Operational Utilization and Evaluation of a Coupled Weather and Outage Prediction Service for Electric Utility Operations

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- Background and motivation
- Approach
  - Meteorology (modelling and analysis)
  - Outages (modelling and analysis)
  - Coupling and calibration
  - Visualization
  - Verification
- Example results
- 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:

- **P782** ***Application of an operational meso-scale modelling system for industrial plant operations***
- **P765** ***Wind farm layout optimization***
- **7B.5** ***Optimal unit commitment and dispatch for wind farm operations***

Background and Motivation

- The operation of the distribution system of an electric utility, particularly with an overhead infrastructure, can be highly sensitive to local weather conditions
- What is the potential to enable proactive allocation and deployment of resources (people and equipment) to minimize time for restoration?
  - Ability to predict specific events or combination of weather conditions that can disrupt that distribution network with sufficient spatial (i.e., area substation level) and temporal precision, and lead time
  - Can highly localized, NWP-based forecasts be adapted to address these problems and reduce the uncertainty in decision making?
  - Can the link between weather and impact be quantified to improve preparation and response?

Weather prediction

↓

Damage prediction

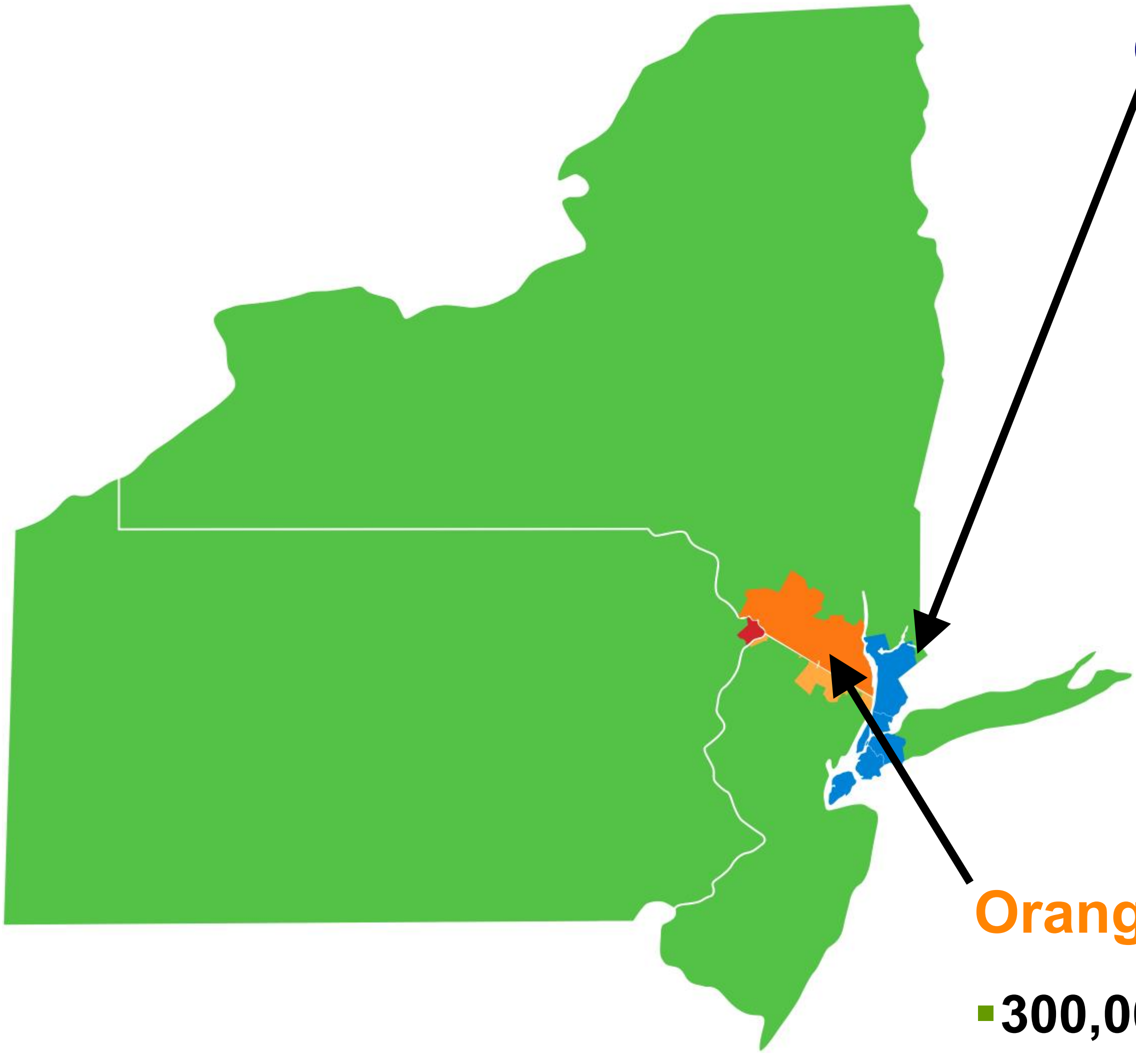
↓

Resource requirement prediction

↓

Restoration time prediction

Consolidated Edison Service Territory



Con Edison Co. of New York

- 3.2 million electric customers
- 1.0 million gas customers
- 1,800 steam customers
- 709 MW of regulated generation

