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Recipe for correcting the effect of mesoscale resolution on the estimation of extreme winds

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Abstract

It is a common issue that the modeled winds from mesoscale models are smeared due to the spatial and temporal resolutions. This is reflected in the spectrum domain as an energy deficit in the mesoscale range. The energy deficit indicates smaller moments and thus underestimation in the extreme winds. We developed two approaches for calculating the smoothing effect due to the mesoscale resolution on the extreme wind estimation by taking into account of the difference of the spectral tail between the modeled and measured spectra in the mesoscale range. Both approaches give the estimation of the smoothing effect in good agreement with measurements from several sites in Denmark and Germany.

The problem

As illustrated in Fig. 1, due to the smoothing effect of resolution, there is an energy deficit in the mesoscale range, here ~ 2 < f < 72 day^{-1}, in the spectra of the simulated wind time series compared to that of the measurements. The spectral tail from measurements has a slope of approximately -5/3, and those from models have slopes -3 and -4. This implies that the extreme winds are underestimated in the mesoscale modeling because the wind variation in this range is important in contributing high winds and hence in the peak effect.

Simulations from three well-used mesoscale models (HIRHAM, REMO and WRF) for wind energy study in Northern Europe are analyzed, see details in Table I.

models	resolution	period	large scale forcing
HIRHAM5-ECHAM5	25 km	1961 - 1990	ECHAM5
HIRHAM5-ERA40	25 km	1961 - 1990	ERA40
REMO	50 km	1979 - 2003	ERA15 and ECMWF analysis
REMO	10 km	1979 - 2003	ERA15 and ECMWF analysis
WRF	45 km	1999 - 2009	NCEP reanalysis II
WRF	15 km	1999 - 2009	NCEP reanalysis II

Table I: Model descriptions. All simulations give hourly outputs.

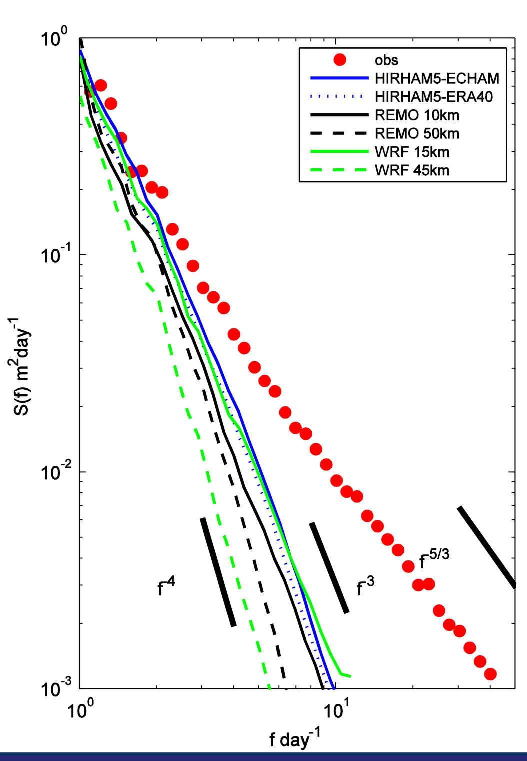

Fig. 1: Spectra of wind speed at 10 m at Horns Rev, measurements and six model simulations. →

Purpose

The purpose is to develope approaches to take into account the difference in the measured and simuated spectrum in the mesoscale range and to estimate the impact from this difference on the extreme wind, in connection with the Annual Maximum Method. The correction by the approaches will bridge the gap between the current models' resolution (tens of km or in hours) to that of the upper limit of the mesoscale range (a few km or in 10 min).

Measurements

In order to validate the approaches, we use 10 min wind measurements from six stations in the mid-latitude, see Table II. We further predict the annual maximum wind using Eq. (1) for the offshore site Horns Rev only while not the land sites in order not to go into discussions about the models' performance induced by factors other than the model resolution.

