A comparison of MM5 and meteo mast wind profiles at Cabauw, The Netherlands and Wilhelmshaven, Germany

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Abstract

The model MM5, developed at Pennsylvania State University / NCAR, was used to study wind regimes at Cabauw, The Netherlands and Wilhelmshaven, Germany. The main goal was to model wind profiles in the lower Boundary Layer, and to compare results with measured profiles. For Cabauw, The Netherlands, a study for the period of 2nd - 22nd April 1993 has been conducted with 4 two-way nests up to 1x1km horizontal resolution and 25 vertical levels, of which four below 200 meter. Initialisation was made with 2.5°x2.5° NCAR/NCEP - reanalysis data. The wind profiles were calculated using Blackadar, ETA and MRF PBL numerical schemes of MM5. Additionally for these PBL-schemes time series of wind speed have also been investigated. The time series of measured wind speed were very similar to the MM5 output. The 21 day-averaged vertical wind profiles at the three different PBL-schemes were also similar to the wind profiles calculated from measurements. A second set of simulations of wind regime have been conducted over Wilhelmshaven, Germany for the period 22nd-28th December 2003. Simulated profiles have been compared to wind measurements recorded by a 130 m meteorological mast. The MM5 two way nesting capabilities have been used in order to get a horizontal resolution of 1 km at the final domain, 31 sigma levels are used in the vertical direction. NCEP-FNL analysis provide the simulation with the necessary initial and boundary conditions. The PBL schemes under study have been MRF, Blackader, ETA Mellor-Yamada-Janjic, Burk-Thompson, and Gayno-Seaman PBL schemes. Results show noticeable influence of PBL parameterization on simulated wind profile. The run conducted according to ETA PBL scheme seems to produce a mean wind profile with the best agreement with measured data. A simple sensitivity study reveals that horizontal resolution plays, on these terrain conditions, a minor role with respect to parameterization for the simulation of wind on the lower PBL.

1. Introduction

Wind energy applications traditionally require long term series of wind observations to properly plan and forecast position, features and energy yield associated to a given turbine. For wind energy projects planned on flat terrain, short term (1-2 years) wind measurement are normally used to describe wind speed and direction on the site of interest. If long term observations (10 years or more) are available for a location not so distant from the prediction site, short term observations can be correlated with long term data to reduce the influence of inter-annual variations. The implicit assumption underlying the use of correlation methods is that the prediction site and reference site belong to the same micro-climatic area. This condition easily occurs for flat coastal areas where, indeed, nearly the totality of wind installations are based on direct measurement and correlation methods (Gerdens and Strack 1999). The more the features of terrain gain in complexity, the less the information provided by methods based on correlation are reliable. An alternative solution to obtain information on wind flowing over a complex orography (or where the availability of observations is poor, such as in off shore regions) is represented by the use of *numerical models*. Presently, different typologies of numerical models are being adopted for wind energy assessment. Most of them have been initially developed for purposes marginally related to wind energy applications. With computational resources presently available, the use of numerical weather prediction (NWP) models is also possible for long term wind simulations. These models, can be applied on a resolution (1-3 km) relevant for wind resource assessment. MM5 is a numerical weather prediction model developed by the Pennsylvania State University and National Center for Atmospheric Research with the ability to simulate the atmospheric conditions with resolution ranging from 100 km to 1 km. Version 3 of MM5 (presently version 3.6) is a non-hydrostatic prognostic model with explicit description of pressure, momentum and temperature. A more complete description of the MM5 model can be found in Grell et al., 1994. Several studies (e.g. Brawn and Tao, 2000, Zhang and Zheng, 2003) enlightened the influence of the MM5 PBL parameterization on the simulated wind conditions in the PBL. These studies focus on the performance of the model with respect either to surface wind speed (through verification against standard 10 m observations) or to deep soundings of the whole PBL. Attention to the output of the model in the lower PBL (which is of main interest in wind energy applications) has been up to now scarce. An attempt to review the formulation of the existing PBL schemes presently implemented in MM5 is given by ATMET 2003. Their study mainly focus on the capabilities of each scheme to reproduce the diurnal wind speed cycle using surface observations as reference. No information about the ability of the model to simulate wind in the lower surface layer is provided in this work. The aforementioned considerations motivated us to further investigate the influence of the PBL parameterization on simulated wind profiles with the use of high-accuracy wind observations recorded by two different meteorological masts. Since the relative little knowledge presently available on this topic, it seemed reasonable to perform the verification under simple conditions. For these reasons, simulations are verified against observations taken at sites with flat and relatively homogeneous terrain. Two set of simulations have been carried out. One set of runs is conducted over Cabauw. The second set of simulation has been performed over Wilhlemshaven in the north-west Germany. Results, in this case, are compared with a 130 m meteorological mast. Next section provides a description of the model configuration used for simulations at Cabauw and outlines the observational dataset used for the verification, section 3 describes the outcomes from the simulations at Cabauw and presents results of the comparison with observational data. Section 4 and 5 have the same function of Section 2 and 3: in the case model configuration, observational dataset and model results refer to the simulation conducted over Wilhelmshaven. Conclusion and discussion of results are given in the final section.

