New Modeling Techniques:
From Wind Assessment and Forecasting to Wind Resource Management

Bonneville Power Administration & California ISO's
International Wind Forecast
Techniques and Methodologies Workshop
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Precision Wind: An Introduction

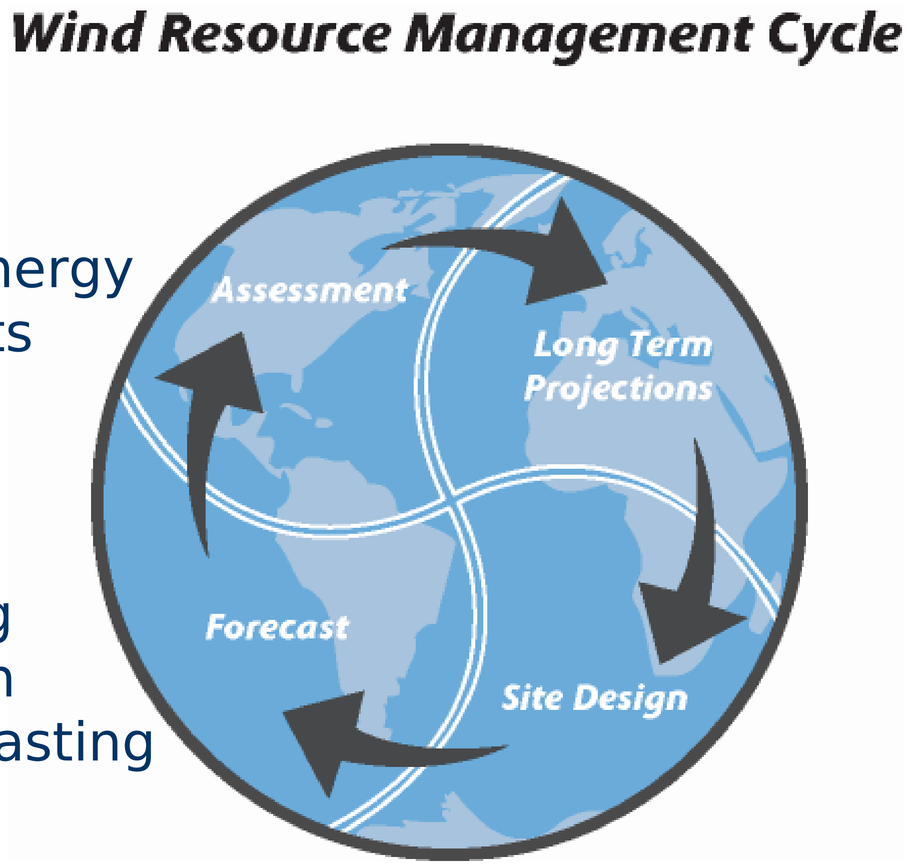
- Wind Measurement
  - Current Best Practices

- Evolution of Forecasting Practice
  - Wind Landscape

- Wind Resource Management
  - Valuable Advancements

- Working with Your Team
  - A Service Approach to Forecasting

What Is Wind Resource Management?



Unified Approach

- Unlock the full value of wind energy
  - Retrospective – Assessments
  - Future – Forecasting

Why Use It?

- Proven, physics-based modeling techniques provide a foundation for both assessments and forecasting

