Development and Deployment of a Mesoscale Weather and Outage Prediction Service for Electric Utility Operations

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- **Background and motivation**
- **Approach**
- **Example results**
- **Discussion and future work**

Other Presentations of Related Work

- **P1.7 *A Spatial Model for the Prediction of Electrical Power Outages Caused by Severe Storms* (Symposium on Urban High Impact Weather)**
- **4.1 *Design and Deployment of Specialized Visualizations for Weather-Sensitive Electric Distribution Operations* (Fourth Symposium on Policy and Socio-Economic Research)**
- **12B.2 *Estimating high-resolution near-surface forecast uncertainty to support optimization of resources* (13th Conference on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface)**
- **JP5.4 *Application of an operational meso-scale modelling system for commercial/industrial plant operations* (Eighth Symposium on the Urban Environment Symposium)**
- **P1.3 *Urban Flood Forecasting using an Integrated Hydrometeorological System* (Urban High Impact Weather Urban Flood Forecasting)**

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 and temporal precision, and lead time
  - Can highly localized, NWP-based forecasts (e.g., IBM Research "Deep Thunder") be adapted to address these problems and reduce the uncertainty in decision making?

Storm Impact and Response Prediction

- **Weather causes damage and outages**
- **Outages require restoration (resources)**
- **Restoration takes time, people, etc.**
- **Build stochastic model from weather observations, storm damage and related data**
  - –**Outage location, timing and response**
  - –**Wind, rain, lightning and duration**
  - –**Demographics of effected area**
  - –**Ancillary environmental conditions**
- **Can this model be coupled to NWP results to enable a forecast of impact and response?**

Weather prediction

↓

Damage prediction

↓

Resource requirement prediction

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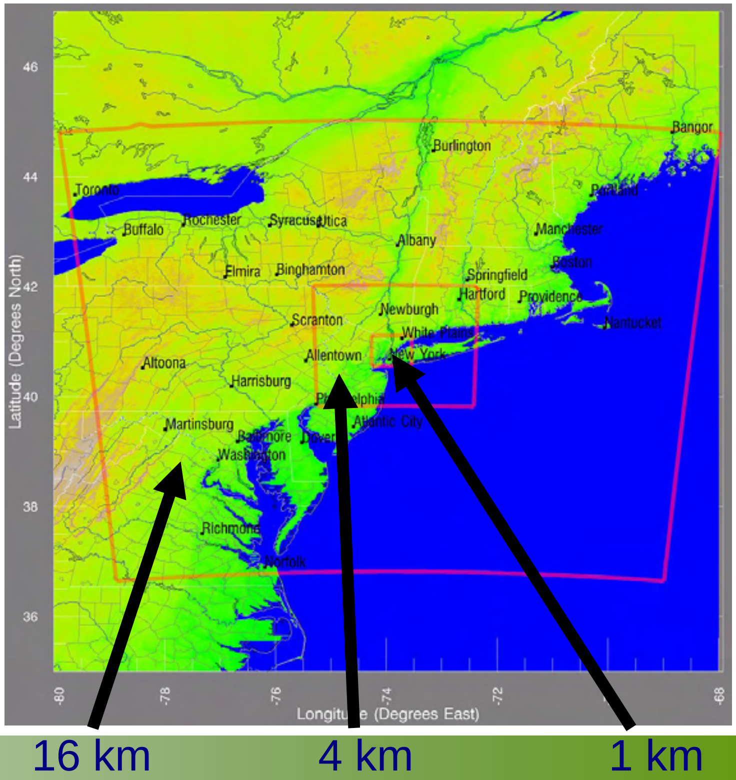
Restoration time prediction

Background and Motivation

- **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
- **Can such capabilities be implement as a service tailored to the requirements of the utility company?**
- **Can the service predict conditions at the area substation level that can lead to outages and their characteristics, thus allowing the utility to proactively plan repairs?**

