Wind Characteristics and Forecasting Challenges

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What is the National Center for Atmospheric Research (NCAR)?

- NCAR is a Federally funded research and development center sponsored by the National Science Foundation.

- NCAR is operated by the University Corporation for Atmospheric Research (UCAR), a non-profit corporation formed in 1959.

- UCAR has 1400 employees and ~$250M budget.

- Research is conducted on solar physics, climate and weather modeling, air chemistry, thunderstorms, hurricanes, icing, turbulence, societal impacts of weather, energy, etc.

NCAR, Boulder, CO
Research Areas:

- Climate Science
- Air Chemistry
- Solar Physics
- Weather Research
  - boundary layer
  - thunderstorms
  - weather models
  - hurricanes
  - land surface
  - coupled models
- Social Sciences
- Supercomputing
- Technology Transfer

National Center for Atmospheric Research (NCAR)
Research Applications Laboratory

Mission

- Perform applied R&D geared toward weather related decision support systems
- Transfer knowledge and technology to U.S. government agencies, the private sector, and foreign governments
Wind Energy Related Research at NCAR

- Weather modeling (global to urban scales)
- Wind characterization (how the wind blows)
- Data assimilation (combining obs and forecast)
- Probabilistic Prediction (ensemble modeling)
- Boundary layer research and modeling
- Applied mathematics & statistics
- Land surface modeling (land climate interaction)
- Coupled models (atmosphere and ocean)
Wind Prediction Challenges

Scale Interactions are Critical

Global Scales

Continental Scales

Regional Scales

Local Scales

Long Island

Urban Scales

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Wind Prediction Challenges

Local Effects & Phenomenon Must be Addressed

- Local Topography
- Surface Roughness
- Land Use
- Vegetation Characteristics
- Urbanization
- Atmospheric Gravity Waves
- Low-level jets
- Convection currents
- Icing
Atmospheric Boundary Waves
Weather predictions are inherently non-precise due to uncertainties in:

- state of the atmosphere
- analyzed initial state
- model resolution
- model physics/parameterizations
- coarse treatment of surface characteristics
- many other simplifications
Atmosphere is a Fluid

Water vapor simulation
Wind Prediction Challenges

Complex Atmospheric Flows

A lot of details are missed between observations!

Balloon soundings

Photo by Bob Henson (UCAR)
GE 1.5 MW
Wind Turbine

80 meter hub height (87 yards)
77 m blade diameter
GE 1.5 MW Wind Turbine

80 meter hub height
77 m blade diameter

Standard surface weather station with a 10 meter (33 ft) high wind sensor.

Assessments & Forecasts

observation

60-80 m

10 m
Statistical post processing will be required to address local effects.

- Regression Techniques
- Neural Network
- Data Mining
- Etc.

Data Needs:

- Turbine height wind speed & direction
- Energy output
- Generator availability
Wind Turbine Size Growth

Size of Wind Turbines

Hub height

150 m

100 m

15-20 m


50 kW Ø 15 m

100 kW Ø 20 m

500 kW Ø 40 m

600 kW Ø 50 m

2,000 kW Ø 80 m

4,500 kW Ø 120 m

10,000 kW Ø 180 m

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Important Atmospheric Boundary Layer Phenomenon

Low-level jets

Low-level jets can damage generators and reduce lifecycle
Flows in Complex Terrain

Clark-Hall model simulation

- Five nested domains
- Inner domain 250 m horizontal resolution
- Initialized with RUC model 2200 UTC 20 Dec 2008
- Vertical cross-section through DIA
- Model showed extreme gustiness at Denver International Airport associated with lee wave amplification

21 Dec 2008 -0118 UTC
Boeing 737-500

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Important Atmospheric Boundary Layer Phenomenon

Ramp-down events
Ramp-up events

Unanticipated ramp events are very costly

Example of Local Effects

Fine-scale Modeling Study

Cedar Creek Wind Farm, Northeast Colorado
Photo by Carleye Calvin, UCAR
274 Wind Turbines at Cedar Creek, Co.

Wind Speed at turbine nacelles
WRF Domains for Intra-farm Wind Studies

D1: 30000m 128x114
D2: 10000m 184x169
D3: 3333m 244x247

D4: 1111m 331x346
D5: 370m 505x490
D6: 123m 262x268
D7: 123m 280x271

Cedar Creek Wind Variation Study

Ramp studies

Terrain height

Photo by Bob Henson (UCAR)
Modeled Wind Speeds at 15m AGL

D5: DX = ~370 m
Every 10 minutes
From: Nov.14, 2008 23:00
To: Nov.15, 2008 19:00

△ Cedar Creek

Wind Speed Variability
Comparison of intra-farm wind variations simulated by different model grid resolutions

(By interpolating model prediction to the turbine sites)
Wind Energy Nowcasting

Causes of Wind Ramp Events

- Cold Fronts
- Warm Fronts
- Thunderstorm Outflows
- Sea Breezes
- Microbursts
- Gravity Waves
- Eroding Surface Inversion
- Momentum mixing

Photo by Bob Henson (UCAR)

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Wind Energy Nowcasting

Gust fronts approaching ‘wind farm’

Wind ramp event is imminent

Need to provide time-of-arrival and magnitude of wind energy ramp.
Wind Energy Nowcasting

Gust fronts approaching 'wind farm'

Wind ramp event is imminent

NCAR Auto-Nowcasting System

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Thunderstorm-induced Wind Energy Ramp Events
Climate Variability & Wind Resource Assessment

Quantifying interannual variability


January winds at 0600 UTC (2300 MST)

Need to understand climate variability for wind resource assessment – (for example, La Nina vs. El Nino)
Summary

- Wind characterization and prediction is complex as wind is influenced by global, regional, and very local conditions.

- Wind energy prediction requires complex data assimilation, physics models and statistical post processing techniques that take advantage of wind plant data.
THANK YOU