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Study of the UK offshore wind resource: Preliminary results from the first stage of the SUPERGEN Wind 2 project Resource assessment

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ABSTRACT

Rapid changes in wind direction can lead to turbine lifetime reduction or even failure. Also, large hub heights for wind turbines are approaching the top of the surface layer so the traditional logarithmic profile may not be wholly appropriate to parameterise variation of wind speed with height. The first steps undertaken as part of the UK EPSRC Supergen Wind II project to improve wind resource assessment and predict the temporal variations in the offshore wind are presented. Data from boundary-layer wind-profiling radar were analysed to extract the diurnal and vertical patterns of the wind speed close to an offshore site for future correlation with offshore mast data.

1 Introduction

The offshore wind development in the UK is moving to wind farms ever further from the coast in deeper water with greater costs as the foundations become deeper and the hub heights become taller. The Supergen Wind Energy Technologies Part II is a project proposed to address some of these problems undertaking research to achieve an integrated, cost-effective and reliable Offshore Wind Power Station. One of the key areas considered by the SuperGen Wind II is focused into the physics and engineering of the offshore wind farm where improved estimates of the offshore wind resource plays a crucial role.

For many of the potential UK offshore wind farm sites, there are few data available to infer the expected overall wind resource, how it varies over different timescales and how it varies spatially. There are also a number of phenomena which are poorly understood including, for example, rapid changes in wind direction which are often observed and which can lead to turbine lifetime reduction or even failure. It should be also considered that, large hub heights for wind turbines are approaching the top of the surface layer so the traditional logarithmic profile may not be wholly appropriate to parameterise variation of wind speed with height.

This paper reports the first results of the Theme 1 of the Supergen Wind II project in order to develop knowledge and tools to improve wind resource assessment and predict the temporal variations in the offshore wind. The data set used comprise measurement from boundary-layer wind-profiling radar operating close to offshore operational sites with the principle of the Doppler Beam Swinging at 1290 MHz which covers an approximate altitude between 150m and 2km at 100m intervals.

Several computational tools were developed to convert the Radar dataset to a database with the proper format to be analysed with statistical methods. A full year of data was selected which is concurrent with mast data available from offshore sites in order to study the correlation between the offshore and onshore data in later stages of the research project.

2 Wind-profiling measurements

The boundary-layer wind-profilers are operated with the Doppler Beam Swinging principle making observations in a cyclic sequence of vertical and near-vertical beam pointing directions in order to derive the speed and direction of the wind as a function of height.

A radar profiler's ability to remotely sense winds aloft is based on the assumption that the induce scattering produced by the turbulent eddies are carried along by the mean wind. Radar transmits an electromagnetic pulse along each of the antenna's pointing directions covering a volume of air defined by the duration of the emitted pulse. Small amounts of the transmitted energy are scattered and Doppler-shifted along the radar beam pointing direction. This signal received by the radar at fixed intervals is used to create a dataset with the scattered energy from discrete altitudes or range gates. The range resolution is controlled with the length of the transmitted pulse. A minimum of 3 non-coplanar beam pointing directions should be used to derive the full three-dimensional wind vector.

The irregularities of atmospheric refractive index (also referenced as Radar target) produces back-scattering (clear-air returns) while the hydrometeors increase the Rayleigh scattering. The hydrometeor returns dominate at frequencies around 1000 MHz and because they only share the horizontal components of velocity with the wind, the vertical velocity of the atmosphere could not always be derived from the radar observations, as can be appreciated from the radar images presented below in Figure 2 and Figure 3.

Considering the distance to an offshore wind farm site and the availability of offshore mast data in concurrent period; the wind-profiling radar at Wattisham site and 2001 [22] were selected as study site and study period, see below Figure 1, in order to correlate in later stages with the available offshore mast data. Information about the geographical position of the measurement site has been listed in Table 1.

(a) (b)

Figure 1. (a) Geographical location of the wind-profiling radar at Wattisham site (yellow arrow), (b) Close up of the Radar position relative to the closet offshore wind farm (white arrow).

