BELGINGUR

Technical Report

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Performance of Wind Forecasts at the Cabauw Meteorological Mast

System description and comparison with observations

Reykjavík
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Introduction

Belgingur has been running an operational weather forecast system for NW-Europe as part of a service agreement with Eneco Ltd., signed in 2011. In order to identify ways to improve the service even further, Belgingur has created a set of wind forecasts for December 2013, using different atmospheric model configurations. This report discusses and analyzes the performance of these wind forecasts with observations from the Cabauw meteorological mast.

The wind forecasts are made with version 3.4.1 of the AR-WRF atmospheric model (Skamarock et al., 2008). The forecasts are generated based on the 00-hour analysis from the NOAA GFS[1] modeling system. The forecast duration is 48 hours, with spin-up times ranging from 24 to 6 hours, depending on domain. The model is run in a nested setup in the horizontal, with 36, 12, 4, and 1.3 km resolution model domains (Fig. 1) and 55 levels in the vertical with approximately 10 levels in the lowest 300 meters above ground level.

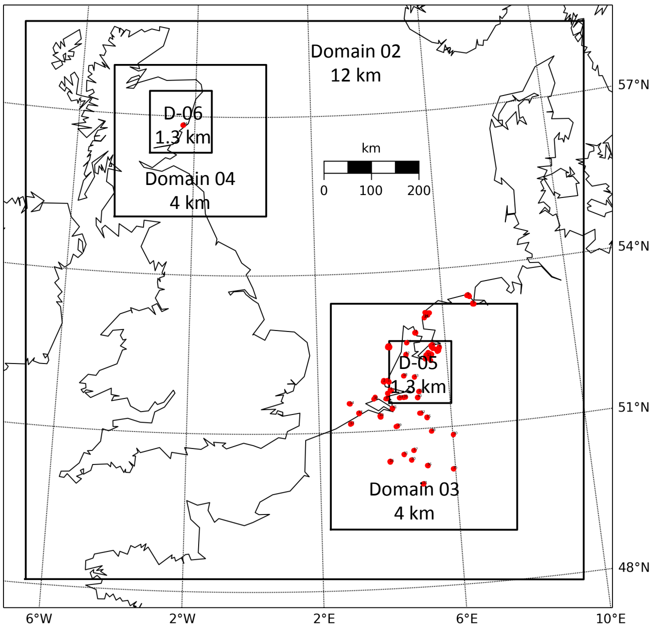

Figure 1: Location of model domains and domain horizontal resolution, the outermost domain (36 km resolution) is not shown. Red dots show the locations of Eneco's wind-farms, the Cabauw meteorological mast is located near the center of Domain 05.

The outermost domain uses four analysis from the previous day (00-, 06-, 12-, and 18-hours) for spin-up, using spectral nudging (von Storch et al., 2000), whilst the inner-more domains are launched 6 (12 km resolution), 12 (4 km resolution), and 18 (1.3 km resolution) hours after the outermost domain. The model is configured using three different combinations of planetary boundary layer (PBL) and microphysics schemes. Configuration *MYJ-WSM5* uses the Mellor-Jamada-Yanjic (MYJ) PBL scheme (Janjić, 2001) and the WSM5 microphysics scheme (Hong and Lim, 2006). Configura-

[1]http://mag.ncep.noaa.gov

tion *MYJ-Thom* uses the MYJ PBL scheme and the Thompson microphysics scheme (Thompson et al., 2004), and finally the *YSU-WSM5* configuration uses the YSU PBL scheme (Hong and Pan, 1996) and the WSM5 microphysics scheme. The forecasts discussed in this report are based on results from the 12, 4, and 1.3 km domains and are interpolated bi-linearly to the location of Cabauw meteorological mast (cf. Fig.) and linearly to the different elevations (20, 40, 80, 140, and 200 m) of the masts observation levels. The wind forecasts are compared to observations taken in the Cabauw mast

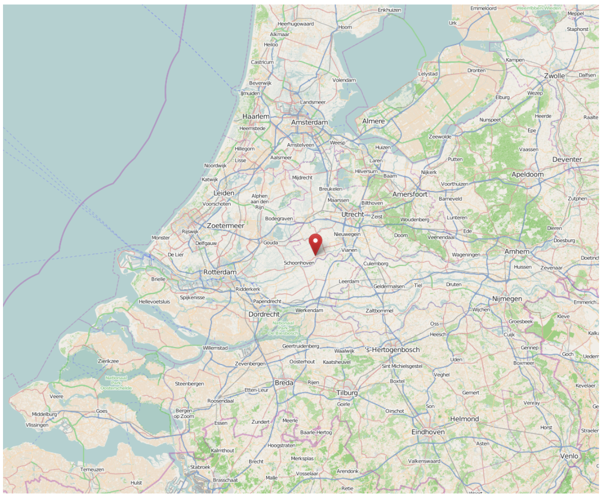

Figure 2: The Cabauw meteorological mast is located approximately 50 km south of Amsterdam.

for the whole of December 2013. Forecast values are written to file every ten minutes, which is the same temporal resolution as the observations taken in the Cabauw 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 December 2013 shows that the bias ranges on average between -0.35 m/s to 0.75 m/s, depending on model configuration, model resolution, and height above ground, throughout the forecast period (0–48 hours), cf. Figs. 3–5. The mean error is within 1 m/s during most of the forecast, but shows a slightly greater spread after approxemately 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 at least two days. About 90% of the data have a mean error of less than 4 m/s, but this also shows a larger spread during the latter half of the forecast period.

There is a clear diurnal signal in the mean error of the forecasts, with errors peaking between forecast hours 2 and 4 and again between forecast hours 26 and 28. This corresponds to 04 and 06 hours CET, i.e. from late night to early morning. This peak in forecast error is more prominent at higher levels, indicating that the model is having

