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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 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.

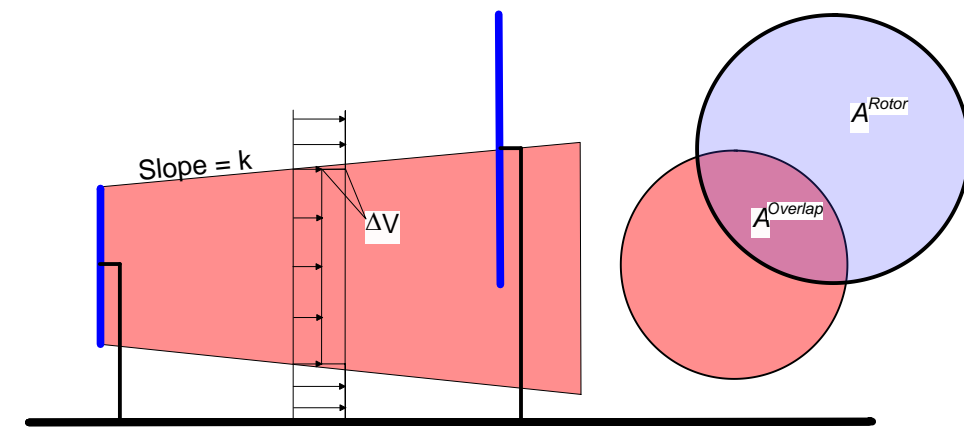
Methods of Park2

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*":

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



- 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 turbine "*j*"

Consistent formulation: 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*).

Wake combination by perturbation: 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).

Wake - surface interaction disregarded: The *Park2* model is simple, thus wake interaction 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].

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

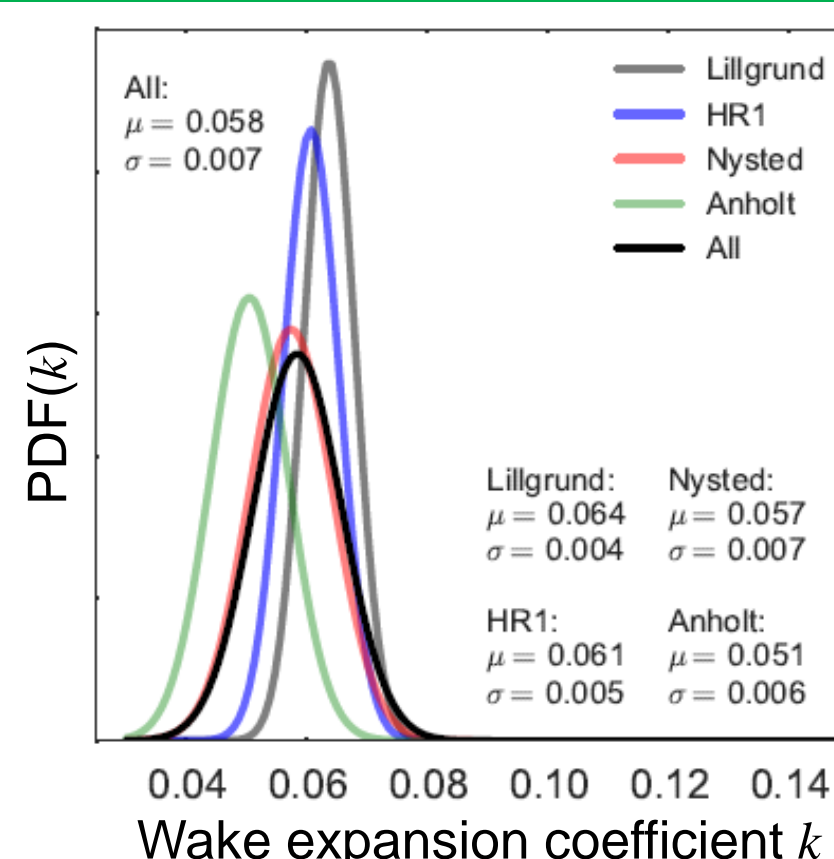
Results: Calibration and Validation – Offshore

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*.

