Modelling of offshore wind resources. Comparison of a meso-scale model and measurements from FINO 1 and North Sea oil rigs.

by

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Summary

The meso-scale model WRF has been set up with three nests with respectively 18km, 6km and 2 km horizontal resolution. The model has been run for 4 years and hourly data were stored. Simultaneous measurements were available from the Fino 1 platform, and a first comparison of the data has been carried out. Monthly and annual average wind speeds from the model compares very well with the observations. Also the four year Weibull distribution and wind rose from the model correspond well with the observed values. Based on the comparison it is concluded that the model is a reliable tool for characterising the average wind conditions, at least in this part of the North Sea. However, for the temporal variations of vertical stability and wind shear larger deviations between the model and the measurements are encountered, and before the model data are applied to for example wake modelling a more detailed study of the statistical properties of the model data are recommended. Comparison of the average wind speeds of the WRF model with data from four oil rigs in the Norwegian sector of the North Sea indicate that the measurements could overestimate the annual wind speeds with as much as 5-10%. Thus, the oil rig data should be applied with care in wind power studies, unless overestimation of the offshore wind energy potential could result.

1 Introduction

The meso-scale meteorological model WRF (Weather Research and Forecasting) has successfully been applied to onshore wind resource assessment in Norway [1]. Annual average wind speeds are typically predicted within ± 10% of observed values in 50m high measuring masts for coastal mountains. For more homogeneous areas lower deviations are found, and for offshore regions even more accurate predictions may be expected.

The aim of this study is to improve our knowledge in how well the wind conditions (annual average wind speed, vertical wind shear, Weibull distribution and wind direction distribution) can be obtained by the numerical meteorological models. The work is a contribution to the EU-project NORSEWIND (NORthern SEas Wind Index Database) which started up in August 2008. The aim of the project is to develop wind atlases for the Irish Sea, the North Sea and the Baltic Sea. Offshore wind measurements, satellite data and numerical model data will be utilized for this purpose.

In the present study the model has been run for four years for the North Sea, and wind speed and wind direction statistics have been generated based on hourly output from the model. Accurate wind speed data are presently public available from the FINO 1 platform in the North Sea. Detailed vertical wind and temperature data are available which have be used to analyse the WRF model results. Meteorological measurements from the oil rigs in the Norwegian sector of the North Sea are also compared with the model calculations. In general, the measurements of the oil rigs have lower quality than the meteorological data from the FINO 1 platform due to wind field distortion effects of the platforms.

2 Model and measurements data

2.1 The measurements of the Fino 1 platform

The Fino 1 platform is located in the south east corner of the North Sea about 50km north of the German coast (see Figure 1). The FINO 1 data have been made available by the BMU (Bundesministerium fur Umwelt, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) and DEWI (Deutsches Windenergie Institut, German Wind Energy Institute). A view of the platform is also seen in the same figure. In the present analysis wind speed data from the levels 60m, 80m and 100m have been utilized. The wind speed data have been corrected for mast effects by employing Lidar measurements. Furthermore, wind direction data are from 90m, while the temperature data utilized are from the levels 30m, 40m, 50m, 70m and 100m. The data set is considered to have high quality compared to for instance wind measurements at oil rigs.

