

Shadowing effects of offshore wind farms - an idealised mesoscale study

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Shadowing effects of offshore wind farms - an idealised mesoscale study

Patrick Volker, Jake Badger & Andrea Hahmann
DTU Wind Energy

Wind Farm Interaction

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

- Hornsrev I – Hornsrev II
- Rødsand 2 – Nysted

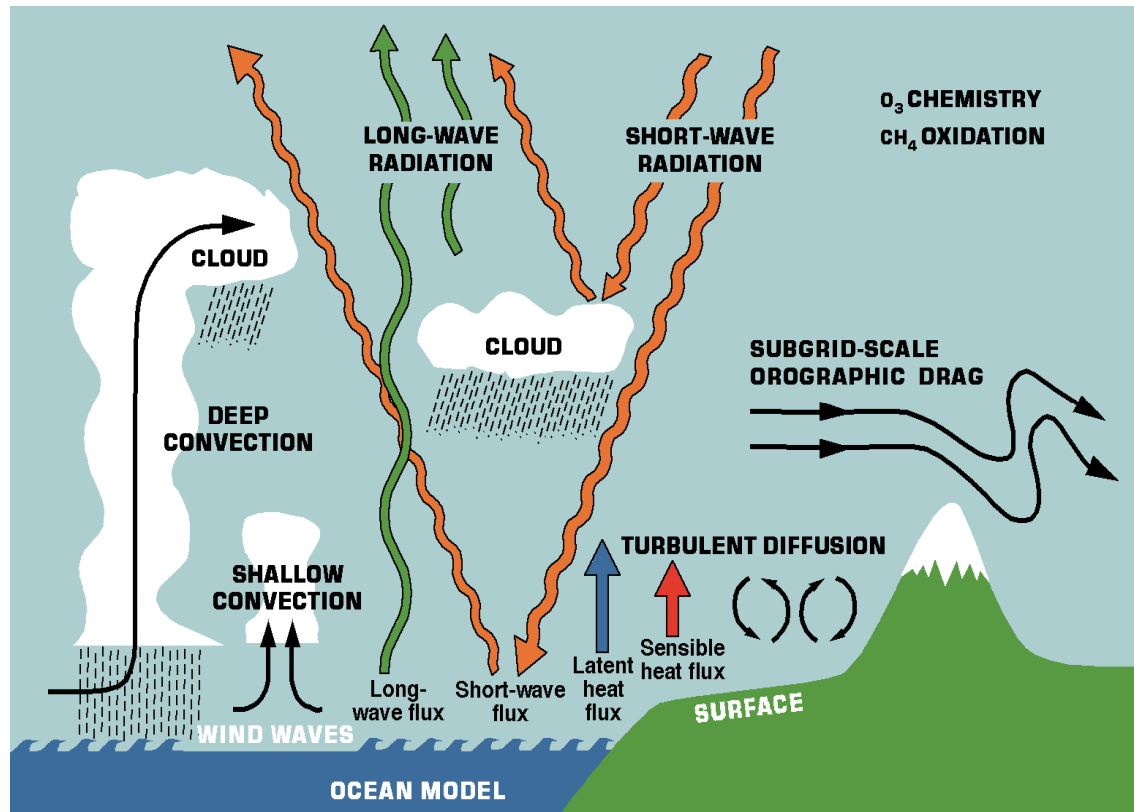
Large scale effects on the WF wake advection are not negligible anymore
⇒ Mesoscale Models are a suitable solution.

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

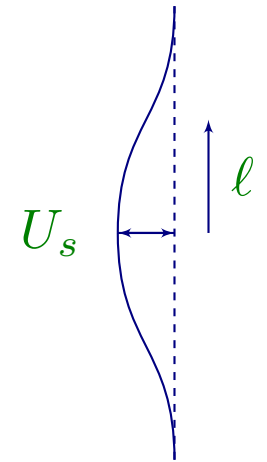
Wind Farm Parametrisation

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

$$(1) \quad \ell^2 = \frac{2K_m}{U_0}x + \ell_0^2 \quad \left\{ \begin{array}{l} K_m \text{ is the turbulence coefficient for momentum} \\ \ell_0 \text{ the initial length scale} \\ U_0 \text{ background hub-height velocity} \end{array} \right.$$