Wind Integration Challenges

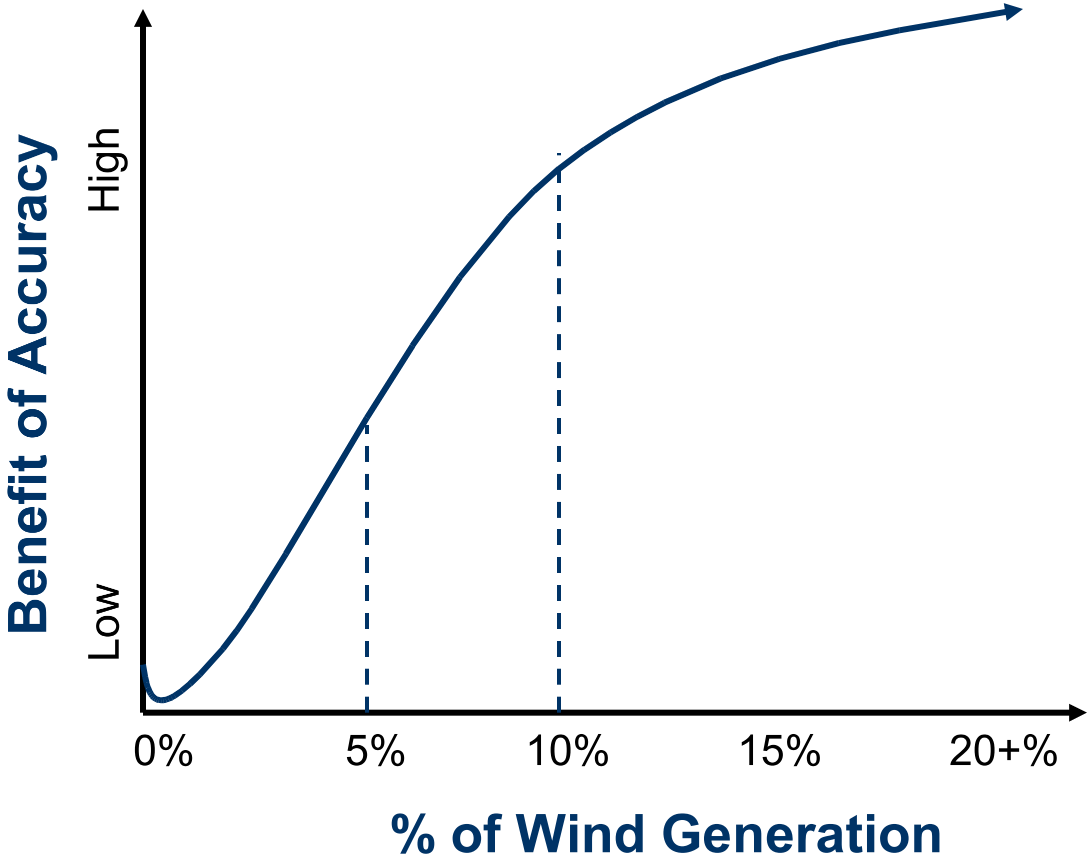
- Reliability
- Generation capacity
- Scheduling and generation forecast ability
- Operation of day-ahead and hour-ahead markets
- Stability / performance
- Regulation
- Long term planning

Impact of Wind Forecast Accuracy

- Unit commitment
- Operating reserve policies
- Market operations

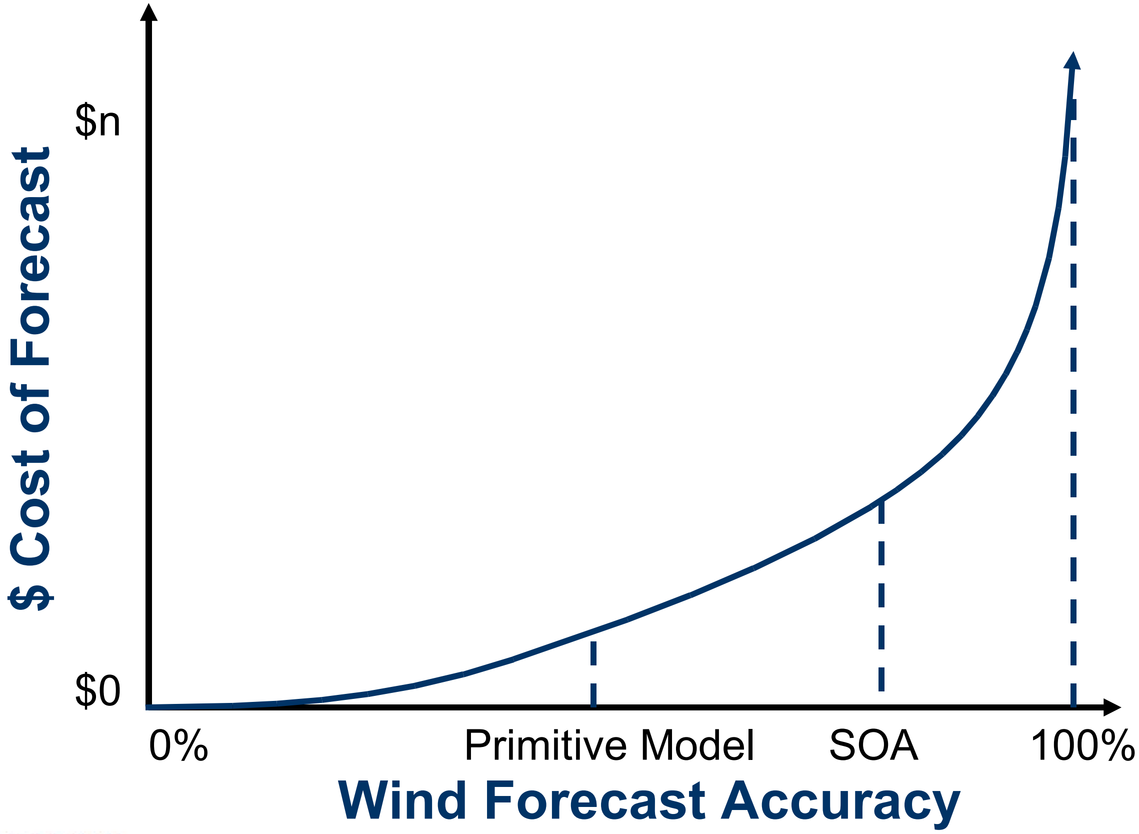
When Do You Need a Forecast?

