Comparison of wind speeds simulated with WRF using seven planetary boundary layer schemes at two offshore met masts in the North Sea

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Introduction

Offshore wind simulations using a mesoscale model, Weather Research and Forecasting (WRF) were carried out. In order to find the optimum setup for offshore wind resource assessments with WRF, **annual simulations using 10 different Planetary Boundary Layer (PBL) schemes** were performed. The accuracies were examined by comparing the simulated winds with in situ observations at the two offshore met masts of FINO1 and the Offshore Wind farm Egmond aan Zee (OWEZ) in the North Sea. In addition to the accuracy verifications for each PBL scheme, an attempt was made to improve the accuracy by using **a multi parameterization ensemble technique**.

Methods

The WRF settings which are identical in all simulations are listed in Table 1. The simulation domains and locations of FINO1 and OWEZ, which are 45 and 17 km away from the nearest coastlines, are also displayed in Fig. 1. The PBL schemes and their associated surface layer schemes are summarized in Table 2. The observations, which the mast shadow effects were corrected, were employed for the accuracy verifications.

Table 1 WRF settings

Version	WRF ARW version 3.5.1
Period	January to December 2006
Input data	NCEP FNL (1° x 1°, 6-hourly) OSTIA SST (0.05° x 0.05°, daily)
Domain	D01: 18 km (100 x 100 grids) D02: 6 km (151 x 151 grids) D03: 2 km (151 x 151 grids)
Vertical layer	40 layers (surface to 50 hPa)
Nesting option	2 way nesting
Physics options	Dudhia short wave radiation RRTM long wave radiation Betts-Miller-Janjic cumulus parameterization (D01 and D02) WSM 6-class graupel scheme Noah land surface model
4DDA	Enable (D01 and D02)