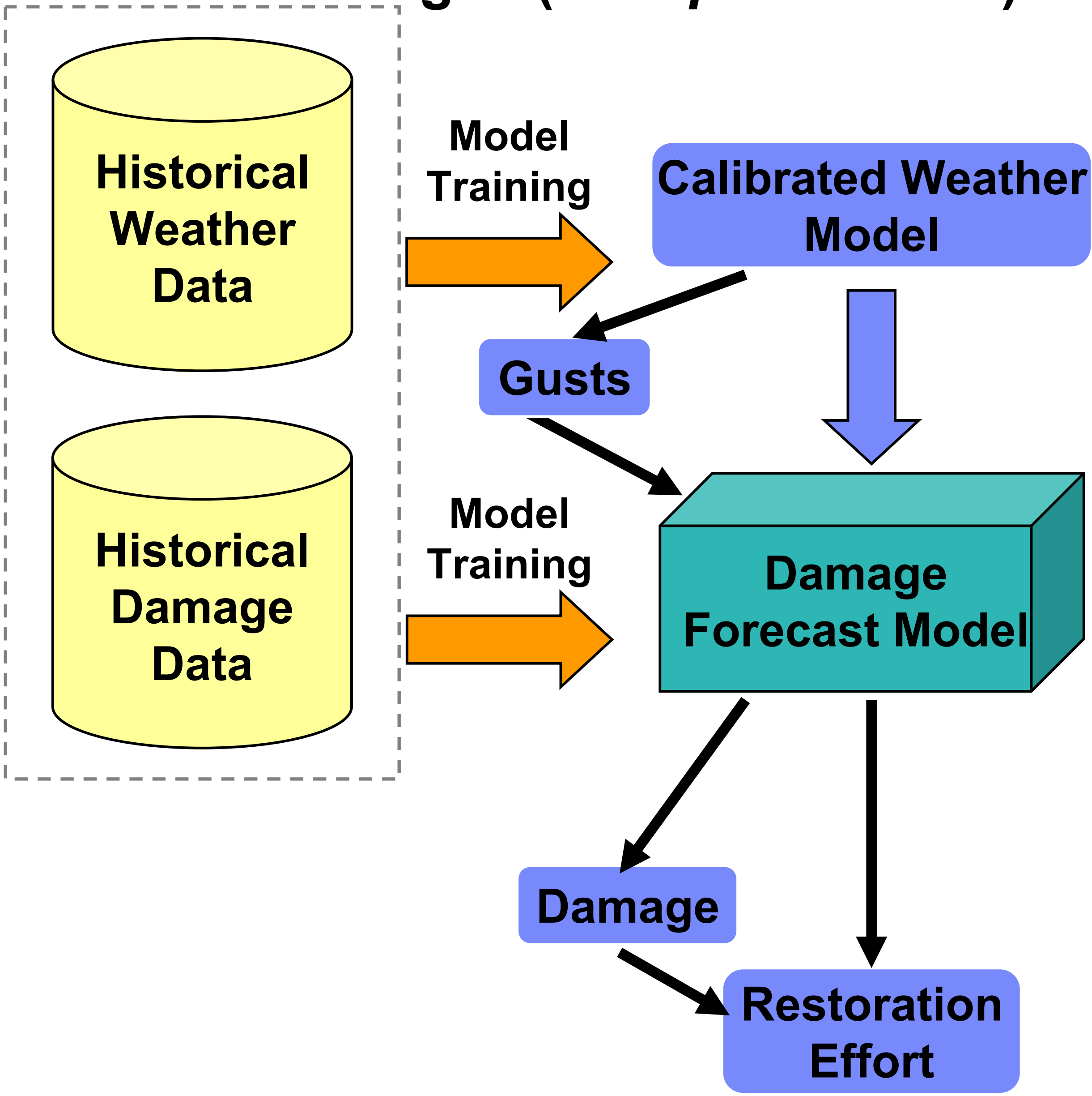
Orange and Rockland

- 300,000 electric customers
- 127,000 gas customers

Coupled Weather and Impact Modelling

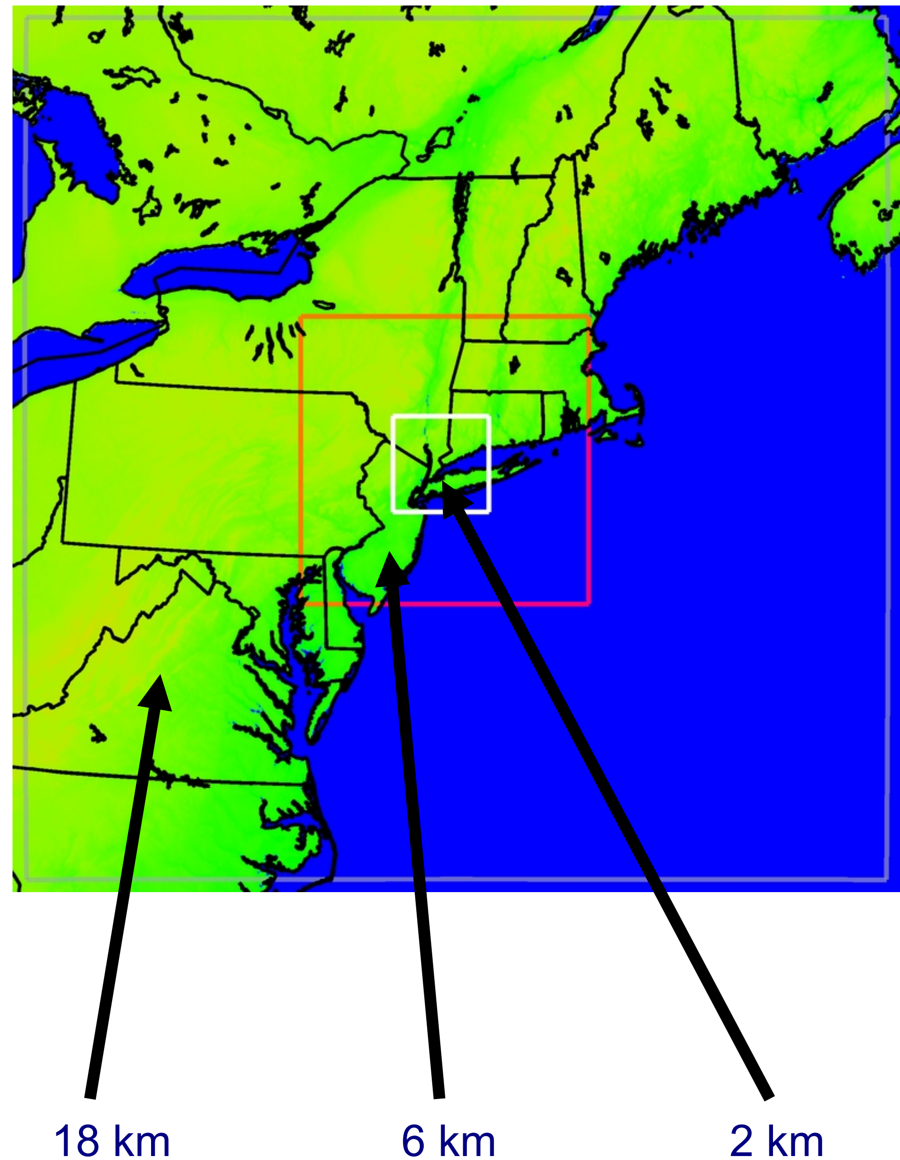
Custom Modelling for Predictions of Outages (“*Deep Thunder*”)

- Weather causes damage
- Damage requires restoration (resources)
- Restoration takes time, people, etc.
- Build predictive model from environmental observations, storm impact and related data
  - Damage location, timing and response
  - Wind, rain, lightning and duration
  - Demographics of effected area
  - Infrastructure impacted in effected area
  - Ancillary environmental conditions



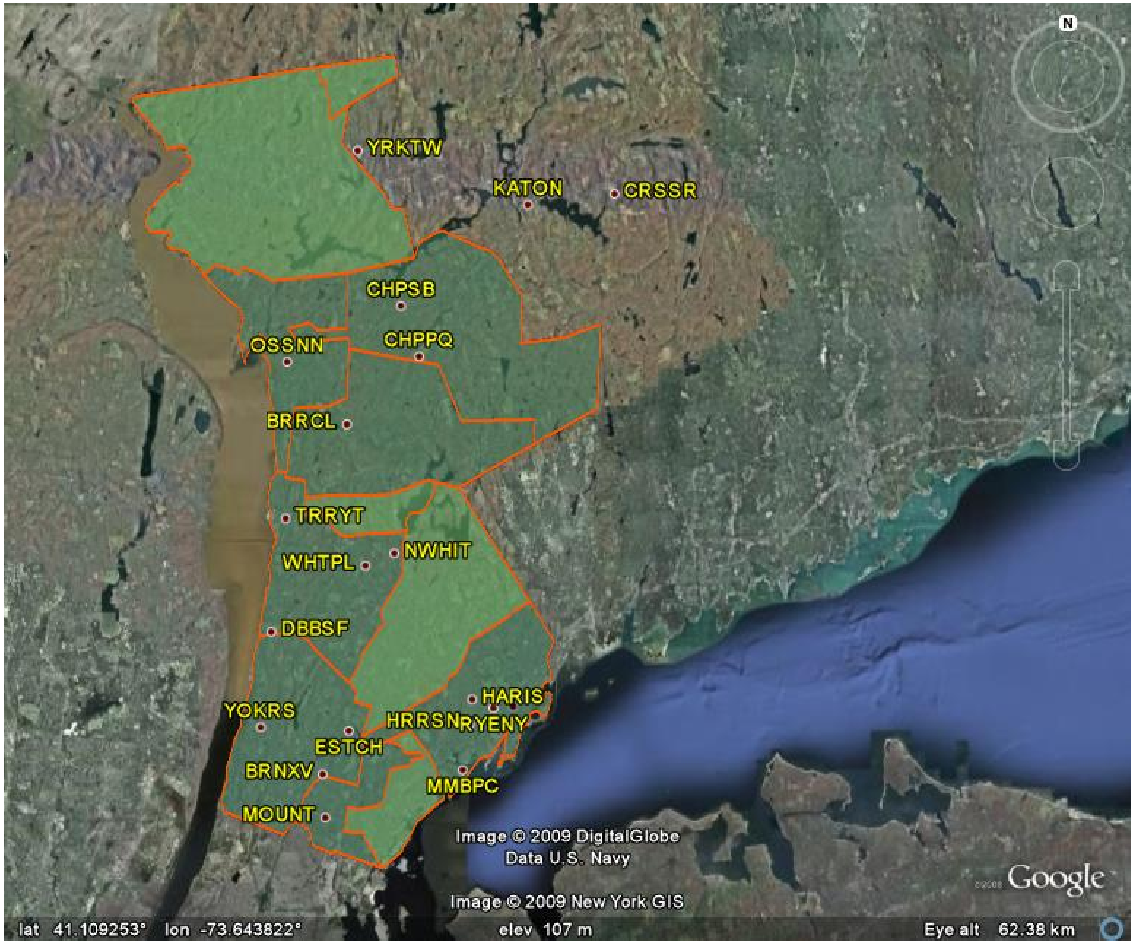
Weather and Damage Model Configuration

- **Modelling**
  - Utilize WRF-ARW (v3.1.1) to enable effective forecasts with up to 72 hours lead time
    - 18/6/2 km nested (76x76x42) with 2 km resolution across entire extended service area for 84 hours
    - Run twice daily (0 and 12 UTC)
    - NAM for background and boundary conditions
    - WSM 6-class microphysics, YSU PBL, NOAH LSM, Grell-Devenyi ensemble, urban canopy model
  - Outages: spatial-temporal modelling to enable predictions of damage
- **Dissemination**
  - Tailored weather visualizations available via a web browser, which are automatically updated for each forecast cycle
  - Gust and outage estimation
  - Uncertainty visualization for operational decision making
  - E-mail alerting system



Weather and Damage Model Configuration

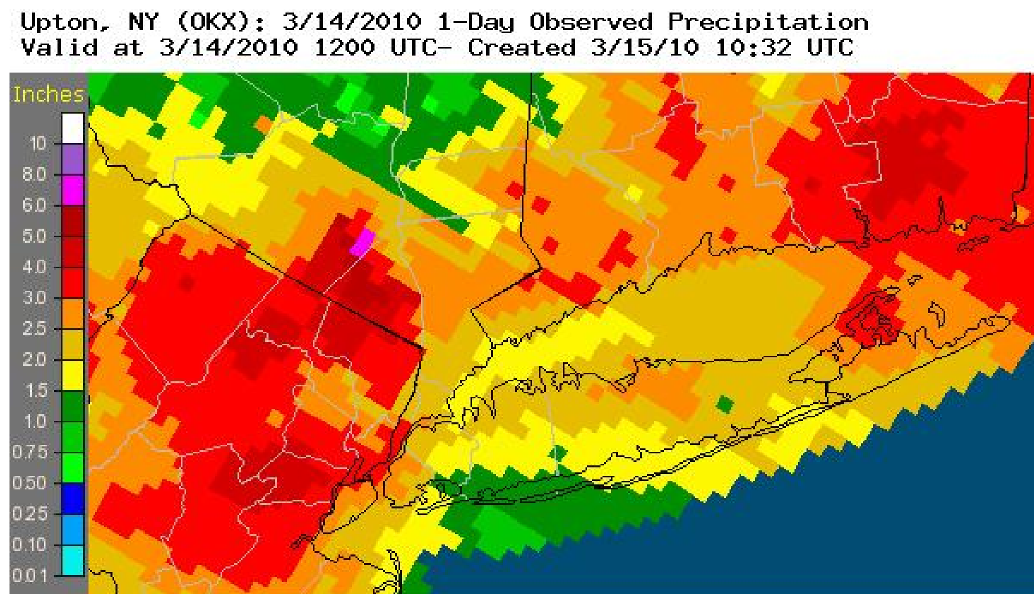
- Post-processor for weather data
  - "Predictive mode" operates on WRF output and generates daily gust maximums
  - "Probable mode" operates on near-real-time WeatherBug data (i.e., nowcasting)
- Produces estimate of number of jobs per substation
- E-mail alert system, triggered by total number of jobs with 75% confidence
- Trained and calibrated with historical weather and outage data
- Uncertainty quantification
  - Multiple sources (not just meteorological)



Location of Consolidated Edison Westchester County Substation Areas and AWS/WeatherBug Stations

Example Event: 13 March 2010 Rain and Wind Storm (NYC)

- **Coastal storm with strong winds and heavy rains**
- **Gusting between 40 and 75 mph observed in the afternoon and evening**
- **Innumerable downed trees and power lines**
- **Local flooding and evacuations**
- **Electricity service lost to over 600,000 residences and businesses in the New York City metropolitan area**
- **Widespread disruption of transportation systems (e.g., road and bridge closures, airport and rail delays)**
- **Other forecasts during the late morning on 11 March: “rain may be heavy at times, east winds 20 to 25 mph with gusts up to 40 mph”**
- **Wind advisories issued (gusts to 45-50 mph) at 1619 EST, 12 March**
- **High wind warnings issued (gusts to 55-60 mph) at 1343 EST, 13 March**

