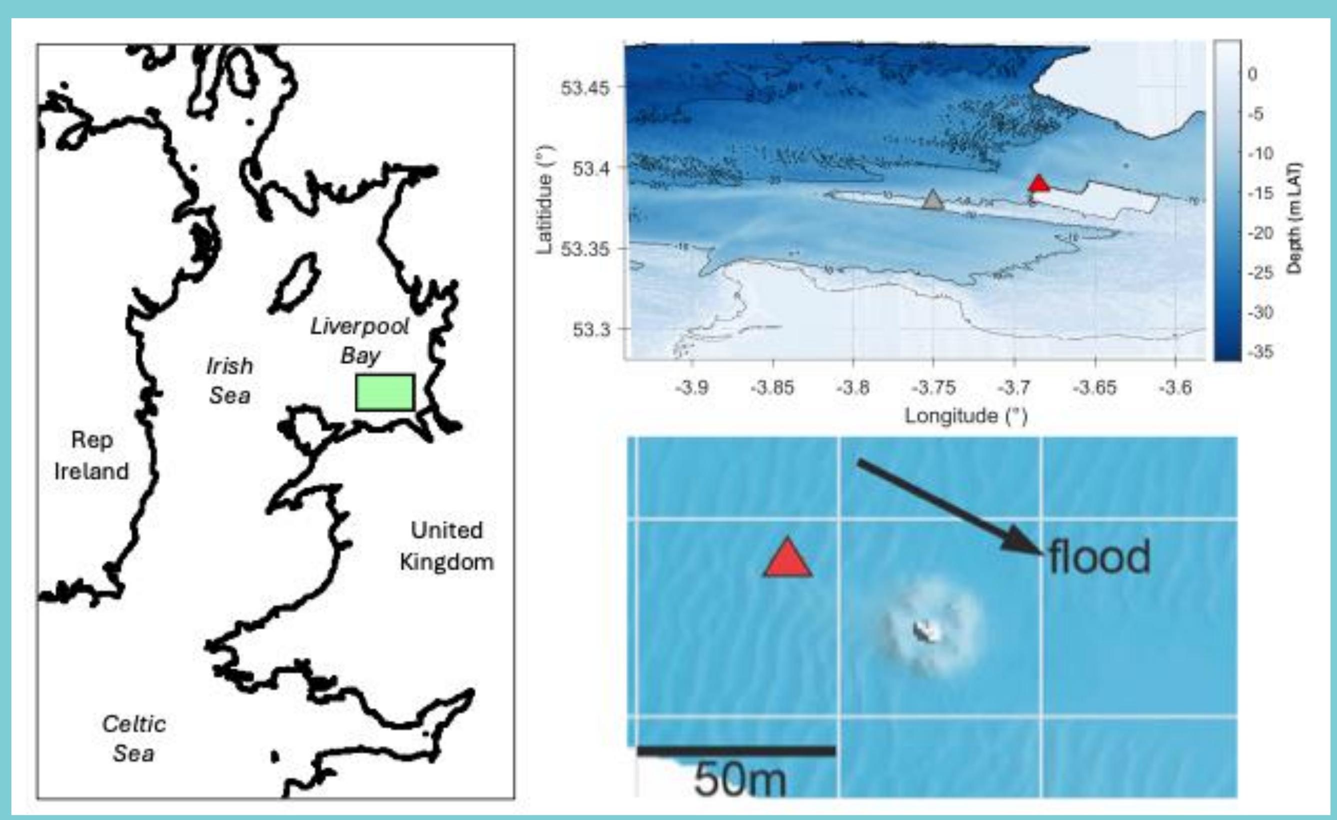
Investigate how the signature of the turbulent wake from an OWF monopile differs from that of the background flow. Specifically, we:

1. Quantify the rate of turbulence production and dissipation inside and outside the wake?
2. What is their vertical distribution through the water column?
3. Quantify the wake impact on seabed stress and water column mixing

We use field observations in a tidally energetic well-mixed environment and use the rectilinear tide to measure natural background flows during the flood tide and the wake during the ebb.

Field methods

Where: Rhyl Flats OWF, Liverpool Bay :: 53.39°N, 3.69°W
When : September 2022 (14-day deployment)
What : Nortek Signature1000 5-beam AD2CP, 40 m away from OWF monopile (x/D = 8.7)



(a) UK outline; (b) bathymetry showing location of Rhyl Flats OWF and ADCP (red triangle); (c) zoomed bathymetry with monopile.

Water depth h = 12 – 21 m, sediment grain size D_{50} = 0.25 mm, roughness k_b = 0.122 m. Cylinder Reynolds number Re_d >> 5x10^5 = fully-developed Karmen Vortex wake.

Temporal variation in rate of dissipation and production

During flood tide, the ADCP is upstream of monopile measuring natural background flow conditions.
During ebb tides, the ADCP is downstream of the monopile sampling the wake-affected flow conditions.

