Comparison of a Mesoscale Model with FINO Measurements in the German Bight and the Baltic Sea

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Introduction

The measurements conducted at the FINO platforms [1] in the North and the Baltic Sea have revealed that the wind conditions vary spatially significantly and have shown that the inter-annual variation of wind speed cannot be disregarded. The wind resource assessment should therefore be based on a site specific evaluation of the wind conditions. The relative rarity of wind measurements requires the extrapolation of wind speed from the measurement mast to the wind farm position, as in the on-shore projects. Differently from the latter, where roughness and terrain elevation influence the wind speed at micro-scale level, under off-shore conditions the variation of wind speed and wind profile is led by patterns of atmospheric pressure and warm air convection and develop on scales of tens of km [6]. These factors are not adequately described by models used for on-shore flow modeling (e.g. WAsP, CFD), on the contrary these parameters are typically included in the equations governing mesoscale models. Furthermore the mesoscale models can be applied without the use of on-site measurements which are relatively rare under off-shore conditions due to the large installation and operation costs. So, the mesoscale models represent a valuable tool for large off-shore areas.

MM5

MM5 is a numerical weather prediction model developed by the Pennsylvania State University and National Center for Atmospheric Research with the ability to simulate atmospheric conditions with resolutions ranging from 100 to 1 km. MM5 Version 3 (MMV3) is a non-hydrostatic, prognostic model with explicit description of pressure, momentum and temperature. The numerical solution is computed...
onto a rectangular-structured staggered grid by finite difference schemes. The vertical coordinate is terrain-following sigma. The physical package of MM5 consists of a set of parameterization schemes for cumulus, radiation, planetary boundary layer, microphysics and surface processes. A four-dimensional data assimilation scheme is implemented in the model with the capability of nudging the solution towards analysis or observations. A more complete description of the MM5 model can be found in [13]. The development of the MM5 model was stopped in 2008 and the model support was interrupted.

WRF

WRF (Weather Research and Forecasting) is a numerical model jointly developed by several institutions including the National Oceanic and Atmospheric Administration (NOAA) and the National Center for Atmospheric Research (NCAR). Similarly to MM5, WRF is a regional atmospheric model. The WRF model includes now all the features already presented in MM5. It also shares with MM5 part of the pre-processing routines and the physical parameterization. A complete description of the model can be found in [13].

Model setup

The MM5 simulations have been performed with three nested domains with a resolution of 27 km, 9 km and 3 km respectively. 27 terrain following levels were used in the vertical direction from 11 meters up to the upper limit of the atmosphere. 6 of the 27 levels are set in the lower 100 m. Tab. 1 shows the main properties of the applied simulation domains. The physics and the grid of the model have been set up according to previous verification analysis performed at DEWI (refer to [5],[9],[10]). One of the issues arising when performing hind-cast simulations for a period exceeding one week is the possibility for the solution to „drift” away from the observed state of the atmosphere. This means that the model can develop synoptic features that may significantly differ from the situation described by the boundary condition. To reduce this problem, nudging techniques together with the use of many consecutive shorter runs were applied. Hence the simulation has been conducted for the period 2008-01-01 – 2010-12-31 as 122 short runs per year, each spanning 78 hours. A spin-up period of 6 hours has been applied in order to allow the model to develop high resolution features over the inner domain. For the calculation of the wind resource only the last 72 hours of each run have been considered. Also, the model’s solution is nudged towards the analysis in the outer, coarser domain at each time step. The setup applied for the WRF model follows very closely the one used for MM5. In particular, the same initial and boundary conditions, the same number of nested domains, resolution, number of vertical levels, and PBL parameterization was used. Differences of the setup can be found in the use of the microphysics schemes (6-class Graupel scheme used for WRF instead of the simple-ice parameterization used in MM5) and the use of Four Dimensional Data Assimilation (FDDA), which was switched off in the WRF runs.

Measurements

In the frame of the FINO research project three offshore platforms were erected, FINO1 and FINO3 are located in the German Bight in the North Sea and FINO2 in the Baltic Sea [1]. Fig. 1 shows their positions. Whereas the first FINO platform FINO1 measured since 2003, FINO2 and FINO3 became operative in 2007 and 2009, respectively. This comparison with MM5 results is concentrated on the period 2008-2010. Tab. 2 gives an overview of the main data of the
Tab. 1: Properties of the simulation domains

<table>
<thead>
<tr>
<th>Domain ID</th>
<th>Resolution x and y direction</th>
<th>Number of grid points x direction</th>
<th>Number of grid points y direction</th>
<th>Number of grid points z (upward) direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27km</td>
<td>60</td>
<td>60</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>9km</td>
<td>88</td>
<td>88</td>
<td>27</td>
</tr>
<tr>
<td>3</td>
<td>3km</td>
<td>121</td>
<td>133</td>
<td>27</td>
</tr>
</tbody>
</table>

Tab. 2: Main data of the wind measurements used in this comparison

<table>
<thead>
<tr>
<th>Mast</th>
<th>FINO 1</th>
<th>FINO 2</th>
<th>FINO 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geogr. Coordinates WGS84</td>
<td>54°0.86' N 6°35.26' E</td>
<td>55°0.42' N 13°9.25'E</td>
<td>55°11.7' N 7°9.5'E</td>
</tr>
<tr>
<td>Evaluated Measurement period</td>
<td>2008-2010</td>
<td>2008-2010</td>
<td>2010</td>
</tr>
<tr>
<td>Measurement height above LAT</td>
<td>91.5 m</td>
<td>102.5 m</td>
<td>90 m</td>
</tr>
</tbody>
</table>

wind measurements used in this comparison\(^1\). All wind data were averaged to 1 hour time series as the MM5 results were logged with 1-hourly resolution.