Stations	Data Period	Location	Height
Horns Rev	1999 - 2006	(7.875E, 55.508N)	15, 62 m
Sprogø	1979 - 1999	(10.974E, 55.331N)	11 m
Tystofte	1982 - 2010	(11.33E, 55.24N)	10 m
Kegnæs	1991 - 2006	(9.936E, 54.856N)	10 m
Jylex	1983 - 2004	(8.449E,55.942N)	10 m
FINO	2004 - 2010	(6.588E,54.014N)	50 m

Table II, details of measurements

Results

- The mean k_p calculated from 10 min wind time series at six stations is 5.07.
- k_p and $\overline{U}_{max}$ from 10 min measurement at Horns Rev are 4.96 and 27.2 m/s. The corresponding peak factors and mean wind maxima corrected from the simulated hourly data using approach I are given in Table II and they are in good agreement with measurement. These numbers fit rather well with the estimation given by approach II (Table II).

Table II For the site Horns Rev.
k_p(I) are peak factors calculated from the simulated hourly wind time series.
k_p(II) are peak factor calculated with the modified spectrum shown in Fig. 2, equivalent to 10 min.
SE, the smoothing effect calculated with SE=1-k_p(I)/k_p(II).
<U_{max}> is the mean annual wind maximum calculated with k_p(II), using Eq. (1).

	variables	OBS	HIRHAM5		REMO		WRF	
			ECHAM5	ERA40	10 km	50 km	15 km	45 km
approach I	$k_p(I)$		4.18	4.17	4.13	4.10	4.17	4.07
approach I	$k_p(II)$	5.01	5.00	4.99	4.98	5.00	5.00	4.97
approach I	SE		16.5%	16.5%	17.1%	18.0%	16.7%	18.1%
approach I	$<U_{max}>$ (m/s)	**27.2**	**26.6**	**25.5**	**26.5**	**26.5**	**26.6**	**25.4**
	k_p (approach II)		12.5-15%	12.5-15%	12.5-17%	15-17%	12.5-16.5%	16.5-17%

The recipe

Approach I: Spectral Correction

The wind time series is assumed to be a Gaussian process and the exceedance following a Possion process at a large thresold. The peak factor k_p , defined as

$$k_p = \frac{\overline{U}_{max} - \overline{u}}{\sigma} \quad (1)$$

is derived as a function of the spectral moments m_0 and m_2:

$$k_p = \sqrt{2\ln(\frac{1}{2\pi}\sqrt{\frac{m_2}{m_0}}T_0)} \quad (2)$$

with the moments defined as

$$m_j = 2\int_0^\infty \varphi(\omega)\omega^j S(\omega)d\omega \quad (3)$$

ω= 2πf, and $\varphi(\omega)$=sin(ωT_a/2)/(ωT_a/2) is a filter due to temporal averaging T_a. The wind variation in high frequency range contributes significantly to m_2/m_0 and hence k_p and the mean annual wind maximum $\overline{U}_{max}$.

The core of this recipe is to replace the spectral tail of the simulated winds (the dots in Fig. 2) with a slope of -5/3 and extend it to f = 72 day^{-1}(solid lines in Fig. 2 with the tail start at f = 1 and 2 day^{-1} respectively).

