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Implications from wind park models for offshore wind park layout

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Wind turbines brake the air flow

➔ **Effectivity of wind parks depends on equilibrium speed in the park interior**

- **equilibrium between momentum uptake by the turbines and momentum supply from above**

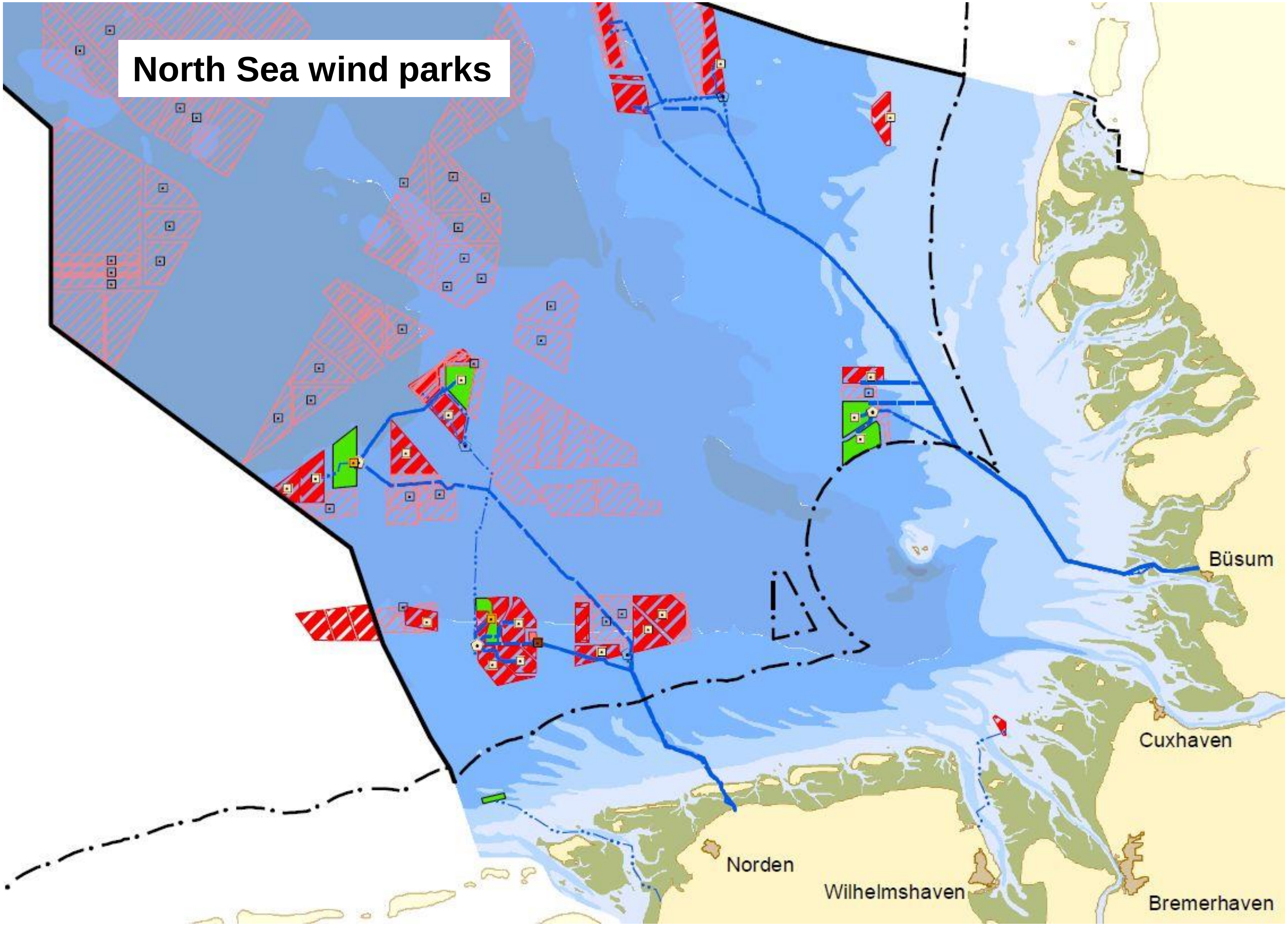
➔ **Wind park wakes influences other parks downstream**

- **wake lengths inversely proportional to momentum re-supply**

➔ **Planners and park designers need to know:**

a) equilibrium speed in park interior
b) park wake length
c) implications for park layout from existing models

North Sea wind parks



Quelle: http://www.bsh.de

several wind park models available

- **numerical models**

  - 3D flow models (Lissaman 1979, Jensen 1983, Crespo et al. 1999, Vermeer et al. 2003**)**

  - LES models (Wussow et al. 2007, Jimenez et al. 2007, Steinfeld et al. 2010, Troldborg et al. 2010**)**

- **analytical models (**Frandsen 1992, Frandsen et al. 2006, Emeis 2012**)**

data from several large wind parks principally confirm model results

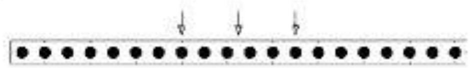
- Horns rev (Méchali et al. 2006, Hansen et al. 2012)

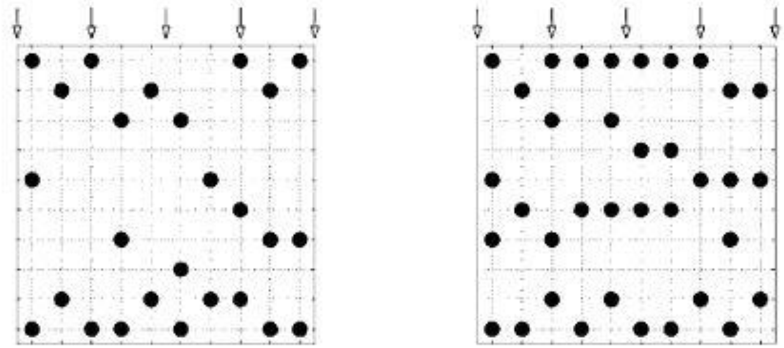
- Nysted (Barthelmie et al. 2007, Barthelmie and Jensen 2010)

- ...

suggestions from existing park layout tools

Table 5-3. The anticipated results for simple, one-dimensional farms optimized for maximum energy production.