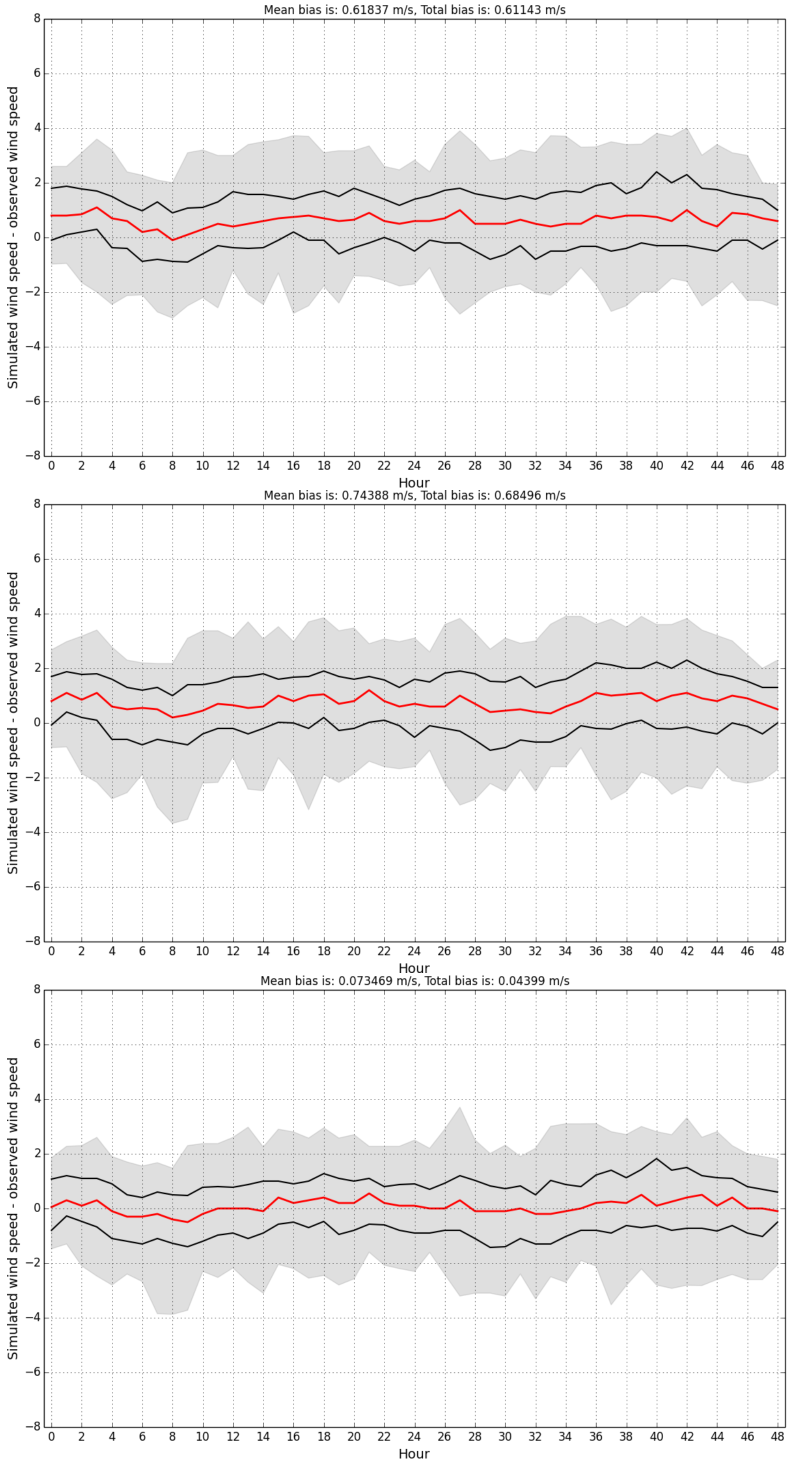

Figure 3: Mean error (forecast-observation) as a function of forecast hour for December 2013. Red line is the median, dark lines show the 25 and 75 percentiles while the grey region extends to the 5 and 95 percentiles. The model configuration is *MYJ-WSM5*, taken at 40 m.a.g. for 12 (top), 4 (middle) and 1.3 (bottom) km resolution.

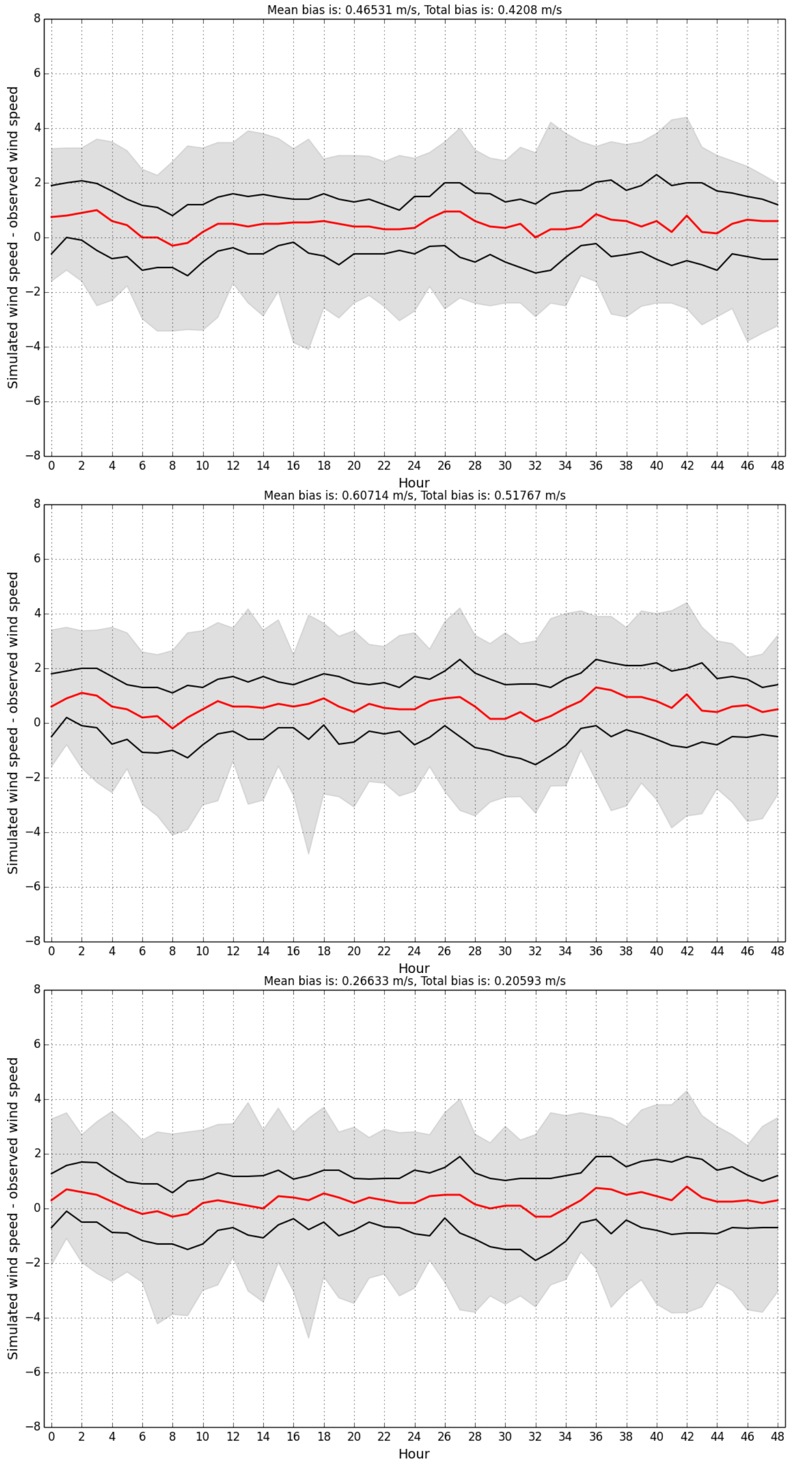

Figure 4: Same as Fig. 3 except at 80 m.a.g.

