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

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The issue:

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

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?

The observation:

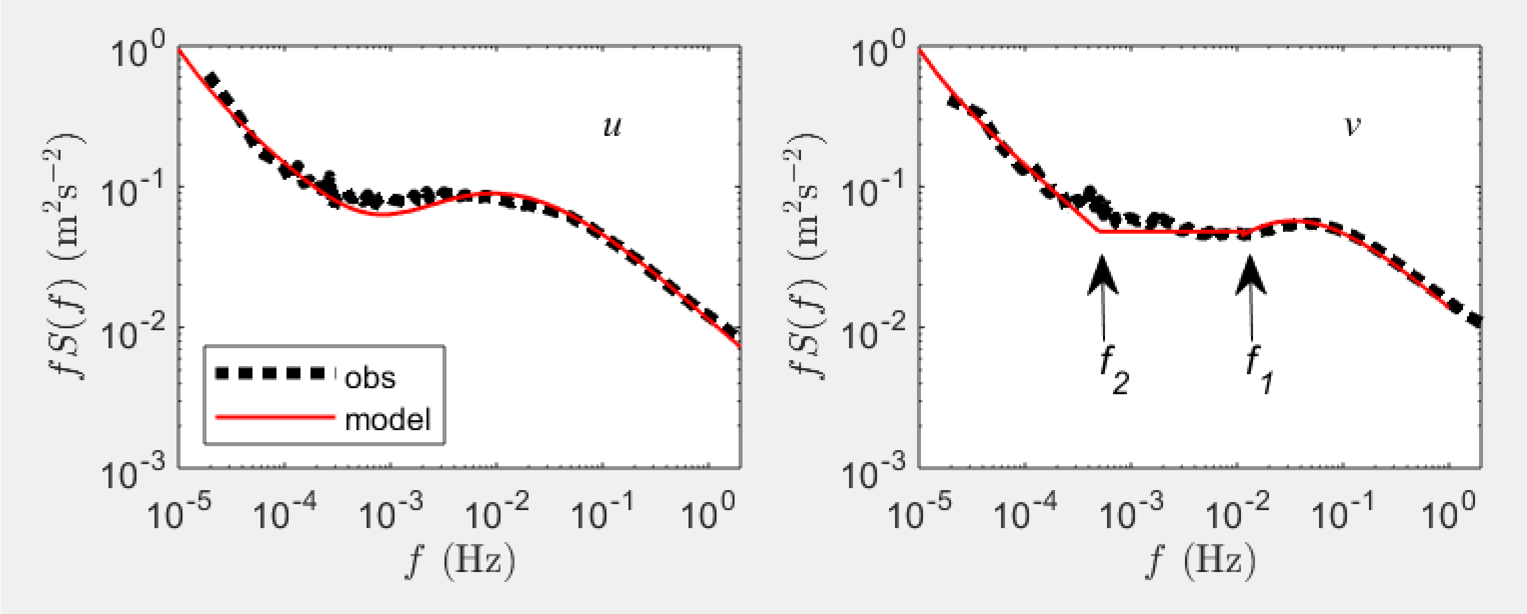

Fig. 2. Mean spectrum of *u* and *v* at 80 m from two years of data of stationary days from Høvsøre. Sonic data with 1-day length were used for calculation of each spectrum.

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:

$$fS_v(f) = Eq.1b \text{ (or } Eq.2b) \quad \text{for } f > f_1$$
$$= \text{Constant} \quad \text{for } f_2 \leq f \leq f_1$$
$$= \text{Eq. 3} \quad \text{for } f < f_2$$

Refer to Fig. 2

Note:

Eq. 1a $$fS_u(f) = \frac{51u_*^2 n}{(1+33n)^{5/3}}$$

Eq. 1b $$fS_v(f) = \frac{8.5u_*^2 n}{(1+9.5n)^{5/3}}$$

Boundary-layer model by Kaimal & Finnigan 1994

Eq. 2a $$fS_u(f) = \frac{0.5a_u u_*^2 n/n_{l,u}}{(1+n/n_{l,u})(1+n/n_{u,u})^{2/3}}$$