Case	Description	Anticipated Result
A	constant winds parallel to long axis	
B	constant winds perpendicular to long axis	

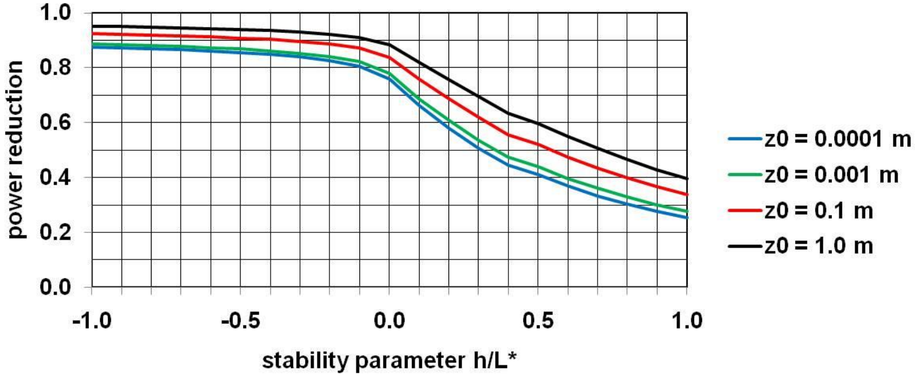


(a)	(b)
Number of turbines: 26	Number of turbines: 36
Total rated power: 12.8 MW	Total rated power: 16.8 MW
LPC: 4.20 ¢/kWh	LPC: 3.98 ¢/kWh

Figure 5-10. Comparison with results from the GA literature for a 50-D by 50-D farm with constant winds of 12 m/s from the north. (a) shows results from Mosetti, et al. [66] in which the objective was a balance of minimum COE and maximum energy, using a simple COE model. (b) shows the results of the OWFLO Optimization Tool using the same configuration, including the same simple COE model. In both cases, the LPC values were estimated using the OWFLO Optimization Tool.

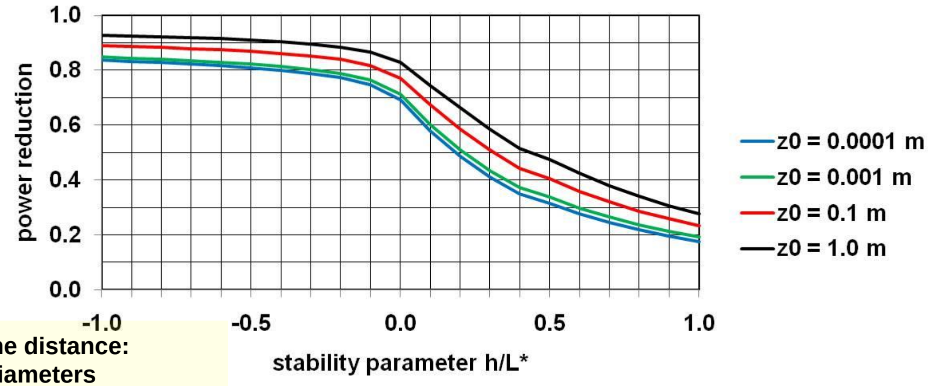
Elkinton, C.N., 2007: Offshore Windfarm Layout Optimization. PhD thesis, Univ. of Massachusetts, Amherst. ProQuest, Ann Arbor, 325 pp.

analytical park model (Emeis 2012): power reduction in



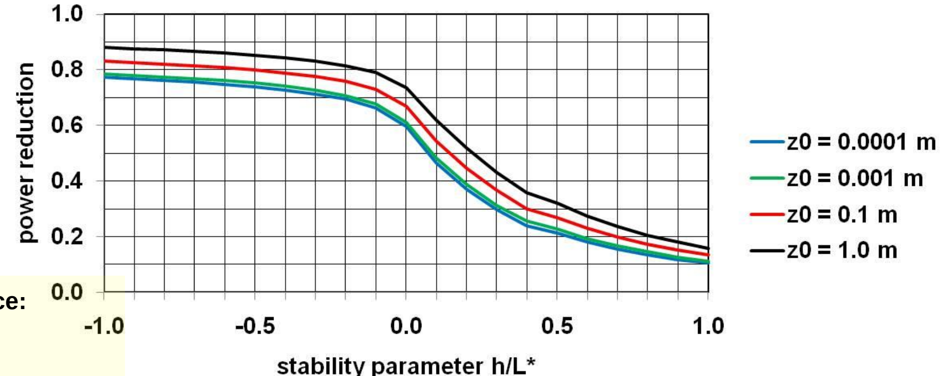
mean turbine distance:
10 rotor diameters

