Prospects for generating electricity by large onshore and offshore wind farms: Letter

The decarbonisation of energy sources requires additional investments in renewable technologies, including the installation of onshore and offshore wind farms. For wind energy to remain competitive, wind farms must continue to provide low-cost power even when covering larger areas. Inside very large wind farms, winds can decrease considerably from their free-stream values to a point where an equilibrium wind speed is reached. The magnitude of this equilibrium wind speed is primarily dependent on the balance between turbine drag force and the downward momentum influx from above the wind farm. We have simulated for neutral atmospheric conditions, the wind speed field inside different wind farms that range from small (25 km²) to very large (105 km²) in three regions with distinct wind speed and roughness conditions. Our results show that the power density of very large wind farms depends on the local free-stream wind speed, the surface characteristics, and the turbine density. In onshore regions with moderate winds the power density of very large wind farms reaches 1 W m⁻², whereas in offshore regions with very strong winds it exceeds 3 W m⁻². Despite a relatively low power density, onshore regions with moderate winds offer potential locations for very large wind farms. In offshore regions, clusters of smaller wind farms are generally preferable; under very strong winds also very large offshore wind farms become efficient.
Wind Farm Wake: The 2016 Horns Rev Photo Case

Offshore wind farm wakes were observed and photographed in foggy conditions at Horns Rev 2 on 25 January 2016 at 12:45 UTC. These new images show highly contrasting conditions regarding the wind speed, turbulence intensity, atmospheric stability, weather conditions and wind farm wake development as compared to the Horns Rev 1 photographs from 12 February 2008. The paper examines the atmospheric conditions from satellite images, radiosondes, lidar and wind turbine data and compares the observations to results from atmospheric meso-scale modelling and large eddy simulation. Key findings are that a humid and warm air mass was advected from the southwest over cold sea and the dew-point temperature was such that cold-water advection fog formed in a shallow layer. The flow was stably stratified and the freestream wind speed was 13 m/s at hub height, which means that most turbines produced at or near rated power. The wind direction was southwesterly and long, narrow wakes persisted several rotor diameters downwind of the wind turbines. Eventually mixing of warm air from aloft dispersed the fog in the far wake region of the wind farm.

General information
State: Published
Authors: Hasager, C. B. (Intern), Nygaard, N. G. (Ekstern), Volker, P. (Intern), Karagali, I. (Intern), Andersen, S. J. (Intern), Badger, J. (Intern)
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BFI (2014): BFI-level 2
Dynamical and statistical-dynamical modelling of wind farm flows with WRF

A pledge to increase the share of renewable energies has led to a focus on offshore wind energy in many western European countries. With an increasing number of offshore wind farms to be installed it becomes important to understand (I) the degree to which wakes from neighbouring wind farms affect the power production of a target wind farm and (II) how large wind farms can get if they are to remain efficient and productive power generators. The modelling of wind farm wake flows is challenging, since it includes processes from the micro- to mesoscale meteorology. We use the Weather Research and Forecast (WRF) model that allows us to simulate mesoscale features of wind farm wakes. Its limited horizontal resolution – in microscale terms – however, requires flow characteristics, such as single turbine wakes, to be parametrised.

Satellite data used in the New European Wind Atlas

General information

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Publication information
Study on offshore wind farm wakes based on Envisat ASAR, Radarsat-2 and Sentinel-1

Downstream of operating wind farms the mean wind speed is reduced as compared to the upwind conditions. In the offshore environment it is of particular interest to quantify the wind farm wake because turbine arrays are often located in the vicinity of other wind farms. The wakes reduce the annual energy production in clustered wind farms. Envisat ASAR, Radarsat-2 and Sentinel-1 are used in the study covering wind farms in the North Sea and Kattegat Strait. Three types of analysis are performed. The first is a case based on a Radarsat-2 Scan-SAR wide VV scene (30th April 2013 at 17:41 UTC) with winds around 8-9 m/s from the northeast and eight operating wind farms all showing long wind farm wakes. The longest wake is around 55 km. The case has been modelled using an industry-standard engineering microscale wake model (PARK) and using mesoscale model (WRF) including a parametrization for wind farm wake. Both models reproduce the observed very long wind farm wakes convincingly regarding their direction and extent. The second analysis is based on 835 Envisat ASAR wide-swath-mode scenes from 2003 to 2012 (Hasager et al. 2015a) covering the Horns Rev-1 wind farm near the Danish North Sea coast. The wind farm covers an area of around 4 km by 5 km and three concentric circles centered at the wind farm are used for extraction of results. The selected radii are 6, 10 and 13 km. The mean wind speeds in each of the three circles (geo-collocated) quantify the coastal wind speed gradient. Next step is rotation of the data such that all scenes are aligned with inflow and downstream (wake region) based on the wind direction in the wind field maps. The rotation is done at 1 degree intervals. The data from rotated circles (not geo-collocated) are normalized with the winds at the side-lobes. Side-lobes are regions expected to be undisturbed by the wind farm wake. The key result of the analysis is the significant wind wake deficit at the inner circle, decreasing at outer circles, as expected. The SAR-based results strongly support the wake model results based on PARK and WRF (Hasager et al. 2015b). The third analysis is based on Sentinel-1 covering the Anholt wind farm located 56.6 °N, 11.25 °E in the Kattegat Strait. The 111 wind turbines, each 3.6 MW, are positioned in irregular lay-out with most turbines at the outer rim. Figure 1 shows Sentinel-1 on 11th September 2015 at 05:32 GMT with winds around 11-12 m/s from the southeast and wind farm wake west of the park with winds around 10 m/s. The wind turbines are visible as hard targets. Cases with winds from 6 to 14 m/s are under investigation. The potential of synergetic use of Sentinel-1a and Radarsat-2 with only few minutes time lag and the forthcoming Sentinel-1b with around 6 hour will increase sampling rate