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

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



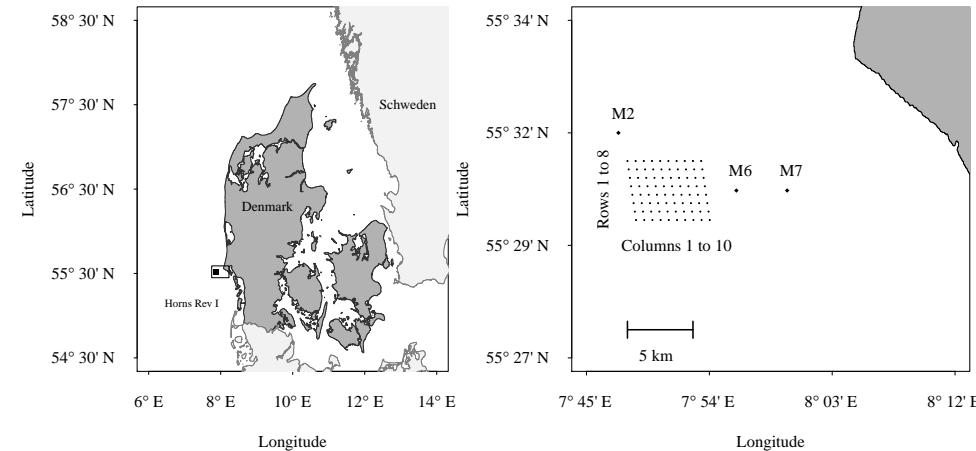
Using (2) we can obtain U_s from the thrust equation:

$$\frac{1}{2}\rho C_t A_0 U_0^2 = W \rho \int_0^{z_{\max}} U_0(U_0 - U) dz \quad \left\{ \begin{array}{l} C_t \text{ is obtained from the thrust curve} \\ W \text{ is the width of the wake} \\ z_{\max} \text{ is the height of the domain} \end{array} \right.$$

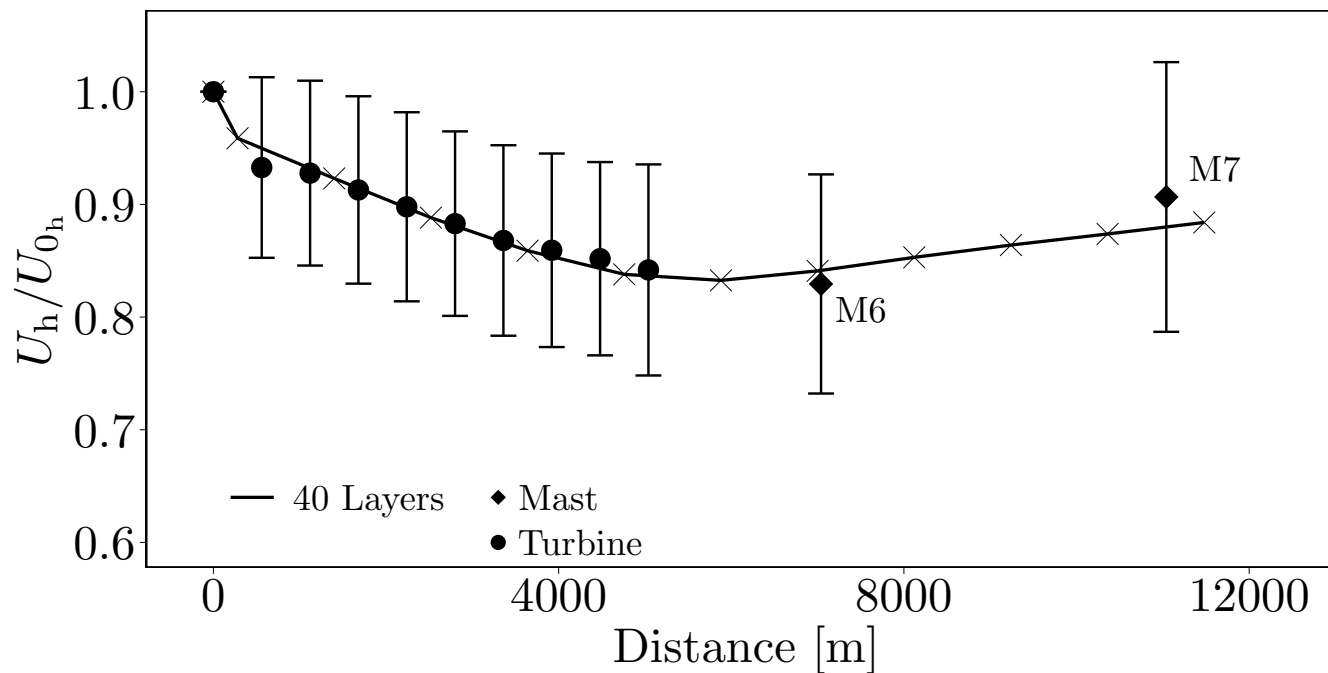
Evaluation for Horns Rev I (80 × 2MW)

Model resolution: $\Delta x = 1.12 \text{ km}$

| | \bar{U} (m/s) | θ (°) |
|--------|-----------------|--------------|
| Obs: | 8 ± 0.5 | 270 ± 15 |
| Model: | 8 | 270 |



Plot: Velocity deficit U_h/U_{0h} VS downstream distance (Volker et al. 2013)
 U_{0h} 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

Horizontal resolution $\Delta x = 1.12$ km. $\bar{U} = 8\text{m/s}$ and $\theta = 270^\circ$. WF size $80 \times 2\text{MW}$

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