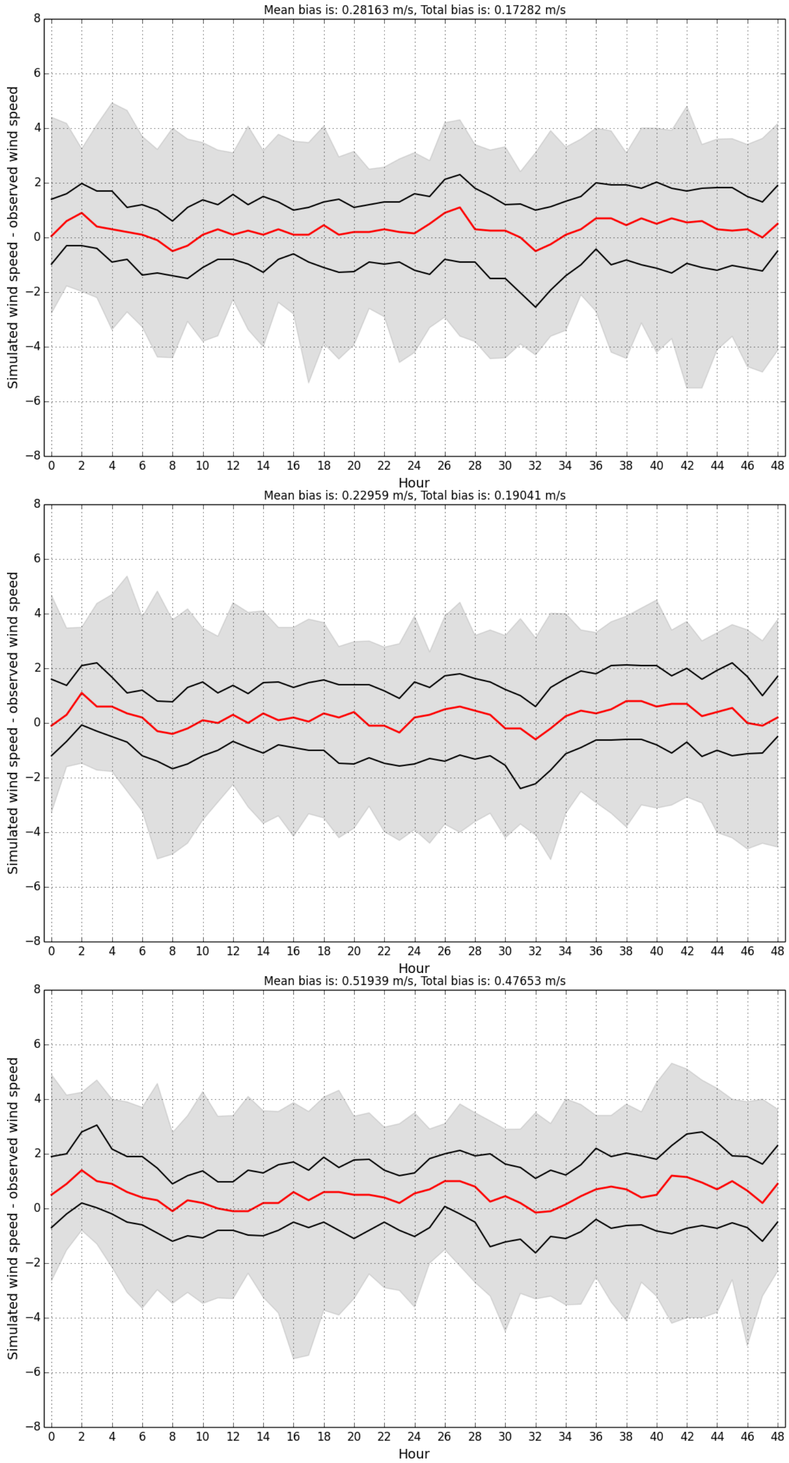

Figure 5: Same as Fig. 3 but for model configurations *MYJ-WSM5* (top), *MYJ-Thom* (middle), and *YSU-WSM5* (bottom), 1.3 km resolution and at 140 m.a.g.

problems correctly simulating the nocturnal atmospheric boundary layer.

It is also evident that increasing the horizontal resolution from 12 to 4 km does not reduce the model bias, in some cases the bias is even increased. A clear improvement in model performance is not seen until the horizontal resolution has been reduced to 1.3 km.

Performance at individual forecast hours

The performance of the forecasts was investigated further at 5 different forecast hours, i.e. at 6, 12, 24, 36, and 48 hours into the forecast. Note that in this report figures are only shown for the 24 and 36 hour forecasts. Scatterograms of observed and forecasted wind speeds show qualitatively the performance of the forecasts (cf. Figs. 6 and 7).

