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Observation of high-resolution wind fields and offshore wind turbine wakes using TerraSAR-X imagery

Tobias Gies, Sven Jacobsen, Susanne Lehner, and Andrey Pleskachevsky
German Aerospace Centre (DLR), Remote Sensing Technology Institute, Maritime Safety Lab, Bremen, Germany

1. Introduction

Numerous large-scale offshore wind farms have been built in European waters and play an important role in providing renewable energy. Therefore, knowledge of behavior of wakes, induced by large wind turbines and their impact on wind power output is important. The spatial variation of offshore wind turbine wake is very complex, depending on wind speed, wind direction, ambient atmospheric turbulence and atmospheric stability. In this study we demonstrate the application of X-band TerraSAR-X (TS-X) data with high spatial resolution for studies on wind turbine wakes in the near and far field of the offshore wind farm Alpha Ventus, located in the North Sea. Two cases which different weather conditions and different wake pattern as observed in the TS-X image are presented.

2. Methods

The space-borne synthetic aperture radar (SAR) is a unique sensor that provides two-dimensional information on the ocean surface. Due to their high resolution, daylight and weather independency and global coverage, SARs are particularly suitable for many ocean and coastal applications. SAR images reveal wind variations on small scales and thus represent a valuable means in detailed wind-field analysis. The general principle of imaging turbine wakes is that the reduced wind speed downstream of offshore wind farms modulates the sea surface roughness, which in turn changes the Normalized Radar Cross Section (NRCS, denoted by $\sigma 0$) in the SAR image and makes the wake visible. In this study we present two cases at the offshore wind farm Alpha Ventus to investigate turbine-induced wakes and the retrieved sea surface wind field. Using the wind streaks, visible in the TS-X image and the shadow behind the offshore wind farm, induced by turbine wake, the sea surface wind direction is derived and subsequently the sea surface wind speed is calculated using the latest generation of wind field algorithm XMOD2.

3. Case study alpha ventus

Alpha Ventus is located approximately 45 km from the coast of Borkum, Germany, and consists of twelve 5-Megawatt wind power turbines. The retrieved results are validated by comparing with QuikSCAT measurements, the results of the German Weather Service (DWD) atmospheric model and in-situ measurements of wind speed and wind direction, obtained from the research platform FiNO1, installed 400 m west of Alpha Ventus.

4. Conclusion

In the presented case study we quantify the wake characteristics of wake length, wake width, maximum velocity de?cit, wake merging and wake meandering. We show that SAR has the capability to map the sea surface two-dimensionally in high spatial resolution which provides a unique opportunity to observe spatial characteristics of offshore wind turbine wakes. The SAR derived information can support offshore wind farming with respect to optimal siting and design and help to estimate their effects on the environment.