BELGINGUR

Technical report

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Performance of Wind Forecasts at Hafið

System description and comparison with observations

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Introduction

This report discusses and analyzes the performance of the wind forecasts of Belgingur, made for the test-bed wind turbines of Landsvirkjun, located at Hafið near Búrfell.

The wind forecasts are made with version 3.4.1 of the AR-WRF atmospheric model (Skamarock et al, 2008). The forecasts are repeated four times a day (0, 6, 12 and 18 UTC), with a forecast horizon of 54 hours. The model is run in a nested setup in the horizontal, with 9, 3 and 1 km model domains (Fig. 1) and 65 levels in the vertical. The forecasts are based on results from the 1 km domain and are interpolated bi-linearly to the location of wind turbine no. 1, and linearly to the elevation (55 m) of the nacelle of the turbine.

The wind forecasts are compared to observations taken in the mast to the north of the wind turbines, between 1 July 2013 and 1 February 2014. The mast is located approx. 145 m to the northeast of turbine no. 2. This difference in location is not relevant at the model resolution as the model can not resolve possible variations in the flow at this scale. In reality there may exist some differences in the wind field between the two locations, in particular as the mast is located in a shallow depression and in the wake of the turbines in southwesterly flow.

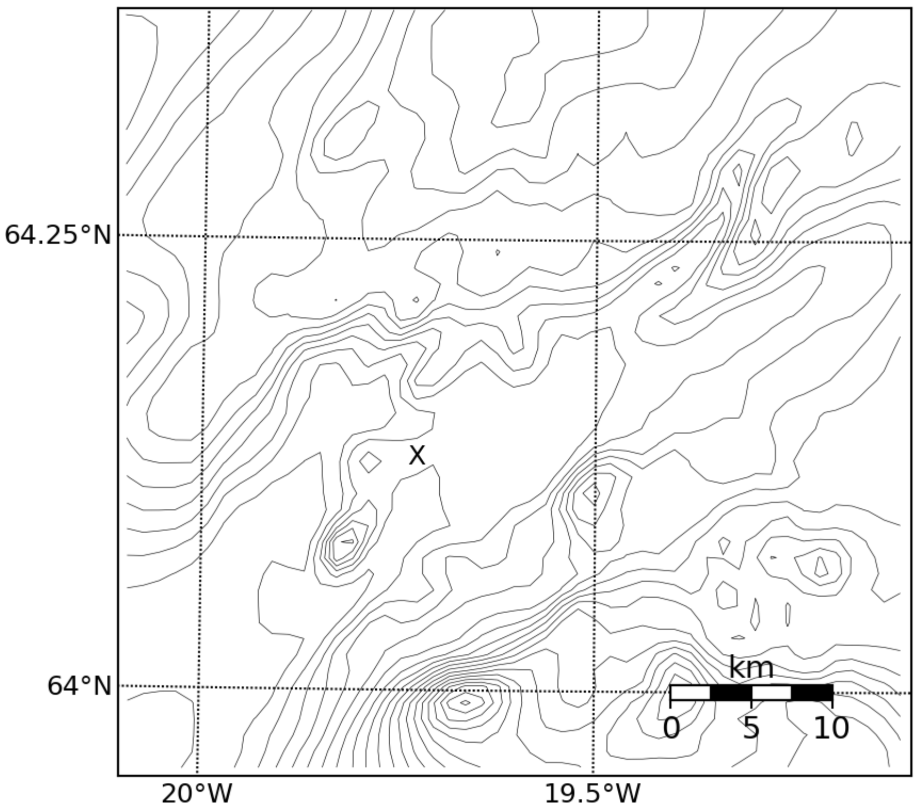

Figure 1: Model topography in the 1 km model domain at Hafið. X marks the location of the wind turbines and meteorological mast.

Comparison of observed and forecasted wind speed

Time development of the mean error

An investigation of the mean error of the wind speed forecasts (forecast-observations) for the period from 1 July 2013 to 1 February 2014 shows that bias is on average very close to 0 m/s throughout the forecast period (0–54 hours), cf. Fig. 2. The mean error is within 2 m/s during most of the forecast, but shows a slightly greater spread after approx. the first day. The mean error at the end of the forecast is however only marginally larger than at the start of the forecast, indicating that the forecasts are giving valuable information for more than two days. About 90% of the data have a mean error of less than 6 m/s, but this also shows a larger spread during the latter half of the forecast period. The spread is considerably greater at the 2 and 98 percentiles than at the 5 and 95 percentiles (cf. Figs. 6 and 7, respectively, in the Appendix).

The performance of the forecasts is similar when observed wind speeds in the range of 5 to 15 m/s are examined (cf. Fig. 6, as opposed to all wind speeds. There is a slight negative bias of approx. 0.5 m/s at these wind speeds, with a greater bias and more spread in the forecast error for both weaker and stronger winds. There is no clear diurnal signal in the mean error of the forecasts, and no dependance of the forecast error on the initializaton time (cf. Fig. 8 in the Appendix).

The previous discussion is relevant for the performance of the forecasts over a period of 7 months, including two summer months, the autumn and three winter months. For a shorter period of 4 weeks, starting 1 January 2014, there is significantly more spread in the data and a negative bias of 1-2 m/s. The total spread of the data is however mostly similar to that during the full 7 months. The difference in the behaviour during the two periods is presumably related to changes in surface characteristics, which is not captured by the current setup of the model.

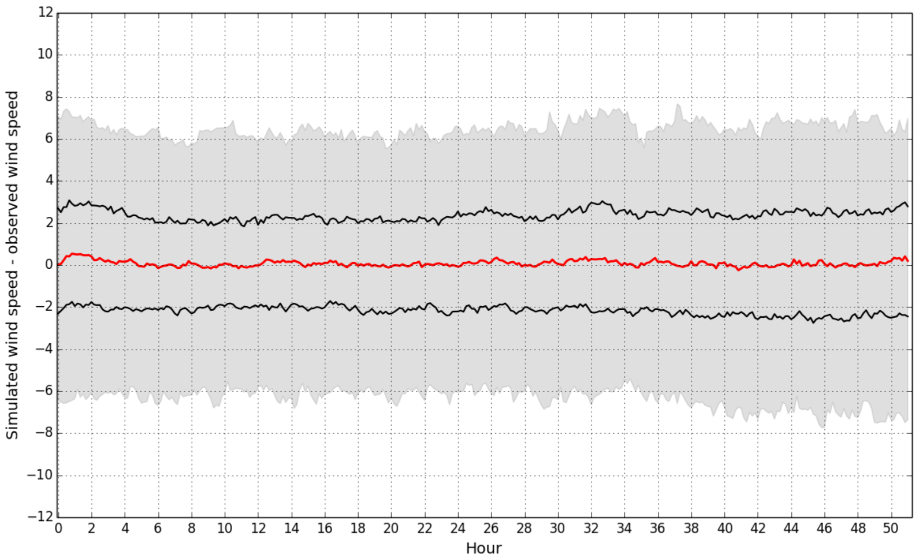

Figure 2: Mean error (forecast-observation) as a function of forecast hour 1 July 2013 to 1 February 2014. Red line is the median, dark lines show the 25 and 75 percentiles while the grey region extends to the 5 and 95 percentiles.

