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Shadowing effects of offshore wind farms - an idealised mesoscale study

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Publication date:
2013

Citation (APA):
Volker, P., Badger, J., & Hahmann, A. N. (2013). Shadowing effects of offshore wind farms - an idealised mesoscale study [Sound/Visual production (digital)]. Danish Wind Power Research 2013, Fredericia, Denmark, 27/05/2013

Shadowing effects of offshore wind farms - an idealised mesoscale study

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Wind Farm Interaction

Wind Farm (WF) interaction is already an issue (e.g.):

- Hornsrev I – Hornsrev II
- Rødsand 2 – Nysted

Large scale effects on the WF wake advection are not negligible anymore
$\Rightarrow$ Mesoscale Models are a suitable solution.

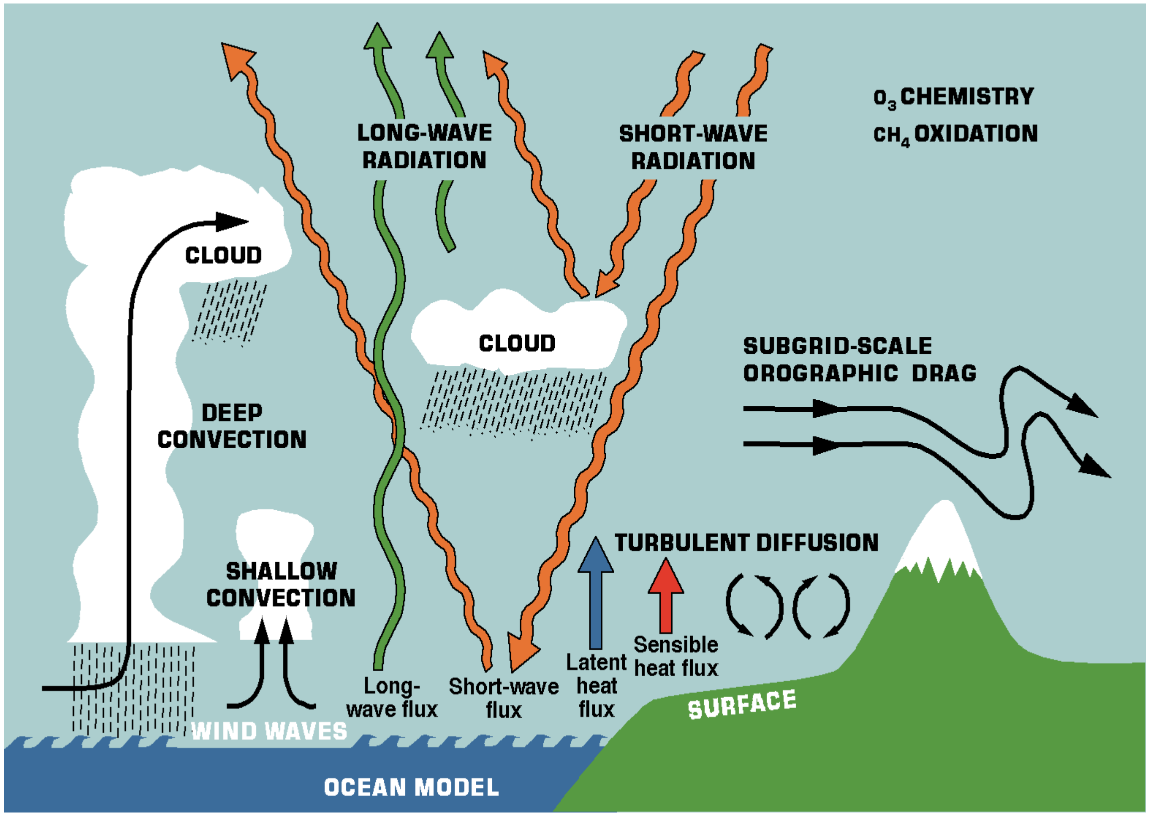
Drawback: Single turbine wakes cannot be resolved! ($D_0 \ll \Delta x$)

Possible solutions:

(1) WF from microscale model & Mesoscale model as a wake transport medium

(2) WF "parametrised" inside mesoscale model

Mesoscale Model



Horizontal scale: $\Delta x \sim km$

Vertical scale: $\Delta z \sim 10m$ (Boundary layer)

Time step: $\leq \Delta x/|U|$

Unresolved processes to be parametrised:

Radiation

Micro physics

Vertical mixing (turbulence & convection)

... Wind turbines

Wind Farm Parametrisation

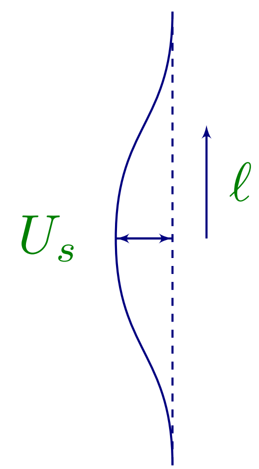
From the diffusion equation, one can obtain the typical length scale ℓ:

(1) $$\ell^2 = \frac{2K_m}{U_0}x + \ell_0^2$$

- K_m is the turbulence coefficient for momentum
- ℓ_0 the initial length scale
- U_0 background hub-height velocity

Assumption: In the far wake the ensemble average will be Gaussian. then U becomes:

(2) $$\underbrace{U(z)}_{\text{Wake velocity}} = \underbrace{U_0(z)}_{\text{Upstream velocity}} - \underbrace{U_s f(z)}_{\text{Velocity deficit}}$$ where $f = e^{-\frac{1}{2}\left(\frac{z}{\ell}\right)^2}$.



Using (2) we can obtain U_s from the thrust equation:

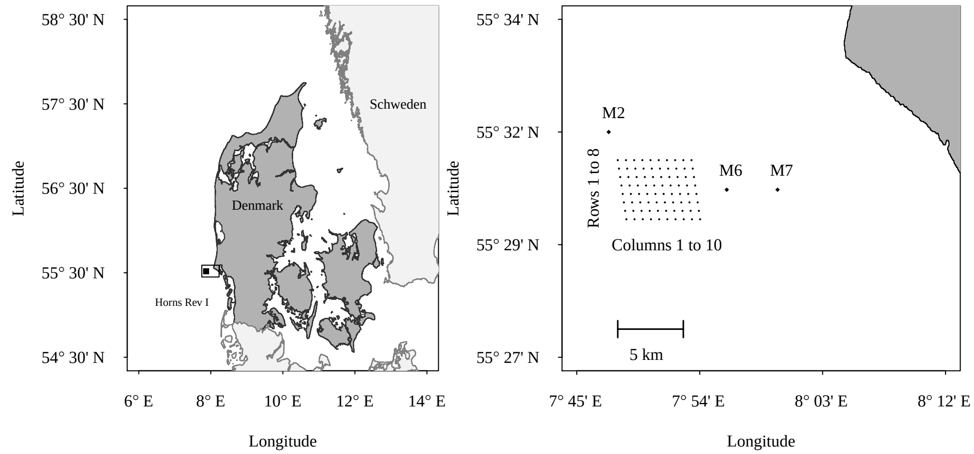
$$\frac{1}{2}\rho\, C_t\, A_0\, U_0^2 = W\, \rho \int_0^{z_{\max}} U_0(U_0 - U)\, dz$$

- C_t is obtained from the thrust curve
- W is the width of the wake
- z_{max} is the height of the domain

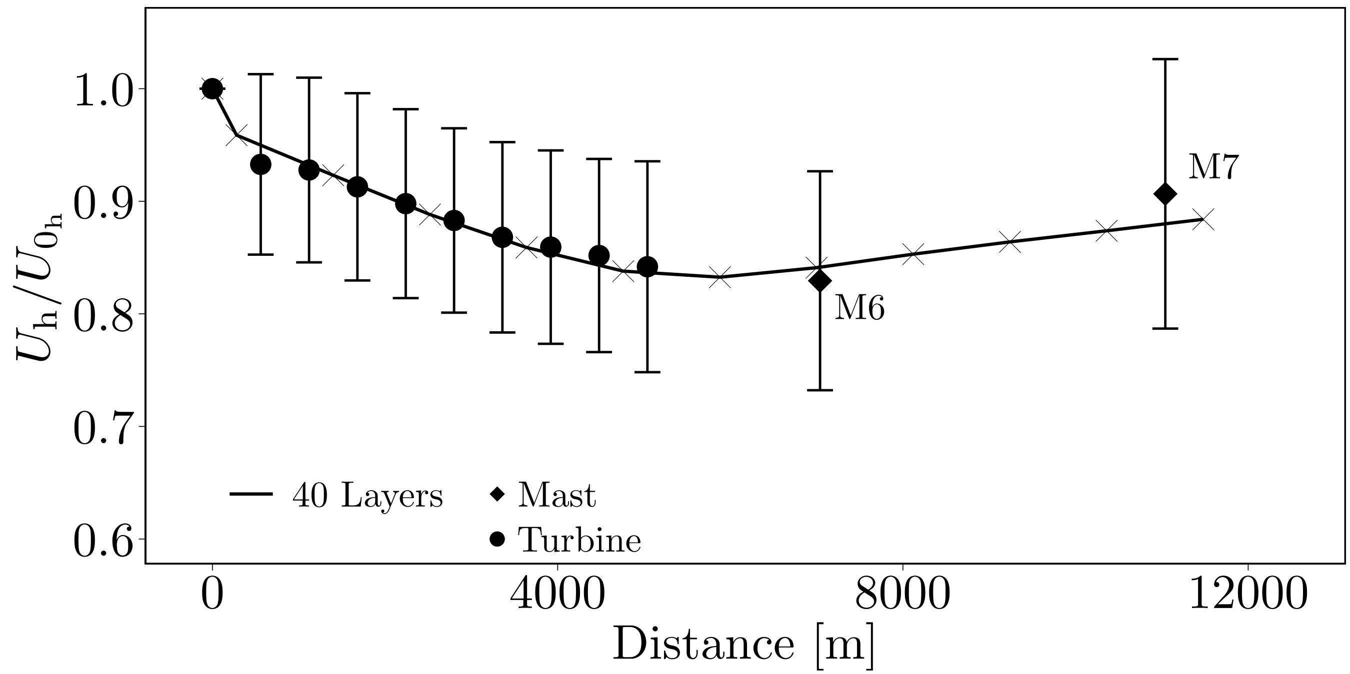
Evaluation for Horns Rev I (80$\times$ 2MW)

