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AWS Truewind

Wind Forecasting Efforts to Improve Renewable Penetration

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Outline

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- The Challenge
- Methods
- Time Scales: How Needs and Challenges Vary
- Performance
- Current Operational Use and Plans
- Value of Forecasting
- Summary

Challenge

The Need

Predict the power production at individual Wind Generation Resources (WGRs) and aggregates of WGRs with the highest possible accuracy over desired time intervals (e.g. an hour, day etc.) from a few minutes ahead to many hours, days, weeks or months ahead

The Meteorological Problem

Predict the wind speed, direction and air density at each turbine location for the same time intervals and look-ahead periods

The Meteorological Challenge

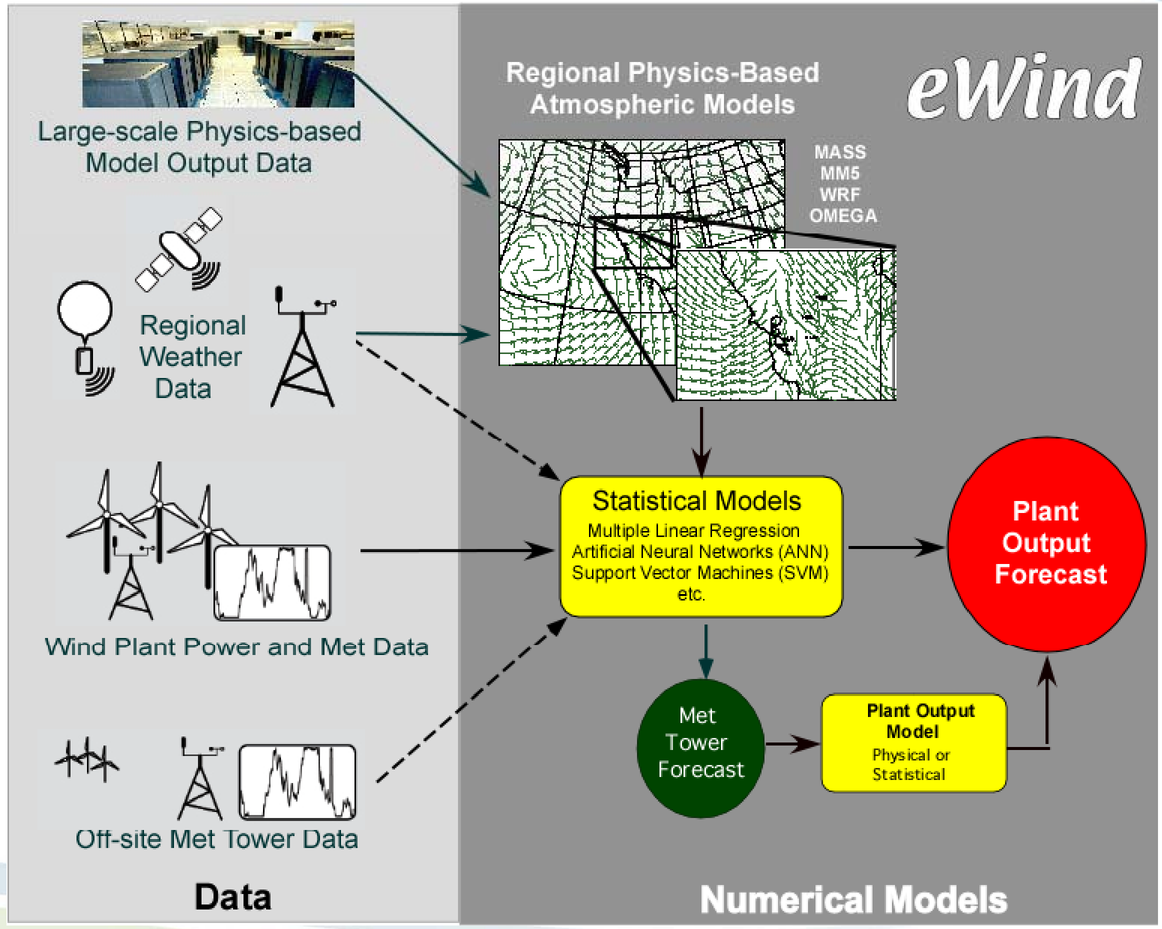
Variations in wind (and other atmospheric variables) are driven by atmospheric features that originate, evolve and dissipate over a wide range of space and time scales under the control of a broad spectrum of physical processes. Current observational systems are able to measure only a small fraction of the variability associated with these atmospheric features.