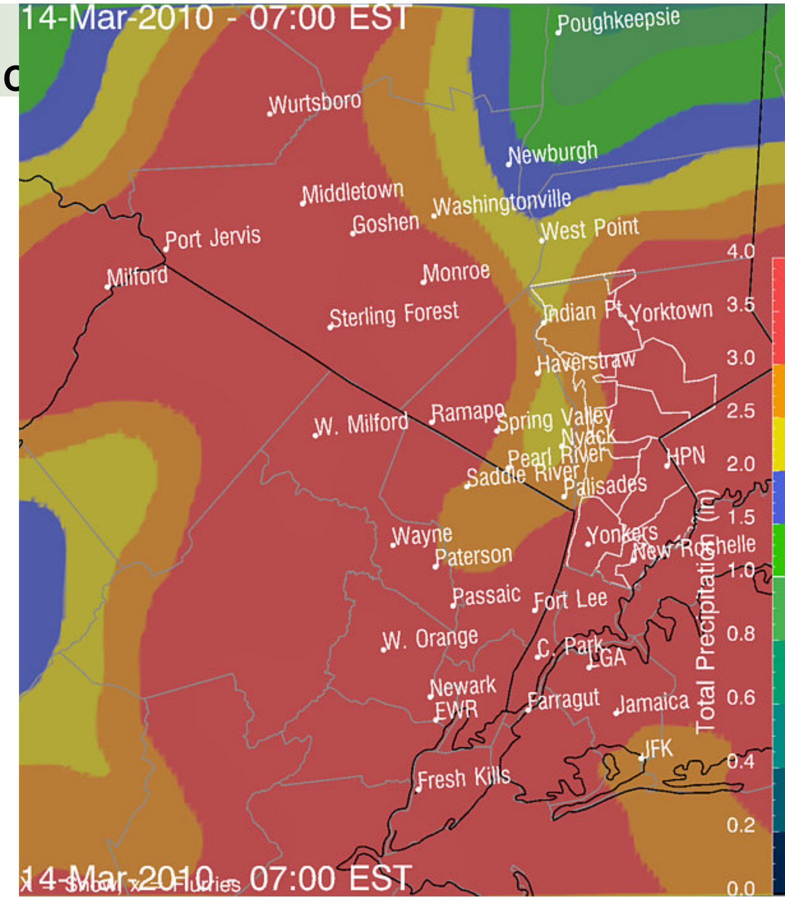


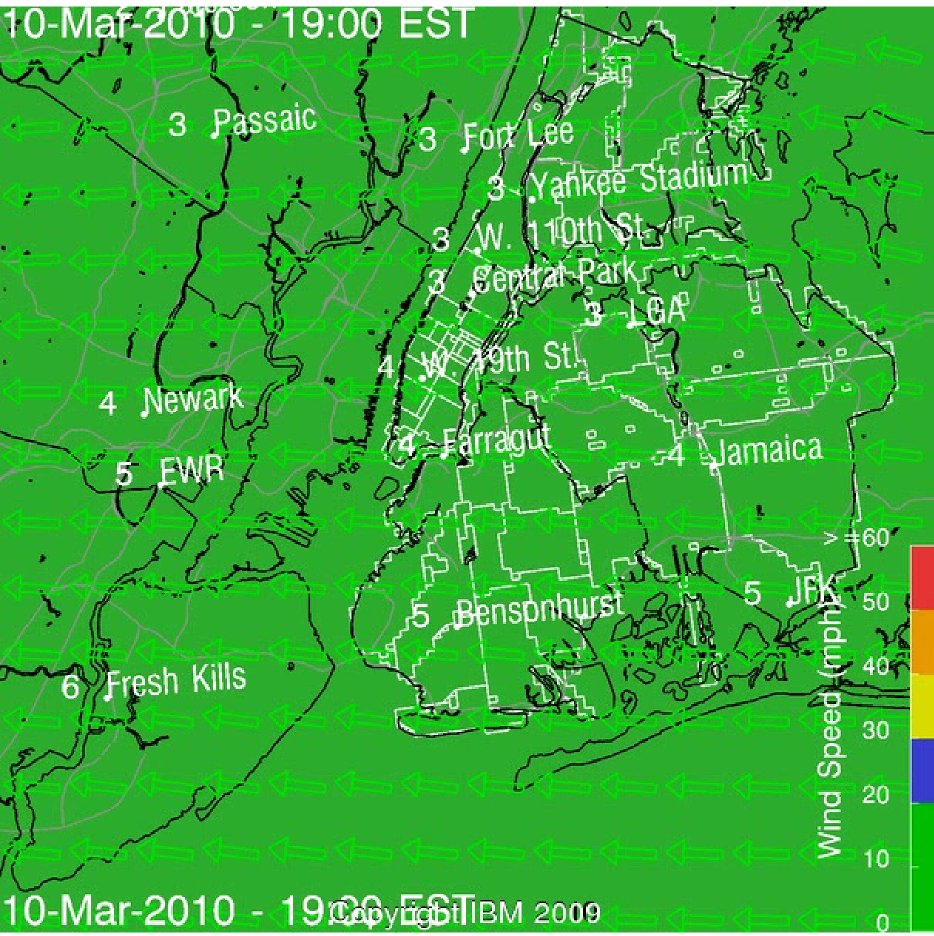
13 March 2010 Nor'easter

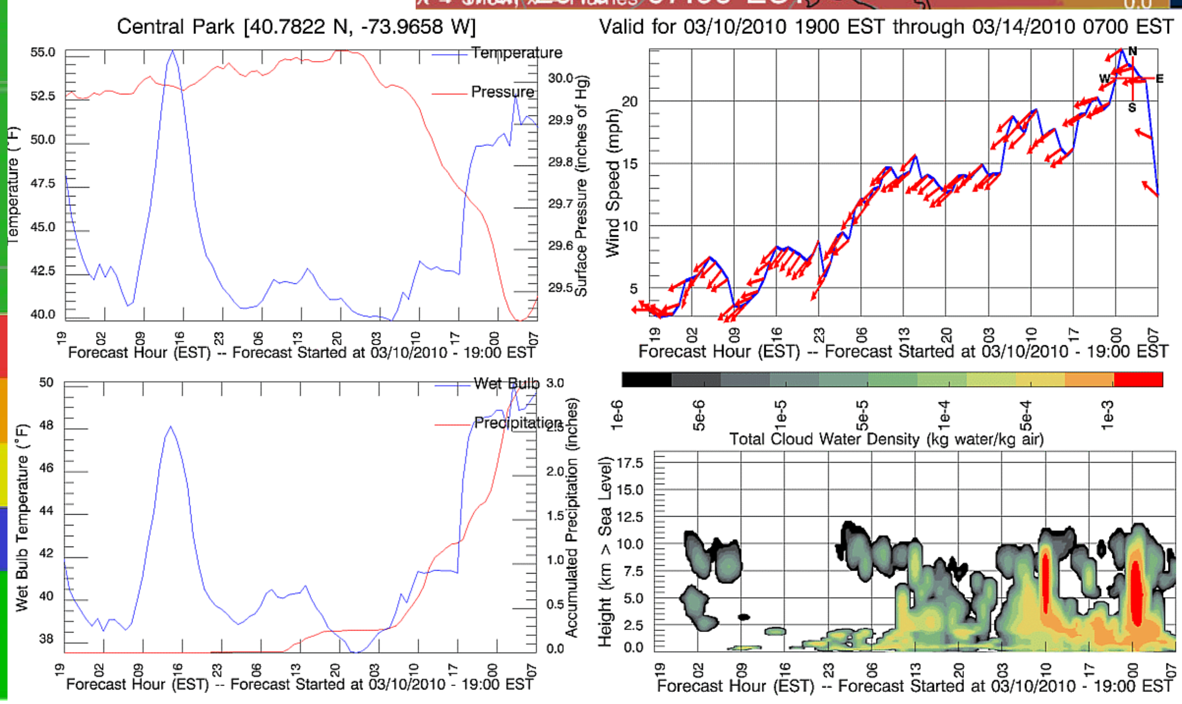
Deep Thunder Weather Forecast

Initiated with data from 00 UTC 11 March
with results available ~08 UTC

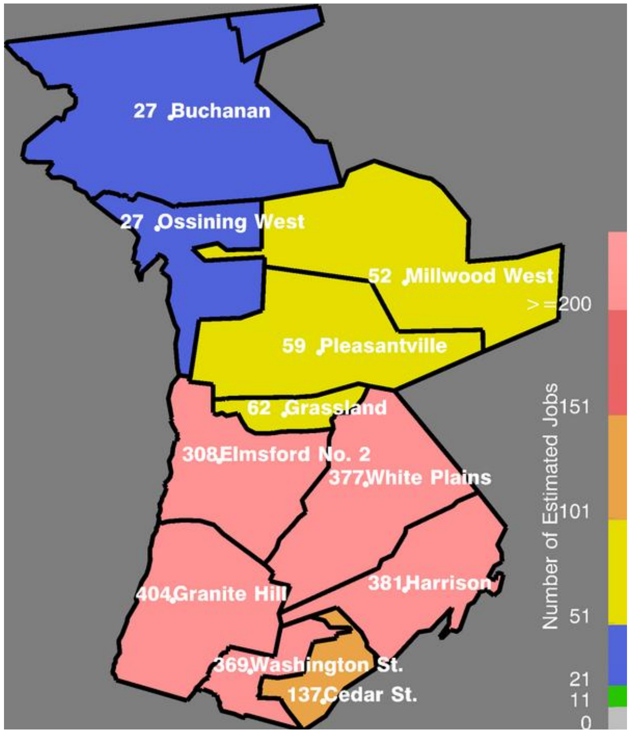
High winds shown in forecast available more than two days before the event and 37 hours before the National Weather Service advisory





