Effects of Offshore Wind Energy on Ocean Circulation and Mixing

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ABSTRACT

Efforts to meet projected energy demands, while also reducing carbon emissions, are leading towards the increased development of renewable energy. To achieve these goals, much of this increase in renewable will not only come from onshore wind energy but also from offshore. While a few isolated turbines may not significantly affect ocean circulation and the atmosphere, the effects of a major deployment of wind turbines on local to regional physical processes of the ocean is for the most part still unknown. This study aims to bridge the gap between atmospheric and ocean modeling and to demonstrate the complex flow physics occurring around offshore wind farms.

A one-way numerical coupling of the ocean and atmosphere was developed to study the effects of offshore wind farms on the ocean. Our in-house UTD-WF LES code was used to model the atmospheric boundary layer and the wind turbines, whereas FVCOM (Finite Volume Community Ocean Model) was used to model the ocean domain. An idealized wind farm, consisting of an array of 2 x 4 turbines uniformly distributed along the direction of the flow, was simulated. For the ocean, a constant depth of $H = 30\ m$ was considered. Two sets of simulations, with a uniform inflow and a turbulent inflow, were performed. The wind flow from these simulations was used as shear forcing for the ocean model.

The wind flow patterns around the wind farm are projected into the ocean surface (Fig.1ab). These patterns include the low-velocity wake regions behind the wind turbines and the induction zone in front of the wind turbine rotors. The wind turbines wakes introduced a lower shear leading to a lower sea surface velocity behind the wind turbines. Additionally, the induction zone from the turbines also introduced a spanwise shear on the ocean surface.

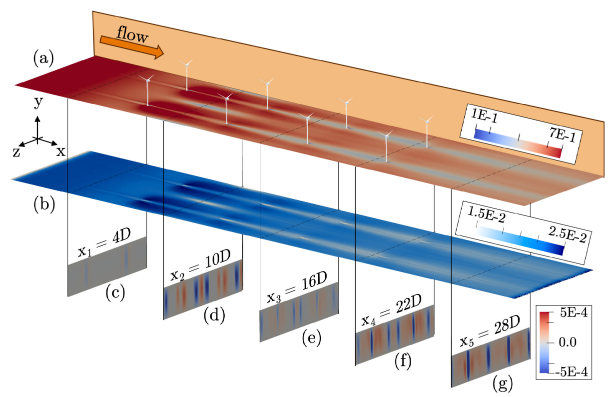

Figure 1: Color contours for **uniform** inflow: (a) time-averaged streamwise wind velocity $\overline{U}_x$ $(m\ \ s^{-1})$ at $y = 10\ m$; (b) time-averaged streamwise sea velocity $\overline{U}_x$ $(cm\ s^{-1})$ at $y = -0.75\ m$; (c,d,e,f,g) time-averaged vertical sea velocity $\overline{U}_y$ $(cm\ s^{-1})$ at x_i.

These two dynamics played a major role in initiating large coherent structures, with upwelling and downwelling (Fig.1c-g), that increased the mixing underneath the ocean surface. Large streamwise-normal vortices, spanning the depth of the ocean domain, also developed in the turbine regions as a consequence. When turbulence was presented at the inlet, the these large vortices no longer retained their coherent structures.