Wind farm efficiency assessed by WRF with a statistical-dynamical approach

A pledge to increase the share of renewable energies has led to a focus on offshore wind energy in many western European countries. With an increasing number of offshore wind farms to be installed it becomes important to understand (I) the degree to which wakes from neighbouring wind farms affect the power production of a target wind farm and (II) how large wind farms can get if they are to remain efficient and productive power generators. The modelling of wind farm wake flows is challenging, since it includes processes from the micro- to mesoscale meteorology. We use the Weather Research and Forecast (WRF) model that allows us to simulate mesoscale features of wind farm wakes. Its limited horizontal resolution – in microscale terms – however, requires flow characteristics, such as single turbine wakes, to be parametrised.
Wind resources at turbine height from Envisat and Sentinel-1 SAR

A comprehensive database with ocean wind fields has been built up at the Technical University of Denmark (DTU) through consistent processing of Synthetic Aperture Radar (SAR) observations from Envisat (2002-12) and Sentinel-1 (2014-present). The archived wind fields cover the European seas up to 100 km from the coastline. They can be seen as a series of snapshots showing the instantaneous wind conditions for the areas most relevant for offshore wind power generation. Through statistical processing, these instantaneous snapshots are combined to give maps of the offshore wind resources for the standard output level of 10 m above the sea surface. This presentation demonstrates the effects of two recent improvements related to satellite-based wind resource mapping:

1) The number of satellite samples has increased dramatically since the launch of Sentinel-1A/B
2) A new method looks promising for routine extrapolation of wind fields to the height of modern wind turbines

At DTU, wind maps are retrieved in near-real-time from ESA’s L1 SAR products using the SAROPS processing tool developed by the US National Oceanic and Atmospheric Administration (NOAA). The geophysical model function CMOD5.N is used to obtain the equivalent neutral wind speed. A correction is applied to compensate for lower radar backscatter at HH polarization compared to VV polarization. Ancillary data used for the SAR-wind processing include wind directions from the Global Forecast System (GFS) and ice mask data from the US National Ice Center.

Once the instantaneous wind maps are stored in our database, they can be organized as time series in order to calculate wind resources for any point location or area. Since the time series comprises data from both Envisat and Sentinel-1, a check of the data calibration against one or more independent data sources is needed. Based on the calibrated time series, a Weibull fit is made to calculate the mean wind speed, Weibull scale and shape parameters, and the wind power density. The spatial grid of the output wind resource maps is 0.02 degrees in latitude and longitude. To extrapolate the 10-m wind resource maps from SAR to higher levels within the atmospheric boundary layer, we estimate a wind profile for each grid cell in the maps. Simulations from the Weather Research and Forecasting (WRF) model are used to correct this profile for long-term atmospheric stability effects. Accounting for atmospheric stability allows us to estimate the wind speed at different levels with greater accuracy compared to methods that assume a neutral atmospheric boundary layer. For the Northern European seas, the inclusion of atmospheric stability increases the mean wind speed at 100 m on the order of 0.5 m/s.

