ALBANY • BARCELONA • BANGALORE

January 2011

WIND ENERGY FORECASTING

Michael Brower
Chief Technical Officer

463 NEW KARNER ROAD | ALBANY, NY 12205
awstruepower.com | info@awstruepower.com

AWS Truepower™
Where science delivers performance.

Wind Forecasting in the US

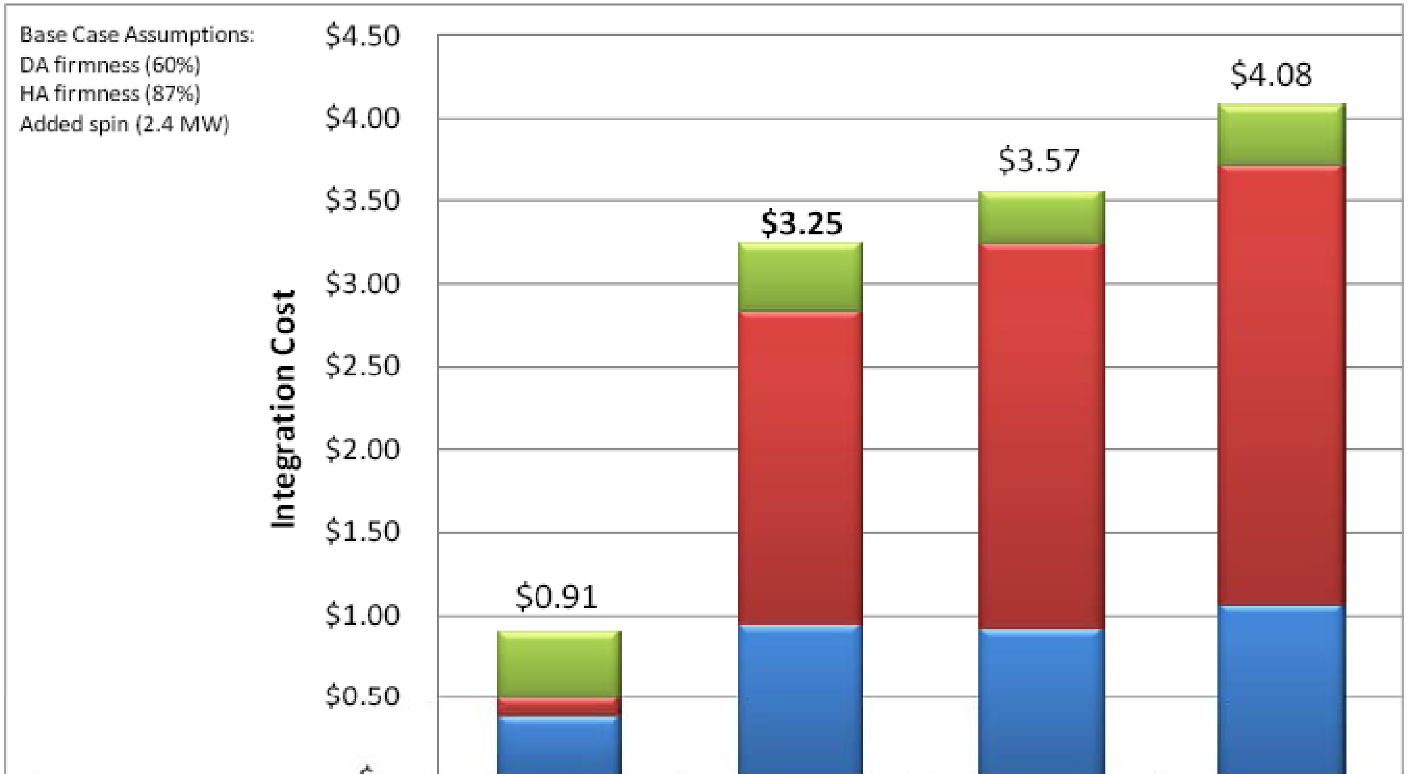
- Southern California Edison: 2000
- California ISO: 2004
- Electricity Reliability Council of Texas: 2008
- New York ISO: 2008
- Midwest ISO: 2008
- PJM: 2009
- Bonneville Power Administration, Xcel Energy, others under development

The great majority of US wind plants are now receiving forecasts

Why Do Wind Forecasting?

- Unforecasted wind fluctuations increase requirements for spinning reserves and raise electricity system production costs
- Unforecasted large ramp events can affect electricity system reliability
- State-of-the-art forecasts have high economic value compared to their cost (but potential savings are not always realized)
- Wind forecasts become essential for effective grid management with high wind penetrations (>5%)

Cost of Intermittent Wind



Wind Energy Penetration	1%	4%	7%	10%
Within-hour Regulating	$0.40	$0.41	$0.31	$0.37
Hour-ahead Uncertainty	$0.11	$1.88	$2.32	$2.65
Day-ahead Uncertainty	$0.39	$0.95	$0.93	$1.06

Arizona Public Service (Acker et al., 2007)
Typical range for all studies: $1.5-$4.5/MWh
Roughly 2.5-7.5% of cost of energy

AWS Truepower™ Where science delivers performance.

