

# Wind Assessment & Forecasting

GCEP Energy Workshop, Stanford University

Mark Ahlstrom, CEO, WindLogics Inc. April 26, 2004

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## WindLogics Background

- Founders from supercomputing industry (1989)
- Modeling and visualization for environmental sciences and meteorology
  - US Air Force Operational Weather Squadrons - 140 seats
  - Israeli Air Force - complete forecast modeling system
  - Harvard University - air quality studies for energy industry
  - City of Cincinnati - 3D terrain-following dispersion modeling
  - DOE - real-time diagnostic wind field monitoring
  - NASA - meteorological data assimilation system
  - Boeing / Autometric - global 3D visualization system
  - ARIA / Air Liquide - air pollution models and imaging
- More than 50 fine-scale forecasting systems delivered
- With VC funding, applying these advanced modeling and analysis technologies to wind energy since 2002

Weather Modeling - Air Quality - Visualization - Systems

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## 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)
  - Turbulence
  - Diurnal & seasonal patterns
  - Long-term interannual variability
- Major planning and financing issue
  - \$1 million/MW and a 25 year timeline
  - Direct return-on-investment issue
  - Major implications for utility operations

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## Measurement – Tall Towers

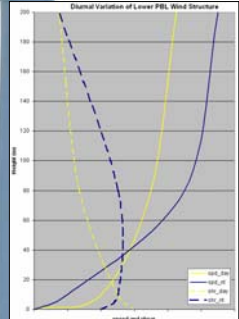
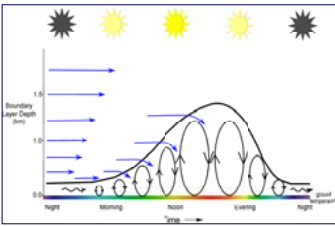


- The accepted practice for wind energy site assessment
- Advantages:
  - Relatively easy to understand & explain
  - Instantaneous sample at a point
  - Wind speed, turbulence & direction
- Disadvantages:
  - Calibration, icing and data integrity
  - Time to collect data (a year or more)
  - Expensive to collect data at hub height, so often measure lower heights and extrapolate to hub height with shear assumptions

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## Boundary Layer Diurnal Variation

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## Measurement – SODAR



- Sonic Detection And Ranging
  - Backscatter from thermal turbulence
  - Using vertical and two tilted beams, timing and Doppler shift can be used to measure wind speed and direction
- Advantages:
  - Measurements at hub heights (150 m or higher)
  - Multiple heights measured (good for wind shear)
  - More easily installed and moved than met towers
  - Measures a volume rather than a point - more closely approximates turbine blade sweep area
- Disadvantages:
  - Measures a volume rather than a point, so not directly comparable to tower measurements
  - Performance impacted by precipitation & humidity
  - Relatively expensive (\$30,000 and more)
  - Typically only used for "spot checks"

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## Wind Modeling

The general concept:

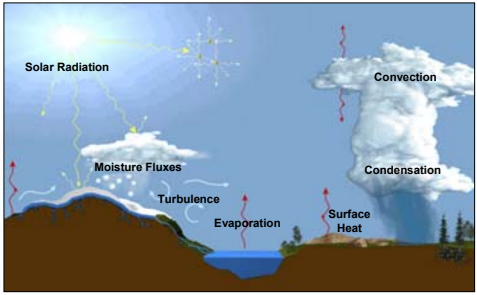
- 1) Use "gridded" assimilations of weather data (originally from the weather services)
- 2) Integrate available tower or SODAR data
- 3) Use high-resolution topography and land cover information
- 4) Properly apply meteorological models and wind field models to analyze the site at a fine resolution



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## Atmospheric Complexity



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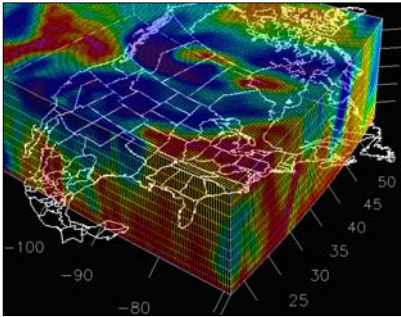
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## Assimilation Data Sets

