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Accuracy evaluation of hub-height wind speeds estimated from scatterometer and mesoscale model

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Objectives

In open oceans, sea surface winds measured from satellite-borne scatterometers are useful for offshore wind resource assessment. But, since they observe 10m-height wind speed, height correction is necessary to estimate hub-height wind speed. This study attempts to make the height correction by using a vertical wind profile simulated with a mesoscale model (**Fig.1**). Then, the accuracy of the hub-height wind speed is evaluated using in-situ measurements from three FINO met masts in the North Sea and the Baltic Sea.

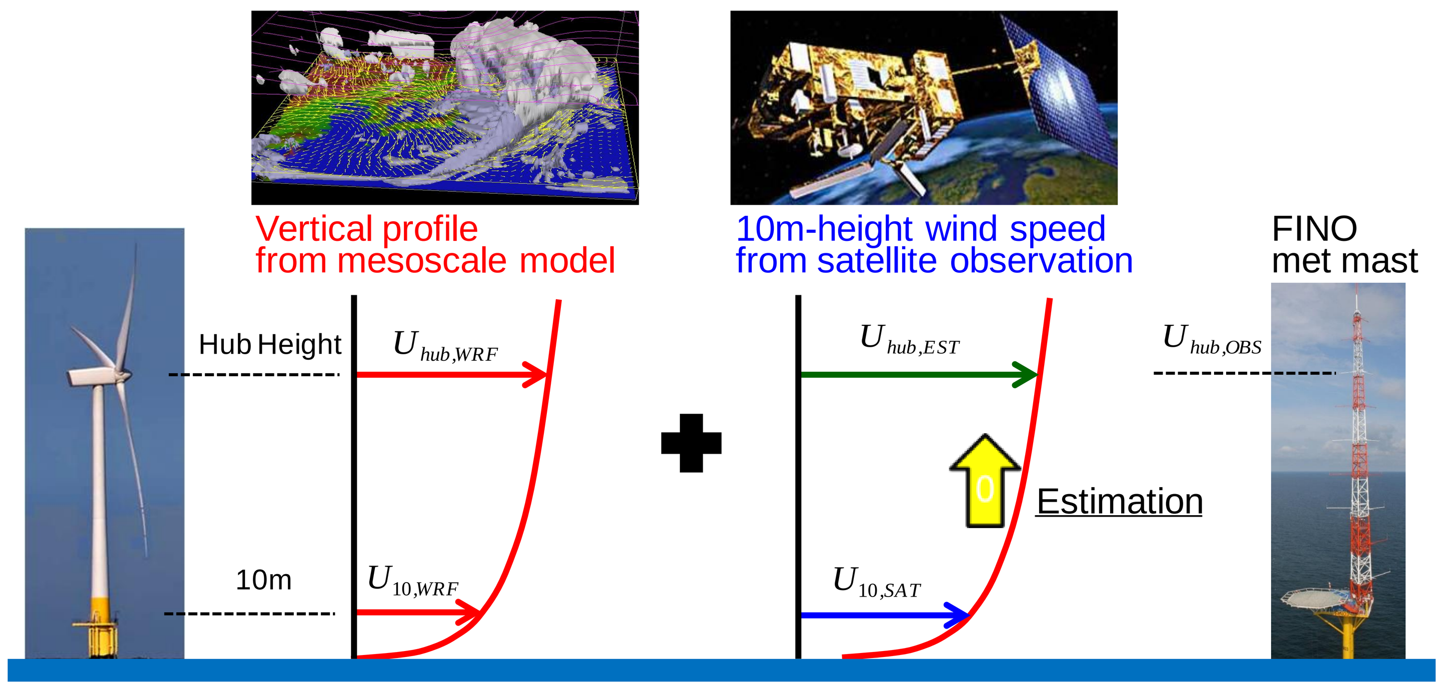

Fig. 1 Outline of this study

Methods

1) Scatterometer data –ASCAT/MetOP-A and SeaWinds/QuikSCAT–

As scatterometer data, this study uses the 12.5 km-gridded level 2 wind vector products of ASCAT/MetOp-A (AS) and SeaWinds/QuikSCAT (QS), which are provided by the Physical Oceanography Distributed Active Archive Center (PO.DAAC), NASA Jet Propulsion Laboratory. Since their 10m-height wind speeds are the equivalent neutral wind speed (ENW), the ENW is converted to the stability dependent wind (SDW) with the LKB code [1], using in-situ measurements of air temperature, relative humidity and sea water temperature at FINO met masts. For accuracy evaluation, the nearest grid point values to each mast are used.

2) Mesoscale model –WRF–

As a mesoscale model, this study uses the Advanced Research WRF (the Weather Research and Forecasting model) (ARW), developed by the National Center for Atmospheric Research (NCAR). The model configuration and domains used in the WRF simulation are shown in **Table 1** and **Fig. 2**, respectively. The simulation is performed for 32 km, 8 km and 2 km-gridded domains, using the ECMWF ERA-Interim analysis and OSTIA sea surface temperature as boundary conditions. As for the planetary boundary layer (PBL) scheme, the Mellor-Yamada-Janjic scheme is used. Four dimensional data assimilation (FDDA) is enabled excluding below 1,000 m in the Domain 3.

