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.

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 threshold. The peak factor kₚ is defined as

\[ k_p = \frac{\bar{U}_{\text{max}} - \bar{U}}{\sigma} \]  

is derived as a function of the spectral moments \( m_2 \) and \( m_3 \):

\[ k_p = \sqrt{2 \ln \left( \frac{1}{2\pi} \sqrt{\frac{m_2}{m_0}} \right) \varphi(\omega) \xi S(\omega) d\omega} \]  

with the moments defined as

\[ m_2 = 2 \int_0^\infty \varphi(\omega) \xi S(\omega) d\omega \]  

\[ \omega = 2\pi f, \text{ and } \varphi(\omega) = \sin(\omega T_p/2)/\omega T_p/2 \] is a filter due to temporal averaging \( T_p \). The wind variation in high frequency range contributes significantly to \( m_2/m_0 \) and hence \( k_p \) and the mean annual wind maximum \( U_{\text{max}} \).

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).

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 underestimated 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 \( \rho \):

\[ \text{ext} = \sqrt{\frac{(1 + \rho) \log N}{\pi} \left( \frac{\bar{U}_{\text{max}} - \bar{U}}{\sigma \rho} \right)^2} \]  

where \( N \) is the number of 10 min values in a year. Both \( N \) and \( \rho \) decrease with increasing averaging time, so does \( k_p \).

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.

Results

The mean \( k_p \) calculated from 10 min wind time series at six stations is 5.07.

\( k_p \) and \( \bar{U}_{\text{max}} \) from 10 min measurement at Horns Rev are 4.96 and 27.2 m/s. The corresponding peak factors and mean 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).

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 underestimate.

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