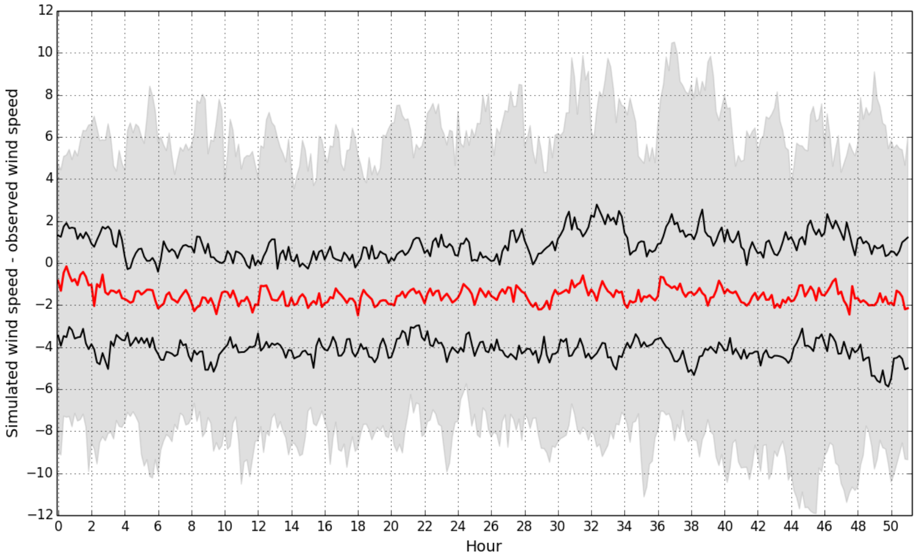

Figure 3: Same as previous figure but for the period 1-24 January 2014.

Performance at individual forecast hours

The performance of the forecasts was investigated further at 4 different forecast hours, i.e. at 6, 12, 24 and 48 hours into the forecast. Note that in this report we only show figures for the 24 hour forecasts. Scatterograms of observed and forecasted wind speeds show qualitatively the performance of the forecasts (cf. Fig. 9. The performance is on average good but there are a significant number of outliers where there is a large error. This appears to occur most frequently for winds in the sector between north and east but the signal is not clear, partly because the strongest winds occur in this wind sector. There is furthermore a significant dependance on the shear in the flow; the winds are more likely to be overestimated in weakly reversely sheared flow (wind speed decreasing with height) while in flow with strong forward shear the winds are more likely to be underestimated (cf. Fig. 10 in the Appendix).

An investigation of histograms of the bias (simulated - observed wind speed) reveals that the spread in the bias increases with the forecast time with the greatest spread at the end of the forecast (54 hours). There is furthermore a strong dependance of the bias on the observed wind speed; it is smallest and slightly above 0 m/s for wind speeds between 5-10 m/s, while weaker (stronger) winds are systematically over (under) estimated by up to 2 (4) m/s.[1] The bias is slightly greater at 6 hours than at 12 hours, which is related to the initial setup of the numerical model. The setup was changed in March 2014 in order to make the 6 hour forecast perform better. As was indicated by the previously discussed scatterograms, then the model error depends on the shear of the observed flow as well as the prevailing wind direction. The performance is generally best in weakly forward sheared flow as well as for southerly winds. Strong forward shear or reverse shear appears to result in larger errors, as is the case for winds from the sector between north and east when there is a negative bias of approx. 2 m/s.

[1]Cumulative histograms, i.e. stepwise increasing lines instead of vertical bars, should be interpreted so: The steeper the line is the sharper the forecast is. If if the lines cross 0-error at 0.5 on the vertical axis then the bias is zero.

Northwesterly winds appear to result in a slight positive bias (appendix).

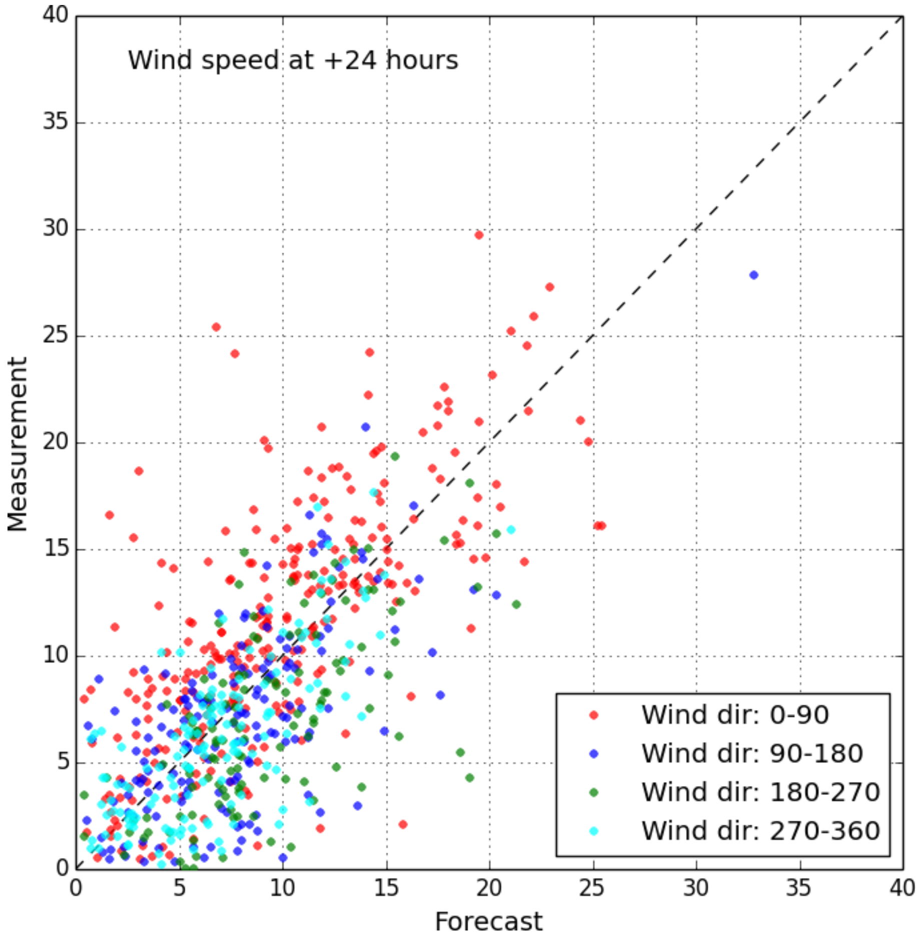

Figure 4: Scatterogram of the observed and forecasted wind speeds at 24 hours into the forecast and their dependance on observed wind direction at 56 m

An investigation of the observed winds

Observed winds from the nacelle of the wind mills were not available at the time of the analysis described in this report. Therefore, the observed winds were investigated in more detail in an attempt to understand better the performance of the wind forecasts, and their dependance on the flow itself and observations of it.