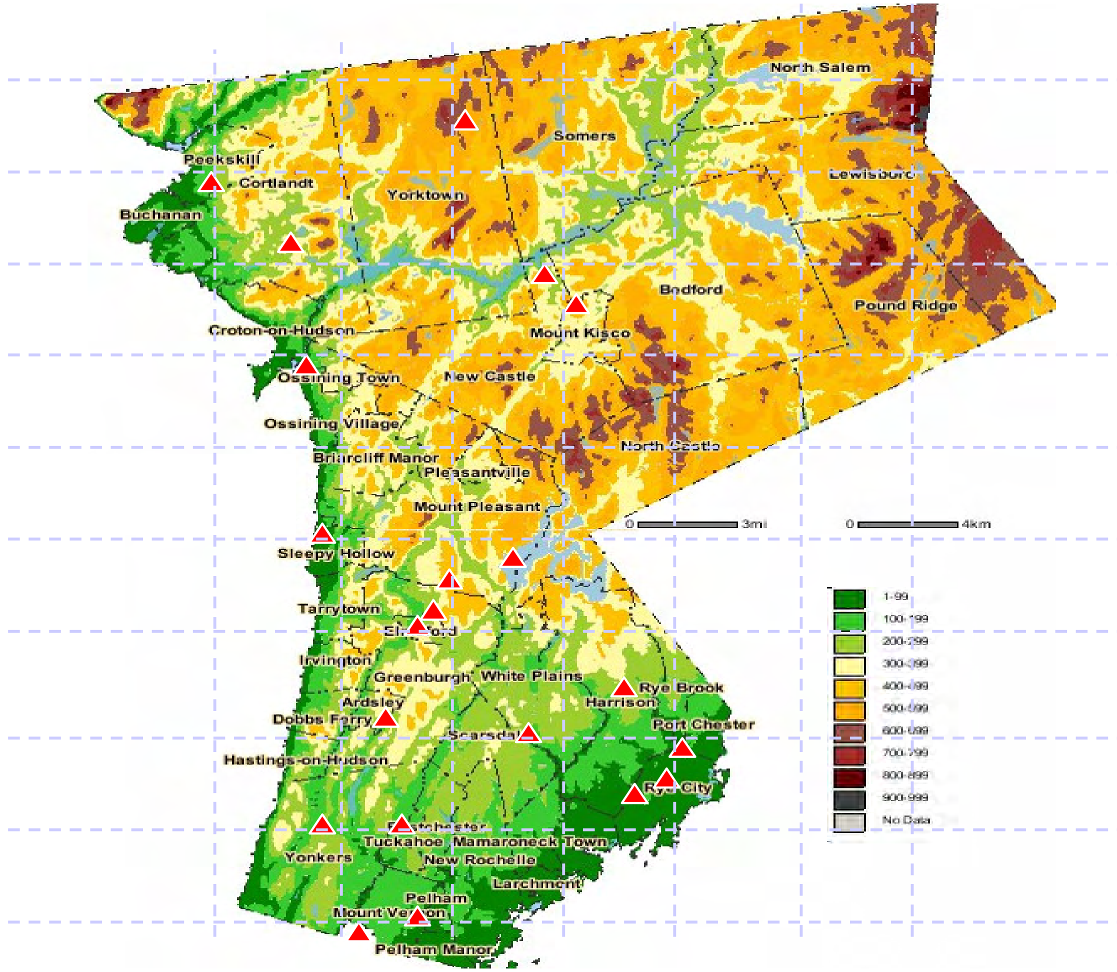
Initial Approach

- **Build on extant "Deep Thunder" capability**
  - Triply nested (62x62x35) at 16, 4 and 1 km (36, 9, 2.25 sec.) for 24 hours
  - Modelling code derived from highly modified version of non-hydrostatic RAMS
  - Explicit, full cloud microphysics (5 species)
  - Typically, three 24-hour runs per day (6, 12 and 18 UTC, available ~9, ~15 and ~21 UTC)
  - Eta-212/215 via NOAAport for initial conditions after isentropic analysis, and lateral boundaries nudged every 3 hours
  - Automated pre- and post-processing, and visualization
  - Accessible to Con Edison emergency management group starting in 2007 with continual enhancement
  - Current execution time 40-60 minutes: 30x1.9 GHz Power5 cpus
- **Assemble an interdisciplinary, collaborative team with diverse expertise with access to disparate data**
  - Weather modelling and observing systems
  - Data analysis, visualization and supercomputing
  - Electric distribution infrastructure and operations
  - Emergency management
- **Establish a foundation for enhancement**
  - Access relevant historical weather and outage/damage data as well as geo-spatial infrastructure and environmental data
  - Define retrospective analysis of key weather events
  - Modify underlying software and hardware system to meet the geographic, throughput and dissemination requirements of the utility operations



Key Steps

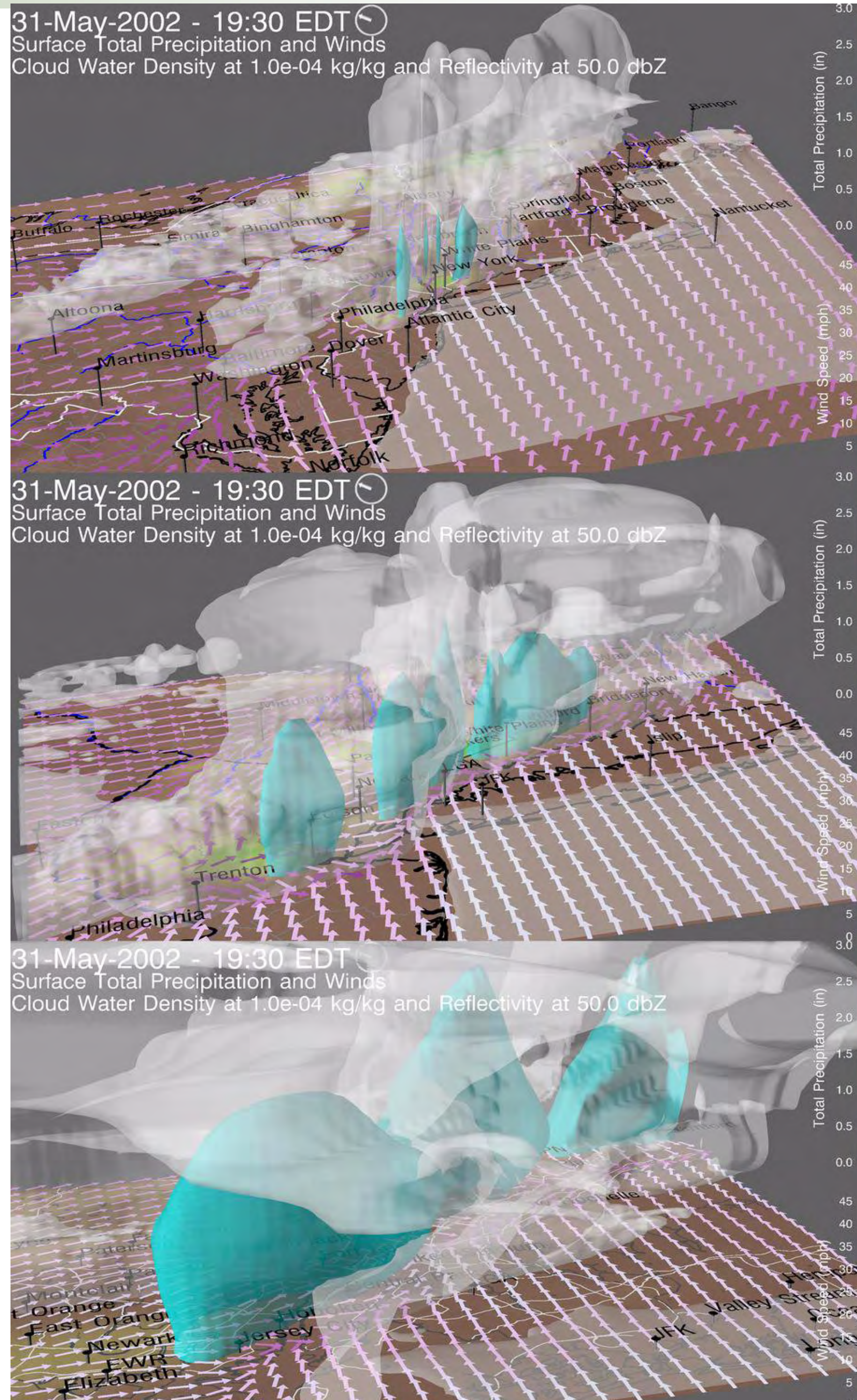
- **Meteorological analysis**
  - **Characterize key historical events that impact utility operations**
  - **Use AWS/WeatherBug observing stations, anecdotal reports and public data to evaluate past forecasts and events**
  - **Employ results to tune and improve modelling**
- **Impact analysis**
  - **Characterize those key historical events from the utility's perspective**
  - **Use ConEd damage data, outage reports, etc. to evaluate past events**
- **Uncertainty quantification**
  - **Multiple sources (not just meteorological) need to be addressed**