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
- Site reports
- Aircraft (over 14,000 ACARS/day)
- NOAA 485 Mite profiles
- Boundary-layer (915 Mite) profiles
- Rawinsondes (balloon soundings)
- Reconnaissance dopplerwinds
- RAAS virtual temperatures
- SMI precipitable water
- QPS total precipitable water
- QDES precipitable water
- QDES cloud-top pressure
- QDES high-density vis. cloud drift winds
- QDES IR cloud drift winds
- QDES cloud drift winds
- VAD winds from WSR-88D NEXRAD radars

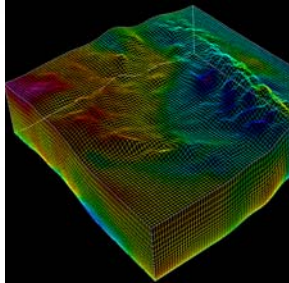


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## Meteorological Models

- 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
  - Grid point difference values
  - Step all points through time using very small steps (a few seconds per step)

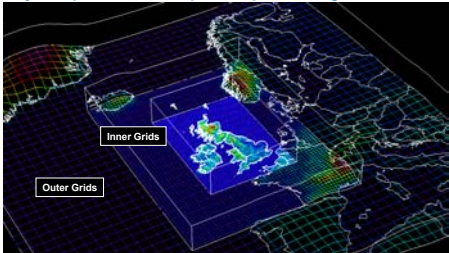


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## Nesting Modeling Techniques

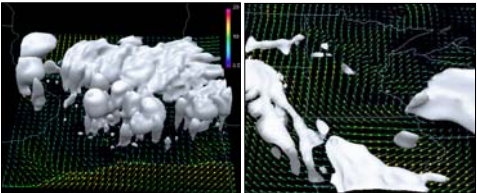
- Modeling can "fill the gaps" in space & time between the data from the assimilation data set archives
- Very computational, but parallel processing can be used



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## Modeling from Weather Data Archives



|  |  |
|--|--|
| <p>July 4, 2003 in IL</p> <ul style="list-style-type: none"> <li>• 5 minute resolution</li> <li>• 1 Second = 30 minutes</li> </ul> | <p>June 9-25, 2003 in MN</p> <ul style="list-style-type: none"> <li>• 1 hour resolution</li> <li>• 1 Second = 6 hours</li> </ul> |
|--|--|