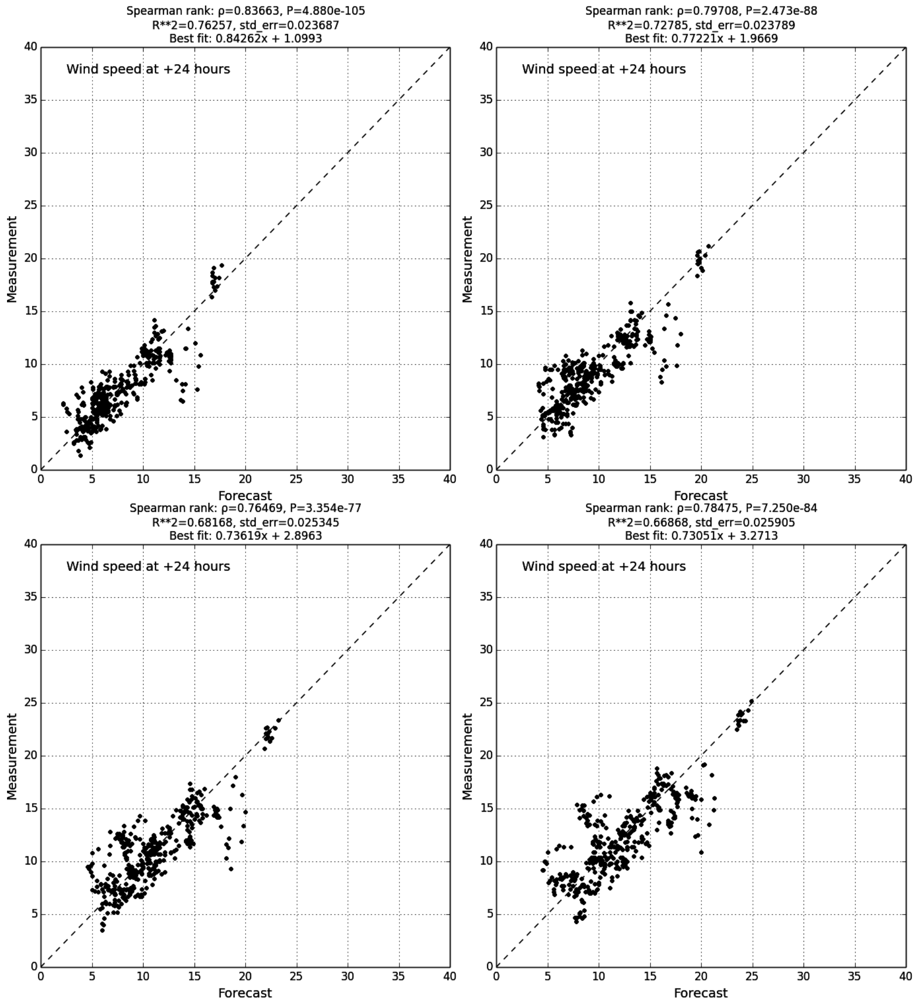

Figure 6: Scatterogram of the observed and forecasted wind speeds at 24 hours into the forecast at 40 (top left), 80 (top right), 140 (bottom left), and 200 (bottom right) meters height a.g.l. for *MYJ-WSM5* at 1.3 km resolution. The R^2 correlation values are in the range of 0.67 (200 m.a.g.) to 0.76 (40 m.a.g.).

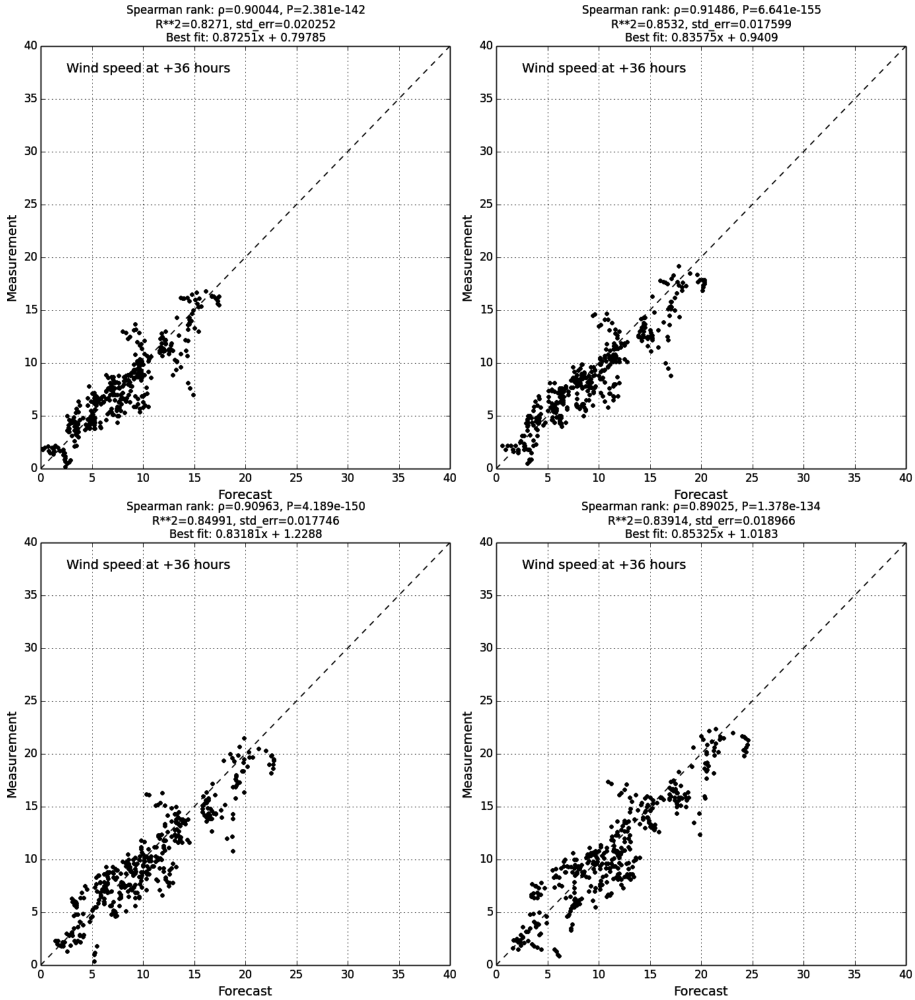

Figure 7: Scatterogram of the observed and forecasted wind speeds at 36 hours into the forecast at 40 (top left), 80 (top right), 140 (bottom left), and 200 (bottom right) meters height a.g.l. for *MYJ-WSM5* at 1.3 km resolution. The R^2 correlation values are in the range of 0.83 (40 m.a.g.) to 0.85 (200 m.a.g.).

The performance is on average good but again we see the effect of the poorly simulated nocturnal flow as the 36 hour forecast outperforms the 24 hour forecast at all heights.

Power production

In light of the results described above it is interesting to note that the power production forecast for Eneco's wind-farm named *FL23*, and which is located close to the Cabauw meteorological mast, is not improved by using better forecast data. Namely, results from the 1.3 km resolution grid, cf. Fig. 8.