Table 1 Model configuration

Model	Advanced Research WRF (ARW) ver. 3.6.1
Levels	40 levels (Surface to 100hPa) Lowest levels: 12m, 40 m, 76 m, 116 m, 161 m, 214 m
Input data	6-hourly, 0.75º×0.75º, ECMWF ERA-Interim Daily, 0.05º ×0.05º, UK Met Office OSTIA SST
FDDA	Domain1: Enabled Domain2: Enabled Domain3: Enabled, but excludimg below 1,000 m
Physical options	Dudhia shortwave scheme RRTM longwave scheme Ferrier (new Eta) microphysics scheme Kain-Fritsch (new Eta) parameterization scheme Mellor-Yamada-Janjic (Eta) TKE PBL scheme Monin-Obukhov (Janjic Eta) surface-layer scheme Noah land surface scheme

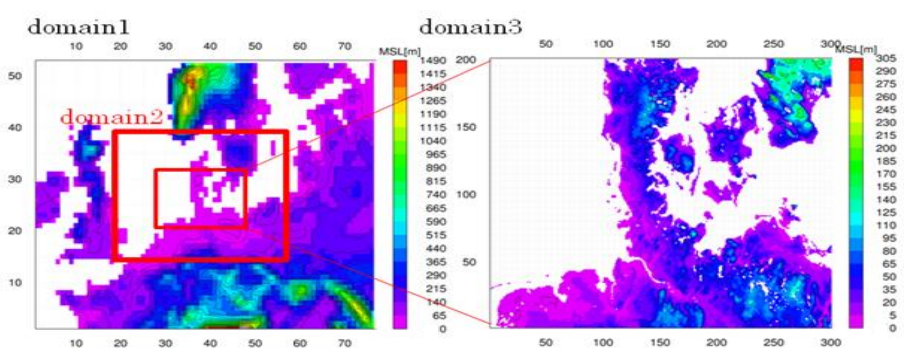

Fig. 2 Domains used in simulation

3) Met mast data

This study uses met mast measurements from FINO 1 and 3 in the North Sea, operated by the Forschungs und Entwicklungszentrum Fachhochschule Kiel GmbH and FINO 2 in the Baltic Sea, operated by DNV GL. All the data were obtained from the website of Bundesamt für Seeschifffahrt und Hydrographie (*http://www.fino-offshore.de*).

4) Estimation and evaluation of hub-height wind speed

The hub height wind speed ($U_{hub,EST}$) is estimated by combining the WRF-simulated vertical wind speed profile to the scatterometer-measured 10m-height wind speed ($U_{hub,EST}$) in two ways, using wind speed ratio and difference, as follows.

Wind speed ratio:
$$U_{hub,EST} = U_{10,SAT} \times \frac{U_{hub,WRF}}{U_{10,WRF}} \quad (1)$$

Wind speed difference:
$$U_{hub,EST} = U_{10,SAT} + (U_{hub,WRF} - U_{10,WRF}) \quad (2)$$

where, $U_{10,WRF}$ and $U_{hub,WRF}$ are WRF-simulated wind speeds at 10 m and hub height, respectively. The hub heights considered in this study are 60 m, 80 m and 100 m (only results for 100 m are shown in this poster). The period of accuracy evaluation is 1 year; from September 2012 to August 2013 for AS and from December 2008 to November 2009 for QS.

Results

Table 2 shows the results of accuracy evaluation for three methods; SAT(AS/QS) + WRF(ratio), SAT(AS/QS) + WRF(difference) and WRF direct simulation.

Table 2 Accuracy of 100 m-height wind speeds estimated in three methods

FINO 1 (AS)	AS + WRF		WRF
	Ratio	Difference	
Bias	0.18 m/s (1.9 %)	0.20 m/s (2.1 %)	0.10 m/s (1.0 %)
RMSE	1.59 m/s (17.0 %)	1.51 m/s (16.1 %)	1.81 m/s (19.3 %)
Corr. coef.	0.94	0.95	0.92

FINO 2 (AS)	AS + WRF		WRF
	Ratio	Difference	
Bias	-0.48 m/s (-5.1 %)	-0.39 m/s (-4.1 %)	-0.28 m/s (-3.1 %)
RMSE	1.71 m/s (18.0 %)	1.48 m/s (15.6 %)	1.89 m/s (20.1 %)
Corr. coef.	0.92	0.94	0.89

FINO 3 (AS)	AS + WRF		WRF
	Ratio	Difference	
Bias	-0.56 m/s (-5.6 %)	-0.51 m/s (-5.0 %)	-0.47 m/s (-4.6 %)
RMSE	1.31 m/s (13.0 %)	1.22 m/s (12.1 %)	1.97 m/s (19.3 %)
Corr. coef.	0.97	0.97	0.91

FINO 1 (QS)	QS + WRF		WRF
	Ratio	Difference	
Bias	0.08 m/s (0.8 %)	0.05 m/s (0.5 %)	-0.18 m/s (-1.8 %)
RMSE	1.96 m/s (20.3 %)	1.72 m/s (17.8 %)	1.70 m/s (17.5 %)
Corr. coef.	0.89	0.92	0.92