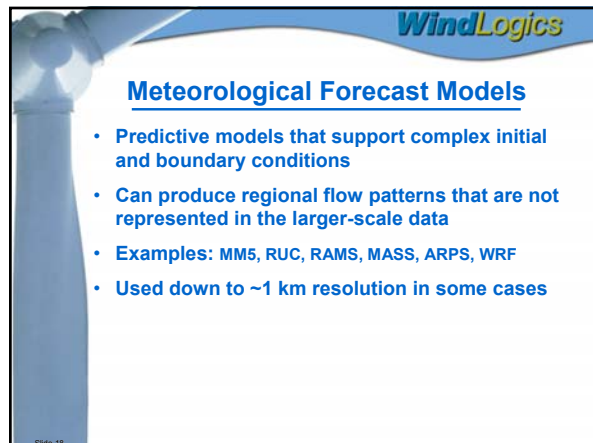
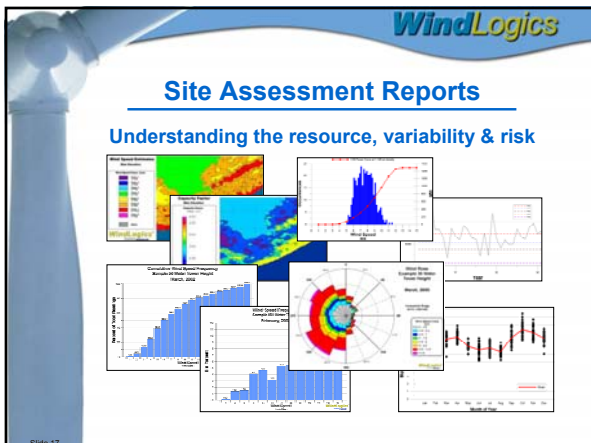
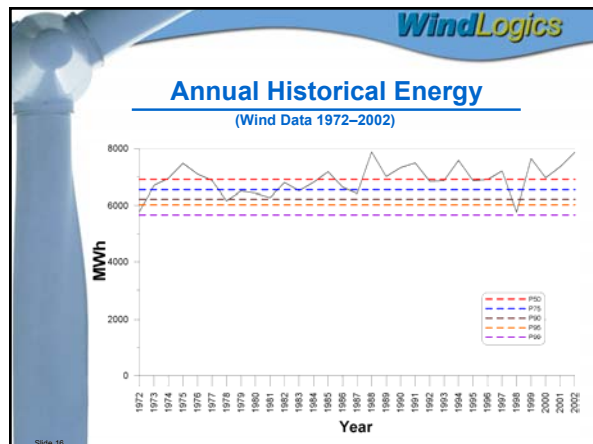
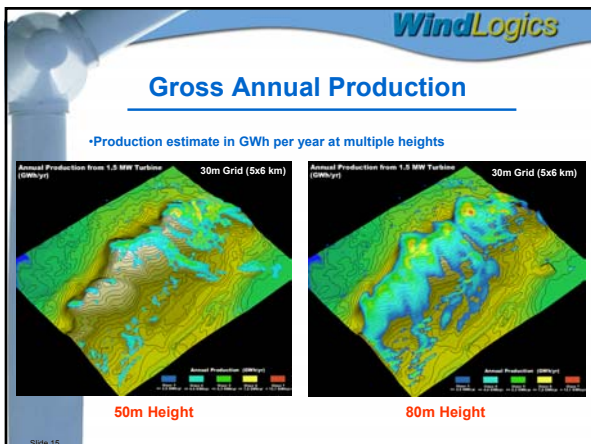
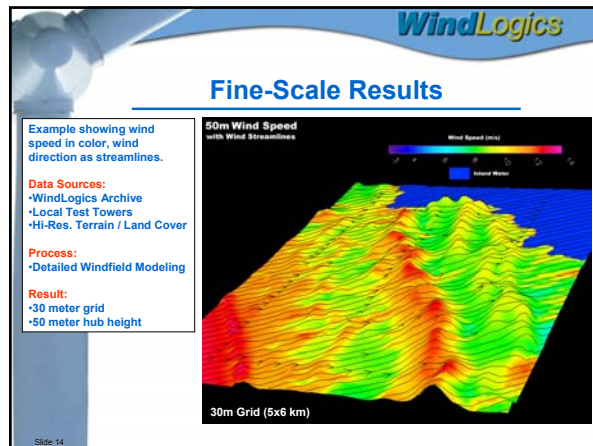
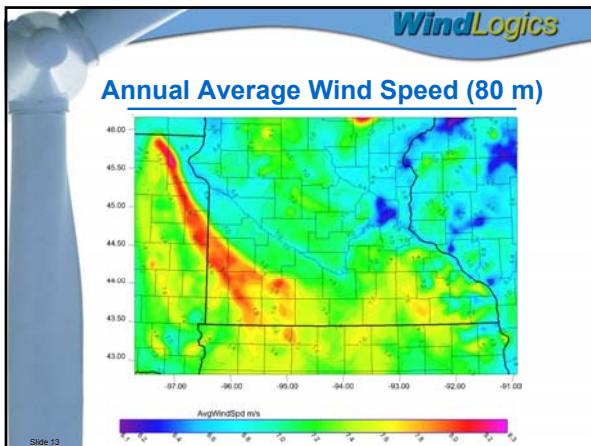
Movies show wind vectors (90 m AGL) and cloud water/precipitation combined isosurface

