Shadowing effects of offshore wind farms - an idealised mesoscale model study

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Shadowing effects of offshore wind farms - an idealised mesoscale model study

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Introduction

The study of wind farm (WF) interaction is expected to gain importance, since the offshore wind farm density will increase especially in the North Sea in the near future. We present preliminary results of wind farm interaction simulated by mesoscale models. We use the Explicit Wake Parametrisation (EWP) parametrisation developed at DTU Wind Energy.

EWP-Parametrisation

In the EWP scheme wind turbines (Volker et al., 2013) are treated as drag devices. Unlike other recently introduced approaches, no turbulence kinetic energy (TKE) is added to the flow, assuming a balance between turbulence production and its dissipation. Instead the sub-grid scale velocity deficit development is described by a turbulence diffusion process.

We assume that the Gaussian shaped far wake can be described by a single length scale $\ell(x)$ and velocity scale $U_s(x)$. From the diffusion equation we can obtain the Gaussian velocity deficit distribution

$$\Delta u(z) = e^{-\frac{1}{2}\left(\frac{z-h}{\ell}\right)^2} = U_s f(z), \quad (1)$$

where h is the hub height and z the height. The diagnostic equation for the length scale reads

$$\ell^2 = \left(\frac{2K_m}{U_0}\right) x + \ell_0^2, \quad (2)$$

where K_m is the turbulence diffusion constant, U_0 the hub height velocity x the downstream distance and ℓ_0 the initial length scale. From the thrust equation

$$\frac{1}{2}\rho C_T A_0 U_0^2 = W\rho \int_0^{z_{\max}} U_0 (U_0 - U)\, dz, \quad (3)$$

where W is the wake width, C_T the thrust coefficient and U the horizontal velocity, we obtain finally

$$U_s = \sqrt{\frac{\pi}{2}} \frac{C_T R_0^2 U_0}{2W\ell} \quad (4)$$

The right hand side of Eq.(3) is applied to the model velocity tendency.

Model Set Up

Model idealised simulation set-up	
Domain (nx,ny):	80 × 30
Domain (nz):	40
Horizontal grid spacing:	Δ x = 1120 m
PBL-Scheme:	MYNN (1.5)
Coriolis perturbation	ON

No lateral boundary forcing and zero surface flux are used. The initial geostrophic wind was constant with height and converged to a westerly wind of $8\,\mathrm{m\,s^{-1}}$ at hub height.

WF interaction set-up

Run	WF Separation (km)
WF08	8×1.12
WF15	15×1.12
WF22	22×1.12

References/Funding

References

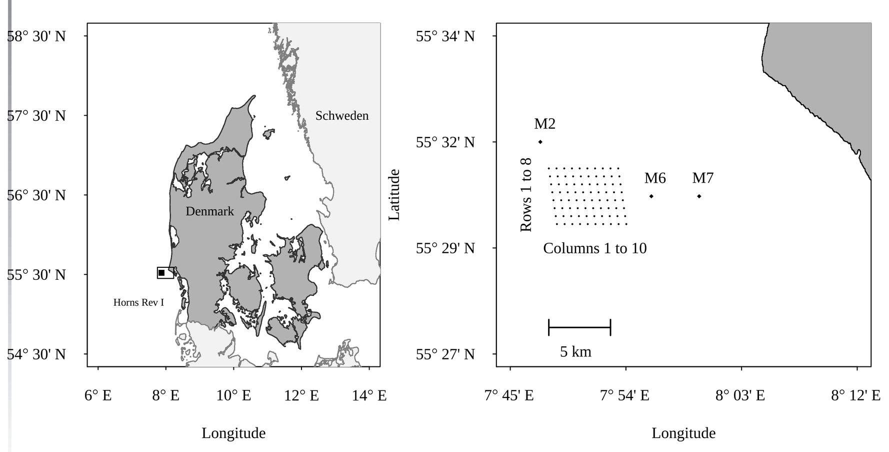
Volker, P. J., Badger, J., Hahmann, A. N., Ott, S. Implementation and evaluation of a wind farm parametrisation in a mesoscale model. To be submitted.

