

Validation of Mesoscale Simulations for Offshore Sites

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Abstract

The MM5 mesoscale numerical weather prediction (NWP) model is applied to simulate wind conditions over the North Sea and over the coastal area of western Germany. Results are analysed and compared with measurements recorded at the offshore FINO Platform where wind speed and further meteorological parameters are measured up to 100 m height. The simulations are initialised and driven by real initial and boundary conditions provided by NCEP analysis at 1° horizontal resolution using a refinement to 3 km² with three two-way nesting steps. The aim of the present study is the investigation of the capabilities of the MM5 model to properly simulate the wind flow and atmospheric stability conditions occurring over the Marine Boundary Layer. An inter-comparison between observation, MM5 wind profiles and results produced by the WAsP model has been done in order to assess the ability of these two models to reproduce the effect of the atmospheric stability on wind profile.

1. Introduction

Mesoscale atmospheric models are increasingly considered for the determination of the wind resources for wind energy assessment and forecast. While the scale of this model class is quite large and too rough for some wind energy relevant questions (such as site assessment on complex terrain), the advantage of these models relies on the ability to simulate the atmosphere including important atmospheric properties like atmospheric energy balance and stability. For many wind energy relevant questions and especially for assessment of offshore wind conditions this is of great importance, as those effects are important factors affecting wind speed in the lower Boundary Layer. The use of any model for wind energy applications requires a proper validation process to understand the accuracy of the model and address possible uses of the model itself. Normally numerical weather prediction (NWP) models are validated during the developing phase with the use of standard ground observation (e.g. wind speed at 10 meters, temperature at 2 meters) or taking as reference vertical soundings of the whole PBL obtained with SODAR or meteorological balloons, measurements typically affected by coarse resolution and low accuracy. For these reasons, high quality information about the response of the model at heights of interest for wind energy application is generally poor. The present work tries to fill, for some aspects, this lack. The attention of this study has been focused on the capability of the MM5 model to reproduce stability effects on wind profile over Marine Boundary Layer. The simulations have been compared with high quality observation recorded at the FINO offshore research platform, sited 45 kilometers offshore from Borkum in the North Sea. The availability of high quality data of wind speed at height up to 100 meters as well as the presence of measurements of air and sea temperature represent an almost unique opportunity to investigate the accuracy over the sea of the surface and PBL parameterization presently implemented in MM5. The following section outlines the main features of the MM5 model. Section 3 describes the observational dataset used for the analysis of the

atmospheric situation and for the validation of the MM5 results, Section 4 reports information about the MM5 configuration. Results from the MM5 model and consideration concerning WAsP model are described in Section 5 and Section 6 respectively. Conclusions follow in Section 7.

2. Model description

MM5 is a numerical weather prediction model developed by the Pennsylvania State University (PSU) and by the National Center for Atmospheric Research (NCAR, Boulder, USA) with the ability to simulate the atmospheric conditions with a grid resolution ranging from 100 km to less than 1 km. Version 3 of MM5 (presently version 3.6) is a non-hydrostatic prognostic model with explicit description of pressure, momentum and temperature. One of the most interesting features of MM5 modelling system is the possibility to select different physical parameterization schemes and the presence of a set of preprocessing and post processing programs that make it easier, as an example, to spatially interpolate terrestrial and meteorological datasets to the model grid or to assimilate meteorological observations into the simulation. MM5 is able to run on a wide range of computer platforms even with parallelization on distributed or shared memory machines. An in-depth description of the numerics, dynamics and physics of the MM5 model can be found in [1].

3. Observational dataset: FINO measurements

Wind speed data measured at the FINO platform were used for the validation. The FINO platform is equipped with a 100 m mast supporting sensors for the main meteorological variables. Wind speed is measured at different heights starting from 30 m up to 100 m with both cup and sonic calibrated anemometers. The list of data used for the analysis of the meteorological situation and for the comparison with the model is reported in Tab. 1. A full description of the FINO measurement system can be found in [2]. A first approach to assess atmospheric stability based on the calculation of the Bulk Richardson number from measurements of air temperature at different heights presented some problems and, generally, was not usable for

a proper determination of stability. Alternatively, an analysis of the relationship between the wind gradient and the differences between sea surface temperature (SST) and air temperature was performed. Results show a quasi-linear dependence of the ratio between wind speed at 70 m and wind speed at 40 m (v_{70}/v_{40}) for temperature differences between -4 and 2 and a constant ratio v_{70}/v_{40} for larger temperature differences, where the lower BL is supposed to be completely well mixed (see Fig. 1). From these considerations it is possible to assume that the difference in sea and air temperature is a main (even if not the only) factor affecting atmospheric stability and eventually wind profile. To understand the capabilities of MM5 to reproduce the effect of heat and momentum fluxes on the wind profile, we decide to simulate two different periods with different stability conditions. The first is a three-day unstable period spanning from the 27th October 2003 through 30th October 2003 (see Fig. 2). The second is a four day stable period spanning from the 14th March 2004 through 18th March 2004 (see Fig. 3). Conditions within these two periods are quasi-stationary both concerning the atmospheric stability and with respect to the angle of wind direction. Special attention was paid in order to choose periods with main wind direction coming from the south-west sector for which the influence of the mast on the measurements is proved to be minimum.

