


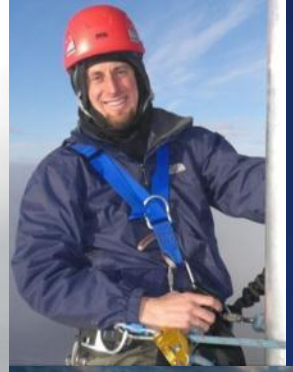

On-Shore Wake Validation Study

Wake Analysis Based on Production Data

AWEA Wind Resource Assessment Symposium 2013

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Outline

- GENIVAR's current wake model
- Current state of wake modeling
- Wake combination methods
- Validation Study
- Case Study

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GENIVAR's Current Wake Model

Date of Implementation	June 2013
Model Theory	-N.O. Jensen model with a deep-array adjustment -Adjustable wake combination methods -Wake decay proportional to direction-specific turbulence
Software Used	WindPRO / In-house software
Proprietary Modifications to Model	Turbine roughness increase
Model Settings Vary by Location	Yes
Uncertainty due to Wake	30% of wake loss

Current State of Wake Modeling

- Improvements are required to represent complex atmospheric conditions
- Need for a comprehensive wind flow model vs. superposition of different models
- Parameterization of the wind farm as a momentum sink as opposed to a surface roughness element[1]
- Dynamic wake model inputs
  - Momentum sink proportional to wind speed (thrust curve)
  - Time dependent turbulence
  - Time dependent thermal stability
- Further Validation

[1] Fitch, Anna C., Joseph B. Olson, Julie K. Lundquist, (2013), Parameterization of Wind Farms in Climate Models. *J. Climate*, **26**, 6439–6458.

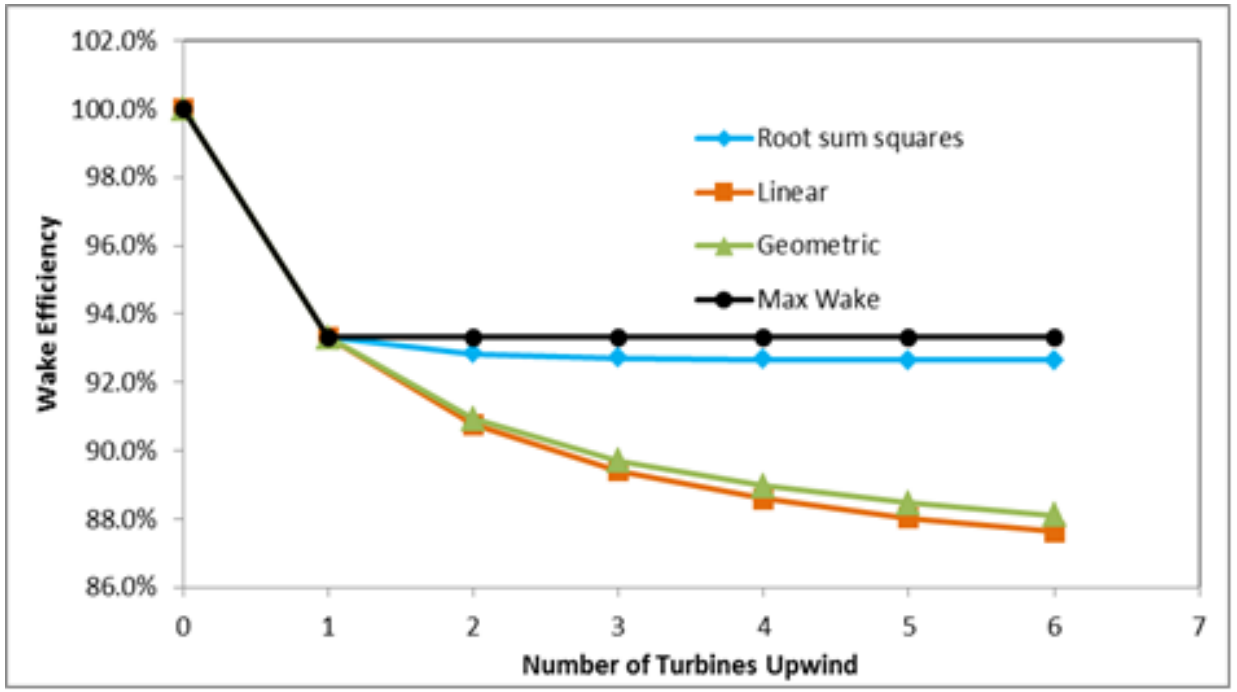
Improving Existing Engineering Models

- Park and Eddy Viscosity models are *single turbine models*
- The combination model is rarely discussed and not adjustable in typical wind flow modeling packages