Observations at 56 m vs. at 57 m

A comparison of the observed winds at 56 (used in the comparison with the forecasts) and 57 m reveals that the winds are on average the same (cf. Fig. 11). There is a clear dependance on wind direction with the greatest discrepancy for southwesterly winds. There appear to be a few observed events with larger errors, both in strong

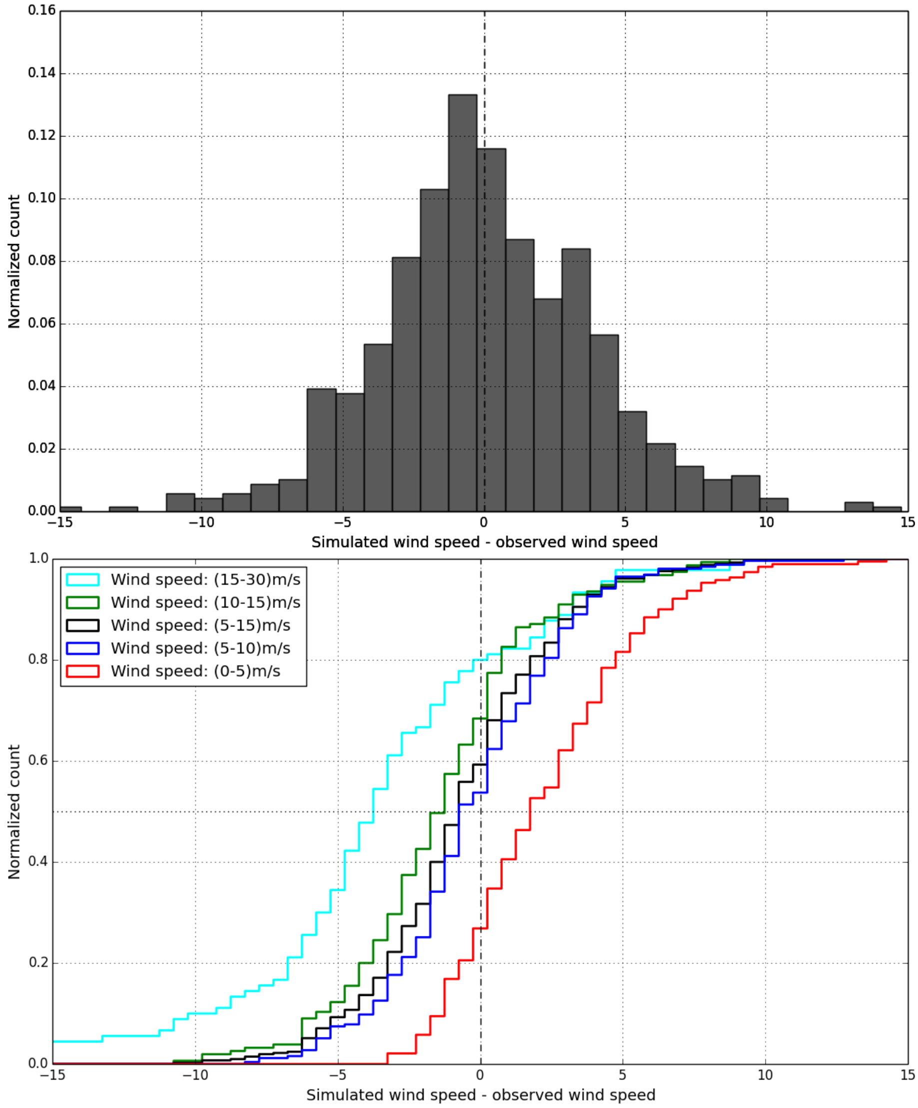

Figure 5: A histogram of the mean error at 24 hours into the forecast and its dependance on observed wind speed at 56 m.

southwesterly and strong northeasterly winds. Overall the winds at 56 and 57 m are similar enough for the comparison performed and presented here.

Observed wind shear

There is a surprisingly large number (+15% of the total) of observed events with large reverse shear (winds decrease with height). We compare the winds observed at 56 m and 57 m (where temperature observations are available) with winds observed at 31 m. There is, as expected, a clear increase in forward wind shear as the wind speed increases (cf. Fig. 12). However, below approx. 15 m/s there are a surprising number of events with reverse wind shear, even in excess of 4 m/s when observed winds at 56 (57) m are close to and below 5 m/s. This reverse wind shear occurs at all temperatures and is apparently not a result of atmospheric icing on the anemometers (cf. Fig. 13). It also occurs at all wind directions but is most frequent for southwesterly winds, when the mast may in many cases be located in the wake of the turbines. That does however not explain the high frequency of reverse shear in other wind direction, in particular for northeasterly winds.

Observed winds and power production

In light of the results described above we have compared the observed power output against the observed winds in the mast[2] (cf. Fig. 14). Here there is a surprisingly good performance of both turbines for weak winds. This occurs mostly in southwesterly winds, when the mast is frequently in the wake of the turbines, and is correlated with a high frequency of reverse wind shear observed at the mast (winds stronger at 31 m height than at 56 (57) m, cf. Fig. 15). This behaviour does however also occur for other wind directions, but less frequently when the whole period is investigated (1 July 2013 to 1 February 2014) than for the first half of the period (1 July to 10 October 2013).

Atmospheric icing

It is furthermore apparent that problems related to icing seem to be neglible for the period investigated, as is also revealed when looking at the temperature dependance of the observed winds and the power production. Hence it may be assumed that the forecast error is not dependant on observational errors related to the possible icing on the anemometers.