Methods

Meeting the Challenge: State-of-the-Art Forecast Systems

- **Combination of physics-based (NWP) and statistical models**
- **Diverse set of input data with widely varying characteristics**
- **Importance of specific models and data types vary with look-ahead period**
- **Forecast providers vary significantly in the way in which they use forecast models and input data**

Input Data, Forecast Model Components and Data Flow for a State-of-the-Art Forecast System



Methods

Physics-based Models

(also know as Numerical Weather Prediction (NWP) Models)

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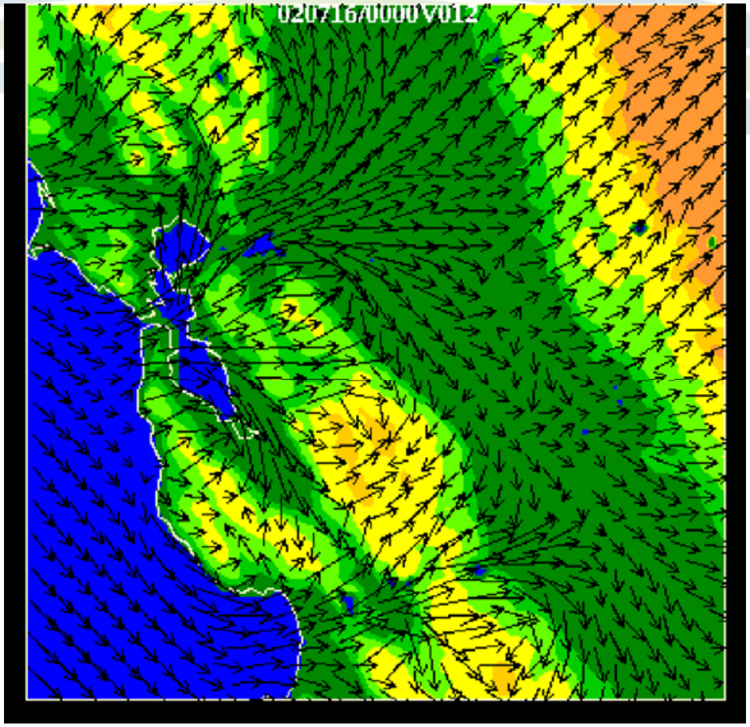
- Differential equations for basic physical principles are solved on a 3-D grid
- Must specify initial values of all variables for each grid cell
- Simulates the evolution of the atmosphere over a 3-D volume
- Some forecast providers rely on government-run models; others run their own models



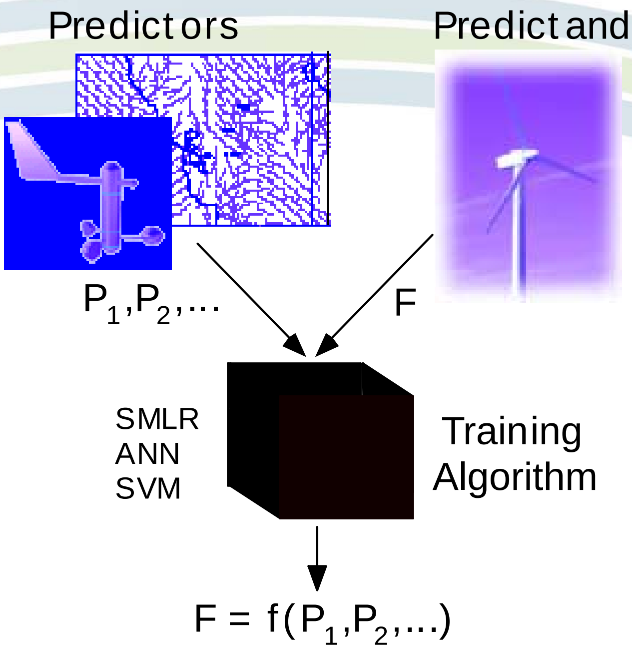
Roles of Provider-run NWP Models

- Optimize model configuration and formulation for the forecasting of near-surface winds
- Use higher vertical or horizontal resolution over area of interest
- Execute simulations more frequently
- Incorporate data not used by government-run models
- Execute ensembles customized for near-surface wind forecasting

Methods

Statistical Models

- **Empirical equations are derived from historical predictor and predictand data ("training sample")**
- **Current predictor data and empirical equations is then used to make forecasts**
- **Many different model-generating methods available (linear regression, neural networks etc.)**



