

Experimental investigation of wind farm flow effects

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Wind farm blockage in the media



The screenshot shows the Windpower Monthly website. The main article is titled "Ørsted admits overestimating output, downgrades long-term targets". The article text includes: "It reduced its targeted 'unlevered lifecycle' internal rate of return (IRR), capacity-weighted for seven of its wind farms from 7.5-8.5% to 7.0-8.0%." The phrase "7.5-8.5%" is circled in red. Other text in the article includes: "After analysing 'a long list of variables' to better understand its production forecasts, Ørsted concluded its current production forecasts underestimated blockage effect — wind speed slowing as it approaches turbines — and wake effect." and "The lower-than-expected production figures prompted the developer to revise its expected potential profit for seven projects."

Wind power monthly, 29.10.2019



The screenshot shows the Dagens Næringsliv website. The main article is titled "Her er vindfenomenet som rystet offshore-giganten". The article text includes: "Har overvurdert energien som produseres av vindmølleparkene." and "Den danske offshore-giganten Ørsted nedjusterte nylig sine langsiktige økonomiske forventninger på grunn av ny kunnskap om to vindfenomener i vindmølleparker, skriver Danske Ingeniøren." Below the text is a photograph of a large offshore wind farm with many turbines visible against a cloudy sky.

Dagens Næringsliv, 6.11.2019

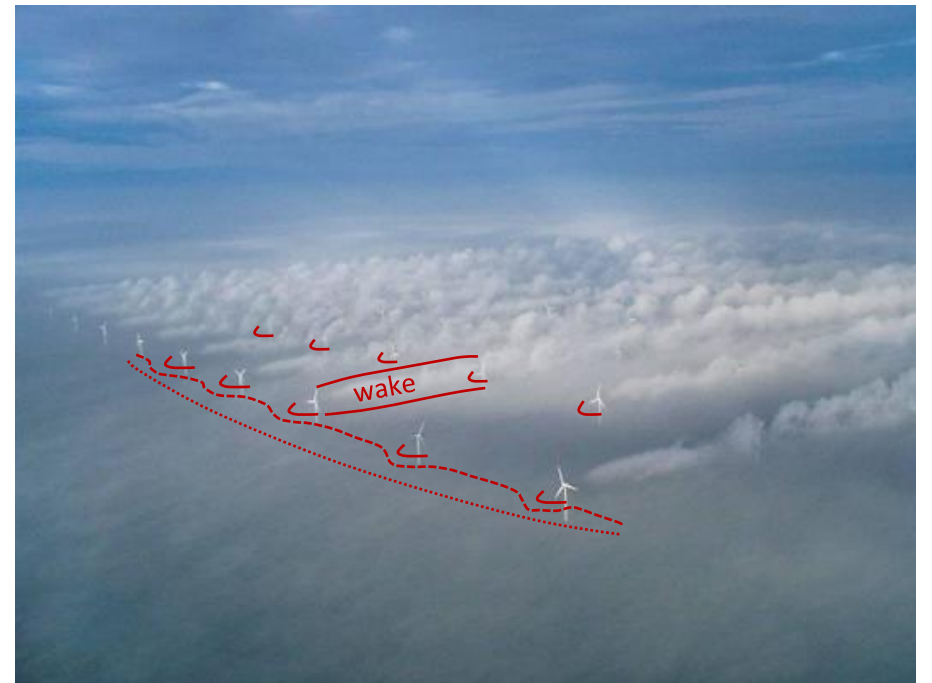
What is *wind farm blockage*?

Press release by Ørsted, Oct 2019

- The blockage effect arises from the **wind slowing down** as it approaches the wind turbines.
- There is an **individual blockage effect** for every turbine and a **global effect** for the whole wind farm, **which is larger than the sum of the individual effects**.

Industry consultant DNV, Oct 2019

- Wind simulation models have **underestimated** these effects
- Wind farm blockage losses represent **0% to 4% of mean annual energy yield**.



Photograph of the Horns Rev 1 wind farm from southeast.
Courtesy Vattenfall. Photographer: Christian Steiness

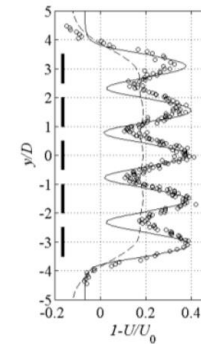
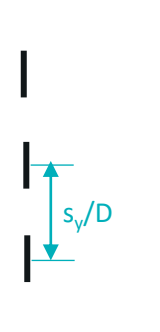
Research objectives

Influence on wind farm flow field by

- Turbine separation
- Turbine numbers and rows
- Turbine layout (aligned / offset)

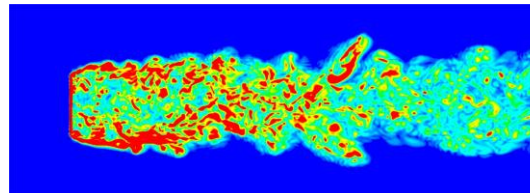
Validation data for computational models

