Wake influence of V44 wind turbines on the field measurements of an 80m mast in Italy

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Wake measurements are an important field within wind energy; however the access to detailed wake data is not easy. Several wind tunnel measurement campaigns offer a valuable dataset to understand the physics behind wakes and can be used to develop and validate numerical codes. Ideally wake measurements should be done in the wakes of full-scale wind turbines. These measurement campaigns are highly expensive and therefore extremely rare. In addition, the measurement points available for full-scale wakes are limited by the number of meteorological masts which can be reasonably installed.

The wake measurements available for this campaign are based on 10-minute and hourly averages and albeit not specifically designed for wake measurements they can offer an important insight into full-scale wake data. In this work we present the measurements behind four V44 wind turbines which have been operating since April 1999.The wind farm is owned by International Power plc. The turbine hub height is 50 m and data are available from two meteorological masts: Mast RSF01 is a 30 m mast and Mast RSF02 is an 80 m mast. The masts have been measuring prior to the start of operation of the wind farm and since August 2009 respectively. The wind turbines are aligned on the ridge of a hill running northwest to southeast, while the predominant winds are from the southwest. Mast RSF01 is approximately aligned with the row of turbines and measures at 10 m and 30 m above ground level. Mast RSF02 is southwest of one of the operating wind turbines albeit at an elevation of 889 m. Mast RSF02 is equipped with calibrated cup anemometers every 10 m from 30 m above ground level up to 80 m. Depending on the wind direction, Mast RSF02 is measuring within the wake from 1.1 up to 5.5 rotor diameters behind the nacelle. The distance, the bearing of the turbine hub as seen from the data measured at Mast RSF02 and the base elevation are reported in the following table:

Turbine	Distance to Mast RSF02 [x/D]	Bearing seen from Mast RSF02 [degrees]	Base elevation [m]
R1	3.1	355	871
R2	1.1	68	892
R3	3.3	107	894
R4	5.5	115	893

Table 1: Distance of the turbines from Mast RSF02

The operational data from the turbines were not available for this study, hence it has been assumed that the 80 m anemometer on mast RSF02 is not affected by the wake and provides free-stream measurements. This is considered to be a reasonable assumption for the winds from the northeast, i.e. from the nearest turbine. The correlations to Mast RSF01 provide some comfort on this approach. The analysis has been carried out considering 1 m/s bins of the reference wind speed to minimise the changing thrust coefficient of the operational turbines. It is also evinced for this terrain that the wake is not following the slopes immediately downstream the turbine rotor. As mentioned above, several measurement levels are available at Mast RSF02 and the effect of the ground and wind shear on breaking any symmetry in the vertical plane of the wake is considerable. The time series of the 10-

minute data recorded at Mast RSF02 have been analysed and provide an interesting dataset for defining the wakes. The wake contours are better defined by considering averages on 2 degrees sectors. The analysis of the standard deviation based on these 10-minute averages is also shown.

