Optimal Unit Commitment and Dispatch for Wind Farm Operations

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Optimal Unit Commitment and Dispatch for Wind Farm Operations

- Background and motivation
- Approach
- Example experimental result
- Conclusions and future work

Other Presentations of Related Work

Conference on Numerical Weather Prediction:

- **1A.4** *Statistical upscaling of numerical weather predictions to enable coupled modelling of local weather impacts*

Conference on Weather, Climate, and the New Energy Economy:

- **J7.1** *Operational Utilization and Evaluation of a Coupled Weather and Outage Prediction Service for Electric Utility Operations*
- **P782** *Application of an operational meso-scale modelling system for industrial plant operations*
- **P765** *Wind farm layout optimization*

Challenges for Wind Power

- **Wind power intermittency creates significant barriers to expanding utilization**
  - Ramp events
  - Spinning reserve
- **Better forecasting and smarter dispatch can alleviate these barriers**
  - Ensemble forecasts
  - Stochastic programming
  - Dynamic reserves

Examples of Weather + Optimization Coupling

- Accurate timing of shut down due to severe weather
  - Lead time required to take preventative measures (e.g., when a storm hits the turbines must be shut down, which takes several minutes)
  - The shut down causes a loss of energy generation
  - The more precise (or less uncertain) the weather forecasting the more optimal can the time of shutdown be determined to minimize the loss
- Accurate reserve margins
  - With improved power estimations and when losses would occur, the need for alternative sources (e.g., fossil fuel plants) can be determined better
  - More cost effective management of all generators as the need for high margins on power reserves and standby production will decrease
- Accurate area for shut down
  - Improved weather forecasting will allow for a more limited shut down of the facility since a subset of the affected areas could be determined

- Overall reduction in variability into the grid

Unit Commitment and Dispatch

- Which power generators should be used, when and at what level in order to satisfy the demand for electricity?
- Conventional fossil-fueled or nuclear power generators require time and expense to power up and have limits on how quickly they can change their production levels
- Unit commitment refers to deciding when to turn these generators on and off
- Dispatch refers to deciding how much to produce from each generator
- Because of the fixed costs and operating constraints on the generators, the power system has inflexibilities in dealing with unexpected load fluctuations and generator outages
- To hedge against these uncertainties, system operators keep a certain amount of spinning reserve -- generators that are turned on but are producing at minimal levels so that they can increase production quickly
- When the power system includes wind generators, the volatility of their output introduces additional uncertainty, requiring more spinning reserves, the cost of which detracts from the economics of using them

Approach

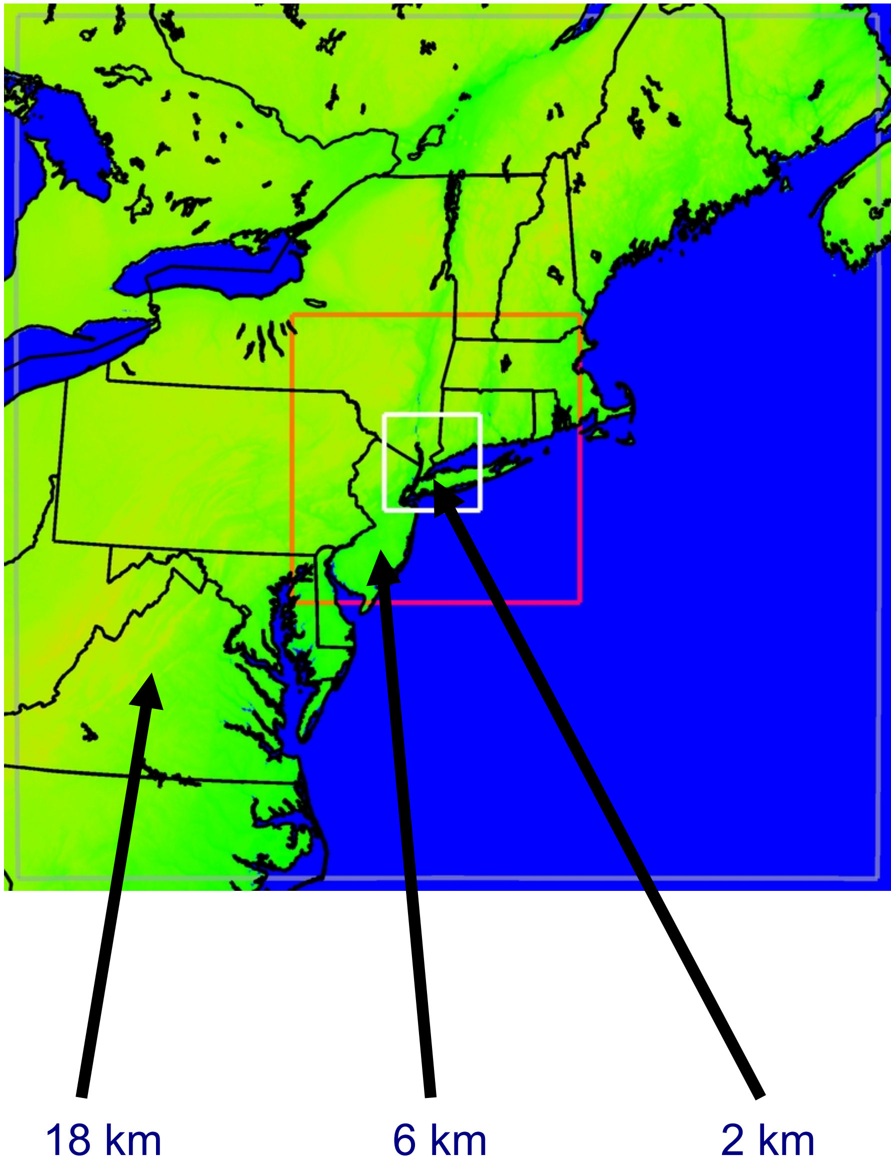
- Coupling of an NWP code to optimization software
  - Output used to define a range of potential wind forecasts and create a scenario tree to estimate the uncertainty in the prediction
- Essentially a linear programming problem with uncertainty in both supply (i.e., wind) and demand
- Use stochastic optimization to hedge the unit commitment decisions
  - Reduce the amount of spinning reserves required
  - Improve the dependability of the wind resource
  - Wind generation is treated implicitly as a reduction in the net demand on the conventional generators

