# "Get Out of My Wind"

## About Wind Farm Shadowing, Wakes and Turbulences

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**Project information: Analysis of shadowing effects and wake turbulence characteristics of large offshore wind farms by comparison of "Alpha Ventus" and "Riffgat" (GW Wakes)**

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Project partners:

- Fraunhofer Institute for Wind Energy and Energy System Technology IWES

Even if it initially sounds like a somewhat unpleasant concept: every time a wind turbine turns, it brakes the incoming wind and then churns it around as it passes through the rotor blades. This creates a wake, a vortex of increased turbulence that has a shadow effect on the turbines behind. This results in reduced yield and increased alternating loads on the wind turbines in the rear rows, which can shorten their service life. The behaviour, especially the dynamics, of these wakes and their interaction in wind farms is complex and difficult to gauge. Up to now, the planning and simulation models contain uncertainties and inaccuracies in the assessment of shadowing and follow-on effects under different meteorological conditions. This leads to risk premiums when planning offshore wind farms or can cause a reduction in electricity supply. This inhibits the economic efficiency of projects. And these shadowing effects do not just occur within a wind farm, but even whole wind farms can be shadowed by one another. It is possible for the wake vortex of a wind farm to extend tens of kilometres.



The shadowing losses and characteristics of the wake turbulences within offshore wind farms were analysed in a large-scale joint research project consisting of two large sub-projects: the measurements in the German offshore test field Alpha Ventus, which are part of the RAVE research initiative, and the measurements in a second, much larger offshore wind farm for comparing and verifying the investigations carried out so far. This was originally intended to be the Bard Offshore 1 wind farm with 80 turbines, each with 122 m rotor diameter. As a result of the insolvency of the Bard Group it was necessary to find a new location for the measurements. A good replacement location was found in the shape of the Riffgat offshore wind farm. The wind farm has 30 turbines with 120 m rotor diameter and measurements began in summer 2015.

## 13.1 Measure More with Multi-Lidar

The first time a multi-lidar system was ever used offshore was in the GW Wakes research project at the Alpha Ventus wind farm. This remote sensing method uses laser beams to determine the wind flow (see ▶ Chap. 12 "Lidar – Shooting into the wind with laser beams"). The GW Wakes project used three so-called "long-range lidar wind scanners" for the measurements in Alpha Ventus as a multi-lidar with a range of several kilometres. For the approximately eight months of the measuring campaign, two of these wind scanners were set up on the Fino 1 research platform west of Alpha Ventus, with the third scanner on the AV0 transformer platform to the southeast (Fig. 13.1). By setting up the scanners at two physically separate locations (Fig. 13.2) it was possible to carry out a variety of measuring scenarios. With this configuration, the intersecting and overlapping lidar measurements make it possible to calculate the horizontal, two-dimensional wind vector in large areas of an offshore wind farm, which is why the MuLiWEA (multiple lidar wind field evaluation) algorithm was developed in this research project. Taking into account a two-dimensional continuity equation, this calculation process generates the so-called 2D wind field, with wind direction and intensity, using the data from several lidar devices.

A specially developed measuring buoy was anchored near Fino 1 (Fig. 13.3), which also records the water surface temperature, the air pressure and the air temperature. These measurements contribute to a better understanding of the dynamics and turbulences above the sea (see ▶ Chap. 17 "Sometimes it almost bubbles like a witches' cauldron"). The measurement profiles of air temperature, atmospheric pressure and humidity have proven to be a source of important information for describing the wakes. This becomes particularly clear with the example of the thermal: onshore, when the sun

**Fig. 13.1** Long-range lidar on the Alpha Ventus transformer platform. © ForWind – University of Oldenburg

shines onto a dry sand hill, the air there heats up faster than over a marsh and then rises. Offshore, the sea is still comparatively warm in autumn, even though the wind is already cold – and this creates an unstable stratification of the atmosphere over the water. These atmospheric stratifications significantly influence the behaviour of the wakes. This influence could be metrologically measured more accurately.

## 13.2 A Deficit Is Obvious – Where the Wind Is Concerned

In the GW Wakes research project the wakes are measured with lidar in up to 240 measuring points with a range up to 6.5 kilometres behind the wind farm.