➔ turbine induced turbulence 10.1%



mean turbine distance:
8 rotor diameters

➔ turbine induced turbulence 12.6%

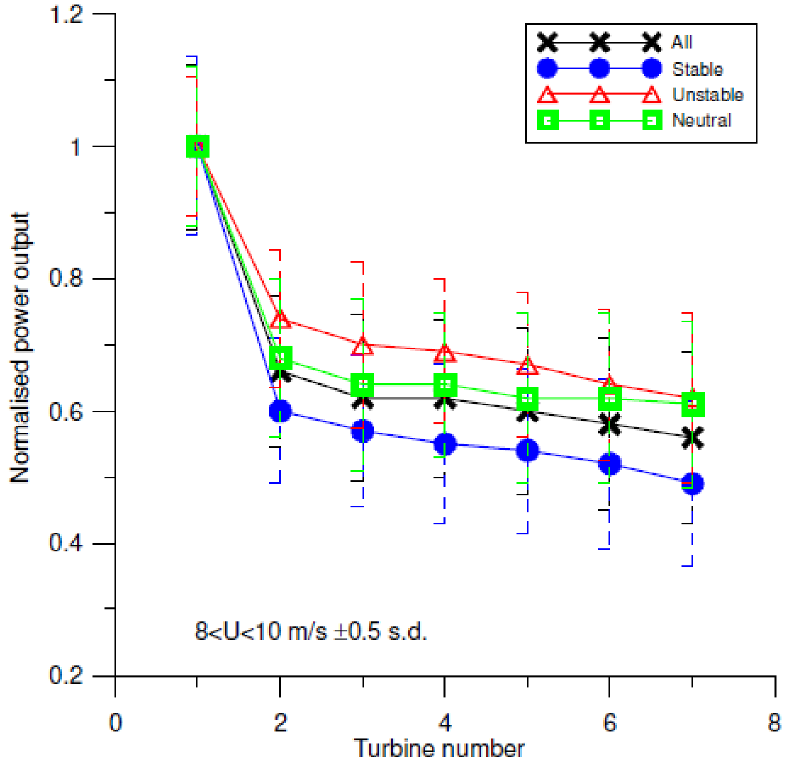


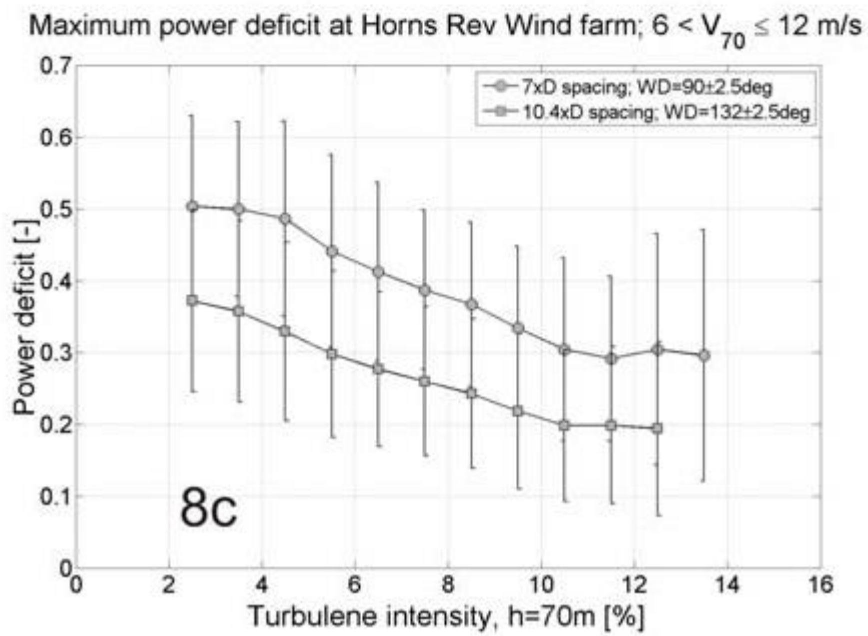
mean turbine distance:
6 rotor diameters

➔ turbine induced turbulence 16.8%

Emeis, S., 2012: Wind Energy Meteorology – Atmospheric Physics for Wind Power Generation. Series: Green Energy and Technology. Springer, Heidelberg etc., XIV+196 pp.

power reduction (left) and power deficit (right) in the park interior measurements at Nysted (Baltic sea) and Horns Rev (North Sea)



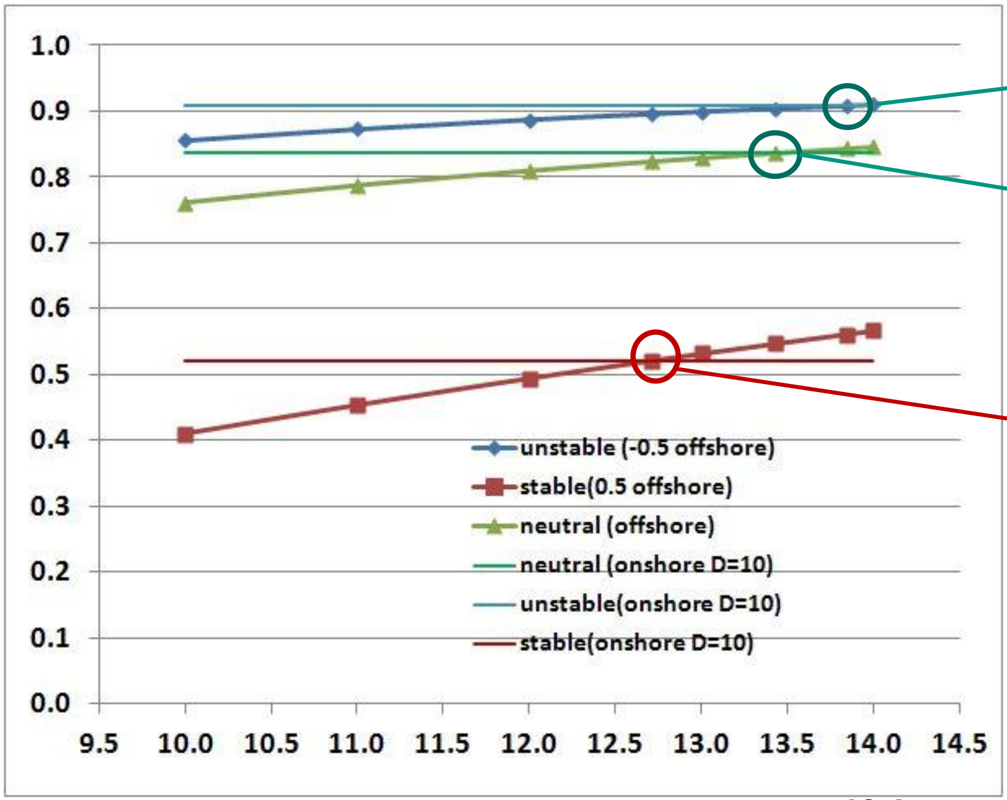


Barthelmie R, Frandsen ST, Rethore PE, Jensen L., 2007: Analysis of atmospheric impacts on the development of wind turbine wakes at the Nysted wind farm. Proceedings of the European Offshore Wind Conference, Berlin 4.-6.12.2007.

Hansen KS, RJ Barthelmie, LE Jensen, A Sommer, 2012: The impact of turbulence intensity and atmospheric stability on power deficits due to wind turbine wakes at Horns Rev wind farm. Wind Energy, 15, 183–196.

offshore power reduction (z_0 = 0.0001 m) compared to onshore park (z_0 = 0.1 m, D = 10)

power output per turbine



square root (park area per rotor area)