Approach

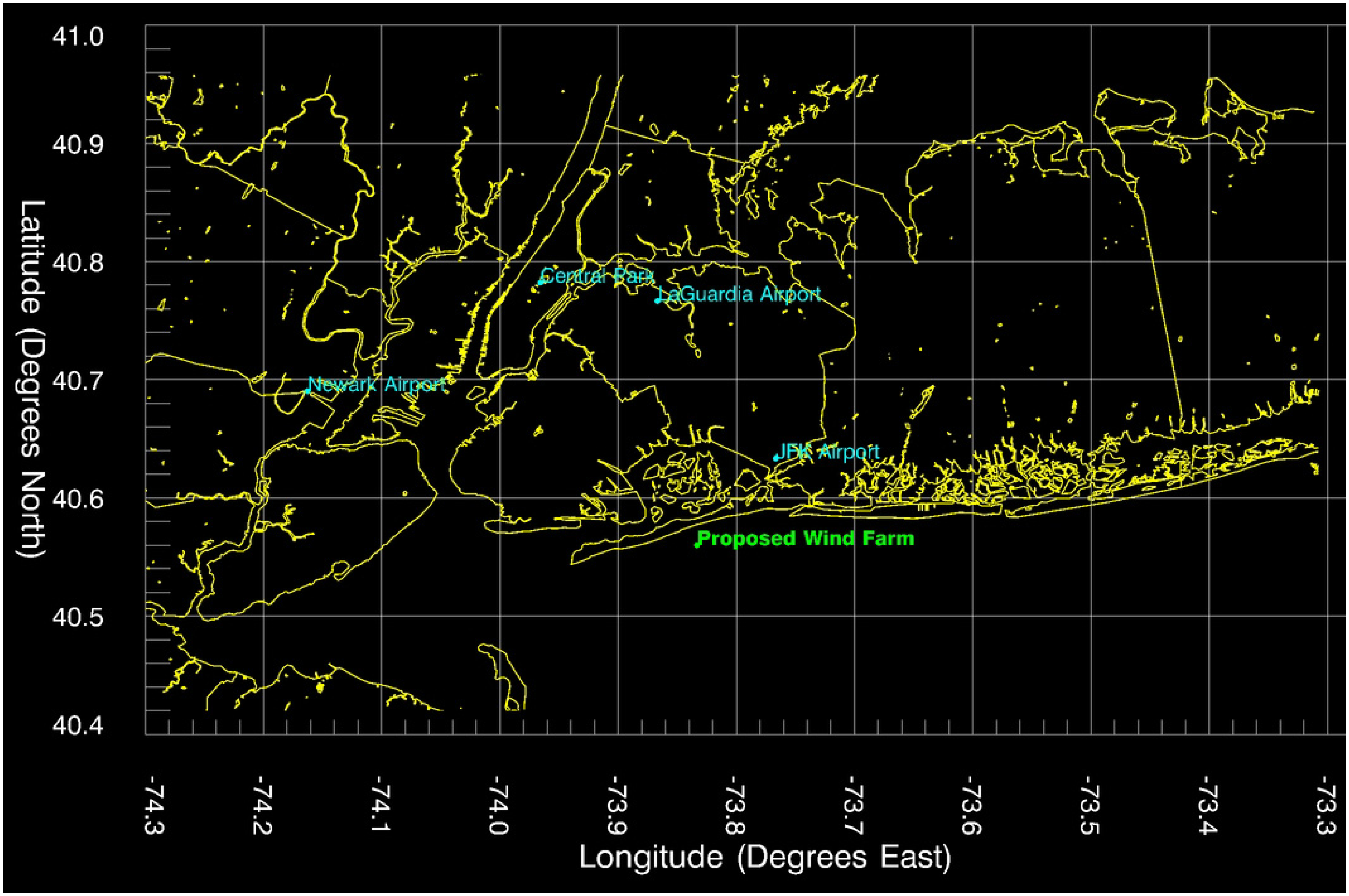
- Required data
  - –Set of electricity demands (loads) forecasted as a set of probabilistic scenarios
  - –Set of generators (units) with several operating characteristics
- This leads to building recourse for each wind scenario and reduces the volume of spinning reserves as well as unmet demand and overall cost, regardless of the variance in the wind forecast
- The optimization model is a mixed integer linear program
  - –Determines when to start up the generators
  - –Assigns generators a production level for each time period, which may depend on the load scenario

Weather Model Configuration

- **WRF-ARW (v3.1.1)**
  - Focused on the region of a wind farm with appropriate physics and sufficient vertical resolution in the boundary layer to capture details in the regime swept out by turbine blades
  - 18/6/2 km nests (76x76x42)
  - 84 hour runs twice daily (0 and 12 UTC) since April 2009
  - NAM for background and boundary conditions
  - WSM 6-class microphysics, YSU PBL, NOAH LSM, Grell-Devenyi ensemble, urban canopy model
- **Select an off-shore location for "proposed" wind farm**
- **Identify simulation of ramping event**
  - Interpolate wind data to 80m AGL (assumed hub height of turbines for the "proposed" wind farm)