At What Critical Business Point Does State-of-the-Art Forecasting Becomes a Requirement?



The Value of Accuracy

Determining the Value of a State-of-the-Art (SOA) Forecast Versus a Perfect Wind Forecast – *and the Incremental Steps Between*



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Wind Forecast Accuracy: Today

Power Production Forecast Margins of Error

- Sub-hour forecasts
  - Struggling to beat persistence
- Hour ahead forecasts
  - 4-9% MAE inst. capacity
- 24 hours ahead power production
  - 10-19% MAE inst. capacity
- Quarterly
  - Rely on climatology
- Annual
  - Rely on climatology

Wind Forecast Methodology: Today

Heavy reliance on *wind speed and wind power data*

- Inability to adequately capture forces that cause wind
- Increased forecast error
- Less visibility into ramps
- Interpolation introduces its own error

Room for Improvement

"Renewable energy must be at least as reliable as conventional supplies."

- The ABB Group, position paper 2 June 2007, global leader in power and automation technologies

Room for Improvement: Wind Forecasting

- Increased wind integration continues to raise valid concerns with respect to reliability of the electric grid
- Scheduling is not yet reliable, load managers must maintain additional reserves
- Non-dispatchable energy in the system
- Current level of accuracy reduces the value of wind energy; like any risk/uncertainty, it pays with value
- Wind park operators will start to see more over/under production penalties enforced

Is Wind A Negative Load (Necessarily)?

Wind integration into the electric grid is a nascent, developing process

Balancing authorities and system operators often rely on inadequate (or non-existent) forecasts

Excess reserves must be held to compensate for the uncertainty of wind power

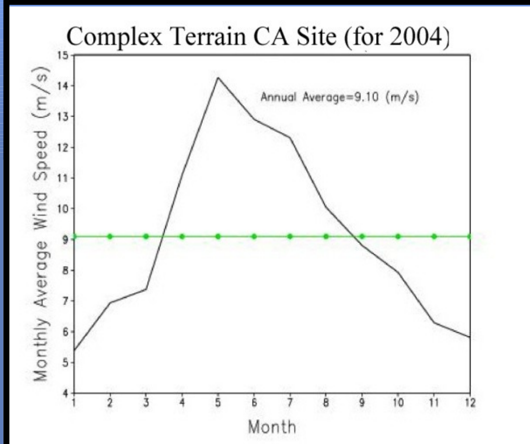
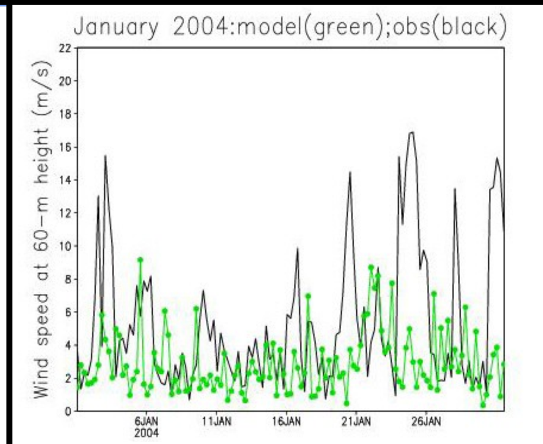
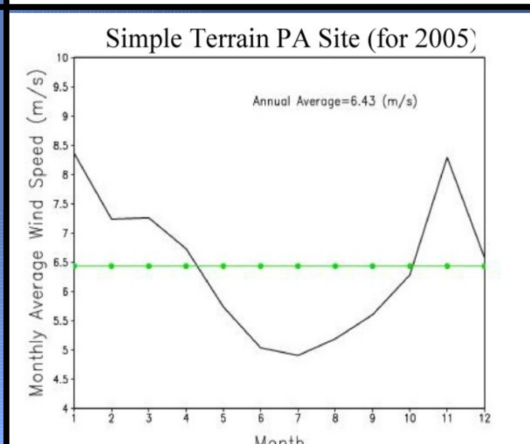
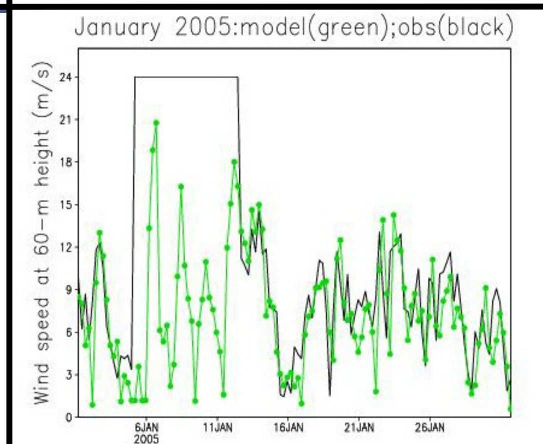
Wind forecasts are not integrated into load managers' control "dashboards"

Training and experience with accurate wind forecasts will improve their effectiveness

What If….