Rectilinear mean flows U_x :

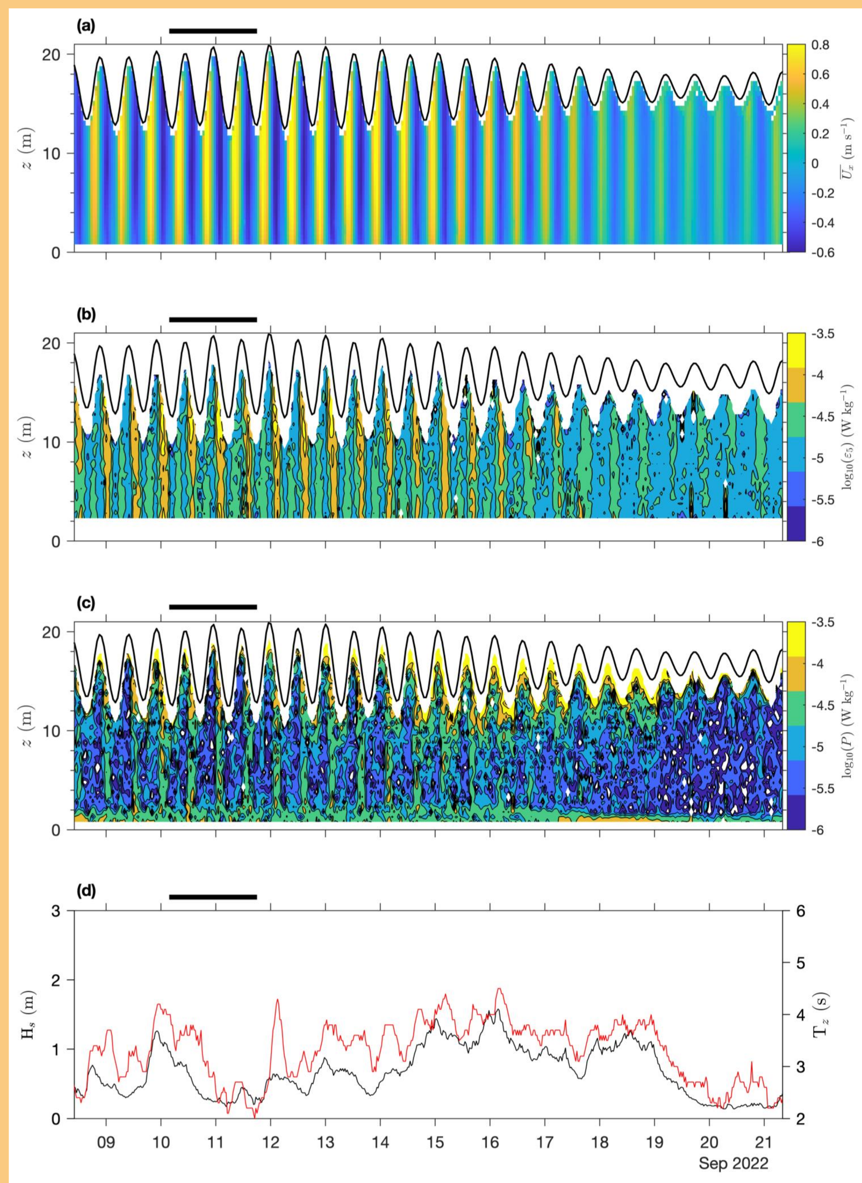
- 0.8 m s^{-1} outside wake
- -0.6 m s^{-1} inside wake

Dissipation rate ε (vertical beam).

- Floods: ε from seabed
- Ebb: strong wake ε through whole water column

Production rate P:

- Flood: P at seabed from tidal shear
- Ebb: P at seabed + full water column from wake
- Surface waves (15th – 19th Sep)



(a) Mean streamwise flow velocity; (b) dissipation rate; (c) production rate; (d) wave height and period.

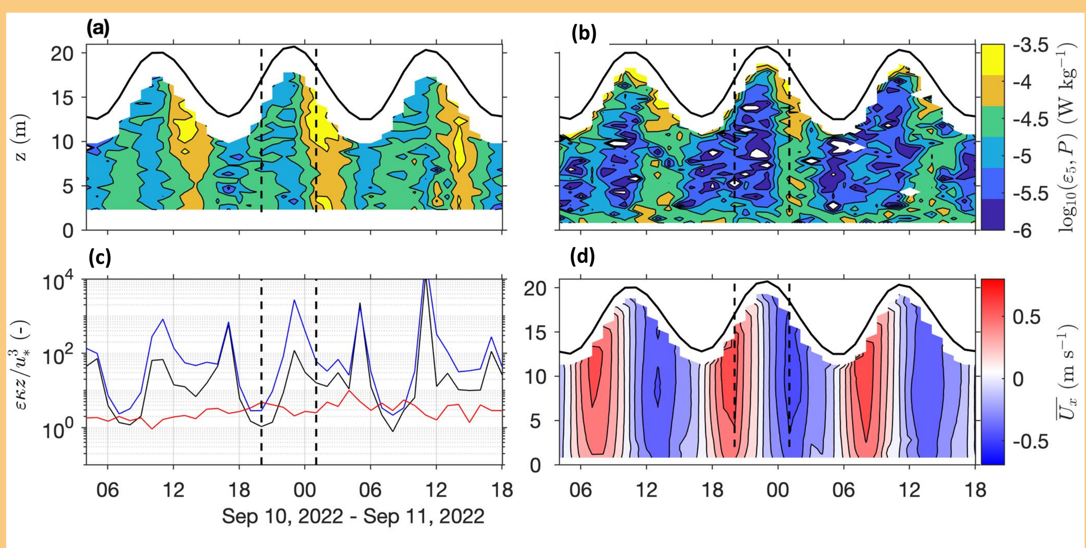
Similarity scaling of TKE dissipation and production