Summary

The performance of the wind forecasts during 1 July 2013 to 1 February 2014 is on average quite good, with a bias close to 0 m/s and errors less than 2 m/s for approx. half of the time. There is, however, a larger spread in the error as well as the bias when a shorter period is investigated, and for weak (<5m/s) and strong winds winds (>15 m/s). The predictability at the end of the forecast (i.e. forecast hour 54) is only marginally less then at forecast hour 12, showing that the forecasting system is giving valuable information for more than two days. These results are promising as they indicate that the forecasts could be used for optimization purposes for at least two day lead time.

There is furthermore a strong dependance of the performance of the forecasts on the prevailing wind direction and the observed shear in the flow. Reverse and strong forward shear appears to be difficult to capture correctly, while the strong northeasterly winds are most often in error when compared to other observed wind directions.

A short investigation of the observed winds and wind power reveals some interesting features. Several of these point to problems with the observational data, which might e.g. in some cases partly explain the apparently worse performance of the forecasts for some wind directions than others. Most significantly, but not limited to, the proximity to the wind turbines might disrupt the airflow at the mast and hence the representability of the observations during southwesterly flow. However, there are other

[2]The black slope is the powercurve from the turbine, fitted using data from provider.

surprising features, such as the high frequency of wind shear for other wind directions than southwesterly that should be investigated in more detail.

References

Skamarock WC, Klemp JB, Dudhia J, Gill DO, Barker DM, Duda MG, Huang XY, Wang W, Powers JG (2008) A description of the Advanced Research WRF version 3. Tech. Rep. NCAR/TN-475+STR, National center for atmospheric research

Appendix

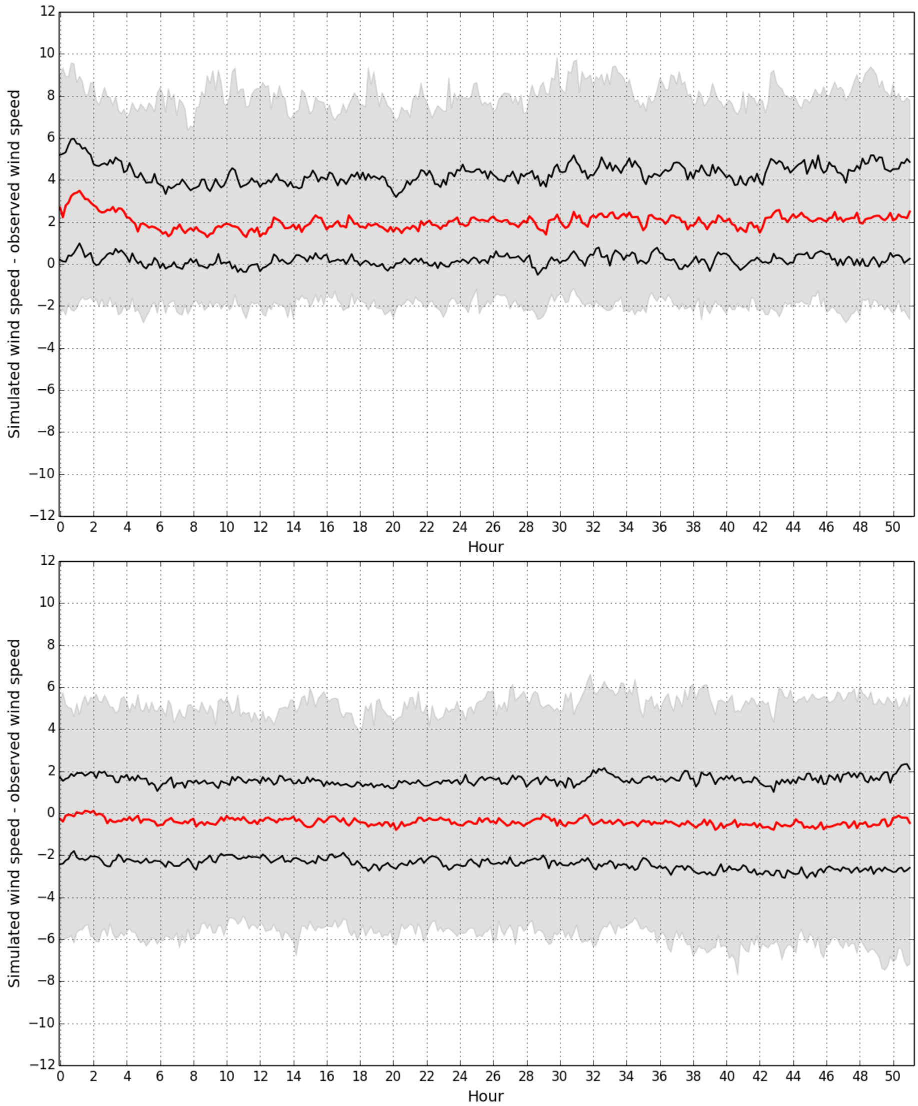

Figure 6: Mean error (forecast-observation) as a function of forecast hour 1 July 2013 to 1 February 2014. Red line is the median, dark lines show the 25 and 75 percentiles while the grey region extends to the 5 and 95 percentiles. For observed winds weaker than 5 m/s above and between 5 and 15 m/s below.