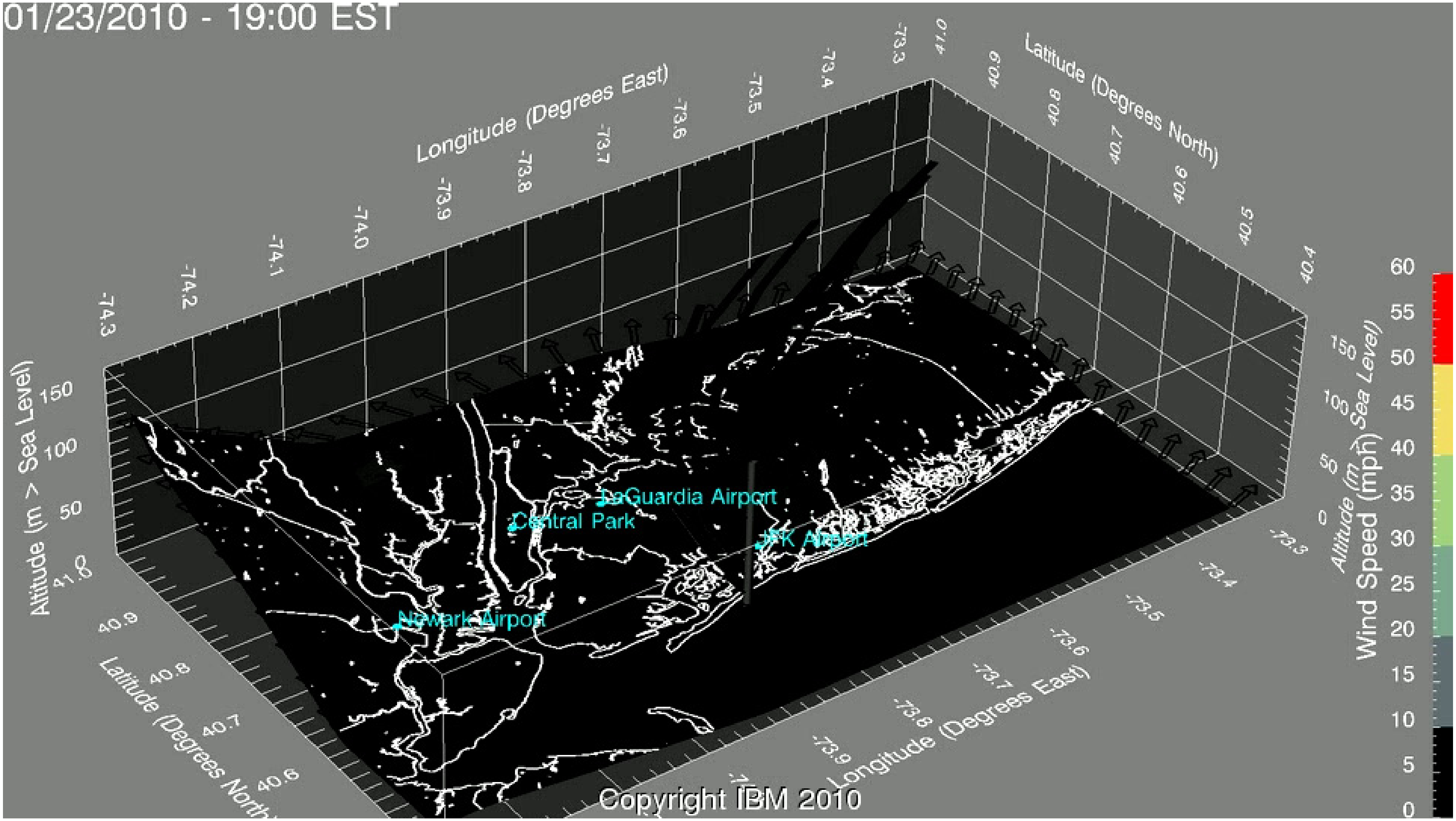


Example “Wind Farm” Forecast for a Ramping Event



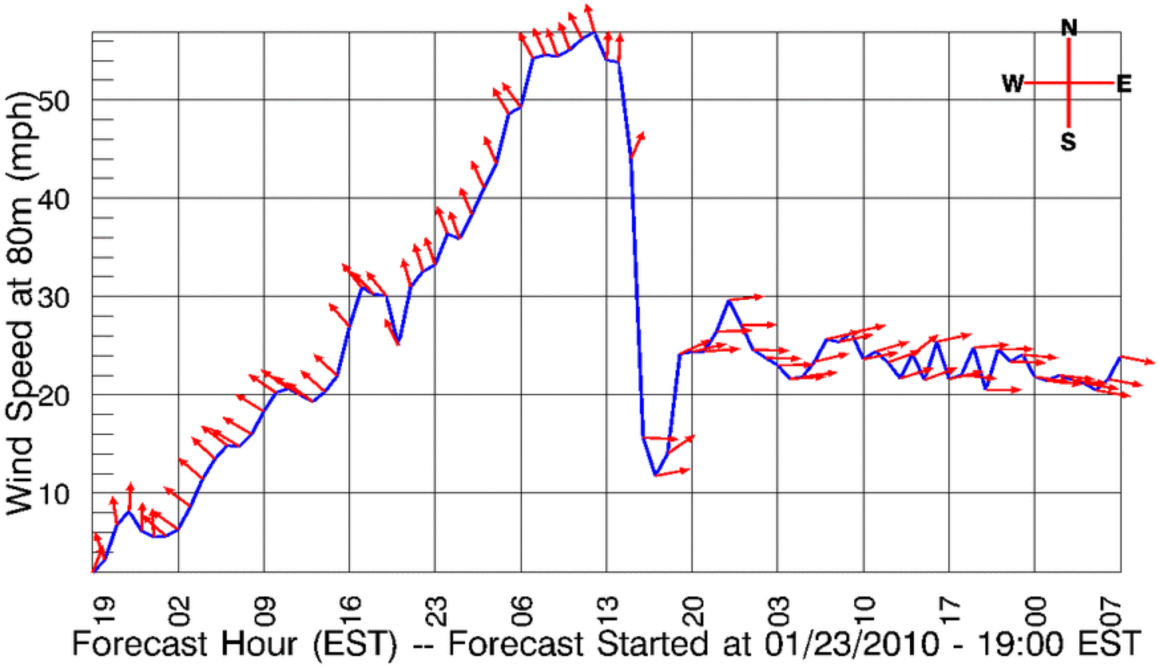
Location of a hypothetical wind farm off the coast of New York City