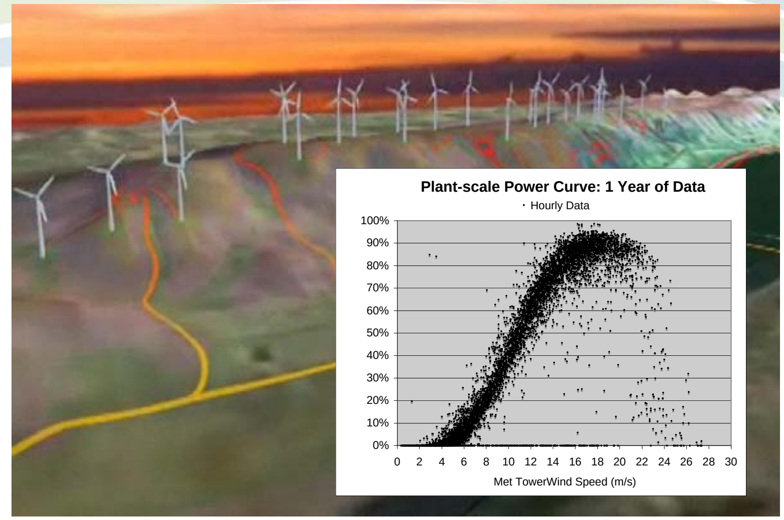
Roles of Statistical Models

- Correct systematic-errors in the NWP forecasts
- Account for (local) processes on a scale smaller than the NWP grid cells
- Incorporate additional observational data
    - received after the initialization of most recent NWP model runs
    - not effectively included in NWP simulations
- Combine met forecasts and power data into power predictions (implicit plant output model)

Methods

Plant Output Models

- **Relationship of met variables to power production for a specific WGR**
- **Many possible formulations**
  - **implicit or explicit**
  - **statistical or physics-based**
  - **single or multi-parameter**



Roles of Plant Output Models

- Facility-scale variations in wind (among turbine sites)
- Turbine layout effects (e.g. wake effects)
- Operational factors (availability, turbine performance etc)

Forecast Ensembles

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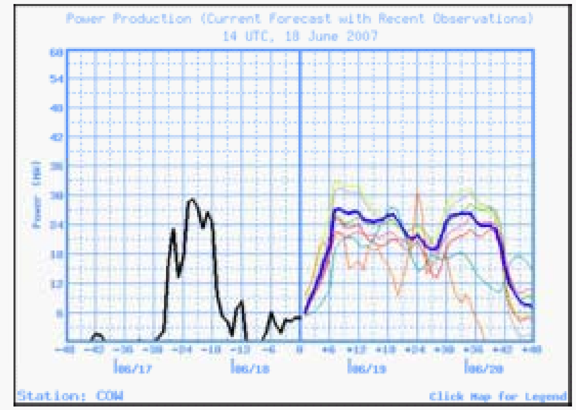
- **Uncertainty present in any forecast method due to**
  - **Input data**
  - **Model type**
  - **Model configuration**



- **Approach: perturb input data and model parameters within their range of uncertainty and produce a set of forecasts (I.e. an ensemble)**
- **Benefits**
  - **An ensemble composite is often the best forecast**
    - Statistical weighting of individual forecasts often yields best performance
  - **Spread of ensemble provides a <u>case-specific</u> measure of forecast uncertainty**

Methods

Forecast Products

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- **Deterministic Predictions**
  - Most likely MW production for a specific time interval (e.g. hourly)
  - Tuned to minimize a performance metric (e.g. RMSE etc.)
    - Often results in "hedging" for extreme event forecasts
- **Probabilistic Predictions**
  - Confidence Bands
  - Probability of Exceedance (POE) Values
- **Event Forecasts**
  - Probability of events in specific time windows
  - Most likely values of event parameters (amplitude, duration etc.)
  - Example: large up or down ramps
- **Situational Awareness**
  - Forecasts of significant weather regimes
    - Produce events (large errors, ramps etc.) that impact user's applications
  - Geographic displays of wind patterns

Forecast Use Time Scales

- **5 - 60 minutes**
  - Regulation
  - Real time dispatch decisions of energy and Ancillary Services (AS)
- **1-6 hours ahead:**
  - Load-following
  - Short-term adequacy analysis
  - Next operating hour unit commitment
- **Day-ahead**
  - Day-ahead unit commitment
  - Ancillary Services forecasting
  - Trading activities (market participants)
- **Multiple days ahead**
  - Long term adequacy analysis