8.8 10.6 12.4

distance between two turbines in rotor diameters

52 % turbines per given area
or
192 % park area required

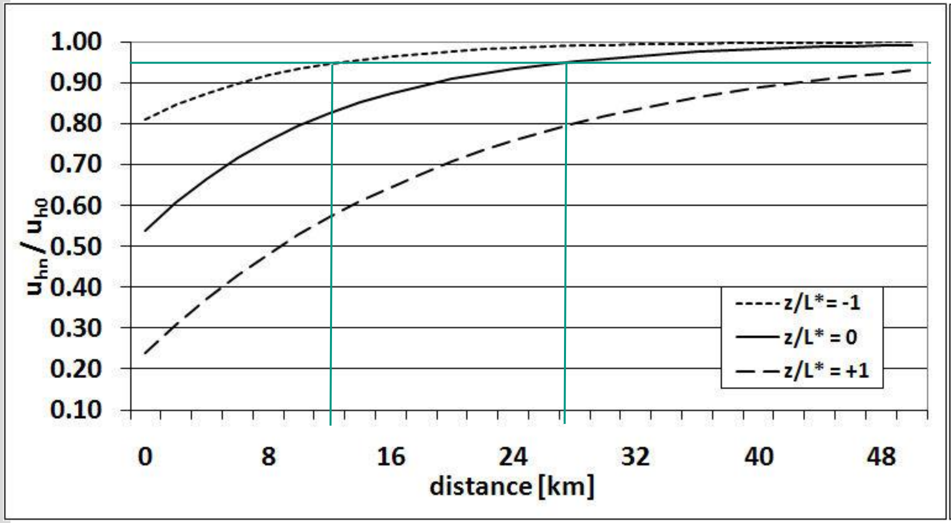
55 % turbines per given area
or
180 % park area required

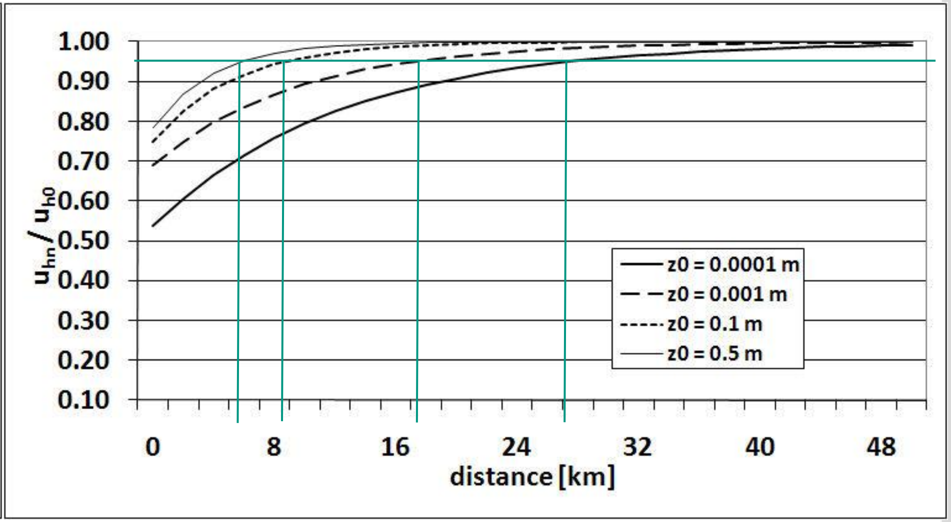
62 % turbines per given area
or
162 % park area required

wind park wake lengths (recovery to 95 % of the undisturbed value)

z_0 = 0.0001 m
(offshore)
different stability

neutral
stratification
different roughness lengths





b) Beschleunigung der Windgeschwindigkeit hinter dem Windpark Messungen (Envisat, SAR), Windpark Horns Rev (4 km x 5 km)

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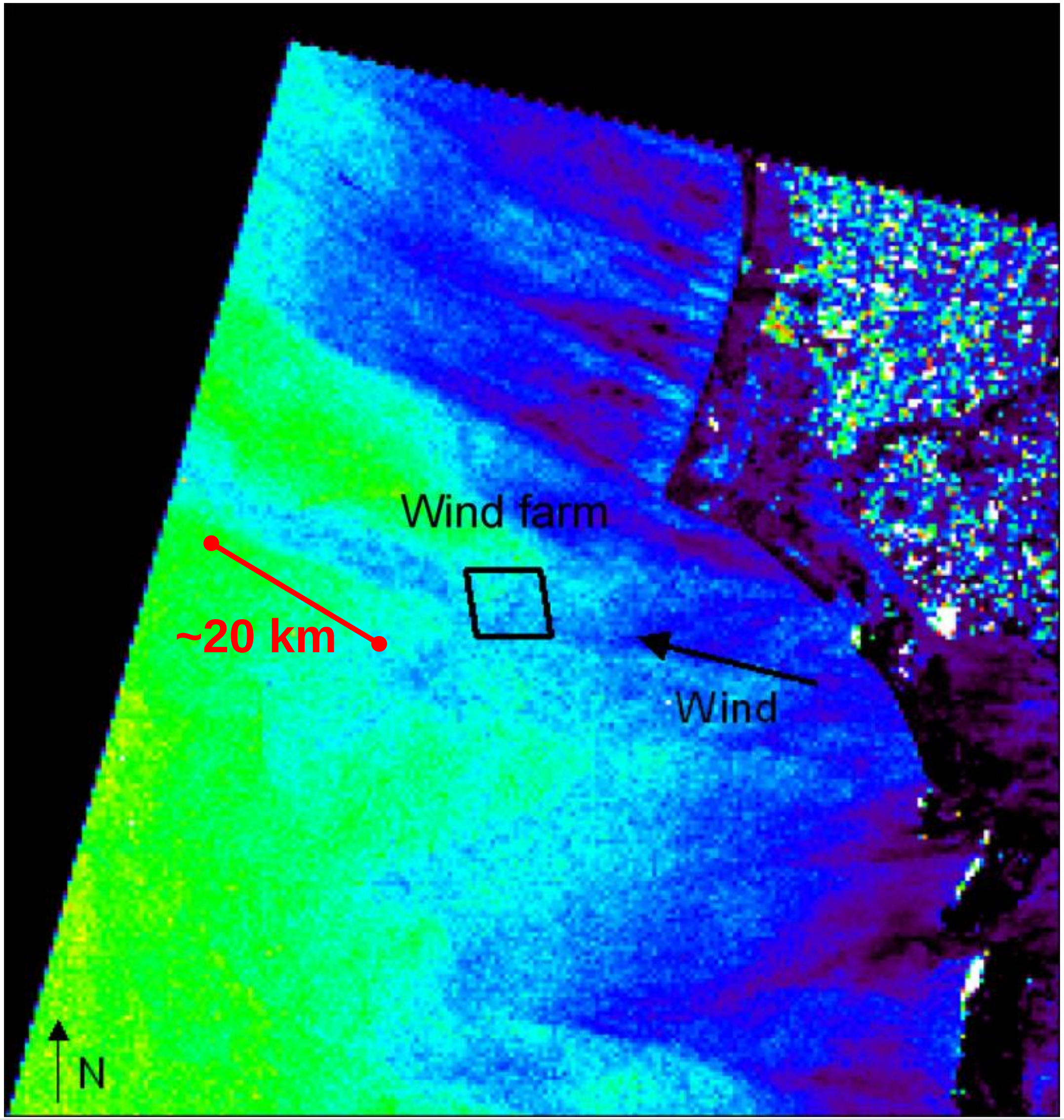
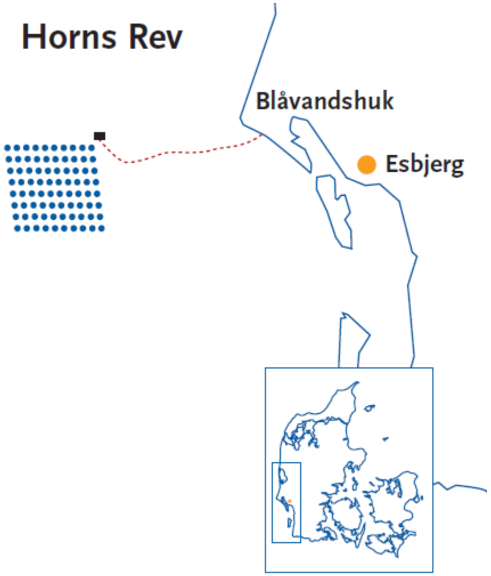