2. Model configuration and observational data at Cabauw

a) Model configuration

A first case study was performed in Cabauw - The Netherlands, using 5 domains with 4 two-way nests with a resolution of the 4th nest of 1.1 km, creating output at every 6 hours for a period of 21 days. MM5 was initialised with NCEP/NCAR reanalysis data. NCEP/NCAR reanalysis are available at a resolution of 2.5°x2.5° every 6 hours. The model was run at 25 levels with four levels below 200 m altitude: 40, 80, 140 and 200 m. The model top was fixed at 100 hPa. The runs were made for 2-4, 22-4, 1993. The run has been conducted according the physics reported in Tab. 1.

b) Observational database

Cabauw meteorological mast is located in the middle of The Netherlands near Utrecht and is operated by the Royal Netherlands Meteorological Institute (KNMI). The surroundings are flat and dominated by grassland with some small rivers. The met mast is 200 m high. For each wind speed measurement in 10, 20, 40, 80,140 and 200 m three booms are installed to minimize the shadow effects by the mast. A closer description of the mast and the surroundings can be found in Beljaars and Bosveld 1997. The wind speed measurements are post processed as described in Wessels 1987. The wind speed data at 40, 80, 140 and 200 m were used to verify the MM5 run. The lower levels were not considered, since MM5 was expected to be very inaccurate in this region. The data of the Cabauw mast were plotted in comparison to the model results (3 hourly).

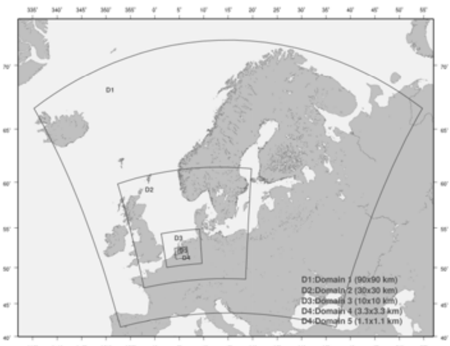

Fig. 1 - Representation of areas covered by each simulation domain in Cabauw. The coarse Domain (D1 in the figure) has grid distance of 30 km. Domain 2 (D2), Domain 3 (D3), Domain 4 (D4), Domain 5 (D5) have grid distance of 30 km, 10 km, 3.3 km, 1.1 km respectively.

Physical Process	***Scheme***
Radiation	Cloud Radiation
Cumulus	Grell
Explicit Cumulus	Dudhia
Surface Scheme	Five-Layer Soil Model

Tab. 1 - List of the physics option used for the simulations over Cabauw.

3. Results at Cabauw

The results of the Cabauw simulation show that wind speed is reasonably described by the MM5 model. The visual investigation of the time series of the simulation in Fig.2 shows a good agreement with the measurements. However, during the simulation time speed ups with an extension lower then 12 hours occurs (2.4., 9.4, 11.4., 21.4.) which are not captured by the simulation. That leads to the explanation that these speed ups are caused by synoptic weather instead of the local surface boundary conditions. So the input data of approx. 250 x 250 km is too coarse. The comparison of the simulations based on different PBL-schemes shows no crucial visual difference if we compare only one height. Observing vertical mean profiles for the whole time period we can investigate a different shape. The simulations based on the MRF and ETA scheme represents the gradient quite well meanwhile the use of the BLK scheme underestimates the gradient up to 80 m significantly.