Eq. 2b $$fS_v(f) = \frac{0.5a_v u_*^2 n/n_{l,v}}{(1+n/n_{l,v})(1+n/n_{u,v})^{2/3}}$$

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

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:

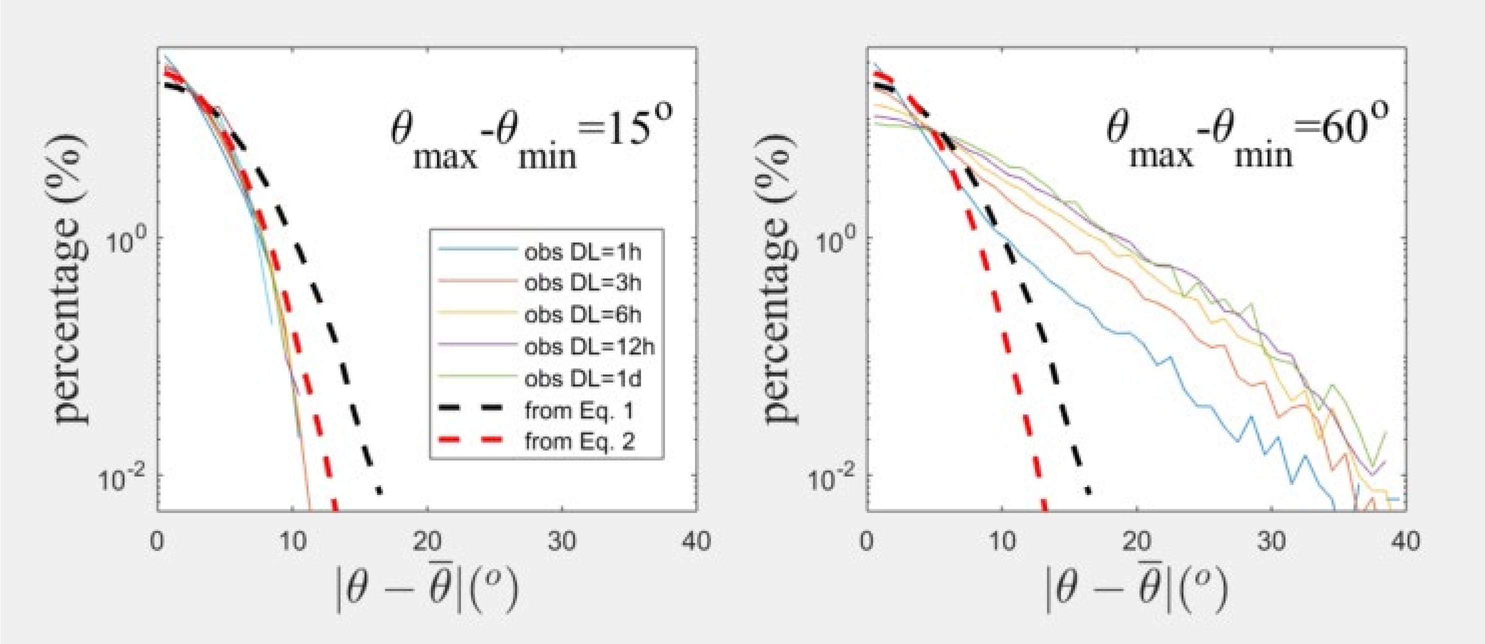

Fig. 3. The distribution of direction deviation with groups of observation data that satisfy: (left) the largest direction difference is 15^o and (right) 60^o, with data length (DL) from 1 h to 1 day.

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^o (stationary), but significantly underestimate the directional change for non-stationary situations.