Utility Service Area, AWS/WeatherBug Stations and Example NWP (4km) Grid

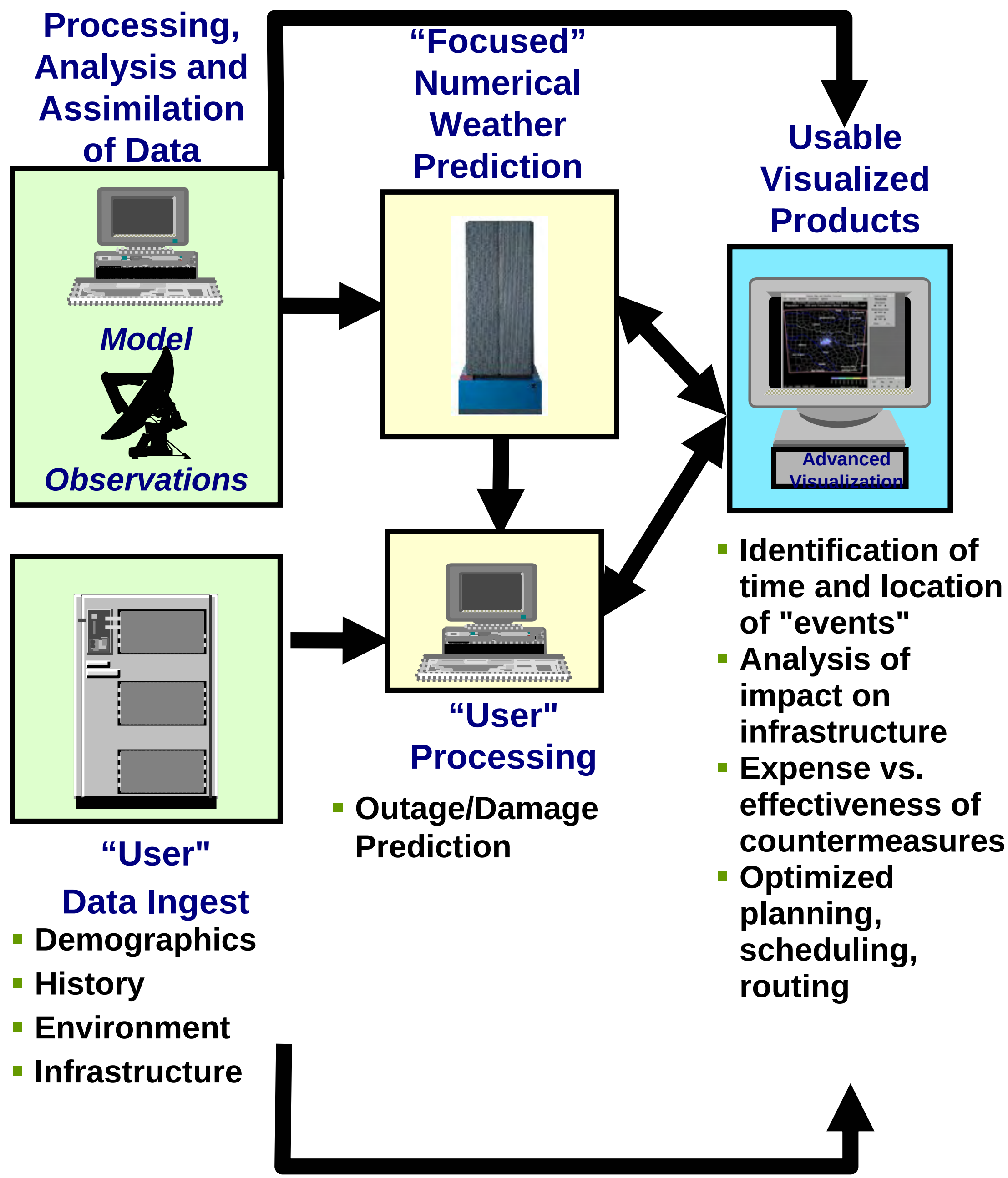
Key Steps

- **Modelling**
  - **Meteorology: utilize WRF-ARW to enable improved forecasts with up to 72 hours lead time**
    - **18/6/2 km nested (76x76x42) with 2 km across extended service area**
    - **NAM/RUC for background and boundary conditions**
    - **WSM 5-class microphysics, YSU PBL, NOAH LSM, Grell-Devenyi ensemble, urban canopy model**
    - **Assimilation of AWS data for initial conditions**
  - **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**
  - **Storm classification and outage estimation**
  - **Uncertainty visualization for operational decision making**



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?**



18 January 2006 Windstorm

- Strong cold front led to a significant wind event along with heavy rains due to a deep upper air trough with a low pressure system
- Gusting between 40 and 70 mph observed from 0600 to 1000 EST
- Innumerable downed trees and power lines

Location	Maximum Wind Speed (mph)	Time (EST)
Central Park	41	0828
LGA	56	0729
JFK	51	0853
White Plains	57	0853
Mount Vernon	64	0749
Yonkers	57	0749
Larchmont	70	0842

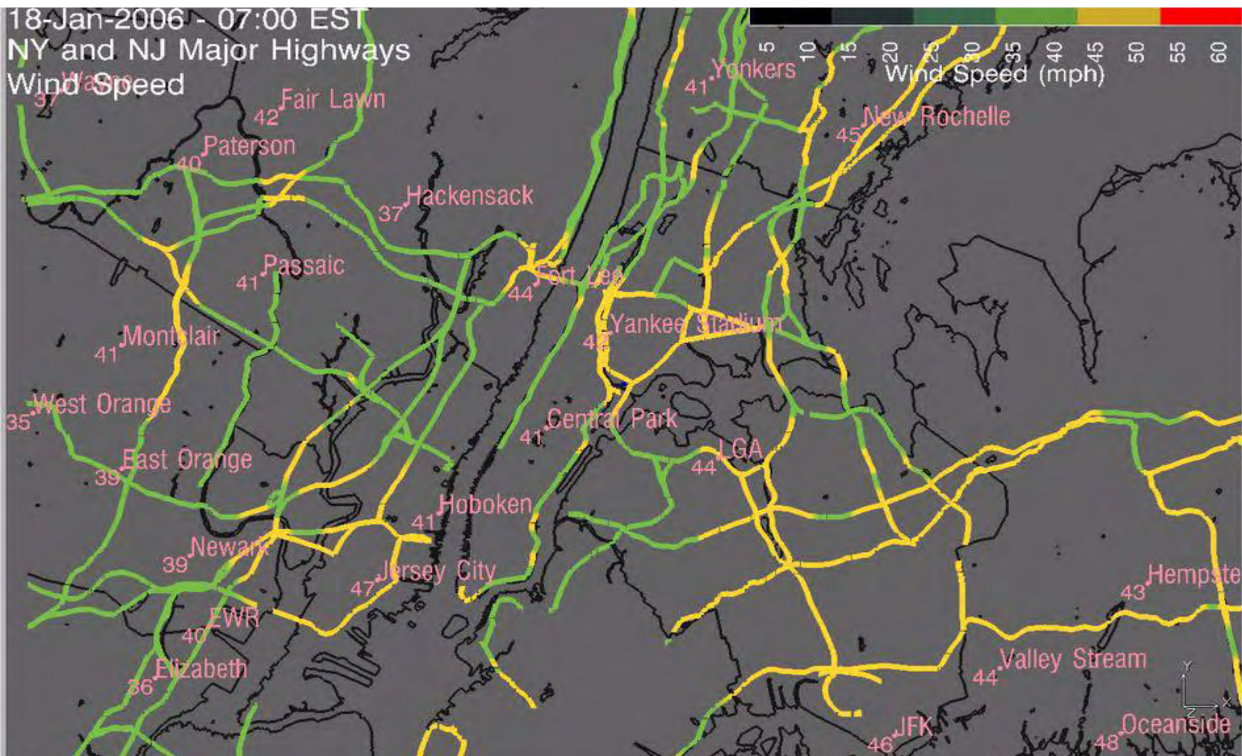
- Electricity service was disrupted to over 250,000 residences and businesses in the New York City suburbs
- Widespread disruption of transportation systems (e.g., road and bridge closures, airport delays) and some local flooding
- Other forecasts during the late morning on 17 January: "heavy rain" and "winds 20 to 30 mph" in Westchester County and New York City
- Wind advisories issued (gusts to 45 mph) at 1600 EST
- High wind warning issued (gusts to 60 mph) at 0300 EST, 18 January