How the Forecasting Problem Changes by Time Scale

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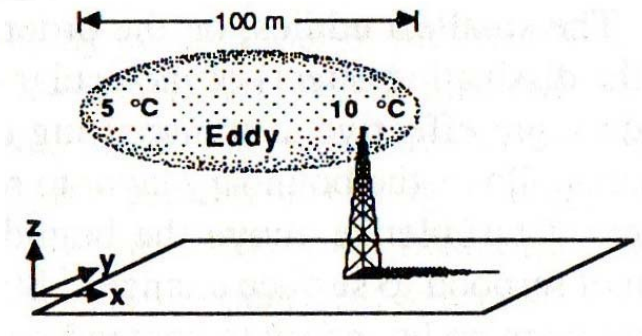
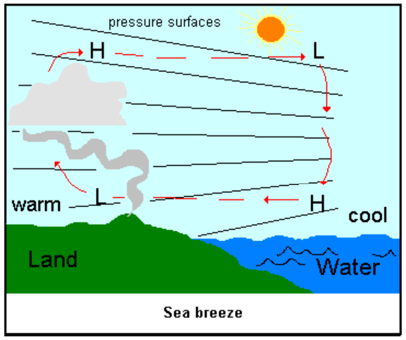


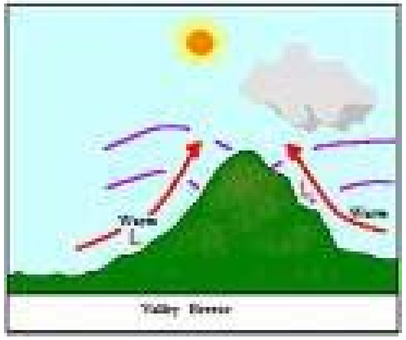
Minutes Ahead

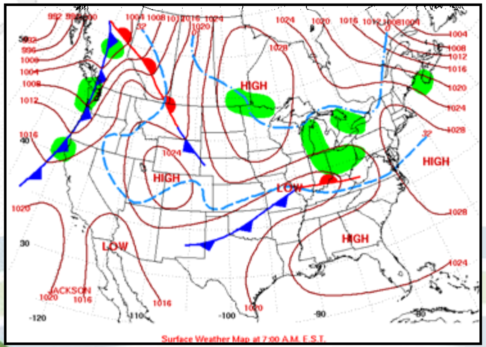
- Large eddys, turbulent mixing transitions
- Rapid and erratic evolution; very short lifetimes
- Mostly not observed by current sensor network
- Forecasting tools: Autoregressive trends
- Very difficult to beat a persistence forecast
- Need: Very hi-res 3-D data from remote sensing

Hours Ahead

- Sea breezes, mountain-valley winds, thunderstorms
- Rapidly changing, short lifetimes
- Current sensors detect existence but not structure
- Tools: Mix of autoregressive with offsite data and NWP
- Outperforms persistence by a modest amount
- Need: Hi-res 3-D data from remote sensing







Days Ahead

- “Lows and Highs”, frontal systems
- Slowly evolving, long lifetimes
- Well observed with current sensor network
- Tools: NWP with statistical adjustments
- Much better than a persistence or climatology forecast
- Need: More data from data sparse areas (e.g. oceans)

Forecast Evaluation Issues

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- **Evaluation approach depends on type of forecast**
  - Deterministic vs probabilistic
  - Interval values (e.g. hourly) vs. events (e.g. ramps)
- **Deterministic forecasts**
  - Standard performance statistics: Bias, MAE, RMSE
  - Many other options: skill scores, error frequency distributions etc.
- **Probabilistic forecasts**
  - Error of a specific forecast can't be calculated
  - Reliability and sharpness are key concepts
- **Event Forecasts**
  - Deterministic: Hit rate, false alarm rate, critical success index (CSI)
  - Probabilistic: Reliability and discrimination ability (sharpness)
- **Objective of the forecast**
  - Forecasts can be optimized for a specific metric (e.g. RMSE)
- **What performance data are relevant to the user?**
  - Depends on user's "cost function" and application

Performance

Typical Range of Forecast Accuracy

(Individual wind farm - Forecast time step of 1 hour)