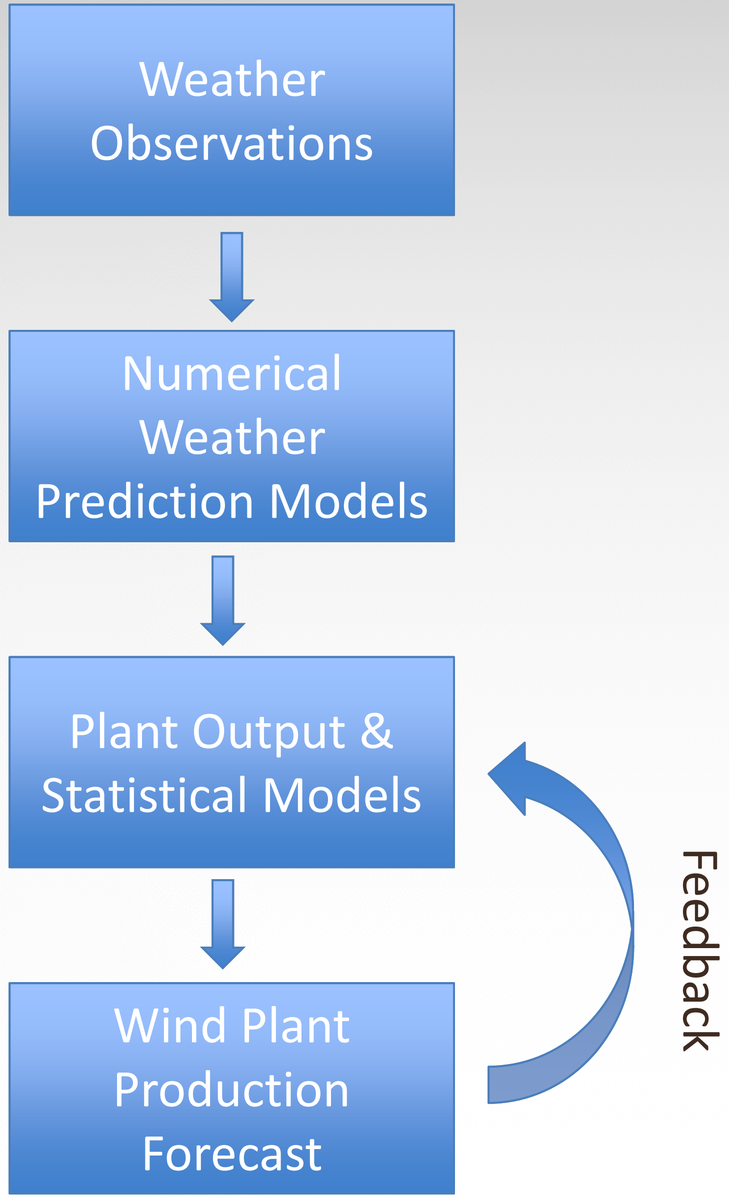
The Forecasting Challenge

If you think ordinary weather forecasting is challenging…

- Wind is typically created by small pressure gradients operating over large distances: hard to forecast accurately
- Turbulent & chaotic processes are also important & even harder to forecast
- Local topography can have a strong influence, but not captured in standard weather models
- Plant power curves are highly non-linear, so small errors in wind = big errors in power
- Plants experience unexpected losses and downtime and may operate sub-optimally

Forecasting Systems

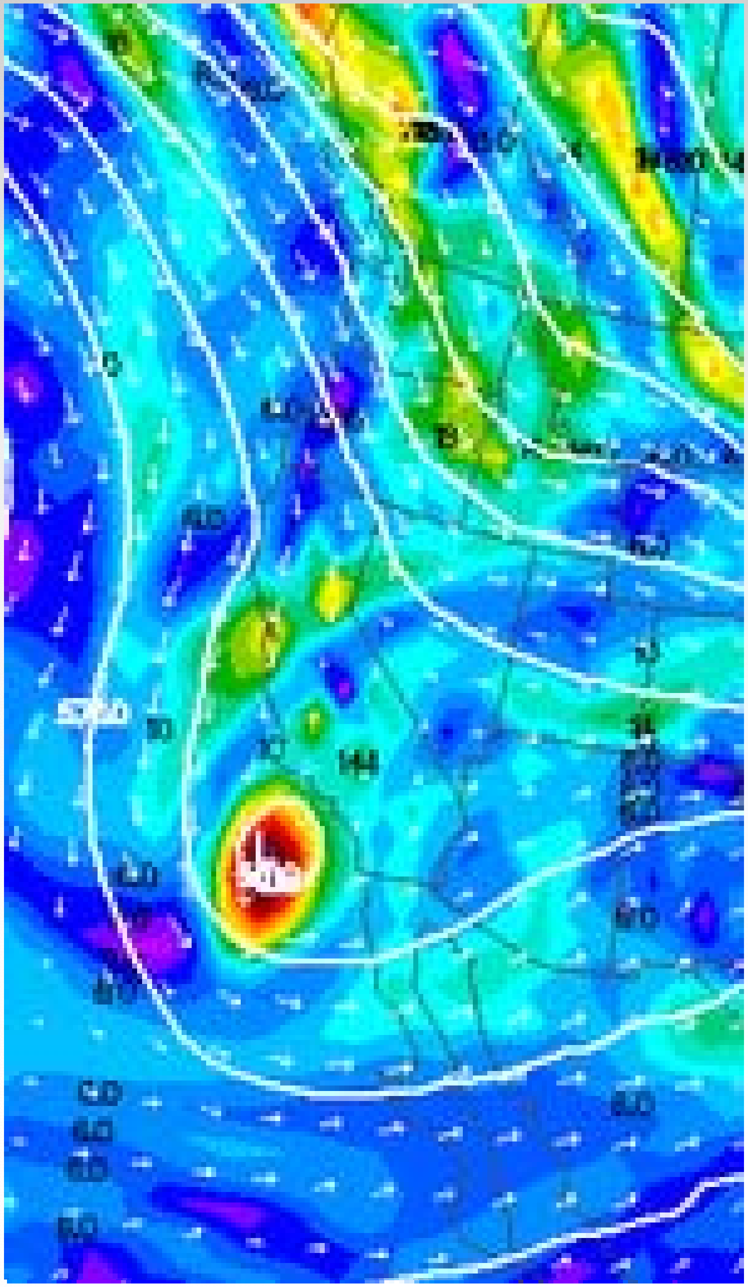
- Weather observations set the initial conditions – but there is never enough data
- Numerical weather prediction (NWP) models forecast evolution of weather systems
- Statistical models convert wind to power output and correct for systematic biases and error patterns
- Actual plant production data provide feedback to improve the statistical models
- Forecast providers use these components in many different ways



AWS Truepower™ Where science delivers performance.