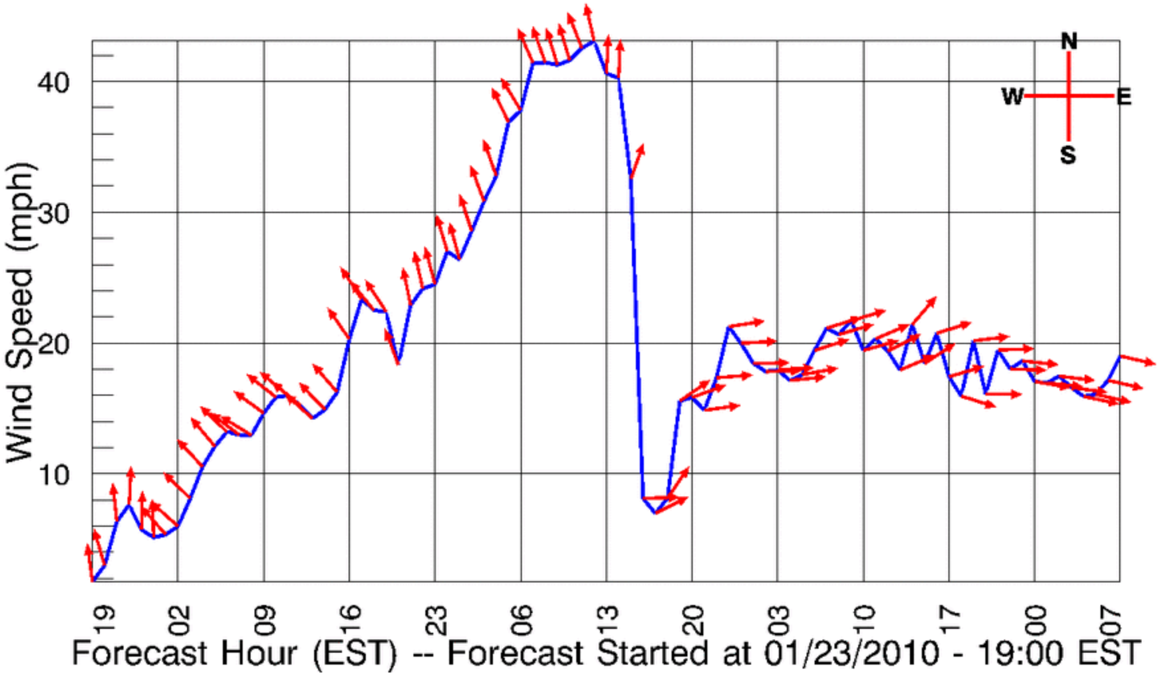
Example "Wind Farm" Forecast for a Ramping Event



84-hour wind forecast showing speed and direction at a height of 10m and at the location of a hypothetical wind farm off the coast of New York City along the blade extent as well as wind trajectories