Maximum wake	(no aggregation)	$\delta V_n = \max\left(\delta V_{k,n}\right)$
Root sum squares	(RSS)	$\delta V_n = \sqrt{\sum_{k=1}^{n-1}\left(\delta V_{k,n}^2\right)}$
Geometric	(product)	$\delta V_n = 1 - \prod_{k=1}^{n-1}\left(1 - \delta V_{k,n}\right)$
Linear	(additive)	$\delta V_n = \sum_{k=1}^{n-1} \delta V_{k,n}$

Improving Existing Engineering Models

- The most common method is the maximum wake, some packages implement root sum squares



- RES research shows good validation with mean of RSS and Linear combination methods [2]

[2] Habenicht G. (2011): Offshore Wake Modelling. Renewable UK Offshore Wind. RES

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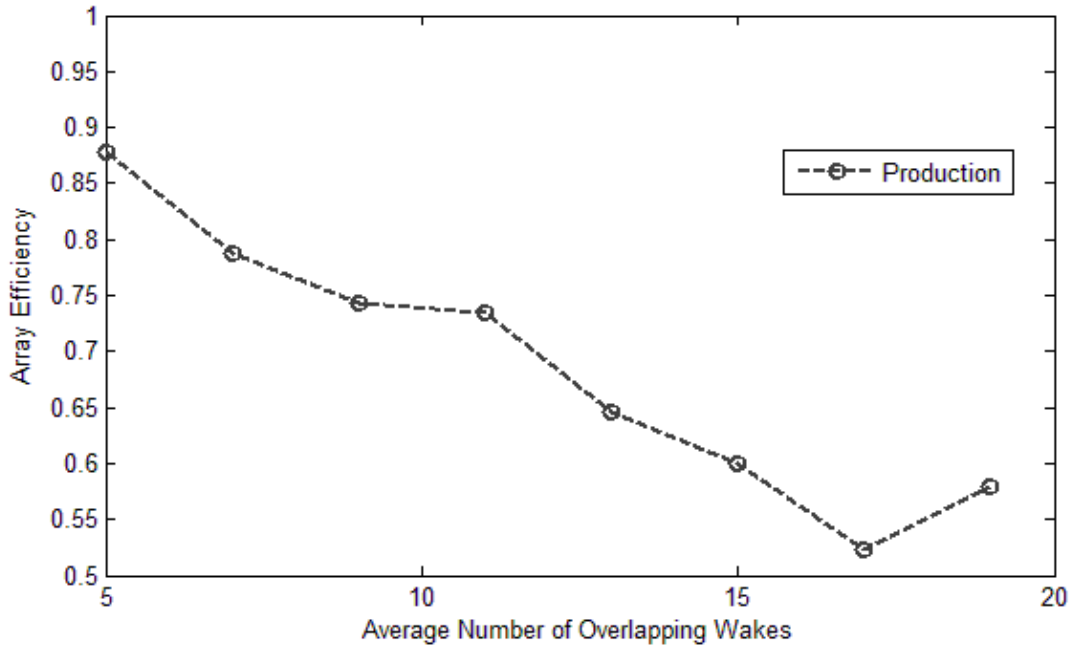
Validation Exercise

- Four projects, average project size: >400 MW
  - 1x very large array (> 1 GW)
  - 1x 300 MW
  - 2x 150 MW projects
- Wake quantified via analysis of production data
  - Turbines binned by number of overlapping wakes
  - Overlapping wakes weighted by wind direction distribution
  - Production normalized to first row of turbines
  - Compared to modeled results (terrain and wake effects)
- Intent of study
  - Test wake combination methods
  - Optimize deep-array model

Case Study: Large Onshore Facility (> 1 GW)

- Case study for a large facility (hundreds of turbines)
- Efficiency relative to first row for a large facility
- Realized production deficit versus number of overlapping wakes, weighted by wind direction distribution