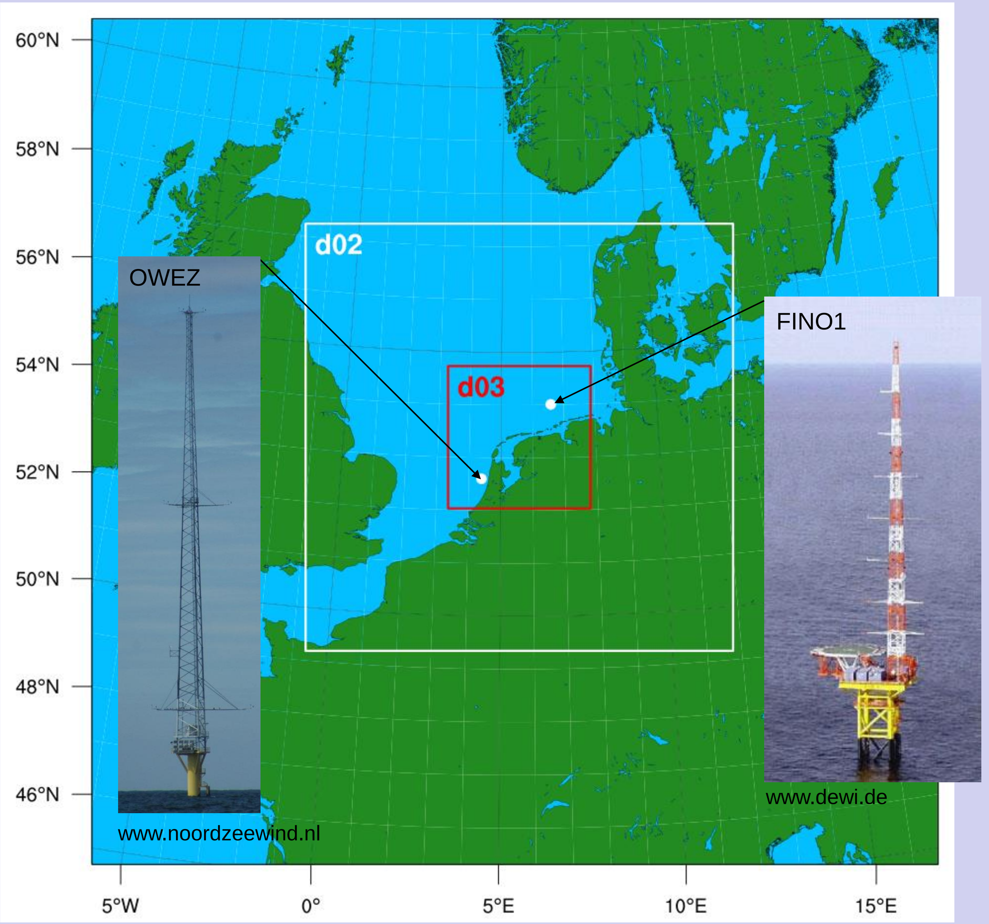

Fig. 1 Domains used in the simulations and the met mast locations

Table 2 Descriptions of the PBL schemes and the associated surface layer schemes

No.	PBL schem	Surface layer scheme	Turbulence closure model	Closure order	Prognostic variables
1	YSU	MM5 similarity	K theory with a counter-gradient term	1	–
2	MYJ	Eta similarity	Mellor-Yamada Level 2.5 model	1.5	TKE
3	QNSE	QNSE	k-ε model	1.5	TKE
4	MYNN2	MYNN	Mellor-Yamada Level 2.5 model	1.5	TKE
5	MYNN3	MYNN	Mellor-Yamada Level 3 model	2	TKE and Potential–temperature variacne
6	ACM2	Pleim-Xiu	Combined non-local and local mixing model	1	–
7	UW	MM5 similarity	Mellor-Yamada Level 2.5 model	1.5	TKE
8	TEMF	TEMF	Total turbulent energy mass flux closure (Level 2.5 scheme)	1.5	Ttotal energy mass flux
9	GBM	MM5 similarity	Mellor-Yamada Level 2.5 model	1.5	TKE
10	MRF	MM5 similarity	K theory with a counter-gradient term	1	–

Results

Comparisons of the annual biases, Root Mean Square Errors (RMSEs) and correlation coefficients for the WRF simulations using 10 different PBL schemes for FINO1 and OWEZ are shown in Table 3 and 4. **The MYNN2 and MYNN3 schemes, which are based on the improved Mellor-Yamada turbulence models and recently implemented parameterizations, are found to have better accuracies** than the other PBL scheme used cases. The results indicate that the MYNN2 and MYNN3 schemes are good alternatives to the MYJ scheme, which was used for WRF offshore wind simulations in previous studies [1, 2].

Table 3 Annual biases, RMSEs and correlation coefficients of the WRF wind speeds for FINO1. The first and second best values at each level are shown in red and blue.

Height	YSU	MYJ	QNSE	MYNN2	MYNN3	ACM2	UW	TEMF	GBM	MRF
Bias [m/s]										
40	-0.10	-0.12	-0.16	0.02	0.03	-0.20	-0.24	-0.19	-0.23	-0.12
60	-0.06	-0.03	-0.04	0.01	0.01	-0.21	-0.19	-0.07	-0.31	-0.10
80	-0.07	-0.05	-0.05	-0.05	-0.06	-0.23	-0.19	-0.13	-0.34	-0.17
100	0.07	0.08	0.11	0.07	0.05	-0.09	-0.04	-0.01	-0.23	-0.07
AVE	-0.04	-0.03	-0.04	0.01	0.01	-0.18	-0.16	-0.10	-0.28	-0.12
RMSE [m/s]										
40	1.56	1.51	1.56	1.51	1.50	1.59	1.59	1.69	1.72	1.55
60	1.59	1.55	1.58	1.55	1.54	1.61	1.63	1.71	1.78	1.60
80	1.67	1.65	1.68	1.63	1.63	1.69	1.73	1.81	1.84	1.68
100	1.69	1.66	1.69	1.64	1.63	1.68	1.74	1.82	1.83	1.69
AVE	1.63	1.59	1.63	1.58	1.58	1.64	1.67	1.76	1.79	1.63
Correl [-]										
40	0.933	0.935	0.931	0.937	0.938	0.932	0.930	0.919	0.920	0.934
60	0.933	0.935	0.932	0.937	0.938	0.932	0.930	0.920	0.918	0.934
80	0.935	0.935	0.933	0.939	0.939	0.934	0.930	0.922	0.923	0.936
100	0.936	0.937	0.935	0.940	0.940	0.936	0.932	0.924	0.925	0.937
AVE	0.934	0.936	0.933	0.938	0.939	0.934	0.931	0.921	0.921	0.935