http://www.hornsrev.dk/nyheder/brochurer/Horns_Rev_TY.pdf

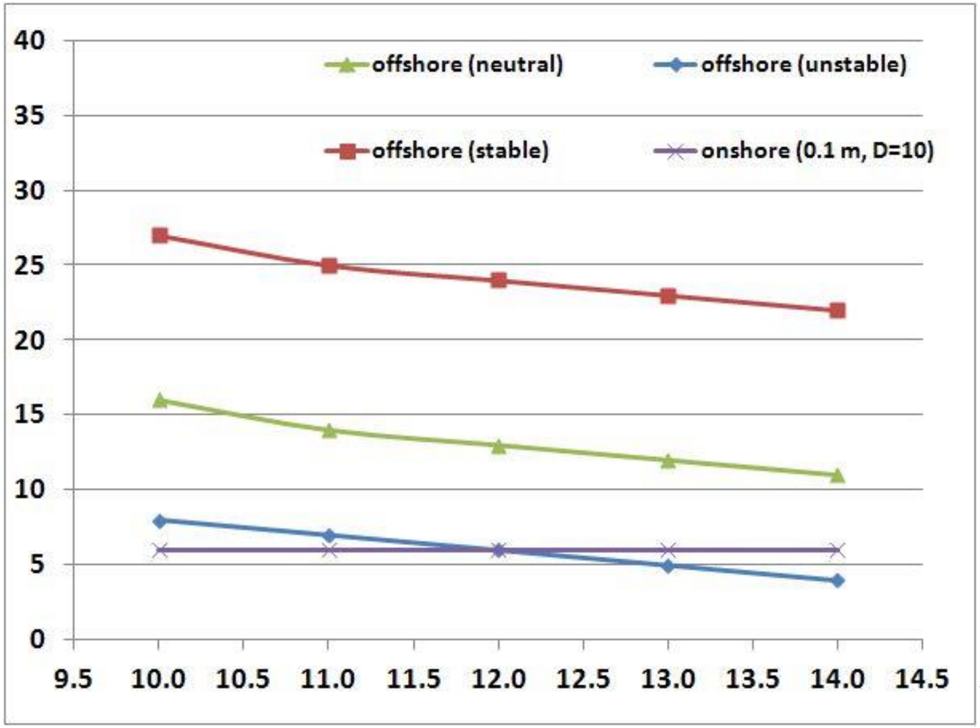
25. 02. 2003

http://galathea3.emu.dk/satelliteeye/projekter/wind/back_uk.html

offshore park wake length (z_0 = 0.0001 m) compared to onshore park (z_0 = 0.1 m, D = 10)

(recovery to 95 % of undisturbed power)

wake length in km



square root (park area per rotor area)

8.8 | 10.6 | 12.4

distance between two turbines in rotor diameters

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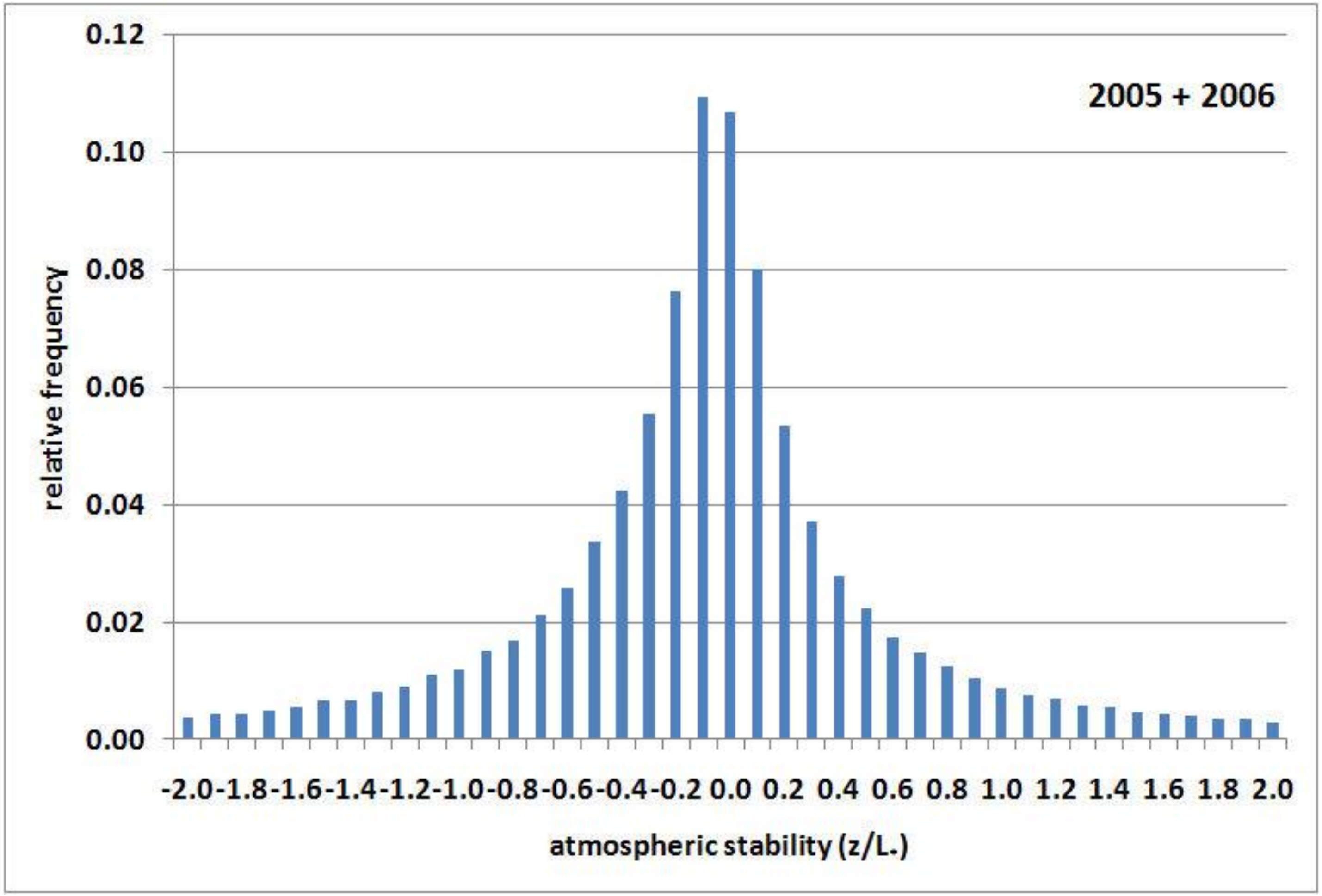
What are the implications for wind park layout?