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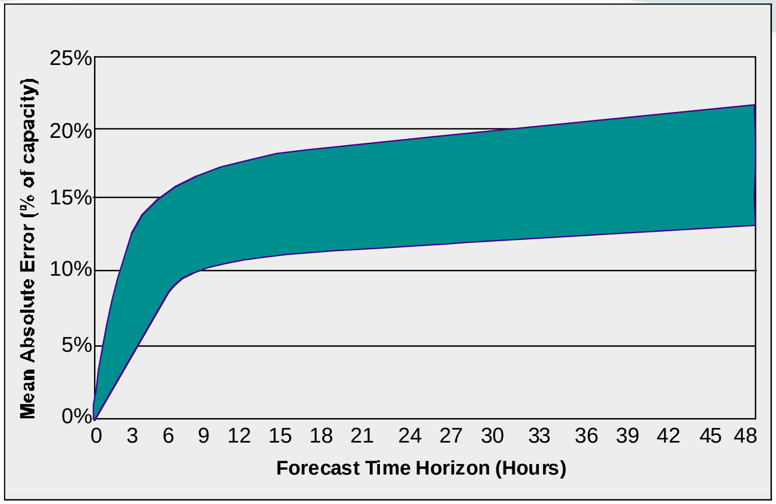
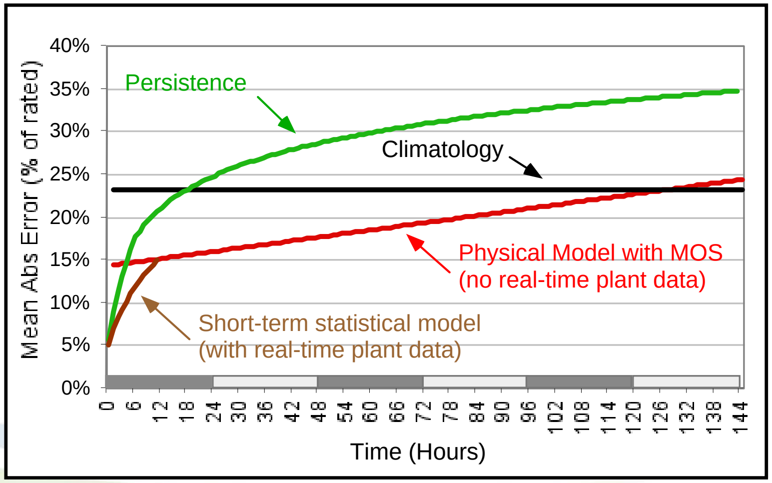
- MAEs of forecasts increase rapidly during first 6 hours and then much more slowly
- Statistically adjusted NWP-based forecasts of hourly production outperform climatology out to about 5-7 days
- Data from the facility is required to outperform persistence over the 0 to 3 hour look-ahead time frame





Performance

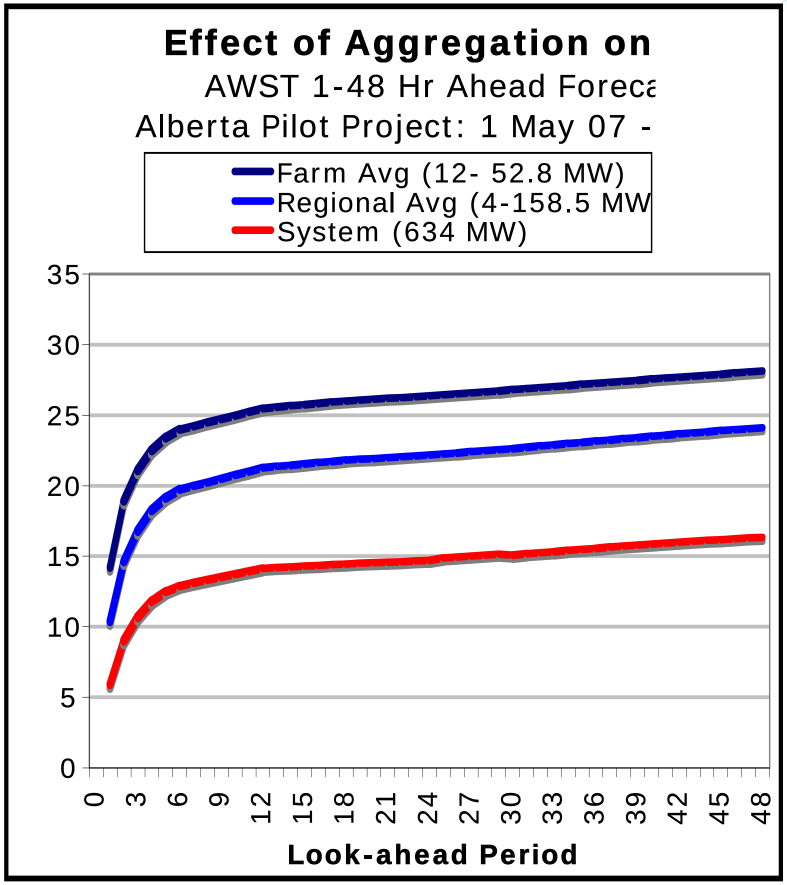
Forecast Performance Comparison Issues

- **Forecast performance varies due to a variety of factors**
  - Forecast time horizon (especially for short-term)
  - Amount and diversity of regional aggregation
  - Quality of generation & met data from the plant
  - Distribution of wind speeds relative to the power curve
  - Type of wind and weather regime
  - Shape of the plant-scale power curve
  - Amount of variability in the wind resource
  - Sensitivity of a forecast to initialization error
- **These factors make casual comparisons of forecast performance very difficult and lead to misconceptions**