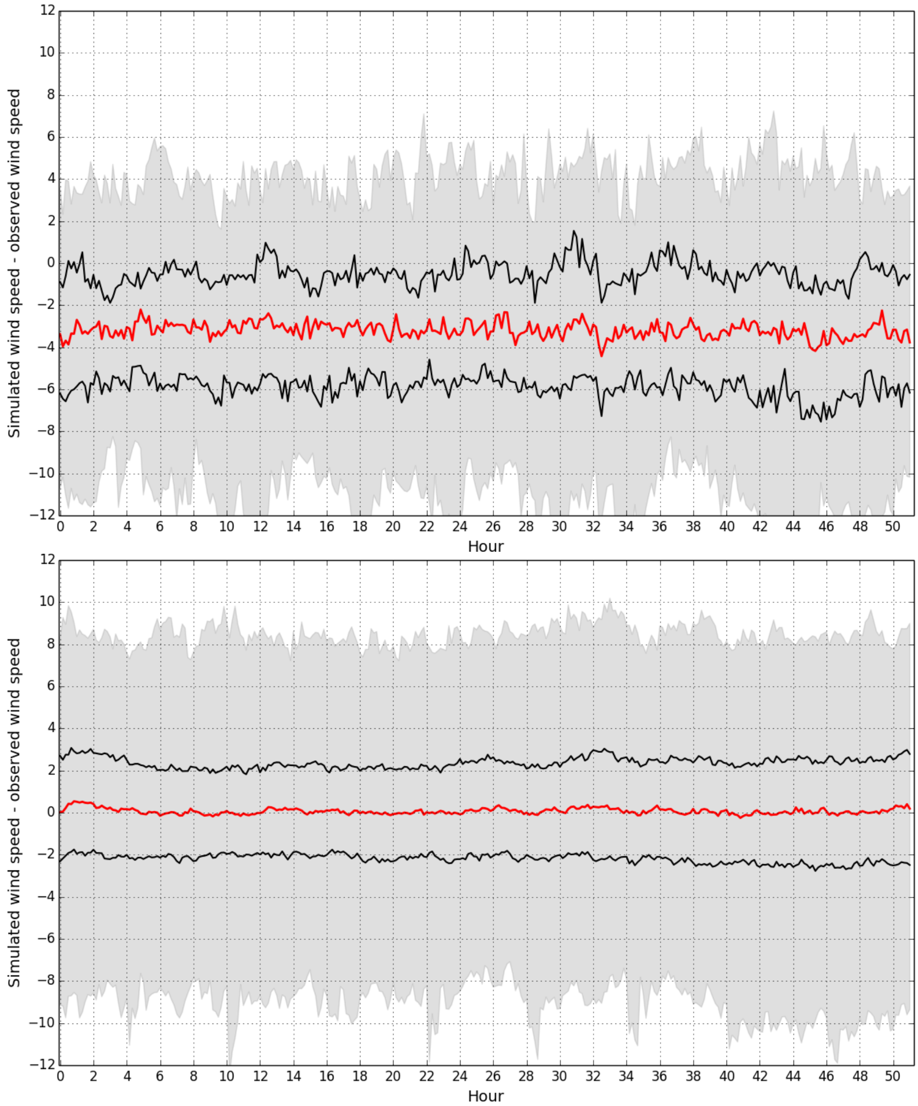

Figure 7: As for the previous figure, but for winds stronger than 15 m/s above and for all winds speeds and the 2 and 98 percentiles.

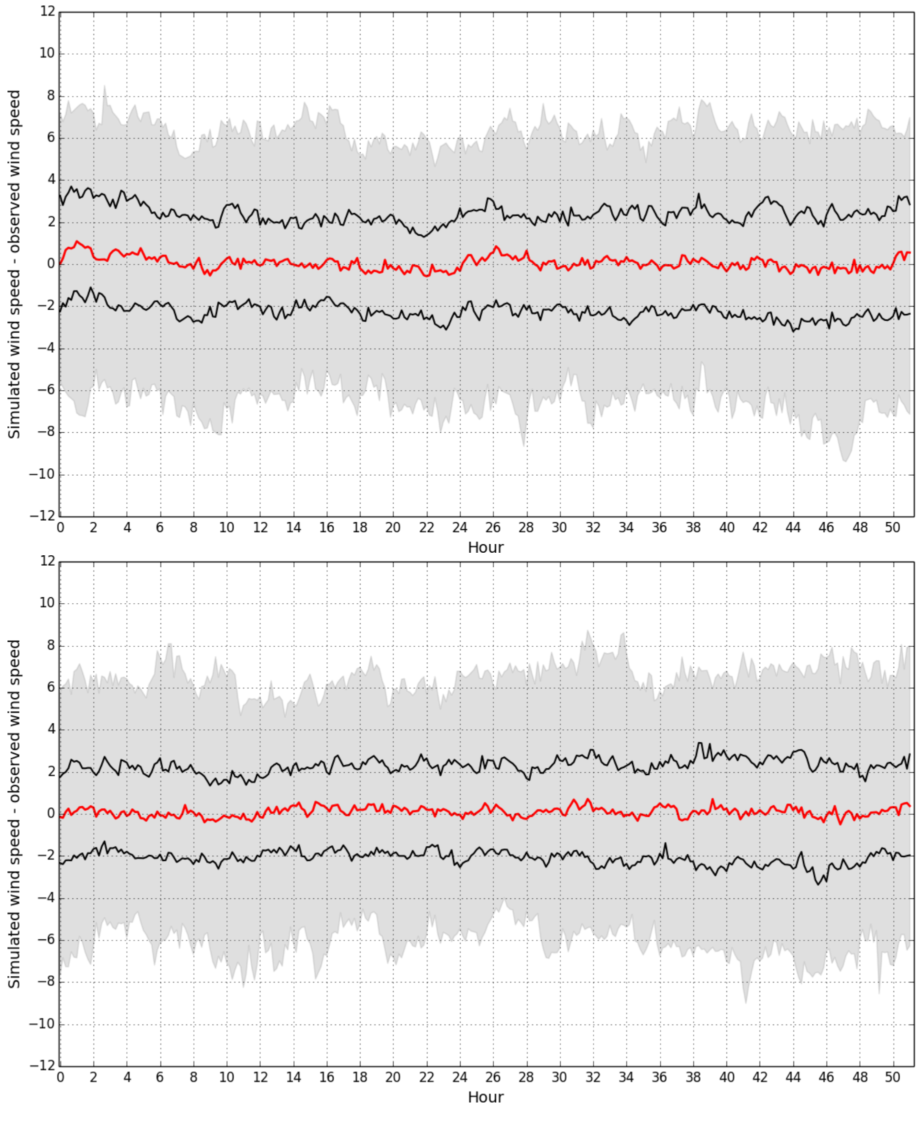

Figure 8: As for the previous figures but for all wind speed and for forecasts starting at 0 UTC above and at 12 UTC below.