- What if you could obtain accurate forecasts the day a new wind park comes online?
- What if your forecast was much more accurate than it has yet been demonstrated?
- What if you could hold less power in reserve based on the increased reliability and accuracy of the forecast?

By the Numbers: Assessment

	Annual Averages	Monthly Averages
Complex Terrain		
Simple Terrain		

MAE WITH SITE DATA

Complex Terrain:
2-4% (+/-1 - +/-2 sd)

Simple Terrain:
0-2% (+/-0.5 - +/-1 sd)

MAE W/OUT SITE DATA

Complex Terrain:
4-8% (+/-2 to +/-4 sd)

Simple Terrain:
3-6% (+/-1 to +/-2 sd)

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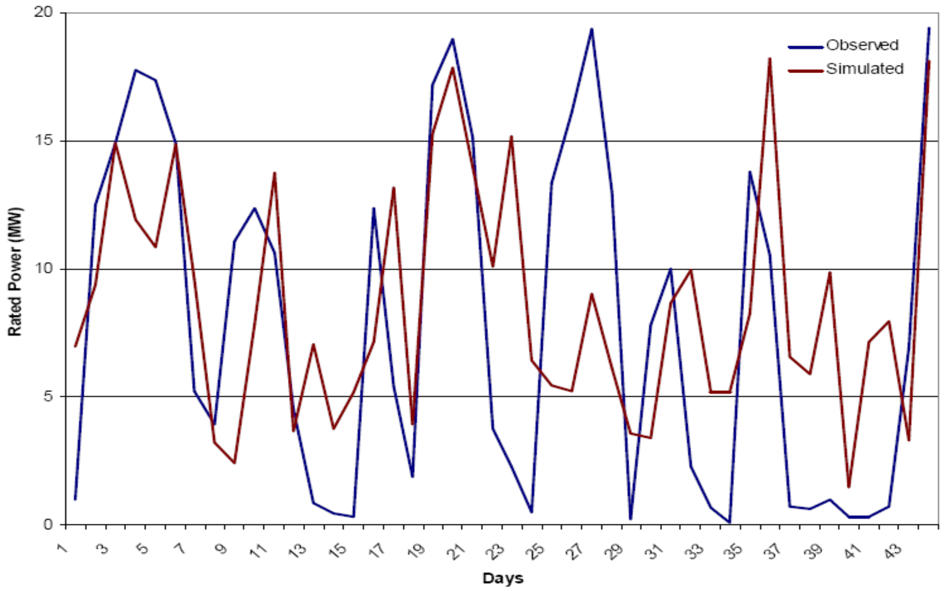
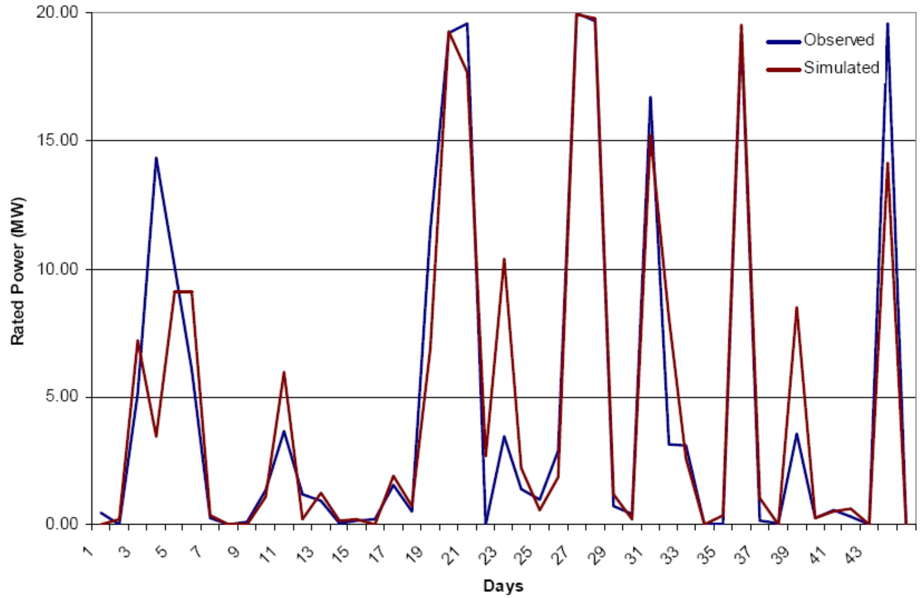
By the Numbers: Forecasting

24 Hour Forecast



1 Hour Forecast



Southern California Wind Farm (Complex) with 15 Turbines of 1300kW
(15x1.3MW Installed Capacity)

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By the Numbers: Forecasting Error Table

Hour(s) Ahead	BIAS	MAE	RMSE
1	<0.2	2-4%	<7%
6	<0.5	2.5-5.5%	<11%
12	<1.7	6-9.5%	<16%
24	<3	10-17%	<24%