- Flow superposition modelling
- Computational fluid dynamics modelling
(*Detached Eddy Simulation DES*)



$$\Delta U_w = \sum_{i=1}^k \Delta U_i$$

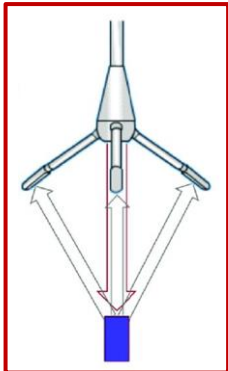
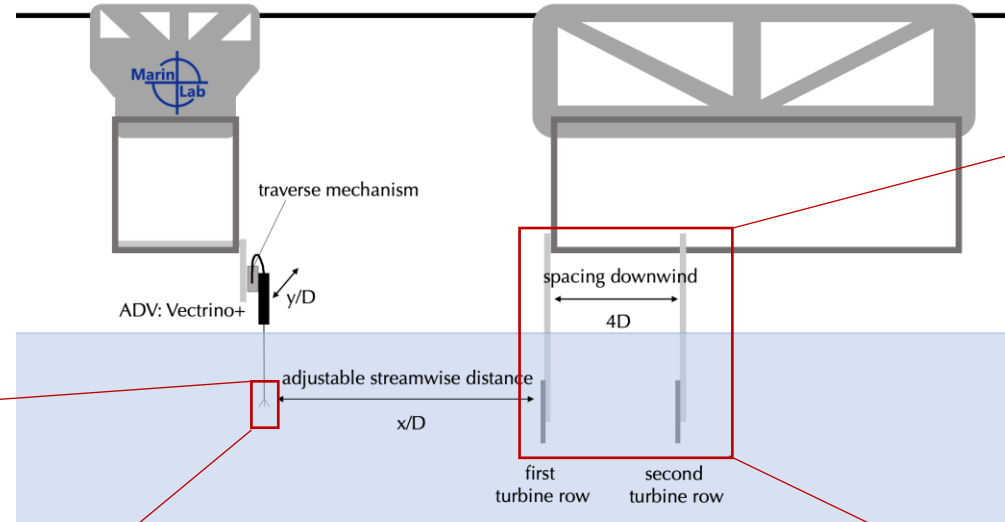
Comparison of actual wake behind a five-rotor array and a superposition model (David Lande-Sudall)



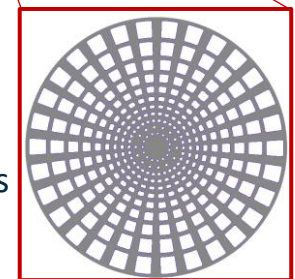
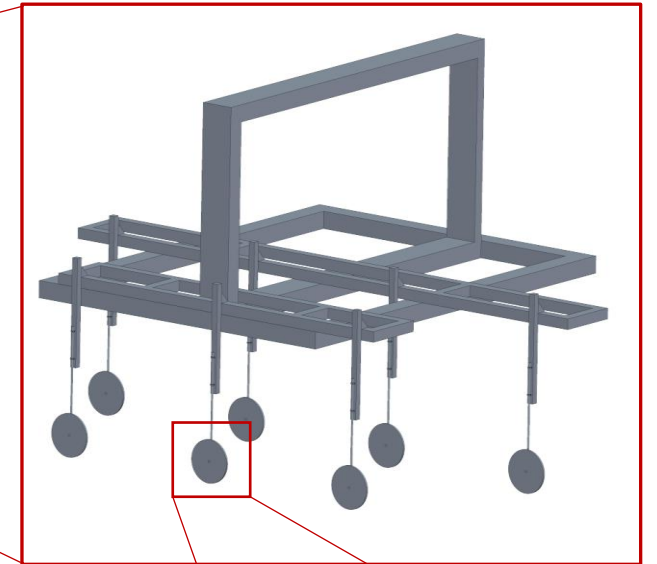
Instantaneous vorticity in a porous disc's wake, DES simulation (Gloria Stenfelt)

