Wind energy research at Indiana University

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Wind Indiana
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Nordic Energy Research (Climate and Energy Systems: Risks, potential, adaptation)

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Bottlenecks

- DoE report (2008): 20% electricity from wind by 2030
- DoE workshop (2008): Key research challenges (PIs attendees).
  - **Cross-cutting themes** included increased modeling and measurement capabilities ✓
  - **Improved wind farm design** ✓
    - i.e. Maximize power output for given land area & turbine set
  - **Improved wind farm operation and grid integration** ✓
    - i.e. Improvements to 24-48 hour predictions of electricity generation to maximize profits and reduce spinning reserve.
- DoE RFPs to address bottlenecks expected 2012 → **We need action now!**

http://www1.eere.energy.gov/windandhydro/wind_2030.html
http://www.nrel.gov/docs/fy08osti/43521.pdf (in brief: Shaw et al 2009 Bulletin of American Meteorological Society)

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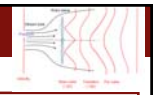
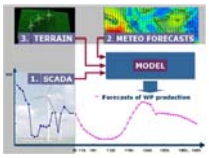
Research needs



Improved resource assessment
•Long-term trends
•Inter-annual variability
•Short-term forecasting

Improved wind farm design to maximize power output
•Wake measurements & modeling



Improved understanding & modeling of causes of extreme loads
•Gusts & extreme wind speeds
•Extreme shear & veer
•Low Level Jets

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Extreme loads: Atmospheric conditions

- Design standards (IEC 61400-1) – onshore turbines
  - Extreme wind speed:
    - 50yr RP 10-minute sustained wind speed
  - Extreme operating gust
    - 3-second gust
  - Extreme wind shear
  - Extreme direction change
  - Extreme coherent gust
  - Extreme coherent gust & change of direction

Turbine class	I	II	III	S
U_{ref} (m s^{-1})	50	42.5	37.5	Values specified by designer
A (I_{ref})	0.16			
B (I_{ref})	0.14			
C (I_{ref})	0.12			

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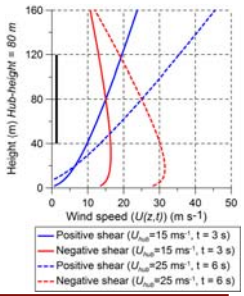
Extreme wind shear

- IEC 61400-1:

$$U(z,t)=\begin{cases} U_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha} \pm \\ \left(\frac{z-z_{hub}}{D}\right)\left(2.5+0.2\beta\sigma_1\left(\frac{D}{\Lambda_1}\right)^{\frac{1}{4}}\right)\left(1-\cos\left(\frac{2\pi t}{T}\right)\right) \\ \quad \text{for } 0 \le t \le T \\ U_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha} \quad \text{otherwise} \end{cases}$$

- Meteorology state-of-art:

$$U_z=\frac{u_*}{\kappa}\left[\ln\frac{z}{z_0}-\Psi_m\left(\frac{z}{L}\right)\left(1-\frac{z}{2z_i}\right)\right]$$



IEC 61400-1 conservative unless z_i < 200 m (L = 10 m)
Caveat: LLJ

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Extreme gust

- IEC 61400-1 (addition)

$$U_{gust}=Min\left\{1.35\left(U_{1yr}-U_{hub}\right),3.3\left(\frac{\sigma_1}{1+0.1\left(\frac{D}{\lambda}\right)}\right)\right\}$$

- Meteorology GF (multiplier) – 10 m

Averaging period	UK structural design (Cook 1986)	Tropical cyclones (Krayer & Marshall 1992)	Mixed climate (Yu & Chowdhury 2009)	
z_0 (m)	0.03	0.03	2×10^{-4} to 1×10^{-3}	0.03 to 0.06
10 minute	1.1	1.1	1.1	1.2
3 second (gust)	1.5	1.7	1.4	1.7

- 10-minute mean U_{hub} = 15 m s^{-1}, z_{hub} = 70 m, a rotor diameter (D) of 80 m, for a Turbine class I with a U_{ref} of 50 m s^{-1} and I_{ref} = 0.16
  - IEC 61400-1: U_{gust} = 7.5 m s^{-1}
  - Met: U_{gust} = 6.3 m s^{-1}

IEC 61400 conservative
Caveat: Thunderstorms

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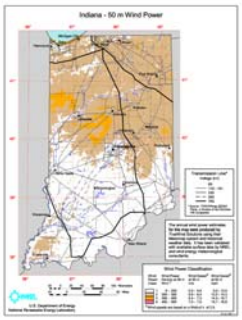
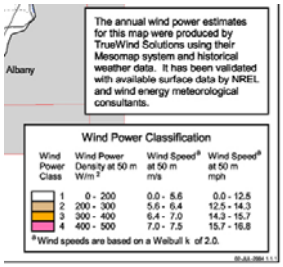
Wind resource estimates