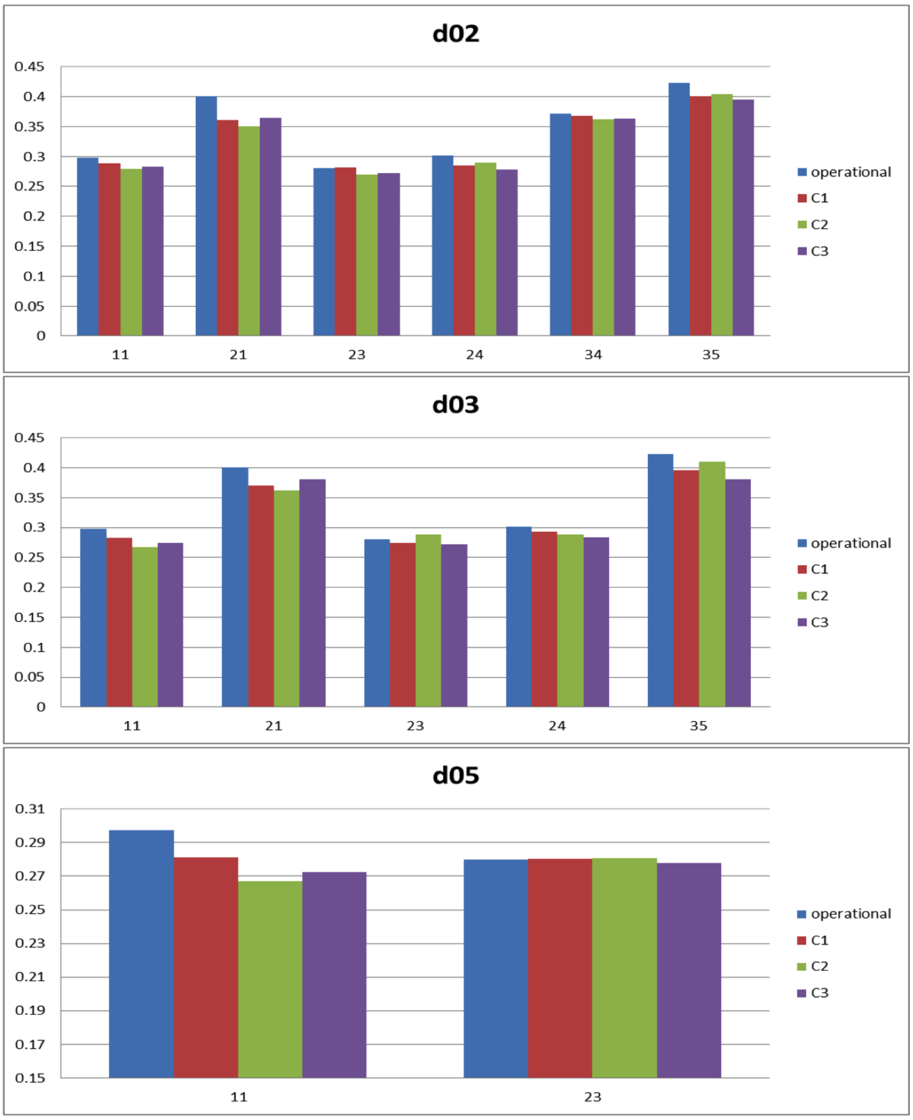

Figure 8: Average relative error (vertical axis) of power production forecasts for various wind farms (horizontal axis) located within different forecast domains (12 km – top, 4 km – center, and 1.3 km – bottom panel). Farm number 23 is located very close to the Cabauw mast. The error is calculated from hourly wind forecast values taken between forecast hours 24 and 47 over a period of 31 day (744 values in total). Different colors represent different configurations of the model, C1 corresponds to *MYJ-Thom*, C2 corresponds to *MYJ-WSM5*, and C3 corresponds to *YSU-WSM5*. The operational forecast system, run at 12 km horizontal resolution, is very similar to *MYJ-WSM5*/C2. Data courtesy of Eneco Ltd.

Downscaling experiment

In order to get a better idea of how well the modeling system can simulate the wind flow observed at the Cabauw meteorological mast we did a one month downscaling simulation using the operational NOAA GFS analysis as initial and boundary forcing. The model was configured in the same way as for the *MYJ-Thom* simulations, but with domains 4 and 6 turned off, i.e. the 4 and 1.3 km resolution domains for NE-Scotland, cf. Fig. 1.

The model wind speed bias is greatest for the 4 km resolution domain and smallest for the 1.3 km resolution simulation, except at 200 meter level, where the 12 km resolution simulation has the least bias. The mean bias is in the range of -0.16 (1.3 km resolution at 40 m.a.g.) to 0.47 (4 km resolution at 40 m.a.g.), see Fig. 9. There is further remarkably small difference in the correlation co-efficients (both Spearman rank and R^2) for different model resolutions (cf. Fig. 10). The spread increases gradually with height and the slope of the best fit line is less than one with a positive intercept. This demonstrates that the simulations are in general underestimating weak winds but overestimate the stronger winds. From Fig. 10 we can see there are two groups of outliers, both overestimations and underestimations of wind speed. By plotting observed and simulated winds together (cf. Fig. 11) we can see there appears to be at least two individual events where the model results deviate considerably from observations (cf. Fig.12). During the former event (5–6 December) there is considerable variability in the observed wind speed that is not captured at coarser resolutions (not shown) but only at the 1.3 km grid. The wind pattern resembles that of a passing frontal system (cf. Fig. 13), but a successful simulation of such a system is very much dependent on high quality input and boundary data. During the latter event (12–13 December) the wind speed drops down to approximately 5 m/s in the evening of 12 December and rises again to about 10 m/s in the afternoon of 13 December. Simulated winds, however, stay close to 10 m/s and only dip down to 7 m/s at mid-day 13 December before rising again in the afternoon. By plotting values from the nearest grid cell, as well as surrounding cells, we get an idea of the spatial variability of the simulated data (cf.

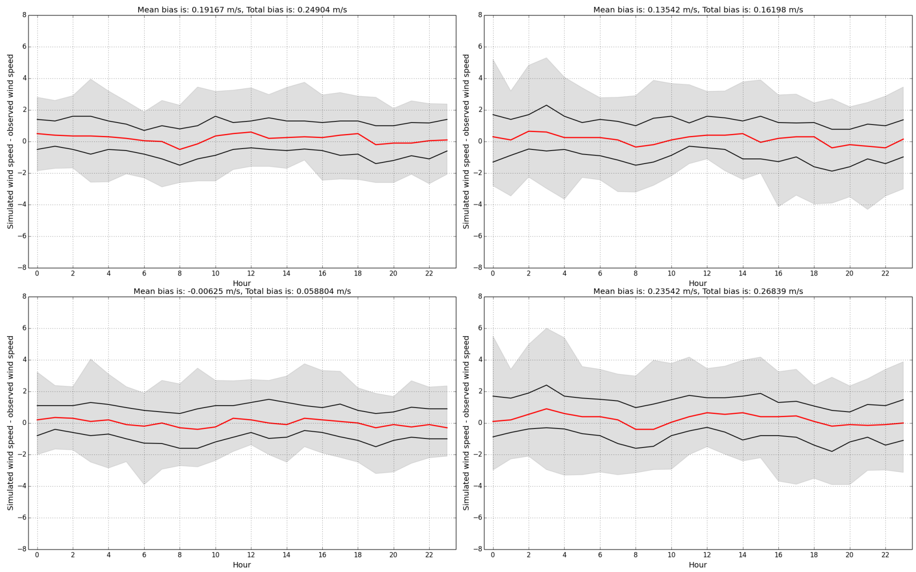

Figure 9: Mean error (forecast-observation) as a function of the time of day at 80 (left panels) and 200 (right panels) meters height at 12 (top row) and 1.3 km (bottom row) resolution. The mean bias is reduced as resolution is increased.