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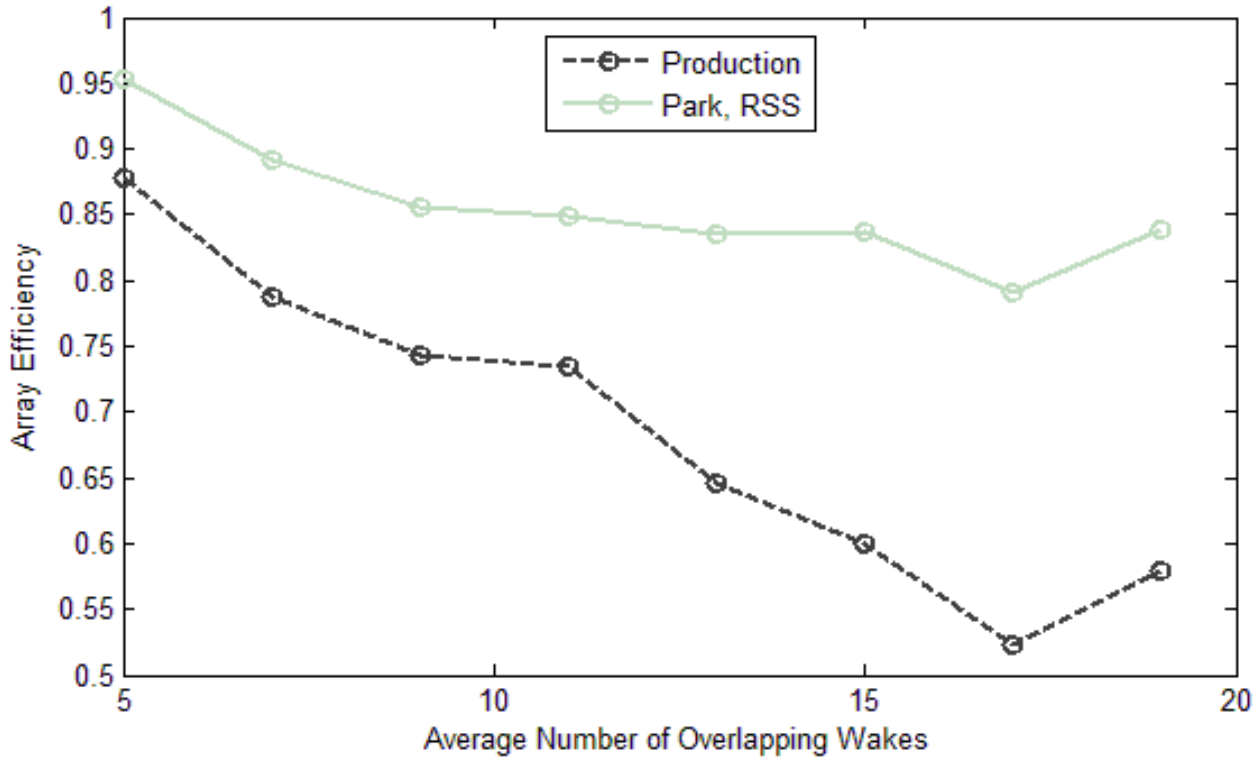
Validation with Production Data

