Influence of large wind farms on the upper ocean circulation

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Introduction

Offshore wind energy is expected to play an important role in near future energy supply around the world. The potential environmental consequences of installing large wind farms include impact of the electric cables on the fish migration as well as having an effect on the local climate. Recently, it has also been shown that offshore wind farms may have an impact on the upper ocean circulation. This has been explained to be caused by the disturbances the wind farm exert on the wind stress, giving a wind stress curl that results in ocean upwelling and downwelling.

The objective of the present study is to investigate the effect of varying wind farm design on the vertical motion in the ocean. Using a wake model that allows for varying wind farm design, 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. However, the applied method is not restricted to this area and may be applied for any offshore wind farm study

Havsul Area

The area of focus in the present study is located in the Havsul region off the Møre coast, as shown in Figure 1a. The topography of the area is associated with small islands, high coastal mountains and fjords. The offshore wind conditions in the Havsul area are considered viable for wind energy installations due to relative high wind speeds [1]. Using the NORA 10 dataset the prevailing wind direction is found to be southwest (Figure 1b), with a mean value of 217.5 °. The time period considered in this study is from March 11, 2014 to March 13, 2014. During this period the wind speed in the Havsul area was higher than 15 m/s and the wind direction southwest (Figure 1c).

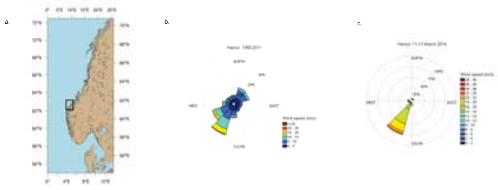

Figure 1. The Havsul area (encapsulated by black rectangle) at the western coast of Norway (a), and wind statistics of the Havsul area for the period 1958 to 2011 (b) and for the study period March 11, 2014-March 13, 2014 (c).

Methods and data

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 [2]. The model is based on conservation of momentum and the assumption of linear expansion of the downstream wake.

Wind farm design
In this study two different wind farm designs are considered: Wind Farm Design 1 and Wind Farm Design 2 (Fig. 2). For Design 1 the turbines are organized in straight rows and columns, whereas for Design 2 the rows are curved. In Figure 3 we show the wakes at 10 m height generated by Designs 1 and 2, for wind direction equal to 217.5 °, and 10 m wind speed equal to 20 m/s.

Model Run
For the time period March 11, 2014 to March 13, 2014 we apply the ROMS model [3] to perform three simulations of the oceanic conditions in the Havsul area: Model run 1, Model run 2 and a control run. The control run is forced by unperturbed wind velocities, i.e. winds not affected by the presence of a wind farm, whereas for Model runs 1 and 2 the model is forced by anomaly wind due to wind farm induced wakes. Input to the wake model that is used to force Model run 1 and Model run 2 are respectively Design 1 and Design 2.

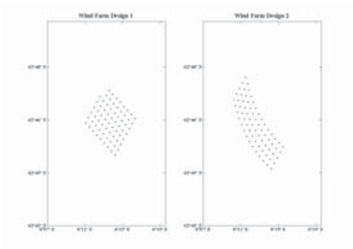

Figure 2. Potential wind farm design at the Havsul area. Number of turbines are 70 in both examples.

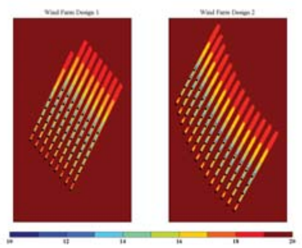

Figure 3. Wind farm induced for the two wind farm designs (Wind Farm Design 1 and 2) at 10 m height. Wind direction is from southwest (217.5 °). Free slip wind speed at 10 m height is 20 m/s.

Results

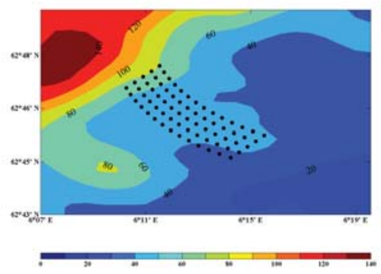

Figure 4. Model depth [m] in the area near the wind farm.