18 January 2006 Windstorm

Operational *Deep Thunder* Forecast

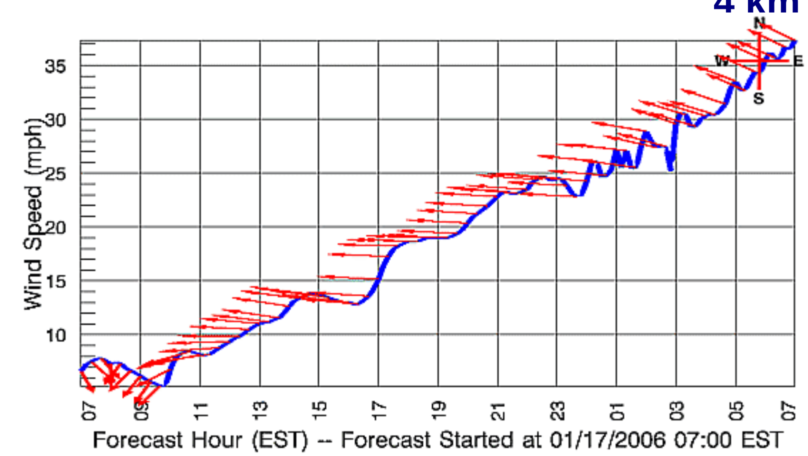
**Initiated with data from 0700 EST on 1/17
with results available late morning on 1/17.**

High winds shown in forecast available 18 hours ahead of event and 15 hours before NWS advisory