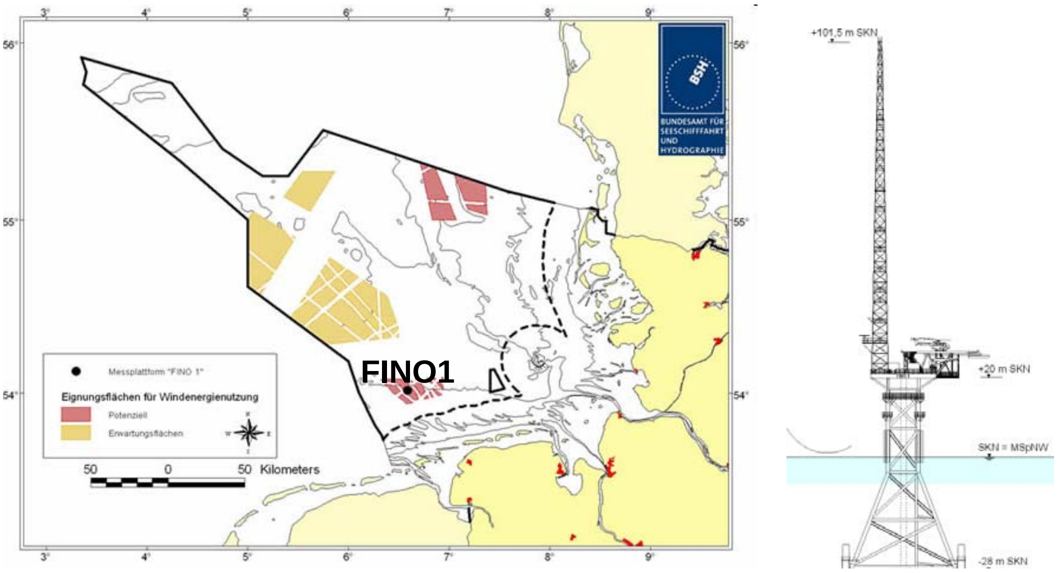

Figure 1. Locations of the Fino 1 platform (black dot in the left panel), and the 100m offshore mast (right panel).

2.2 The meso-scale meteorological model

The Weather Research and Forecast (WRF) model is a meso-scale numerical weather prediction system, aiming at both operational forecasting and atmospheric research needs. A description of the modeling system can be found at the home page http://www.wrf-model.org/. Details about the modeling structure, numerical routines and physical packages available can be found in for example [2] and [3]. In the following we give a brief overview of how the WRF-model has been set up and run for the offshore areas in the North Sea.

Global meteorological data with about 1 degree resolution have been available from the National Centers for Environmental Protection (NCEP) with 4 time-frames per day. The data originates from the Final Global Data Assimilation System (FNL), see http://wwwt.emc.ncep.noaa.gov/gmb/para/parabout.html for further description of the data. The global data are analysis based on observational data for the time-frames 00, 06, 12 and 18 UTC. The global data have been interpolated to the WRF-grid. For the land-areas the WRF-model is set up with terrain and land-use data of a resolution of approximately 1 km based on data accessible from the WRF-home page. The set-up of the model domain for the present runs is shown in Figure 2. The outer domain has 18 km resolution, the second domain 6 km resolution, while the inner domain has 2 km horizontal resolution. 32 layers are employed in the vertical direction. The lowest layers in the model are at approximately the heights 20m, 60m, 115m and 190m. The model has been run for four years (2004-2007) to cover the measuring period. Hourly data in each grid-point and for each vertical level is stored from the runs. Thus a large database is available. Note that for the comparison with the Fino 1 measurements the results from the inner domain are applied.

The sea is characterized by a low roughness value. This roughness is, however, dependent on the state of the sea surface, wave heights and pattern etc., which is dependent on the surface stress. The roughness over open sea has in WRF been expressed by Charnock's relation ([4]).

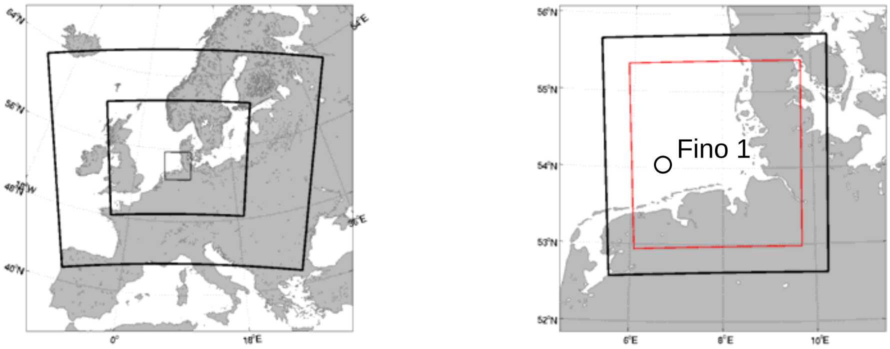

Figure 2. The WRF modelling domains. Left panel shows the outer, middle and inner domains with the horizontal resolutions 18 km, 6 km and 2 km respectively. The right panel shows the inner domain and the approximate position of the Fino 1 plattform.