Forecast Performance Factors:

Amount and Diversity of Regional Aggregation

- **Example: Alberta Wind Forecasting Pilot Project**
  - 1 year: May 2007-April 2008
  - 3 forecast providers
  - 12 wind farms divided into 4 geographic regions of 3 farms each
  - Hourly 1 to 48 hrs ahead forecasts for farms, regions and system-wide production
- **RMSE for regional day-ahead forecasts was 15-20% lower than for the farms**
- **RMSE for system-wide day-ahead forecasts was 40-45% lower than for the farms**



Impact of Aggregation on Performance Comparisons

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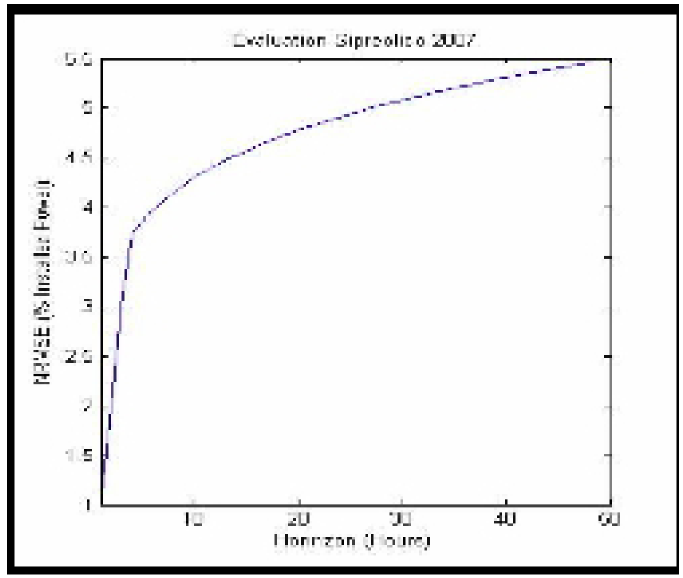
- **Lack of a consideration of the impact of size and diversity of the generation resource leads to misconceptions about relative forecast performance**
- **Example: US visitors to the Spanish TSO "RED Electrica" concluded that forecast performance was "phenomenal"**
- **The size and diversity of this aggregation is so great that there is a huge aggregation effect and when this is considered the performance is typical**

From the Visit Report:

"SIPREOLICO provides detailed hourly forecasts up to 48 hours updated every 15 minutes. The accuracy of the forecast is phenomenal: The forecast root mean square error for the 48-hour- ahead forecast is below 5.5% of the installed wind generation capacity. "



RED Electrica System Characteristics:

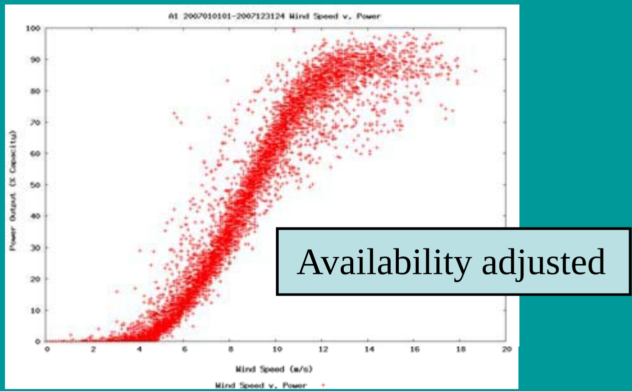
- 14,877 MW installed; 575 wind parks
- Average of about 30 MW capacity/park
- Peak Generation ~ 10,000 MW

Forecast Performance Factors:

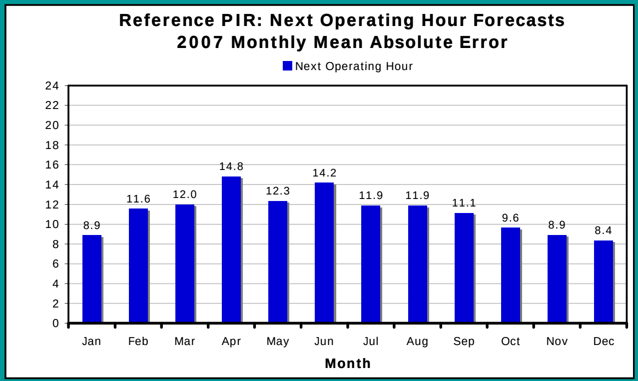
Quality of WGR Data

A comparison of forecast performance over a 1-year period at two adjacent WGRs with very different onsite data quality