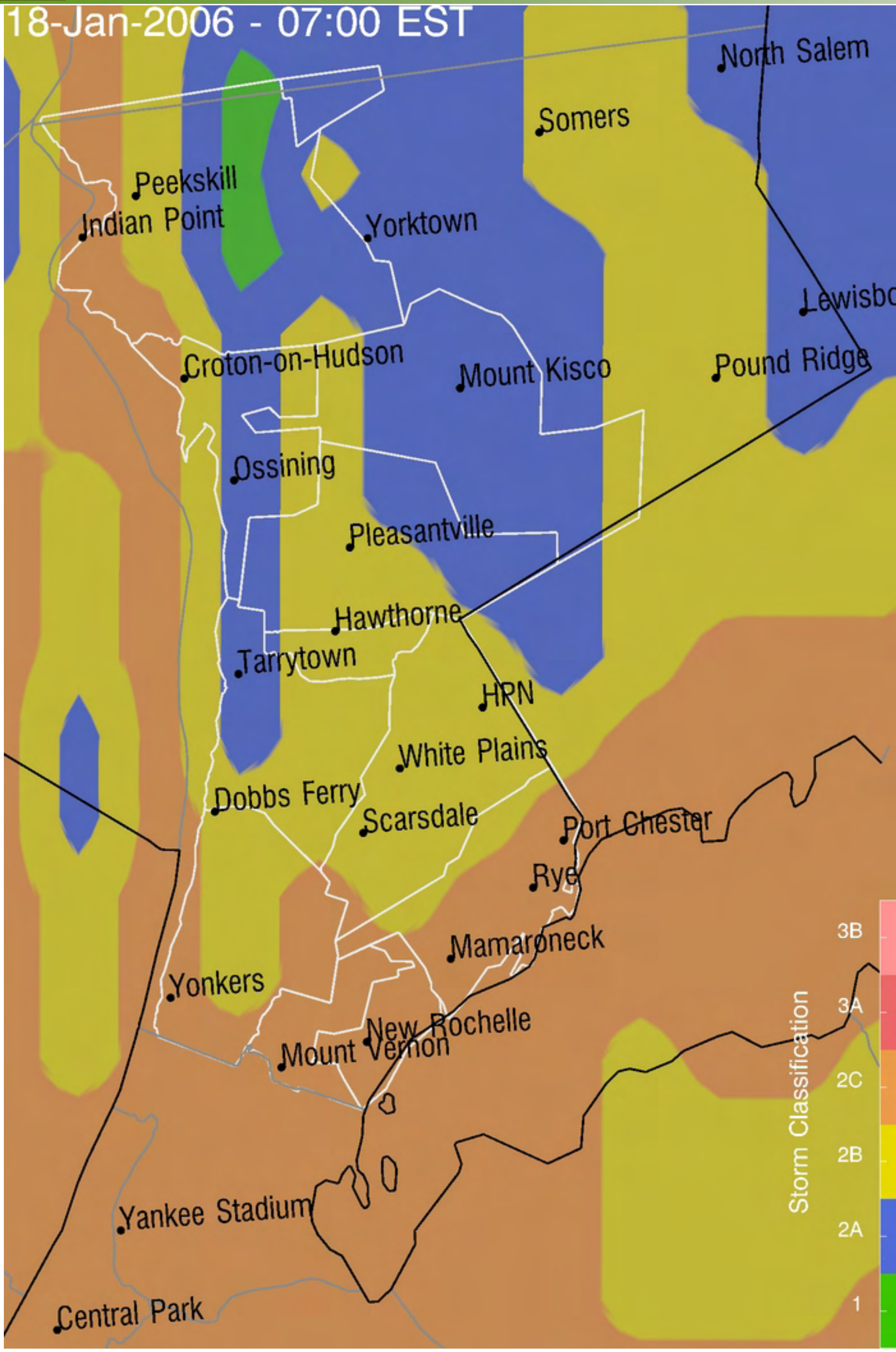


1 km

4 km



White Plains Airport



Forecast Results 18 January 2006 Storm Classification

Storm Category/Plan and Number of Customers Out of Service

1. **Upgraded (e.g., thunderstorms), < 7000**

2A. **Serious (e.g., heavy thunderstorms), 7000-9000**

2B. **Serious, 9000-12000**

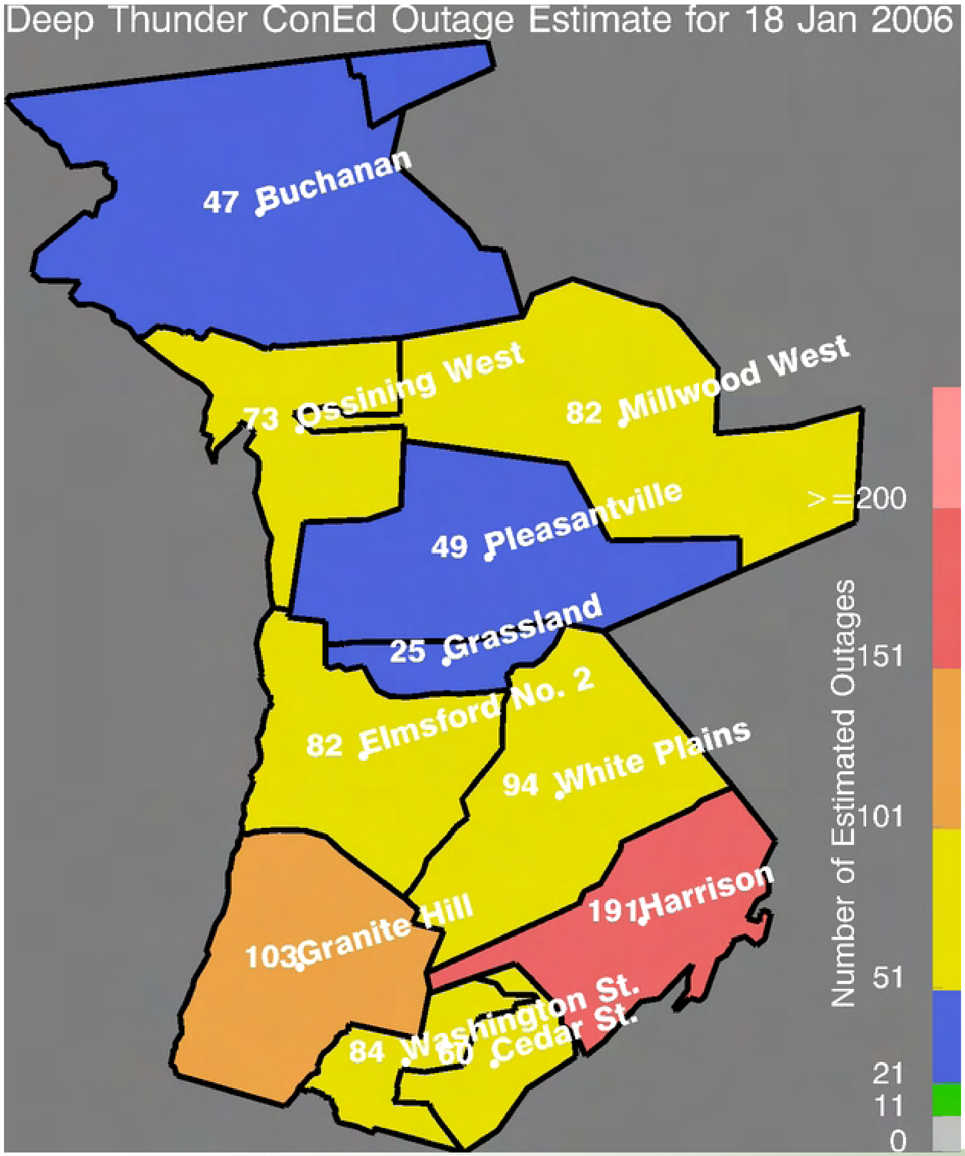
2C. **Serious, 12000-15000**

3A. **Full Scale (e.g., severe storm), 15000-40000**

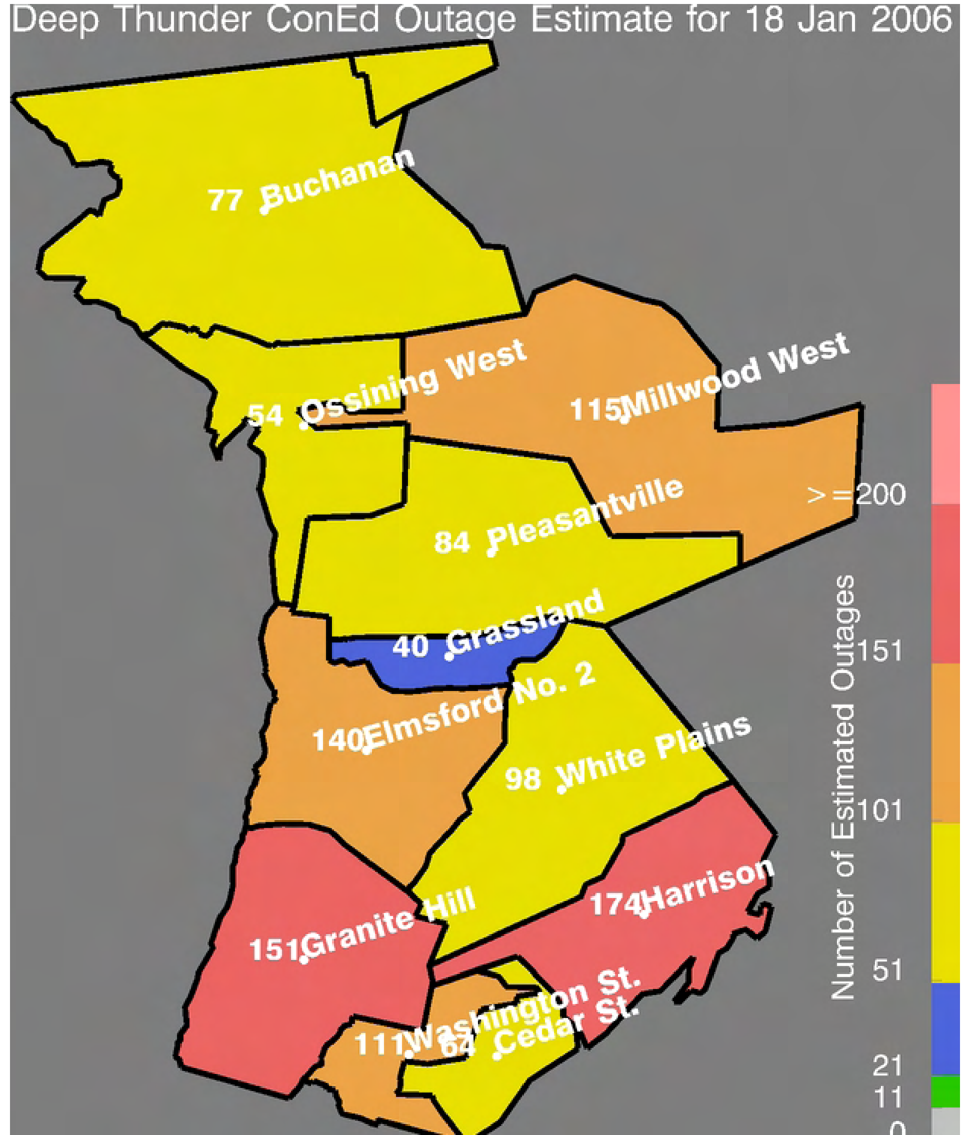
3B. **Full Scale (e.g., hurricane), > 40000**