Wind Resource Management Suite Overview

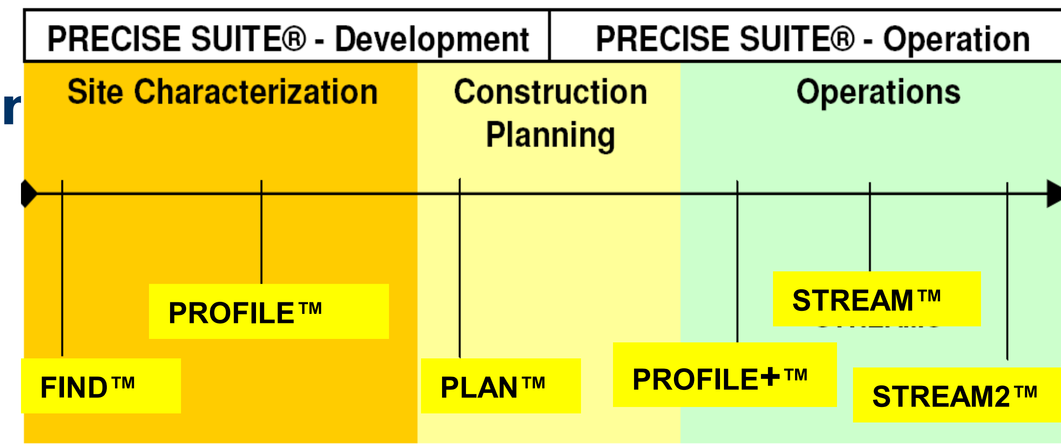
WIND RESOURCE MANAGEMENT SUITE ®

PRECISE SUITE® - Assessment

- Stage I – PRECISE FIND™
- Stage II – PRECISE PROFILE™
- Stage III – PRECISE PLAN™

PRECISE SUITE® - Forecastir

- PRECISE STREAM™
- PRECISE STREAM2™



Key Benefits of Our Approach

Precision Wind's Meso-Microscale Atmospheric Modeling Approach Leads to Increased Reliability & Greater Efficiency of Operations

- Emphasis on physics-based modeling
- Requires minimal site measurement data
- Captures both local and regional factors that influence wind speed
- More computational resources committed
- Performs well in all weather regimes
- Reduces time required to establish client-specific, custom forecasts

Our Forecasting Method: Overview

Measured wind is an end result of many forces, not the force in itself.

Accurate, reliable wind assessment and wind forecasting requires an accurate accounting of the forces that give rise to the wind.

Our Forecasting Method: Overview
(continued)

Precision Wind's Model

- Meso-microscale atmospheric modeling based on computational fluid dynamics (CFD) techniques, specifically numerical weather prediction (NWP) techniques
    - Simulations leverage three nested grids with different horizontal resolution to define a large area around the site, and at the same time, resolve fine topographic and other features (streams, bluffs, ridges, etc.) in the innermost domain around the site
- Regional Atmospheric Modeling System (RAMS)
- 12-km North American Mesoscale (NAM) model data sets*
- Large computational resources

*5-km "test" data sets are available; Precision Wind will use 5-km data sets as soon as they become available.

Atmospheric Modeling Basics: Scales, Forces, Wind and Computing

- Scales are the lengths at which relevant physical processes are captured in the model
- Within these scales lie the forces that give rise to wind
- Wind is derived from the forces (both local and non-local), and the reverse is not true
- Measuring wind is a remedy while measuring forces is the cure
- It is NOT practical to measure all the forces in order to derive wind
- Modeling techniques offer a great alternative to finding these forces (and accurately determining wind)

Atmospheric Modeling Basics: Limiting Factors

Inherent limitations of modeling methods

- Input data limitations
- Accurate model of the physical forces of wind
- Computational resources

Our Forecasting Method: A Combined Meso-Microscale Modeling Approach

- A high-resolution (1-km) meso-microscale model is combined with a post-processing adjustment method from site measurements.
- Adjustments based on measured wind speed result in 40-60% reduction in error compared to pure simulations.
- Secondary adjustments based on generated wind power result in additional 30-50% reduction in error, but more importantly, they may result in better definitions of loss factors due to wake effects, turbine management, etc.