How often do unfavourable stable conditions occur?

Are they linked to certain wind directions?

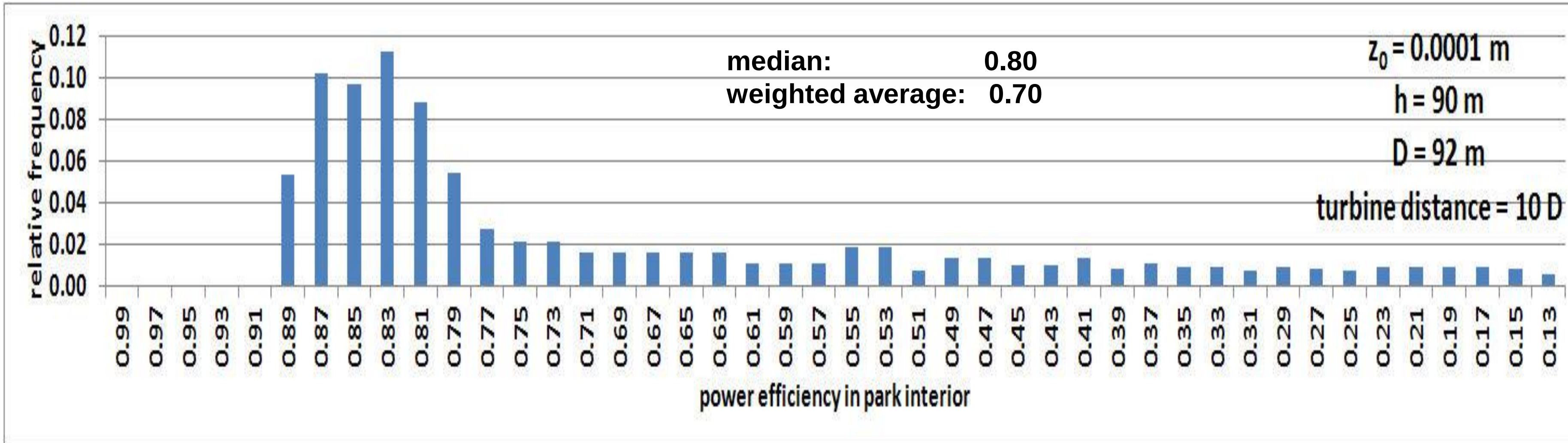
frequency of offshore thermal stabilities at FINO1 (80 m)