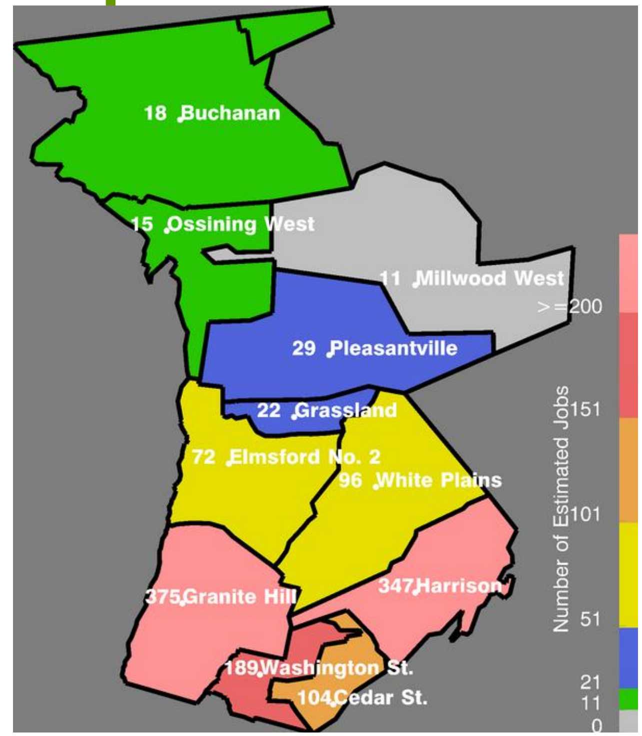


13 March 2010 Nor'easter Deep Thunder Impact Forecast



Actual Outages per Substation (Repair Jobs)

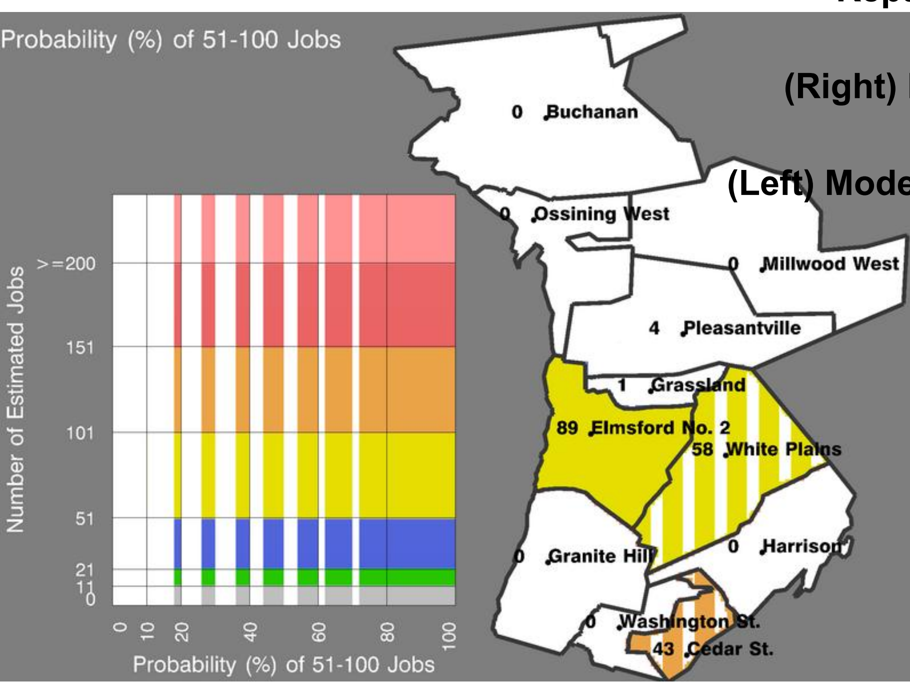
Estimated Outages per Substation (Repair Jobs)

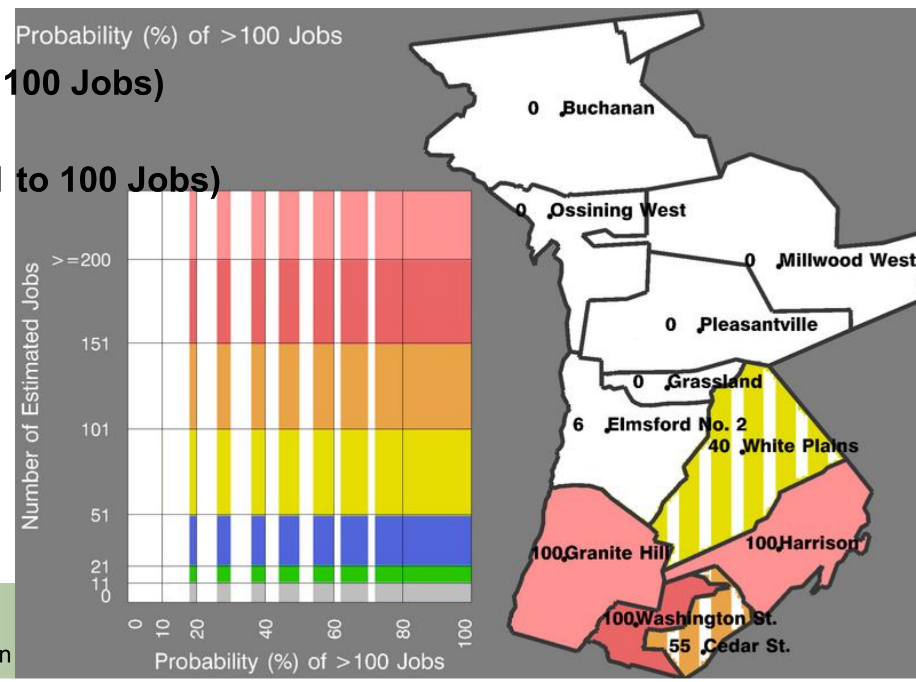


Likelihood (Probability) of a Range of Repair Jobs per Substation

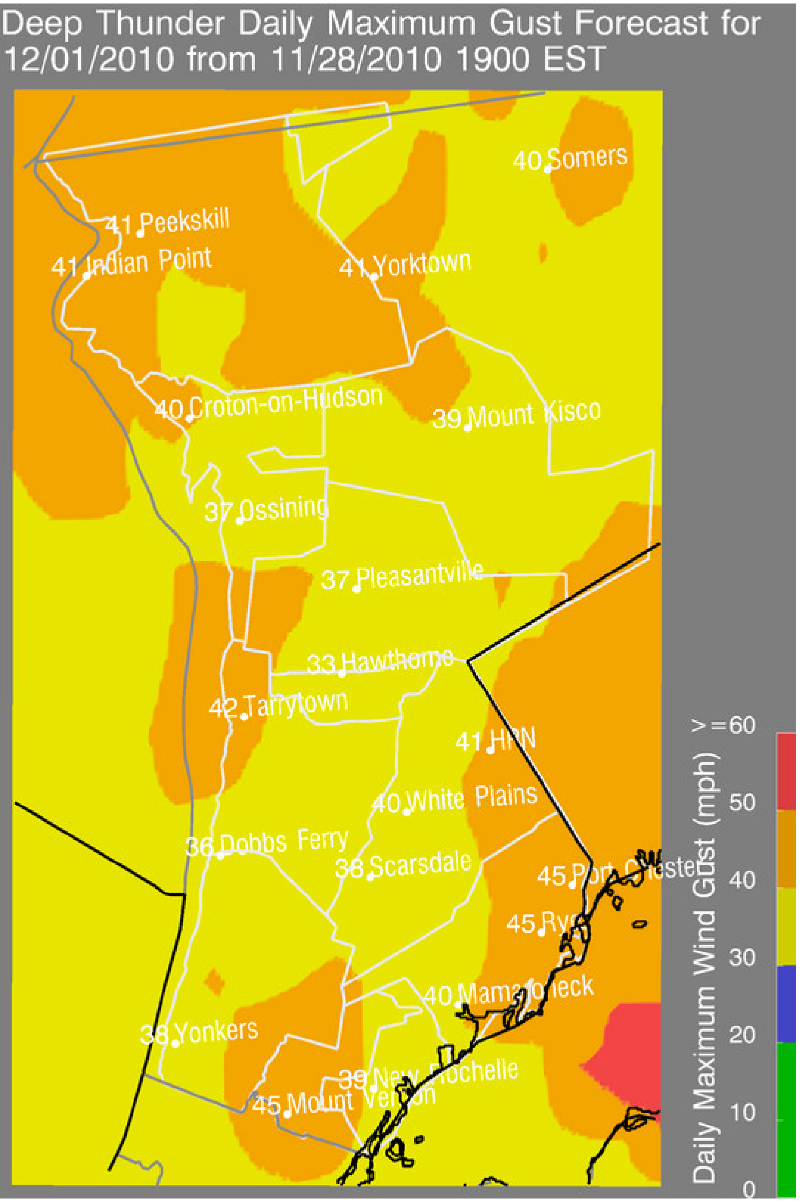
(Right) High Severity (> 100 Jobs)

(Left) Moderate Severity (51 to 100 Jobs)