Experimental setup

MarinLab towing tank
(50m x 3.0m x 2.2m)
at HVL, Bergen, Norway



Vectrino+
Acoustic
Doppler
Velocimeter



Submerged
porous disc
represent rotors
 $C_T=0.90$

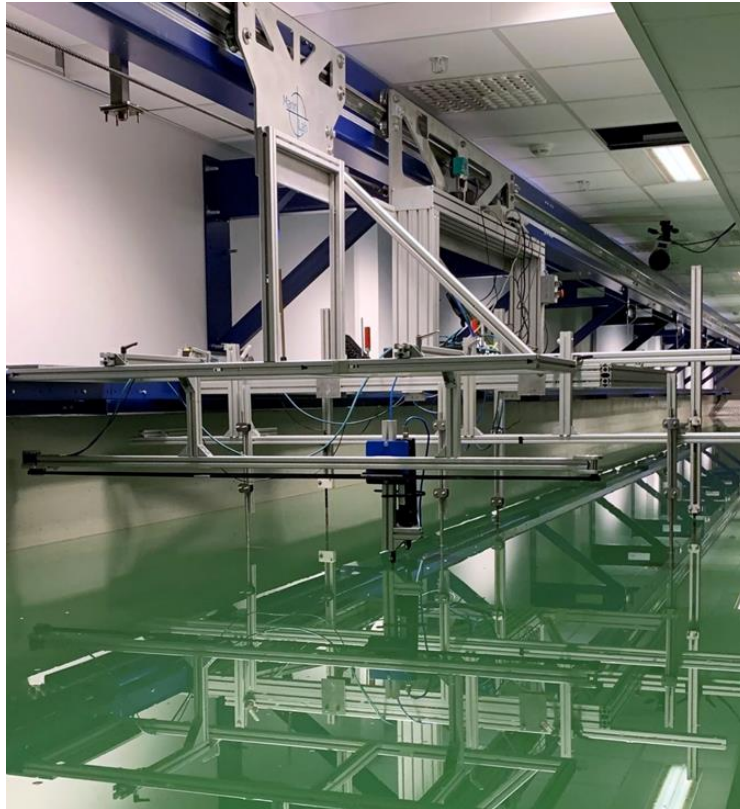


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Master's thesis, Ocean technology, UiB-HVL, 2022