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## Fine Scale - CFD Models

- Useful for extremely complex geometries
- Very computationally expensive
- Used for special-case studies of a single wind direction
- Not generally used for forecasting, site assessment or historical weather analysis
- Potentially useful for flow separation turbulence, turbine wake effects, etc., but computationally impractical to run months of detailed wind data

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## Wind Flow Models

- Useful for the fine-scale local effects of topography, land use and roughness
- Simplified equations make them faster to run
- Some are overly simplified:
  - Linear assumptions, unsophisticated thermal effects, etc.
  - Poor results in terrain of any significant complexity
- Some are very advanced:
  - Multiple inputs, nonlinear, mass conserving, thermal stability effects...
  - Requires more computation
  - Good results even in complex terrain and fine resolutions

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## Statistics and Artificial Intelligence

- Not based on physics, but still useful
- Examples:
  - Correlation models
  - Artificial learning models
    - Artificial Neural Net (NN) models
    - Support Vector Machine (SVM) models
- Very useful for long-term normalization
  - Correlating measured or modeled period with other longer-term measurements or assimilation archives
- Can be used as adaptive learning systems for final steps in optimizing a forecast

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## Example Forecast System

Forecasting for a specific wind facility uses:

- Ensemble techniques used on multiple models
- Custom modeling, custom domains
- Micro-scale modeling to include local terrain effects
- Adaptive adjustment based on local observations

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## Forecast Accuracy

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## Forecasting Value

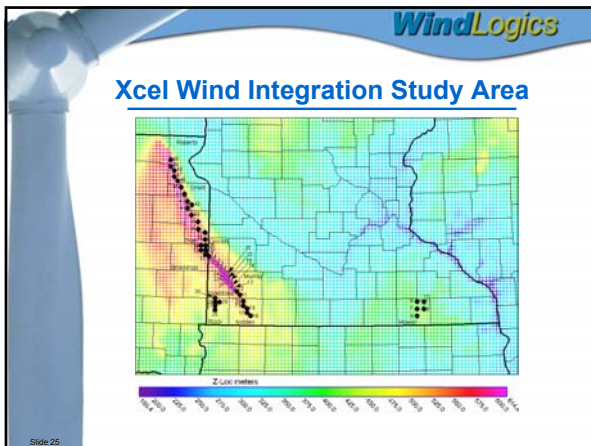
- Benefits to utility system operators
  - Ancillary service cost impact for wind integration
  - Transmission congestion and scheduling
  - Forecast uncertainty is major cost component (irrespective of wind variability)
  - Forecast value grows with increasing wind on grid
- Benefits to wind plant operators?
  - Some, but amount depends on agreements, penalties, etc.
- Regional differences in power and transmission systems is a challenge as well

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- ### Research Topics
- **Measurement technologies**
    - Advanced SODAR, LIDAR, others
  - **Understanding of planetary boundary layer**
    - Transitional structures in presence of multiple land use types
    - Nocturnal structures such as very low level jets
    - *“Never underestimate the nighttime boundary layer. It’s the nastiest problem there is.”* – personal conversation with Dr. Walt Lyons, FMA Research, Fort Collins, CO
  - **Longer-term forecasting**
    - Seasonal, multi-year, multi-decadal
    - Climate change impact on wind resource
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- ### Research Topics
- **Advanced models**
    - Coupling of Land Surface Model with mesoscale model, with remote sensed soil/vegetative properties
    - Small-scale wind-field modeling with Navier-Stokes/turbulence
  - **Advanced statistical & computational learning system methods**
    - Uncertainty assessment
    - Long-term normalization of wind assessment data
    - Advanced application of computational learning systems to wind forecasting and load forecasting
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