N.B. Resource looks MUCH better at 80 or 100 m…

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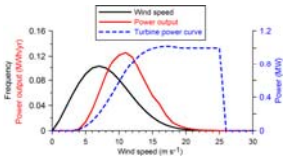
Wind resource: Long term trends

- Weibull distribution of wind speeds $P(U) = 1 - \exp\left[-\left(\frac{U}{A}\right)^k\right]$
  - A = Scale parameter (ms^{-1})
  - k = Shape parameter
- Energy density $E = \frac{1}{2}\rho A^3 \Gamma\left(1+\frac{3}{k}\right)$
  - An example:
    - $U_{50th\ percentile} \approx 7\ ms^{-1}$
    - 11% of power
    - $U_{90th\ percentile} \approx 12.5\ ms^{-1}$
    - 75% of power



Pryor & Barthelmie (2010): Renewable and Sustainable Energy Reviews

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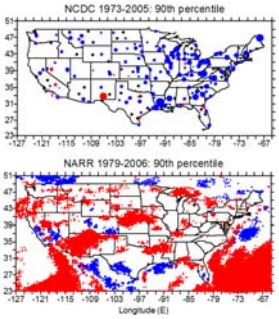
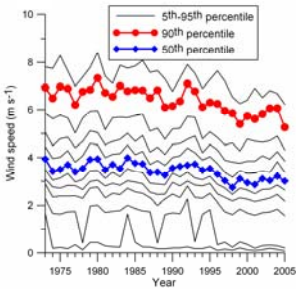
Long-term trends… Historical





Pryor et al. (2009): JGR

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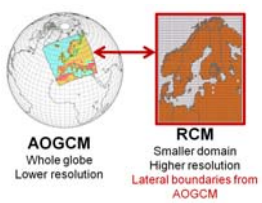
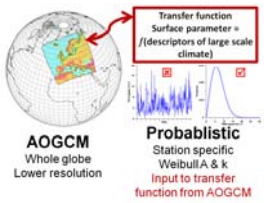
Making climate projections: Approaches

- Dynamical downscaling: Apply Regional Climate Model (0.22 × 0.22°)
- Probabilistic downscaling: Apply transfer functions (station specific)





Pryor et al. (2005): Climate Dynamics

Pryor et al. (2005): JGR, Pryor et al (2006): GRL, Pryor & Schoof (2010): Meteorologische Zeitschrift

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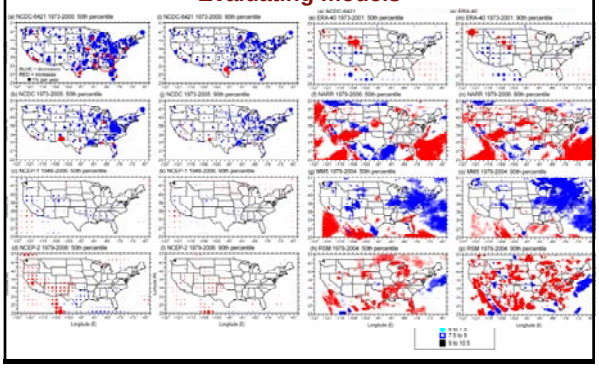
Evaluating models



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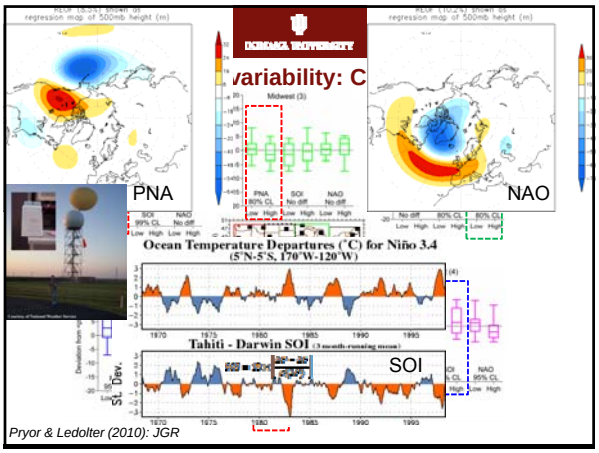
Increased resolution improves skill!

