Wind energy research at Indiana University: large wind farms

R.J.Barthelmie and S.C. Pryor

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Data: DONG Energy A/S

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Atmospheric and Sustainability Sciences at IU

- A concentration of top faculty associated with atmospheric and environmental research
- A range of major and minors including a Ph.D. minor in Sustainable Energy Science and a certificate in Atmospheric Sciences
- Courses including wind power meteorology, climate change, sustainable energy systems
- B.Sc., M.Sc., Ph.D. degrees
- Collaboration across disciplines – Environmental Science and Policy, Physics, Chemistry, Informatics, Biology

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Atmos. & Sustainability Sciences: Facilities

- Computational facilities at IU are ranked in the top 10 nationally. Extensive GIS and remote sensing facilities
- Extensive instrumentation and field stations available for experimental research. These include two towers in forest environments, a fully equipped chemical laboratory and remote sensing instrumentation.

Specifically for wind energy:

- Two lidar systems (currently) and a full range of meteorological instruments
- WRF model run at high resolution for short-term forecasting

Barthelmie et al. 2010

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Atmos. & Sustainability Sciences: Research

Renewable energy:

- Inter-comparison of methods for wind and turbulence profiling
- Measurements of vertical wind shear, wind veer and turbulence applied to load estimation in large wind farms
- Quantifying power losses due to wakes in large wind farms
- Climate change impacts on the renewable energy sector
- Application of the WRF model for wind resource and short-term forecasting
- Carbon footprints

Regional manifestations of climate change and variability:

- Variability and trend analyses of wind speed and precipitation in the USA and Europe
- Detecting changes in geophysical probability distributions & extremes
- Influence of surface climate network distributions on estimates of global change
- Downscaling for regional climate change assessments (dynamical and probabilistic)

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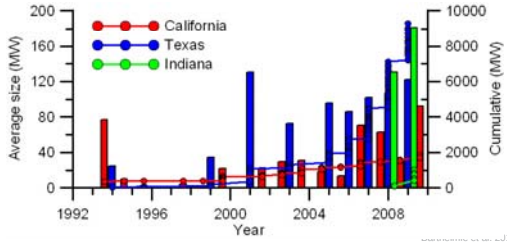
Large wind farm issues

1. Large turbines – hub-height above 'traditional' measurements
   - Wind shear and veer, loading
2. Multiple wake effects
   - Deep array losses
   - Regular vs irregular grids



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Vertical profiles

- Standard 2-3 MW turbine hub-height 70-80 m
- New methods to measure wind speed/turbulence/veer
- Remote sensing – more mobile, more accurate, extends to ~200 m
- Better estimate of hub-height wind speed/shear across the blades

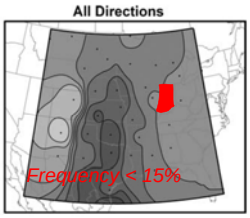
State-of-the-art remote sensing of wind and turbulence. IU's lidar being evaluated with

Example of lidar wind speed and turbulence measurements in Indiana on a sample day during May 2008

Barthelmie et al. 2010

Low-level jets

- Frequent occurrence of high wind speed maxima in the MidWest
- Indiana frequency ~ 8% (Whiteman et al)
- >50% of the LLJs have wind maxima < 500 m (Whiteman et al)
- Most frequent at night
- High shear and veer
- High turbulence
- Winter campaign planned with lidar at an open site in N. Indiana to determine impact across the rotor plane

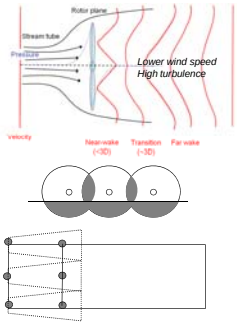


From Walters et al. AAG 2008

Barthelmie et al. EWEC 2010

Wind-turbine interactions: wakes

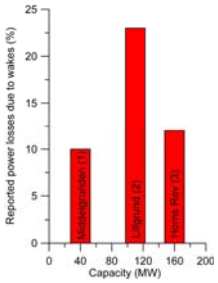
- Wakes: area of high turbulence, lower wind speed behind turbines
- Wake recovery depends on many factors:
  - Environment - Wind speed, turbulence, atm. stratification
  - Turbine type – Pitch, stall, thrust coefficient, hub-height
- Multiple wakes
  - Continue to interact with each other and the environment



Barthelmie et al. 2010

Power losses due to wakes

- For offshore reported in the range 10-23% of average power
- Highly dependent on:
  - Wind speed distribution
  - Turbine number
  - Turbine layout
  - Turbine characteristics
  - Wind direction distribution
  - Turbulence/atmospheric stability
- Difficult to calculate
- Generally not reported



(1) Barthelmie Wind Eng. 2007
(2) Dahlberg European Offshore 2009
(3) Sørensen EWEC 2008

Barthelmie et al. 2010

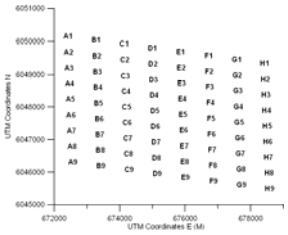
Examples of individual wake profiles

- Test from N. Indiana wind farm
- Measurements by lidar
- At 3 D from the turbine
- Wind speed is ~15% lower at hub-height
- Turbulence is ~15% higher at hub-height
- Not representative data period

Barthelmie et al. EWEC 2010

Wind farm size and layout: Europe offshore

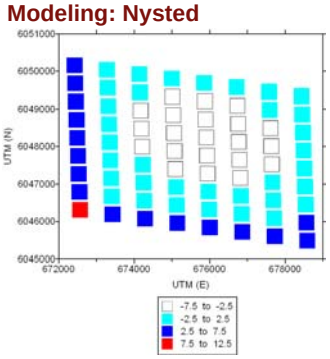
- Example Nysted (DONG Energy)
- 72 wind turbines
- 11 km from nearest coast
- 2.3 MW turbine
- Turbine spacing 5.8 D /10.6 D
- Data 2004-2006



Barthelmie et al. 2010

WAsP Modeling: Nysted

- Nysted
- Using standard parameters
  Wake decay coefficient =0.03
- Losses shown as % difference from average



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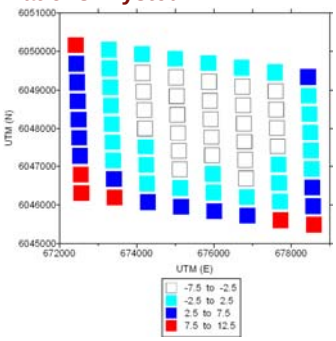
Observations: Nysted

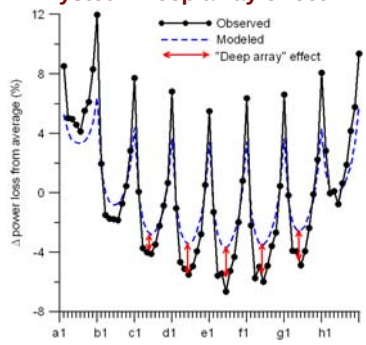
- Losses shown as % difference from average
- Similar magnitude to modeled
- Some spatial difference especially corner turbines



Barthelmie et al. 2010

Nysted: 'Deep array effect'

FROM: Barthelmie and Jensen Wind Energy 2010



Barthelmie et al. 2010

Conclusions

- Modified parameterization of wind farm models captures power losses due to wakes
- Focus on physical understanding of wake development in large wind farms
- Measurements in large arrays

Lidar wind speed/turbulence measurements to heights of ~200 m

Barthelmie et al. 2010