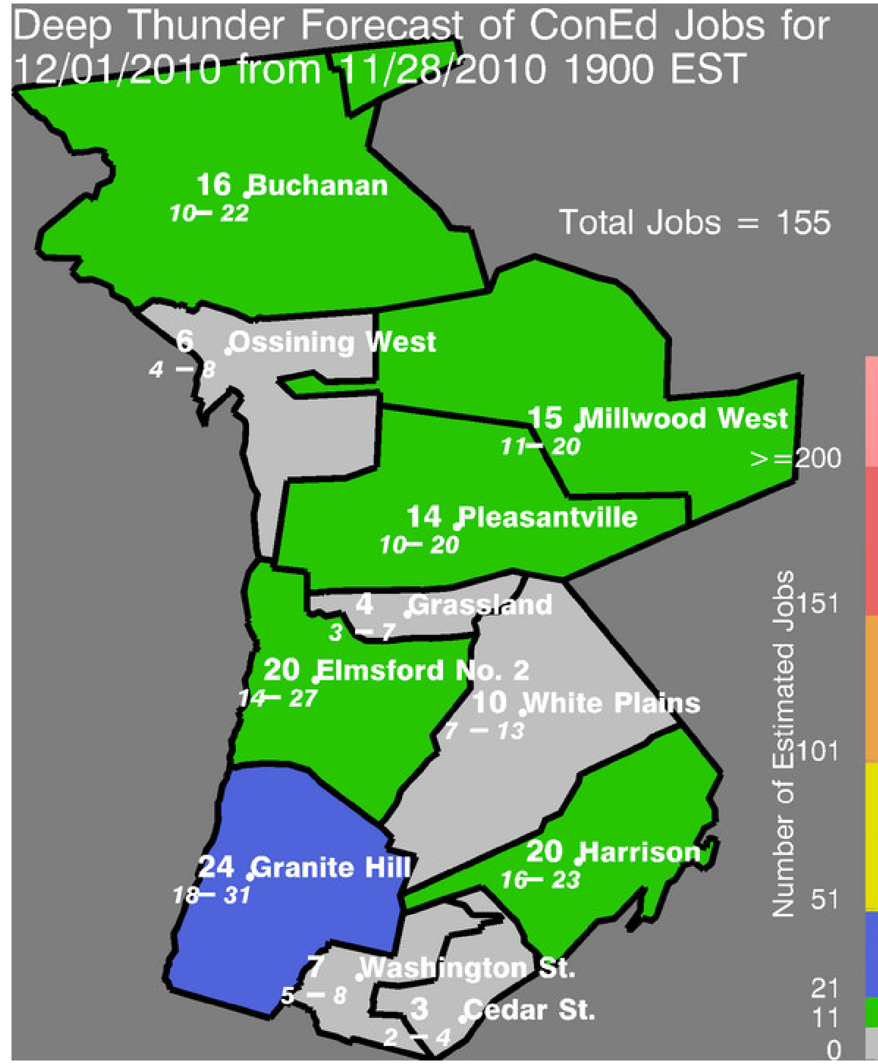


1 December 2010 Deep Thunder Impact Forecast



Estimated Daily Wind Gust Speed Maximum

Initiated with data from 00 UTC 29 November with results available ~08 UTC



Estimated Outages per Substation (Repair Jobs)

Forecast Verification

- **Meteorological metrics**
  - How should the model results be evaluated?
- **Business metrics**
  - What is the value of the forecast information, even with meteorological errors?
  - Identification of what is “good enough” for decision making
- **Initial focus is on evaluation of the weather model**
  - Utilize Model Evaluation Tools (MET V3) and WeatherBug data
- **Methods to evaluate probabilistic outage model under consideration**

Quality of Deep Thunder Forecasts

- Westchester County: April 2009 to March 2010 with April 2010 to December 2010 to be completed shortly
- Deep Thunder, NOAA North American Model (NAM), 2 private services, 2 public services
- Parameters
  - Forecast vs. actual
  - Temperature, wind, precipitation
  - RMSE, MAE, bias, contingency table

	Observe Rain Yes	Observe Rain No
Forecast Rain Yes	HIT	FALSE ALARM
Forecast Rain No	MISS	CORRECT NEGATIVE

Methodology - Forecast Score (FS)

- **Maximum Score is 100**
- **Component Scores**

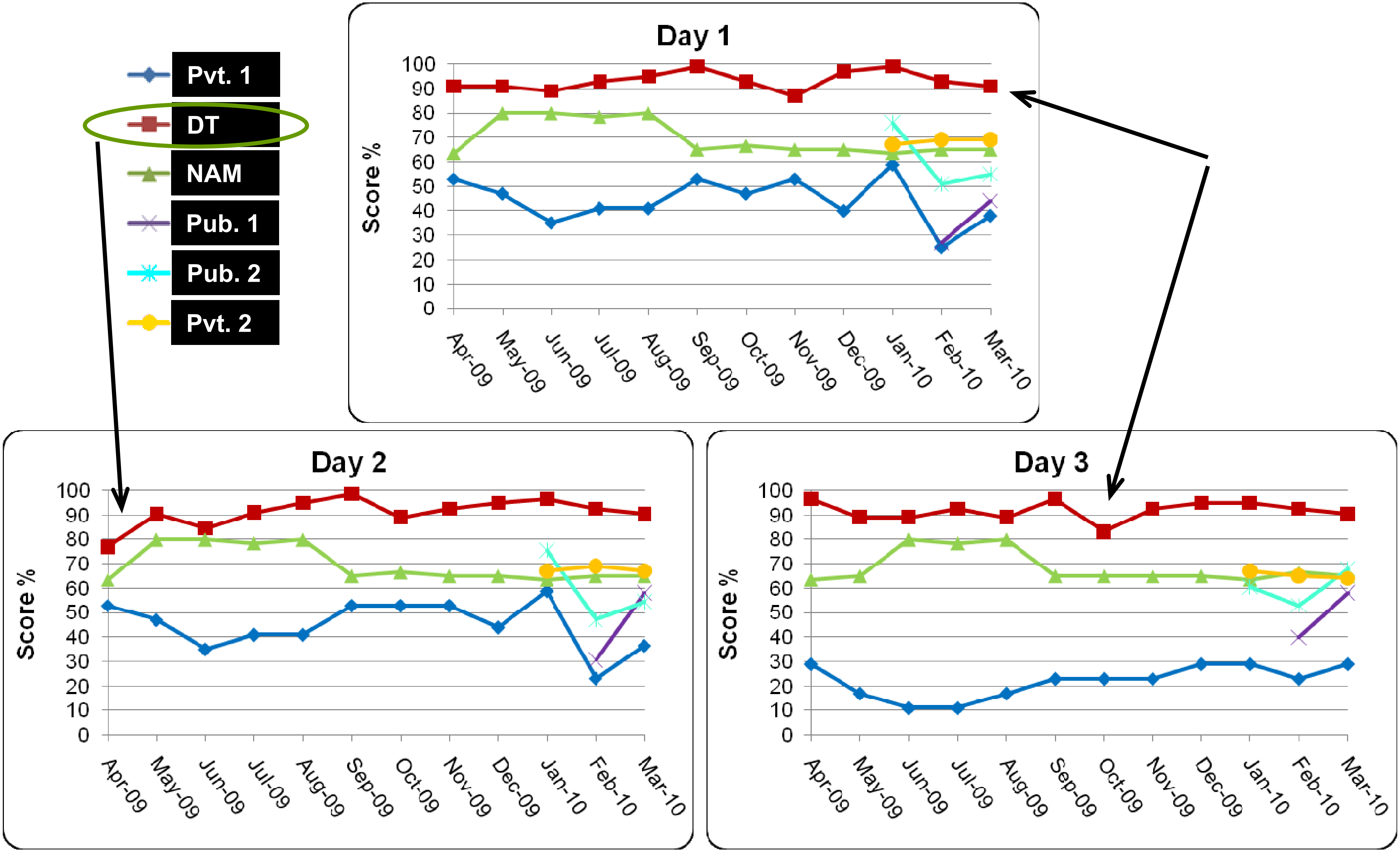
Temperature (°F)	
Error (TE) Bias (TB)	Points
0 to 2	10
2 to 4	7
4 to 6	3
>6	0

Wind (mph)	
Error (WE) Bias (WB)	Points
0 to 5	10
5 to 10	7
>10	3

Precipitation (%)	
% Correct (PC)	Points
90-100	10
80-90	8
70-80	6
60-70	4
50-60	2
<50	0

$$FS = [(TE + TB)(0.5)] + [(WE + WB)(3)] + [(PC)(3)]$$

Performance Forecast Score



Discussion

- **We enabled an operational capability useful for overhead distribution network emergency management**
- **Yet, there are many on-going challenges…**

On-Going Challenges

- **Quality of weather observations**
  - –Relatively dense network of surface stations from WeatherBug
  - –Reporting inconsistent from WeatherBug network
  - –Lack of availability of upper air data at the appropriate scale
- **Quality of outage (job ticket) data**
  - –Must rely on field crews and service representatives
  - –Need to filter storm-related damage
- **Inconsistent skill for localized, convective events for weather model**
- **Impact model**
  - –Determining appropriate inputs (e.g., gusts, soil moisture, foliage, etc.) and their relative correlation
  - –Incorporation of “Black Swan” events
  - –Insufficient events to adequately evaluate
- **Utilization**
  - –Need to build trust with diverse users
  - –Deliver complex information succinctly (e.g., visualization of probabilistic data)
  - –Must be integrated with utility company procedures