3 Comparison of WRF results and measurements at Fino 1

3.1 Average wind conditions.

In Figure 3 we present the average monthly and annual wind conditions during the period 2004-2007. On an annual basis the differences are small between the model and the measurements. On average the model yields 0.1 m/s lower wind speed than measured during the four years period. The average wind speed values for this period were 10.0 m/s and 9.9 m/s based on the measurements and the WRF-model respectively. On a monthly basis the deviations are larger and up to ~ 0.5m/s. The hourly correlation between the model and the measurements is 0.92. The high correlation is also visualized in Figure 4, which shows the temporal variation of the 100m wind speed during January and July 2009. The model and the measurements follow each other closely most of the time with a few exceptions where rather large deviations occur.

In Figure 5 the wind roses are shown. We note a small veering of the modelled wind in the clockwise direction. Also the modelled Weibull distribution fits very well with the observed distribution, though the model overestimates the occurrence of wind speed in the range 8-10 m/s with about 1%.

Finally, the average wind shear is presented in Table 1. The measurements indicate an increasing wind shear factor from 0.05 between 80m and 100m to 0.08 between 60m and 100m. On the other hand, the model data indicate a reduction of the wind shear moving from the layer 80m-100m to the layer 60m-100m, which may appear somewhat unrealistic. Still, the vertical resolution is low in the model for such detailed comparison and inaccuracies in the vertical interpolation could also affect the results. It is important to be aware of that atmospheric stability effects also could play a role. It is therefore recommended to analyse the wind shear data more closely together with the stability data. A first comparison of the link between the wind shear and the stability is given in the next section.

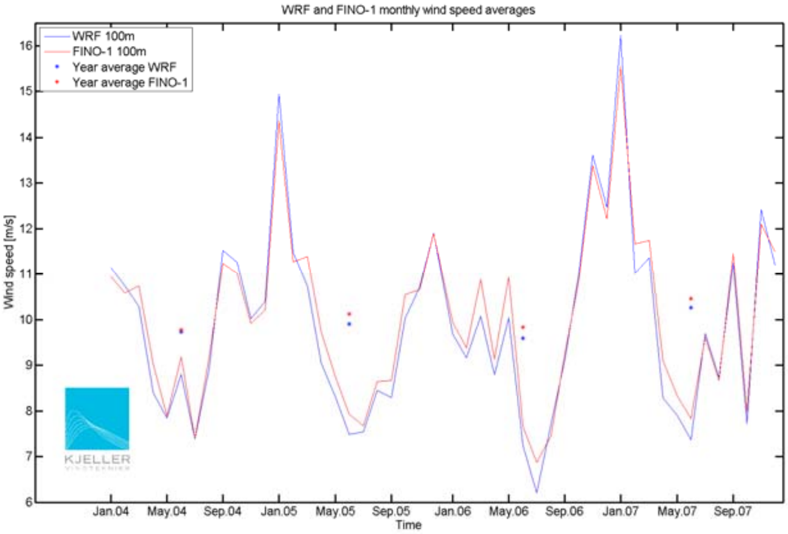

Figure 3. Monthly and annual average wind speed based on the WRF-model and the Fino 1 measurements at 100m.

The overall impression is that the model is very capable of generating the average wind conditions at Fino 1. Based on the above discussion we would recommend utilizing the model data for offshore wind resource assessment and preliminary energy estimates and wind farm layout. The model should also be well suited as a tool to develop offshore wind atlases of the Irish Sea, the North Sea and the Baltic Sea within the framework of NORSEWIND.