	Index	***40m***	***80m***	***140m***	***200m***
BLK	RMSE (m/s) BIAS (m/s)	1.95 0.07	2.31 0.47	2.72 - 0.62	2.94 - 0.59
ETA	RMSE (m/s) BIAS (m/s)	1.97 0.07	2.44 - 0.14	2.97 - 0.10	3.18 0.09
MRF	RMSE (m/s) BIAS (m/s)	1.94 0.07	2.47 - 0.06	2.96 - 0.19	3.10 - 0.29

Tab. 2 - Root Mean Squared Error and Bias for the considered PBL schemes for simulation in Cabauw.

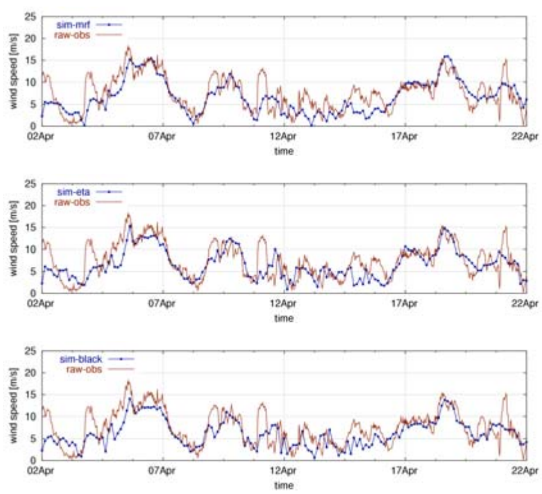

Fig. 2 - Time series of the observed and simulated wind speed at 140 m for Cabauw. Figures refer to simulations using MRF (top), ETA (middle) and Blackadar (bottom) PBL schemes.

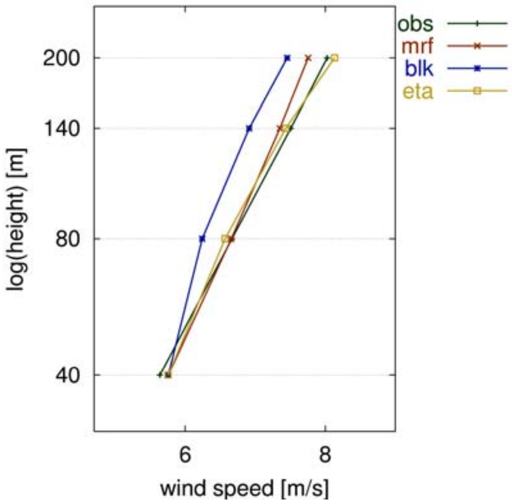

Fig. 3 - Mean observed and simulated vertical wind profile at Cabauw.

4. Model configuration and observational data at Wilhelmshaven

a) Meteorological situation

The second set of simulations have been performed for the period 22nd-28th December 2003. This period was characterized by a low pressure slowly moving from the Scandinavian Peninsula towards Central Europe. Wind at 850 mb is steadily south-westerly for the whole period, with maximum speeds of 40 m/s. NCEP FNL analysis showed high cloud cover over the region of interest (northern Germany) during the period under concern. This meteorological situation has been favourable to the presence of near-neutral atmospheric stability conditions. A time series of the Bulk Richardson number (Ri_b, not shown) has been calculated on the base temperature, wind speed and pressure measured at the meteorological mast in Wilhlemshaven. Ri_b was greater than 0 and below 0.25 (neutral conditions) for most of the simulated period.

b) Model configuration

In order to investigate the influence of parameterization on the simulation of the near-neutral wind profile, five different simulations have been performed using the following PBL schemes: Hong-Pan (MRF), Blackader (BLK), Mellor-Yamada-Janjic (ETA), Burk-Thomphson (B-T), Gayno-Seaman (G-S). The other physics options, which have been kept as fixed as possible for all the simulations, are reported in Tab. 3. NCEP FNL analysis with 1° resolution provide the simulation with the initial and boundary conditions. 31 sigma levels are used in the vertical direction with nine layers in the lowest 130 m. The model top is fixed at 10 hPa. The simulation has been performed on four nested domains (as shown in Fig. 4) using a two-way interaction between the parent domain and the nested domain. The grid distance over the final domain is 1 km. When possible[1] 4DDA is used to nudge the coarse domain towards the analysis and the NOAH land surface model (NOAH LSM) is used to provide lower boundary conditions.