NWP Models

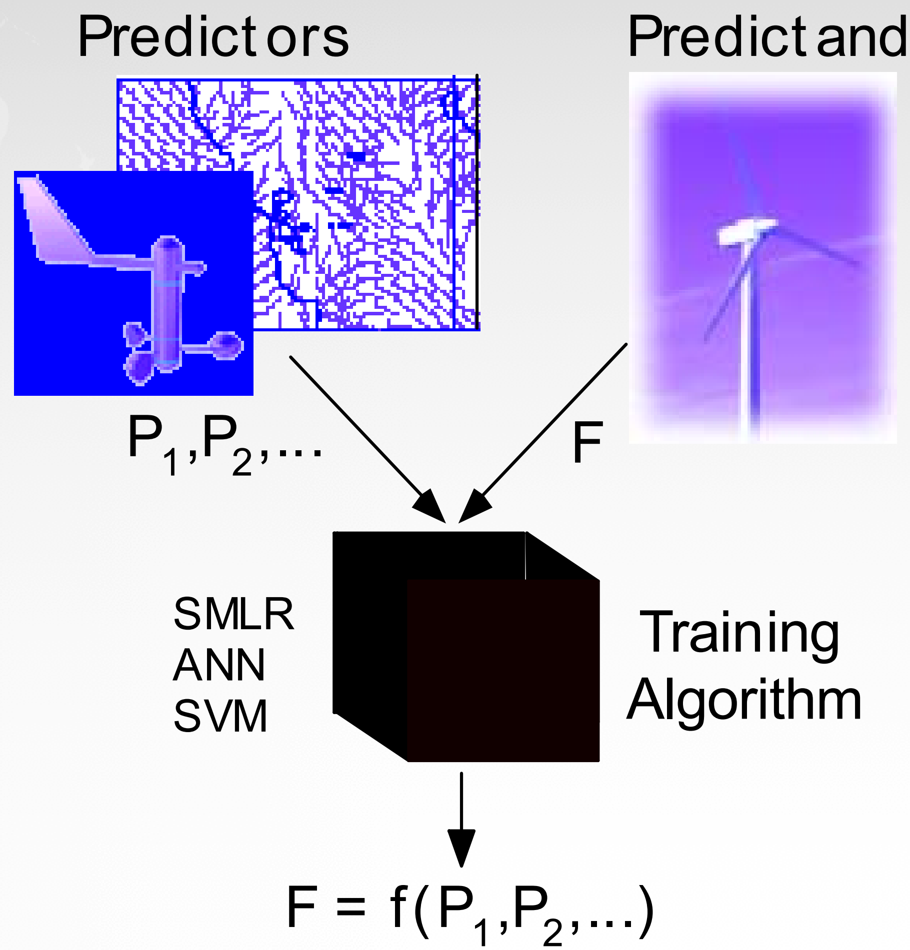
- Physical equations of the atmosphere are solved on a 3-D grid
- Initial conditions are obtained from observations (surface, balloons, satellites, Doppler radars, etc.)
- Models typically run 2x or 4x per day out 1-5 days
- Some forecast providers rely on government-run models; others run their own



AWS Truepower™
Where science delivers performance.

Statistical Models

- Correct for systematic NWP biases & sub-gridscale effects
- Incorporate recent data from the site or nearby locations
- Often include conversion of forecasted winds to plant output
- Many different statistical models are used: linear regression, neural networks support vector machines...