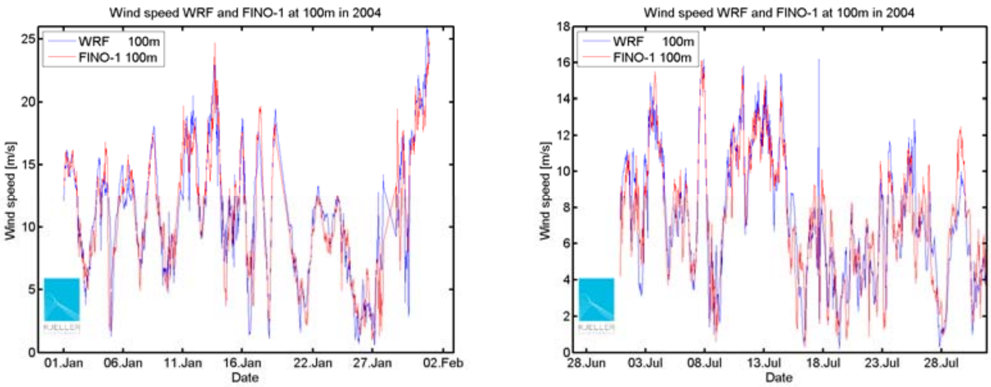

Figure 4. Time-series of the measured and modelled wind speed at 100m at FINO 1 for January and July 2004.

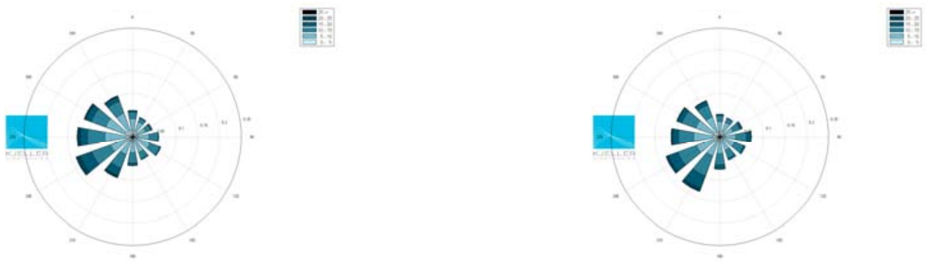

Figure 5. Wind rose based on 4 years (2004-2007) of data from measurement (right) and WRF (left).

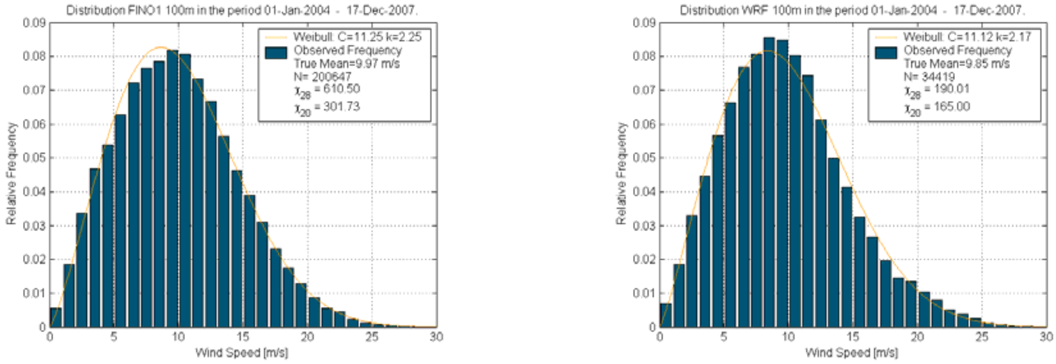

Figure 6. Weibull distribution based on 4 years of data from measurement (left) and WRF (right).

Table 1. Average wind shear for the period 2004-2007 at Fino 1.

Wind shear	100m-80m	100m-60m
Fino 1	0.05	0.08
WRF	0.07	0.06

3.2 Wind shear and atmospheric stability

An example on the temporal variation in the temperature at 100m is given for January 2004 in Figure 7. We note that the modelled follows the measured temperature closely, but the model is slightly biased toward too low temperatures. This could be linked to too low sea surface temperatures of the model, but this issue has not been investigated any further yet. The offset is typically ~ 0.5-1.0ºC.