Theoretical constant stress relationship driven by tidal stress at the seabed

$$\varepsilon_s = -u_*^3/\kappa z$$

In the **wake ε is 1.5 orders of magnitude greater than predicted at seabed** and surface. Consistent near-bed TKE P, but additional P through full water column (wake).

Depth integrated ε and P in close agreement and observed budget of ε/P remains within an order of magnitude.



(a) Dissipation rate ε; (b) production rate P; (c) similarity scaled ε at seabed (black), surface (blue) and total observed ratio ε/P (red); (d) mean streamwise velocity.

Enhanced stress, seabed drag and mixing

Wake impacts on seabed stress and vertical mixing are explored by deriving the seabed drag coefficient C_d and the eddy viscosity N_z, respectively, from ensemble-averaged vertical profiles over seven spring tidal cycles between 9th and 13th Sep.

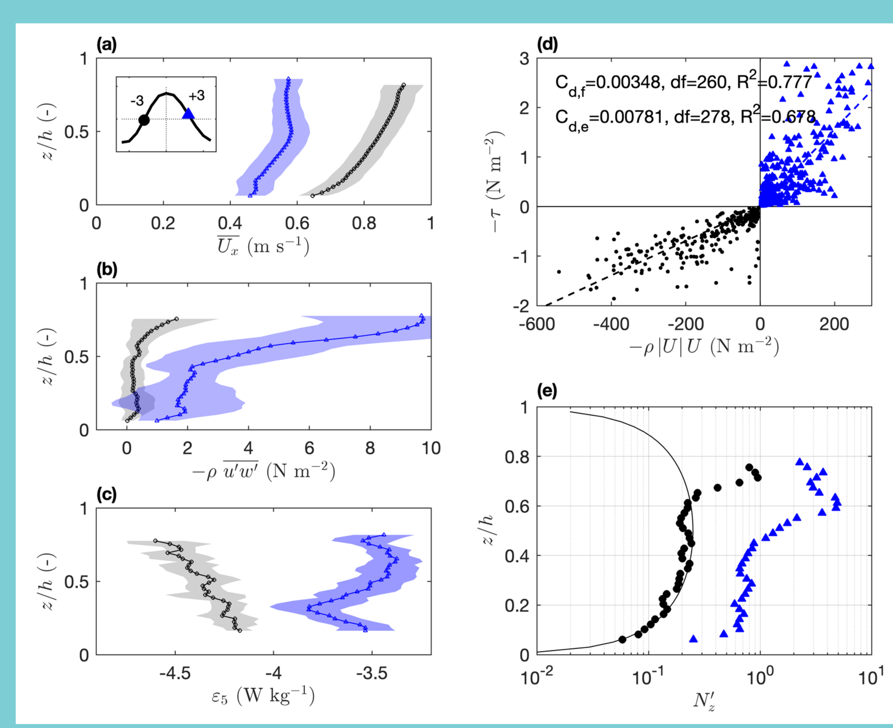
Strong mean flow velocity deficit in the wake.

Regression of total shear stress in lowest 2m of water column vs. quadratic stress law.

The wake doubles the seabed drag coefficient.

Using a steady flow model, background upstream N_z is in accordance with theory.

Within the wake N_z is almost an order of magnitude larger.



Upstream (black) and wake-affected (blue) ensemble-averaged (a) mean velocity profiles; (b) stress; (c) dissipation rate; (d) regression of stress and quadratic stress law; (e) non-dimensional eddy viscosity (solid line = steady flow model).

Conclusions

- During upstream flows, tidal shear at the seabed drives TKE ε and P.
- Wake causes a strong mean velocity deficit drives enhanced ε and P through the full depth of the water column.
- Wake enhanced stresses:
    - double the seabed drag coefficient and will enhance sediment transport
    - increase eddy viscosity by an order of magnitude and will drive greater vertical water column mixing.

This poster provides a summary of:

Austin, M. J., Unsworth, C. A., Van Landeghem, K. J. J., and Lincoln, B. J.: Enhanced bed shear stress and mixing in the tidal wake of an offshore wind turbine monopile, Ocean Sciences, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-2056, 2024.