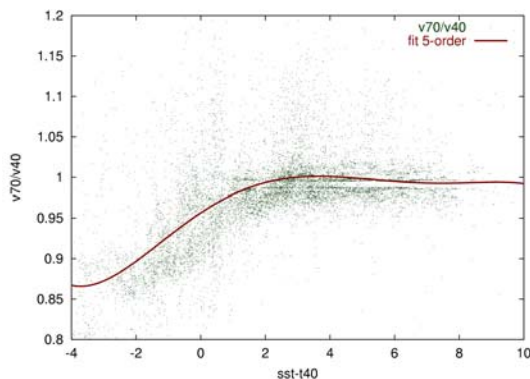


Fig. 1 - Scatter plot showing the relationship between the ratio v_{70}/v_{40} and the difference between sea and air temperature at 40 m.

variable	Heights [m]
Wind speed (CUP-A)	30,40,50,60,70,80,90,100
Air temperature	60
Wind direction (US-A)	60
Sea temperature	-3

Tab. 1 - Measurements at FINO used for the analysis of the meteorological situation and for model validation.

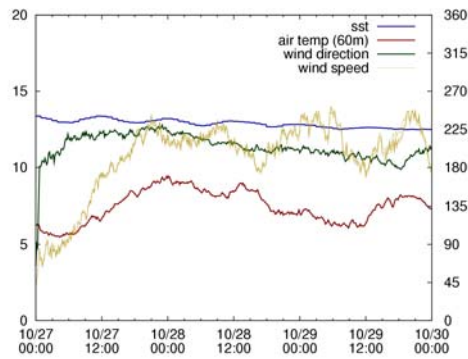


Fig. 2 - Time series of SST (blue line) and air (red line) temperature, wind speed (yellow line) and wind direction (black line) measured at FINO for the period 27th October 2003 - 30th October 2003.

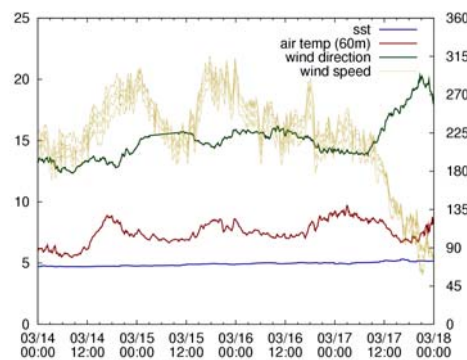


Fig. 3 - Time series of SST (blue line) and air (red line) temperature, wind speed (yellow line) and wind direction (black line) measured at FINO for the period 14th March 2004 - 18th March 2004

4. Model configuration

The MM5 model has been run over three nested domains coupled with a two way nesting interaction between the parent and the nested domain. The simulation domains have grid distance (from the outer to the inner) of 30 km, 10 km, 3.3 km. 39 sigma levels are used in the vertical direction. NCEP FNL analysis provide the simulation with the necessary initial and boundary conditions. The full list of physics schemes used to parameterize the sub-grid processes is reported in Tab. 2.

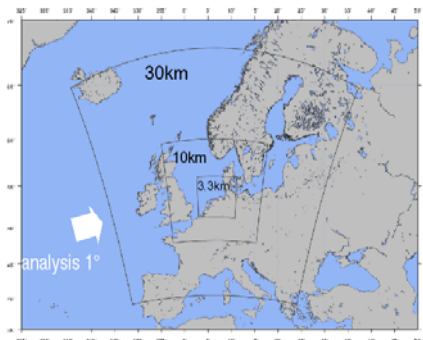


Fig. 4 - Representation of the simulation domains.

Physical process	Scheme
Radiation	Cloud Radiation
Cumulus	Grell
Explicit cumulus	Dudhia
Surface Scheme	NOAH land surface model
Planetary Boundary Layer	Mellor – Yamada – Janijc (ETA)

Tab. 2 - List of the schemes used to parameterize the sub-grid processes.

5. Results

The output of wind field of the third, hi-resolution domain has been vertically and horizontally interpolated to get values of wind speed at the position of the anemometers. A mean wind vertical profile has been calculated for both periods and compared with measured profile. Results show a very good agreement between simulated and measured profile for the unstable period. MM5 was able, under these conditions, to reproduce both the wind gradient and the absolute values of wind speed, with a bias at 90 and 100 m equal to 0.13 m/s corresponding to a relative error of about 1%. The simulation relative to the stable period shows overall worse results. Even if the absolute value of wind speed at the lower level (30m) seems to be properly described, MM5 underestimate both the wind gradient and the absolute value of wind speed for higher heights. This outcome confirms the fact that the stable boundary layer is generally less easily modelled by the present turbulence schemes. The time series (not shown) of wind speed present similar results for both the unstable and the stable period, with a RMSE near 1.9 m/s at 90 m and 100 m.