Table 1. Geographical information of the wind-profiling radar at Wattisham

Latitude:	52° 7'26.25"N
Longitude:	0°57'28.59"E
WMO Number:	03591 (Wattisham)
Site height:	87 m

Figure 1(b) show a close up of the measurement site representation the relative position of the closest offshore wind farm. Details of the distance and direction from the measurement site to other relevant positions are also listed in Table 2.

Table 2. Positions of relevant coastal regions relative to the wind-profiling radar at Wattisham site. The direction has been measured from the North of the Wattisham site in clockwise direction.

	Direction	Distance
Closest Coast	126 degrees	32 km
Coast in east direction	90 degrees	43 km
Offshore farm site	44.34 degrees	75.34 km

Wind-profiling radar makes observations in two interlaced modes; the low mode which covers the approximate altitude range 0.1 - 2.0 km at 0.1 km intervals and the high mode which with 0.2 km intervals covers the approximate altitude range 0.2 - 8.0 km. In the case of wind resources applications, the low mode is more appropriated. The main technical information of the wind-profiling radar instrument installed at Wattisham is presented in Table 3.

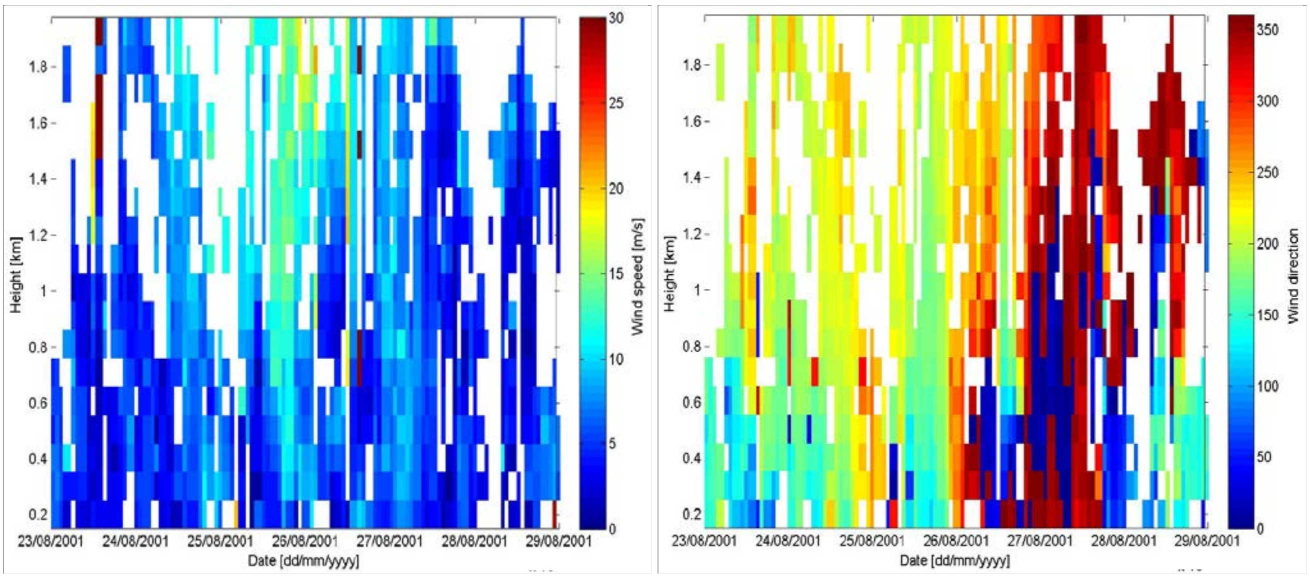
Table 3. Main technical characteristics of the wind-profiling radar at Wattisham

Frequency:	1,290 MHz
Range for high resolution:	152 m to 1,973 m
Vertical resolution:	101 m
Beam angle:	15.5°

Each data file available from the wind-profiling radar contains with a sequence of 96 records; 48 for the low mode and 48 for the high mode. These records were measured every 30 minutes and stored in single files for each day since the end of January 2001. A set of computational tools were developed to process and convert the wind-profiling radar data to databases which allow to study the wind cycles and the vertical profiles over the whole study period.