The SAR-based wind resource maps are used in the New European Wind Atlas – an EU-funded project where European nations work together to produce an updated and validated wind atlas for Europe.
Application of mesoscale models with wind farm parametrizations in eera-dtoc

General information
State: Published
Organisations: Department of Wind Energy, Meteorology, Technical University of Denmark
Authors: Volker, P. J. (Intern), Badger, J. (Intern), Hahmann, A. N. (Intern), Hansen, S. (Ekstern), Badger, M. (Intern), Husson, R. (Ekstern), Vincent, P. (Ekstern), Longépé, N. (Ekstern), Mouche, A. (Ekstern), Hasager, C. B. (Intern)
Number of pages: 3
Publication date: 2015
Event: Abstract from EWEA Offshore 2015 Conference, Copenhagen, Denmark.
Main Research Area: Technical/natural sciences

Abstract
The aim of the paper is to present offshore wind farm wake observed from satellite Synthetic Aperture Radar (SAR) wind fields from RADARSAT-1/-2 and Envisat and to compare these wakes qualitatively to wind farm wake model results. From some satellite SAR wind maps very long wakes are observed. These extend several tens of kilometres downwind e.g. 70 km. Other SAR wind maps show near-field fine scale details of wake behind rows of turbines. The satellite SAR wind farm wake cases are modelled by different wind farm wake models including the PARK microscale model, the Weather Research and Forecasting (WRF) model in high resolution and WRF with coupled microscale parametrization.

Comparing satellite SAR and wind farm wake models
The aim of the paper is to present offshore wind farm wake observed from satellite Synthetic Aperture Radar (SAR) wind fields from RADARSAT-1/-2 and Envisat and to compare these wakes qualitatively to wind farm wake model results. From some satellite SAR wind maps very long wakes are observed. These extend several tens of kilometres downwind e.g. 70 km. Other SAR wind maps show near-field fine scale details of wake behind rows of turbines. The satellite SAR wind farm wake cases are modelled by different wind farm wake models including the PARK microscale model, the Weather Research and Forecasting (WRF) model in high resolution and WRF with coupled microscale parametrization.
Design tool for offshore wind farm cluster planning

In the framework of the FP7 project EERA DTOC: Design Tool for Offshore wind farm Cluster, a new software supporting the planning of offshore wind farms was developed, based on state-of-the-art approaches from large scale wind potential to economic benchmarking. The model portfolio includes WASP, FUGA, WRF, Net-Op, LCoE model, CorWind, FarmFlow, EeFarm and grid code compliance calculations. The development is done by members from European Energy Research Alliance (EERA) and guided by several industrial partners. A commercial spin-off from the project is the tool 'Wind & Economy'. The software has been compared and validated to a wide extent. Around 10 wake models have been compared to SCADA data from the Horns Rev 1 offshore wind farm in the North Sea, and the Lillgrund and Rødsand-2 wind farms in the Baltic Sea. The Rødsand-2 wind farm is located nearby the Nysted-1 wind farm, thus an investigation of the wake influence between dual operation twin farms was possible. Furthermore both micro- and mesoscale wake models have been compared to satellite-based wind farm wake data in the North Sea. Regarding the planning of the electrical grid, both inter-array and long-distance cables were modelled by the software and several tests were performed. The calculations include the smoothing effect on produced energy between wind farms located in different regional wind zones and the short time scales relevant for assessing balancing power. The grid code compliance was tested for several cases and the results are useful for wind farm planning of the grid and necessary components and controls.

General information
State: Published
Organisations: Department of Wind Energy, Meteorology, Wind Energy Systems, Aeroelastic Design, Fluid Mechanics, Energy Research Centre of the Netherlands, Overspeed, University of Strathclyde, SINTEF, University of Porto, Fraunhofer Gesellschaft, Carl Von Ossietzky University Oldenburg, Cornell University, Centre for Renewable Energy Sources, National Technical University of Athens
Number of pages: 10
Publication date: 2015

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Publisher: European Wind Energy Association (EWEA)
Main Research Area: Technical/natural sciences
Electronic versions:
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015
ESA ResGrow: Trial cases for SAR lifting. Aegean Sea
This report presents results related to lifting of wind maps retrieved from satellite Synthetic Aperture Radar (SAR) over the Aegean Sea. For this case study DTU Wind Energy collaborates with the Hellenic Wind Energy Association. Preliminary results have been presented to HWEA and their feedback has been incorporated in this final version of the report.

General information
State: Published
Organisations: Department of Wind Energy, Meteorology
Authors: Badger, M. (Intern), Hasager, C. B. (Intern), Hahmann, A. N. (Intern), Volker, P. (Intern), di Bella, A. (Intern), Bingöl, F. (Intern)
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Publication: Research › Report – Annual report year: 2015

Is the Power Density of Large Offshore Wind Farms Limited?