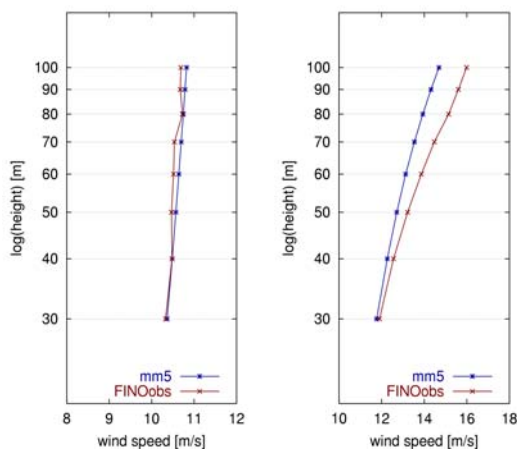


Fig. 5 - MM5 simulated and observed mean vertical wind profile for the unstable (left graph) and the stable (right graph) period.

6. WAsP MM5 inter-comparison

In order to assess the usability of results described above for wind energy applications and to get an impression about the accuracy of models currently used for wind resource assessment, we decided to simulate the mean wind profile for the same

periods mentioned in the previous sections with the Wind Atlas and Application Program (WAsP). A full description of the WAsP model can be found in [3]. A direct comparison of results of MM5 and WAsP present some difficulties for the following reasons:

- 1) WAsP is a diagnostic model that takes a climatological description at one point (typically from long term measurements) and is able to extrapolate climatology on a surrounding area, simulating the effects of roughness length changes and the presence of obstacles.
- 2) MM5 is a prognostic model that, provided initial and boundary conditions, integrates further in time the equation describing the dynamic and the thermodynamic of the atmosphere. The use of measurements to improve the simulations is allowed, but not required.

The aforementioned considerations pushed us to limit the comparison only on the capabilities of these two models to simulate stability effects, avoiding any consideration regarding the absolute values of wind speed that would be necessarily misled by the use of measurements in WAsP. To perform the comparison we provided WAsP with the wind distribution of wind speed of the site calculated from the 100 m anemometer of the FINO platform together with a statistical description of the heat fluxes at the surface. WAsP wind profiles are then scaled so that calculated wind speed fits FINO measurements at 100 meters. Measured wind profile, and profiles calculated by WAsP and MM5 model are reported in Fig. 6. An analysis of these results show that, under unstable conditions, WAsP simulated an higher wind shear in comparison to both MM5 and to measurements. For stable conditions WAsP and MM5 present similar wind gradients, being the measured wind shear underestimated by both models. Nevertheless WAsP profile seems to be limited by a logarithmic gradient while MM5 better simulate stability effects for higher heights. Furthermore the WAsP wind profiles show similar wind shear for the two period. This model seems to be, therefore, generally less sensible to the input of different heat fluxes and, consequently, less accurate to describe different stability conditions.

7. Conclusions

From the results outlined in the previous sections the following considerations can be derived:

- MM5 is able to properly simulate wind gradient for well mixed unstable atmospheric conditions.
- For unstable conditions the absolute values of mean wind speed are predicted with high accuracy.
- MM5 has a “slow” bias and underestimates the wind gradient under stable conditions.
- Deviations from the observed wind profile under stable conditions start at 40m and become constant at 80m
- A comparison of profiles calculated by MM5 and WAsP model suggests that MM5 shows better results concerning the simulation of the atmospheric stability effects.

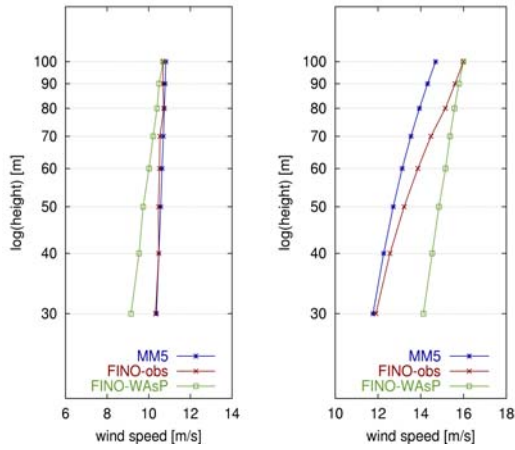


Fig. 6 - MM5, WAsP and observed mean vertical wind profile for the unstable (left graph) and the stable (right graph) period.

Acknowledgements

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References

- [1] G. Grell, J. Dudhia, D. Stauffer – A description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5) – TN-398+STR
- [2] T. Neumann – One Year Operation of the First Offshore Wind Research Platform in the German Bight – FINO1 - DEWEK 2004
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