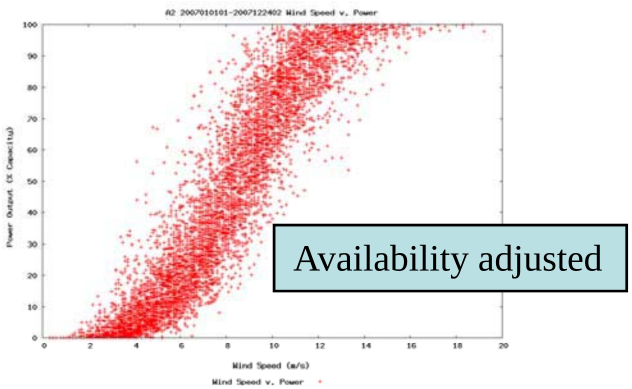
Reference WGR



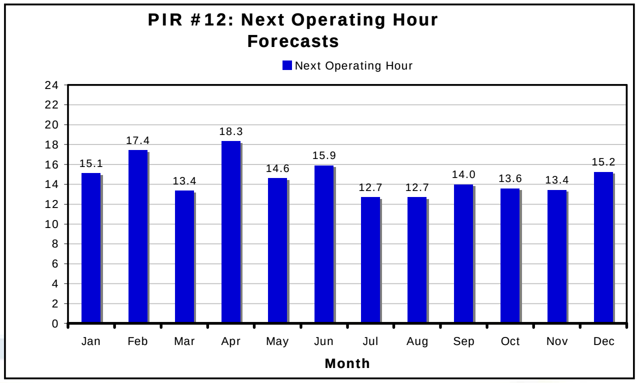
Annual MAE: 11.3%



Adjacent WGR



Annual MAE: 14.6%



Current Status of Wind Forecasting at Major U.S. Balancing Authorities

- **CAISO: Forecasting for PIRP implemented in 2004**
  - Forecasting used for market purposes only; not currently used in grid operations
  - Hourly delivery of 4 to 10 hr ahead forecasts
  - Once per day (5:30 AM) delivery of next calendar day forecast
  - RFP process to expand scope and use of forecasting services is in progress
- **ERCOT: Operational forecasting began on 7/1/08**
  - Hourly delivery of 1 to 48 hr forecasts in hourly increments
  - Used for management of grid operations
- **NYISO: Operational forecasting began on 7/1/08**
  - 15-minute delivery of 0 to 8 hr forecasts in 15-minute intervals
  - Twice per day (4 AM and 4 PM) delivery of next 2 calendar day forecast
  - Short-term (1 hr ahead) forecast used for management of grid operations
- **Midwest ISO: Forecast provider recently selected**
- **PJM Interconnect: Forecasting procurement in progress**
- **BPA: Looking at options; receives forecasts from wind plants**

Operational Use

California ISO: PIRP

- ***P**articipating **I**ntermittent **R**esource **P**rogram (PIRP)*
- **Voluntary program: can opt in or out hourly**
- **Requirements**
  - Must pay forecast fee: $0.10/Mwh
  - Must provide real-time meteorology, production and availability data according to PIRP protocols
  - Must schedule to PIRP next operating hr forecast for your facility
- **Benefits**
  - Reduction in market price risk
    - In program: settle on net deviation for month with average monthly market price
    - Out of program: settle deviations on market price every 10 minutes
  - Exemption from some system management charges
  - Get hour ahead and day ahead forecasts for other uses as well
- **Only wind now - likely inclusion of solar by 2009**

Value

Value of Forecasting

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- **Value of forecast is hard to quantify and still under debate**
- **Value realized in multiple interconnected ways**
  - Cost savings from an efficient selection of the generation mix
    - Day-ahead
    - Hours-ahead
  - Efficiently maintaining grid reliability
  - Market activities (e.g. trading)
  - Enabling high grid reliability with higher wind penetration
- **Recent grid integration studies have attempted to quantify cost savings associated with forecasting**
  - California
  - New York
  - Ireland