Unpublished data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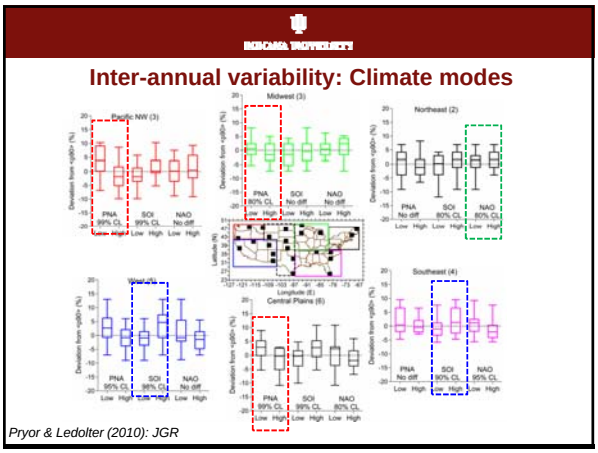
variability: C
PNA
NAO
Ocean Temperature Departures (°C) for Niño 3.4
(5°N-5°S, 170°W-120°W)
Tahiti - Darwin SOI
SOI
Pryor & Ledolter (2010): JGR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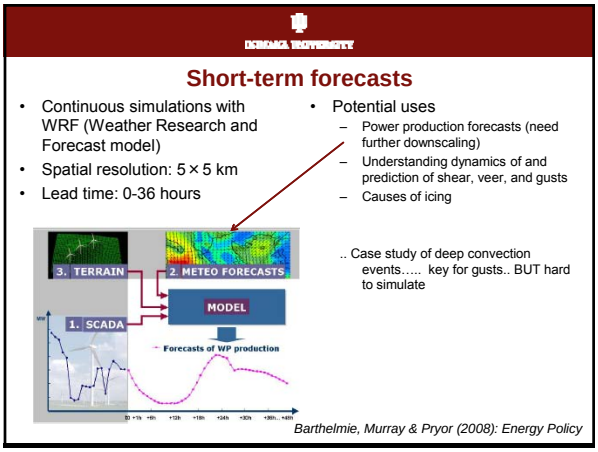
Inter-annual variability: Climate modes
Pryor & Ledolter (2010): JGR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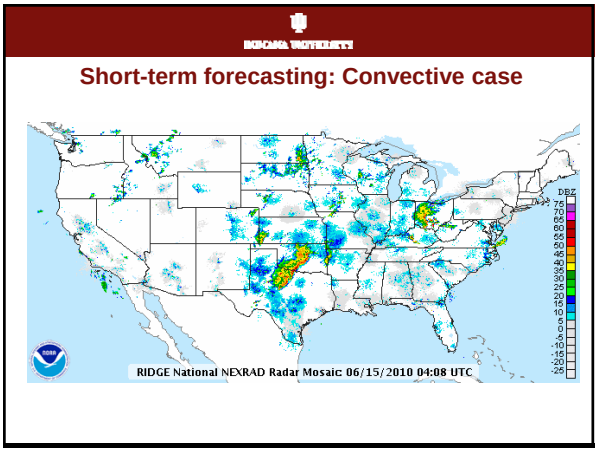
Short-term forecasts
• Continuous simulations with WRF (Weather Research and Forecast model)
• Spatial resolution: 5 × 5 km
• Lead time: 0-36 hours
• Potential uses
– Power production forecasts (need further downscaling)
– Understanding dynamics of and prediction of shear, veer, and gusts
– Causes of icing
.. Case study of deep convection events..... key for gusts.. BUT hard to simulate
3. TERRAIN
2. METEO FORECASTS
MODEL
1. SCADA
Forecasts of WP production
Barthelmie, Murray & Pryor (2008): Energy Policy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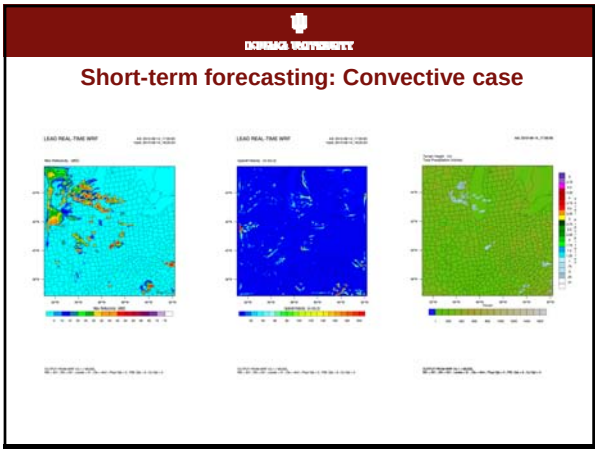
Short-term forecasting: Convective case
RIDGE National NEXRAD Radar Mosaic 06/15/2010 04:08 UTC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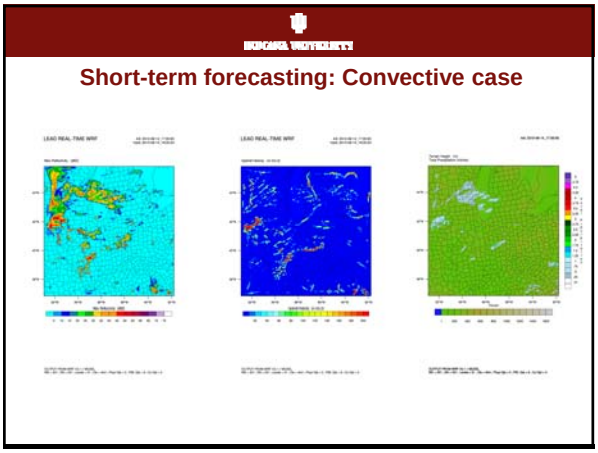
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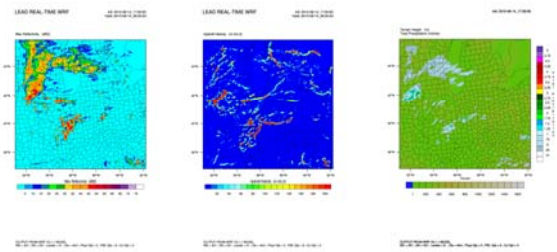