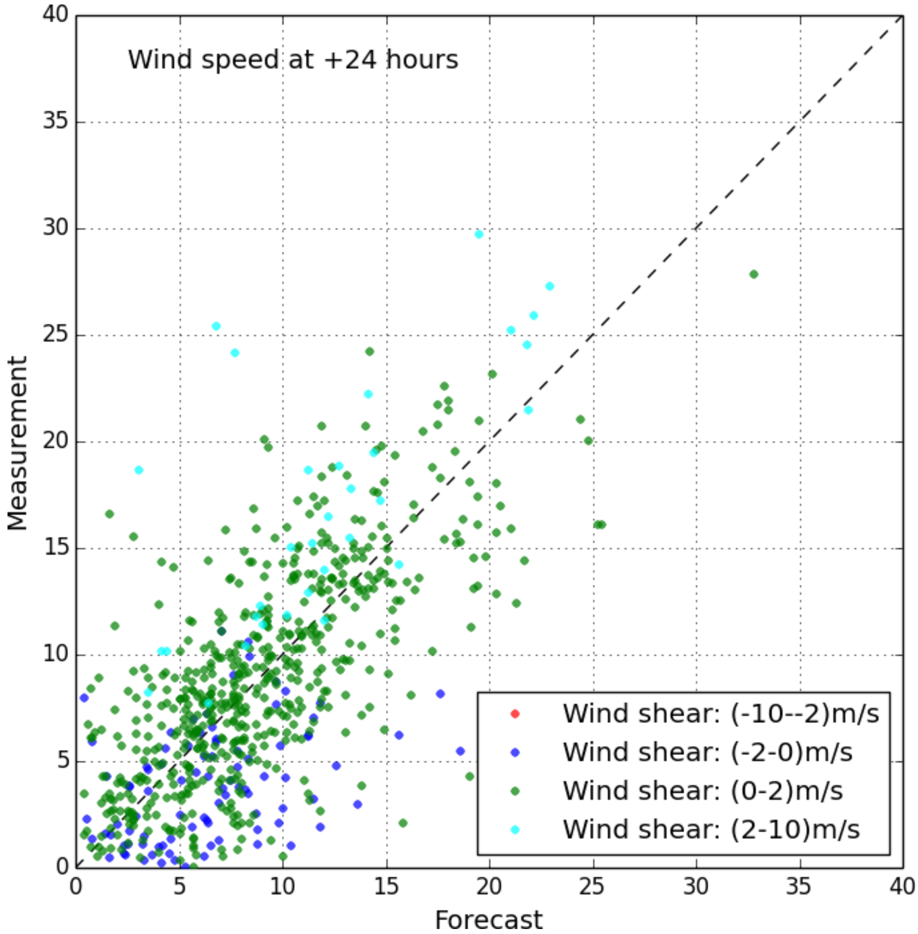

Figure 9: Scatterogram of the observed and forecasted wind speeds at 24 hours into the forecast and their dependance on observed wind shear between 56 and 31 m.

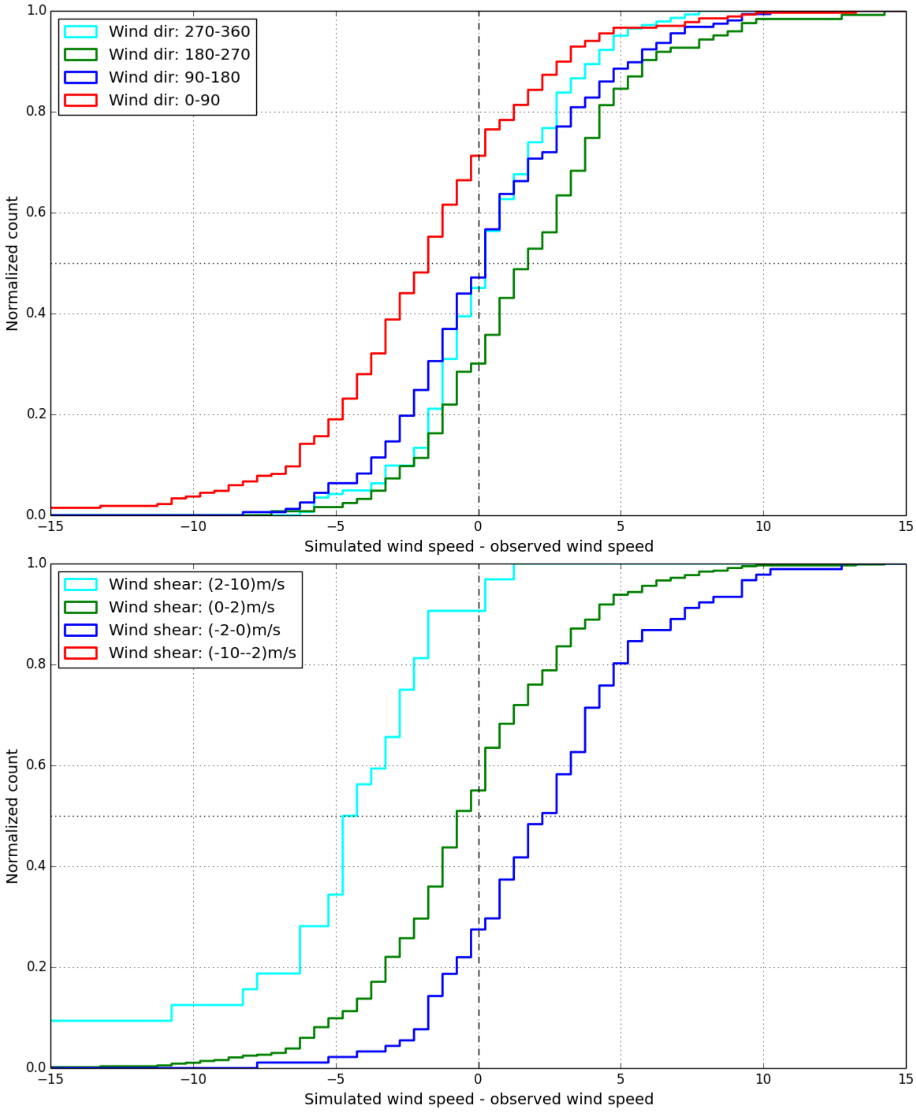

Figure 10: A histogram of the mean error at 24 hours into the forecast and its dependance on observed wind speed at 56 m (above) and on the observed wind shear between 56 and 31 m.

