An engineering model for 3D turbulent wind inflow based on a limited set of random variables

Fluck and Crawford

Response to comments from anonymous reviewer #2

1. *Page 5, line 15-17: main advantage of Veers' model.*
   We consider three main advantages of Veers model and write:
   "Due to its comparatively high independence of site specific parameters, ease of use, and low resource requirements, Veers' model is the preferred model for many applications (Lavely et al., 2012)."
   Is there anything else the referee would like to be included?

2. *Page 7, line 10-15: reduction of numbers of frequencies.*
   In a frequency model the frequency bins as chosen arbitrarily, but such that the energy in the frequency spectrum can be represented adequately. As discussed on P5, L7-9, using a large set of frequencies (i.e. a large set of random numbers) was not a problem for deterministic models. However, moving to stochastic models requires a significant reduction of random variables, and hence frequencies. We show, that using 10 to 20 random variables for 10 to 20 frequencies is sufficient. This choice is not driven by physical arguments, but by the limitations of the stochastic models where such a reduced order wind field formulation is to be used.

3. *Page 8, line 1: experimental of theoretical justification for grid resolution.*
   The choice of grid resolution is a tradeoff between accuracy and computational effort. For a typical D = 90 m diameter rotor 15 x 15 points is a common choice. We change the bracket to "(for a D = 90 m diameter rotor somewhere in the order of 15 x15 points over the rotor disk is are usually used)".

4. *Page 11, line 19: The number of frequencies.*
   The number of frequencies does affect the quality of the resultant wind field. Too few frequencies result either in periodic wind speeds or distinct wind speed oscillations. Eight to ten frequencies for a 333 s sample was found to be the minimum. See also comment 2.

5. *Location of Figure 4.*
   We will consider this for the final version.

6. *Size of Figure 5.*
   We will change this accordingly.

7. *Page 12, line 16: grid resolution.*
   In this study we are not concerned with wind turbine loads. Hence it is not necessary to model the wind field over the full wind turbine rotor disc. To assess the reduced order wind model it is important to show that it adequately represents wind field properties both for close and distant points. In order to do this without unnecessary computational effort, we use a study grid, which contains only a few close and a few distant points.
   To make this clearer we change p12, ll 12ff to:

"Since the goal here is not to calculate wind turbine loads, but to merely asses the quality of the reduced order wind model, we used a test a wind field generated on N_{Py} x N_{Pz} = 5 x 3 = 15 points located on a regular grid as depicted in Fig. 4. This is fewer points than the usual grid for the analysis of a modern D = 90 m rotor diameter wind turbine. However, the reduced number of grid points enabled us to solve the equations quickly with all models and more clearly illustrate the method. At the same time, the configuration of Fig. 4 still allowed us to study both the wind speed time series of points in close proximity (e.g. P1 and P6), as well as at more distant points (e.g. P1 and P5). The origin […]"

8. *Page 15, line 2-10: model names*
   Thank you for catching this! We erroneously swapped model names in line 3. With a few modifications for clarity this paragraph should read:

"From Fig. 8 it can be seen that the covariance from all three model agrees fairly well. Our implementations of Veers' model, $\text{Veers}_{\text{red}}$ and $\text{Veers}_{\text{red},\,\Delta\Theta}$, which both use a limited set of frequencies, agree almost perfectly. The TurbSim version with the full set of roughly 3,000 frequencies, on the other hand, yields slightly different covariance. A more detailed investigation reveals the reason for this: the covariance depends on the cross-spectrum and thus the spectrum at each individual point. Consequently, the discrepancy between the covariance functions is connected to the fact that Veers' model distorts the spectrum at each individual point, such that with Eq. 3 $|U_{mk}| = \sqrt{\tilde{S}_{mk}} \neq \sqrt{S_{mk}}$ (see discussion in section 2.1). When we replace S in our implementation by the distorted spectrum $\tilde{S}$ at each particular point P_k in Eq. 8 all three curves do match. However, $\tilde{S}$ does not in fact represent the prescribed Kaimal spectrum. Thus we conclude that our phase increment model actually represents the desired covariance better than Veers' original model and TurbSim."

9. *Page 16, line 7-8: logarithmically spaced bins.*
   With a logarithmic spacing more bins are located at low frequencies and fewer at high frequencies. This enables us to represent the wind and its spectrum more efficiently. For clarity we change on p. 11, ll. 19-20 to: "[…] with N_f = 10 logarithmically spaced frequencies, which allowed a more efficient representation of the wind and its spectrum. We set f= […]"

10. *Page 18, line 15: auto spectrum*

The auto-spectrum is included in Fig. 2. We realize that this might get lost towards the end of the paper. We will change the heading of section 3.3. to "Spectra" and change the beginning of the section:

"Wind speed spectra are again obtained as average from 100 realizations (from 100 different random seeds). However, this time 6,000 s were sampled to obtain sufficiently long data sets for a proper resolution of the low frequency components. Note that the same set of 20 frequencies $[f_k] \in [1 = 600;\ 5]$ Hz are used for both the 20 frequency ($\text{Veers}_{\text{red}}$) and the phase increment ($\text{Veers}_{\text{red},\, \Delta\Theta}$) implementations. Hence the T = 6,000 s signal repeats after 600 s. The spectrum is binned into discrete bins of frequencies f_m equal to the logarithmically spaced frequencies initially used to generate the wind speed time series.

The wind speed auto-spectrum is included in Fig. 2. By definition (Eq. 8) the reduced order model produces the prescribed (auto-) spectrum exactly. Fig. 9 shows a comparison of the cross-spectra estimates for different […]"