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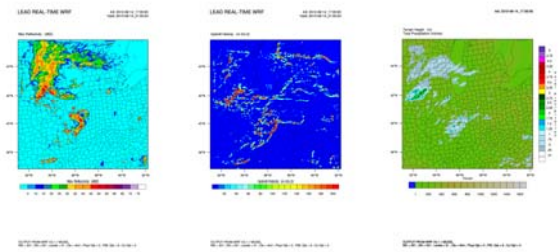

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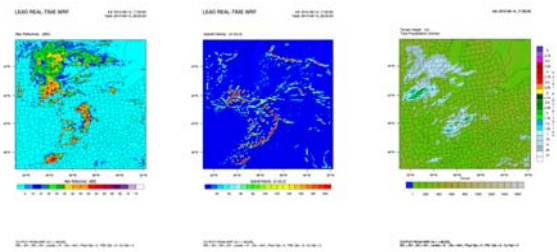

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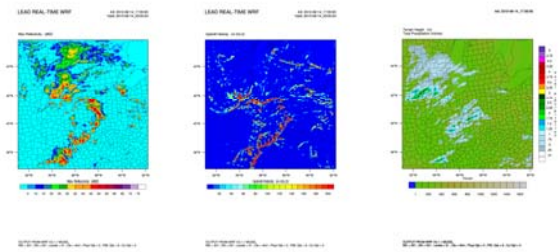

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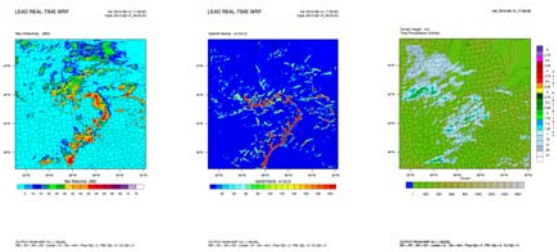

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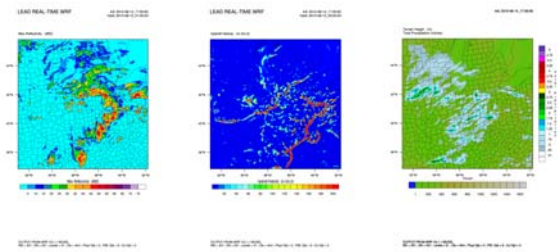

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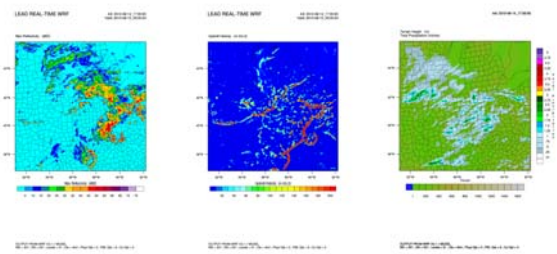

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Summary

- Climate projections of parameters relevant to wind energy industry
  - Tools being developed & applied exhibit some skill! More research underway.. Enhanced resolution brings benefits (to approx. 12 km)
  - Wind resource: High inherent variability. MUST be accounted for in climate change projections & power production
- Extreme events
  - IEC 61400 design guidelines generally conservative: Exception – thunderstorms? & combined extremes leading to excess loads
  - Incomplete scientific understanding of phenomena responsible for extreme loads particularly in climates away from N. Europe
- Short-term forecasting
  - Capability = available. Skill is demonstrable for the special conditions that challenge wind farm operation in the Midwest.