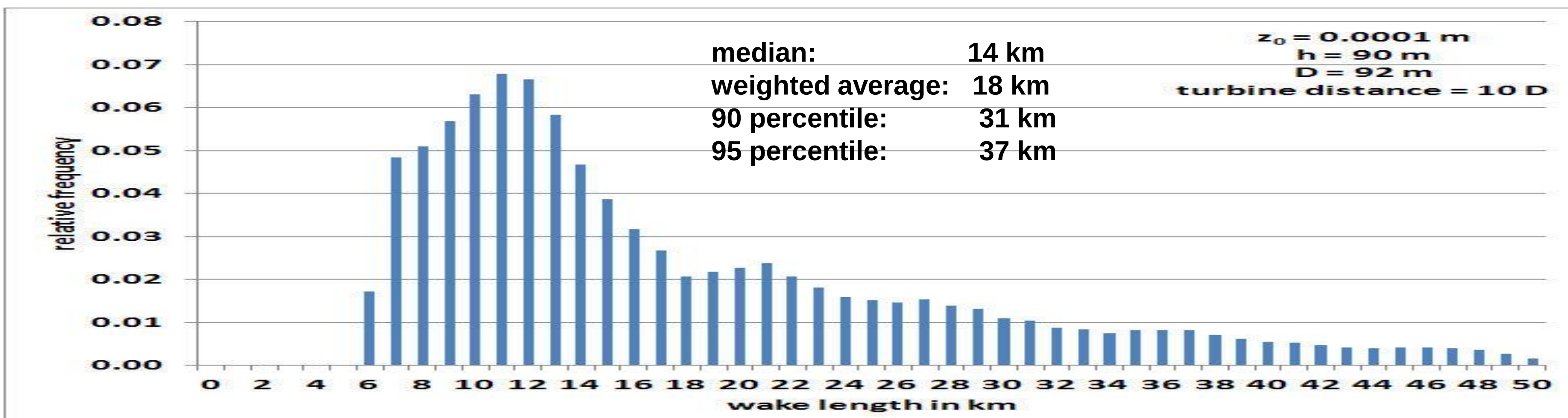


91.16% of all data shown

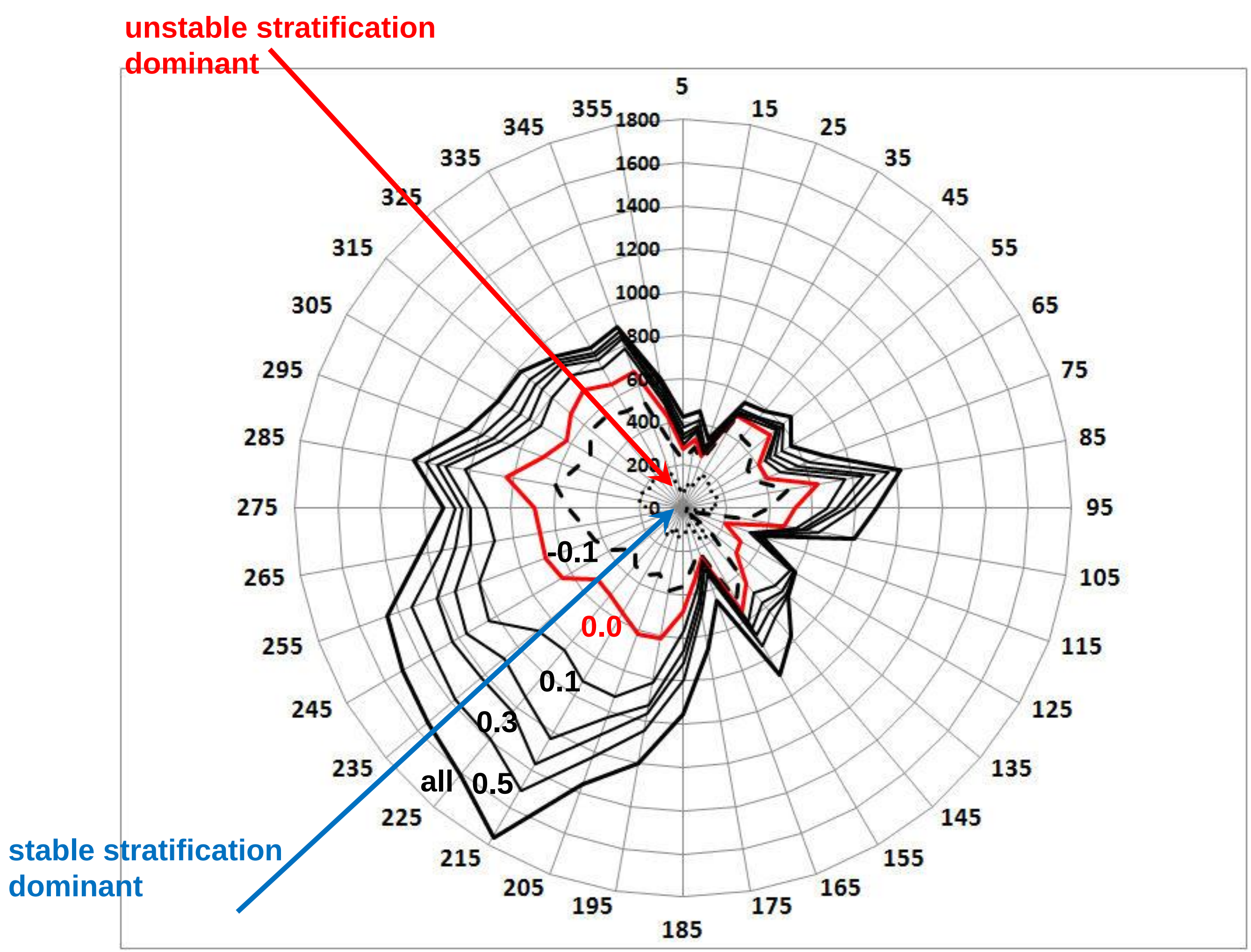
median: -0.07

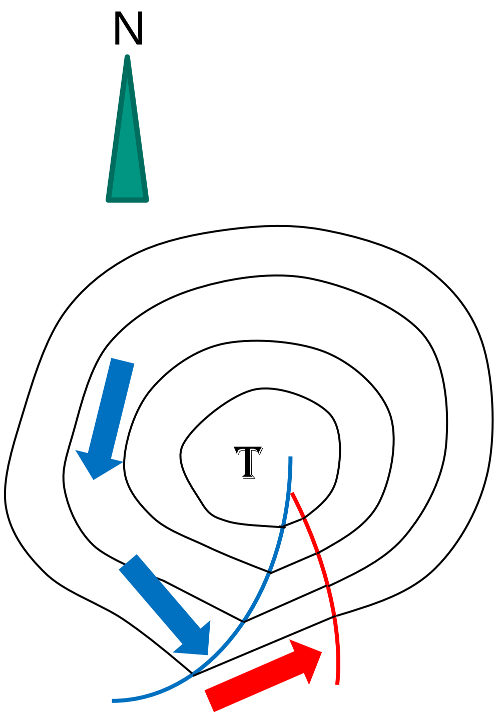
stability-dependent frequency distributions





wind direction-dependent frequency of stability
(FINO1, 2005, stability at 60 m, wind direction at 80 m)