Value

California Intermittency Analysis Project

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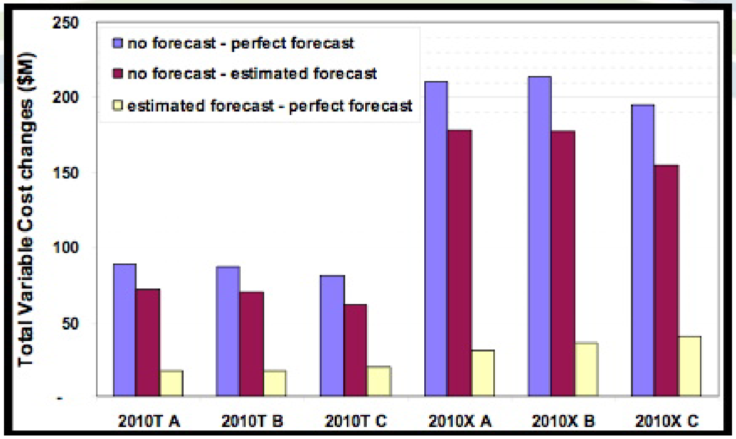
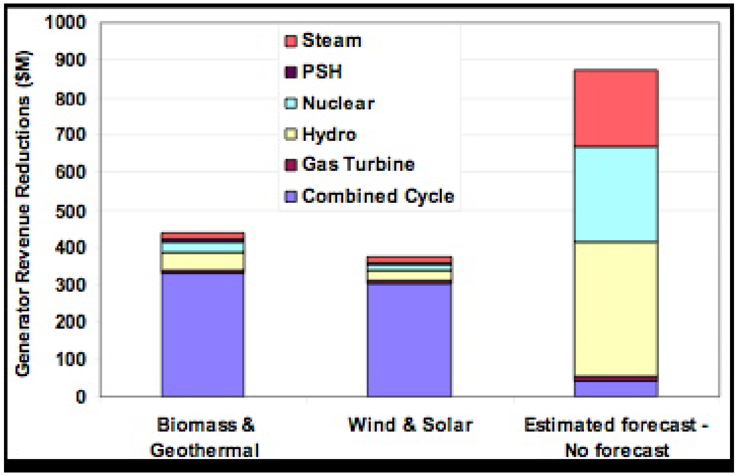
- **Project conducted by GE with AWST as a subcontractor**
- **Examined four scenarios, two for 2010:**
  - 2010T: 20%RE; 7,500 MW wind
  - 2010X: 33% RE; 12,500 MW wind
- **Value of day-ahead forecasting analyzed for these two scenarios**
- **"State-of-the-art" forecasts saves about $75 M/year for 2010T; $175 M/year for 2010X**
- **A large fraction of the potential savings of a perfect forecast can be realized by current forecast skill**
- **Most of the savings are realized by non-wind generators**





From: INTERMITTENCY ANALYSIS PROJECT: APPENDIX B IMPACT OF INTERMITTENT GENERATION ON OPERATION OF CALIFORNIA POWER, July 2007, CEC-500-2007-081-APB

Future

How will forecasts be improved?

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(Top Three List)

- (3) Improved physics-based/statistical models
  - Improved physics-based modeling of sub-grid and surface processes
  - Better data assimilation techniques for physics-based models
  - Learning theory advances: how to extract more relevant info from data
- (2) More effective use of models
  - Enabled by more computational power
  - Higher resolution, more frequent physics-based model runs
  - More sophisticated use of ensemble forecasting
  - Use of more advanced statistical models and training methods
- (1) More/better data
  - Expanded availability and use of "off-site" data in the vicinity of wind plants, especially from remote sensors (e.g. Sodar. LIDAR, Doppler radar)
  - Substantial potential to improve 0-6 hr forecasts
  - A leap in quality/quantity of global satellite-based sensor data

Summary of Key Points - Part 1

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- **State-of-the-art forecasts are produced with a combination of physics-based (NWP) and statistical models**
  - Used to construct an ensemble of forecasts
  - A composite of the ensemble is used to create deterministic forecasts
  - The dispersion (spread) of the ensemble provides an estimate of uncertainty
- **The relative importance of different forecast methods and data types varies with look-ahead period**
- **Forecasts are customized for a specific objective**
- **Forecast performance varies due to many factors which makes casual performance comparisons difficult**
- **Quality of data from a wind park is a significant factor in forecast performance (especially for 0-6 hr forecasts)**

Summary of Key Points - Part 2

- **Centralized forecast systems have been implemented at several balancing authorities in the US and others are in the process of designing or implementing systems**
- **Grid integration studies suggest that day-ahead forecasts have a potential value on the order of $100s M to the stakeholders of a grid system.**
  - A large fraction of it is realizable by using current state-of-the-art forecasts
  - The majority of it is associated with the savings of non-wind generators
  - Additional benefits may be realized through the use of forecasts to improve short-term grid management and trading decisions