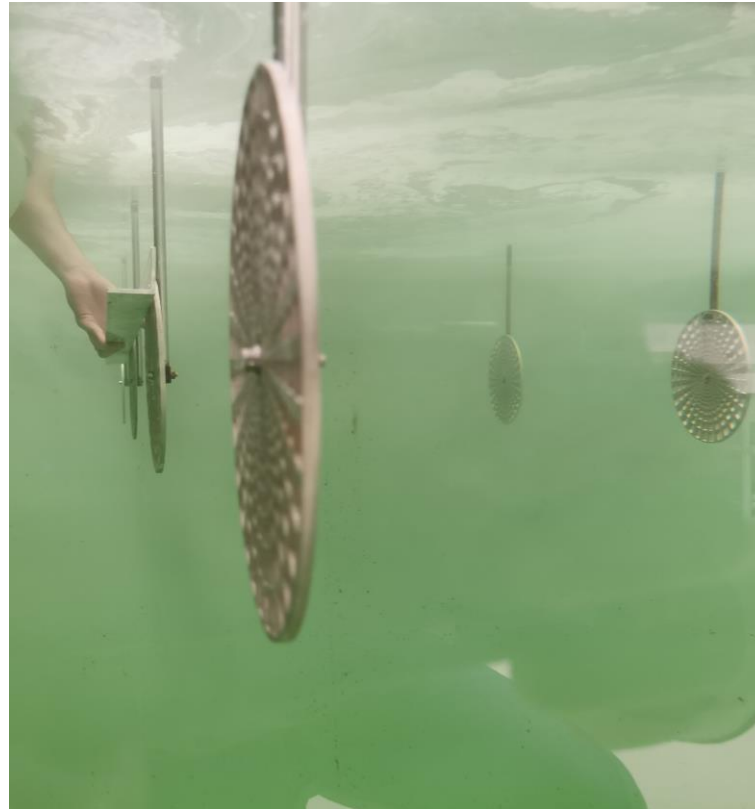


Høgskulen
på Vestlandet

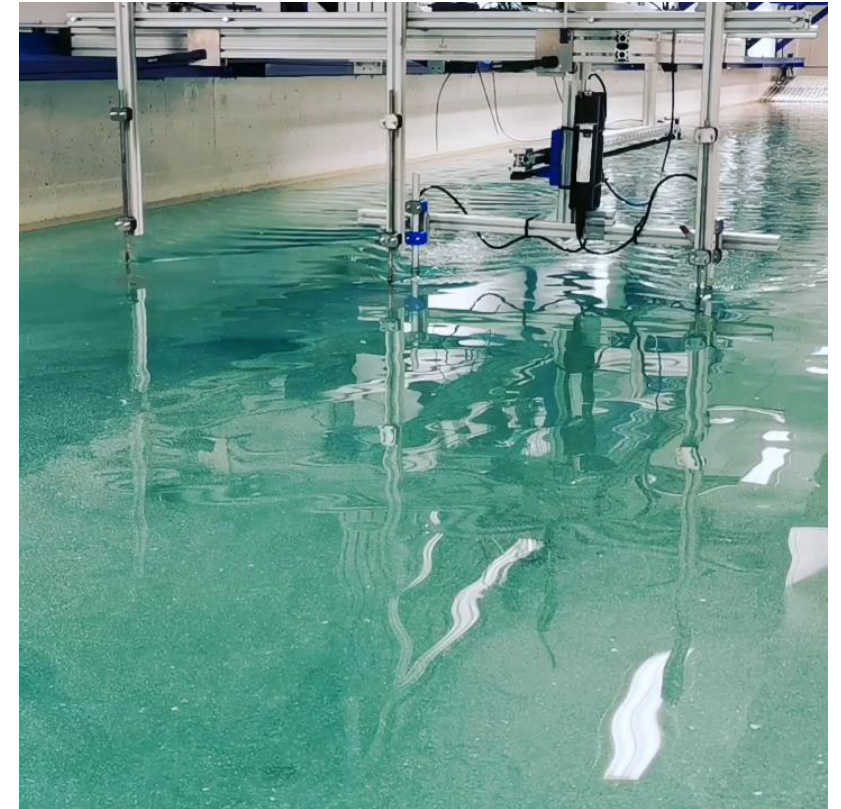
Experimental setup



WF6 setup in standstill



Installing WF7 setup