Table 4 Same as Table 3, but for OWEZ

Height	YSU	MYJ	QNSE	MYNN2	MYNN3	ACM2	UW	TEMF	GBM	MRF
Bias [m/s]										
24	−0.08	−0.24	−0.25	−0.01	0.00	−0.14	−0.22	−0.12	−0.19	−0.01
70	−0.12	−0.12	−0.13	−0.04	−0.04	−0.23	−0.21	−0.15	−0.44	−0.05
116	−0.10	−0.04	0.00	−0.04	−0.06	−0.22	−0.11	−0.11	−0.48	−0.13
AVE	−0.10	−0.13	−0.12	−0.03	−0.03	−0.19	−0.18	−0.13	−0.37	−0.06
RMSE [m/s]										
24	1.49	1.50	1.52	1.47	1.45	1.51	1.52	1.56	1.76	1.51
70	1.57	1.57	1.60	1.56	1.54	1.60	1.59	1.68	1.88	1.59
116	1.61	1.61	1.66	1.61	1.59	1.64	1.66	1.75	1.95	1.64
AVE	1.56	1.56	1.59	1.54	1.52	1.58	1.59	1.66	1.86	1.58
Correl [−]										
24	0.909	0.908	0.902	0.911	0.913	0.907	0.906	0.893	0.877	0.907
70	0.927	0.925	0.921	0.929	0.931	0.924	0.924	0.912	0.903	0.930
116	0.935	0.934	0.930	0.938	0.939	0.933	0.932	0.921	0.913	0.937
AVE	0.924	0.922	0.918	0.926	0.928	0.921	0.920	0.909	0.897	0.925

Additional findings for the WRF wind speeds can be obtained when the ensemble means and spreads are calculated from the simulated wind speeds with the 10 PBL schemes. Fig. 2 exhibits time-series of wind speeds at 100 m height from the observations and the WRF ensemble means, which is simply the arithmetic mean of the 10 PBL time-series at FINO1. **The ensemble means (blue line) are found to provide less noisy results** than results from the single PBL scheme used cases (gray lines).

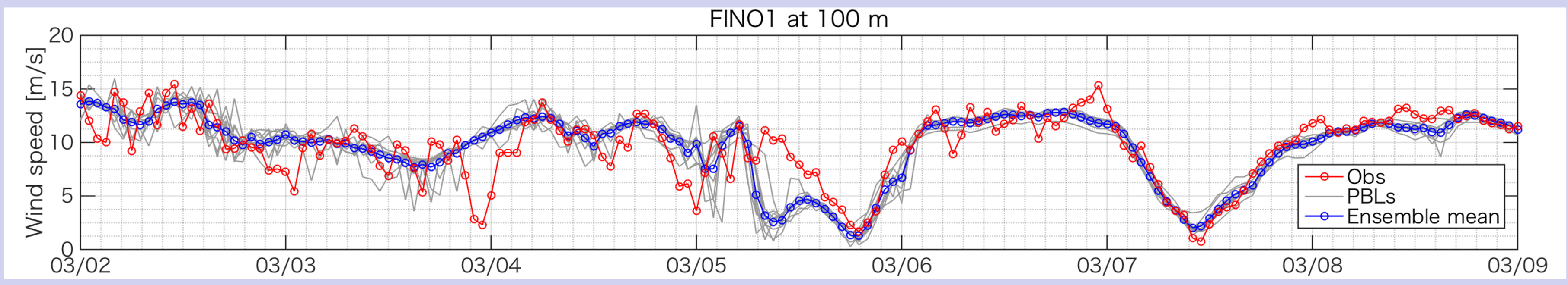

Fig. 2 Time-series of the observed and ensemble mean wind speeds at FINO1.

The WRF ensemble means showed slightly better accuracies than the MYNN2 and MYNN3 scheme used cases for FINO1 and OWEZ. A further improvement in RMSE can be obtained when a ensemble spread filter, which is based on the standard deviation of the WRF wind speeds normalized by the average standard deviation dependent on the mean wind speeds, is used as an index for measuring the uncertainty of the ensemble mean wind speeds.

Scatter plots of the observations against the WRF ensemble means using the ensemble spread filter with different thresholds, are compared in Fig. 3 and 4. As the threshold becomes smaller (more strict), the RMSE gradually decreases. Since the satellite-based offshore wind estimations have RMSEs of 1.53 and 1.41 m/s for FINO1 and OWEZ at 10 m height [3], **the WRF ensemble means are found to archive the accuracies, which are comparable with them**.