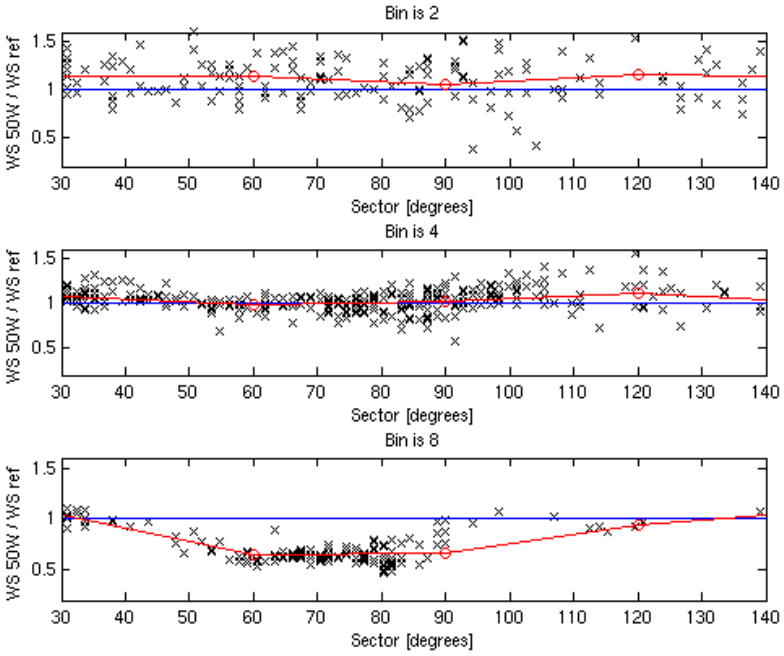

Figure 1: Examples of hub height measurements at Mast RSF02 at 50 m plotted according to the wind speed bins and wind direction sectors at Mast RSF01 at 30 m. The wind speeds are normalised by the wind speeds measured at Mast RSF01 at 30 m. Turbine R2, given the bearing in the 68 degrees sector, is clearly in operation in the 8 m/s bin only among those shown in the figure; no clear wind speed reduction and hence wake is measured for the other two wind speed bins. The red circles mark the speed-up values for the 30 degrees sectors.

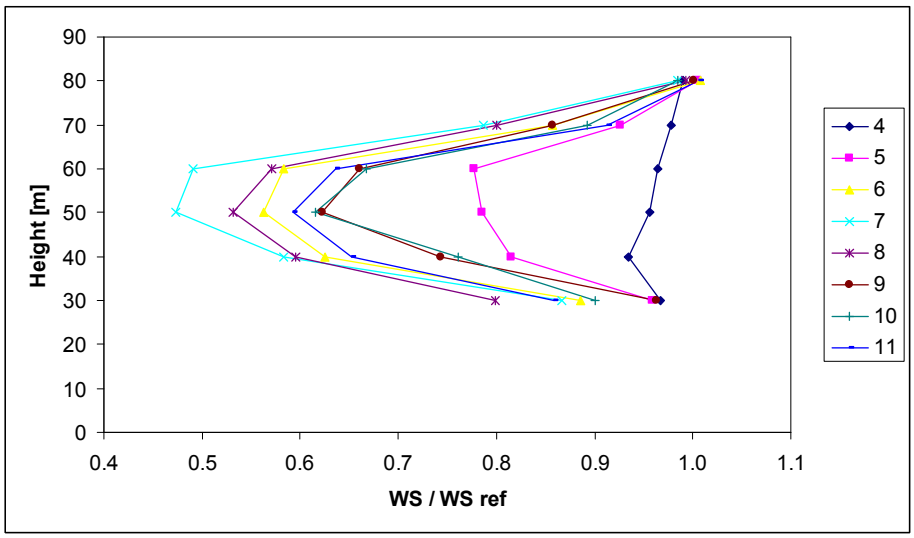

Figure 2: Vertical profiles measured at Mast RSF02 at different wind speed bins of the reference wind speed at 80 m for a bearing of 80 degrees. The wind speeds are normalised with the wind speed bin at 80 m at Mast RSF02, shown in the legend.