Model resolution: $\Delta x = 1.12km$

	$\overline{U}\ (m/s)$	$\theta\ (°)$
Obs:	8 ± 0.5	270 ± 15
Model:	8	270



Plot: Velocity deficit U_h/U_{0_h} VS downstream distance (Volker et al. 2013)
U_{0_h} is the upstream and U_h the downstream hub wind velocity.



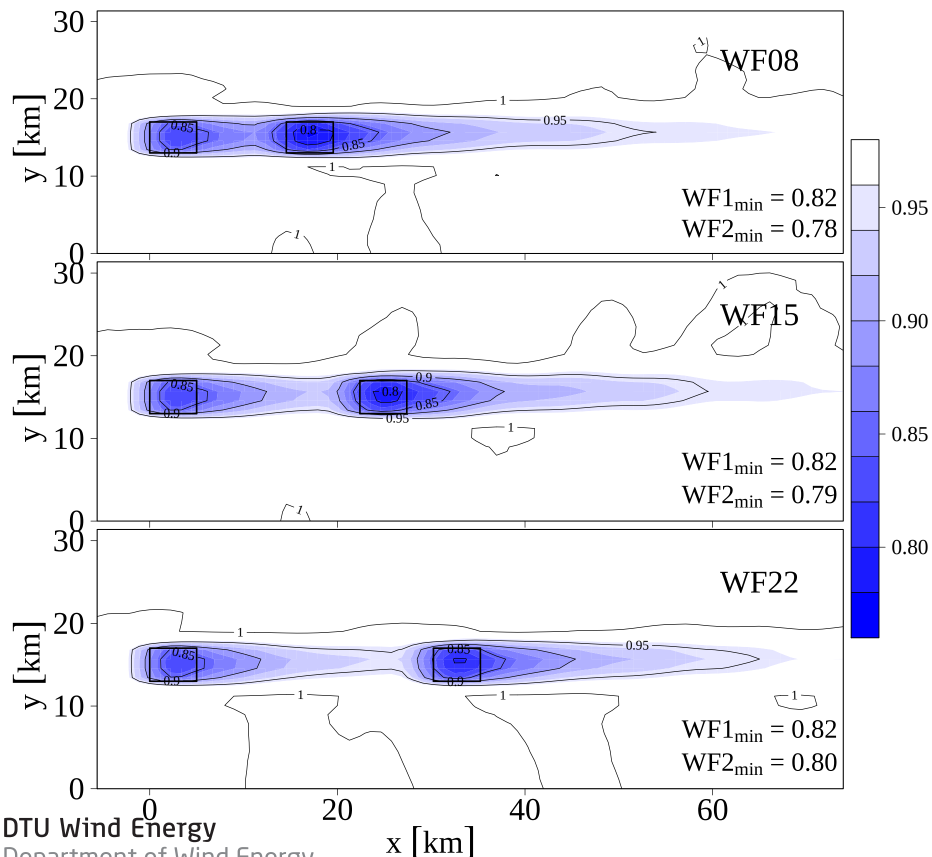
Volker, P. J., Badger, J., Hahmann, A. N., Ott, S. Implementation and evaluation of a wind farm parametrisation in a mesoscale model. To be submitted.

Wind Farm Interaction - and idealised case study

Horizotal resolution $\Delta x = 1.12$ km. $\overline{U} = 8m/s$ and $\theta = 270°$. WF size 80× 2MW

Run	WF Separation (km)	P_{down}/P_{up}
WF08	8×1.12	0.80
WF15	15×1.12	0.86
WF22	22×1.12	0.91

Velocity Deficit: U/U_0



Power Production: $P = \frac{1}{2}\rho C_P \pi R_0^2 U_0^3$