Deep Thunder Damage Prediction -- 18 January 2006

Forecasted Outages

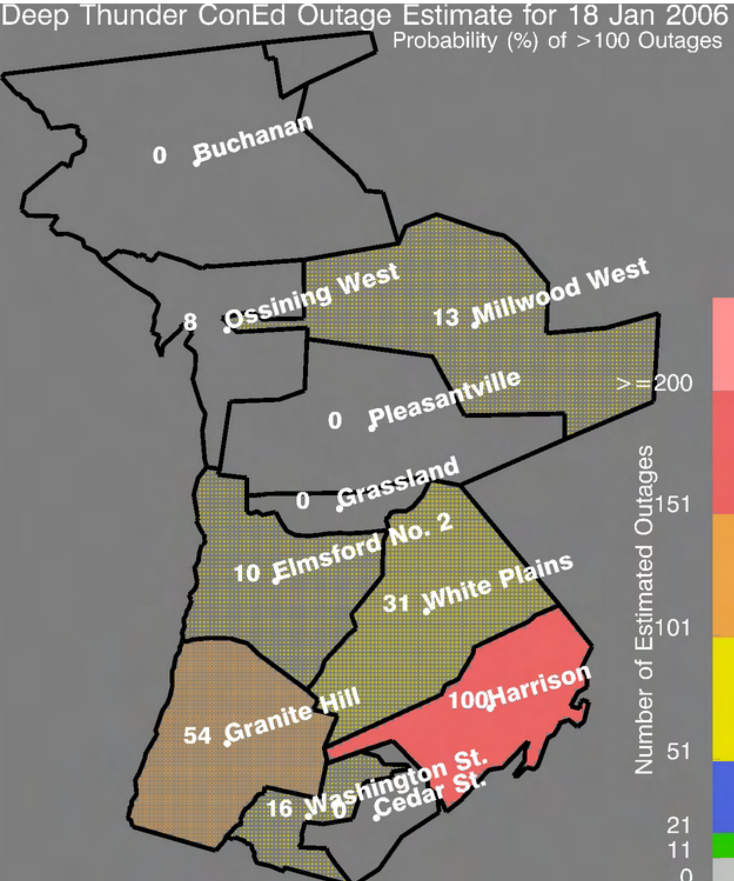


Actual Outages

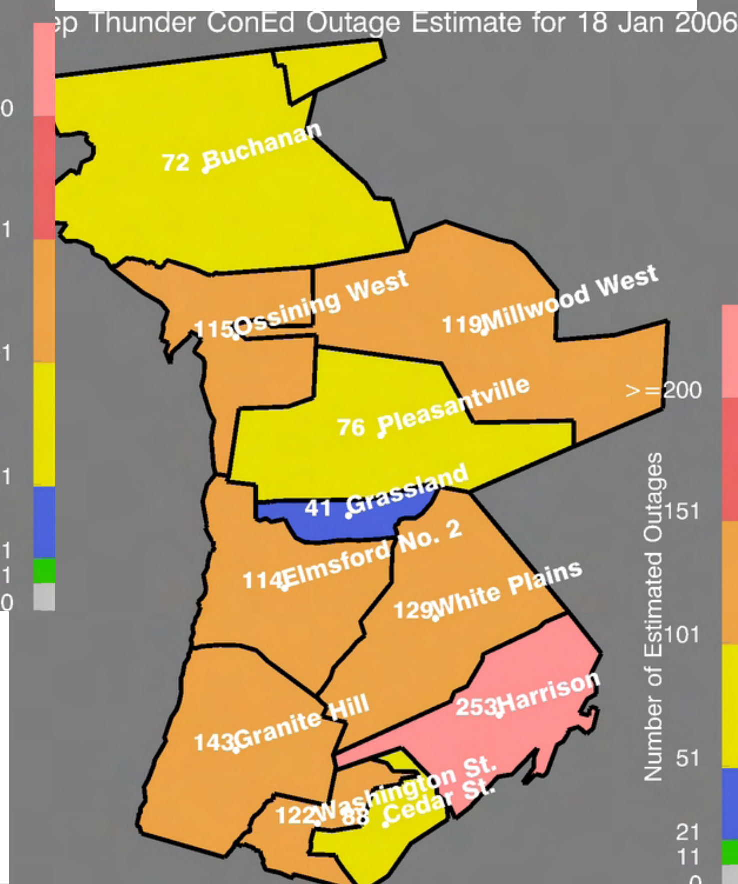


Uncertainty in Damage Prediction -- 18 January 2006

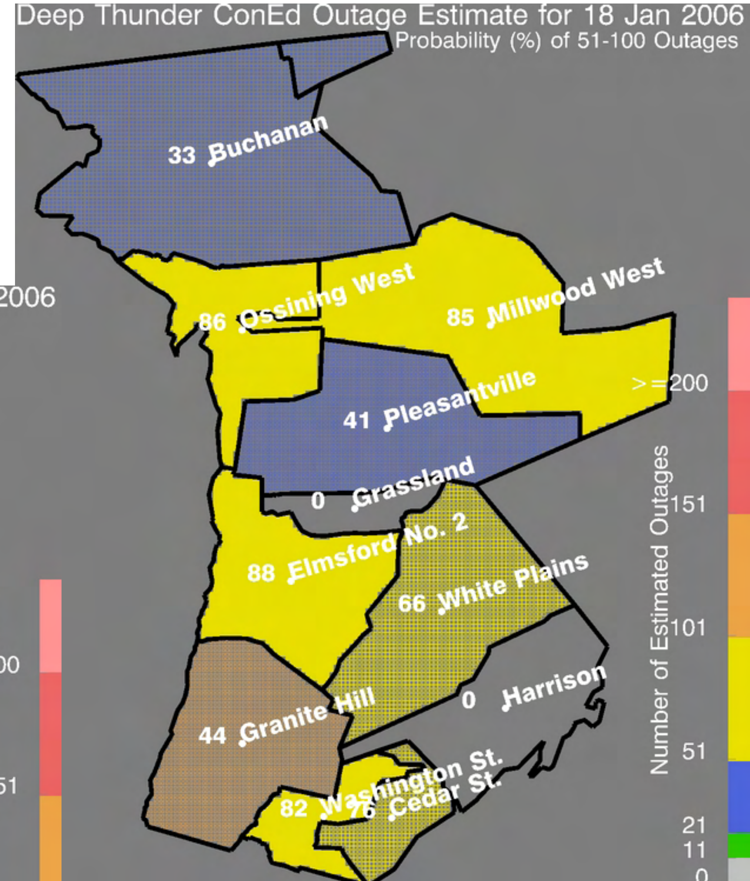
Forecasted Outages with Probability Exceeding 100 Outages