Funding

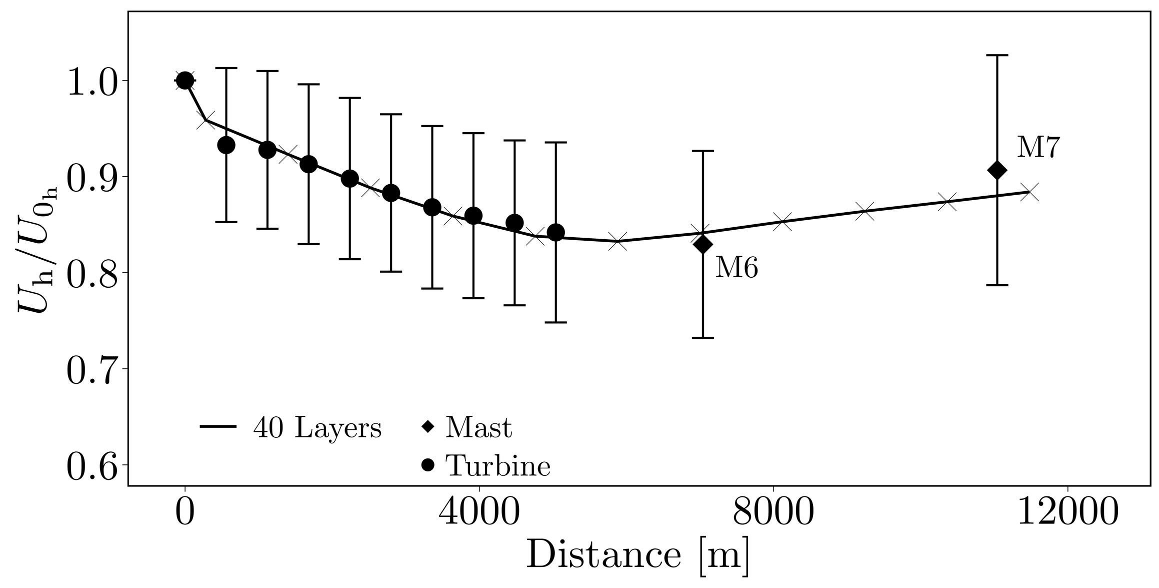
WAUDIT-Project (Marie Curie ESR)

EWP Evaluation

Comparison between long term measurements from Horns Rev I (80× 2MW) and the WRF model with EWP scheme using the same set-up as shown in the table. Horns Rev I:

