Wind energy research at Indiana University: large wind farms

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Funding: NSF CBET-0828655, EU UPWIND # SES6 019945
Data: DONG Energy A/S

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

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

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
• Influences of surface climate network distributions on estimates of global change
• Downscaling for regional climate change assessments (dynamical and probabilistic)

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

Vertical profiles

• Standard 2-3 MW turbine hub-height 70-85 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

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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

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
  - Wake decay coefficient
  - Hub-height
- Difficult to calculate
- Generally not reported

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

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

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

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WAsP Modeling: Nysted
- Using standard parameters
  - Wake decay coefficient
  - Losses shown as % difference from average
Observations: Nysted
• Losses shown as % difference from average
• Similar magnitude to modeled
• Some spatial difference especially corner turbines

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

FROM:
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Wind Energy 2010

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