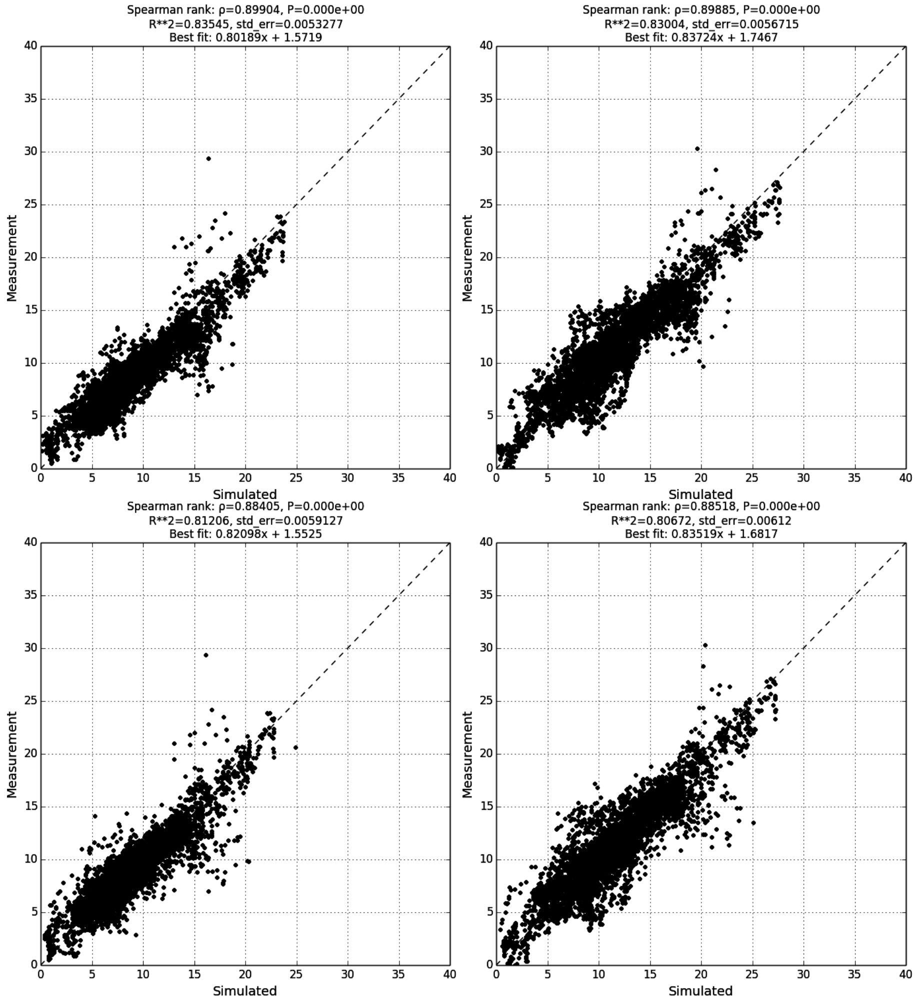

Figure 10: Scatterogram of the observed and simulated wind speed at 80 (left panels) and 200 (right panels) meter height at 12 (top row) and 1.3 km (bottom row) resolution. The R^2 correlation values are in the range of 0.80 to 0.84.

Fig. 14). It is clear from the figure that there is limited spatial variability in the wind speed around the Cabauw mast.

Erroneous simulations, most likely stemming from poor input data, of wind speeds for these two events are likely to have caused large errors in power production simulations.

Discussions and suggestions for future work

Increasing model resolution from 12 to 4 km does not improve wind speed forecasts for Cabauw, it's only when model resolution is increased to 1.3 km that the forecast is improved. For some reason, improved wind forecast does not lead to improved power production forecasts. Forecasted winds of up to 48 hours lead time are of similar quality