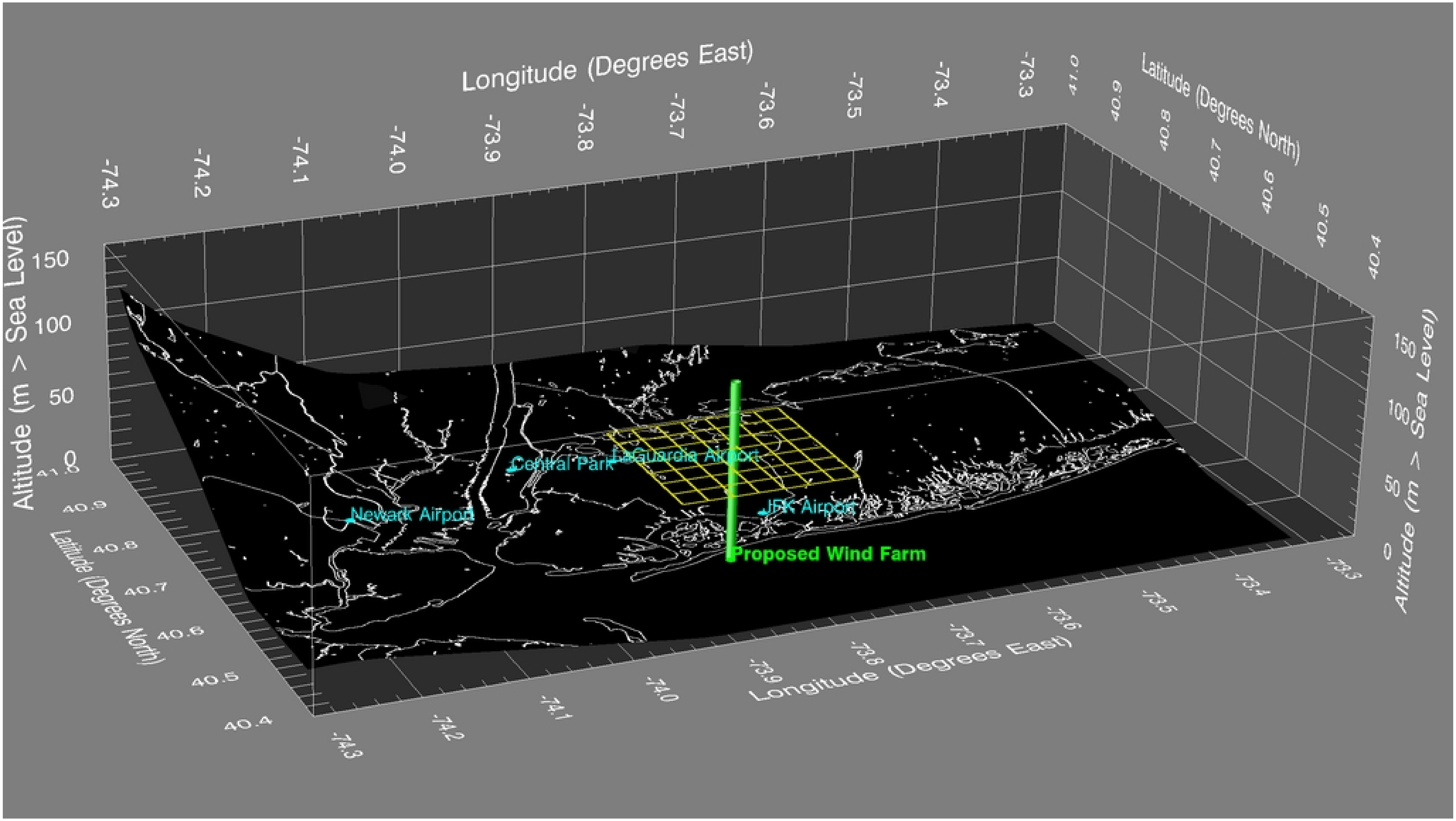
Example “Wind Farm” Forecast for a Ramping Event





- **84-hour wind forecast showing speed and direction at a height of 80m (top, i.e., hub height for turbines at the location of a hypothetical wind farm off the coast of New York City) and at height of 10m (bottom)**
- **Peak wind speed before the ramp down is close to the cut-out speed of some turbines**
- **There is not lot of shearing from the 10m to 80m because the off-shore flow is relatively laminar**

Example “Wind Farm” Forecast for a Ramping Event



Location of a hypothetical wind farm off the coast of New York City and 8x8 samples at hub height (80m) to capture uncertainty due to phase errors

Example Use Case: System Operator Perspective

- System operator has to adjust dispatch to account for variations in wind energy for a ramping event
- Unit commitment with multiple net load scenarios
- 10 generating units with various characteristics (e.g., power levels, operating time, costs)
- 85 time periods from the hourly WRF output from 20 of the sample points are used to represent the wind generation and uncertainty
  - 1045 states reflecting temporal and spatial phase errors for the ramp event

- Solution identifies the best set of units to commit and the optimal production level for all units for all scenarios

Wind Intermittency and Ensemble Forecasting

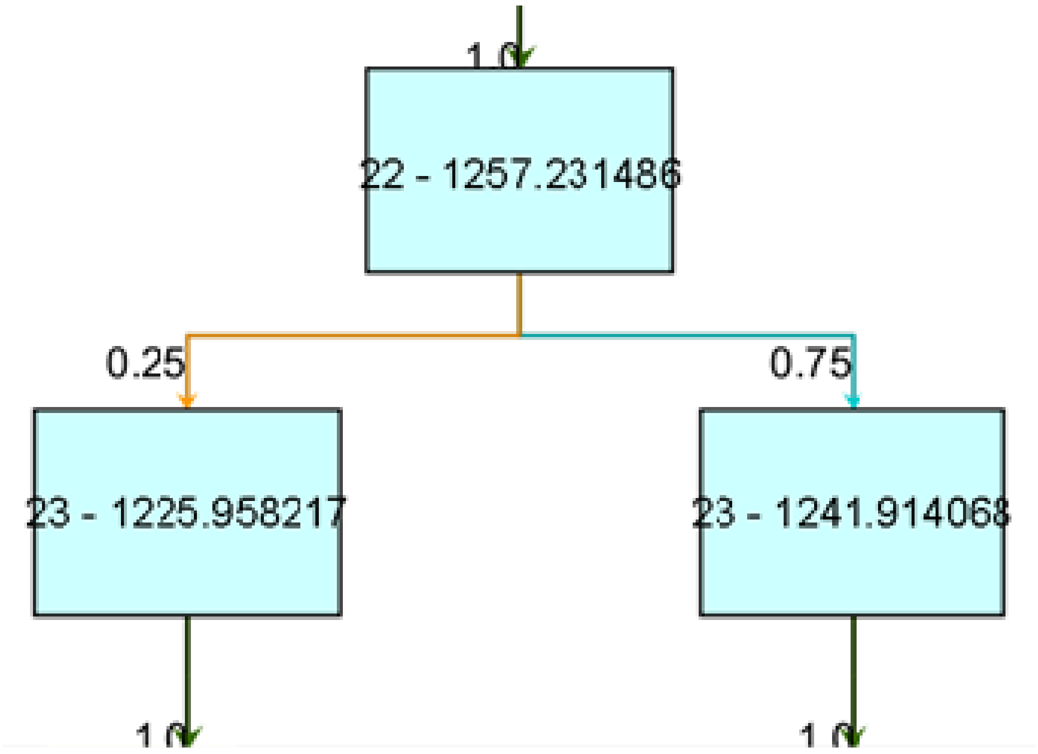
- **Transitions represent the uncertainty in the net load resulting from wind power volatility**
- **In a given state at a given hour, there may be multiple possibilities for the net load in the next hour**
- **Each possibility represents a transition**