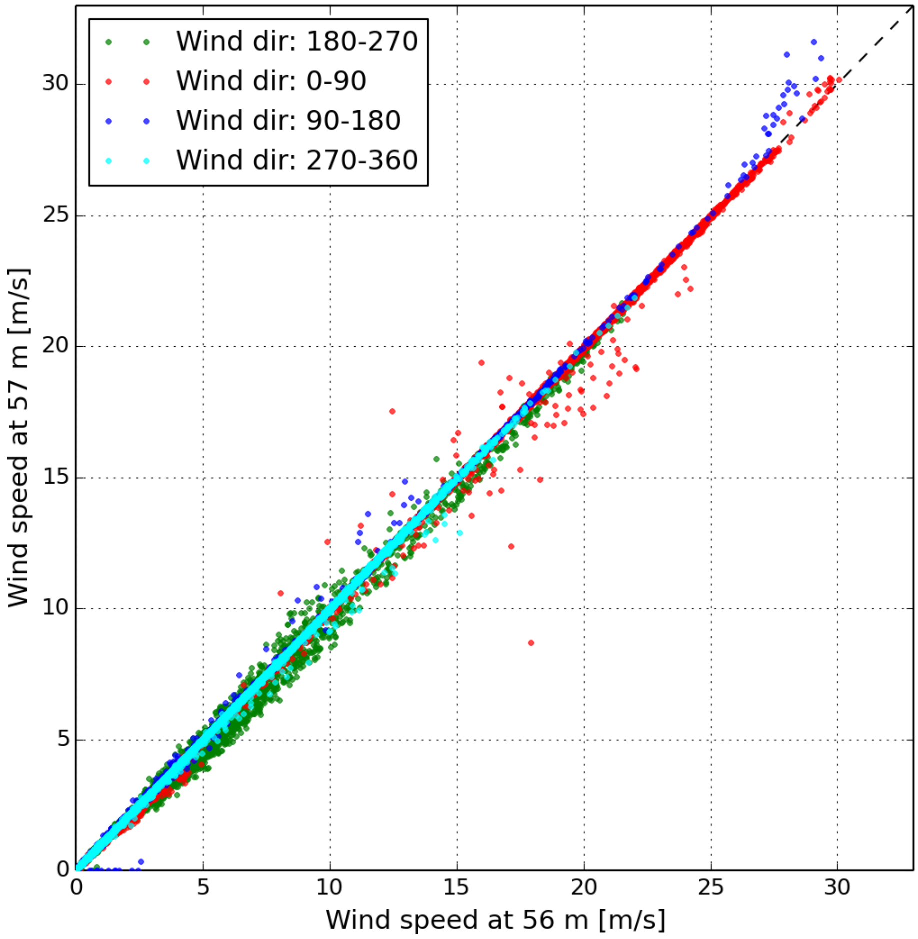

Figure 11: Scatterogram of observed winds at 56 and 57 m.

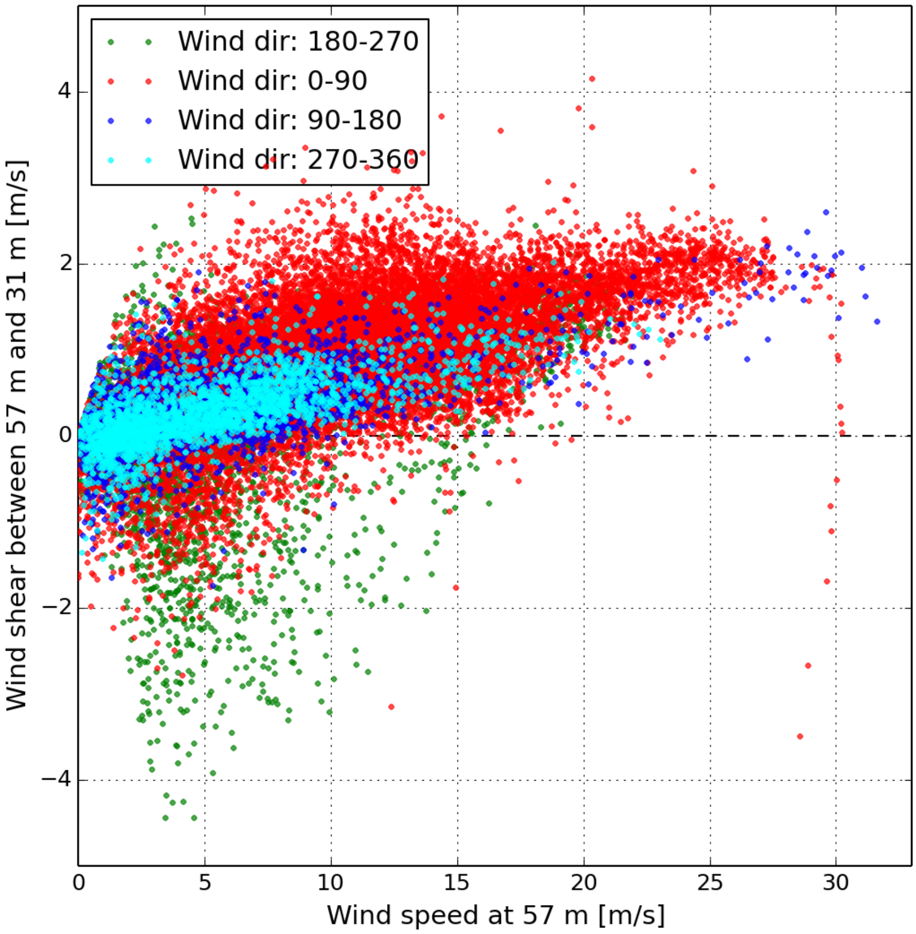

Figure 12: Scatterogram of observed wind speed at 57 m and observed wind shear between 57 and 31 m, and its dependance on observed wind direction at 57 m.

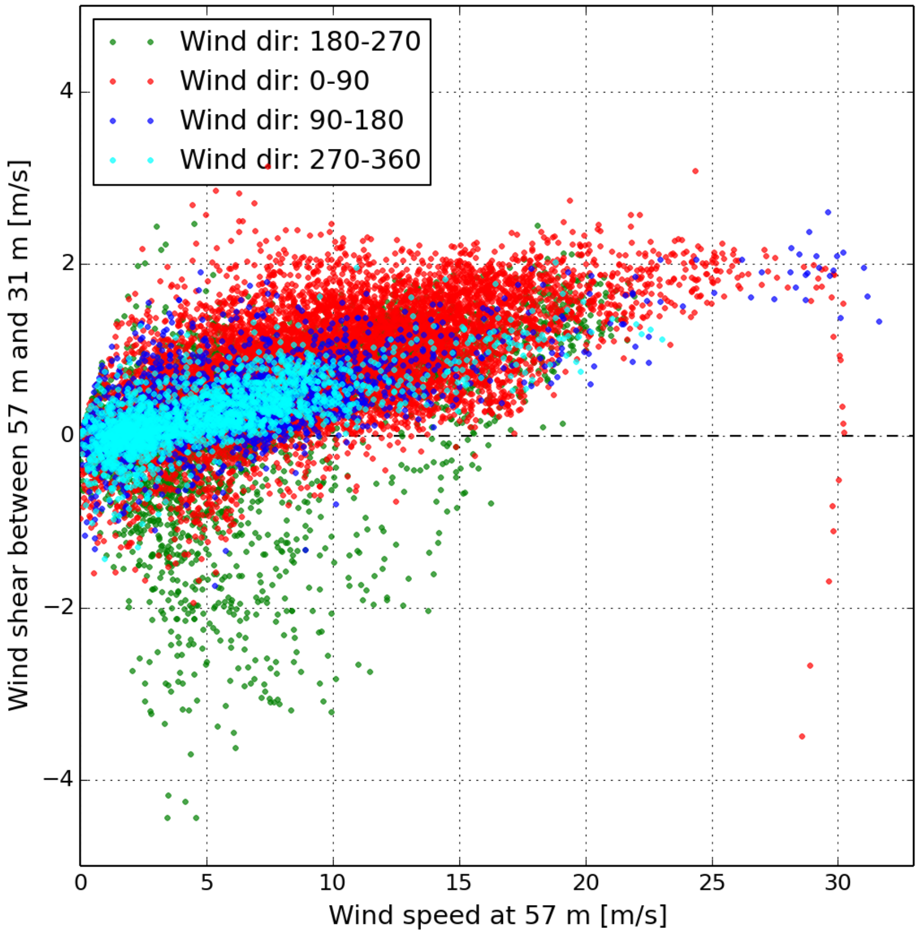

Figure 13: Scatterogram of observed wind speed at 57 m and observed wind shear between 57 and 31 m, and its dependance on observed wind direction at 57 m, for observed temperature at 57 m above 1°C.