General information
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Organisations: Department of Wind Energy, Meteorology
Authors: Volker, P. (Intern)
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Publication: Research › Sound/Visual production (digital) – Annual report year: 2015

Mesoscale modeling for the Wind Atlas of South Africa (WASA) project
This document reports on the methods used to create and the results of the two numerical wind atlases developed for the Wind Atlas for South Africa (WASA) project. The wind atlases were created using the KAMM-WAsP method and from the output of climate-type simulations of the Weather, Research and Forecasting (WRF) model, respectively. The report is divided into three main parts. In the first part, we document the method used to run the mesoscale simulations and to generalize the WRF model wind climatologies, which was used for the first time in a wind atlas project. The second part compares the results from the numerical wind atlases (NWA) produced by the KAMM-WAsP with that produced with the WRF method, and verifies the two wind atlases from the two methods against the observed wind atlas (OWA) generated from wind observations from the 10 WASA masts. The KAMM-WAsP method was found to underestimate the generalized mean wind speeds at the sites (mean bias of -8.2% and mean absolute bias of 9.3%). In the WRF-based method there is, on average, a difference of 4.7% (either positive or negative) between the WRF-based NWA results and the corresponding observed values. The combined average across all the sites is an over-estimate of 2.5%. The report also documents the variability of the 62 m AGL wind speed at the 10 sites in the seasonal and diurnal time scale and compares it with the WRF-simulated winds.

General information
State: Published
Simulation of wake effects between two wind farms

SCADA data, recorded on the downstream wind farm, has been used to identify flow cases with visible clustering effects. The inflow condition is derived from a partly undisturbed wind turbine, due to lack of mast measurements. The SCADA data analysis concludes that centre of the deficit for the downstream wind farm with disturbed inflow has a distinct visible maximum deficit zone located only 5-10D downstream from the entrance. This zone, representing 20-30% speed reduction, increases and moves downstream for increasing cluster effect and is not visible outside a flow sector of 20-30°.

The eight flow models represented in this benchmark include both RANS models, mesoscale models and engineering models. The flow cases, identified according to the wind speed level and inflow sector, have been simulated and validated with the SCADA results. The model validation concludes that all models more or less are able to predict the location and size of the deficit zone inside the downwind wind farm.

General information
State: Published
Organisations: Department of Wind Energy, Fluid Mechanics, Aeroelastic Design, Meteorology, Centro Nacional de Energias Renovables
Authors: Hansen, K. S. (Intern), Réthoré, P. (Intern), Palma, J. (Ekstern), Hevia, B. (Ekstern), Prospathopoulos, J. (Ekstern), Pena Diaz, A. (Intern), Ott, S. (Intern), Schepers, G. (Ekstern), Palomares, A. (Ekstern), van der Laan, P. (Intern), Volker, P. (Intern)
The Explicit Wake Parametrisation V1.0: a wind farm parametrisation in the mesoscale model WRF

We describe the theoretical basis, implementation and validation of a new parametrisation that accounts for the effect of large offshore wind farms on the atmosphere and can be used in mesoscale and large-scale atmospheric models. This new parametrisation, referred to as the Explicit Wake Parametrisation (EWP), uses classical wake theory to describe the unresolved wake expansion. The EWP scheme is validated against filtered in situ measurements from two meteorological masts situated a few kilometres away from the Danish offshore wind farm Horns Rev I. The simulated velocity deficit in the wake of the wind farm compares well to that observed in the measurements and the velocity profile is qualitatively similar to that simulated with large eddy simulation models and from wind tunnel studies. At the same time, the validation process highlights the challenges in verifying such models with real observations.

General information
State: Published
Organisations: Department of Wind Energy, Meteorology
Authors: Volker, P. H. J. (Intern), Badger, J. (Intern), Hahmann, A. N. (Intern), Ott, S. (Intern)
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Main Research Area: Technical/natural sciences
The Explicit Wake Parametrisation V1.0: a wind farm parametrisation in the mesoscale model WRF

We describe the theoretical basis, implementation and validation of a new parametrisation that accounts for the effect of large offshore wind farms on the atmosphere and can be used in mesoscale and large-scale atmospheric models. This new parametrisation, referred to as the Explicit Wake Parametrisation (EWP), uses classical wake theory to describe the unresolved wake expansion. The EWP scheme is validated against filtered in situ measurements from two meteorological masts situated a few kilometres away from the Danish offshore wind farm Horns Rev I. The simulated velocity deficit in the wake of the wind farm compares well to that observed in the measurements and the velocity profile is qualitatively similar to that simulated with large eddy simulation models and from wind tunnel studies. At the same time, the validation process highlights the challenges in verifying such models with real observations.