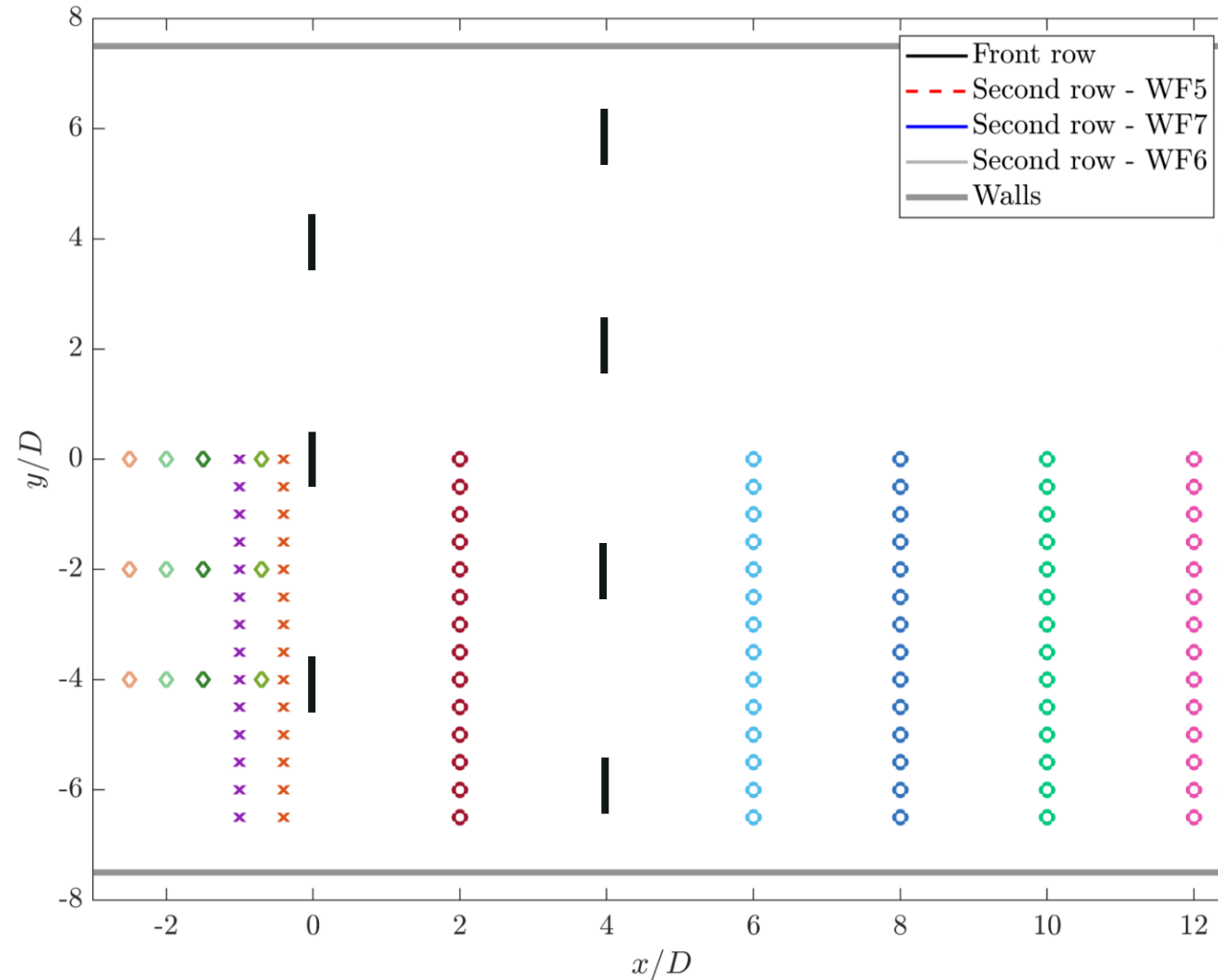


WF3 setup in towing

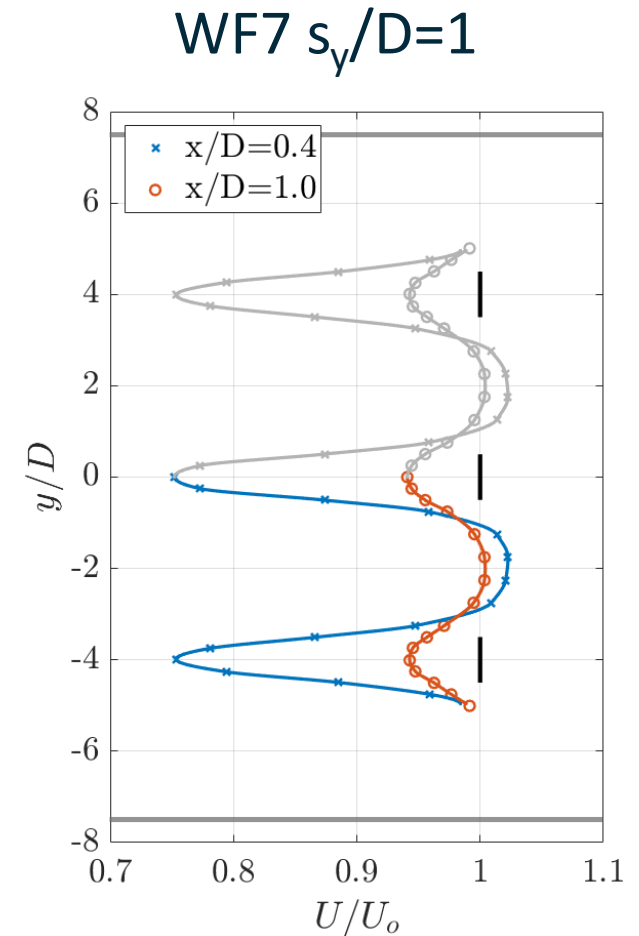
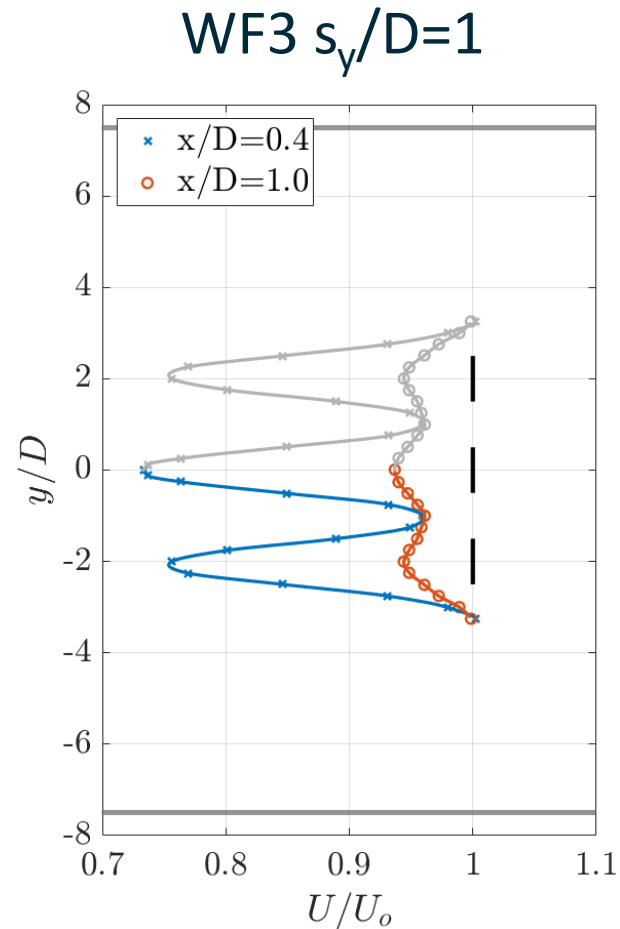
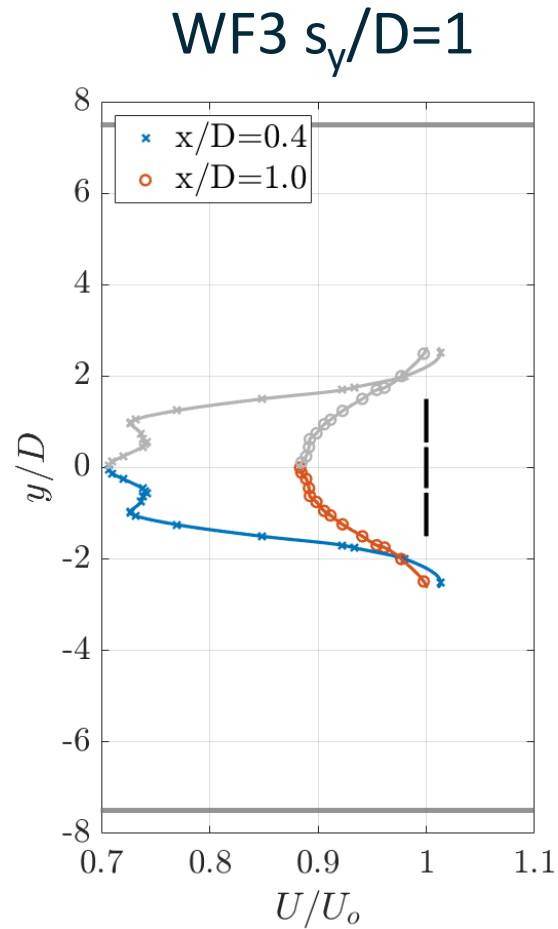
Measurement layout

Farm layouts tested:

- WF3 $s_y/D=1$
- WF3 $s_y/D=2$
- WF3 $s_y/D=4$
- WF5 $s_y/D=4$ *offset*
- WF6 $s_y/D=4$ *aligned*
- WF7 $s_y/D=4$ *offset*