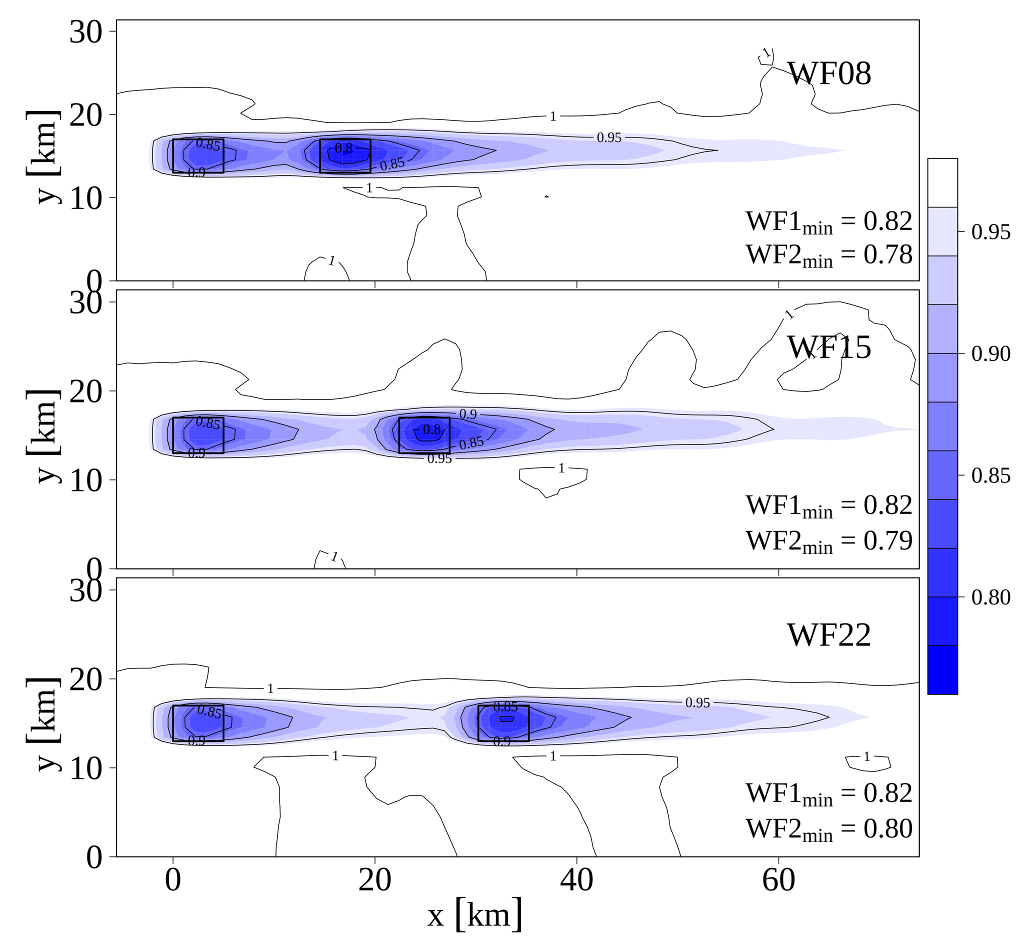


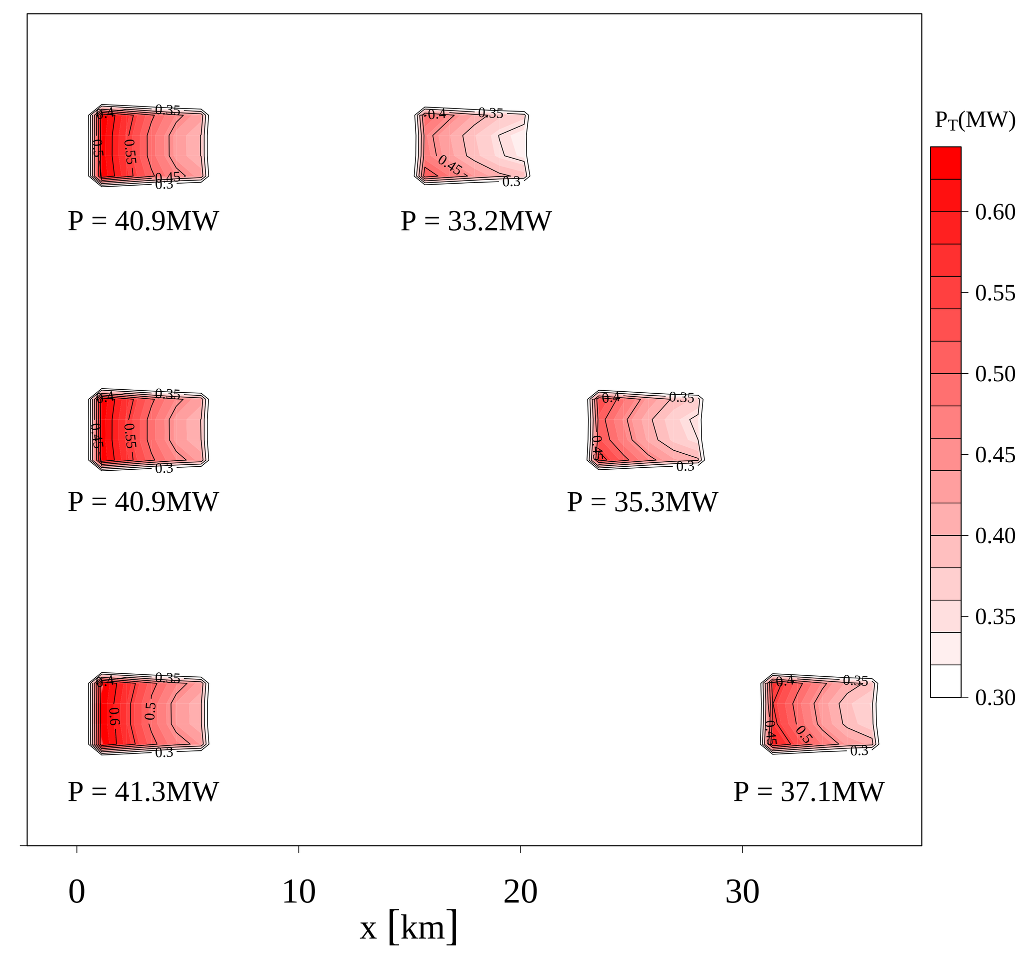
Below the velocity deficit U_h/U_{0_h} is plotted as in Volker et al. (2013), as a function of the downstream distance. U_{0_h} is the upstream and U_h the downstream hub wind velocity. The line represents the model simulation, whereas the dots represent the measurements. The error bars are the measurements' standard deviations.