The results:

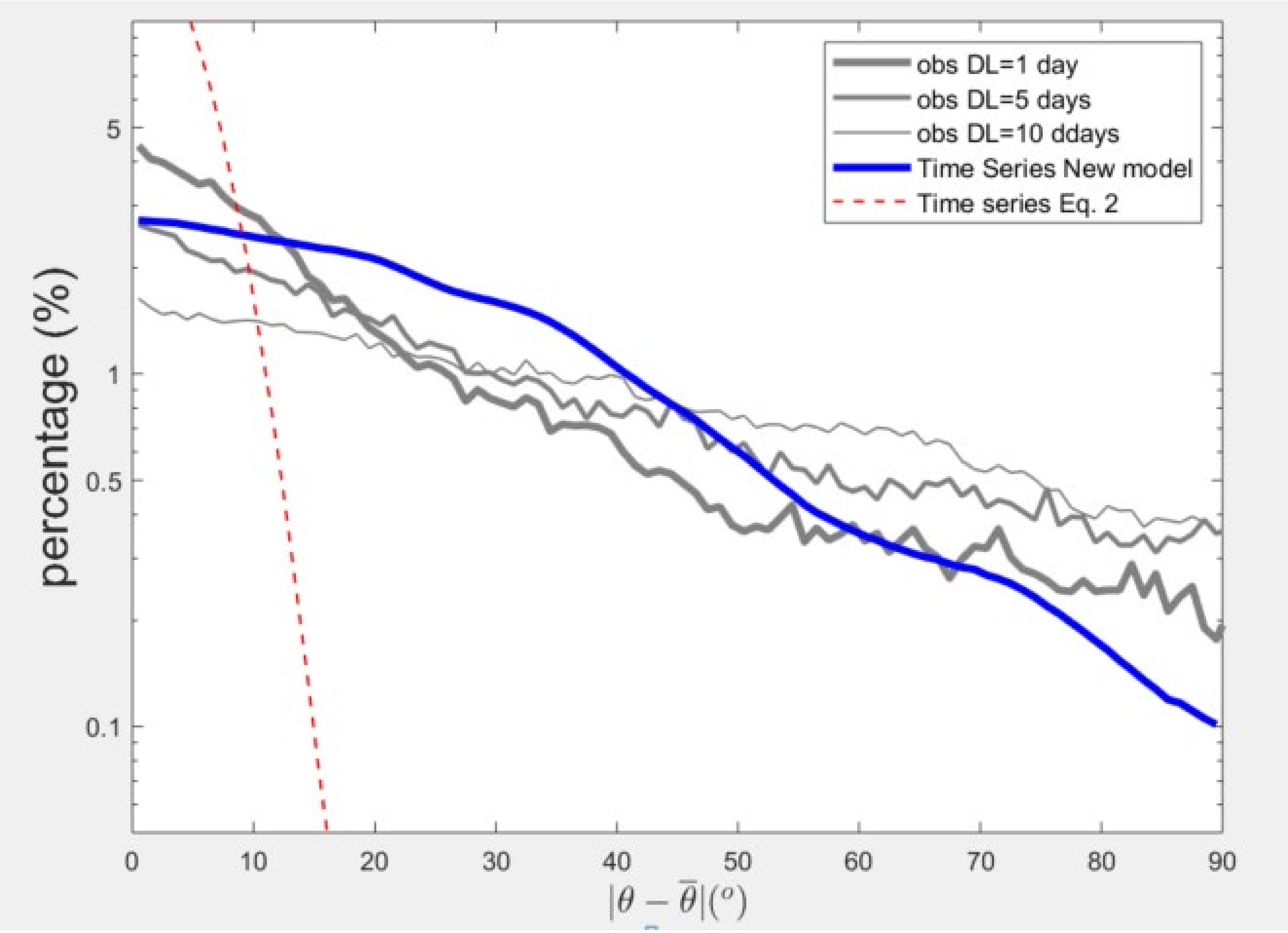

Fig. 4. Deviation of direction distribution, from measurements (gray curves) and from models. The new spectral model (blue curve) provides much improved estimation for non-stationary condition (an example of data length DL= 5 days) in comparison with the boundary-layer model Eq. 2 (red dashed curve).

The conclusion:

- We defined a mesoscale version of the lateral, v-spectrum, extending the description of v-variability 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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