From State ID	Load	Probability	To State ID	Load
0	1,112.958	0.388	1	1,102.072
0	1,112.958	0.179	2	1,191.000
0	1,112.958	0.149	3	1,152.175
0	1,112.958	0.224	4	1,134.028
0	1,112.958	0.060	5	1,165.991

In state 0 above (representing the start of the planning period) there are 5 possible transitions, shown above with their probabilities

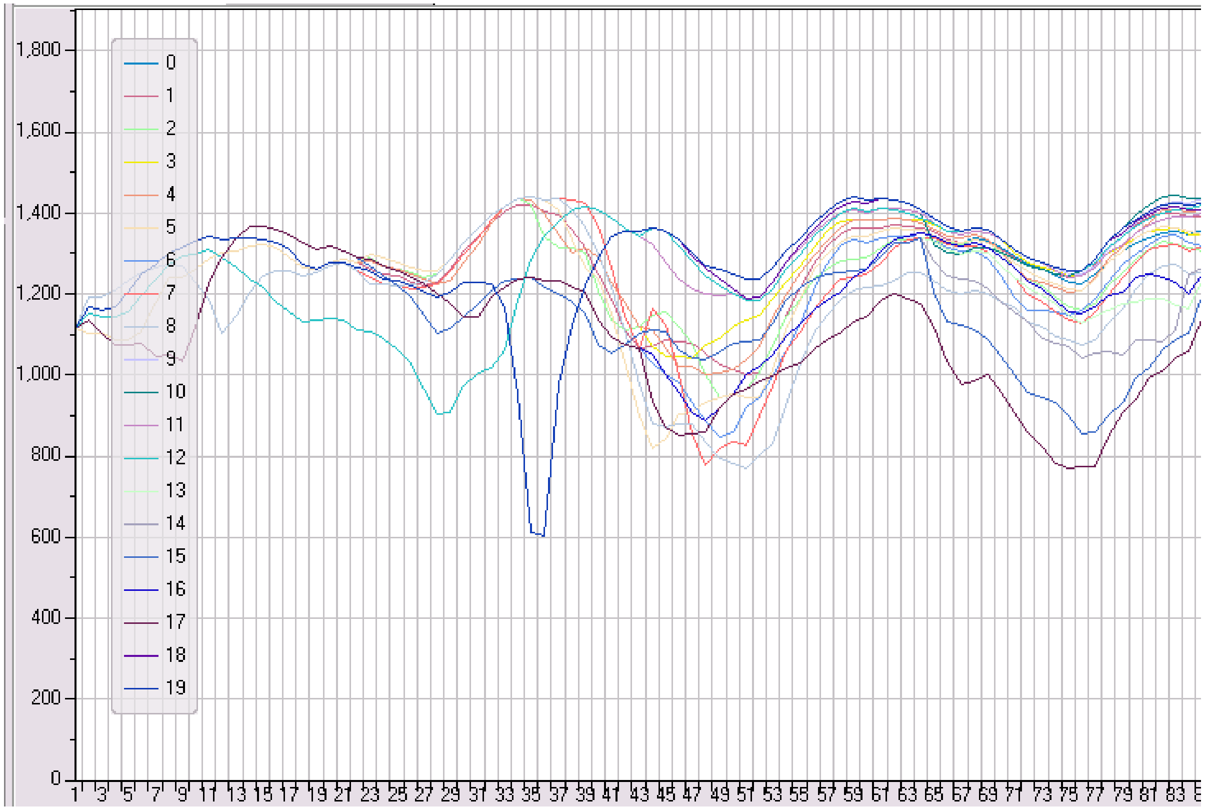
Scenario Tree

- **A scenario is a sequence of states in chronological order, linked together by transitions**
- **All scenarios start at the same state and branches occur when there are multiple possibilities for the net load in the next period**
- **The boxes in the tree represent states (e.g., <period 22, load 1257 MW>)**
- **The branches represent transitions, e.g., from state <period 22, load 1257 MW>**
  - **25% of the time a transition occurs to state <period 23, load 1226 MW>**
  - **75% of the time a transition occurs to state <period 23, load 1242 MW>**