FINO 2 (QS)	QS + WRF		WRF
	Ratio	Difference	
Bias	-0.12 m/s (-1.3 %)	-0.15 m/s (-1.6 %)	-0.39 m/s (-4.1 %)
RMSE	1.88 m/s (19.6 %)	1.56 m/s (16.2 %)	1.68 m/s (17.5 %)
Corr. coef.	0.89	0.93	0.92

FINO 3 (QS)	QS + WRF		WRF
	Ratio	Difference	
Bias	-0.09 m/s (-0.9 %)	-0.13 m/s (-1.3 %)	-0.49 m/s (-4.6 %)
RMSE	1.45 m/s (13.7 %)	1.34 m/s (12.7 %)	1.62 m/s (15.3 %)
Corr. coef.	0.95	0.96	0.94

* The first and second best values are shown in red and blue, respectively.

1) Comparison between SAT(AS/QS) + WRF and WRF direct simulation

The AS + WRF(difference) method is found to have the best values of RMSE and correlation coefficient (CC) at all the FINO met masts. On the other hand, the WRF direct simulation exhibits the smallest bias at all the masts. In the QS cases, the QS + WRF(difference) method seems to be more accurate than other two methods, having the first or second best values for all the statistics at all the masts. These results indicate that the scatterometer-WRF combined method can estimate a hub-height wind speed more accurately than the WRF direct simulation, except the large bias found in the AS + WRF methods.

2) Large bias in AS+WRF methods

The large bias in the AS + WRF methods is examined here in terms of stability conditions, defined with the Monin-Obukhov length L; unstable (-200<L<0), neutral (|L|≥200) and stable (0<L<200). The results are shown in **Table 3**. It is obvious that the biases of AS + WRF become worse than those of WRF only in stable conditions. In other words, the AS + WRF methods are superior to the WRF direct simulation in unstable and neutral conditions.

Table 3 Same as Table 2, but for three stability conditions at FINO 3.

Unstable	AS + WRF		WRF
	Ratio	Difference	
Bias	-0.24 m/s (-2.6 %)	-0.22 m/s (-2.4 %)	-0.24 m/s (-2.7 %)
RMSE	0.98 m/s (11.0 %)	0.98 m/s (10.9 %)	1.67 m/s (19.0 %)
Corr. coef.	0.97	0.97	0.90

Neutral	AS + WRF		WRF
	Ratio	Difference	
Bias	-0.71 m/s (-5.3 %)	-0.72 m/s (-5.3 %)	-1.29 m/s (-9.4 %)
RMSE	1.30 m/s (9.6 %)	1.22 m/s (9.0 %)	1.90 m/s (13.9 %)
Corr. coef.	0.97	0.97	0.93

Stable	AS + WRF		WRF
	Ratio	Difference	
Bias	-2.09 m/s (-24.7 %)	-1.70 m/s (-20.1 %)	-0.96 m/s (-10.0 %)
RMSE	2.57 m/s (30.3 %)	2.19 m/s (25.8 %)	1.93 m/s (20.1 %)
Corr. coef.	0.96	0.96	0.93

* The first and second best values are shown in red and blue, respectively.

3) Comparison between two methods with wind speed ratio and difference

According to **Table 2**, the SAT + WRF(difference) method always exhibits a better RMSE and CC than the SAT + WRF(ratio) method. On the other hands, no large differences can be found between both biases. These results mean that the wind speed difference, shown in Eq. (2), performs better than the wind speed ratio.

4) Other comparisons

From **Table 2**, it is found that the AS + WRF methods show better RMSEs and CCs than the QS + WRF methods. In contrast, the biases are mostly negative and obviously worse than that of the QS + WRF methods. A possible reason for this is the underestimation of ASCAT-measured 10m-height wind speed. In **Table 2**, it is also found that the accuracies at FINO 3 are better than those at FINO 1 and 2, which may be too closer to coast lines for the use of scatterometers.

Conclusions

Results obtained in this study are summarized as follows.

- The hub-height wind speed estimated by combining a scatterometer-measured 10m-height wind speed with a WRF-simulated vertical profile is mostly more accurate than that from the WRF direct simulation.
- It is better to use the wind speed difference ($U_{hub,WRF}$-$U_{10,WRF}$) rather than the wind speed ratio ($U_{hub,WRF}/U_{10,WRF}$) to lift up the 10m-height wind speed to the hub height based on a WRF-simulated vertical profile.
- The accuracy of the scatterometer-WRF combined method is found to become worse in stable conditions. This is probably attributed to worse reproducibility of the vertical profile which the MYJ PBL scheme calculates in stable conditions.
- Since unstable conditions prevail though the year in Japanese coastal waters, this scatterometer-mesoscale model combined method is expected to perform better than in the German coastal waters.

References

[1] Liu, W. T. and W. Tang, “Equivalent neutral wind”, Jet Propulsion Laboratory Publication 96-17, 1996, 8p.