The temperature differences between 30m and 100m are also given in the figure. We note that the variability in the temperature differences is larger in the observations than in the model. Note also the step like form of the temperature difference which is simple due to the truncation of the data. Most of the time the temperature drop over the 70m is in the range -0.5 ºC to -1.0 ºC, which corresponds to near neutral stability conditions. The relatively warm sea surface in January gives rise to a well mixed near surface boundary layer. Actually, the model tends to give a ~ -0.7 ºC temperature drop over the 70m during long periods corresponding closely to neutral conditions. In the measurements we note a couple of incidents of strong vertical stability, which are not captured by the model. We also encounter a few cases of rather strong vertical instability which is not picked up by the model either. The vertical profiles of temperature are in the model parameterized and thus forced to follow more closely a standard profile. Instantaneous mixing also will take place within the vertical layers in the meso-scale model, thus smoothing out vertical differences to some degree. In addition, any turbulence on a sub-grid horizontal scale (below ~ 2 km) is also parameterized in the numerical model, which in turn will contribute to a smoothing of spatial and temporal differences in the physical quantities.

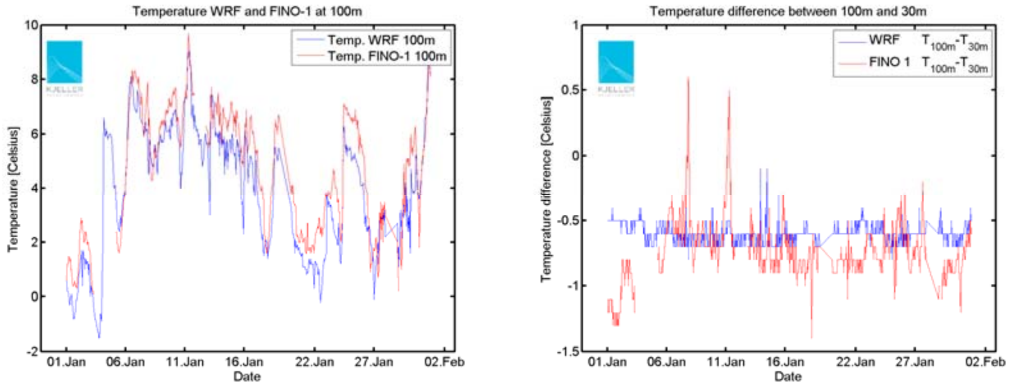

Figure 7. Temporal variation of 100m temperature (left) and temperature difference 100m-30m (right) during January 2004.

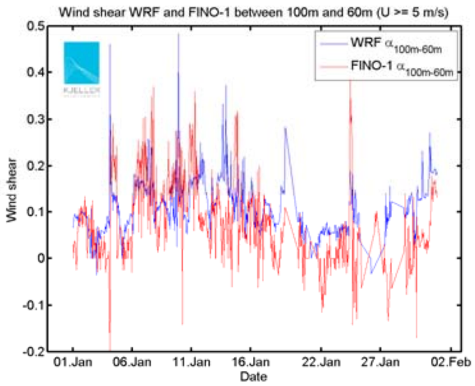

Figure 8. Wind shear coefficient based on the wind speed difference between 100m and 60m during January 2004.

Finally, in Figure 8 the temporal variation in the wind shear coefficient is presented for January 2004. From the figure it is clear that the wind shear was larger in the first half of the month compared to the second half of the month. This trend is also captured by the model. Still, the short term variability in the wind shear is quite much larger in the measurements compared to the model, which partly will be due to the smoothing effects of the numerical model. We also note that during the second half of the month the model has a more pronounced bias in the wind shear which is not the case during the first half of the month. Negative wind shear (higher wind speed at 60m than at 100m) seldom occurs in the model, while it occurs more often in reality as shown from the measurements.

From the above discussion we see that the short term wind- and temperature differences are much more difficult to model correctly compared to the average wind conditions. This may imply that it is more difficult to utilize meso-scale models for accurate wake-modelling since information on vertical wind shear, static stability etc. then are essential parameters. It is therefore recommended to study the statistical behaviour of the model calculations further to increase the knowledge of the capabilities of the model.

4 Average wind conditions at offshore oil rigs

Meteorological measurements, including wind speed and direction, are collected on the oil platforms in the North Sea. A major difficulty with wind data from these installations are the disturbance of the platforms of the local wind field. Such disturbances are difficult to detect unless undisturbed measurements are available in the vicinity. Unfortunately, undisturbed measurements are not available in the Norwegian sector of the North Sea, thus an alternative is to utilize the model for comparison. In the present study we have compared measurements from four oil rigs in the Norwegian sector with data from WRF for a two years period (2005-2006). The WRF-run was carried out with 2 km horizontal resolution for this region as well. The positions of the four rigs are shown in Figure 9.