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The new worldwide microscale_rev

Bibliographical note
Oral presentation

The Simulation of Wind Farm Wakes with Mesoscale Models

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Organisations: Department of Wind Energy, Meteorology
Authors: Volker, P. (Intern), Badger, J. (Intern), Hahmann, A. N. (Intern), Badger, M. (Intern), Hasager, C. B. (Intern)
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Using Satellite SAR to Characterize the Wind Flow around Offshore Wind Farms

Offshore wind farm cluster effects between neighboring wind farms increase rapidly with the large-scale deployment of offshore wind turbines. The wind farm wakes observed from Synthetic Aperture Radar (SAR) are sometimes visible and atmospheric and wake models are here shown to convincingly reproduce the observed very long wind farm wakes. The present study mainly focuses on wind farm wake climatology based on Envisat ASAR. The available SAR data archive covering the large offshore wind farms at Horns Rev has been used for geo-located wind farm wake studies. However, the results are difficult to interpret due to mainly three issues: the limited number of samples per wind directional sector, the coastal wind speed gradient, and oceanic bathymetry effects in the SAR retrievals. A new methodology is developed and presented. This method overcomes effectively the first issue and in most cases, but not always, the second. In the new method all wind field maps are rotated such that the wind is always coming from the same relative direction. By applying the new method to the SAR wind maps, mesoscale and microscale model wake aggregated wind-fields results are compared. The SAR-based findings strongly support the model results at Horns Rev 1.

General information
State: Published
Organisations: Department of Wind Energy, Meteorology
Authors: Hasager, C. B. (Intern), Vincent, P. (Ekstern), Badger, J. (Intern), Badger, M. (Intern), di Bella, A. (Intern), Pena Díaz, A. (Intern), Husson, R. (Ekstern), Volker, P. (Intern)
Wake Effects of Large Offshore Wind Farms - a study of the Mesoscale Atmosphere

The power production contribution to the power system from offshore wind energy is continuously increasing in the northern European countries. A better understanding of the influence of wind farms to those downstream and to the lower atmosphere will help optimising energy production from large wind farm clusters. Mesoscale models allow the simulation of large domains sufficiently to capture large wind farms and surroundings at reasonable computational costs, but processes below the horizontal resolution remain unresolved and have to be parametrised, such as the effects of the wind turbines to the flow. In the past, several approaches have been introduced, ranging from surface roughness change to drag approaches which usually also add turbulence. A new scheme is implemented in the Weather Research and Forecast (WRF) model. Measurements from Horns Rev I are used to evaluate the new scheme together with that in the WRF model. Results show an improvement of robustness in vertical resolution dependency. Furthermore, the velocity and “turbulence kinetic energy” fields agree better to those of high resolution models. The two schemes are applied to various problems. A hypothetical offshore wind farm in northern California, shows a sensitivity of the velocity field around the wind farm to atmospheric conditions aloft. For a shallow boundary layer capped by a steep inversion, gravity waves were generated, with related anomalies of the atmospheric variables aloft. Dependencies of the wind farm efficiency and the wind farm’s wake recovery to different atmospheric conditions aloft were found in an idealised case study. Moreover, the wind farm efficiency to different climates for wind farm sizes up to 375 km² was examined. The modelled production varied with wind climate and were well above 1Wm⁻², contrary to another study. Finally, wind farm shadowing was studied for the worst case scenario, in which two wind farms are perfectly aligned. For this scenario, considerable production losses of the downstream wind farm are expected, even with a separation of 5 wind farm lengths.
Wind Farm Group Efficiency - A Sensitivity Analysis with a Mesoscale Model

The total installed capacity in the North Sea was in 2012 5 GW, and it estimated that it will grow to 40 GW by 2020 (EWEA). This will lead to an increasing wind farm density in regions with the most favourable conditions. In this study, we investigate the sensitivity of power density losses to wind farms that are in the wake of an upstream wind farm.

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Organisations: Department of Wind Energy, Meteorology
Authors: Volker, P. (Intern), Badger, J. (Intern), Hahmann, A. N. (Intern)
Number of pages: 7
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Source-ID: 103527906
Publication: Research - peer-review › Article in proceedings – Annual report year: 2014

Wind Farm Group Efficiency - A Sensitivity Analysis with a Mesoscale Model

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General information
State: Published
Organisations: Department of Wind Energy, Meteorology
Authors: Volker, P. (Intern), Badger, J. (Intern), Hahmann, A. N. (Intern)
Number of pages: 1
Publication date: 2014
Main Research Area: Technical/natural sciences
Electronic versions:
Wind_Fram_Group_Efficiency_poster.pdf
Publication: Research - peer-review › Poster – Annual report year: 2014

Offshore Wind Farm Clusters - Towards new integrated Design Tool

In EERA DTOC testing of existing wind farm wake models against four validation data test sets from large offshore wind farms is carried out. This includes Horns Rev-1 in the North Sea, Lillgrund in the Baltic Sea, Roedsand-2 in the Baltic Sea and from 10 large offshore wind farms in Northern European Seas using satellite remote sensing.