1 - With the current implementation of MM5 it almost impossible to use the same configuration for all the simulations. One PBL scheme (B-T) cannot be used with 4DDA, some others (G-S, BLK) do not work with the NOAH LSM

c) Observational dataset

The observational data used for the assessment of stability and for the verification of the model are taken at a 130 m meteorological mast equipped with five cup-anemometers (at 32 m, 62 m, 92 m, 126 m, 130 m) and two thermometers (at 2.5 and 90 m). Wind speed measurements are post-processed in order to correct the effect caused by the structure of the tower. An earlier study (M. Strack 1999) enlightened the influence of the surrounding wind turbines and of the non-homogeneous roughness length on the wind profile and turbulence intensity registered at the anemometers. Furthermore he identified the south and south-west sectors as relatively undisturbed. These issues should do not affect the comparison since the wind was mostly southerly, south-westerly for the almost the complete period of the simulation.

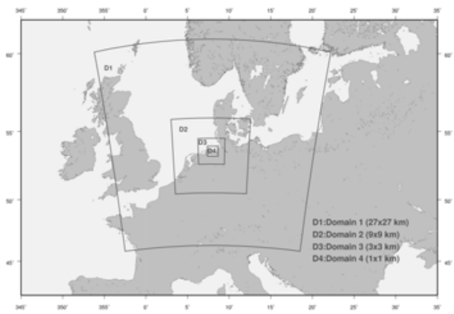

Fig. 4 - Representation of areas covered by each simulation domain in Wilhelmshaven. The coarse Domain (D1 in the Figure) has grid distance of 27 km. Domain 2 (D2), Domain 3 (D3), Domain 4 (D4) have grid distance of 9 km, 3 km, 1 km respectively.

Physical Process	***Scheme***
Radiation	Cloud Radiation
Cumulus	Grell
Explicit Cumulus	Dudhia
Surface Scheme	Depending on PBL scheme

Tab. 3 - List of the physics option used for the simulations over Wilhelmshaven.

5. Results at Wilhelmshaven

A visual investigation of the time series of the simulated and observed wind speed reveal significant differences between the five simulations according to the used PBL parameterization. Fig. 5 shows results for the period from 22nd December to 28th December. From this figures it is possible to detect a phase error that affect three PBL schemes (BLK, G-S, BRK) in predicting the slow down that occurred on the 22nd December at 21 UTC. All the mentioned schemes seems to predict the slow down about two hours in advance. This error was not present for ETA and only slightly visible for MRF. Observing the complete time series and referring to the statistical indexes reported in Tab. 4, it is possible to state that ETA and BLK better fit the measurements, with MRF presenting the largest (fast) error. The average simulated wind profiles, presented in Fig. 6, show a general overestimation with respect to the observed profile. Wind profile simulated by BLK has a good agreement with observation at 62 m but it presents a low vertical gradient compared with the observed profile. The vertical gradient seems to be better reproduced by ETA and BRK schemes (that have a very similar formulation) but they are affected by a “fast” bias. In order to get an impression on how resolution affects the accuracy of the simulations, two further runs have been performed with the ETA PBL parameterization at 2 and 3.3km resolution. An analysis of the time series (see Fig. 5.d) and of the relative statistical indices (not shown) revels that, under these conditions, a decrease in resolution from 1 to 3 km do not degrade significantly the score of the verification.

	Index	32m	62m	92m	126m	130m
BLK	RMSE (m/s)	1.60	1.74	1.89	2.14 -	2.18 -
	BIAS (m/s)	0.55	0.04	0.39	0.78	1.00
BRK	RMSE (m/s)	1.92	2.15	2.20	2.22	2.13
	BIAS (m/s)	1.04	1.00	0.80	0.58	0.38
ETA	RMSE (m/s)	1.64	1.92	2.02	2.12	2.00
	BIAS (m/s)	0.82	0.94	0.81	0.64	0.44
G-S	RMSE (m/s)	2.46	2.71	2.70	2.71	2.55
	BIAS (m/s)	1.85	1.93	1.72	1.43	1.21
MRF	RMSE (m/s)	3.63	4.69	4.88	4.85	4.62
	BIAS (m/s)	3.22	4.16	4.23	4.01	3.77

Tab. 4 - Root Mean Squared Error and Bias for the considered PBL schemes for simulation in Wilhelmshaven.