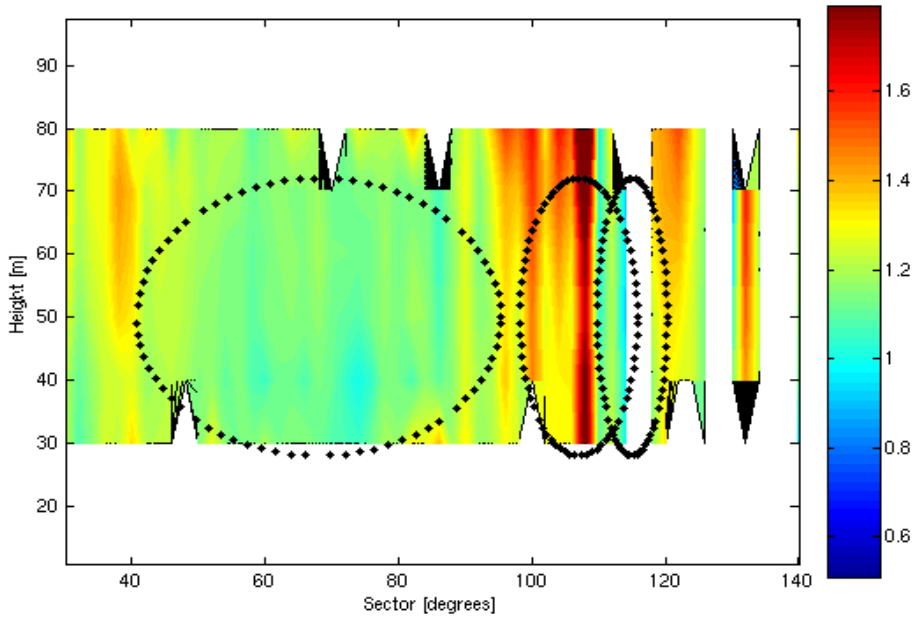

Figure 3: Contour of the wind speeds measured at Mast RSF02 normalised with the wind speed bin at 30 m at Mast RSF01, here 4 m/s. The sectors are referred to the wind direction data measured at Mast RSF01. The data are hourly averages. The areas swept by the Turbines R2 to R4 (from left to right) as seen from Mast RSF02 are also represented. Turbine R1 is outside the sector range in the plot.

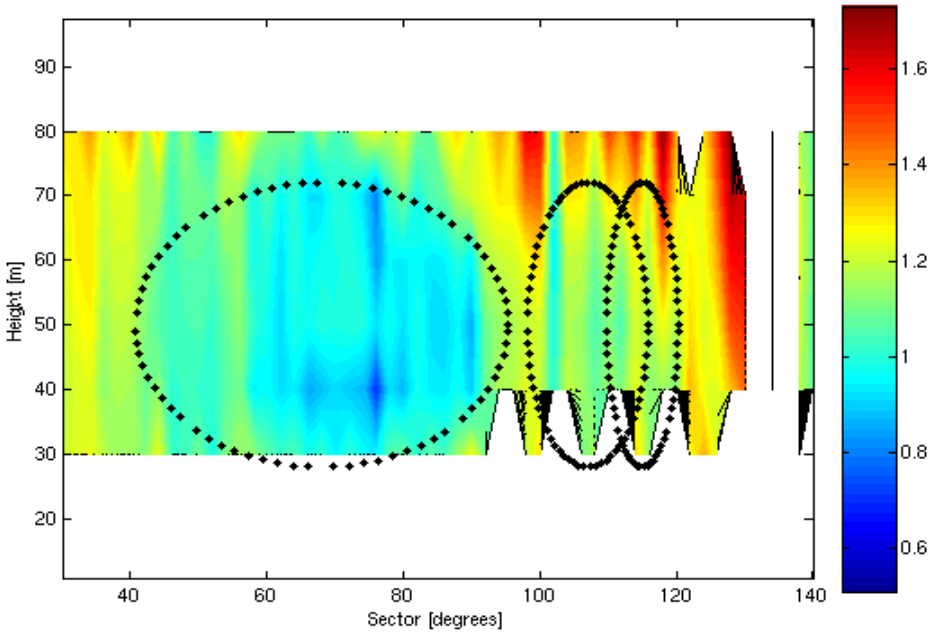

Figure 4: As Figure 3 for the wind speed bin of 5 m/s. The wake from Turbine R2 is observed.