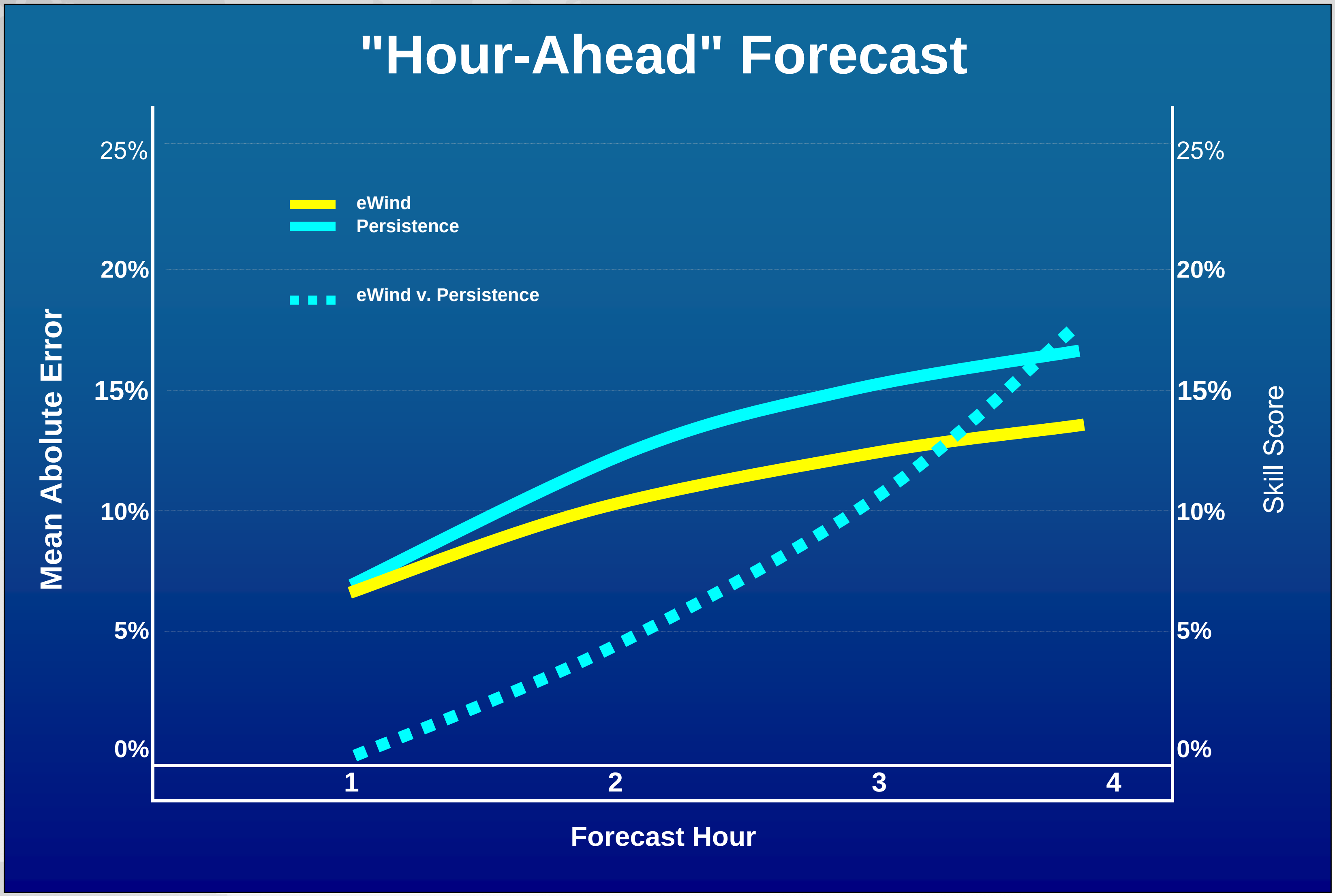
Forecast Time Horizons

- 5 - 60 minutes
  - Uses: Regulation, real-time dispatch decisions
  - Phenomena: Large eddies, turbulent mixing transitions
  - Methods: Largely statistical, driven by recent measurements
- 1-6 hours ahead:
  - Uses: Load-following, next-operating-hour unit commitment
  - Phenomena: Fronts, sea breezes, mountain-valley circulations
  - Methods: Blend of statistical, NWP models
- Day-ahead
  - Uses: Unit commitment and scheduling, market trading
  - Phenomena: “Lows” and “Highs,” storm systems
  - Methods: Mainly NWP with corrections for systematic biases
- Seasonal/Long-Term
  - Uses: Resource planning, contingency analysis
  - Phenomena: Climate oscillations, global warming
  - Methods: Based largely on analysis of cyclical patterns

How is Forecast Skill Measured?

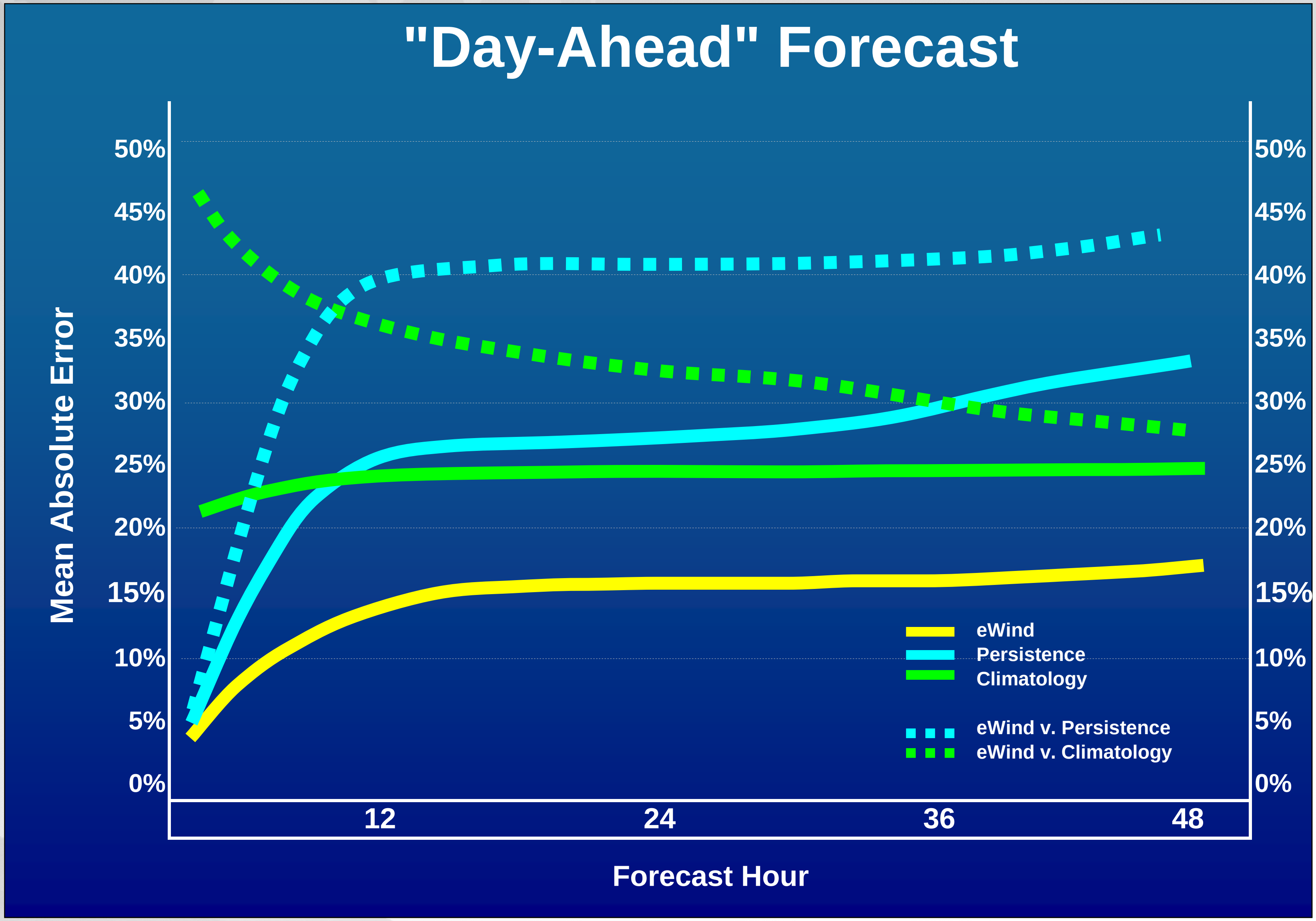
- Typical: mean error (ME), mean absolute error (MAE), root-mean-square error (RMSE)
- More refined “skill scores” are sometimes used, e.g.
  - Improvement over persistence, climatology, or other “dumb” forecast
  - Skill at predicting special conditions, e.g. ramp events, max/min output, cumulative output in critical periods
- Skill scores should be customized to the user’s cost or risk function (but rarely are)