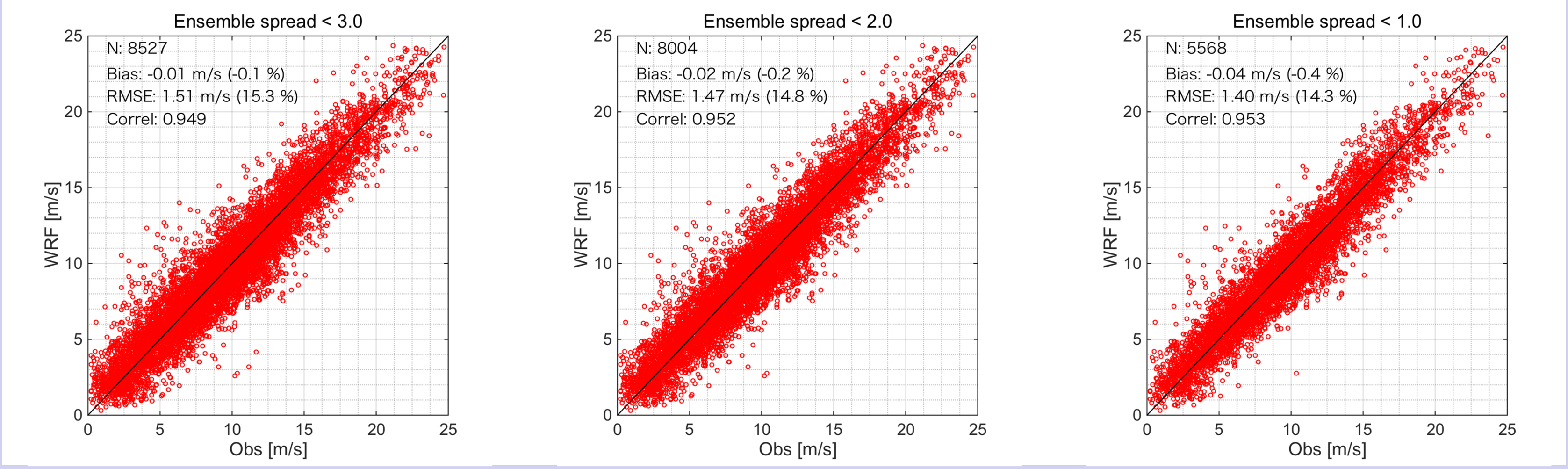

Fig. 3 Scatter plots after applying the ensemble spread filters for FINO1 at 100 m.

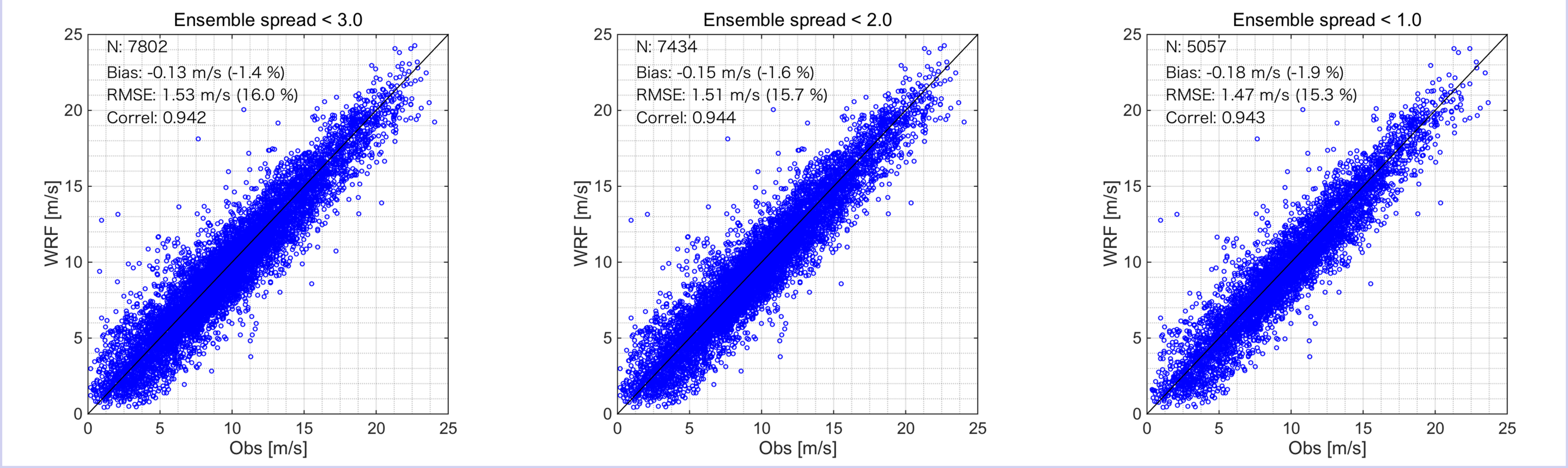

Fig. 4 Same as Fig. 3, but for OWEZ at 116 m.

Conclusions

The MYNN2 and MYNN3 schemes showed better accuracies than the other PBL schemes for FINO1 and OWEZ. It was also found that the accuracies presented in this study were much better than those from WRF simulations shown in the previous studies. Moreover, the WRF ensemble means obtained from the 10 PBL simulations were shown to have better accuracies than the single PBL scheme used cases. Finally, the WRF ensemble means using the spread filter were found to have the accuracies, which are comparable with the satellite-based wind estimations.

References

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