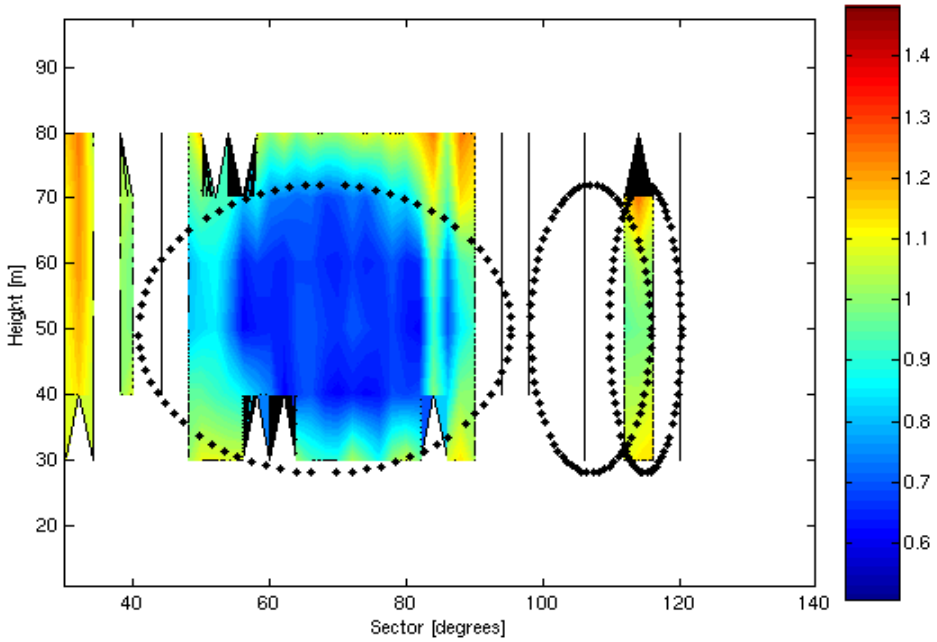

Figure 5: As Figure 3 for the wind speed bin of 8 m/s. The wake from Turbine R2 is clearly visible and the measurements at 80 m show that the effect of the wake on the data is limited, if any.

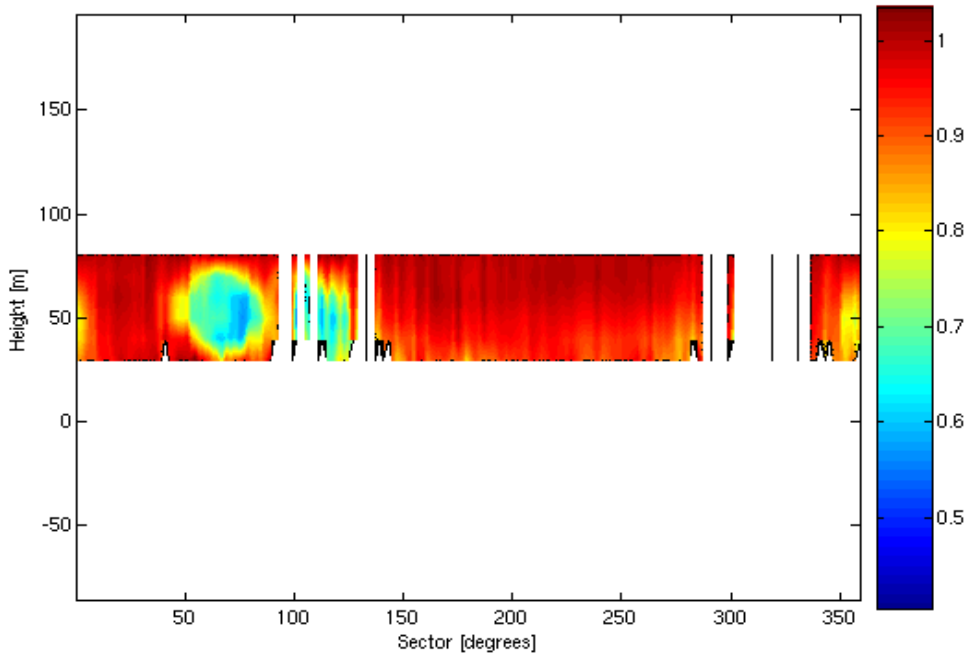

Figure 6: Contour of the wind speeds measured at Mast RSF02 normalised with the wind speed bin at 80 m at Mast RSF02, here 10 m/s. The sectors are referred to the wind direction data measured at Mast RSF02. The data are 10-minute averages. The wakes from the 4 turbines are visible, albeit the results also depend on the number of points available for each sector.