Typical Forecast Performance



AWS Truepower™
Where science delivers performance.

Typical Forecast Performance



AWS Truepower™
Where science delivers performance.

Apples and Oranges

- **Forecast performance varies with many 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**

AWS Truepower™
Where science delivers performance.

How to Improve Forecasts

(3) Improved models

- ✓ Improved NWP modeling of sub-grid and surface processes
- ✓ Improved statistical models and training methods

(2) More effective use of models

- ✓ Higher resolution, more frequent NWP model runs
- ✓ Better data assimilation techniques
- ✓ Ensemble forecasting

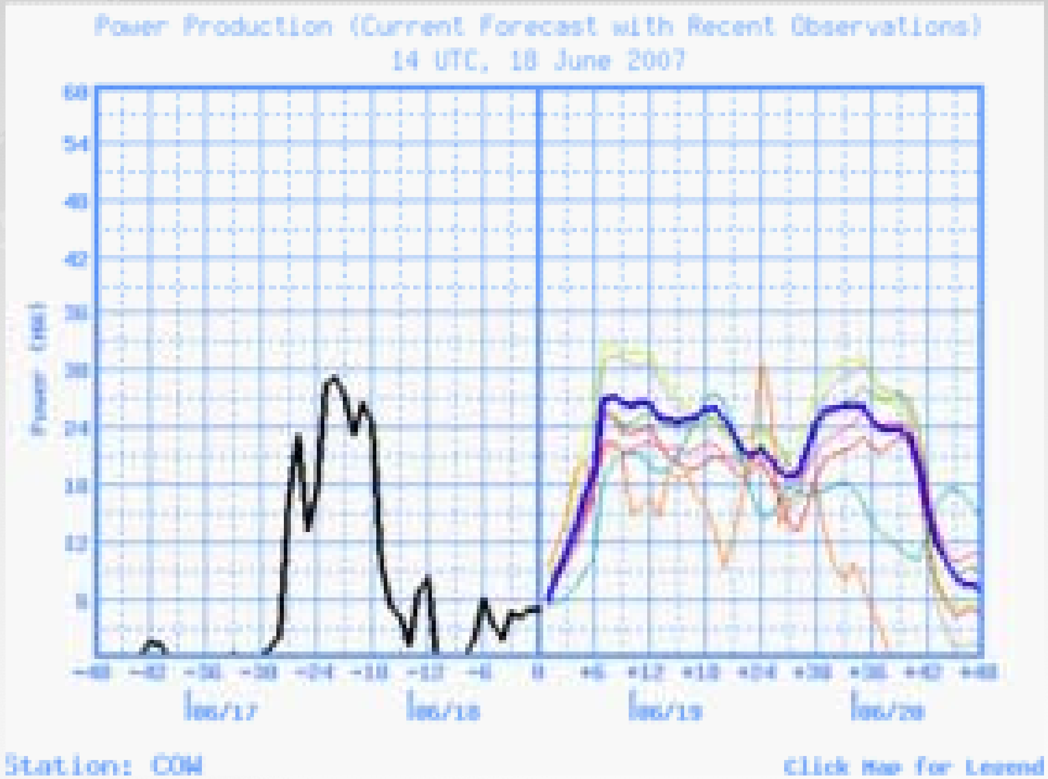
(1) More and better weather data

- ✓ Greater and more effective use of “off-site” data
- ✓ A leap in quality/quantity of global satellite-based sensor data

AWS Truepower™
Where science delivers performance.

Ensemble Forecasts

- Uncertainty is present in any forecast method
  - Input data & initial state
  - Model type
  - Model configuration