Data preparation

For FINO1 the comparison has been performed for the measurement height of 91.5 m above LAT. The measurement of the boom-mounted anemometer at 91.5 m LAT is disturbed by the mast. Not only wind speed reduction downwind and upwind of the mast, but as well lateral acceleration of wind speed is observed. The data have been corrected for the mast effects based on the vanishing vertical wind gradients during very unstable situations, thus enabling a “uniform ambient flow mast correction scheme” (UAM-scheme) \( [3] \). Since 2009-08-12 the first wind turbines of the adjacent wind farm alpha ventus are in operation. At eastern wind directions the wind measurements at FINO1 are disturbed by the wind farm. The undisturbed wind data from east directions have been reconstructed with the use of CFD simulations \( [9] \).

At FINO3 at 90 m above LAT there are three anemometers installed at the same measurement height. A combined data set has been created with the data set from the three booms, choosing the data from the boom perpendicular to the wind direction ±30°. No further mast correction has been applied on the data. The applied procedure is valid under the assumption that there is no lateral acceleration effect on the wind data when the wind direction is almost perpendicular to the boom orientation. It cannot be excluded that the wind data slightly overpredict the actual wind speed, but this effect cannot be removed so far. Later comparison with LiDAR measurements or CFD calculations might resolve this issue.

FINO2 data of the top-mounted anemometer at 102.5 m LAT has been used. No mast correction has been applied. A minor acceleration effect over the top of the mast cannot be ruled out, therefore there might be a slight overprediction of the wind speed.

The measurement data from FINO2 and FINO3 have been provided from recent energy yield assessments performed by DEWI. Apart from the above described data processing, data gaps are filled by correlation with data from another height level (FINO1) or filled with a correction function from another anemometer from the same height level (FINO3).

Comparison Results

MM5 – FINO comparison

The measured data and MM5 results were compared year by year. Tab. 3 shows an overview of the comparison results. Fig. 2 to Fig. 4 show the measured and modeled Weibull distributions and wind roses. Fig. 5 shows a scatter plot of MM5 and FINO1 wind speed data. The comparison shows high agreement for the MM5 results in the German Bight for FINO1 and FINO3. The bias is about 0.1 m/s corresponding to 1% in wind speed. The correlation is quite high with \( R^2=75\% \) to \( R^2=82\% \).

With respect to FINO2, the agreement regarding the wind speed distribution is lower. The MM5 results underpredict the measured wind speed about 4-5%. A similar underprediction of wind speed of FINO2 by a mesoscale model was reported by Peña \( [10] \).

The wind direction distributions show satisfying coincidence of measured and modeled data for all three sites.
In 2010 the wind direction distribution at FINO1 has shown a different pattern compared to the other years with highest frequency in the NW sector and not a SW predominant wind direction. At FINO3 the NW sector is even more pronounced. Even though FINO1 and FINO3 are located in only about 140 km distance, the wind direction distribution in 2010 differed distinctively. However, during a longer period, 2008-2010, the MM5 simulations show much less differences in the wind direction distribution between FINO1 and FINO3. Tab. 3 provides an overview of the comparison MM5-FINO platforms.

**WRF – MM5 comparison**
The inter-comparison of WRF and MM5 results with observations at 90 m at FINO1 and FINO3 platforms is outlined in Tab. 4. The comparison refers to the simulation period 2010-01-01 - 2010-04-30. The results suggest that WRF was able to be more precise in the predicted mean wind speed at FINO1, but less precise at FINO3. In general WRF results seem to slightly overestimate the wind speed at the considered height. The correlation coefficient and the RMSE have also been worse than those from MM5 model. The analysis of the time
series generated by the two models (not included here) has shown that WRF depicts a more detailed solution and less smooth evolution of the wind speed. These results indicate that further investigation should be done in order to improve the settings used for the WRF model configuration.

Conclusions

The study represents a systematic comparison of the MM5 model for different offshore locations and a first attempt to inter-compare the WRF and MM5 models with the FINO data. The following conclusions can be derived:

- The MM5 model is a valuable tool for the determination of the offshore wind conditions. The deviation from the measurements of the annual mean wind speed for the two North Sea platforms is equal or lower than the anemometry uncertainty.
- Over the North Sea the results of the comparison showed to be independent from the location and from the simulation year. The comparison resulted in an almost constant high agreement.
On FINO2 a stronger underestimation of mean wind speed was found. The correlation scores and the RMSE are, on the contrary, similar to those found for the North Sea. With the applied configuration the WRF model did not perform as good as MM5. A further optimization of the WRF setup is therefore required.

References:


Tab. 3: Overview of the comparison results for the MM5 model.

Tab. 4: Overview of the inter-comparison WRF, MM5 and FINO observations.