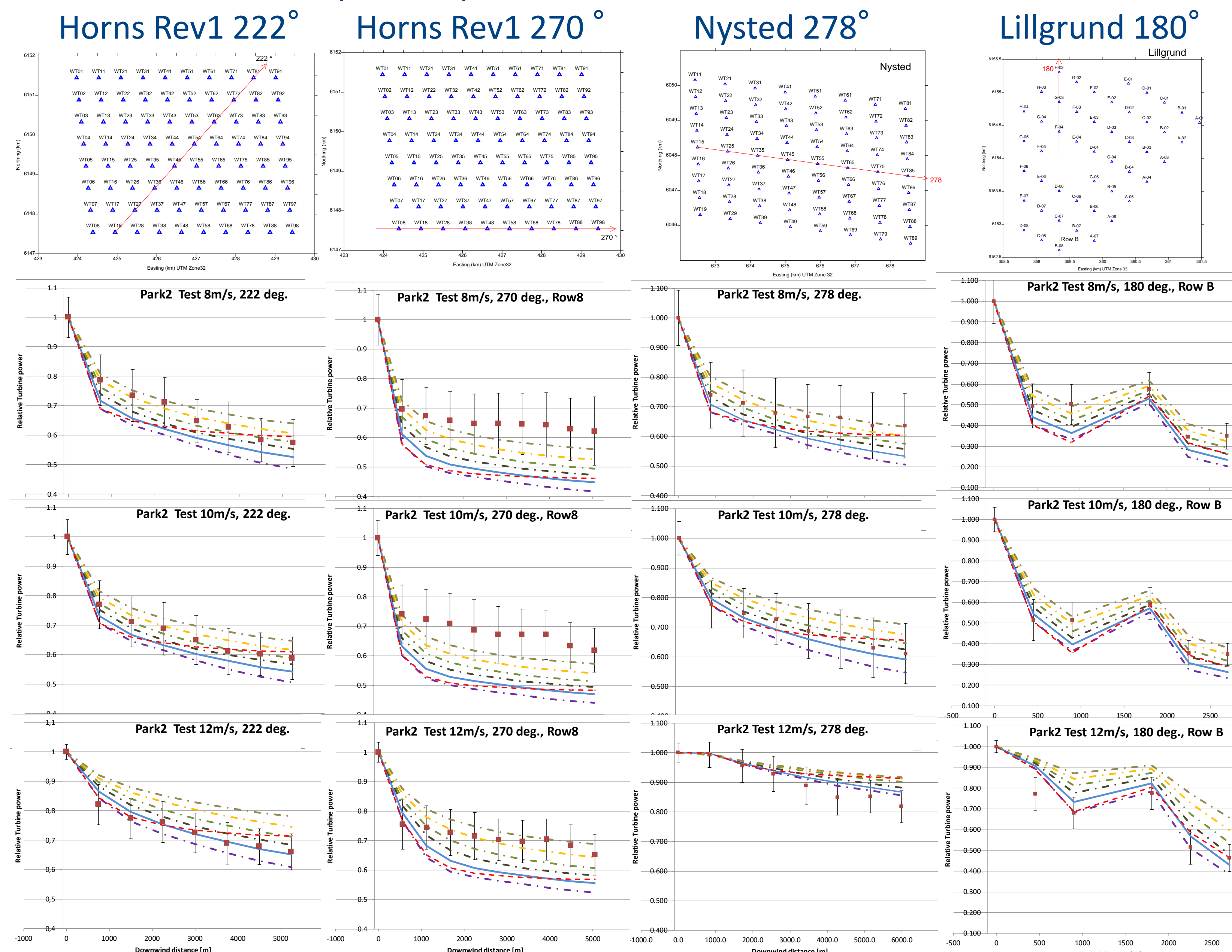


Wind farm	μ	σ
Horns Rev 1	0.061	0.005
Nysted	0.057	0.007
Lillgrund	0.064	0.004
All	0.06	0.006
Anholt	0.051	0.006

(Only included for reference)

