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Validation of the Revised WAsP Park Model

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Abstract

The DTU Wind Energy wind-resource model WAsP contains a wind farm wake model *Park (Park1)*. This *Park* model in has been revised, ***Park2***, to improve prediction accuracy in large wind farms, based on sound physical and mathematical principles: consistent wake-modelling and perturbation theory for wake-wake-interaction.

Park2 has been validated and calibrated using a number of off-shore and on-shore wind farms. The calibration has resulted in recommended values for the wake-expansion coefficients of the ***Park2*** model.

Objectives

Why revise the Park-model?: To some extent the original Park-model [2, 3] is based on empirics to a higher degree than on physics. Also, there have been doubts regarding the applicability to large wind farms.

What should Park2 fulfill? Park2 should be based on sound physical modelling and on accepted mathematical principles. Park2 should be calibrated and validated against available wind farm operational data.

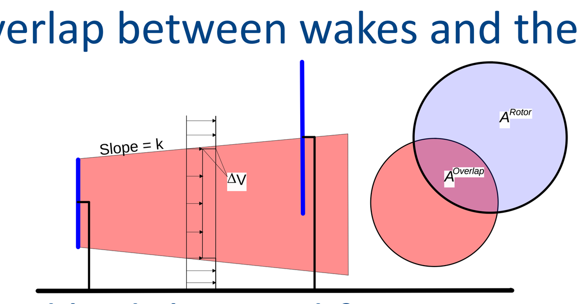
Methods of Park2

Single-turbine wake: The wake from a single-turbine "i" in a wind-farm is modelled, following the classical approach by N.O.Jensen [1], by a top-hat speed-deficit profile (constant inside, zero outside wake), as a function of the down-wind coordinate x:

$$\Delta V_i(x) = V_i^{inc}\left(1-\sqrt{1-C_t^i(V_i^{inc})}\right)\left(\frac{D_i^{rotor}}{D_i^{wake}(x-x_i)}\right)^2, \; D_i^{wake}(\Delta x) = D_i^{rotor} + 2k\Delta x$$

Combined wakes: speed deficit at turbine j by linear superposition of wakes from turbines upwind of turbine "j", considering partial overlap between wakes and the rotor of turbine "j" :

$$V_j^{inc} = U_0 - \sum_i^{uw\,turbs} \Delta V_i(x_j)\frac{A_{i,j}^{overlap}}{A_j^{rotor}}$$



U_0:	free wind speed, i.e. hypothetical wind speed had the wind farm not existed
D_i^{rotor}:	rotor diameter of turbine "i"
D_i^{wake}:	diameter of wake from turbine "i"
x_i:	down wind coordinate of turbine "i"
V_i^{inc}:	incident wind speed at turbine "i"
$C_t^i(V)$:	thrust coefficient of turbine "i" as a function of hub-height wind speed.
k:	model wake expansion coefficient
A_i^{rotor}:	rotor area of turbine "i"
$A_{i,j}^{overlap}$:	partial overlapping area of wake "i" on rotor of tubine "j"

<u>Consistent formulation</u>: The wake speed deficit from a single turbine depends only on local incident wind speed V_i^{inc} at the turbine considered (not on free wind speed U_0 as is the case in *Park1*).

<u>Wake combination by perturbation</u>: The speed deficits are considered to be small perturbations, so that linear superposition can be used (2nd and higher order effects of wake mixing can be disregarded).

<u>Wake - surface interaction disregarded</u>: The Park2 model is simple, thus wake inter-action with surface is disregarded. The reflection model of the original *Park* model [2,3] was not considered to represent aerodynamics at the surface correctly [4, 5].

<u>Simple terrain effects model</u>: Terrain effects on wakes are disregarded. However, onshore free wind speed U_0 is calculated individually for all turbines incl. terrain effects.

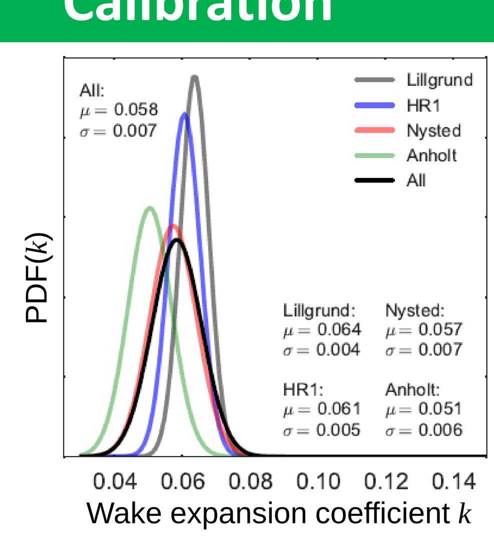
Results: Calibration and Validation – Offshore

Calibration and validation were performed vs. Danish offshore wind farm data sets.