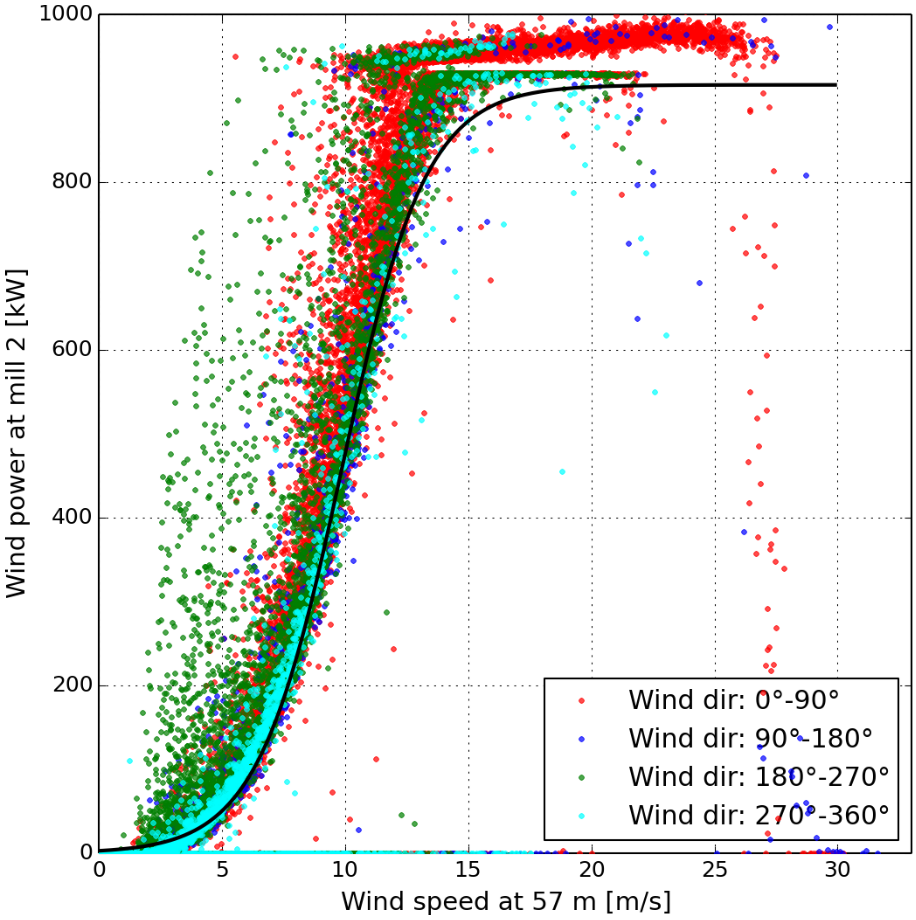

Figure 14: Scatterogram of observed wind speed at 57 m and observed wind power at turbine no. 2 and its dependance on observed wind direction at 57 m.

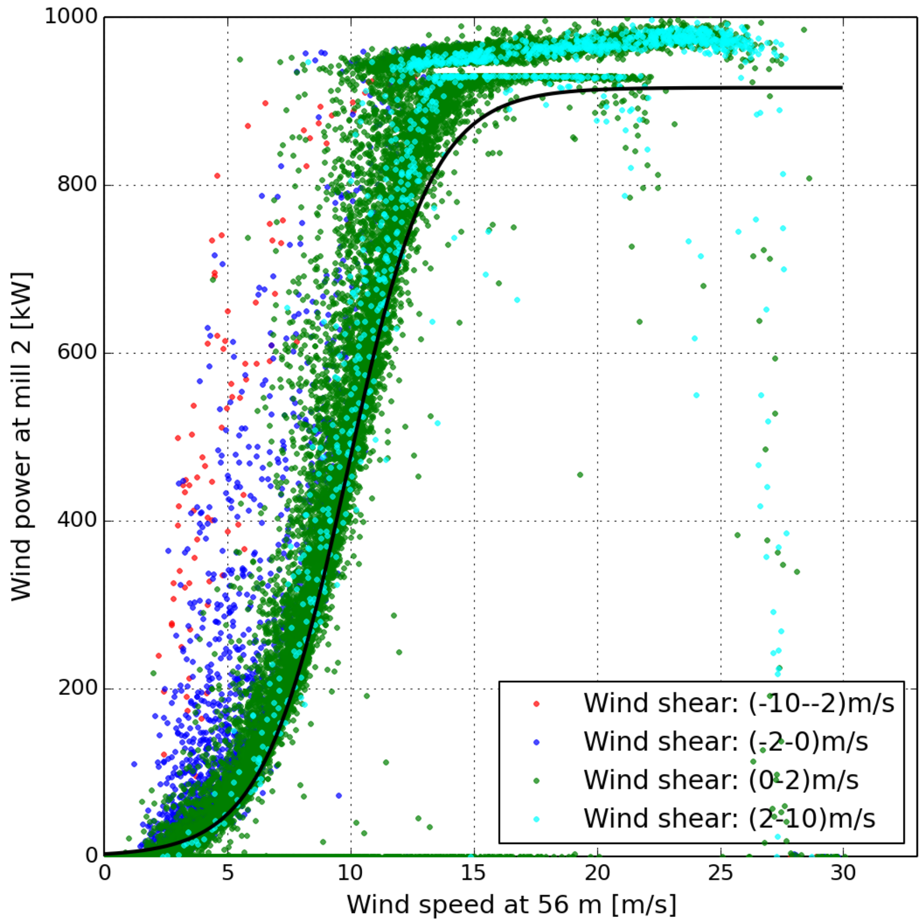

Figure 15: Scatterogram of observed wind speed at 56 m and observed wind power at turbine no. 2 and its dependance on observed wind shear between 56 and 31 m.