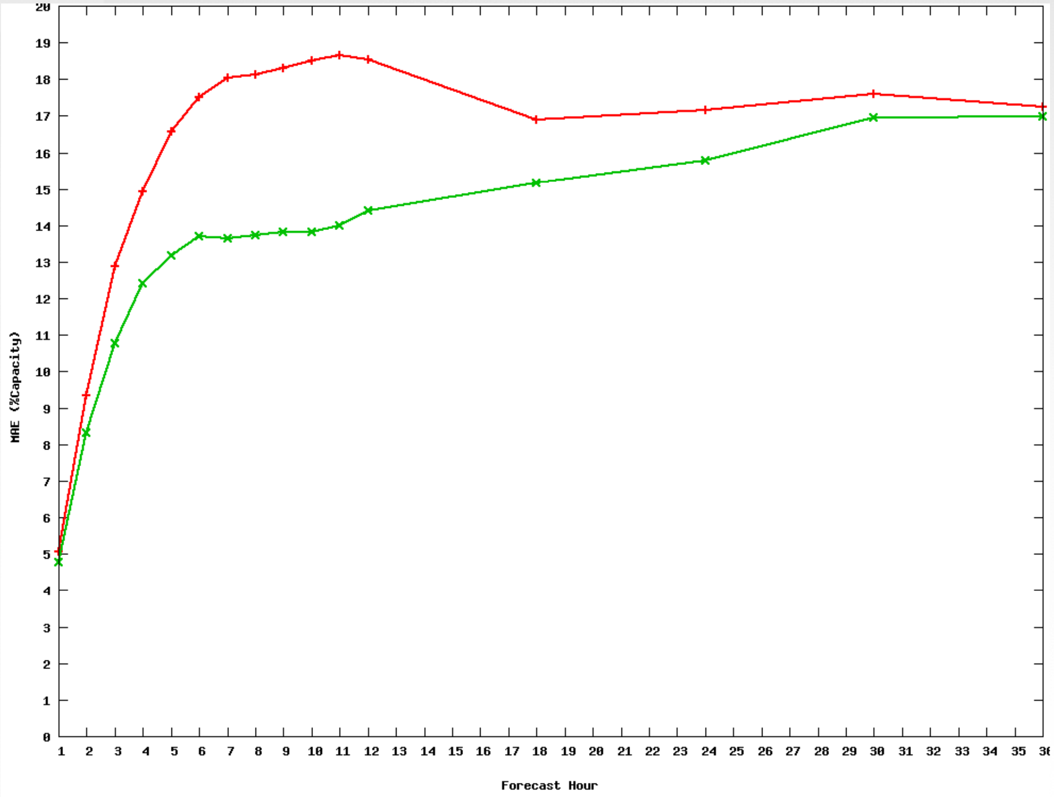


- By varying the initial state and model parameters, an ensemble of plausible forecasts is produced
- On average, the ensemble forecast is usually the best – but costly in computer resources

AWS Truepower™
Where science delivers performance.

Regime-Based Forecasts

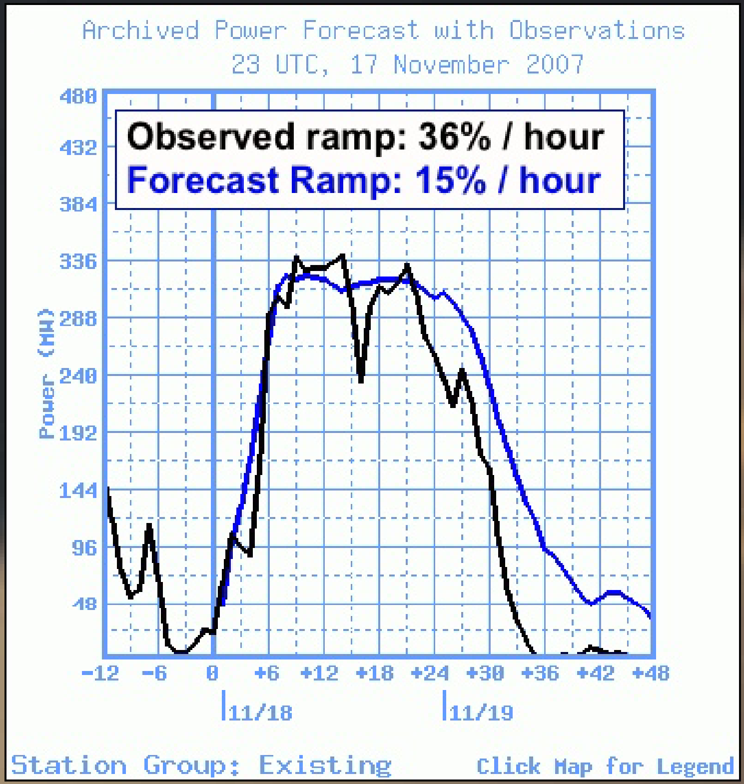
- Divide weather conditions into characteristic regimes
- Optimize forecasts for each regime
- Often yields a substantial improvement in accuracy…
- …but requires more thought and expertise



AWS Truepower™
Where science delivers performance.