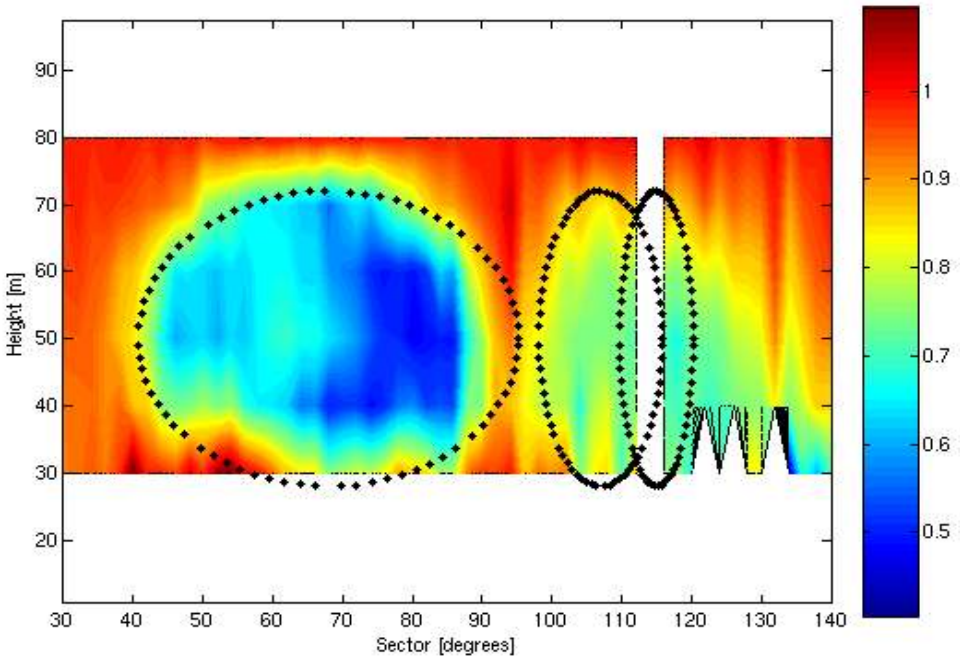

Figure 7: As Figure 6 for the wind speed bin of 7 m/s.

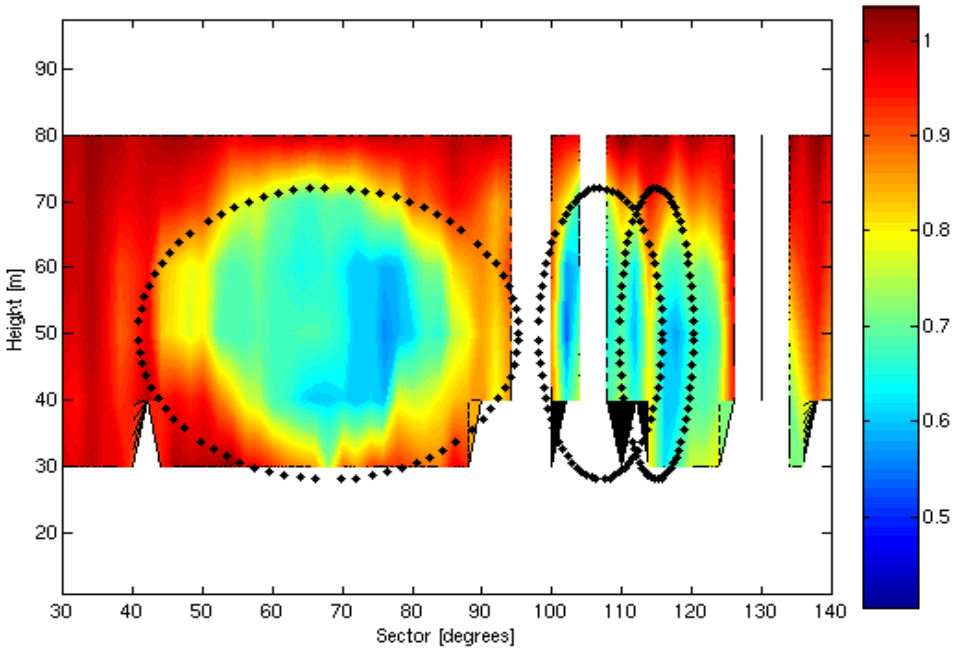

Figure 8: As Figure 6 for the wind speed bin of 10 m/s.