Our Forecasting Method: Model Set-Up

- Nested grids are used to achieve highest horizontal resolution (<=1-km)
- A small time step (<2 seconds) is often used to complete these simulations
- This combined approach uses about 90% (physics-based modeling) and about 10% (adjustments based on site measurements / statistical adjustments)
- Forecast horizons: From several minutes to several days
- Other model combinations may be necessary for different forecast horizons (e.g., beyond a week)

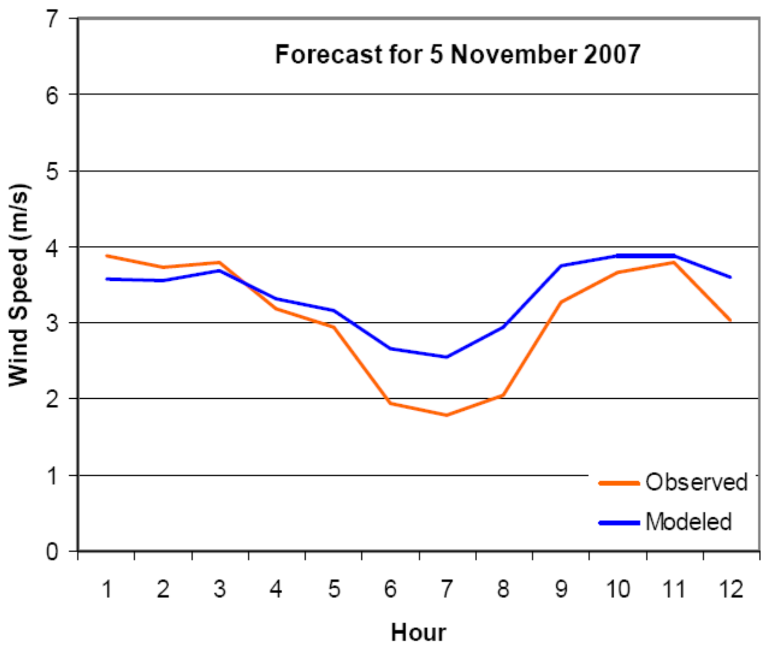
Our Forecasting Method: Computing Capacity

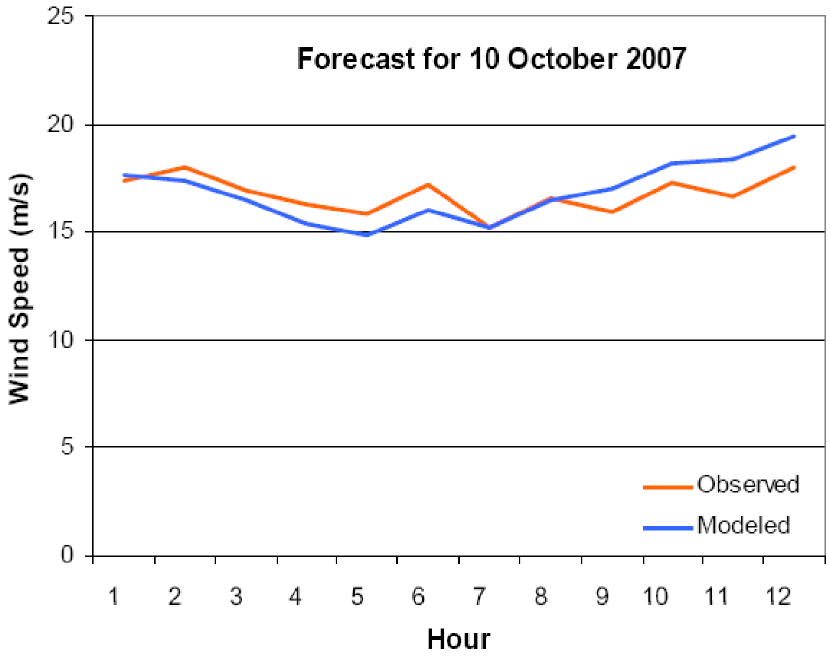
The need for massive parallel computing capacity is essential to a robust, physics-based model. To provide forecasts in a useful period of time, the complex calculations required by our comprehensive, physics-based model are performed in "parallel" or processed simultaneously.

Simulation models that can be performed with limited computational resources sacrifice forecast accuracy by discarding the majority of available data, and are subject to error-prone interpolation.

Our Forecasting Method: Results

Results of two 12-hour simulations for a complex site in California, USA, are shown here:





Forecast & Assessment Projects, Horizons, and Results

- Assessment and Prospecting
  - Terrascale 1km Resolution – For land ranking and assessments
  - Park scale 1km Resolution – For bankable assessments
  - Tower scale 100 meter Resolution – For micrositing
- Forecasting and Management
  - Precision forecast capability from <1 hr to 48 hrs
  - 6hr forecasts 2.5% to 5.5% MAE
- Required knowledge for effective wind park owners, ISO’s, utilities, energy traders, and operations and maintenance firms
- Exemplary Results
  - Multi-year assessments in under 4-6 weeks per 12 month analysis
  - Margin of error of 4-8% depending on terrain complexity
  - Errors rates of 2-4% when calculated with site measured data

Forecasting: Service or Product?

