Wind Farm Wake

Hasager, Charlotte Bay; Karagali, Ioanna; Volker, Patrick; Andersen, Søren Juhl; Nygaard, Nicolai Gayle

Published in:
Windtech International

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
On 25 January 2016 at 12:45 UTC several photographs of the offshore wind farm Horns Rev 2 were taken by helicopter pilot Gitte Lundorff with an iPhone. A very shallow layer of fog covered the sea. The photos of the fog over the sea dramatically pictured the offshore wind farm wake. Researchers got together to investigate the atmospheric conditions at the time of the photos by analysing local meteorological observations and wind turbine information, satellite remote sensing and nearby radiosonde data. Two wake models and one mesoscale model were used to model the case and explain what was seen.

**Motivation for the Research**

Because the photos of fog over the sea stunningly visualised the offshore wind farm wake, five researchers from DTU Wind Energy and one senior wind energy analyst from DONG Energy got together to analyse and model the atmospheric conditions and processes of the eye-catching photos.

The research questions posed were:
- Do the fog trails correspond to the wakes?
- Why did the fog end?
- Do the visual wakes match the wind speed pattern?
- Does the wake model match the production pattern?

**Horns Rev 2 Offshore Wind Farm**

The Horns Rev 2 Offshore Wind Farm is located in the Danish North Sea. It covers approximately 35km2 and consists of 91 wind turbines and one transformer station. The transformer station is located east of the turbines and is visible as a white dot in the clearing of the fog (Figure 1). A service ship is also seen east of the wind farm. The turbines have rotor diameters of 93 metres and, with a hub height of 86 metres, the tip of the blades reaches from 21.5 to 114.5 metres above mean sea level. The distance between turbines is variable with a curved layout. The production was near the rated power of 2,300kW at the time of the photos.

**Atmospheric Conditions**

The shallow layer of undisturbed fog extends less than 20 metres above sea level (i.e. is below the lower tip of the blades). The wind speed was 13m/s and its direction 223 degrees at hub height. The sea surface temperature was around 5.2°C, while the air temperature at 26 metres was around 8.0°C. The ambient turbulence estimated from wind lidar data was around 3%. There was stable atmospheric stratification.

**Satellite Data**

Several Earth-observing satellites provided observations near the time of the photos. Cloud cover images from a mixture of geostationary and polar orbiting satellites show clear skies west of the wind farm and cloudy conditions east of it (Figure 2). A thin cloud layer at the site allows sunlight to light up the scene. The fog cones are sunlit at the southern part and in shade at the northern part.

Night-time sea surface temperatures retrieved from a mixture of thermal and passive microwave satellite data, gap filled and interpolated by the Danish Meteorological Office, show warmer surface water west of the wind farm up to 8°C and cooler water east of the wind farm down to 2°C (Figure 3).

During windy, winter conditions sea surface temperatures are relatively constant during day and night, thus representative for the time of the photos. Scatterometer satellite data shows winds from the southwest in the region.

**Wake Modelling by Two Approaches**

The first approach used was the PARK model, a simple engineering model, with input of wind direction from the front row turbine nacelle anemometers and wind speed 13m/s. The results on wind power production from the SCADA data and model results compare well. The other approach was to perform large eddy simulation (LES) for a single
Mesoscale Modelling

Large-scale wind flow at the time of the photos was modelled by the Weather Research and Forecasting (WRF) mesoscale model. Further details as well as SCADA and meteorological data are given in Hasager et al. 2017 (Energies, 10, 317). The WRF model produces detailed results on the humidity, temperature and winds at several heights compared to nearby radiosonde data at Norderney.

The model has been run with and without a parametrisation for the wind farms in the Horns Rev area. Results from the two runs are subtracted (Figure 4). The differences in liquid water content at hub height between simulations with and without wind farms show a clearing of fog in the downwind area which extends for more than 100 kilometres. The tendency for dissolving of the fog layer at the end of and behind the wind farm in the photos is ascribed to admixture of warmer air from aloft. This process is caused by the wind farm wake with continuously seeding particles upwind of the rotor at two heights. The downwind movement and expansion of the wake is visualised from tracing the position of particles. Furthermore, an assumption that the particles behave as saturated/non-saturated at the dew point temperature is included. This gives estimates of the fog emergence and dispersion. The LES results compared with visual inspection of the fog in the photos thus gives indication of the fog development and pattern.

Summary

In summary the main conclusions related to the key questions are:

• Mixing associated with wakes can cause fog. The wakes are long and narrow due to the stable atmospheric stratification.
• The fog ends most likely due to downward mixing of warm, dry air from aloft. The process is caused by the wind farm wake.
• The fog is prevalent along the individual turbine wakes and builds up matching the wind speed pattern observed.
• The wind direction is critically important to reproduce the production of the wind farm correctly with the wake model.