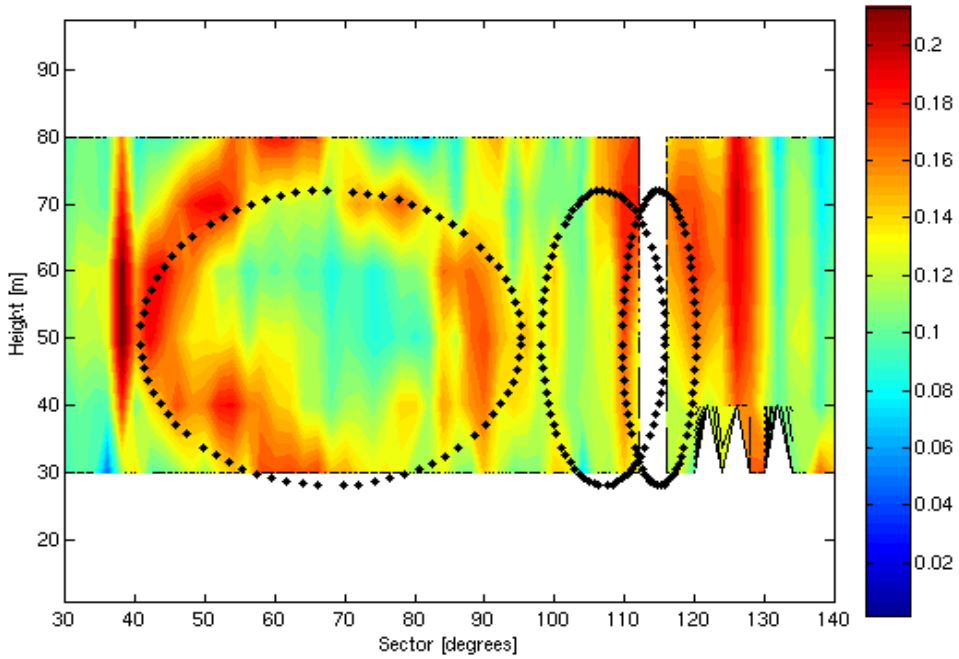

Figure 9: Contour of the wind speed standard deviation measured at Mast RSF02 normalised with the wind speed bin at 80 m at Mast RSF02, here 7 m/s. The sectors are referred to the wind direction data measured at Mast RSF02. The data are based on the 10-minute averages.

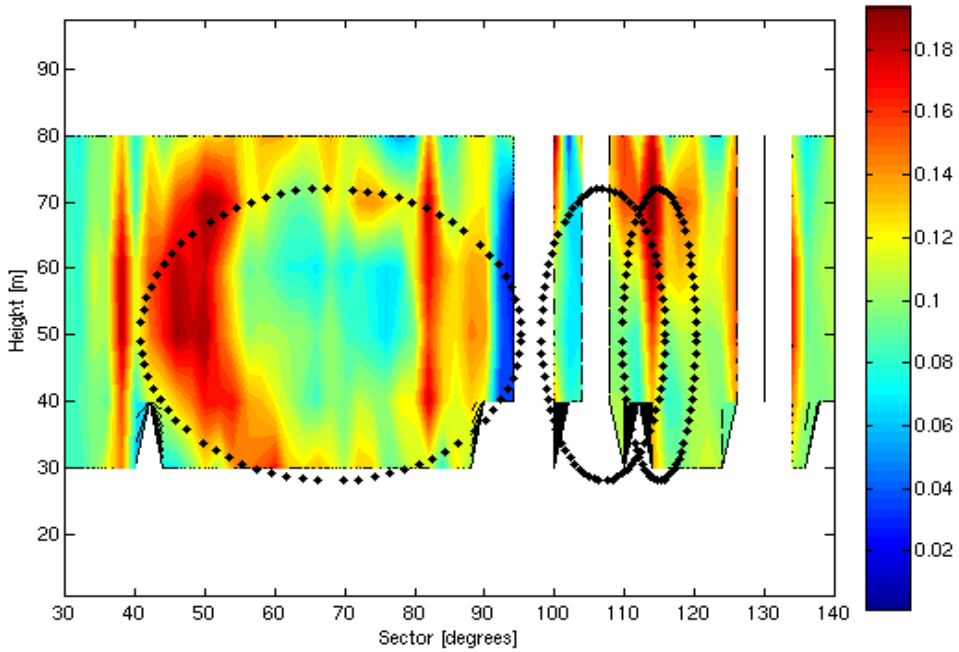

Figure 10: As Figure 9 for the wind speed bin of 10 m/s.