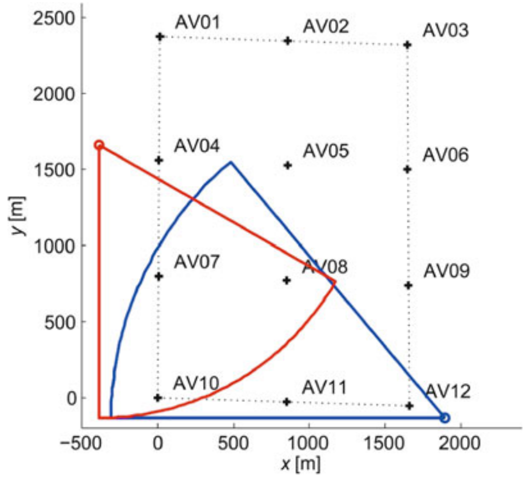


**Fig. 13.2** Schematic representation of the measurement scenario in the Alpha Ventus offshore test field. One lidar on Fino 1 (*red*) and one on the transformer platform (*blue*) measure the wake vortex of turbine AV10. The *areas* captured by the instruments are *outlined in red and blue*. © ForWind – University of Oldenburg

Thanks to the high temporal resolution of the measurements it was possible to detect and investigate the dynamics of the wakes in detail. The evaluations of the measurements clearly show the meandering wake behind the wind turbines, with this example showing it with a southeast wind (Fig. 13.4).

The wake flow behind the wind turbines very much depends on the incoming wind direction in front of the turbines. The graphic (Fig. 13.5) shows how the wind velocity deficit behind the wind turbines depends on the inflow direction on the basis of numerical computer simulations.

## 13.3 Satellites, Lidars and a Source Code

Measurements made with long-range lidars were also compared and combined with those taken using satellite radar. The radar technology covers a very large area, making backscatter images of the sea surface and thereby using the intensity of the backscatter to measure the roughness of the sea surface. This can be used to derive the wind speed. This method can capture significantly larger areas than lidar, though the satellite can only measure

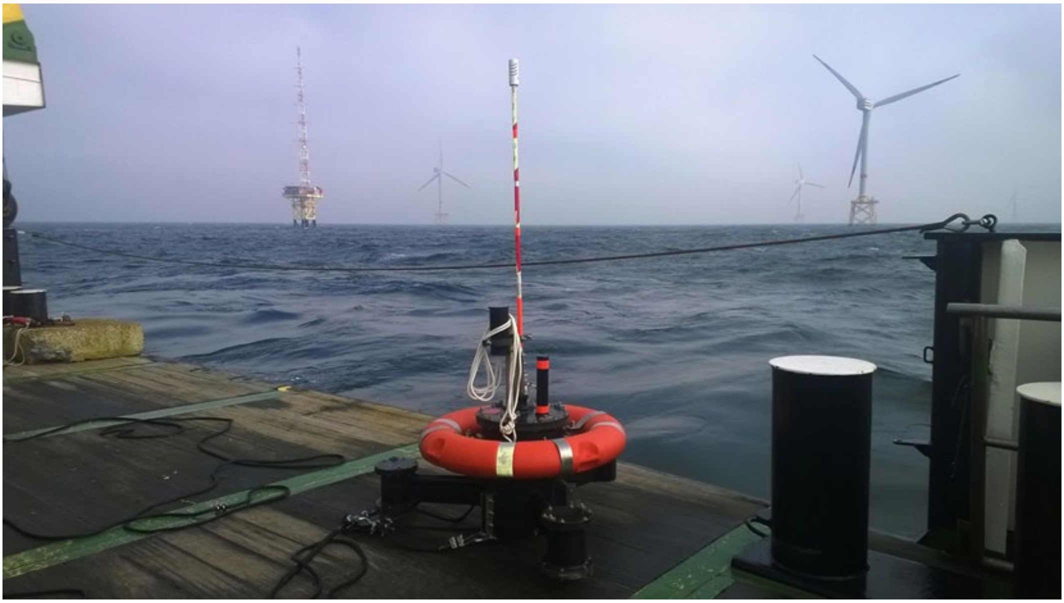

**Fig. 13.3** The measuring buoy used in the GW Wakes project before it was positioned near the Fino 1 research platform. © BSH