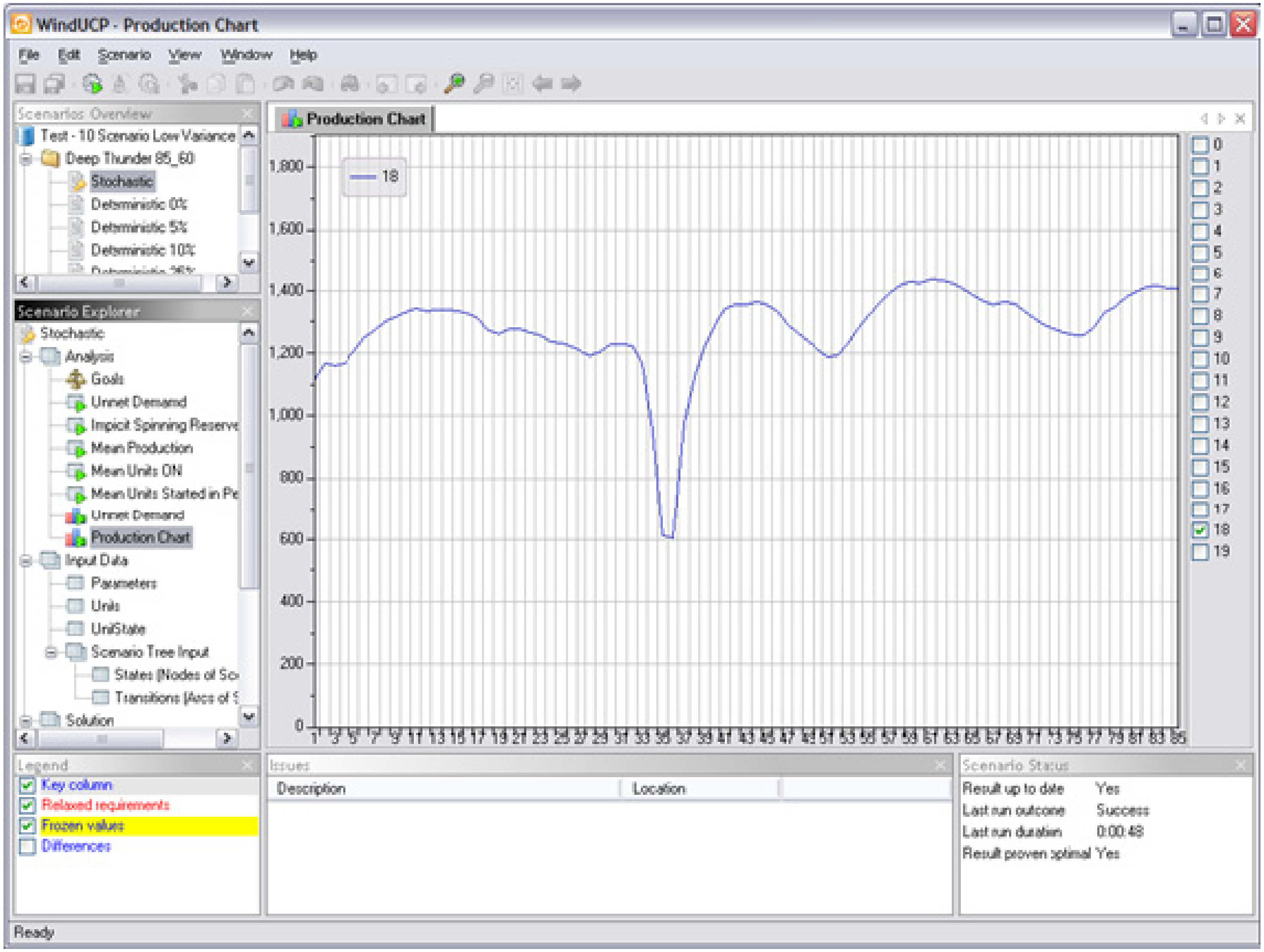


Power Production

- Total (conventional) power generation for each scenario
- Since the dispatch satisfies all the demand in each scenario, the total power generation equals the load



Power Production During Ramping Event



Result up to date Yes
Last run outcome Success
Last run duration 0:00:48
Result proven optimal Yes

The stochastic optimization model will adjust to the changing demand profiles for all scenarios

Conclusions and Future Work

- Using a stochastic load forecast derived from NWP output, together with stochastic optimization substitutes analytic risk assessment for ad hoc adjustments to spinning reserves made based on operator judgment
- Stochastic unit commitment can achieve lower cost and comparable (or better) reliability to deterministic dispatch methods
- Predictive optimization with sufficient lead time can improve both dispatch and commitment
- Future work will include:
  - Use of true NWP ensemble to represent uncertainty in weather forecast
  - Including full three-dimensional representation of wind to determine power