General information
State: Published
Shadowing effects of offshore wind farms - an idealised mesoscale study

The study of wind farm (WF) interaction is expected to gain importance, since the offshore wind farm density will increase especially in the North Sea in the near future. We present preliminary results of wind farm interaction simulated by mesoscale models. We use the Explicit Wake Parametrisation (EWP) parametrisation developed at DTU Wind Energy.

General information
State: Published
Organisations: Department of Wind Energy, Meteorology
Authors: Volker, P. (Intern), Badger, J. (Intern), Hahmann, A. N. (Intern)
Number of pages: 6
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Event: Poster session presented at Danish Wind Power Research 2013, Fredericia, Denmark.
Main Research Area: Technical/natural sciences
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Publication: Research › Sound/Visual production (digital) – Annual report year: 2013

Wake effects of large offshore wind farms - a study of mesoscale atmosphere and ocean feedbacks

General information
State: Published
Organisations: Department of Wind Energy, Meteorology
Authors: Volker, P. (Intern)
Wake modelling combining mesoscale and microscale models

In this paper the basis for introducing thrust information from microscale wake models into mesoscale model wake parameterizations will be described. A classification system for the different types of mesoscale wake parameterizations is suggested and outlined. Four different mesoscale wake parameterizations are demonstrated in the Weather Research and Forecasting mesoscale model (WRF) in an idealized atmospheric flow. The model framework is the Horns Rev I wind farm experiencing an 7.97 m/s wind from 269.4°. Three of the four parameterizations use thrust output from the CRESflow-NS microscale model. The characteristics of the mesoscale wake that developed from the four parameterizations are examined. In addition the mesoscale model wakes are compared to measurement data from Horns Rev I. Overall it is seen as an advantage to incorporate microscale model data in mesoscale model wake parameterizations.

General information
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Organisations: Department of Wind Energy, Meteorology, Aeronautical Design, Centre for Renewable Energy Sources
Authors: Badger, J. (Intern), Volker, P. (Intern), Prospathopoulos, J. (Ekstern), Sieros, G. (Ekstern), Ott, S. (Intern), Réthoré, P. (Intern), Hahmann, A. N. (Intern), Hasager, C. B. (Intern)
Number of pages: 12
Publication date: 2013

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Editor: Shen, W.
Main Research Area: Technical/natural sciences
Conference: International Conference on aerodynamics of Offshore Wind Energy Systems and wakes (ICOWES 2013), Lyngby, Denmark, 17/06/2013 - 17/06/2013
Electronic versions:
Wake_modelling_combining_mesoscale.pdf
Publication: Research - peer-review › Article in proceedings – Annual report year: 2013
**Impact of Wind Farms on the Marine Atmospheric Boundary Layer**

The presented work is part of a study sponsored by the California Institute of Energy and Environment, in which the impact of the aimed increasing contribution of clean alternative energy sources in the next 30 years will be investigated. Due to the huge wind energy potential along the Californian coast, we will focus on the environmental impacts of large offshore wind farms which become feasible, since offshore turbine technology has matured significantly in the last decade.

**General information**

State: Published
Organisations: Department of Wind Energy, Meteorology, University of California, Los Angeles
Authors: Volker, P. J. (Intern), Hall, A. (Ekstern), Capps, S. B. (Ekstern), Huang, H. J. (Ekstern), Sun, F. (Ekstern), Badger, J. (Intern), Hahmann, A. N. (Intern)
Number of pages: 1
Publication date: 2012
Event: Poster session presented at 2012 AGU Fall Meeting, San Francisco, United States.
Main Research Area: Technical/natural sciences
Electronic versions:
Impact_of_Wind_Farms.pdf
Publication: Research › Poster – Annual report year: 2012

**Wake effects of large offshore wind farms on the mesoscale atmosphere**

We present a new approach, which allows us to simulate the flow distortion caused by the thrust of wind farms in a mesoscale model. The atmospheric flow is simulated with the WRF mesoscale model, since it has significantly lower computational costs compared to higher resolution models. Due to the fact that its typical horizontal grid spacing is on the order of 2km, the energy extracted by the turbine, as well as the wake development inside the turbine-containing grid-cells, are not described explicitly, but are parametrized as another sub-grid scale process.