Precision Wind's Service Approach

- Identification of key operational, functional, and control aspects for your forecasting system
- Customized dashboard functionality
- Situation analysis for your wind regime
    - Updated reserve recommendations and protocols
- Process, technology, and wind-specific training
- Dedicated support
- Long term resource planning

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Wind Power Management

Precision Wind Power Management Dashboard - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.precisionwind.com/forecasting/projections.htm

used car loan rates

Latest Headlines Yahoo Hotmail ASK Maps Yahoo! Mail

Logout

Precision Wind Power Management Dashboard

Welcome **John Davis**. If you are not John Davis, please click here

Monday, February 18, 2008

Forecasting: Aggregate Dashboard

Print Help

Projected Production (MW)

Please select a date:

Local Time	Aggregate	White Water	Des Moines	Cedar Creek
00:00	156.20	35.22	25.43	95.55
01:00	161.94	36.25	26.26	99.43
02:00	153.72	34.56	24.56	94.60
03:00	155.12	35.43	25.34	94.35
04:00	149.20	33.33	23.45	92.42
05:00	159.49	36.45	26.50	96.54
06:00	150.60	33.57	23.35	93.68
07:00	159.45	36.89	26.36	96.20
08:00	147.44	31.67	21.40	94.37
09:00	153.51	34.67	24.38	94.46
10:00	156.72	35.98	25.41	95.33
11:00	160.31	37.43	27.39	95.49
12:00	145.14	30.22	20.42	94.50

Selected Facilities

White Water
Des Moines
Cedar Creek

Add a Facility

Select Facility--- Add

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Near-Term Forecast Enhancements

- Produce wind park-wide forecasts using plant scale power curves based on past wind power data
- Use of residual error minimization techniques (e.g., Kalman filters) to increase accuracy (including in ramping situations) based on more site data
- Use of increased model domain to reduce spurious boundary influences at the expense of increased computational resource requirements – also increases accuracy of ramp forecasting

Mid-Term Forecast Enhancements

- Add a small-scale CFD code as part of the post-simulation procedures
- Develop an optimal strategy for maximizing the accuracy of our forecast system within geographically diverse wind farms

Summary

- Assessments and forecasting can be accomplished using the same modeling techniques: Wind Resource Management
- New modeling techniques, atmospheric scales, and forces
- A combined meso-microscale approach
- Robust physics representations in models that lead to better accuracy *require more computational resources* ($)
- Importance of site measurements (wind and power) for post-simulation adjustments must be noted and re-emphasized

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Thank You.

Questions?

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Be Precise.

Wind Resource Management Suite

Precision Wind provides high-resolution modeling services for:

- Developers & Owners
- System Operators & Utilities
- Financiers & Consultants

- **Precise Find™**
  – Rapid land assessment
- **Precise Profile™**
  – Accurate long term projection
- **Precise Plan™**
  – Optimized site plans
- **Precise Stream™**
  – Near term forecasting

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Appendix

Atmospheric Scales

Horizontal model domain dimensions to capture any atmospheric phenomena are classified into three different scales:
Macroscale, Mesoscale, and Microscale.

These three scales are further divided into sub classes (e.g., alpha, beta, etc.). Typical lower bounds on the scales for the three classes are: 2000-km (macro-beta); 2-km (meso-gamma); 20-m (micro-beta), respectively

Corresponding to the horizontal scales, time scales exist as well.

- Macroscale phenomena have time scales of 1 day to several days;
- Meoscale phenomena show time scales from 1 minute to 1 day;
- Microscales are from 1 second to 1 hour

Atmospheric Scales

While ensuring the proper domain coverage, the model resolution employed must also be adequate to capture all the relevant forces within such a domain. In order to ensure large domains and finest resolution simultaneously, nested grids are employed to reduce required computational resources.

There is a real danger of using inadequate domain and resolution, in order to reduce computations, that will only degrade the simulation accuracy.

The number of computations, proportional to physical processes captured, determines simulation accuracy. A schematic on how simulation accuracy is affected by computations and input data resolution is shown later in this Appendix