Upper Bounds of Outage Estimates

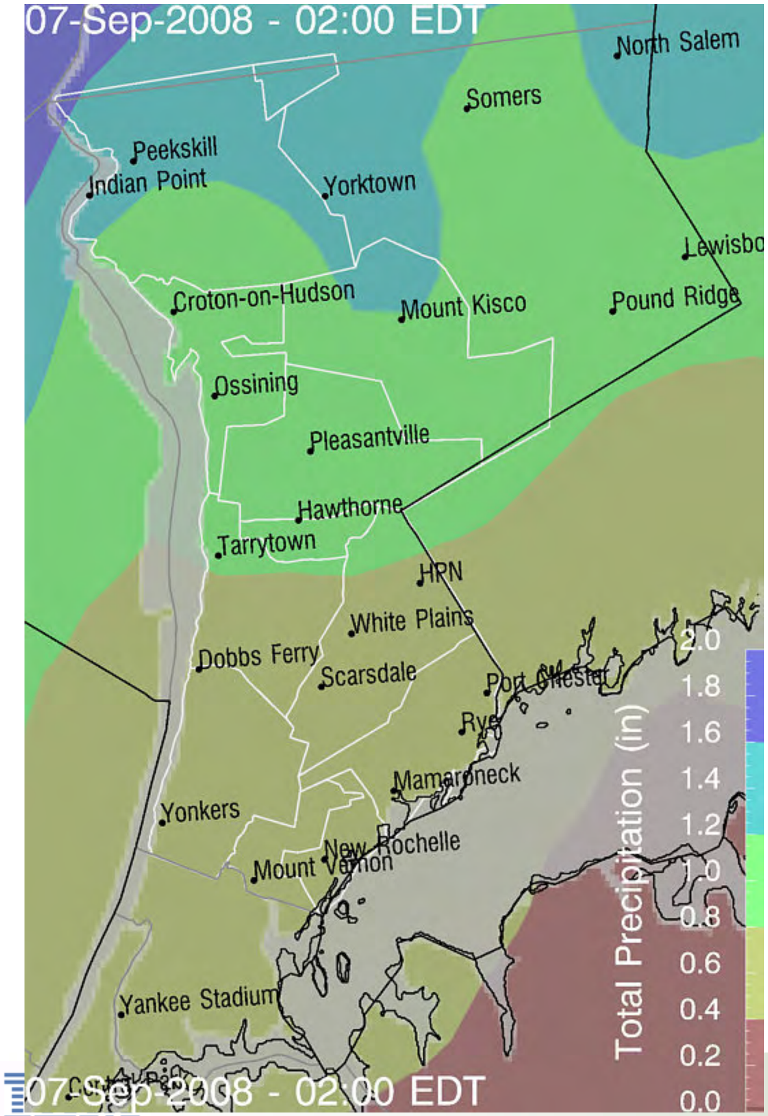


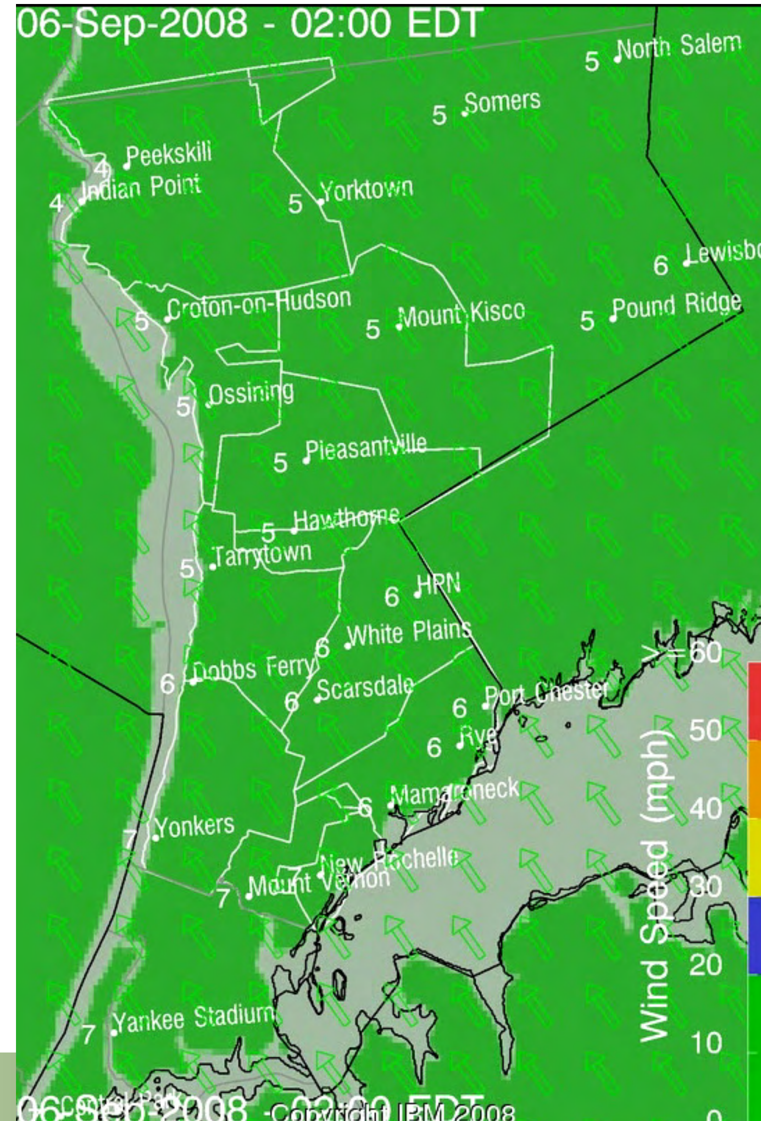
Forecasted Outages with Probability of 51 to 100 Outages



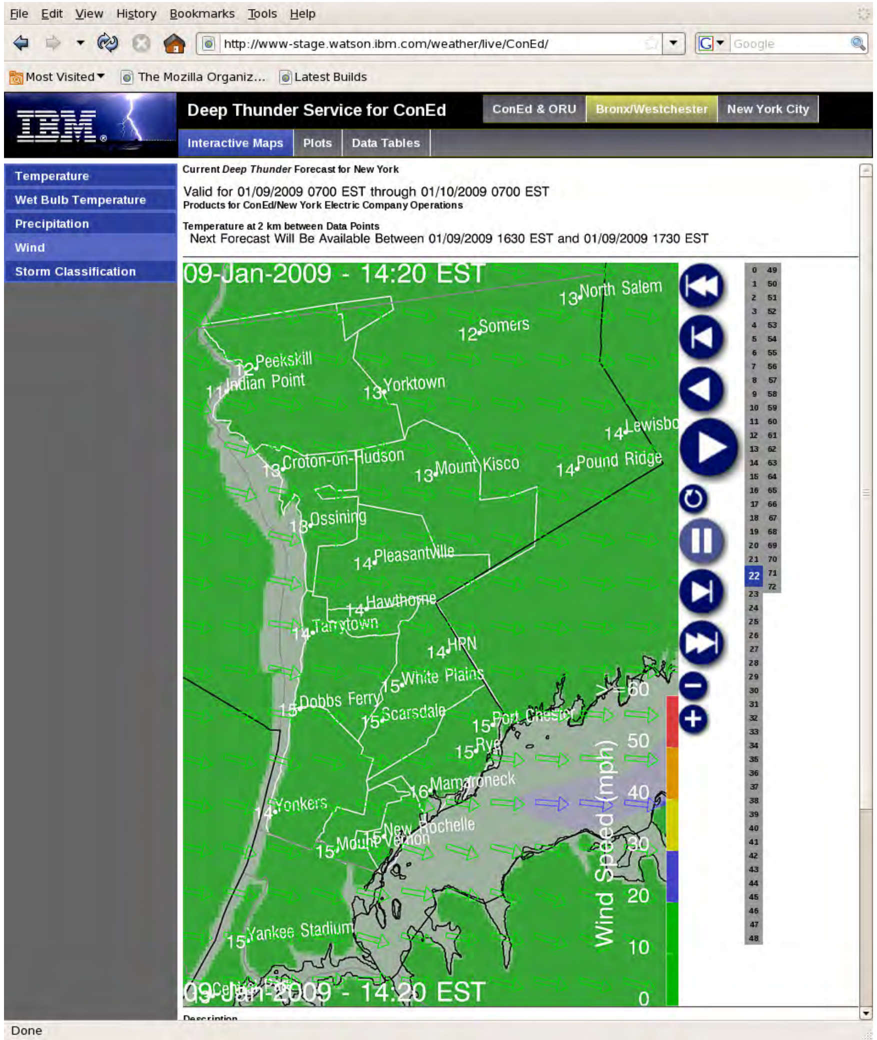
Other Example Visualizations

- **Forecast initiated with data from 0200 EDT on 06 September 2008 with results available about 0600 EDT (Tropical Storm Hanna)**
- **Focus on ConEd Bronx-Westchester Service Area**