- Horns Rev 1: production data 2005.Jan.01 – 2009.Dec.31
- Nysted: production data 2004.May.24 – 2006.Nov.16
- Lillgrund: production data 2008.Jan.01 – 2012.Dec.31

Calibration

Bayesian calibration [6, 7] was used for the wake expansion coefficient k. Based on filtered wind farm production data (all turbines running) the PDF graphs show the probability distribution of the expansion coefficient k.

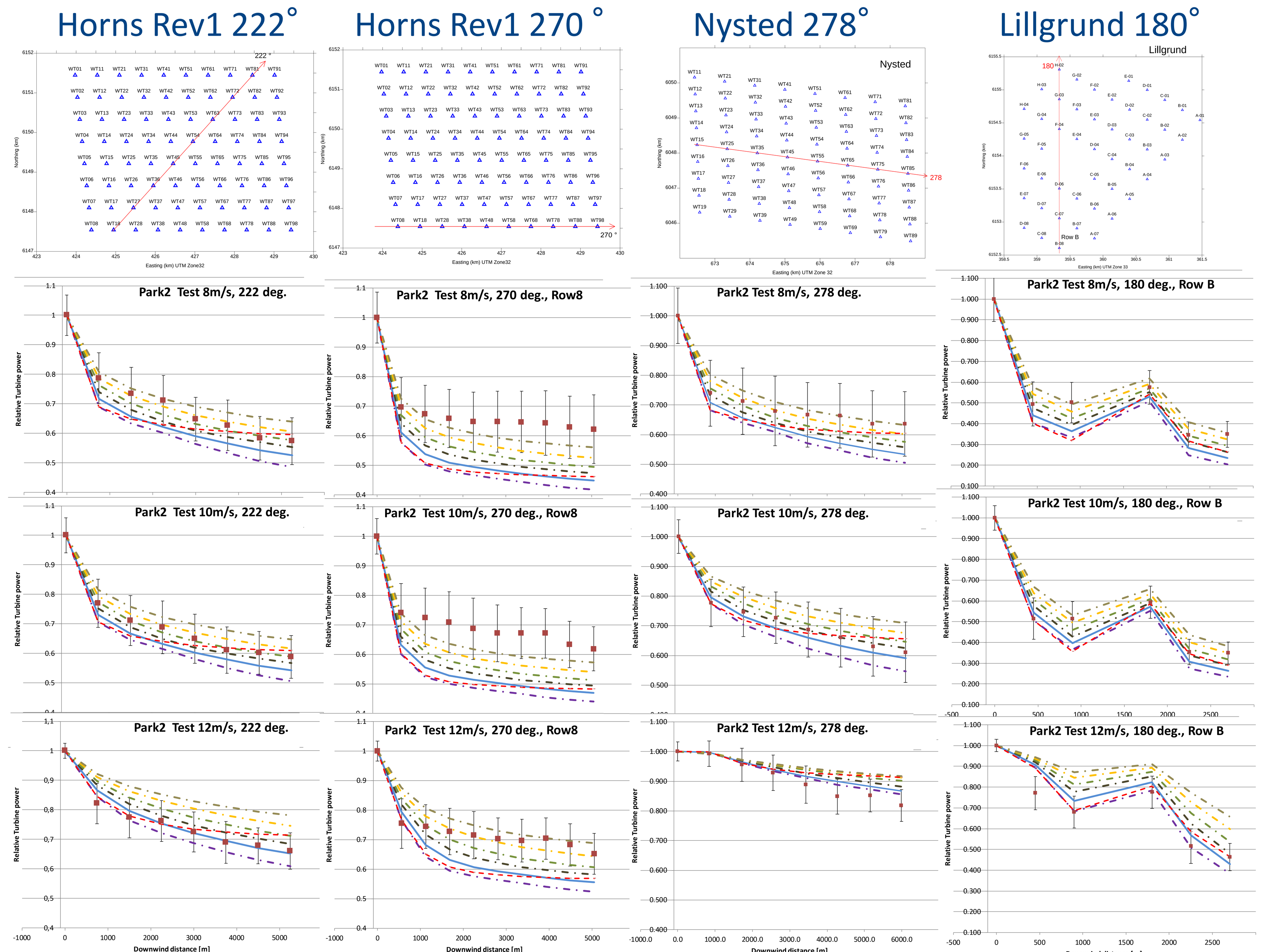


Wind farm	μ	σ
Horns Rev 1	0.061	0.005
Nysted	0.057	0.007
Lillgrund	0.064	0.004
All	**0.06**	**0.006**
Anholt	*0.051*	*0.006*
(Only included for reference)		

Validation

Modelled turbine production deficit profile downwind in a wind farm compared to observed data. Examples are presented below.

Horns Rev1 222° Horns Rev1 270 ° Nysted 278° Lillgrund 180°

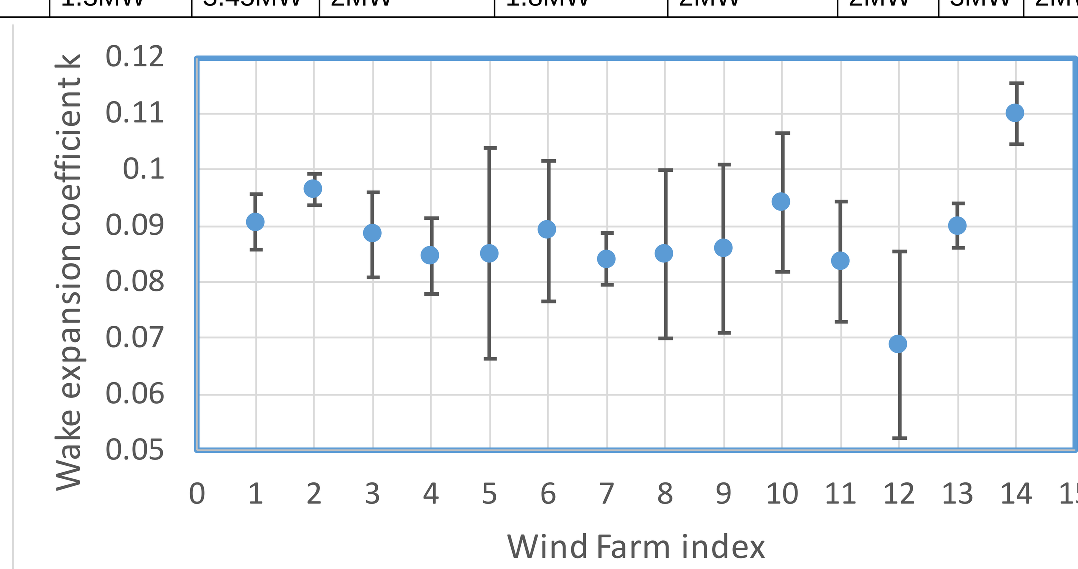


Observations	Park2						Park1
	k = 0.05	k = 0.06	k = 0.07	k = 0.08	k = 0.09	k = 0.10	k = 0.05

Results: Calibration – Onshore

Calibration for onshore wake expansion coefficient k was performed vs. wind farm production calculations by *Park1* with standard parameters, for 14 wind farms.

Creyap 1	Creyap 2	Napier	Jasseines (2 Wind Farms)		La Ventosa	Capel Canyon (5 wind farms)						Vredens-burg	Ras Ghared
GB	GB	S.AFR.	France		Mexico	GB						S.AFR:	Egypt
14 x 2MW	22 x 1.3MW	27 x 3.45MW	6 x 2MW	4 x 1.8MW	51 x 2MW	18 X 2MW	6 x 3MW	7 x 2MW	9 x 2MW	4 x 3MW	6 x 0.81MW	34 x 3.6MW	100 x 3.02MW



Error bars: k-values where Park2 production calculation differs +/- 0.15% from *Park1*.

Result from all on-shore wind farms		
k	μ	0.088
	σ	0.009

Conclusions

Park2 was found to produce predictions at least as close as Park1 to observed offshore wind farm productions. The calibration resulted in recommended wake-expansion coefficient values for both off- and on-shore wind farms.

Windfarm type		Offshore	Onshore
k	μ	**0.06**	**0.09**
	σ	**0.006**	**0.009**

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