Summary

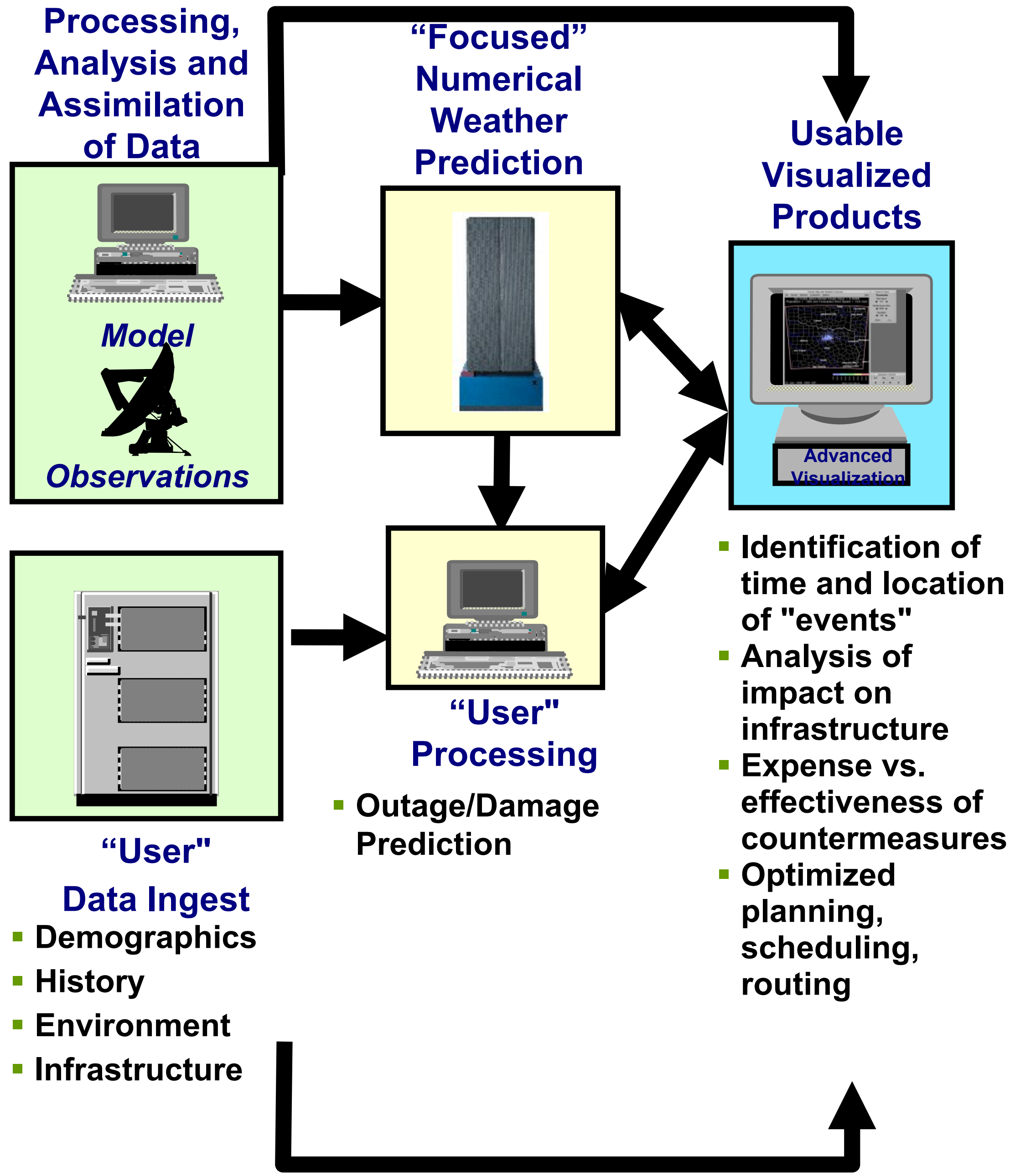
- Enabled an operational capability
- Collaborative and diverse team critical to success
- 84-hour weather model disseminated operationally
  - Updates every twelve hours
  - Full service territory and control center views of weather forecasts
  - Better results compared to other sources
- Sophisticated outage model shown to be feasible
  - Assuming calibration, can be coupled to different sources of weather data
  - Ability to incorporate all sources of uncertainty in damage estimates
  - Daily outage estimate per day (three) of model output for Westchester County
- Continue to improve calibration of weather and outage models, and characterization of uncertainties
  - Operational statistics for evaluation
  - Retrospective analysis and tuning using new events that have impact
- Deploying real-time outage estimate using WeatherBug data
- Developing additional specialized visualizations and methods of dissemination
- Coupling the weather prediction to business impact forecasts is operationally viable, yet challenges remain

Backup

Slides

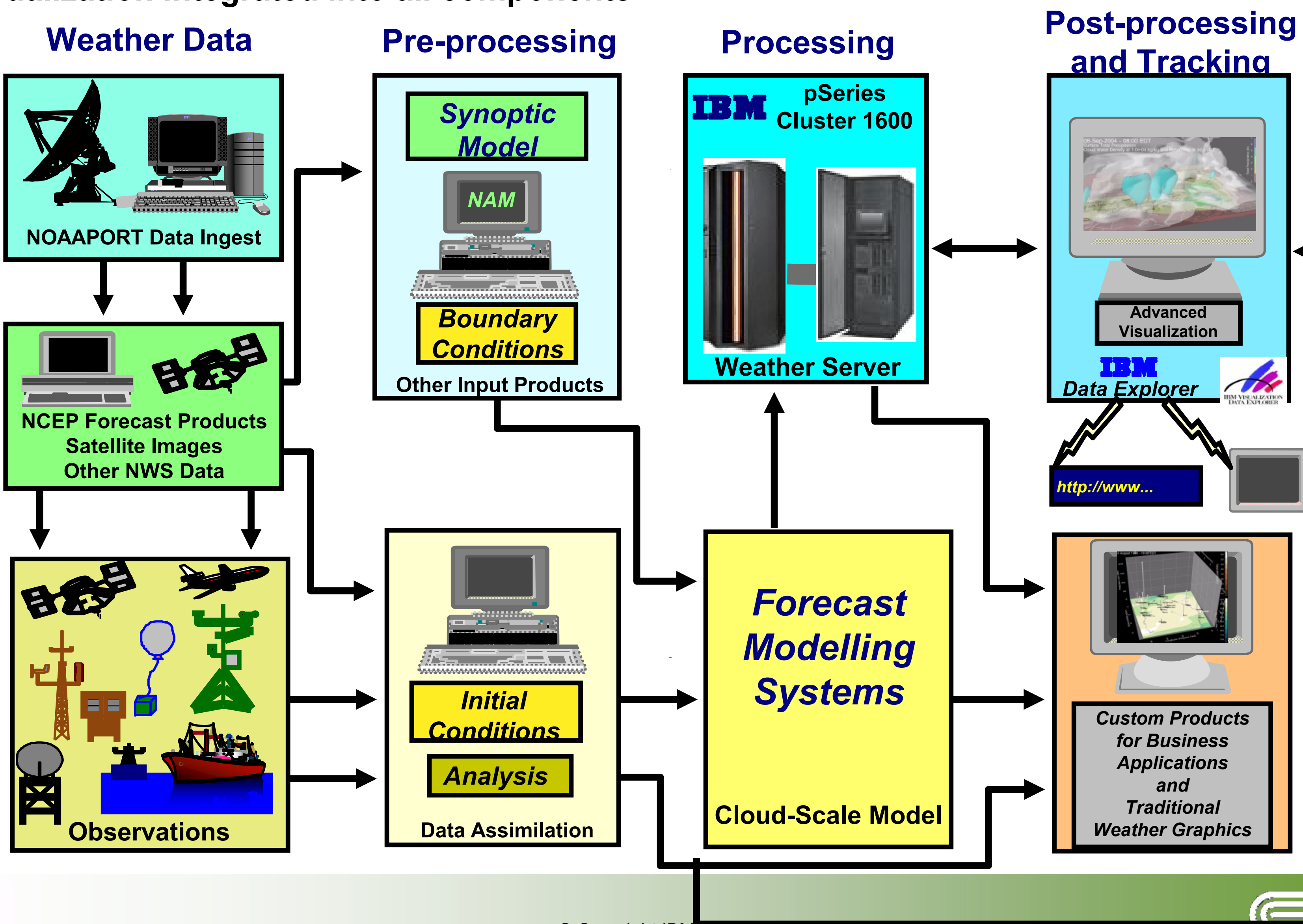
Challenges of Coupling NWP to the Decision Making Process

- **Damage forecast model inputs**
  - Which weather data really matter (avoid multicollinearity)?
  - For example, gust speed has a stronger relationship to damages vs. wind speed
- **Weather forecast calibration**
  - Forecasted variables (e.g., wind speed) may differ in meaning vs. observations used in the damage-forecast-model training
  - How should physical model outputs be calibrated so that they can be used as the inputs of damage forecast model?
- **How should damage forecasts, multiple spatial resolution interpolations and calibration be integrated in one framework?**

