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 #1

Moderate comments:

1. *P8 & 9. Confirming that the temporal variability is more important than the spatial variability.*
   This is an original thought derived from Veers' model. We have not come across any literature studying this fact.
   Here is another way to look at it. Hopefully this clarifies our thoughts:
   Assuming Veer's spectral model is adequate, we note that phase angles are independent over frequencies $Cov(\Theta_{mk}, \Theta_{nk})=0$, but somehow dependent between points $|Cov(\Theta_{mk}, \Theta_{ml})|>0$. Without further discussion of the actual structure of this dependence we infer that the phase angle matrix Θ contains more randomness in the columns (time) than in the rows (space). Thus we decide to include randomness in time, but neglect randomness in space. The results presented in section 3 confirm the validity of this assumption.

   We will revise the manuscript to better reflect these thoughts.

2. *P9 & 10. Regarding Eq. (3), choosing $\Delta\Theta_{mk}$ to be deterministic.*
   This indeed boils down the comment 1:
   In order to arrive at a reduced order model something needs to be simplified. We choose to set $\Delta\Theta_{m(kl)}= \Theta_{ml} - \Theta_{mk}$ as deterministic constant. Thus we generate a realization for one part of the stochastic process, i.e. we collapse a part of the random domain of the problem into one sample, but we retain randomness in the other part. Comment 1 provides the reason for this choice, and although this means we neglect the randomness in the rows of Θ, and with it some part of the randomness in the wind field, the good agreement of our results with Veers original wind model justify this choice.

3. *P9 and later in the text. The concept of $\Delta\Theta_{mk}$.*
   This is a nice way to put paraphrase our concept. We will include something along these lines to more graphically explain that concept to the reader.

4. *P10. L9. Spatial and temporal variability.*
   See comment 1. This is a new thought, and we have not come across any studies in this direction.

5. *Figure 7. Difference between for the times lags less than 10 s?*
   The cross correlation curves do not perfectly agree. The difference is most prominent in the oscillations of the (P1,P5) curve, and in the (P1-P6) curves around 10s and 50s. We do not think that this is related to high or low frequencies, but due to the fact that our model uses significantly less frequencies than TurbSim. Hence the turbulent energy is discretized over fewer modes in our model, and the curves are not as smooth.

6. *More emphasis on Figure 10.*
   We fully agree. However, representing the underlying BEM model and the modifications made to transform it into a stochastic BEM model would exceed the scope of a single paper. These results will be presented in a separate paper (Fluck and Crawford: "A fast stochastic solution method for the Blade Element Momentum equations for long-term load assessment", Wind Energy, submitted). A reference will be included in the next revison.

7. *Validity of our method would be for the case of highly unsteady winds.*
   Our method (like Veers' method) is a spectral representation of a random process. The wind field is generated through inverse Fourier transform with random phase increments. Thus the underlying process is (per definition) assumed to be stationary.
   Consequently, fronts, downbursts, and other singular transient events can naturally not be modelled directly in any spectral model.

   It might be possible to model these event through superposition of a discrete deterministic event with our random model, similar to Chay et al. (2006) who superposes a deterministic downburst profile over an ARMA model for the turbulent fluctuations. However, it is our goal to derive a formulation for wind as input to stochastic models. These models will have difficulties dealing with singular deterministic events themselves. We doubt if moving this way is beneficial. Nonetheless, this could obviously be the subject of a future study.

Minor comments:

1. *P4, L24. Correction of "Moreover the stochastic wind…"*
   This should be: "Moreover this model is driven by the decomposition (bi-orthogonal and Karhunen-Loève) of a specific set of wind."

2. *P5, L7-9 difficult to understand.*
   We change this to: "However, none of the previous models had an application in stochastic aerodynamic models in mind. Since random numbers can be generated very quickly, existing models rely on a large set of random variables to be used as a seed for a wind field realization. However, this random seed usually contains too many random variables to be applicable to a direct stochastic modeling of the aerodynamic wind turbine equations (path C in Fig. 1)."

3. *P5, L12. It should be Veers (1988).*
   Thanks for pointing this out. We have changed citation style before submission and obviously missed adopting references to the new style at a few places.

4. P6. L2-6.
   We believe it is important to state why Veers model is briefly revisited. To avoid repetition, we rephrase this paragraph:
   "Veers' method represents the established method for synthesizing turbulent wind (Nielsen et al., 2007; Lavely et al., 2012) and at the same time is the baseline for our contribution. Hence the method is briefly summarized here to lay out the basics for the following work. For a complete introduction the reader is referred to Veers' original paper (Veers, 1988) and successive work, e.g. Kelley (1992); Nielsen et al. (2004); Burton et al. (2011)."

5. *P6. L13.*
    We will reword this accordingly and include the suggested reference.

6. *Figure 2.*
    We will clarify this in the figure.

7. *P8, L15, "block of wind".*
    We will discard the footnote and reword the sentence: "This is indeed the streamwise and thus the temporal variability of the wind field."

8. *P11, L21. "I; the results" and **Veers**$_{red}$.*
    This is a typo, which we will remove. We will also remove the bold typeface for the labels.

9. *9. P12, L1.*
    We will also remove the bold typeface for the labels.

10. *Figure 5 caption.*
    We will change this accordingly.

11. *Figure 6 caption.*
    We will change this accordingly.

12. *Eq. 9.*
    We will change this accordingly.

13. *Figure 9.*
    We will change this accordingly.

14. *Figure 10 caption.*
    We will change this accordingly.

15. *References.*
    We will double check this.

Grammatical and stylistic comments:

We will revise the manuscript and correct the errors pointed out.