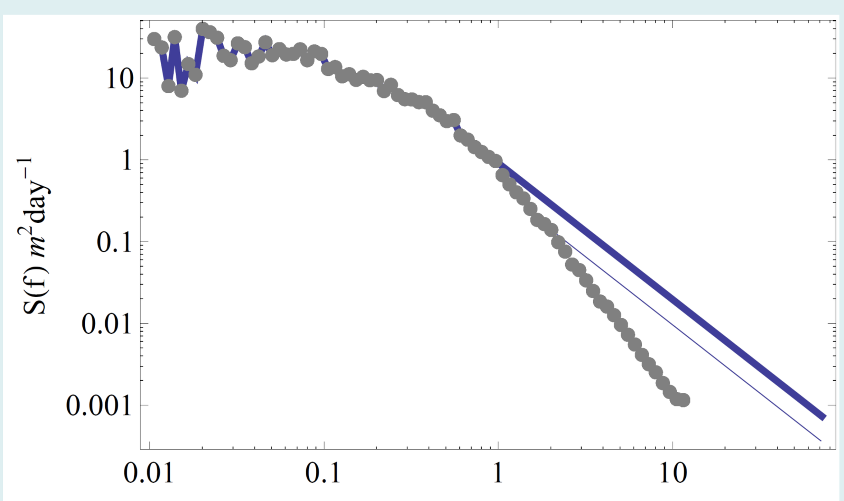

Fig. 2: Modification of the spectrum of hourly simulated winds by replacing the tail for $f > f_c$, here f_c =1 and 2 day^{-1} up to 72 day^{-1}. (Approach I)

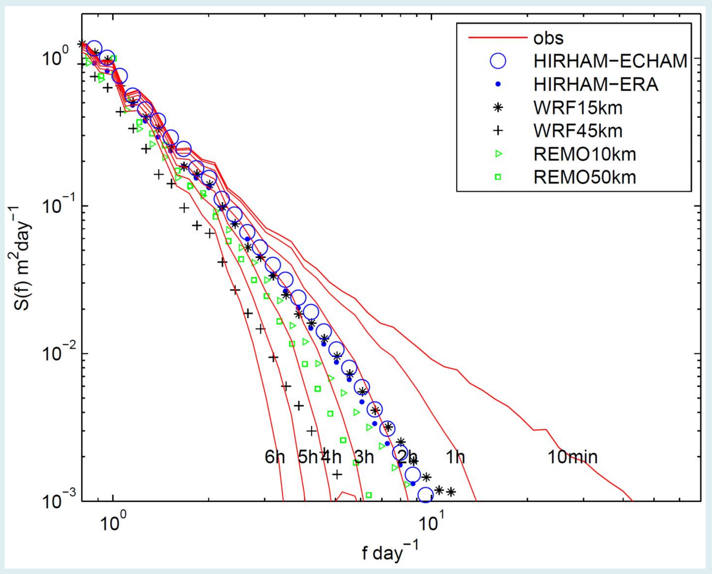

Fig. 3: Lines show the spectrum from measurements varying with averaging time from 10 min to 6 hours. Also shown are six spectra from simulations. (Approach II)

Approach II: Effective Temporal Averaging

We approximate the combined spatial and temporal averaging effect in the mesoscale modeled winds into the temporal effect and use the statistical model derived in [1] to calculate the underestimation in the extreme wind (see Fig. 3). The model from [1] assumes the wind time series a Gaussian process and it calculates the temporal resolution effect on the annual wind maxima. The peak factor is a function of the autocorrelation coefficient ρ:

$$k_{pt} = \sqrt{(1+\rho)\ln(\frac{N}{\pi}\sqrt{\frac{1-\rho}{1+\rho}})} \quad (4)$$

where N is the number of 10 min values in a year. Both N and ρ decrease with increasing averaging time, so does k_{pt}.

Drawback: there is not always a good approximation for the combined effect as a temporal effect, e.g. REMO and WRF spectra in Fig. 3. Thus the estimation of the smoothing effect is rather in a range (Table II), which means larger uncertainty.

Conclusions

- For the mesoscale modeled winds, the spectral energy deficit in the mesoscale range reflects the smoothing effect of both spatial and temporal resolution. This energy deficit is essential in the extreme wind underestimation.
- Both approaches give consistent estimates in the smoothing effect in the peak factor, with the first approach more straightforward in handling the combined spatial and temporal smoothing effect.
- The estimation of the smoothing effect in peak factor using the recipe is in good agreement with measurements. For the offshore site Horns Rev, the conversion to the mean annual wind maximum is successful according to the data validation.

References

1. Larsén X. G. and Mann J. The effects of disjunct sampling and averaging time on mean maximum wind *J. Wind Eng. Ind. Aerodyn.*, 94, 581-602, 2006.
2. Skamarock W. Evaluating mesoscale NWP models using kinetic energy spectra. *Monthly Weather Review*, 132, 3019 – 3032, 2004.

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