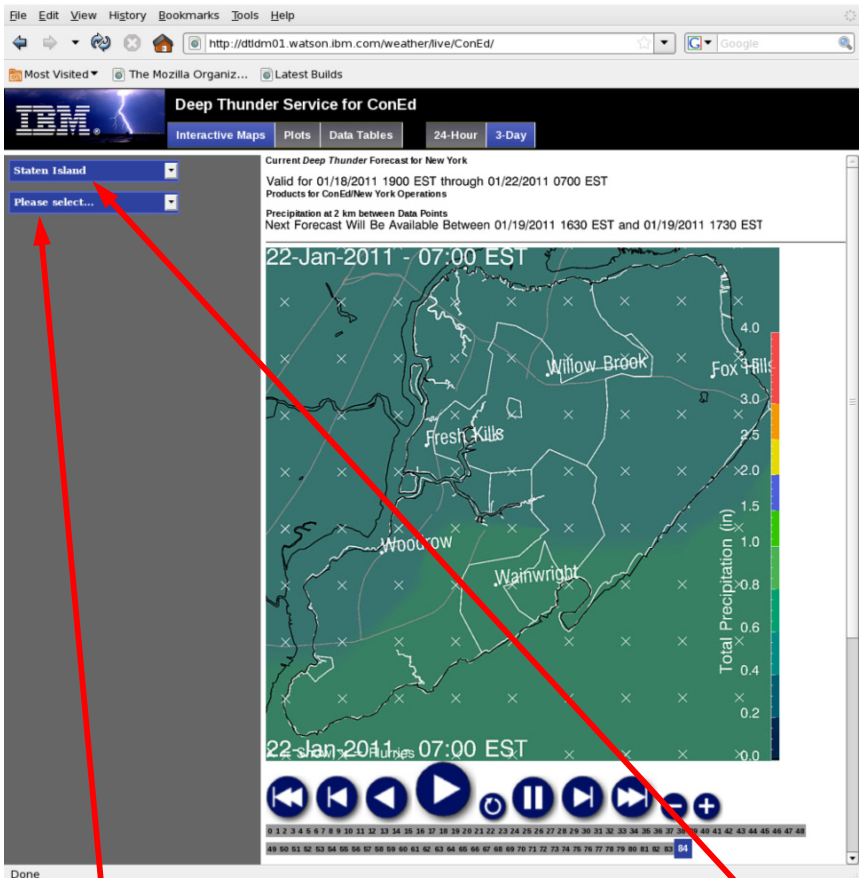


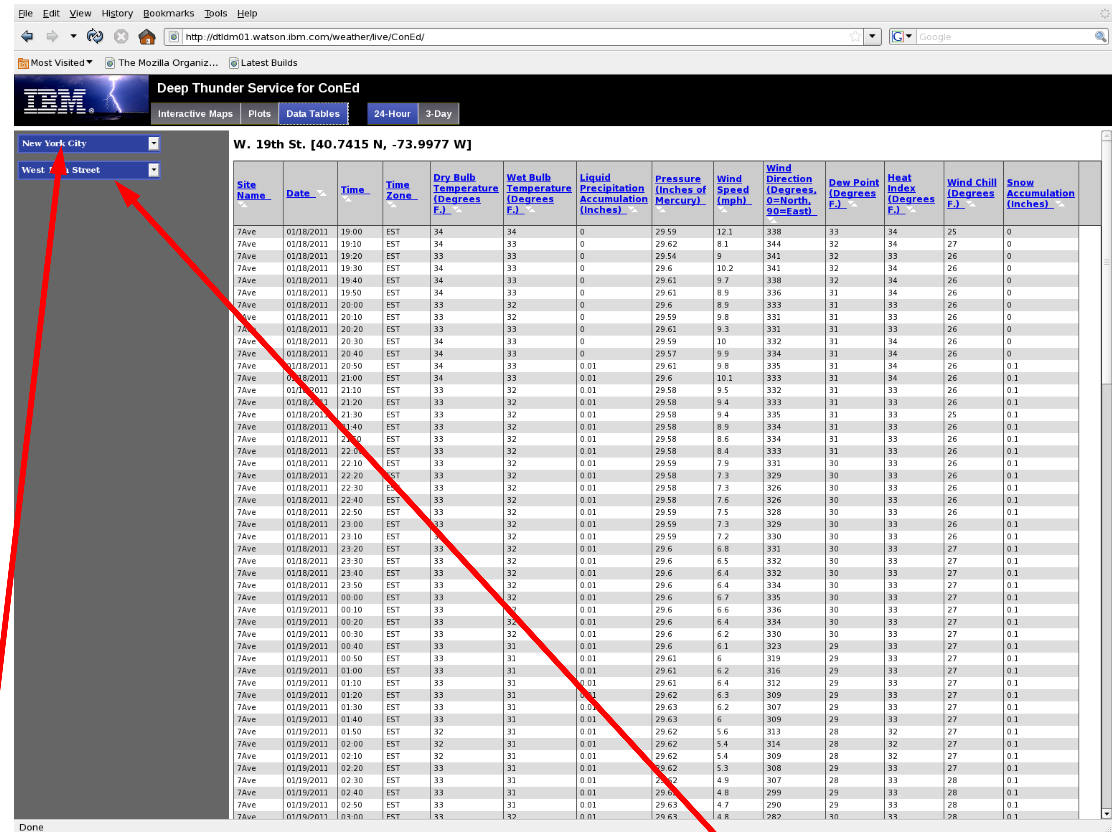
Deep Thunder Implementation and Architecture

- User-driven not data-driven (start with user needs and work backwards)
- Sufficiently fast (>10x real-time), robust, reliable and affordable
- Ability to provide usable products in a timely manner
- Visualization integrated into all components



Web Interface for Consolidated Edison





Temperature Animation

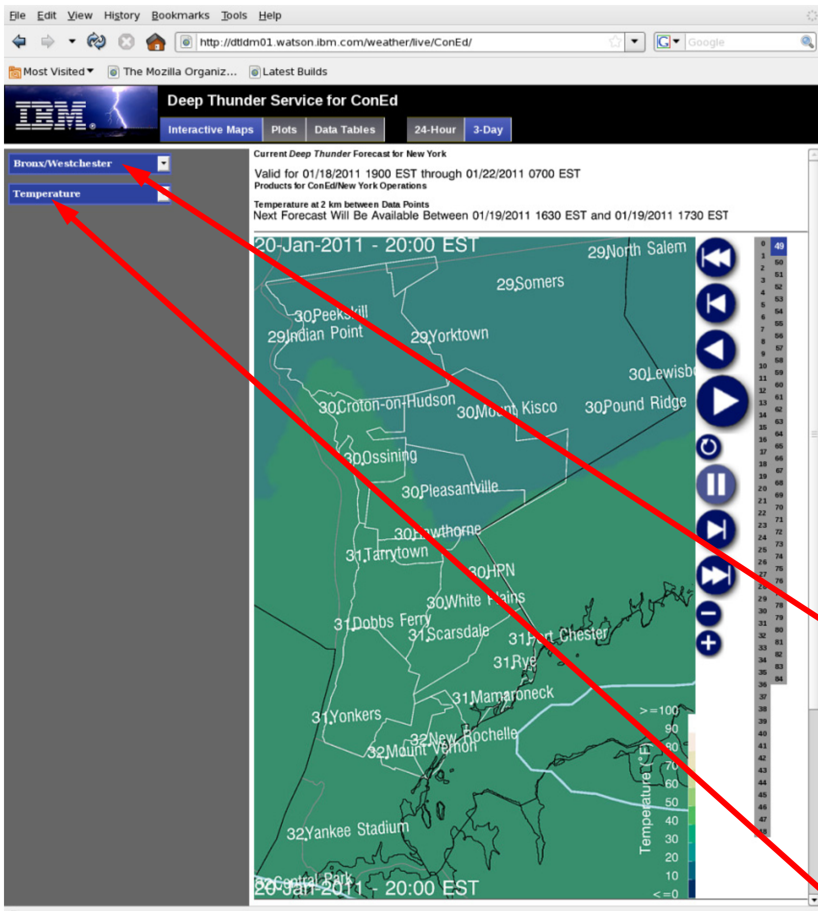
Interactive Site-Specific Forecast Table

Selection of Geographic Area (7 Choices)

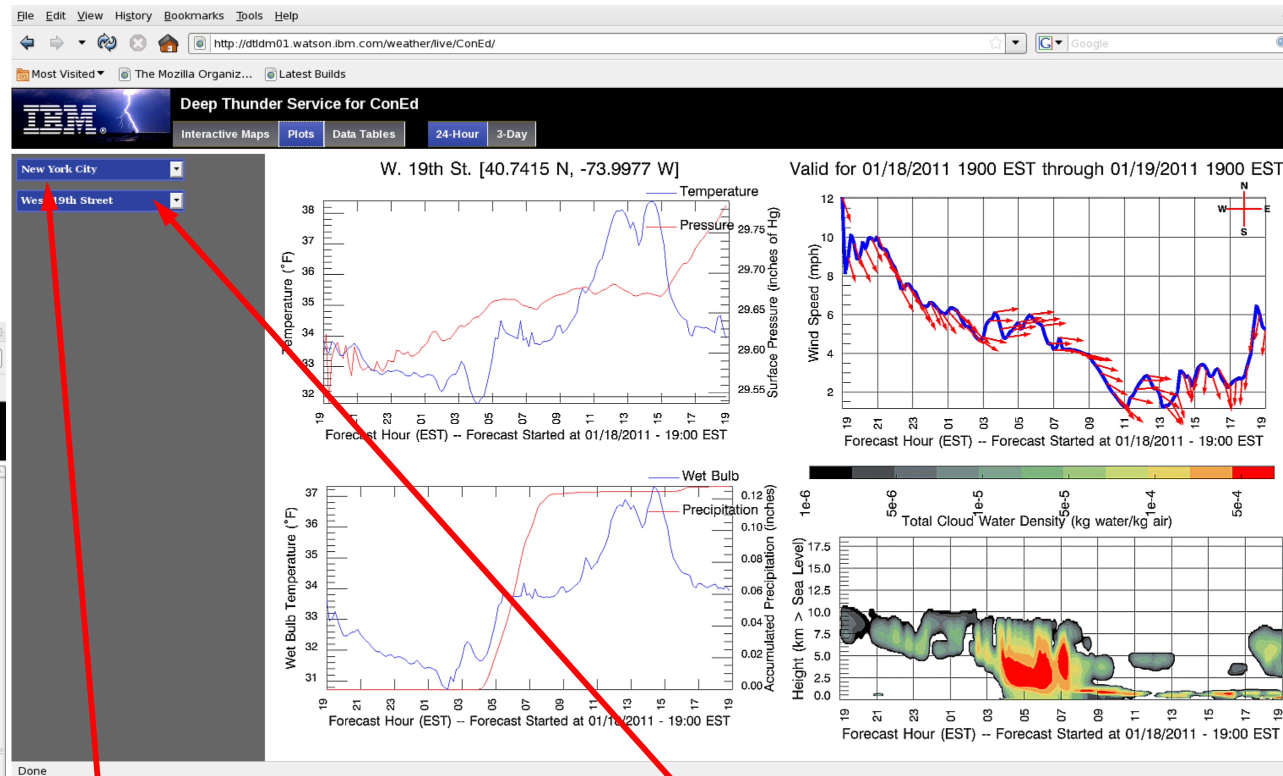
Site Selection

Selection of Animation Variable (Dry Bulb, Wet Bulb, Precipitation, Wind)

