Understanding the Local Wind Resource

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WindLogics Today

46 people focused on 3 things:
1. Wind Resource – over 700 studies completed
2. Wind Variability – long-term analysis standard
3. Wind Forecasting – currently ~5000 MW

Grand Rapids Sciences Center
Ph.D. atmospheric sciences team
150 processors & 36 terabytes of storage
Data center with NOAAport Satellite System

Saint Paul Operations Center
Meteorology and GIS production, Sales, Operations
500 processors & 110 terabytes of storage
Data center with NOAAport Satellite System
US Market Trends

Annual Installed U.S. Wind Energy Capacity On the Rise

Source: AWEA
Minnesota Market

Minnesota RPS (Renewable Portfolio Standard) – 20% by 2025

Minnesota currently has about 2 - 4 % wind penetration

Net metering law of 40 kW

Almost 300 MW of Community Wind and ~1200 MW total
Facilitating Market Growth

Need for commercial and community developments

Transmission growth needed, massive backlog in the interconnection queue

Due diligence required for wind projects

Understanding of atmospheric and meteorological complexities
The Need for Wind Assessment

Location & terrain make big difference

Power in the wind is proportional to the cube of wind speed, so great value in optimizing location, layout & height

Many characteristics to consider
Shear (speed increase with height)
Diurnal & seasonal patterns
Long-term interannual variability

Major planning and financing issue
A large investment with a 25-year timeline
Variability on many time scales
Implications for operations
Traditional Methods - MCP

**Measure on-site data**
- Number of met towers – Spatial Coverage
- Number of months – Temporal Coverage

**Correlate to another longer-term measurement**
- Extend on-site data by correlating to another source

**Predict project energy output**
- Predict hub height wind speeds from lower measurements
- Model wind flow over site using one representative tower
- Model wake losses and estimate other project losses
Predicting Long-term Project Energy

Challenges of distance, height, time & space
Integrated Wind Understanding

Take advantage of all the available data:

1) Use best available “gridded” archives of real weather data from government agencies
   - Actual recorded weather data, used to initialize weather forecast models

2) Integration of tower data and other on-site measurement points

3) Add the best available high-resolution topography and land cover information

4) Properly apply meteorological models and wind field models integrating data over space and time

5) Analyze long-term variation and the financial impact on your specific situation

6) Use wind forecasting to minimize cost and operating impacts & maximize revenues
### Atmospheric Complexity

<table>
<thead>
<tr>
<th>Solar Radiation</th>
<th>Convection</th>
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<tr>
<td>Moisture Fluxes</td>
<td>Condensation</td>
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<td>Turbulence</td>
<td>Evaporation</td>
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<td>Surface Heat</td>
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The atmosphere is so complex... So how does this work?
Integrates all available data sources, from the surface to the upper atmosphere, into a unified and physically consistent state of all grid cells at a given point in time.

Over 160 weather variables collected from:

- Surface / METAR station data
- Oceanographic buoys
- Ship reports
- Aircraft (over 14,000 ACARS/day)
- NOAA 405 MHz profilers
- Boundary-layer (915 MHz) profilers
- Rawinsondes (balloon soundings)
- Reconnaissance dropwinsonde
- RASS virtual temperatures
- SSM/I precipitable water
- GPS total precipitable water
- GOES precipitable water
- GOES cloud-top pressure
- GOES high-density vis. cloud drift winds
- GOES IR cloud drift winds
- GOES cloud drift winds
- VAD winds from WSR-88D NEXRAD radars
Resolution of Gridded Data

ReAnalysis Gridded Data

High Resolution Gridded Data
**Meteorological Models**

**Numerical gridded representation of the laws of physics**

- Conservation relations
  - Mass
  - Energy
  - Momentum
  - Water, etc.

- Physical processes
  - Radiation
  - Turbulence
  - Soil/ocean interactions, etc.

- Use lots of fast computers
  - Partial differential equations
  - Gridpoint difference values
  - Step all points through time using very small steps
  - (a few seconds per step)
Long-term Variability

We must extend our understanding to 30 years or more.
Internal study:
Coarse-grid result showing standard deviation of annual average wind speed over 30 years

Annual Variation is Site Specific
Long-Term Wind Speed Variations

Even at a low variability site like this (annual sigma 3.5%) choice of 8-year period can affect energy projection by 8% or more
Annual Historical Energy

(Wind Data 1972–2002)
Computational Learning System

Used to establish relationship between short-term onsite data and long-term surrounding reference data
Based on Support Vector Machine (SVM) methods
Non-linear multi-parameter regression
Estimated values retain probabilistic nature of underlying distributions
Extensive research into tuning CLS for wind-based applications
Using Multiple Correlation Points

Wind Farm Location

NCEP / NCAR Reanalysis Gridded Data
Gross Energy to Net Energy

1) **Start with a gross energy value (P50, P90, etc.)**

   Predictive intervals (P90, etc.) are statistically derived directly from the long-term variability of the project site at hub height

   Predictive intervals are **NOT** confidence intervals

   A long-term time series of energy data at hub height, generated with best available data & practices, is a very powerful tool... consider combinations of projects, etc.

2) **Subtract other net losses for a net energy value**

3) **What about uncertainty & confidence intervals?**
Net Project Losses

Other project losses, usually linear in nature and related to the project design and turbines:

- Wake and array losses..........3-7 % typical, less for single row or small project
- Turbine availability...............3 % typical, negotiable in turbine agreement
- Turbine power curve............2 % typical, negotiable in turbine agreement
- Electrical losses................2-3 % typical, based on design & current levels
- Parasitic/icing losses.........1-2 % typical, site & turbine/technology dependent

Other items that apply to some projects:

- Wind sector management..............if needed on project, perhaps 1 %
- Substation maintenance/downtime.....on remote feeders, perhaps ½ %
- High wind hysteresis..................for high wind sites, frequent cutouts

Bottom line:

- Total net losses of 9% – 15%
- Turbine layout has the biggest impact on this value, and accuracy of wake/array losses depends on accuracy of long-term wind data
Statisticians chuckle at the way we talk about uncertainty and confidence intervals in the absence of samples...

Example where we have samples: anemometer uncertainty
New, calibrated #40 anemometers have relative uncertainty in wind speed of ~1.6%
Concerns about time (e.g., bearing wear), installation (booms, vane alignment),
data quality (missing data), calibrated vs uncalibrated anemometers, etc.
Errors are magnified if used for shear to hub height & power calculations

Examples where site-specific data is limited:
Depending on approach, could also adjust for “uncertainty” in the methods, data or model for power curve, wake losses, hub height values, long-term normalization, etc.
It is very difficult to justify meaningful values

We should focus on best practices rather than uncertainty
Financial Risk is the Bottom Line

Improved understanding of wind resource and variability has great value

Need **integrating approaches** that unify all data and reduce the risk inherent in single-point data sources

- Meteorological Towers
- Modeling
- Statistics

The goals:

- Accurate results based on scientific and statistical methods
- Consistent ways to view risk and compare projects
- Take wind plants into the mainstream of power generation projects in terms of process, financing, operations and utility perception
Minnesota’s Wind Resource
Questions

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