3 Images derived from the Wind-profiling radar

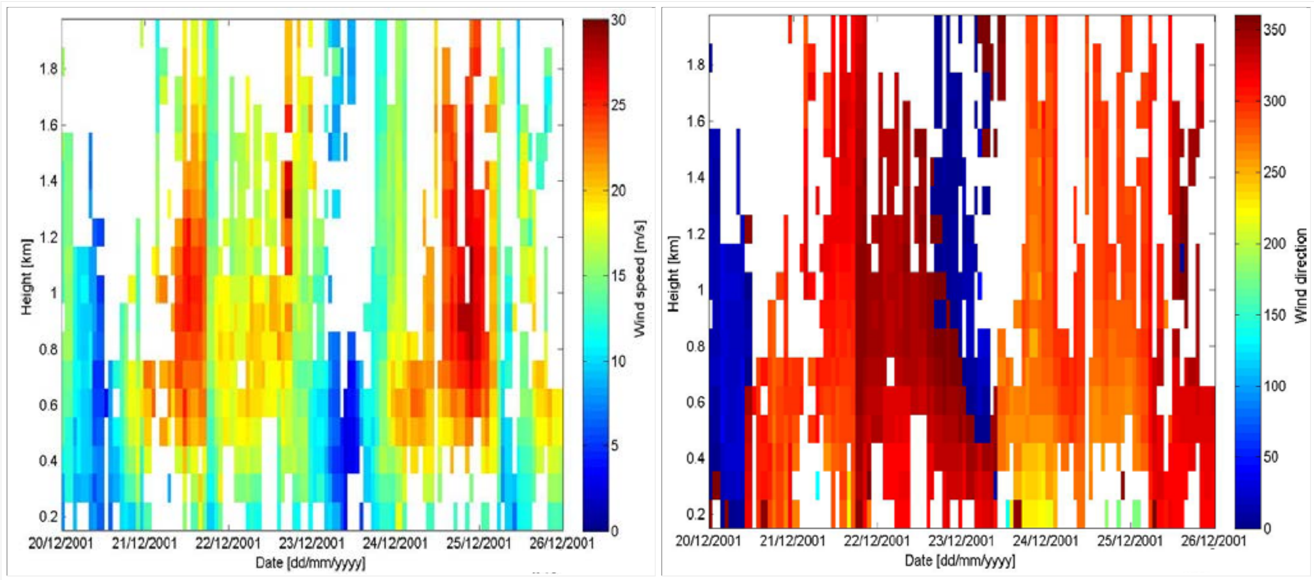
Sequences of high resolution vertical readings of wind speed and direction were extracted from the Radar datasets. Figure 2 below shows a sample of a week with the majority of the data registering wind speeds in the lower region of the scale.



(a) (b)

Figure 2. Sample of calm week image extracted from the dataset of the wind-profiling

Another sample of wind-profiling radar image is shown in Figure 3 in the case of a week with stronger wind speeds. The white spaces in the images represent intervals with no data useful available.



(a) (b)

Figure 3. Sample of windy week image extracted from the dataset of the Wind profiling.

The statistical analysis applied to the extracted data over the whole study year shows that the lowest height has approximately 6% fewer data than the other heights. Thus, it should be expected that it shows a higher degree of variability.