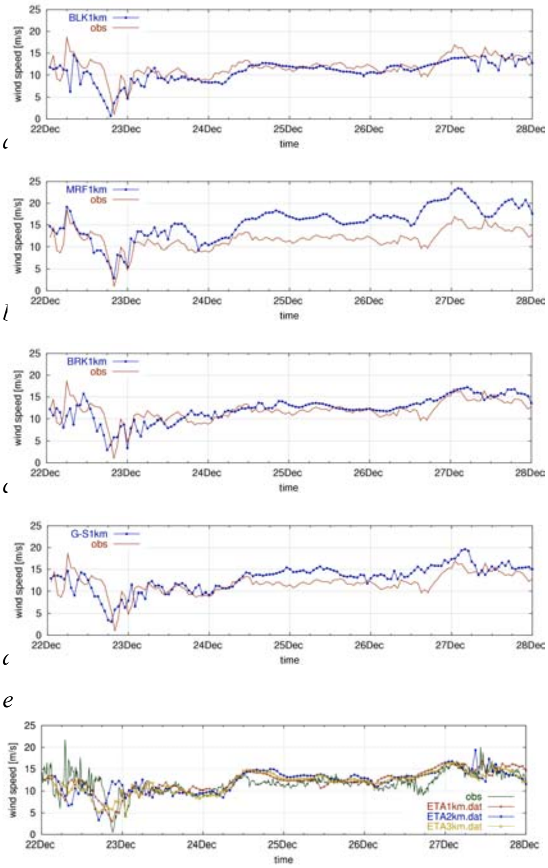

Fig. 5 - Time series of the observed and simulated wind speed in Wilhemlshaven. values refer to wind speed at 130 m for the period 00 UTC 22[nd] December - 00 UTC 28[th] December. Fig 4.a, 4.b, 4.c, 4.d, present times series for Blackader, MRF, Burk-Thompson and Gayno-Seaman respectively. Fig. 4.e presents results obtained using ETA PBL scheme with gird space of 1km, 2km, 3.3km.

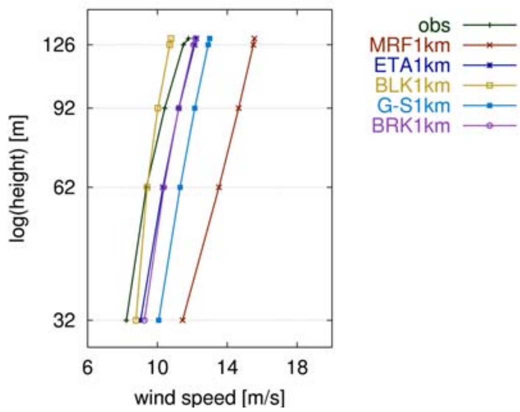

Fig. 6 - Mean observed and simulated vertical wind pro le at Wilhelmshaven.

6. Summary

Results presented in the previous sections can be summarized as follows:

1) the PBL parameterization affects significantly simulated wind conditions.
2) the influence of parameterization was visible both on the wind speed time series evolution and (even more clearly) on the mean wind gradient.
3) the observed wind evolution present time variability (e.g. speed ups) that seem not be correctly reproduced by the simulation. These errors are probably associated to large synoptic situation which is described with sufficient resolution in the boundary conditions. The fact that those errors more visible for the simulations performed with 2.5° degree resolution suggests us that the problem do not relies on MM5 (and its parameterization) but on a too temporally and spatially coarse BCs.
4) The analysis of wind profile indicates a general overestimation of wind speed of all PBL schemes with respect to the observation for Wilhelmshaven. For Cabauw an overall underestimation of measured wind profile is visible.
5) The analysis of wind profile indicates that wind vertical gradient is properly described by the ETA (BRK presents similar results). BLK scheme show in all the experiments a too low wind shear.
6) Changes in resolution from 1 to 3 km produce no significant differences regarding the accuracy of the simulation.

Acknowledgements

We like to thank the KNMI for providing data for Cabauw. This work was partly founded by the EU (Network WindEng: Wind Energy Assessment and Wind Engineering).

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