In order to appropriately capture the wind farm wake recovery and its direction, two properties are important, the total energy extracted by the wind farm and its velocity deficit distribution. In the considered parametrization the individual turbines apply a thrust dependent on a local sub grid scale velocity, which is influenced by the up-stream turbines. For the sub-grid scale velocity deficit, the entrainment from the free atmospheric flow into the wake region, is taken into account. Furthermore, since the model horizontal distance is several times larger then the turbine diameter, it has been assumed that the generated turbulence and dissipation are balanced. From version 3.2.1 onwards, the WRF model includes a wind farm parametrization option (Fitch-Scheme). Contrary to the above described parametrization where the wind turbines are positioned explicitly, the wind farms in the default scheme are treated as a density distribution, which limits the description of the internal wind farm velocity deficit development and its related efficiency. In the Fitch-scheme the extracted force is proportional to the turbine area interfacing a grid-cell. The subgrid scale wake expansion is achieved by adding turbulence kinetic energy to the flow. The validity of both wind farm parametrizations has been verified against observational data. We use met. mast measurements and power measurements from wind turbines, at HornsRev. The wind farm measurements have been used to compare the total thrust produced by both types of parametrization, as well as the down-stream velocity recovery in the first 6km after the wind farm.

**General information**

State: Published
Organisations: Meteorology, Department of Wind Energy
Authors: Volker, P. (Intern), Badger, J. (Intern), Hahmann, A. N. (Intern), Ott, S. (Intern)
Number of pages: 1
Publication date: 2012
Wind Farm parametrization in the mesoscale model WRF

The project's objective is to investigate and develop methods for prediction of mesoscale climate, wake effects and atmospheric feedbacks, for scenarios where large portions of the sea are covered with wind farms. The atmospheric flow is simulated with the WRF mesoscale model, since it has significantly lower computational costs compared to high resolution models. Due to the fact that its typical horizontal grid spacing is on the order of 2km, the energy extracted by the turbine, as well as the wake development inside the turbine-containing grid cells, are not described explicitly, but are parametrized as another sub-grid scale process.

In order to appropriately capture the wind farm wake recovery and its direction, two properties are important, among others, the total energy extracted by the wind farm and its velocity deficit distribution. In the considered parametrization the individual turbines produce a thrust dependent on the background velocity. For the sub-grid scale velocity deficit, the entrainment from the free atmospheric flow into the wake region, which is responsible for the expansion, is taken into account. Furthermore, since the model horizontal distance is several times larger then the turbine diameter, it has been assumed that the generated turbulence and dissipation are balanced.

From version 3.2.1 onwards, the WRF (Weather Research and Forecast) model includes a wind farm parametrization option (Fitch Scheme). In contrary to the above described parametrization where the wind turbines are positioned explicitly, the wind farms in the default scheme are treated as a density distribution, which limits the description of the internal wind farm velocity deficit development and its related efficiency. In the Fitch Scheme the wind turbines act as drag devices, where the extracted force is proportional to the turbine area interfacing a grid cell. The wake expansion is achieved by adding turbulence kinetic energy (proportional to the extracted power) to the flow. The validity of both wind farm parametrizations has been verified against observational data. We use Synthetic Aperture Radar (SAR) satellite data, as well as mast measurements from meteorological masts and power measurements from wind turbines, at Horns Rev and Nysted. From the SAR satellite data the wake extension can be derived.

The wind farm measurements have been used to compare the total thrust produced by both types of parametrization. In case studies the wake deficit has been estimated by the deflection of the wake due to the slowing down of the wind speed.

The results of the wind farm parametrization will be used to investigate eventual climate impacts of large wind farms. Furthermore it will develop techniques for up-scaling the effects simulated by wind farm wake models into mesoscale atmospheric planetary boundary layer (PBL) parameterisations and perform simulations using these parameterisations to understand the feedbacks between the wind farms and the regional wind climate. The work will extend the current knowledge about wake effects from observations and small-scale models to potential feedbacks in the PBL atmosphere.
Projects:

Wind Atlas for South Africa (Phase 2)
Capacity development and research cooperation through the development of wind resource mapping for the remaining parts of the Eastern Cape, KwaZulu-Natal and parts of the Free State Province.

Phase 1 of the project ended in 2014.