Validation

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

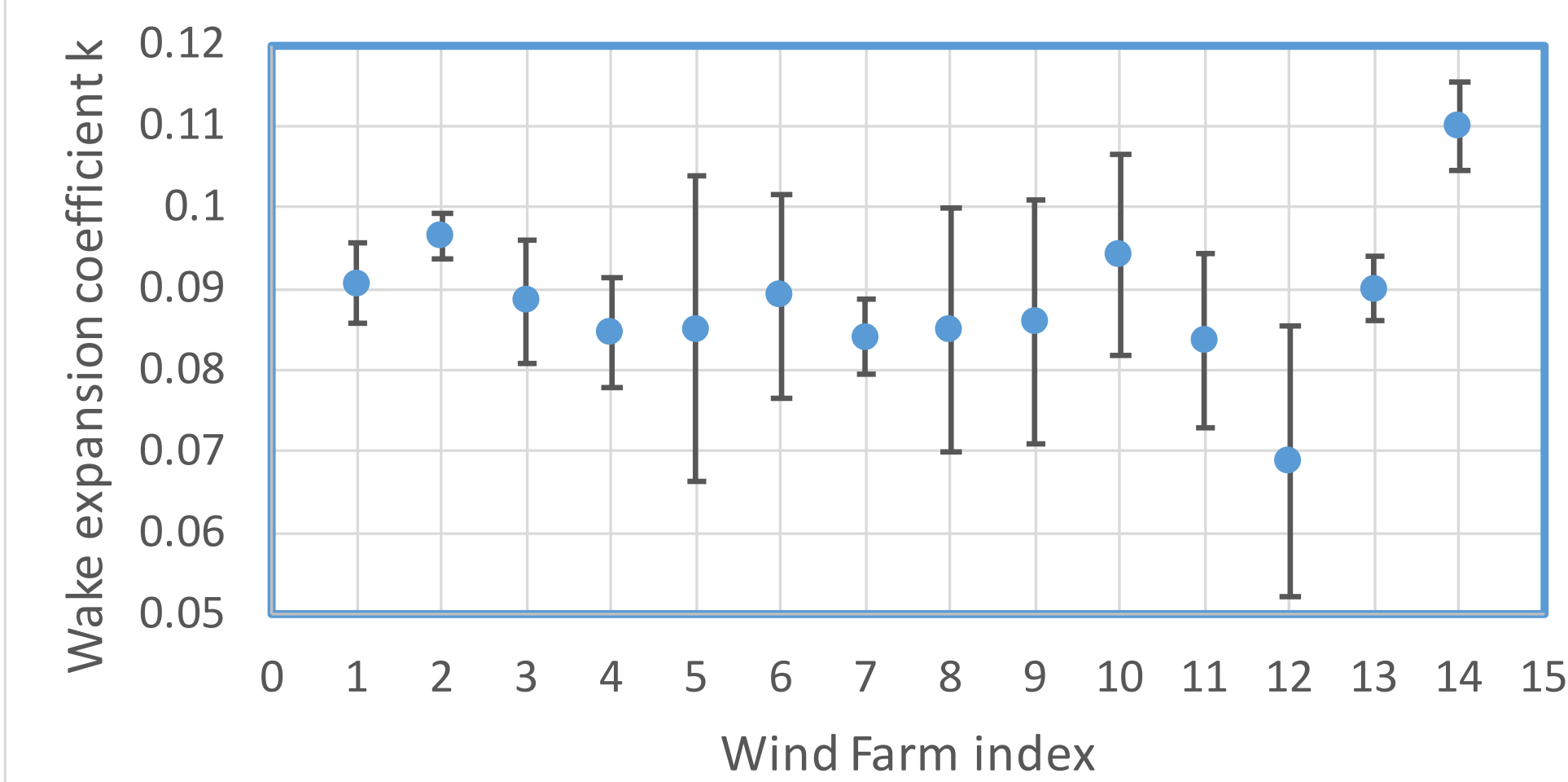


Observations	Park2					Park1
	$k = 0.05$	$k = 0.06$	$k = 0.07$	$k = 0.08$	$k = 0.09$	$k = 0.10$

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		
μ	k	0.088
σ	k	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	
	μ	σ	μ	σ
k	0.06	0.006	0.09	0.009

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