Web Interface for Consolidated Edison



Surface Temperature Animation



Site-Specific Forecast Plots

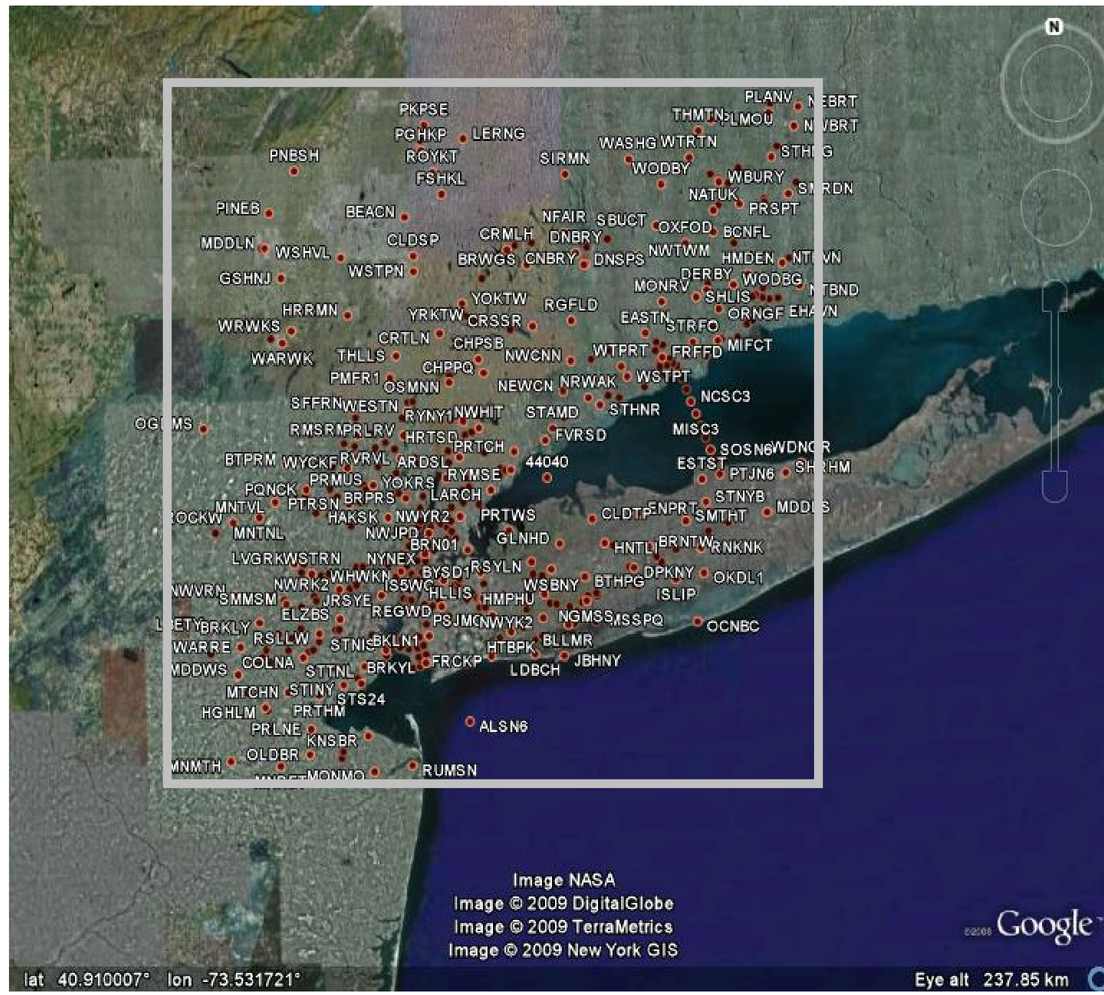
Selection of Geographic Area (7 Choices)

Site Selection

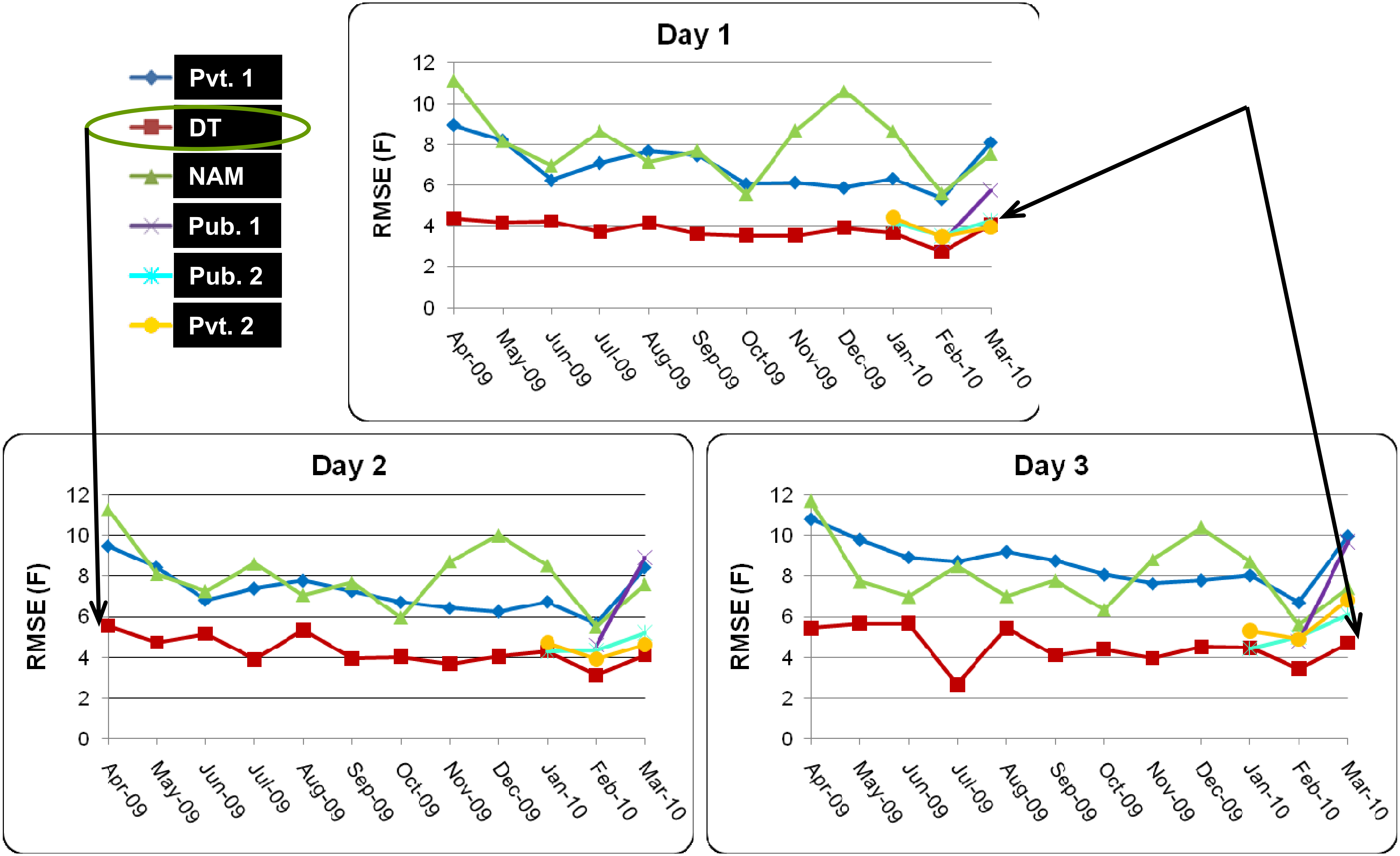
Selection of Animation Variable (Dry Bulb, Wet Bulb, Precipitation, Wind, Gust and Outage Jobs)

AWS/WeatherBug Surface Observations

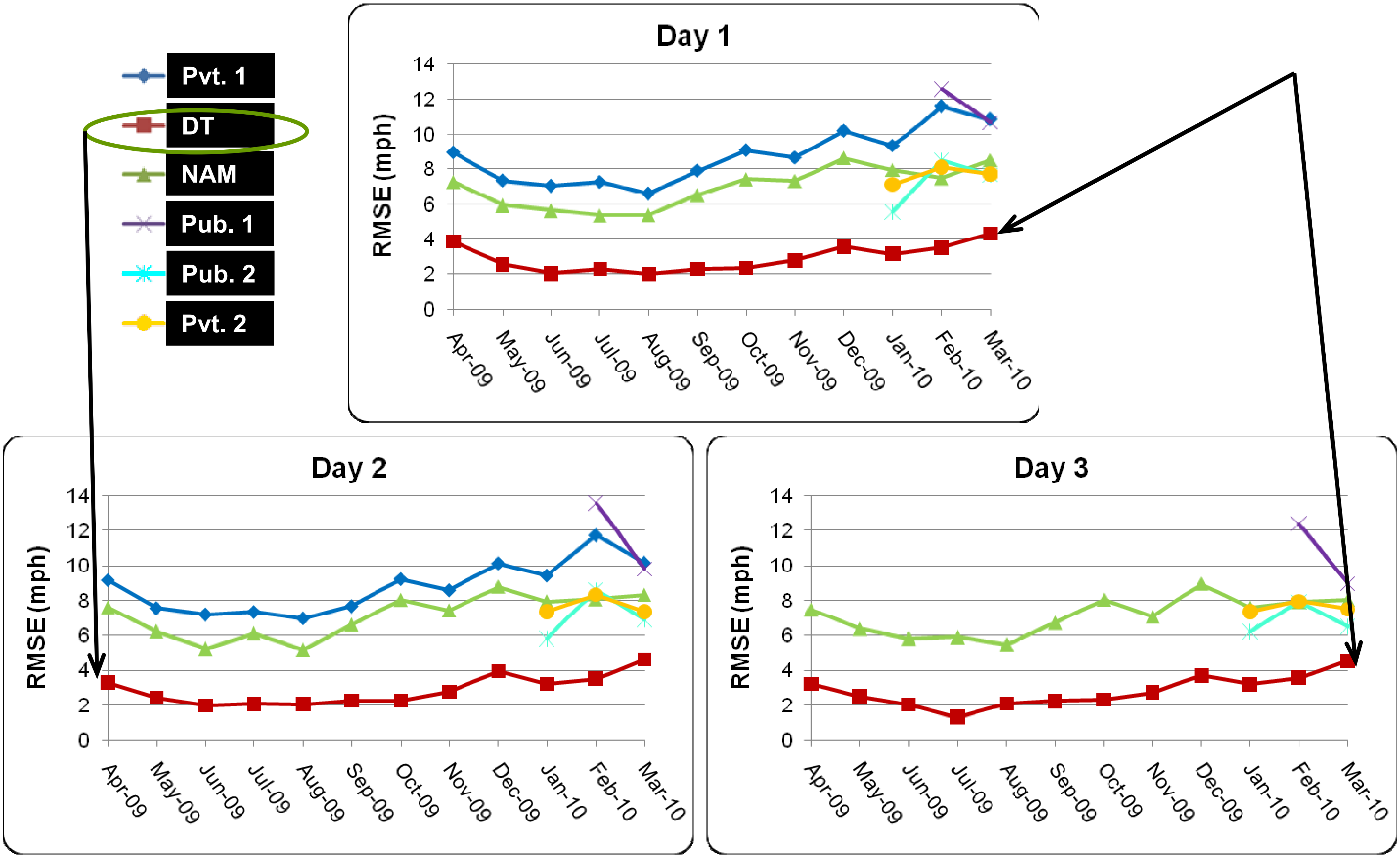
- **More than 400 stations in model domain that covers extended ConEd service territory – close sampling to model resolution**
- **Primary data used include temperature, relative humidity, wind speed and direction, rainfall**
- **Real-time data used for damage assessment during severe weather**
- **Improve model initialization via data assimilation in near-real time**
- **Historical data used for retrospective analysis, forecast verification and tuning**
- **Data also used to calibrate model and other sensor data**



Validation: Monthly Temperature RMSE



Validation: Monthly Wind RMSE



Validation: Monthly Precipitation Error