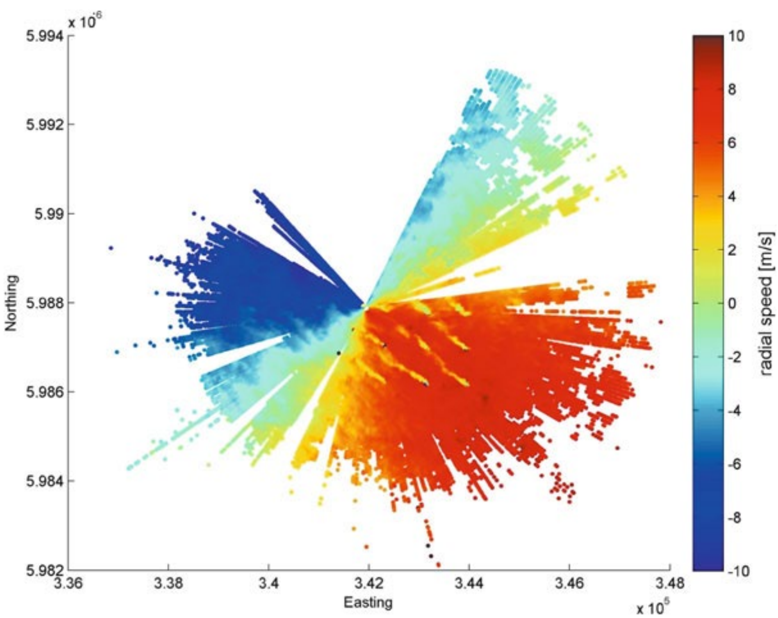


**Fig. 13.4** Measurement of the wind flow in Alpha Ventus with a lidar mounted on Fino 1. The speed component is shown in *different colours* looking towards the lidar (radial speed or line of sight speed). The prevailing wind direction is southeast (*red fields*). The wakes of the wind turbines of the southernmost three rows of turbines can be seen clearly (*below right*). The *white sectors* show where the view of the lidar is blocked by objects on Fino 1. © ForWind – University of Oldenburg



the same position every two or three days. A lidar on the other hand can take measurements in the same region continuously, with higher spatial resolution than the radar satellite and at various heights. But when both were combined – lidar and satellite technology – the initial comparison proved to be a promising instrument for detecting the characteristics of the wakes, and should be used to do this in future measuring campaigns to make the most of the respective advantages of the individual systems.

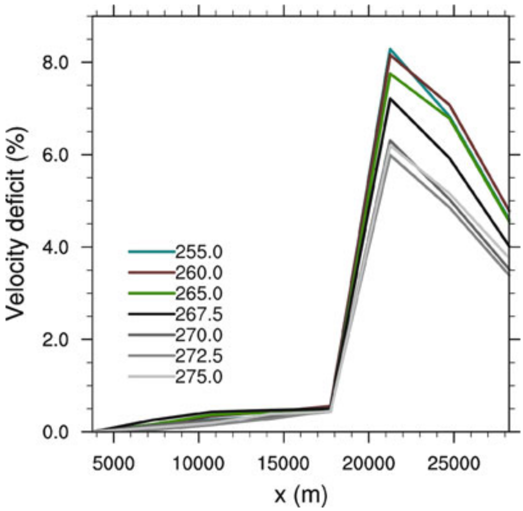


**Fig. 13.5** Average velocity deficit from numerical calculations by averaging over grid elements sized 3.5 × 3.5 $km^2$ for inflows at the Alpha Ventus wind farm from directions between 255 and 275 degrees. The farm's turbines stand in an area 19,500 to 23,000 m behind the inflow margin, and here a marked increase of the deficit is clearly visible. In the area behind the wind farm it slowly decreases again. © ForWind – University of Oldenburg

The GW Wakes project partner Fraunhofer IWES used the findings and approximation models from the GW Wakes research project to augment the "Flap-FOAM" wind farm optimisation software. The programme continues to be developed further within the scope of the ongoing project and validated with real measurements.

## 13.4 More Accuracy Without a Mainframe Computer

The first measuring campaign in Alpha Ventus has been successfully completed. With northerly or southerly inflowing wind it was only possible to measure fourfold overlapping wakes at most, because the offshore wind farm only consisted of four rows with three wind turbines each. In the summer of 2015 measurements were taken at the Riffgat offshore wind farm for purposes of comparison and for mapping the results onto large offshore wind farms – with lidar and additional measuring systems on four wind turbines. Riffgat, around 15 kilometres northwest of Borkum, is suitable for investigating multiple overlapping wakes, in that there are 30 turbines on the wind farm. While their rated capacity of 3.6 MW is a bit less than the 5 MW wind turbines in Alpha Ventus, what is interesting for the research project is the arrangement of the turbines. In Riffgat the turbines are arranged in three rows of ten machines. So if for example the wind comes from the southwest, this results in tenfold overlapping wake currents behind the wind turbines, which can be measured and investigated.

The overriding objective of the ongoing, overall research project is to gain a better understanding of the wakes that arise behind the wind turbines and their interactions. The next step will be the application of this knowledge and its transfer into industrial practice: the development of efficient, numerical computer models that do not just run on a mainframe computer, but which can be used directly in the planning of wind farms. This will lead to significantly reduced uncertainties in the calculation of wind farm shadows and wake turbulences – and to more precise wind yield estimations, which could in the end contribute to better wind farm planning and operation.

## 13.5 Sources


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