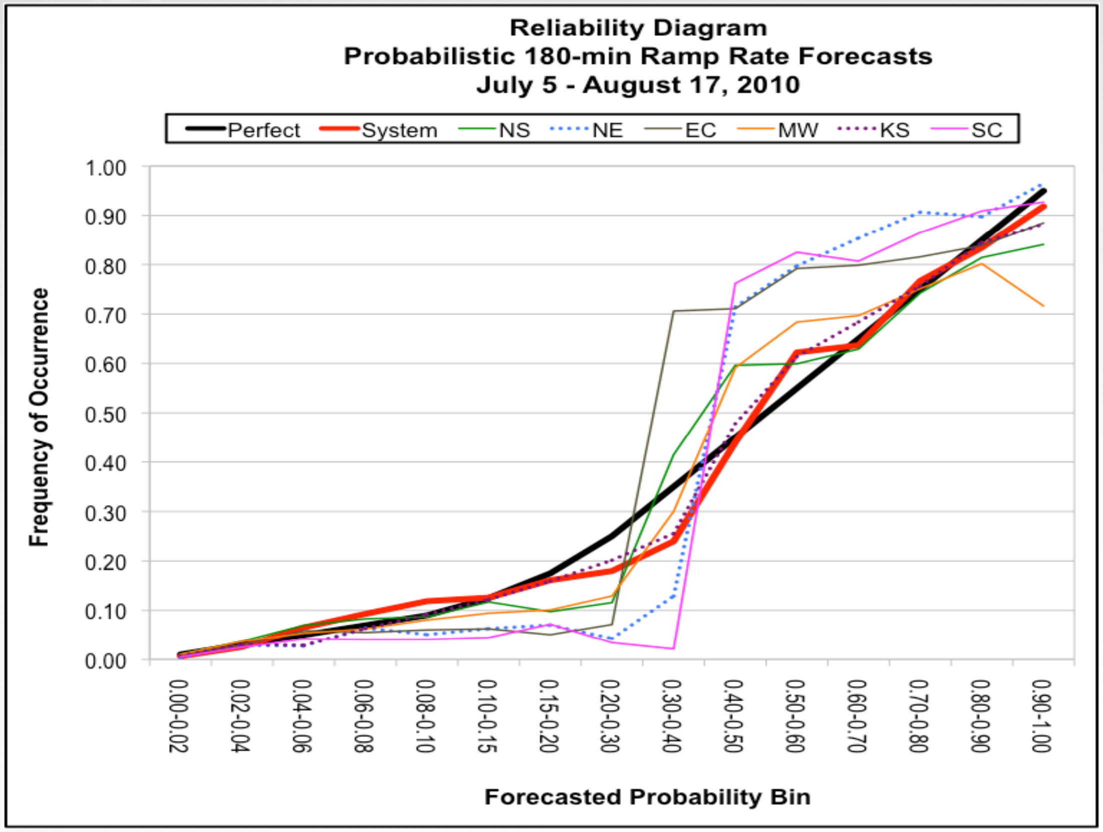
Ramp Forecasting

- Large ramp events are gaining attention since they can drive grid reliability
- Optimizing forecasts to MAE or RMSE tends to reduce ramp-forecasting skill
- Attempting to maximize ramp-specific skill scores may solve this problem



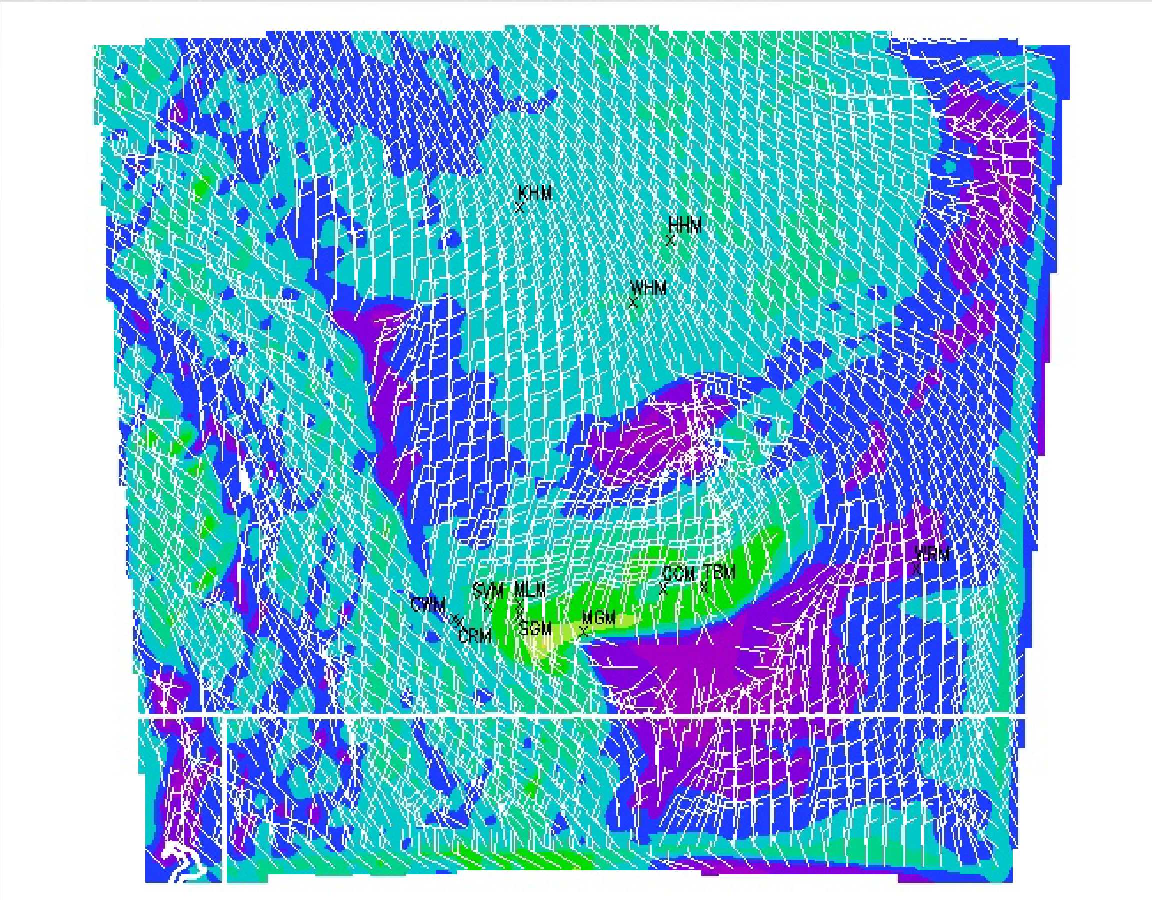
Reliability Diagram

- Compares forecasted probabilities to observed frequencies
- Forecasted probabilities are grouped into bins
- Example: 180-minute ramp rate probabilities
- Issue: Small sample size



Weather Data

- There is a great need for more weather observations
- Can use mesonets, profilers, offsite towers, Doppler radars, other…
- Custom observing networks may be key in the future
- Imply frequent NWP updates (e.g., Rapid Update Cycle 8x per day)



Rapid Update Cycle NWP forecast of a ramp event caused by a frontal system propagating southward