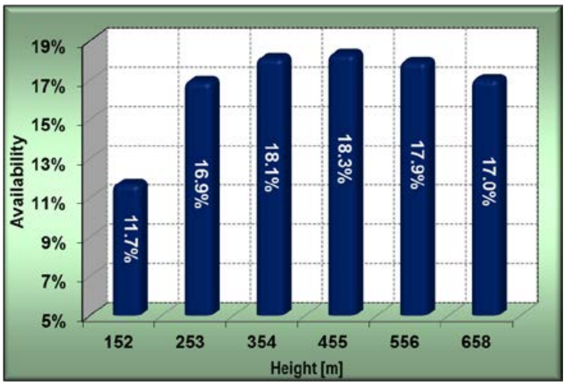


Figure 4. Data availability for each of the six selected heights over the whole study period.

The availability of the data throughout the diurnal cycle also reveals fewer data in the early morning and late evening periods.

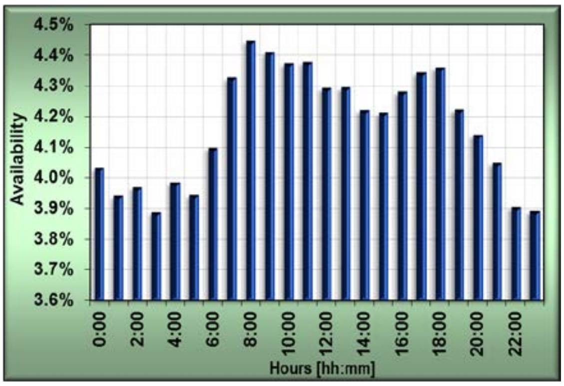


Figure 5. Data availability over the diurnal cycle considering the whole study period.

4 Results

4.1 Diurnal wind patterns

The diurnal patterns available from the radar images up to 700 metres height were computed over the whole study period comprising six different heights plotted below in Figure 6.

It can be seen that there is an inverted diurnal profile compared with data normally measured closer to the ground. The magnitude of the diurnal oscillation appears to decrease with height and the change in wind speed with height declines significantly moving above the surface layer. There is evidence of the geostrophic wind being approached for the higher measurements.

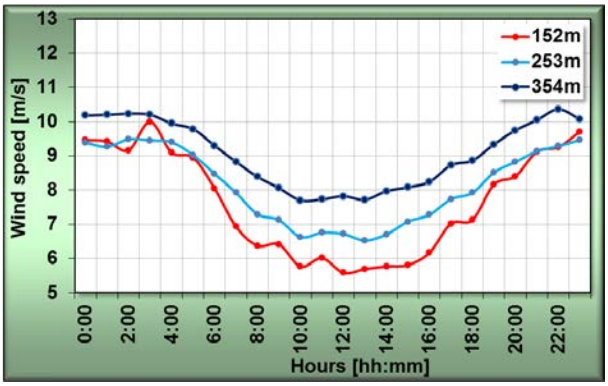


Figure 6. Wind speed behaviour over the diurnal cycle for the three lower heights.

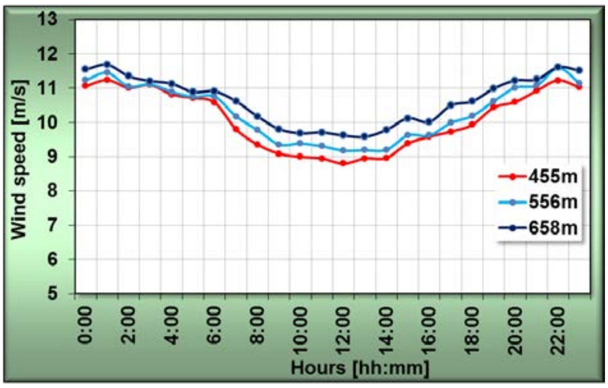


Figure 7. Wind speed behaviour over the diurnal cycle for the three upper heights.

Wind direction patterns over the diurnal period show a relative stable pattern around the west direction, for all the heights with the exception of the lower one which registered some additional oscillations at the beginning and the end of the cycle.