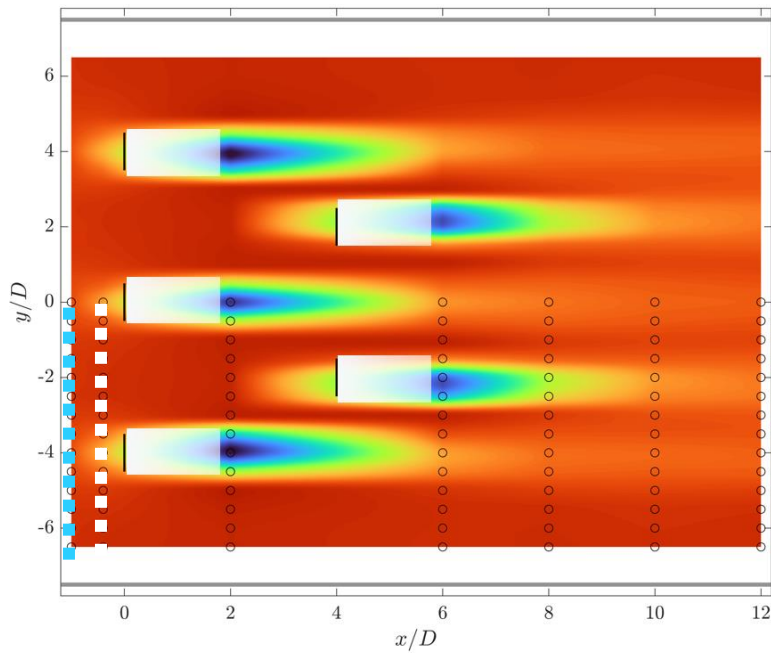


Upstream flow: one-rowed wind farm



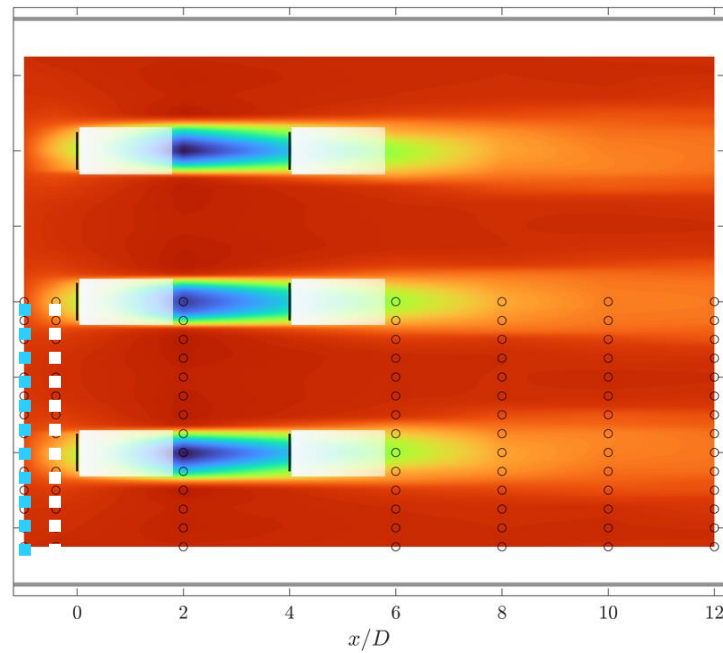
Full flow field: two-rowed wind farm

WF5



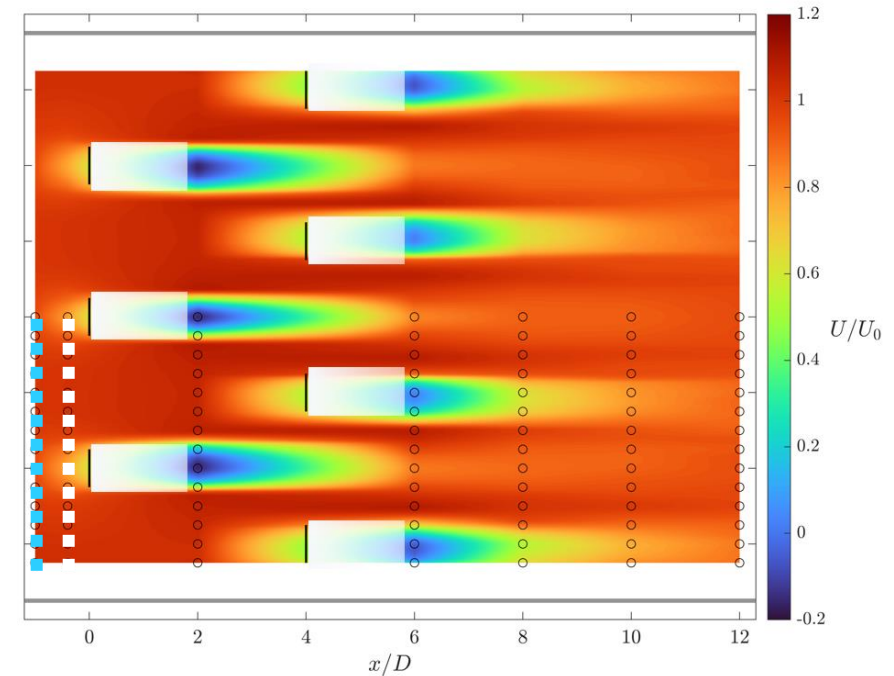
offset

WF6



aligned

WF7



offset



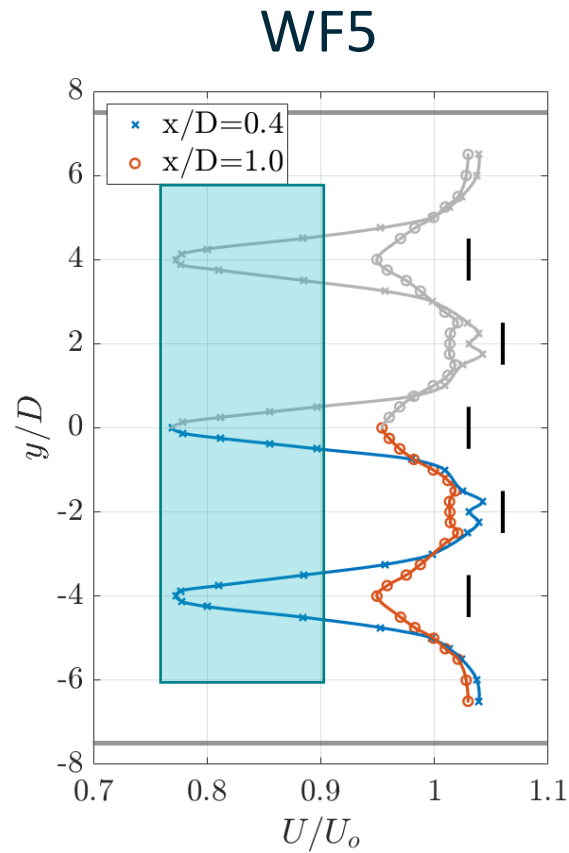
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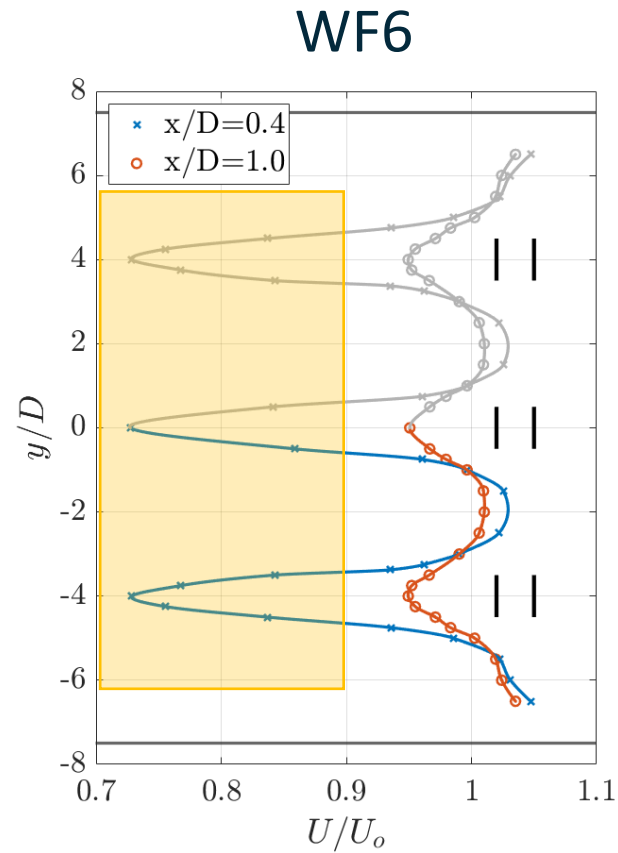
○ measurement locations