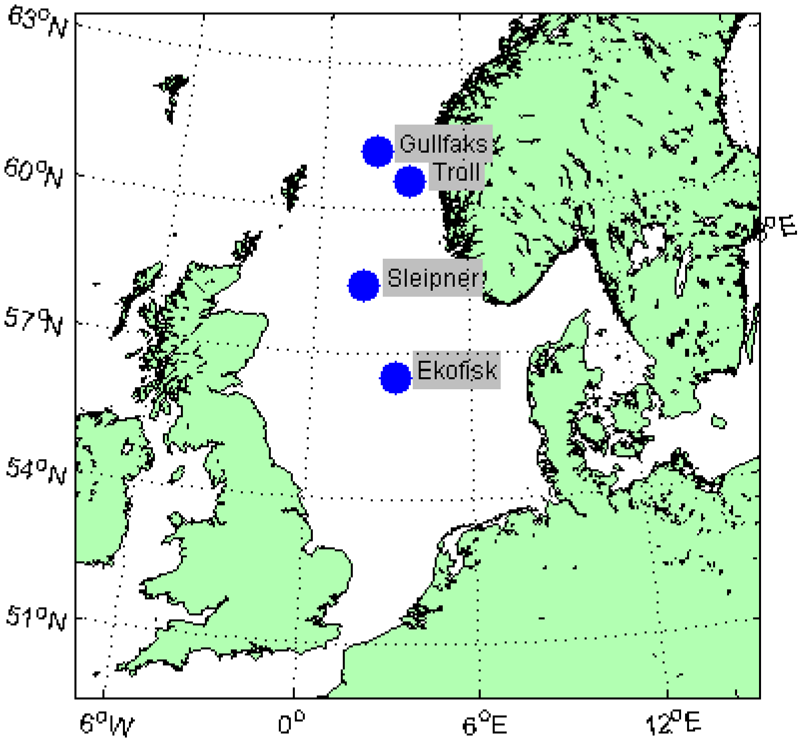

Figure 9. North Sea basin with the position of the Ekofisk, Sleipner, Troll and Gullfaks oil rigs.

This analysis yields higher measured average wind speed of 5-10% compared to the modelled averages for all the four platforms (see Table 2). At Fino 1, where high quality measurements have been collected, only 1% difference is encountered. The data clearly indicate that the rigs give some speed-up of the wind speed, and that this speed-up could be substantial.

Table 2. Average wind shear for the period 2004-2007 at Fino 1.

	Height of measurement (m)	Observed average (m/s)	WRF-average (m/s)	% deviation	Correlation
Gullfaks	143	11.8	10.7	-10%	0.90
Troll	94	10.9	10,4	-5%	0.90
Sleipner	136	11.8	10.7	-10%	0.91
Ekofisk	100	10.9	10.3	-5%	0.91
Fino 1	100	10.0	9.9	-1%	0.92

A wind resource assessment based on the oil rig data could systematically overestimate the energy production potential. With the present strong emphasize on offshore wind development, it is of outmost importance to obtain reliable wind data for the offshore areas, and to have a good knowledge of the different data sources. Focus should therefore be put on further studies on the data quality of both measurements and model data, and to improve the understanding of the different data.

5 Conclusions

Monthly and annual average wind speeds from the WRF model compares very well with the observations. Also the four year Weibull distribution and wind rose from the model correspond well with the observed values. The model is a reliable tool for characterising the average offshore wind conditions, at last in the south eastern part of the North Sea. However, for the temporal variations of vertical stability and wind shear larger deviations between the model and the measurements are encountered, and before the model data are applied to for example wake modelling a more detailed study of the statistical properties of the model data is recommended. Comparison of the average wind speeds of the WRF model with data from four oil rigs in the Norwegian sector of the North Sea indicate that the measurements could overestimate the annual wind speeds with as much as 5-10%. Thus, the oil rig data should be applied with care in wind power studies, unless overestimation of the offshore wind energy potential could result.

6 References

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