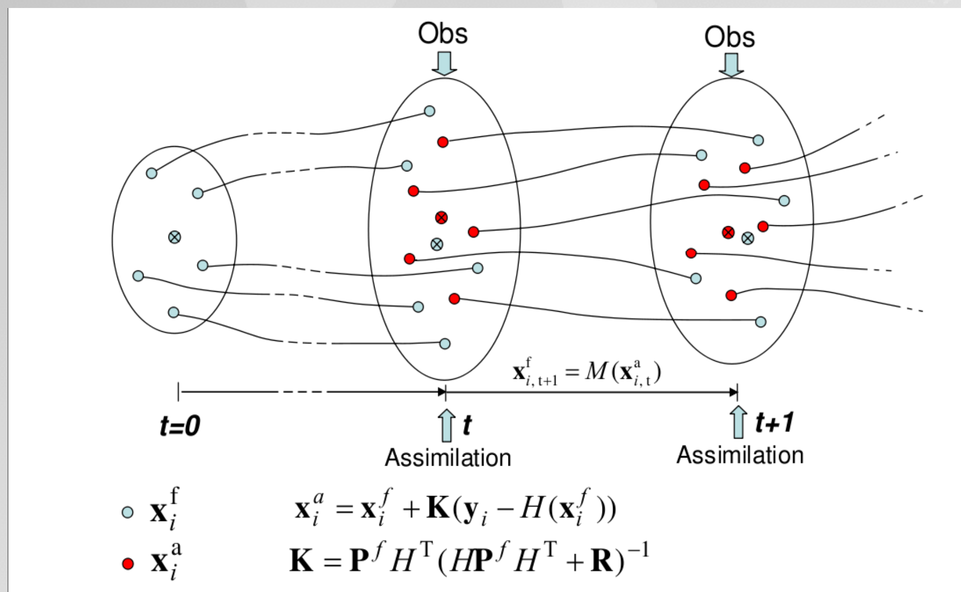
AWS Truepower™ Where science delivers performance.

But Where to Measure?

- Improving forecasts 6 hours ahead may require measurements up to 300 km away: a huge area!
- Don't forget the vertical dimension: surface measurements alone are generally not sufficient, even for "next hour" forecasts
- Be smart: Some locations, heights, parameters may have far more predictive value than others
  - *Corollary:* "Masts of opportunity" may have little value
- US DOE-funded research under way to optimize observing systems for short-term forecasts

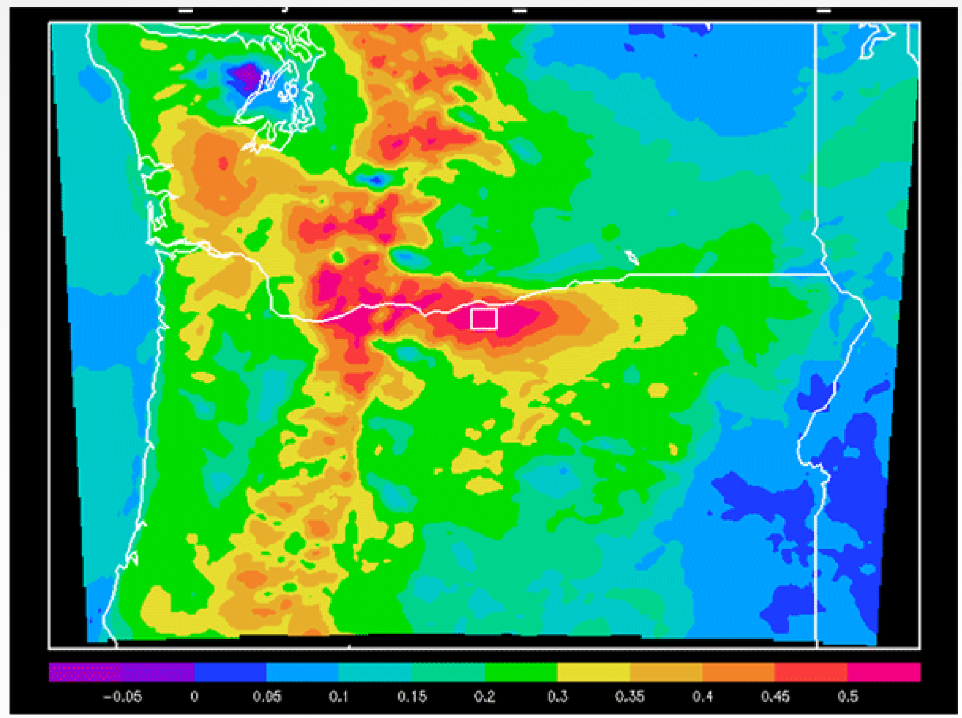
AWS Truepower™
Where science delivers performance.

Observation Targeting Procedure



Schematics of EnKF Cycles

- Initiate many forecasts over a range of initial states



- Map the sensitivity of forecast errors to the variations in each parameter
- Experimental but promising

AWS Truepower™
Where science delivers performance.

Centralized v. Decentralized Systems

- Centralized systems
  - Owned or contracted by the grid operator
  - Lower total cost for multiple plants
  - Easier to set and enforce standards, maintain consistent quality
  - Potential to aggregate data from different plants and improve forecast quality
  - Can make shared investments, e.g., targeted observational network
  - May not allow enough competition
- Decentralized systems
  - Forecasts supplied individually by wind projects
  - No external funding needed – therefore often the easiest choice
  - Standards can be set, but enforcement may be difficult
  - May lead to greater competition among forecast providers

Integration with Grid Operations

- The forecasts may be fine, but will they be used?
- Forecasts should be customized to the real needs of the grid operators
  - Confidence levels on routine forecasts
  - Focus on critical periods, e.g., times of maximum load or maximum load swing
  - Ramp forecasts
  - Severe weather forecasts
- Dedicated staff should be assigned to monitor forecasts
- Other steps to make integration more effective: training, visualization tools, plant clustering

Summary

- Wind forecasting is becoming ever more important as wind penetration grows
- Current forecasting technology is far from perfect but nonetheless highly cost effective compared to no forecast at all
- Improvements lie in better models, better use of models, and more observational data
- Benefits of aggregation and need for large investments (e.g., observational networks) favor centralization of forecasting operations

Thank you

Michael Brower
Chief Technical Officer
AWS Truepower, LLC
463 New Karner Road
Albany, NY 12205
mbrower@awstruepower.com
Ph. 978-835-8263
awstruepower.com

AWS Truepower™
Where science delivers performance.