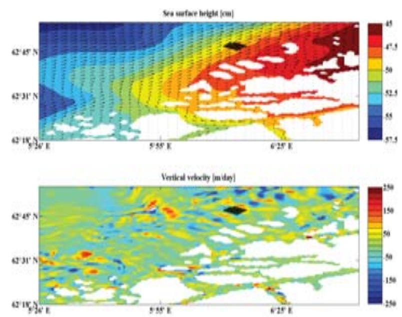

Figure 5. Mean sea surface height and surface currents (upper) and vertical velocity at sigma layer 3 (lower) in the Havsul area for the time period March 11, 2014 to March 13, 2014.The black regions denote the area intended for wind farm installations.

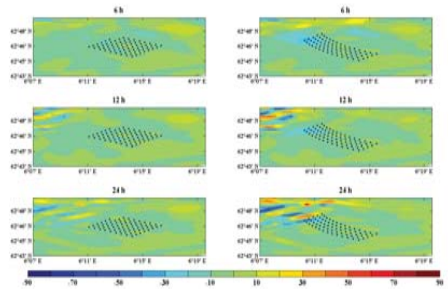

Figure 6. Vertical velocity at sigma layer 3, corresponding to approximately 20 m depth in the vicinity of the wind farms, relative to the control run, for the two model experiments: Model run 1 (left) and Model run 2 (right), after 6 h, 12 h and 24 h of simulation. Units are m/day. Wind direction is from southwest for all cases

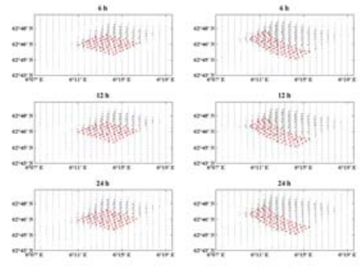

Figure 7. Difference in surface stress between Model run 1 and the control run (left) and Model run 2 and the control run (right) in the vicinity of the wind farms after 6 h, 12 h and 24 h of simulation. Units are N/m². Also plotted are the locations of turbines included in the wind farm designs (red dots). Wind direction is from southwest for all cases.

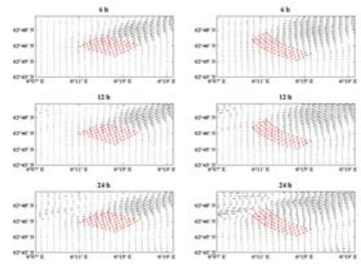

Figure 8. Difference in near bottom (sigma layer 3) horizontal velocity between Model run 1 and the control run (left) and Model run 2 and the control run (right) in the vicinity of the wind farms area after 6 h, 12 h and 24 h of simulation. Units are m/s. Also plotted are the locations of turbines included in the wind farm designs (red dots). Wind direction is from southwest for all cases.

Conclusions

In this study shows that that vertical oceanic motion may be induced by the presence of large wind farms. Using a wake model that allows for calculation of the surface wind stress as a function of the wind farm design, it has further been shown that the ocean upwelling/downwelling is influenced by the wind farm design. In this study we have outlined the method of how the ocean response to a specific wind farm design can be calculated, which allows for inclusion of ocean effects in future planning of new offshore wind projects. For the Havsul region it appears that topographic effects play a dominant role in generating vertical velocities, and that Ekman pumping is of less significance.

References

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2. González-Longatt, F., Wall P., Terzija V. Wake effect in Wind Farm Performance: Steady-State and Dynamic Behaviour. Renewable Energy, 2011, p. 329-338
3. Shchepetkin, A.F., McWilliams J.C. The Regional Ocean Modeling System: A split-explicit, free-surface, topography following coordinates ocean model, Ocean Modelling, 2005, 9, p. 347-404