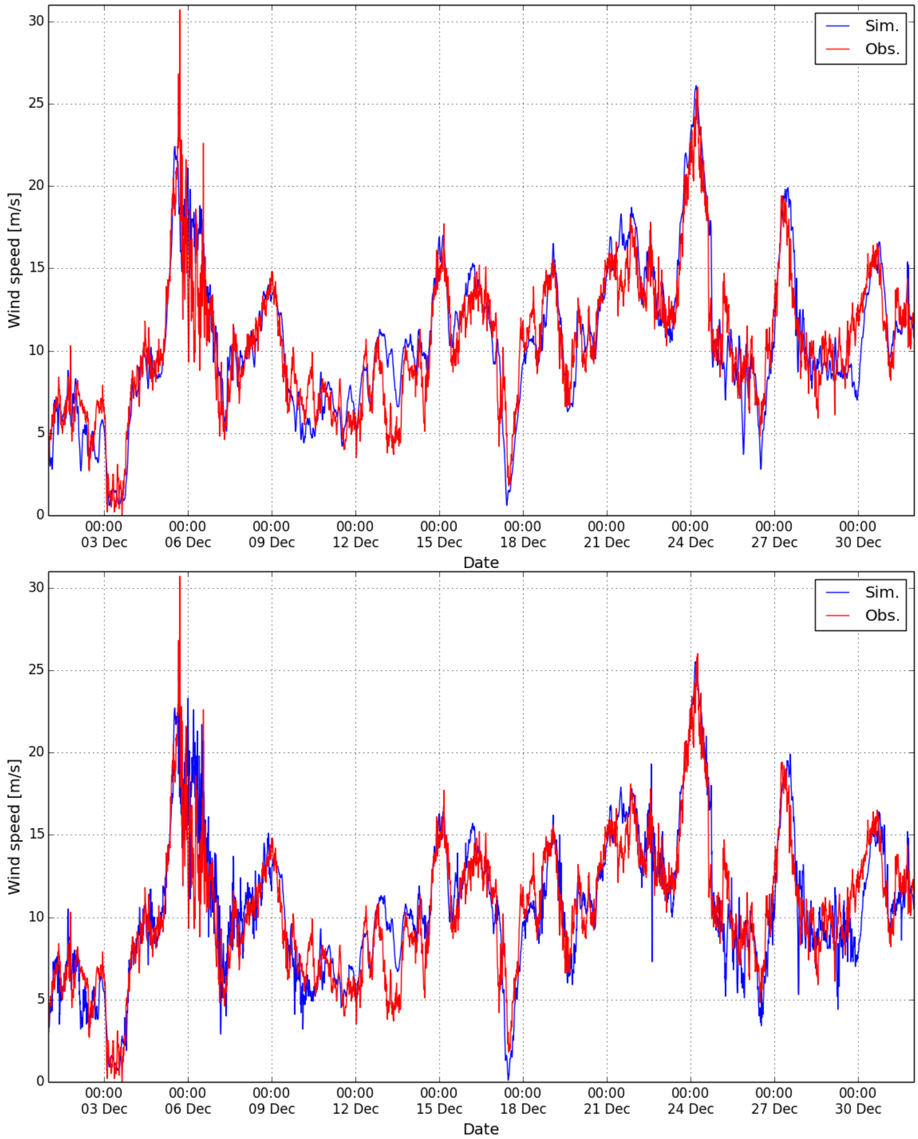

Figure 11: Time-series of simulated (blue line) and observed (red line) wind speed at 140 m.a.g. for December 2013. Temporal resolution is 10 minutes and horizontal model resolution is 12 (top) and 1.3 km (bottom).

as dynamically downscaled winds at comparable model grids.

Belgingur has developed a linear regression method to improve point forecasts from a dynamical weather model using available observations of wind speed and temperature. The method identifies the best combination of nearby model grid cells to minimize the mean square difference of the forecast value with observations. Results from over twenty observation sites in the complex terrain of the Faroe Islands (cf. Fig. 15) reveal that by using Belgingur's post-processing the RMS error of the 24 hour wind speed forecast could be reduced on average by 45%.

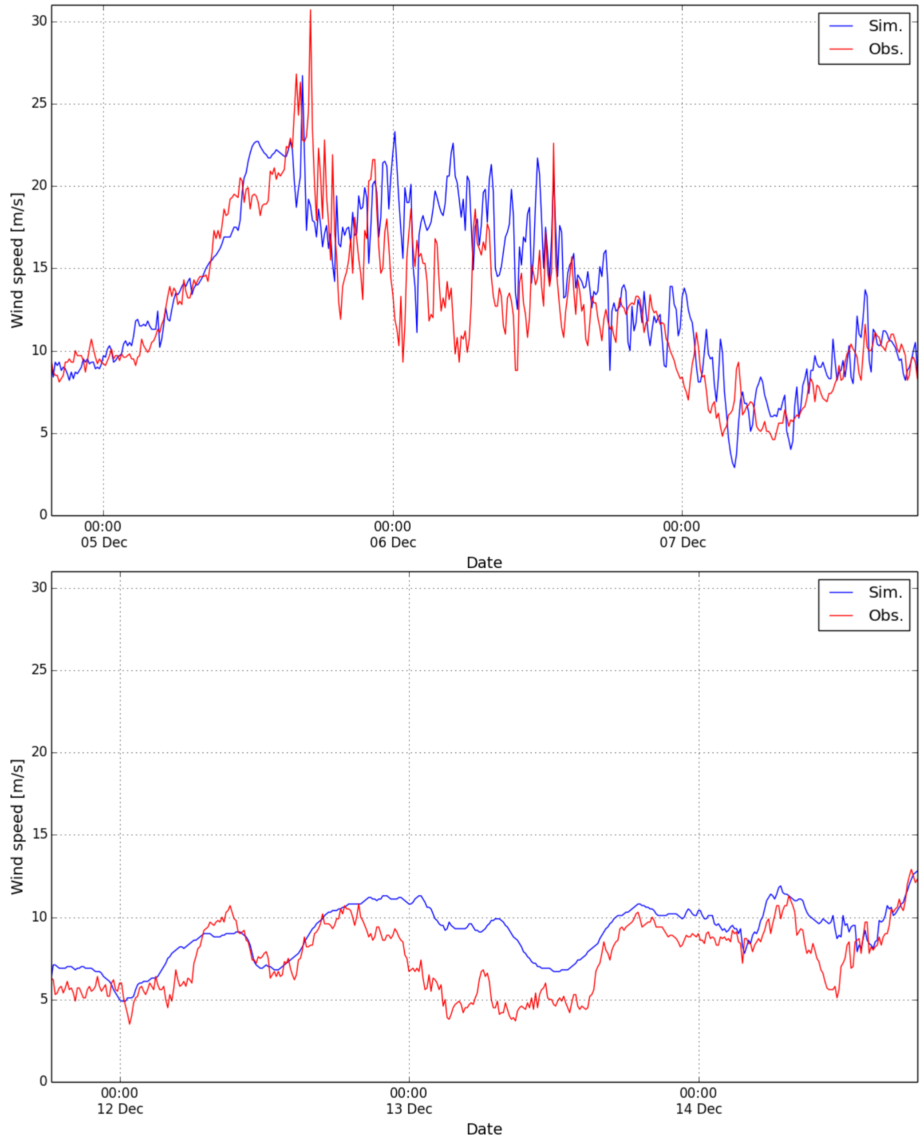

Figure 12: Same as Fig. 11 but zoomed in for the two individual events. Model resolution is 1.3 km.

It is our firm believe that it would be worth investigating if a similar method could be used to improve the power production forecasts for Eneco.