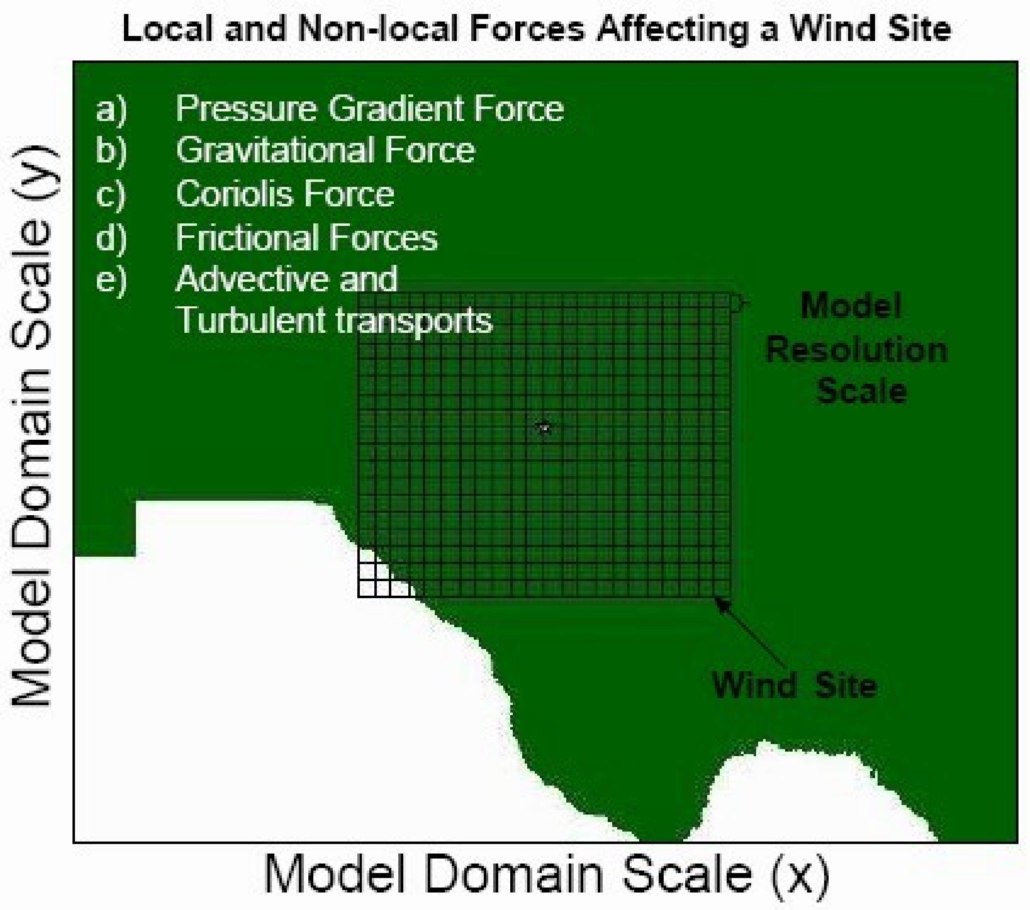
Atmospheric Forces

There are the following forces and transport processes that affect local wind speed at a site:

- Pressure gradient force
- Gravitational force on dry air parcels and air parcels laden with water particles
- Coriolis (rotational) force
- Frictional force(s)
- Advective and turbulent transports

Conservation of mass, energy, and momentum based on the interplay of the above forces, leads to the local wind speed and direction

Atmospheric Forces



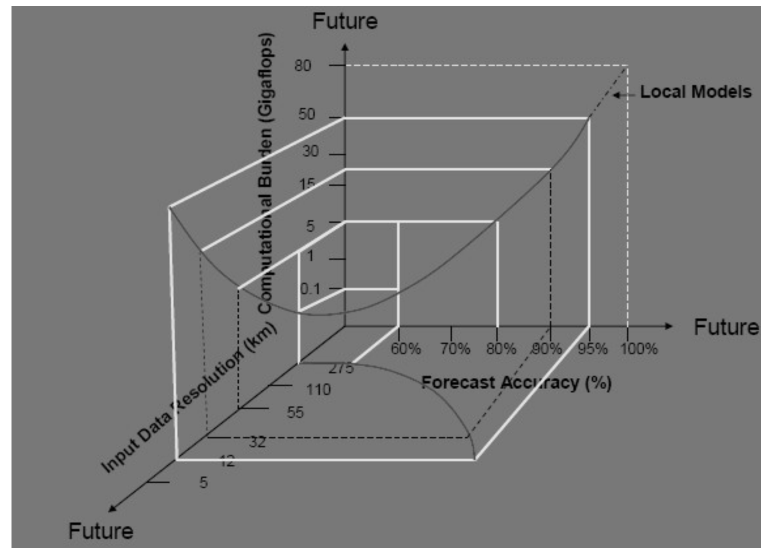
Atmospheric Forces

At any given time, some of the forces may be dominant compared to the others, while others may originate and gain dominance or become weak over the existing forces. Any modeling framework employed to capture such a complex physical system, with evolving forces, must be able to handle all the forces dynamically to be successful

In this context, for example, a model that employs very high resolution (200-m), but does not capture the physics at that resolution will complete simulations fast (in other words, requires fewer computations) and will also likely yield very poor results

Input Data Resolution, Computational Resources, and Simulation Accuracy

For any given input data resolution, adequate computational resources (proportional to the physics) will yield the most accurate simulations. Other scenarios can be viewed from the schematic to the right



Combined Models

A number of combinations between numerical weather prediction (NWP) models and other statistical or empirical models can be devised

The right combination may critically depend on the forecast horizon, the complexity of the site, and the desired accuracy

The NWP portion must be significant if the evolving forces are to be captured adequately. Other combinations may be more desirable, especially when the forecast horizons are rather short (< a few minutes) or really long (> a week)

Statistical or empirical models may be employed to perform adjustments to simulations based on site measurements