Department of Wind Energy
Wind Energy Systems
Meteorology
Test and Measurements
Council for Scientific and Industrial Research
University of Cape Town
South African Weather Service
South African National Energy Development Institute
Period: 01/04/2014 → 31/03/2018
Number of participants: 9
Acronym: WASA
Project participant:
Mortensen, Niels Gylling (Intern)
Hahmann, Andrea N. (Intern)
Badger, Jake (Intern)
Volker, Patrick (Intern)
Larsén, Xiaoli Guo (Intern)
Enevoldsen, Karen (Intern)
Storen, Steen Arne (Intern)
Cronin, Tom (Intern)

Project Manager, organisational:
Hansen, Jens Carsten (Intern)

EERA DTOC: European Energy Research Alliance Design Tools for Offshore wind farm Clusters
The project is funded by the EU – Seventh Framework Programme (FP7) – and runs from January 2012 to June 2015. It is coordinated by the Technical University of Denmark - DTU Wind Energy.

The EERA-DTOC project combines expertise to develop a multidisciplinary integrated software tool for an optimized design of offshore wind farms and clusters of wind farms.

Charlotte Bay Hasager is the daily manager of the project.
Peter Hauge Madsen is coordinator.

Department of Wind Energy
Meteorology
Department of Applied Mathematics and Computer Science
Wind Energy Systems
Aeroelastic Design
Risø National Laboratory for Sustainable Energy
Fluid Mechanics
Period: 01/01/2012 → 30/06/2015
Number of participants: 15
Offshore wind, wind clusters, design, optimization
Acronym: EERA-DTOC

Project participant:
Giebel, Gregor (Intern)
Réthoré, Pierre-Elouan (Intern)
Cutululis, Nicolaos Antonio (Intern)
Badger, Merete (Intern)
Hahmann, Andrea N. (Intern)
Peña, Alfredo (Intern)
Badger, Jake (Intern)
Volker, Patrick (Intern)
Karagali, Ioanna (Intern)
Maule, Petr (Intern)
vander Laan, Paul (Intern)
Cutululis, Nicolaos Antonio (Intern)
Hansen, Kurt Schaldemose (Intern)

Project Manager, academic:
Hasager, Charlotte Bay (Intern)

Project Coordinator:
Madsen, Peter Hauge (Intern)

Relations
Activities:
Ocean winds from satellites – applications for offshore wind energy
Publications:
Shadowing effects of offshore wind farms - an idealised mesoscale study
Energy Yield Prediction of Offshore Wind Farm Clusters at the EERA-DTOC European Project
EERA DTOC wake results offshore
EERA Design Tool for Offshore wind farm Cluster (DTOC)
Offshore winds mapped from satellite remote sensing
Wind Farm Wake: The Horns Rev Photo Case
Transmission of wave energy through an offshore wind turbine farm

Wake effects of large offshore wind farms - a study of mesoscale atmosphere and ocean feedbacks

Department of Wind Energy
Period: 01/10/2010 → 28/04/2014
Number of participants: 6
Phd Student:
Volker, Patrick (Intern)
Supervisor:
Badger, Jake (Intern)
Main Supervisor:
Hahmann, Andrea N. (Intern)
Examiner:
Réthoré, Pierre-Elouan (Intern)
Barstad, Idar (Ekstern)
Gayle Nygaard, Nicolai (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Marie Curie (EU-stipendium)
Project: PhD

Wind Atlas for South Africa (Phase 1)
Capacity development and research cooperation through development of wind resource mapping for the Western Cape and areas of Northern and Eastern Cape.

Phase 2 of the project starts in 2014.
Period: 01/11/2008 → 31/03/2014
Number of participants: 10
Acronym: WASA
Project participant:
Mortensen, Niels Gylling (Intern)
Hahmann, Andrea N. (Intern)
Badger, Jake (Intern)
Volker, Patrick (Intern)
Larsén, Xiaoli Guo (Intern)
Kelly, Mark C. (Intern)
Enevoldsen, Karen (Intern)
Sørensen, Steen Arne (Intern)
Cronin, Tom (Intern)
Project Manager, organisational:
Hansen, Jens Carsten (Intern)

Relations
Related projects:
Wind Atlas for South Africa (Phase 2)
Publications:
Large-scale, high-resolution wind resource mapping for wind farm planning and development in South Africa
Mesoscale modeling for the Wind Atlas of South Africa (WASA) project
Application of the spectral correction method to reanalysis data in South Africa
Validation and comparison of numerical wind atlas methods: the South African example

Activities:

Is the Power Density of Large Offshore Wind Farms Limited?
Period: 27 Mar 2014
Patrick Volker (Speaker)
Department of Wind Energy
Meteorology

Description
Presentation
Documents:
pvol_dtuwindenergy

Related event
The Danish Wind Industry Annual Event 2014
26/03/2014 → 27/03/2014
Herning, Denmark
Activity: Talks and presentations › Conference presentations