Shadowing effects of offshore wind farms - an idealised mesoscale study

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Shadowing effects of offshore wind farms - an idealised mesoscale study

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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 $\ell$:

\begin{equation}
\ell^2 = \frac{2K_m}{U_0} x + \ell_0^2
\end{equation}

\begin{align*}
K_m & \text{ is the turbulence coefficient for momentum} \\
\ell_0 & \text{ the initial length scale} \\
U_0 & \text{ background hub-height velocity}
\end{align*}

**Assumption:** In the far wake the ensemble average will be Gaussian. Then $U$ becomes:

\begin{equation}
U(z) = U_0(z) - U_s f(z) \quad \text{where } f = e^{-\frac{1}{2}(\frac{z}{\ell})^2}
\end{equation}

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

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

\begin{align*}
C_t & \text{ is obtained from the thrust curve} \\
W & \text{ is the width of the wake} \\
z_{\text{max}} & \text{ is the height of the domain}
\end{align*}
Evaluation for Horns Rev I (80 × 2MW)

Model resolution: $\Delta x = 1.12 km$

<table>
<thead>
<tr>
<th></th>
<th>$\bar{U} (m/s)$</th>
<th>$\theta (^\circ)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obs</td>
<td>8 ± 0.5</td>
<td>270 ± 15</td>
</tr>
<tr>
<td>Model</td>
<td>8</td>
<td>270</td>
</tr>
</tbody>
</table>

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. $\overline{U} = 8 \text{m/s}$ and $\theta = 270^\circ$. WF size $80 \times 2\text{MW}$

<table>
<thead>
<tr>
<th>Run</th>
<th>WF Separation (km)</th>
<th>$P_{\text{down}}/P_{\text{up}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>WF08</td>
<td>$8 \times 1.12$</td>
<td>0.80</td>
</tr>
<tr>
<td>WF15</td>
<td>$15 \times 1.12$</td>
<td>0.86</td>
</tr>
<tr>
<td>WF22</td>
<td>$22 \times 1.12$</td>
<td>0.91</td>
</tr>
</tbody>
</table>

**Velocity Deficit:** $U/U_0$

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

- $P_{\text{WF08}} = 40.9\text{MW}$
- $P_{\text{WF15}} = 41.3\text{MW}$
- $P_{\text{WF22}} = 37.1\text{MW}$

*Images show the distribution of velocity deficit and power production for different wind farm separations.*