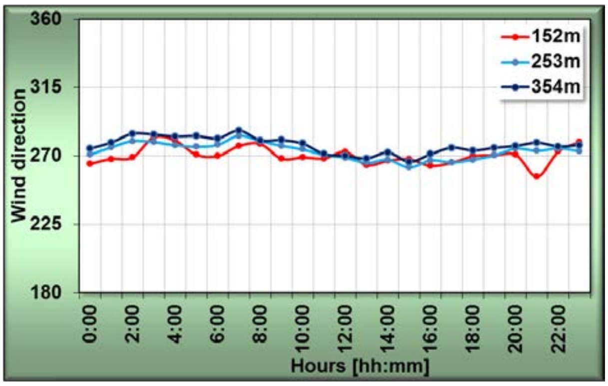


Figure 8. Wind direction behaviour over the diurnal cycle for the three lower heights.

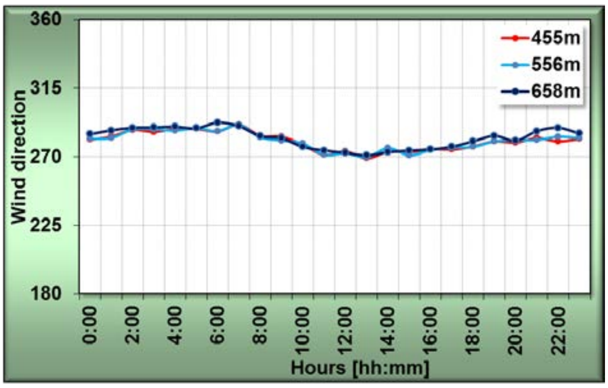


Figure 9. Wind direction behaviour over the diurnal cycle for the three upper heights.

4.2 Vertical wind profiles

The vertical profiles of wind speed at the six study heights have been plotted every six hours over the diurnal cycle for the whole study period. At 00:00 and 18:00 and for lower heights there is some deviation from the pattern compared with the other two periods

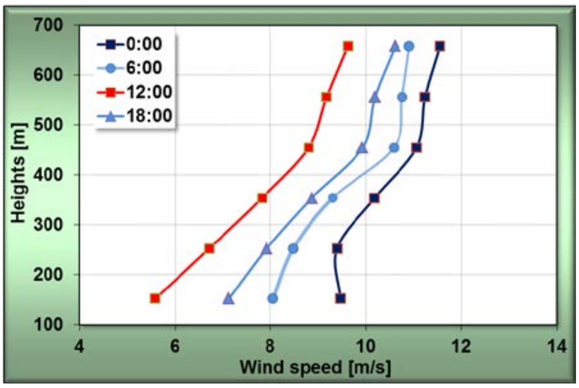


Figure 10. Vertical wind speed profile every six hours from 0:00 hours.

In the case of the vertical profiles for wind direction a clearly defined pattern can be seen just above 300m height for the four study periods. Clear evidence of the Ekman spiral can be observed.

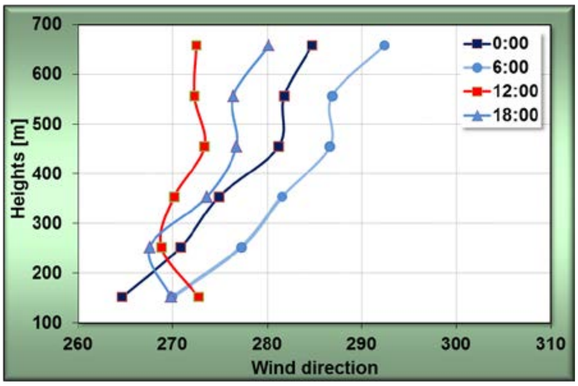


Figure 11. Vertical wind direction profile every six hours from 0:00 hours.

5 Conclusions

The work presented here summarises some early analysis of remote sensing data as part of the on-going research project "SUPERGEN Wind II – Theme I". The analysis tools developed and the vertical and diurnal patterns will be used in the next stages of the project to correlate with the data from surface onshore stations and offshore mast data in order to improve wind resource assessment and predict the temporal variations in the offshore wind.

6 Acknowledgements

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