Summary

The performance of the wind forecasts during December 2013 is on average quite good, with a bias ranging from -0.35 to to 0.75 m/s, depending on model configuration, model resolution, and height above ground, throughout the forecast period (0–48 hours). The mean error is within 1 m/s during most of the forecast, but shows a slightly greater

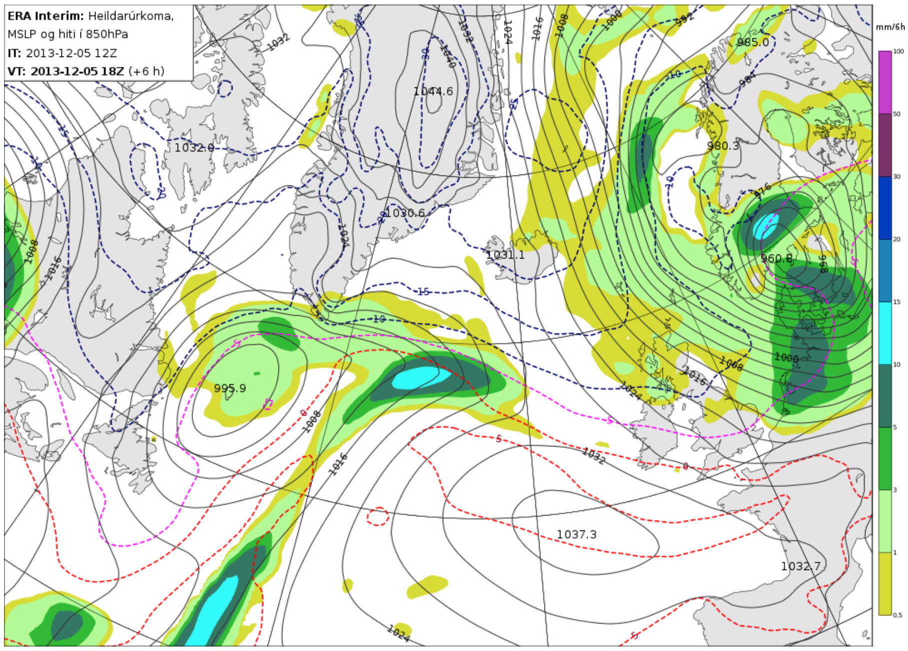

Figure 13: Analysis chart from ERA-Interim, valid at 12UTC on 5 December. The chart shows mean sea level pressure (solid black lines) and temperature at 850 hPa (colored stabled lines) as well as six hour accumulated precipitation (color bar to the right). Picture taken from http://brunnur.vedur.is/kort/era/2013/201312/era-i_msl_t850_tp.html, retrieved on 4 July 2014.

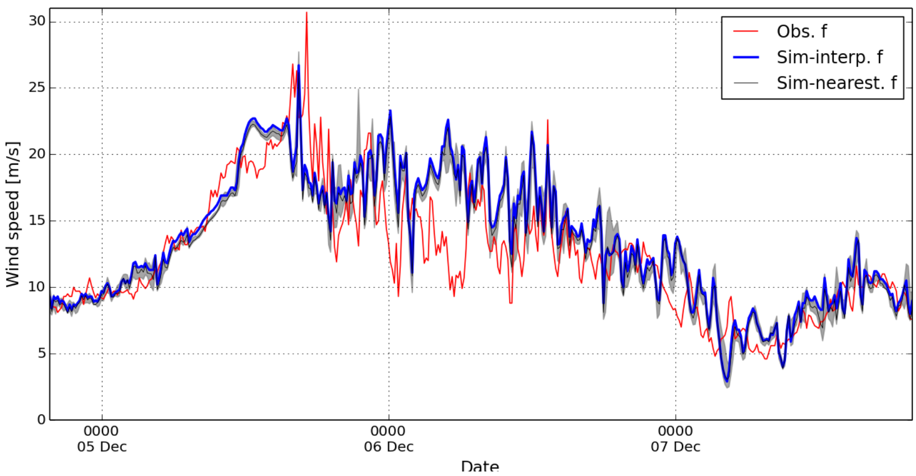

Figure 14: Timeseries from 5 to 7 December of observed (red line), vertically interpolated (heavy blue line), nearest neighbor (thin black line) wind speed, and wind speed from adjacent grid cells (gray overlay). Observed and interpolated values are taken at 140 m.a.g. and direct model output data are taken from the fifth lowest sigma level at approximately 126 m.a.g. Model resolution is 1.3 km.

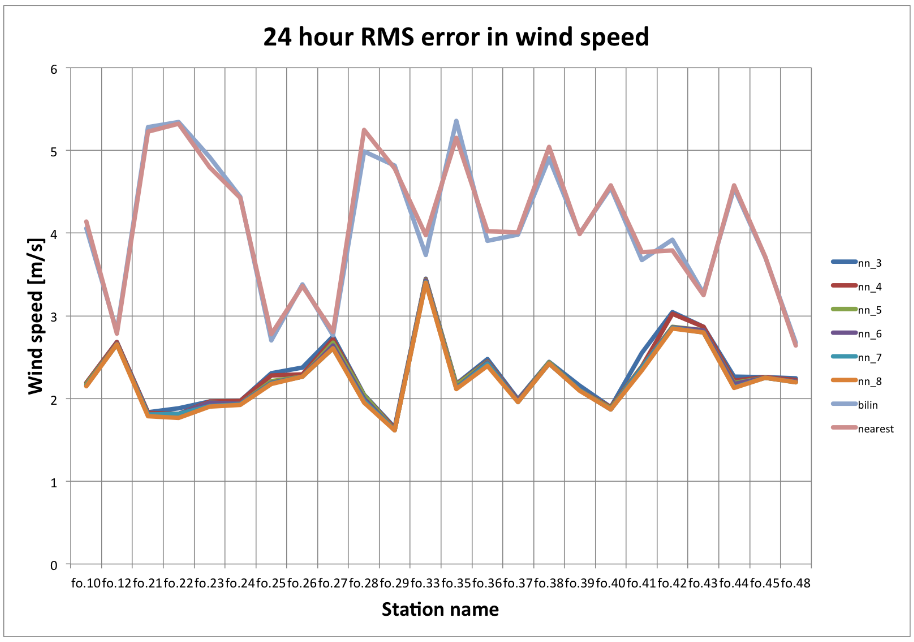

Figure 15: Wind speed forecasts can be significantly improved by using observations to correct the forecast. On average the Root-Mean-Square (RMS) error of the 24 hour wind speed forecast was reduced by 45%.

spread after approxemately the first day.

For Cabauw, best results are found for 1.3 km horizontal grid resolution, independent of model configuration. On average, the *MYJ-WSM5* configuration had the least forecast bias, whilst the *YSU-WSM5* configuration performed the least.

The predictability at the end of the forecast (i.e. forecast hour 48) is only marginally less then at forecast hour 12, showing that the forecasting system is giving valuable information for at least 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.

A short investigation of the forecasted winds and predicted wind power reveals some interesting features. Firstly, the improved power predictions for the 12 km resolution, as compered to forecasted winds from the operational system, can most likely be linked to increased spin-up time of the model. Secondly, the improved wind forecast at 1.3 km resolution does not result in improved power predictions. Why this is the case calls for further investigation.

Belgingur has developed a post-processing method that can greatly reduce forecast error in simulated wind speed by using available observations. We propose that available observations will be used in the future to reduce forecast error and that Eneco's power production methods will also be reconsidered.

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