- Park Model with Root Sum Squares Combination Method



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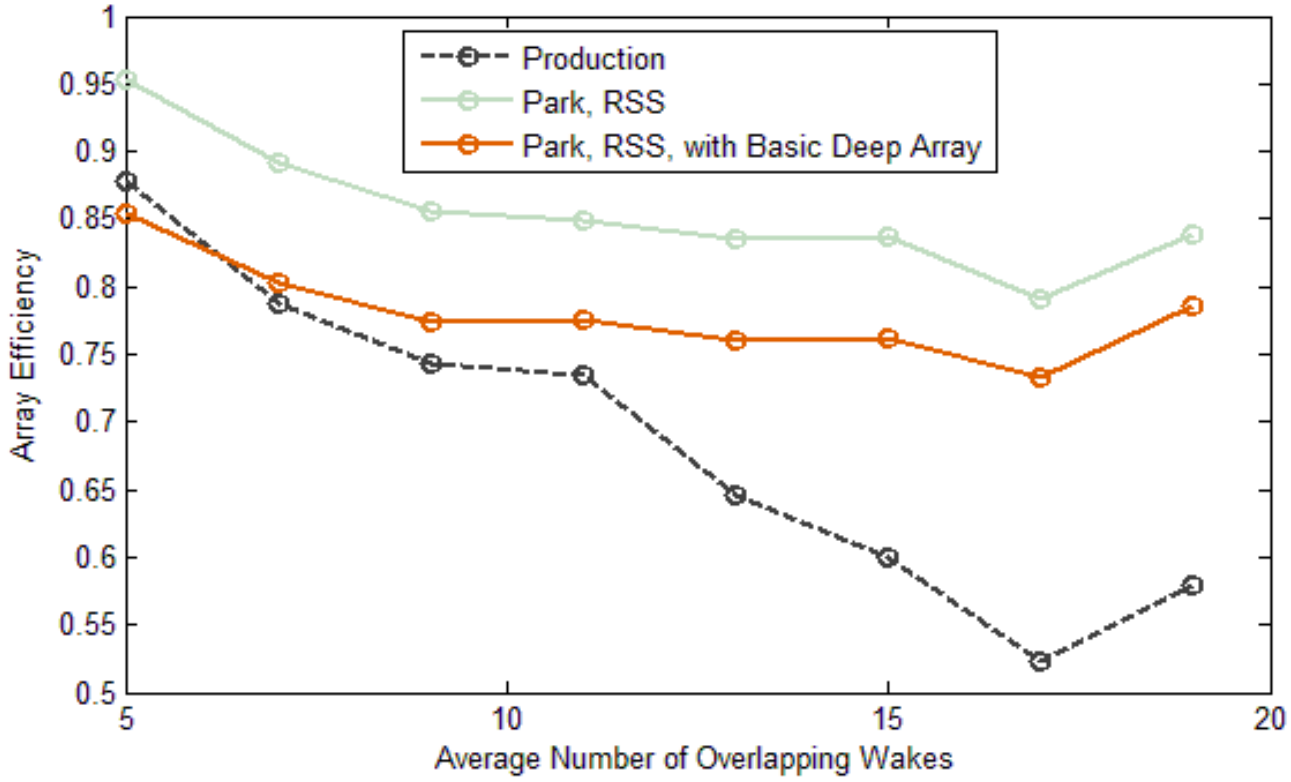
Validation with Production Data

- Deep array doesn't improve the slope of the relationship



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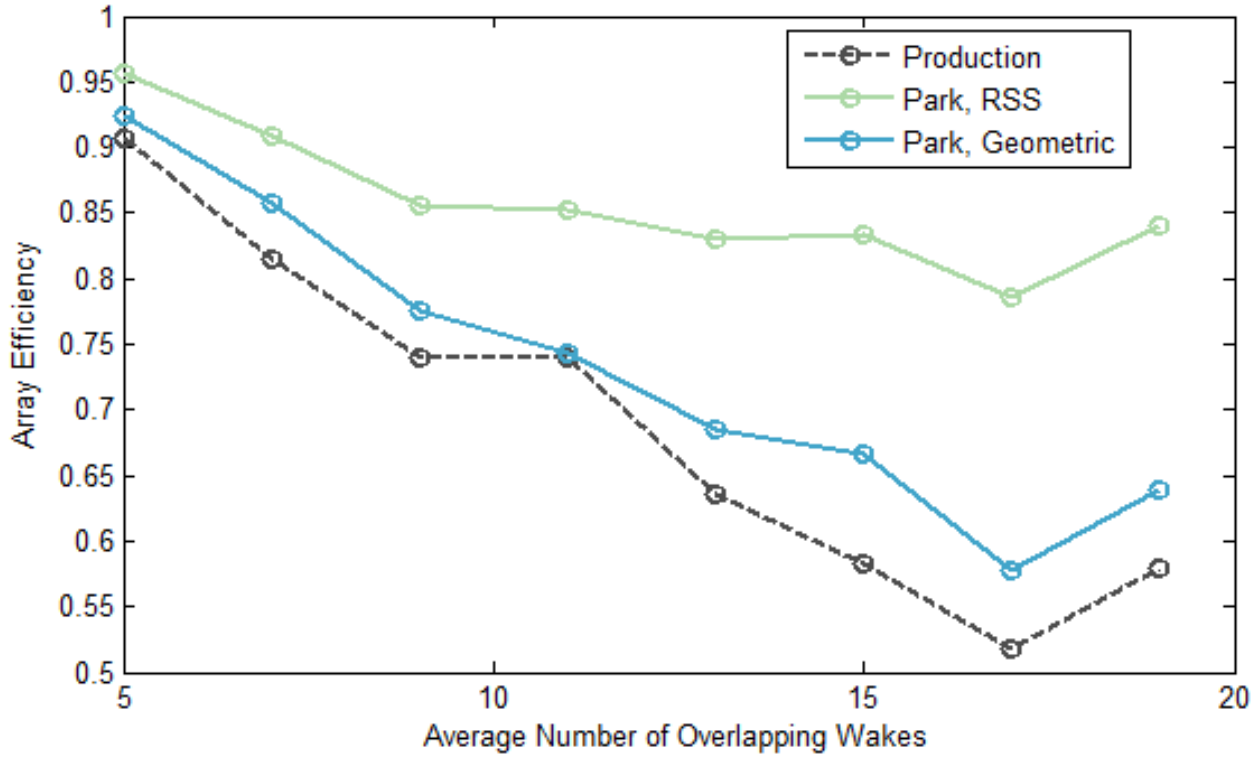
Validation with Production Data