Results

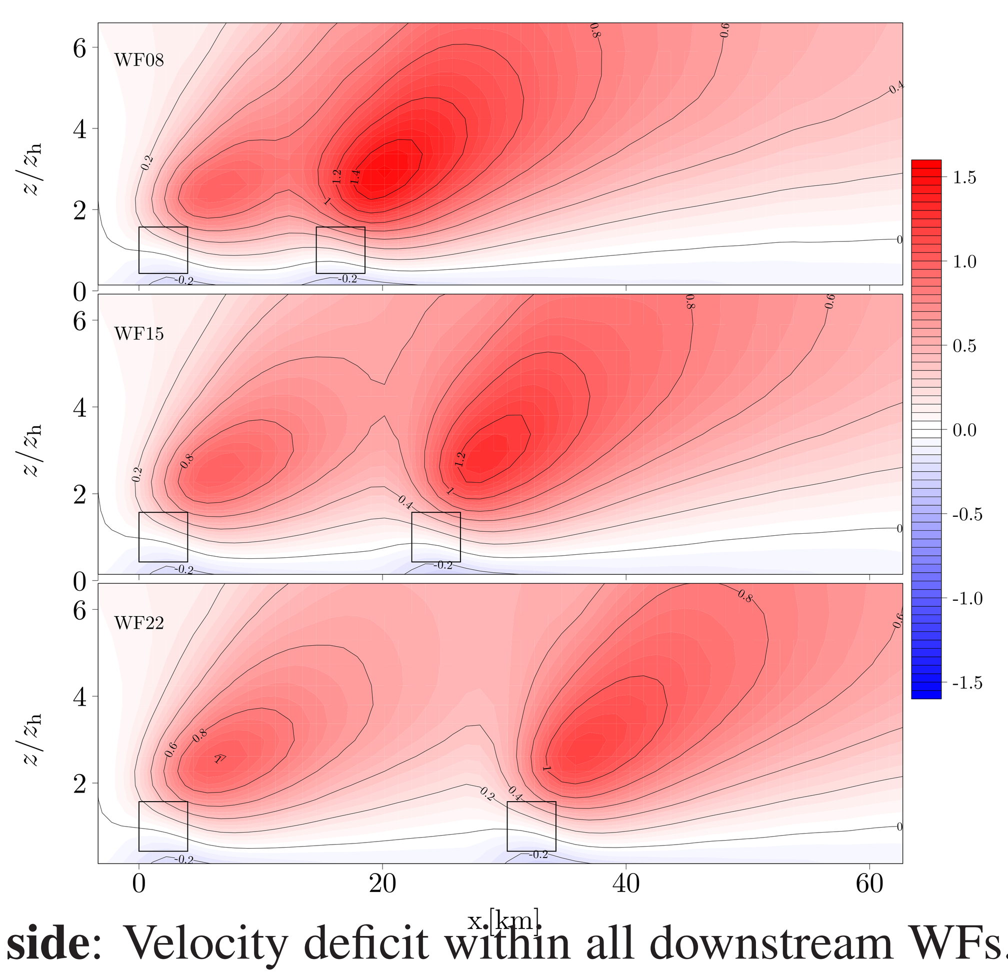
Left side: The velocity deficits for the WF08, WF15 and WF22 run, from top to bottom, are plotted. The WFs are marked by a rectangular box. The velocity deficit is the ratio between the WF run and the reference run without WF. In the WF08 run the downstream wind farm is still in the deep wake of the upstream one, causing a larger velocity deficit at the downstream WF with respect to the other runs.

