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Effect of Offshore Wind farm Design on the Vertical Motion of the Ocean

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Abstract

In this study the vertical motion of the ocean is studied numerically. A wake model that includes details of the wind farm design, such as the location of the turbines, diameter of rotors and hub height, is used to calculate the change in surface wind speed resulting from potential wind farms in the Havsul area. Using the calculated wind velocities to force a three dimensional ocean model (Regional Ocean Modeling System), the ocean response to two different wind farm designs is estimated. It is found that the wind farm design has a significant effect on the upwelling and downwelling near the wind farm, as the difference in maximum upwelling velocity after 1 day of simulation exceeds 30 m/day. The pronounced changes in vertical velocities are attributed to changes in the horizontal flow over varying topography due to wind stress modifications by the wind farms.

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Keywords:

1. Introduction

Offshore wind energy is expected to play an important role in future energy supply [1, 2, 3]. Whereas offshore wind farms are advantageous due to the higher wind speeds and their locations away from highly populated areas, potential environmental consequences of installing large wind farms may be pronounced. These include impact of the electric cables on the fish migration [4], collision of endangered birds with the turbines [5] as well as having an effect on the local climate [6, 7]. Recently it has also been shown that offshore wind farms may have an impact on the upper ocean circulation [8, 9]. Changes in the vertical motion of the ocean are likely to be important to the local ecosystems [10], and detailed information about how the wind farm may modify the circulation in its vicinity should be provided prior to installation. Although it has been indicated that wind farms are likely to affect the local ocean circulation, previous studies have focused on idealized model experiments. In particular, details of the wind

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farm design have not been taken into account when calculating the wake. The objective of the present study is to investigate the effect of wind farm design on the vertical motion in the ocean. Using a wake model that allows for varying wind farm designs, the change in wind velocity will be calculated. We will then perform two experiments with a three dimensional ocean model, forced by the wind velocities calculated by the wake model, and investigate the effect of the wind farm design on the ocean upwelling and downwelling. The study will be performed in the Havsul area, where high wind speed and the potential for offshore wind energy production have been documented [11]. However, the applied method is not restricted to this area and may be applied for any offshore wind farm study.

2. Methods and data

2.1. Wake model

In order to estimate the modification of the wind field due to the presence a wind farm, we will in this study apply the wake model described by [12]. The model is based on conservation of momentum and the assumption of linear expansion of the downstream wake [13]. For a single turbine the velocity U_w at the downwind distance *X*, is calculated according to

$$U_w = U_0 + U_0(\sqrt{1-C_t} - 1)\left(\frac{r_o}{r}\right)^2, \tag{1}$$

where U_o is the undisturbed wind speed upstream the turbine, C_t is the thrust coefficient of the turbine and r_o is the radius of the rotor. It is assumed that the spread of the wake is symmetric in the vertical and lateral directions, and that the radius of the cone, r, at the distance *X* downstream the wind turbine, is given as

$$r = r_o + \kappa X, \tag{2}$$

with κ being the wake decay constant. For a wind farm consisting of multiple turbines, the effects of the individual wakes are combined into one single effect using the methods described in [12]. The wake behind a turbine is then multiplied by a factor, β, defined as

$$\beta = 1 - (1 - \sqrt{1-C_t})(\sum_{i=1}^{N}\left[\left(\frac{r_o}{r_i}\right)^2\left(\frac{\Delta A}{A_o}\right)_i\right], \tag{3}$$

where A_o is the area spanned by the turbine experiencing shadowing (Turbine *k*), ΔA is the overlapping area of the upstream wake cone and the area spanned by Turbine *k*, and r_i is the radius of the wake cone generated by Turbine *i* at the same downstream location as Turbine *k*. In order to retain the undisturbed wind speed downstream the wind farm a layer where β is gradually increased toward 1, is introduced

$$\beta = \beta_{\text{int}} + (1-\beta_{\text{int}})\sin\left(\frac{\pi x}{2L}\right) \qquad \text{if } x < L \tag{4}$$

and

$$\beta = 1 \qquad \text{if } x > L. \tag{5}$$