- The combination method improves the slope of the curve



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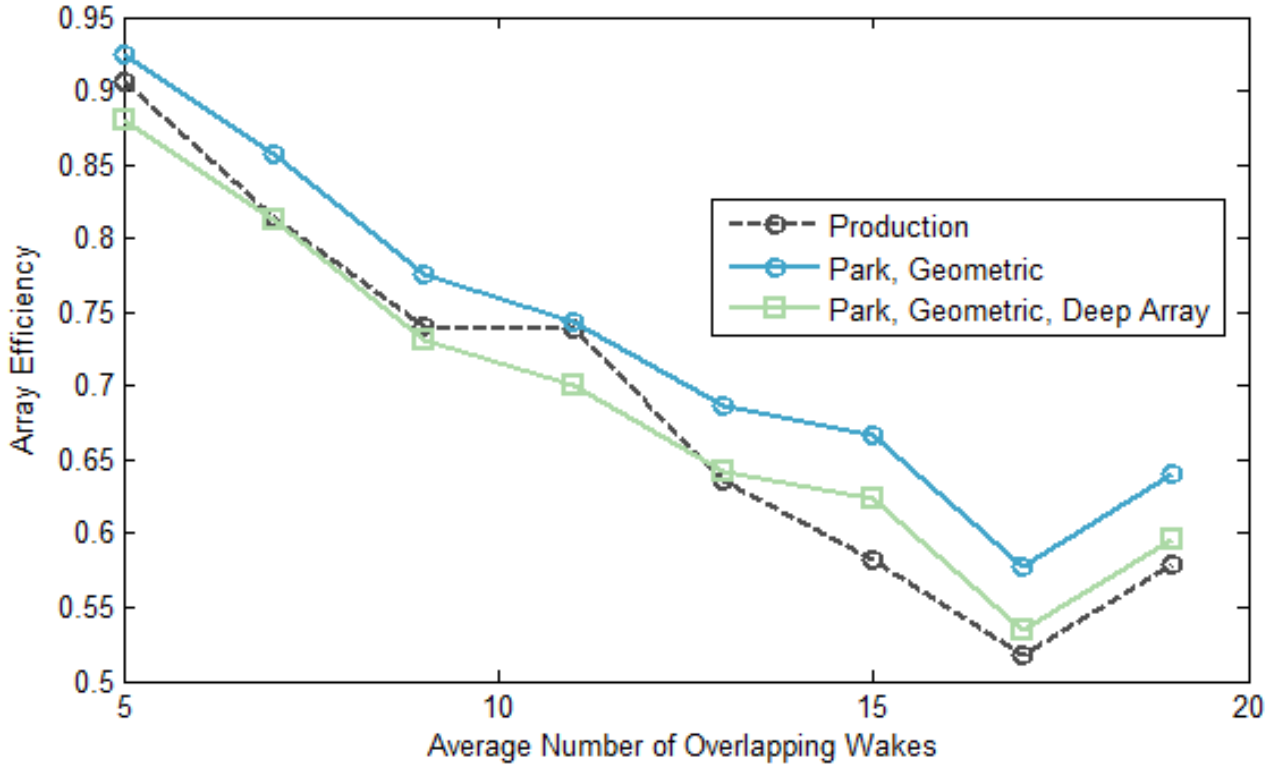
Validation with Production Data

- A deep-array adjustment based upon turbine density



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Conclusions

- Typical wake models are single turbine models only (Park, Eddy Viscosity) and consideration of the wake combination method is important, especially for large projects
- More flexibility in wake combination methods in modeling software would enhance capability of the WRA community
- Lots of opportunity to improve wake modeling tools based upon fundamental principles and time dependent inputs
- Continual validation studies are important

Thanks for your attention!

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