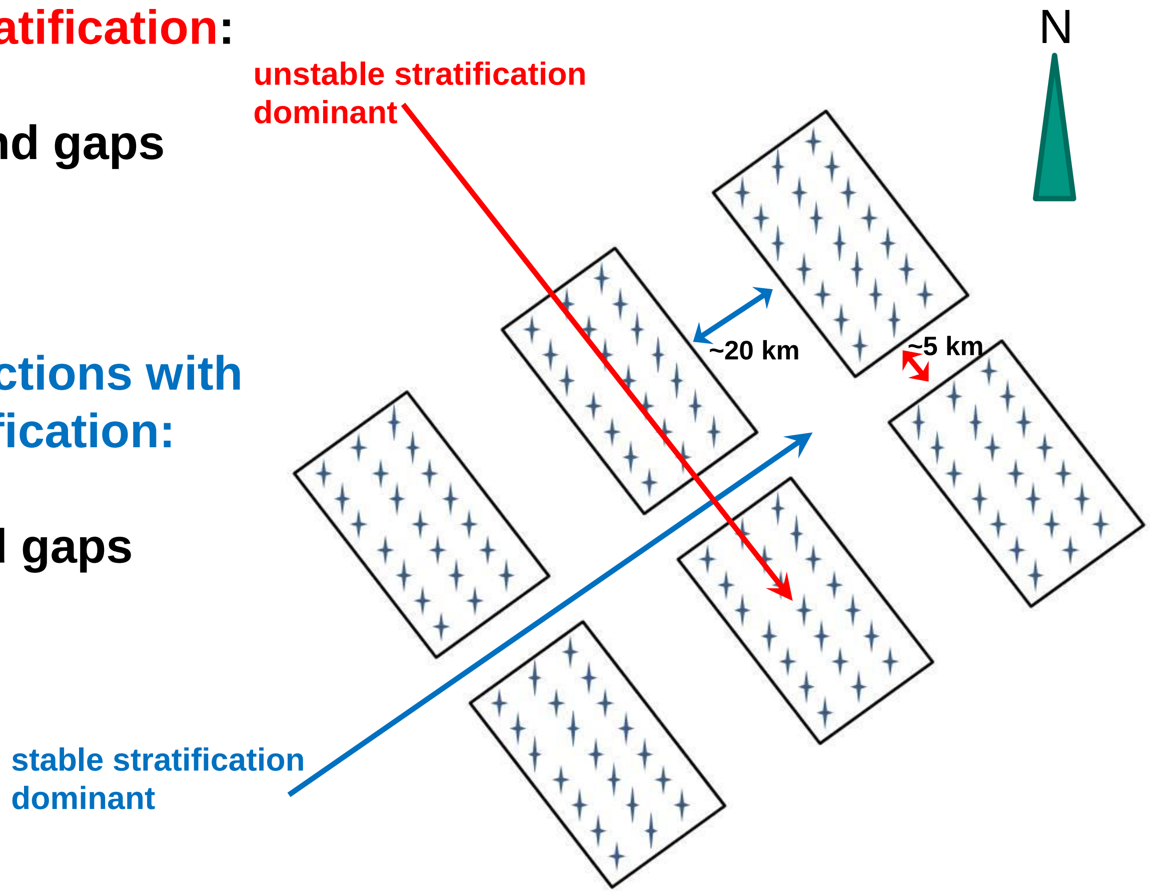
stability-adapted wind park layout:

parallel to wind directions with usually unstable stratification:

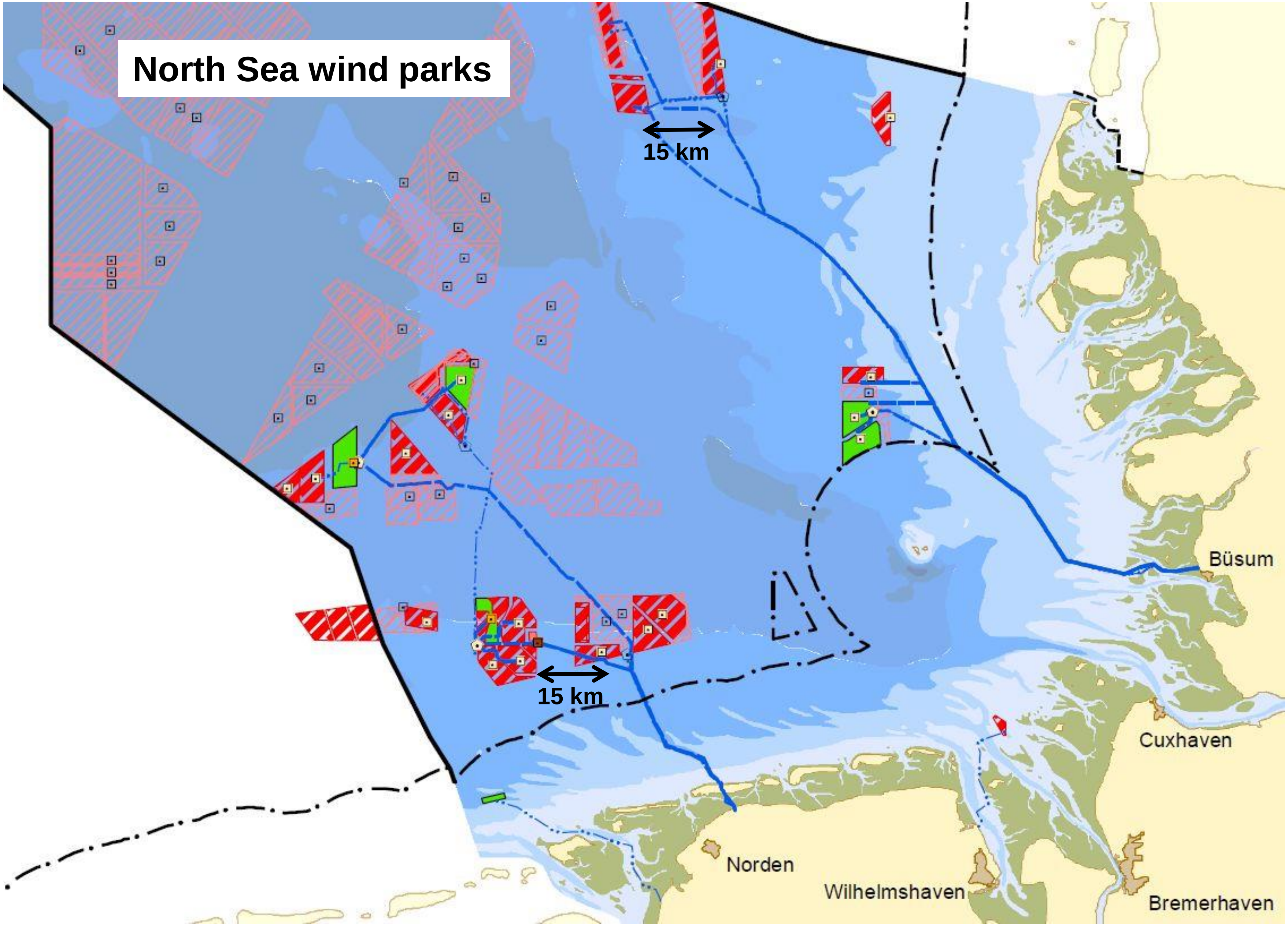
shorter distances and gaps
elongated parks

parallel to wind directions with usually stable stratification:

larger distances and gaps



North Sea wind parks



Quelle: http://www.bsh.de

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Conclusions:

Offshore wind parks should be optimized according to the local wind climate.

Wind direction-dependent atmospheric stability is an important parameter for offshore wind parks.

Wind climate varies from region to region.
Therefore, region-specific climatic analyses necessary

Onshore: stability shows diurnal variation rather than annual variation,
stability depends on sunshine, not on wind direction,
friction-induced turbulence is much more important,
therefore, stability-dependent optimization is not necessary.

Vielen Dank für Ihre Aufmerksamkeit