Coastal wind speed gradients at the Anholt wind farm from SCADA, SAR and WRF

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Abstract

High resolution offshore wind maps derived from space borne Synthetic Aperture Radars (SAR) may offer access to site specific wind data in very early phases of offshore wind farm projects. Yet, cases showing prediction capabilities of SAR for offshore wind farm projects are missing. We present a study at the Anholt wind farm showing that SAR and Supervisory Control And Data Acquisition (SCADA) derived winds are comparable with 2.23m/s RMSE at hub height. Horizontal coastal wind speed gradients caused by the proximity of the land are predicted from SAR data, similarly to the observed wind turbine SCADA data and results from numerical weather prediction models.

Keywords: *Coastal wind speed gradient, Synthetic Aperture Radar (SAR), SCADA, WRF*

Introduction

With the number of offshore wind farms increasing every year some sites are affected by existing wind farms or built in lee of the land. Information about site specific meteorological phenomena early in the project planning phase can help to identify the best locations for future wind farms. Numerical weather prediction models like the Weather Research and Forecasting model (WRF) are able to predict wind resources, but their accuracy at a specific site can be affected by e.g. the presence of a coast line [1]. Introducing local measurements early in the project could help to increase confidence in modelling results or raise awareness of possible issues with such results. Local measurements from meteorological masts, LiDARs and buoys are scarce and data access can be restricted. Wind fields from space borne SAR offer local wind data with high spatial resolution. Since the launch of Sentinel-1A (2014-present) and B (2016-present), SAR data is available under an open access licence granted by the European Space Agency. This allows commercial applications free of charge. DTU Wind Energy produces wind maps from Sentinel-1A/B and holds an archive of Envisat ASAR wind maps from 2002 to 2012 (https://satwinds.windenergy.dtu.dk/).

Wind turbine status is stored continuously in the Supervisory Control And Data Acquisition (SCADA) system. The Anholt wind farm consists of 111 Siemens 3.6 MW turbines and is located in the Kattegat Strait approximately 20km east of the peninsula Jutland. SCADA data is available from 01.01.2013 to 30.06.2015. We aim to show that SAR wind retrievals are comparable to SCADA wind speed measurements. Long archive of SAR images could allow detection of wind farm wake by comparing wind fields before and after the construction of the wind farm.

Methods

Wind maps are calculated from C-band SAR images from Envisat (2002-2012) and Sentinel-1 (2014-present). Measurements of the radar backscatter of the ocean surface are calculated into wind speed at 10m height using the Geophysical Model Function (GMF) CMOD5.N [2] with wind direction inputs from a Global Forecasting System (GFS) model with 0.25 degree grid spacing. SCADA data is available in 10 minute averages. For this study the power production, pitch, and yaw are used. The free stream wind speed is inferred from the power of the wind turbine using the power production and manufacturer's power curve from cut-in wind speed onwards. Above rated power the pitch angle is used additionally to infer the wind speed. The 10-minute mean SCADA wind speed is compared with SAR wind retrievals by taking an area average upstream of the turbine from the SAR wind maps [3]. Due to a lack of local stability measurements, the 10-m winds speeds retrieved from SAR are extrapolated to hub height assuming neutral stratification. A WRF model outputs with 2km horizontal resolution was used to calculate the wind speed at all turbine locations from 2002 to 2012.

Results

Figure 1 on the left shows the location of the turbines. 42 images from Sentinel-1 are coinciding with available SCADA data making comparisons possible for 1026 individual SCADA measurements, all with free stream conditions. The correlation between SAR and SCADA wind speed is high and the RMSE is 2.23 m/s. In Figure 1 on the right, averaged wind speeds of the Western row are shown for wind directions between 245° and 275°. For these wind directions, the peninsula (Djursland) to the West of the wind farm has a strong influence on the wind speed. SAR wind speeds at the turbine location are calculated from Envisat images that were available for the construction of the wind farm. Averages are taken for an area upwind, in the same way that SAR/SCADA comparisons were calculated. The wind speeds are nondimensionalized with the turbine located in the middle of the Western row to emphasise the relative change rather than the absolute value. The SCADA wind speed shows a clear horizontal wind speed gradient. Wind speeds form WRF and Envisat (SAR) show a similar trend. Sample sizes and maximum differences are given in Table 1.

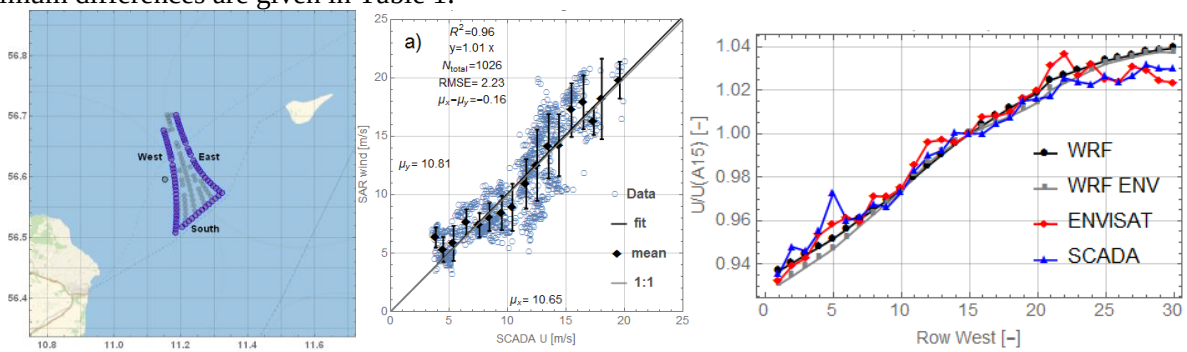

Figure 1: Left: Location of the wind turbines of the Anholt wind farm. In blue, turbines used for comparisons with SAR wind retrievals. Middle: Comparison of Sentinel-1 SAR and SCADA for turbines in the free stream for row west, south, and east. Right: SCADA, SAR and WRF wind speeds nondimensionalized with turbine number 15 for row West with wind directions between 245° and 275°. The turbines are numbered from South to North.

Table 1: Sample size and difference between most Northern and Southern turbines ΔU (three turbine location averaged).

	SCADA	ENVISAT	WRF	WRF ENV
Samples [-]	4625	72	10524	72
ΔU /U_15 [%]	8.7	8.8	9.8	10.3

Conclusions

Wind speed retrievals from SAR and wind speeds derived from SCADA are very different types of measurements. SAR is based on the ocean surface and SCADA on the power production of a wind turbine. Nonetheless, there is a strong correlation between wind measurements from both systems. Missing stability correction will partially account for the scatter, but this cannot be quantified.

A reduction in wind speed is present at the location of Anholt wind farm where land is influencing the upstream flow. Both WRF and Envisat data were available before the wind farm was erected and this information could have been available in the planning phase of the wind farm. WRF and SAR (Envisat) both show strong horizontal wind speed coastal gradients. SAR wind retrievals can assess coastal effects at potential wind farm sites and can thereby help by offering an independent measurement alongside numerical models like WRF. Additionally, long SAR archives can help to assess the influence of wind farms on the wind conditions at a particular site.

References

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