

A new spectrum model for the atmospheric crosswind component applicable from mesoscales to microscales

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The issue:



Meandering effect is described through classical boundary-layer turbulence theories that are valid for t < 1 h, l < a few km.

How is meandering effect over modern wind farm clusters?

Fig. 1. Overview of wind farms (4coffshore.com)

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The observation:



Fig. 2. Mean spectrum of u and v at 80 m from two years of data of stationary days from Høvsøre. Sonic data with 1-day length were used for calculation of each spectrum.

The red curves are the new spectral models for u and v that cover meso and micro scales.

This new model has also shown to be valid over 5 years of data from Østerild, from 37 m to 241 m.



The approach:

- Spectral model development for u and v over micro and mesoscale.
- *u*-spectrum from Larsén et al. (2016, 2019)

 $fS_u(f) = Eq. 1a \text{ (or } Eq. 2a) + Eq. 3$

v-spectrum derived here:

 $fS_{v}(f) = Eq. \, 1b \text{ (or } Eq. \, 2b) \quad \text{for } f > f_{1}$ = Constant for $f_{2} \le f \le f_{1}$ = Eq. 3 for $f < f_{2}$

Refer to Fig. 2

Note: Eq. 1a $fS_u(f) = \frac{51u_*^2n}{(1+33n)^{5/3}}$ Eq. 1b $fS_v(f) = \frac{8.5u_*^2n}{(1+9.5n)^{5/3}}$ Boundary-layer model by Kaimal & Finnigan 1994 Eq. 2a $fS_u(f) = \frac{0.5a_u u_*^2n/n_{l,u}}{(1+n/n_{l,u})(1+n/n_{u,u})^{2/3}}$ Eq. 2b $fS_v(f) = \frac{0.5a_v u_*^2n/n_{l,v}}{(1+n/n_{l,v})(1+n/n_{u,v})^{2/3}}$ Boundary-layer model by Mikkelsen et al. 2017 Eq. 3 $fS_{lu}(f) = a_1 f^{-2/3} + a_2 f^{-2}$ Mesocale model by Larsén et al. 2013

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The approach:

- Time series (1-day and 5-day for a year) are generated for *u* and *v* using the spectral models:
 - Boundary-layer model Eq. 1 & 2
 - The new model combining meso and boundary-layer models
- Statistics of modelled direction are compared with observations



The results:



Fig. 3. The distribution of direction deviation with groups of observation data that satisfy: (left) the largest direction difference is 15° and (right) 60°, with data length (DL) from 1 h to 1 day.

The boundary-layer model (Eq. 1 and 2, dashed curves) seems to capture well this distribution when the largest direction change is less than 15° (stationary), but significantly underestimate the directional change for non-stationary situations.

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The results:



Fig. 4. Deviation of direction distribution, from measurements (gray curves) and from models. The new spectral model (blue curve) provides much improved estimation for non-stationary condition (an example of data length DL= 5 days) in comparison with the boundarylayer model Eq. 2 (red dashed curve).

The conclusion:

- We defined a mesoscale version of the lateral, v-spectrum, extending the description of vvariability to mesoscale: the meso-BL-model.
- The new meso-BL-models of u and v are used to simulate the climatology of wind direction.
- This method pertains at least to the western Denmark and North Sea regions, but can be applied in other regions with calibrations for the spectral models using measurements.
- At the scale of modern wind farm clusters, stationary conditions are challenging to meet. Meandering calculation needs to take large scale variability of u and v into account.



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