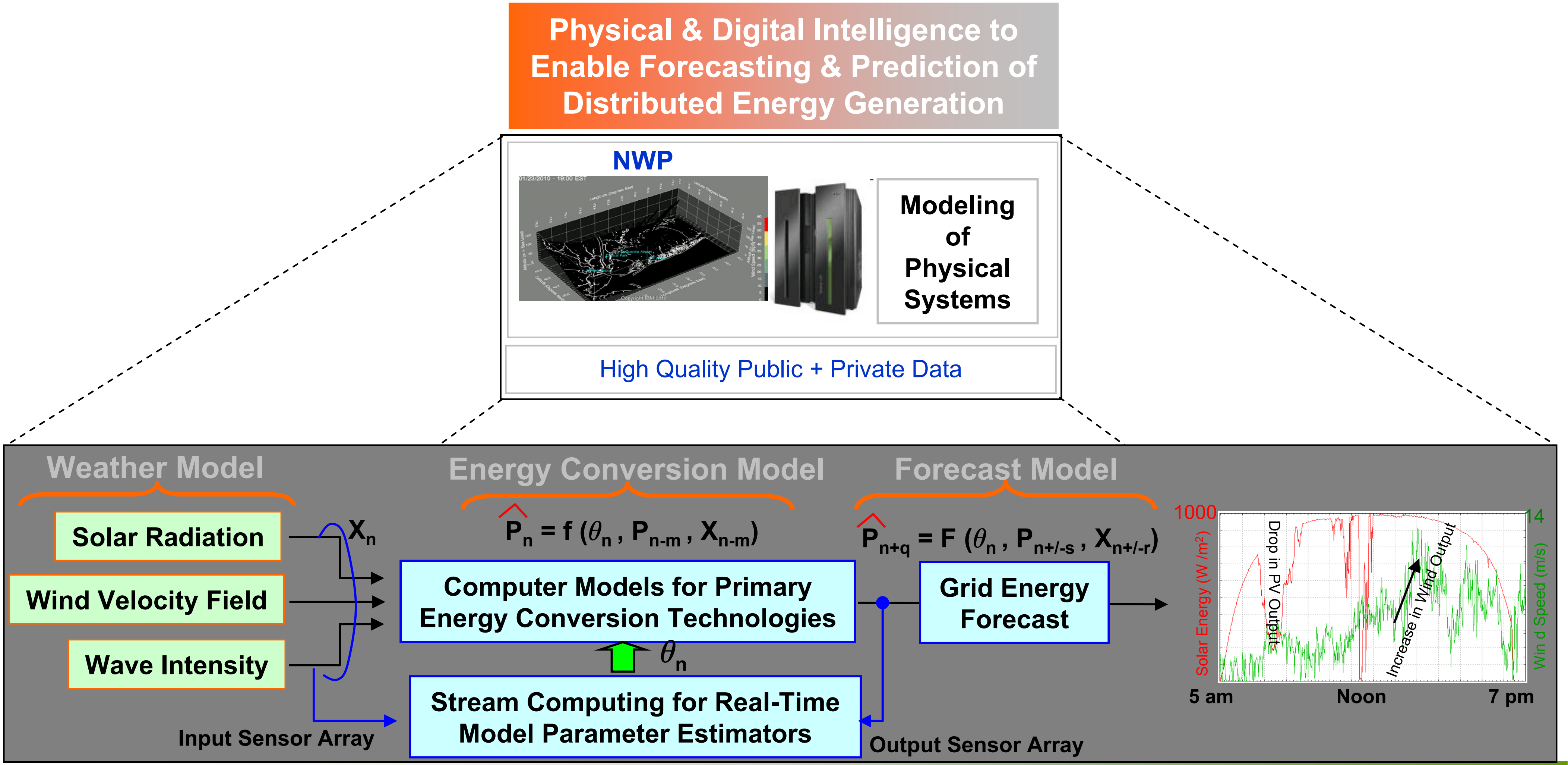
Backup

Slides

Physical & Digital Intelligence Applied to Smart Grids

IT Intermittency Solution

Coordinated control of centralized and distributed energy generation, transmission, and storage with advance warning via forecasting and prediction from generation to user



Physical & Digital Intelligence to Enable Forecasting & Prediction of Distributed Energy Generation

NWP

Modeling of Physical Systems

High Quality Public + Private Data

Weather Model

Solar Radiation

Wind Velocity Field

Wave Intensity

X_n

Input Sensor Array

Energy Conversion Model

$\hat{P}_n = f(\theta_n, P_{n-m}, X_{n-m})$

Computer Models for Primary Energy Conversion Technologies

θ_n

Stream Computing for Real-Time Model Parameter Estimators

Forecast Model

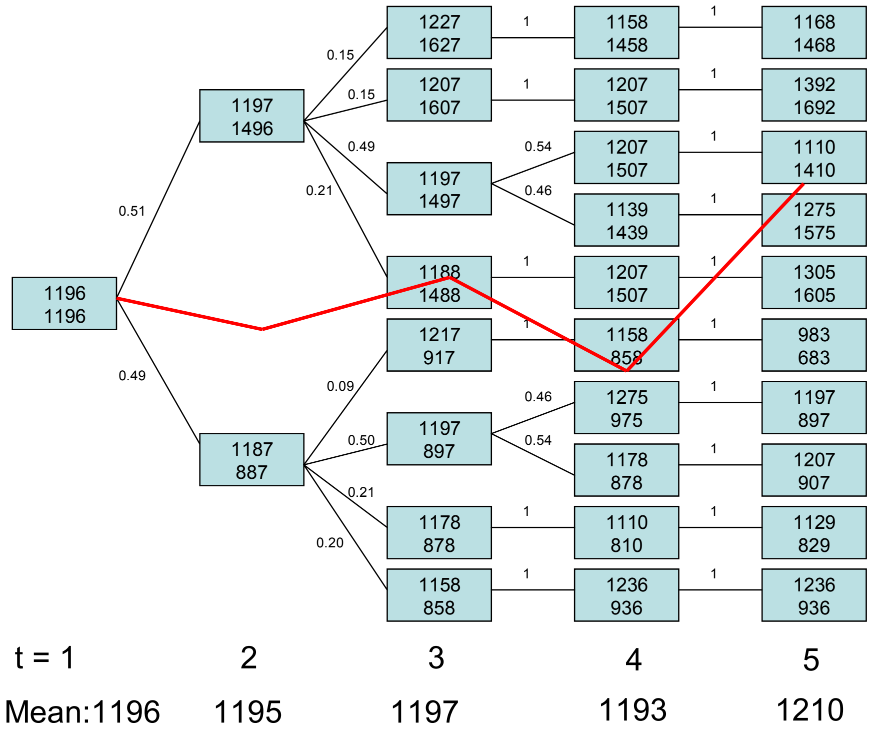
$\hat{P}_{n+q} = F(\theta_n, P_{n+/-s}, X_{n+/-r})$

Grid Energy Forecast

Output Sensor Array

Dynamic Decision Making Using Stochastic Programming

Demand scenario trees



- Values in the boxes show demand values for two scenario trees.
- Red line shows mean demand
- Values on the arcs represent probabilities.
- Both trees have equal means at each time period
- Lower demand values have higher variability

- **Risks change dynamically**
  - Forecast updates
  - Information sets
- **Hedging risks**
  - Recourse decisions
- **Deterministic vs. stochastic decisions**
  - Average case leaves unserved demand in extreme cases
  - Extreme cases overcompensate on reserves