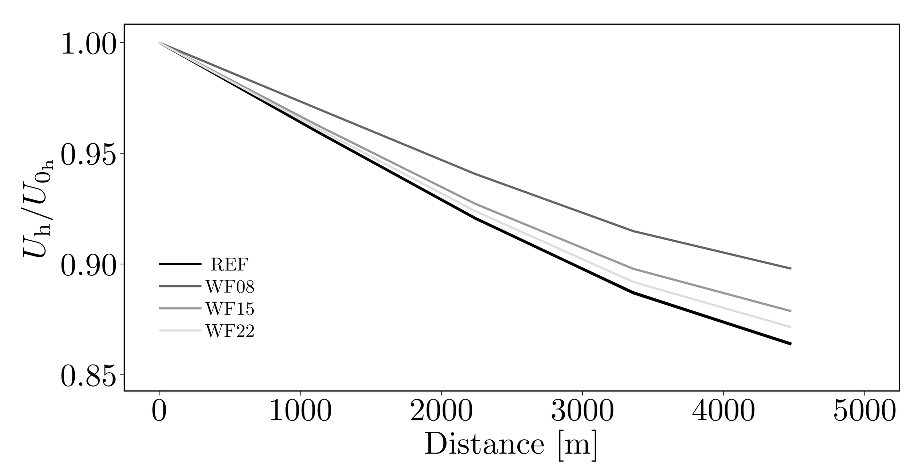




Right side: The power production P from the WF08, WF15 and WF22 run, from top to bottom. For the production, $P = 0.5\rho C_P \pi R_0^2 U_h^3$, where ρ is the air density, U_h the hub height (70.9 m) velocity and C_P the turbine power coefficient. The upstream WF production depends slightly on the WF separation. In this study the power deficit, at the second WF is almost a linear function of the distance. The power deficit is 0.8, 0.86 and 0.91 for the WF08, WF15 and the WF22 simulations.

Left side: We show the normalised turbulence kinetic energy (TKE) reduction, $(\mathrm{TKE_{WF}} - \mathrm{TKE_{REF}})/\mathrm{TKE_{REF}}$ as a function of the downstream distance for a slice passing through the WF. We find that the turbulence levels depend on the WF spacing and is higher at the downstream WF. The turbulence increase is a function of an enhanced shear in the vertical profile.





Right side: Velocity deficit within all downstream WFs. The WF grid cell velocities have been normalised with the first turbine containing grid cell. We find that a lower velocity deficit in the downstream WF of the WF08 compared to the other WF configurations. The reduced turbine interaction probably caused by the enhanced turbulence mixing. This effect, anyhow, is not able to compensate for the reduced upstream WF velocity.

Conclusions

In this first results we find that in the simulations the power deficit was significant in all simulations. Even at a distance of 22×1.12 km WFs with a size of Horns Rev I will affect the downstream WF. We have, however, to consider that the WF interaction is simulated for a steady wind direction, which means that for example in the WF22 simulation this would require an unchanged wind direction for at least 30 minutes with an upstream wind speed of $8\,\mathrm{m\,s^{-1}}$.