□ white boxes indicate locations with large interpolation errors

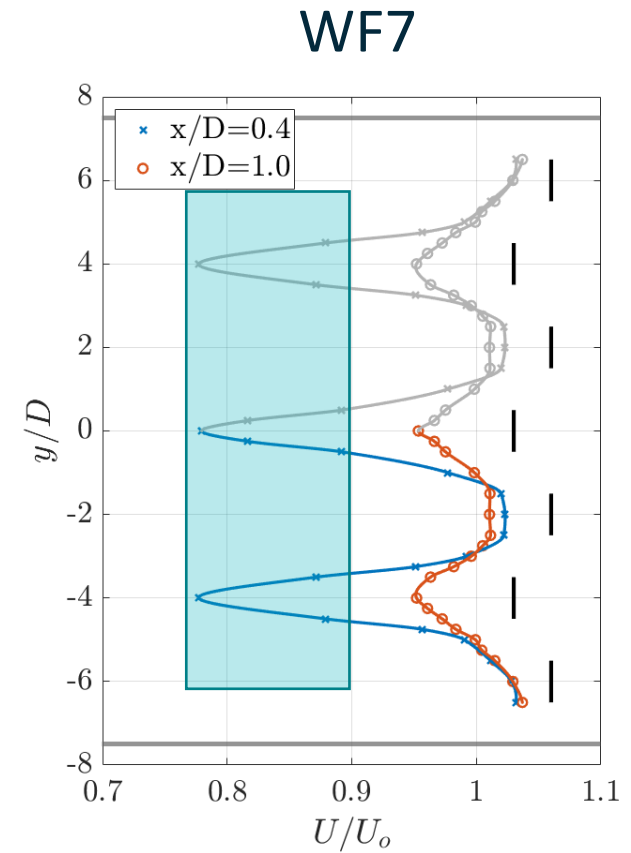
Upstream flow: two-rowed wind farm



offset



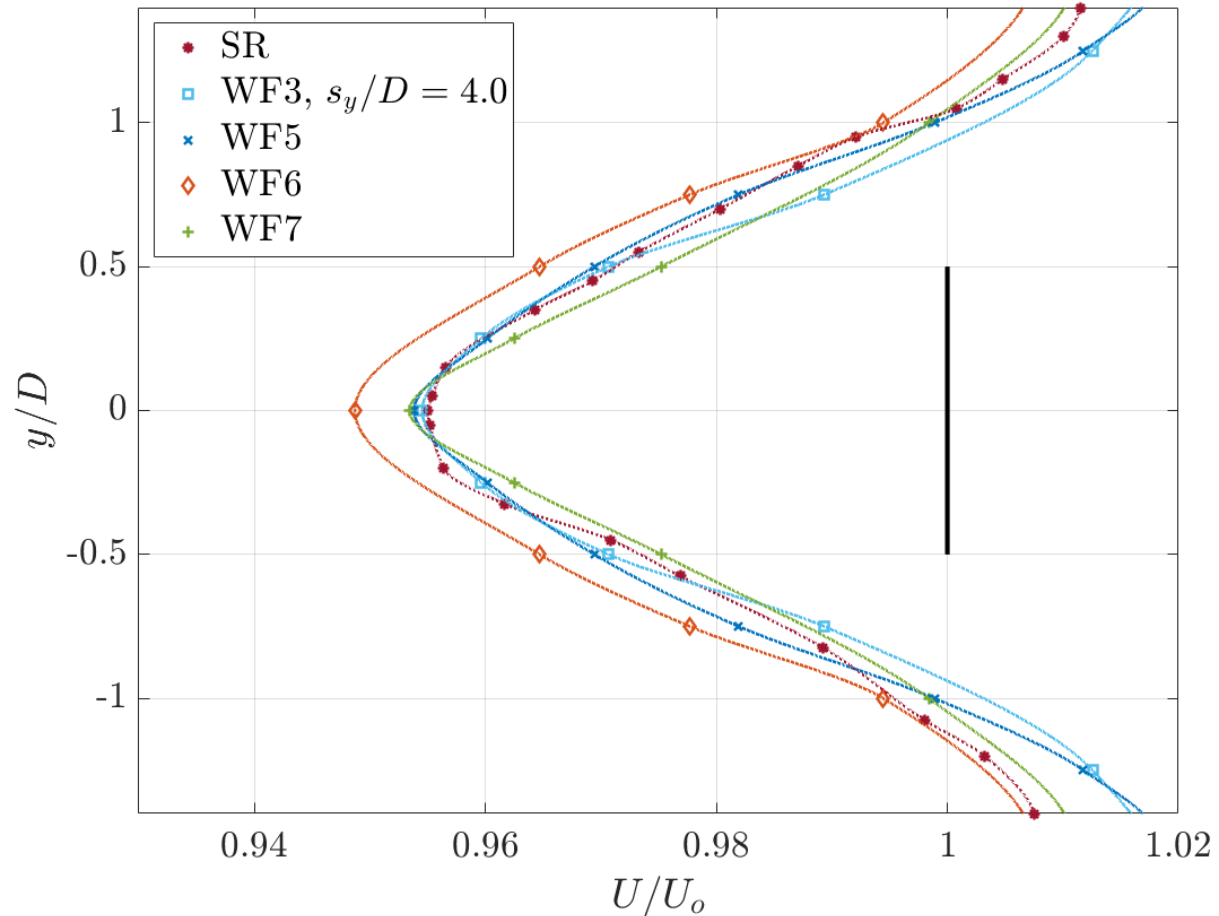
aligned



offset



Induction zone at $x/D=-1$



Conclusions

- **One row:** Larger induction at central turbine for decreasing turbine separation s_y/D
- **One row:** At turbine separations $s_y/D \geq 4$ no significant influence on individual induction zone is observed
- **Two rows:** Adding an offset second row at $s_x/D = 4$, does not significantly influence upstream induction either
- **Two rows:** An aligned second row at $s_x/D = 4$ shows a small increase in induction on central upstream turbine

Further research

- More detailed measurements in induction zone using particle image velocimetry (PIV)
- Larger number of disc
- Thrust measurements on discs (and power measurements on rotors)
- Influence of turbine height and rotor diameter
- Influence of turbulence and boundary layer height
- Computational modelling: superposition model, DES model



Høgskulen
på Vestlandet

Thank you for
your attention!



hvl.no/marinlab



[instagram.com/marinlab_hvl](https://www.instagram.com/marinlab_hvl)