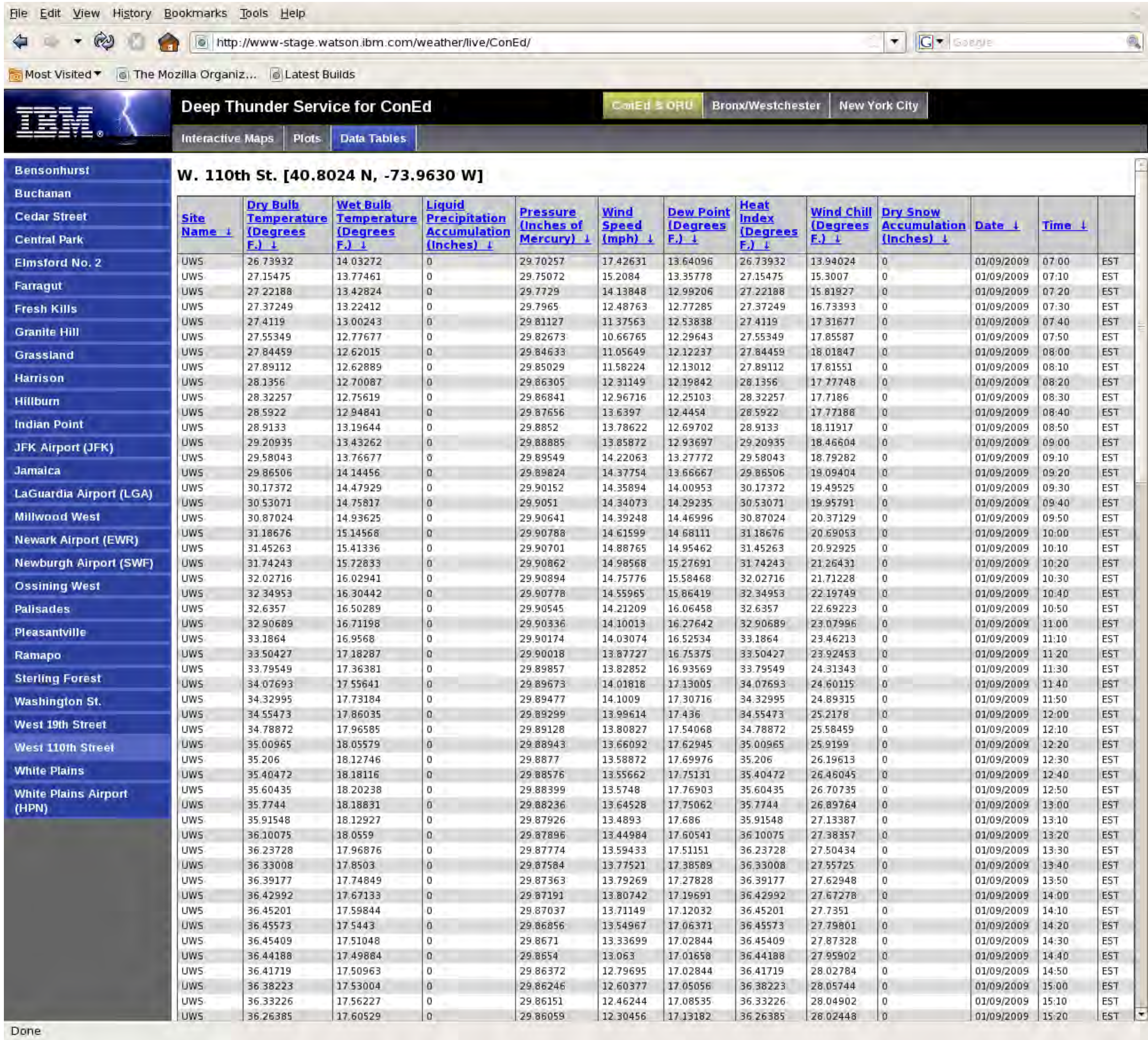




Web Interface for Consolidated Edison

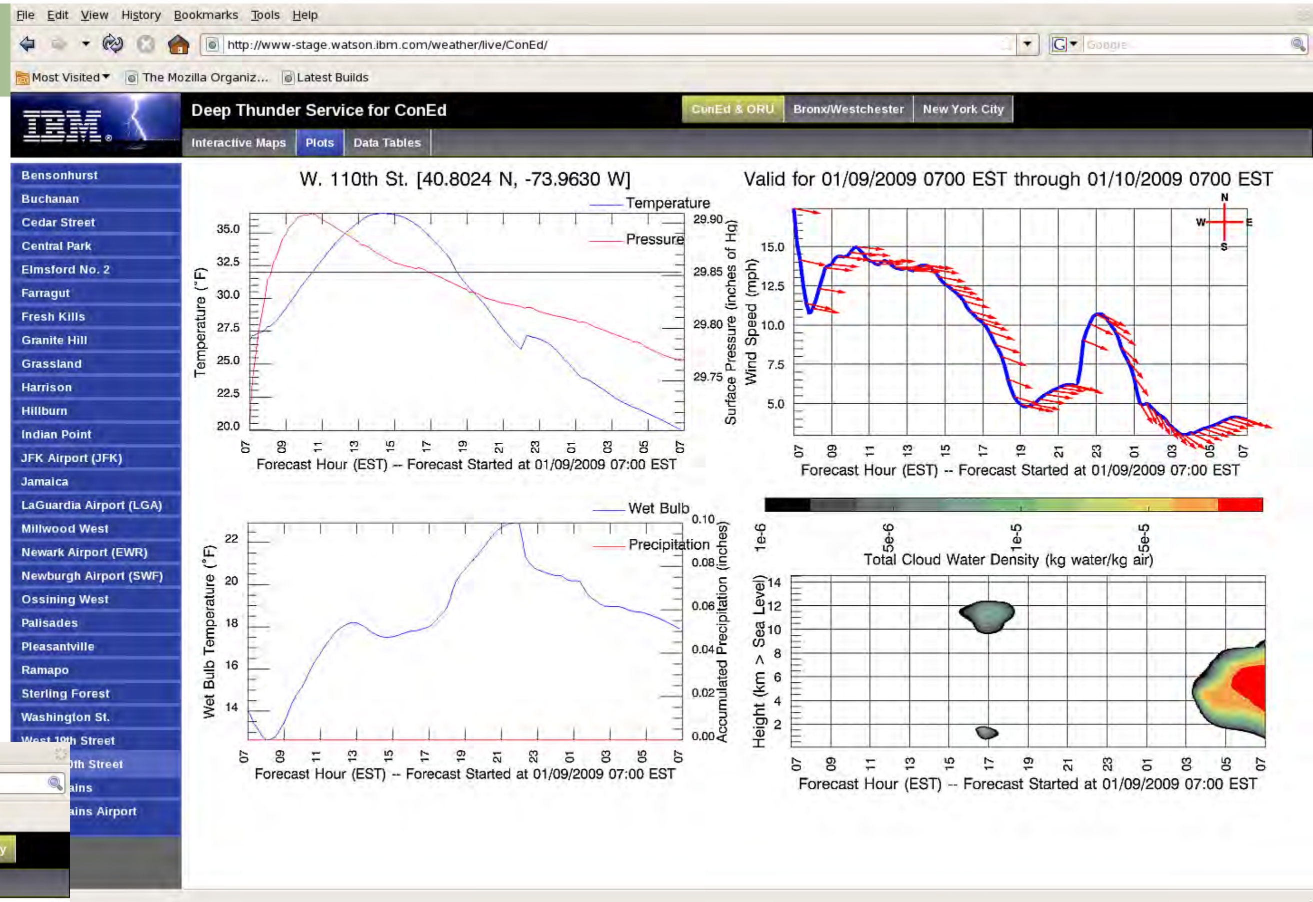


Surface Wind Animation

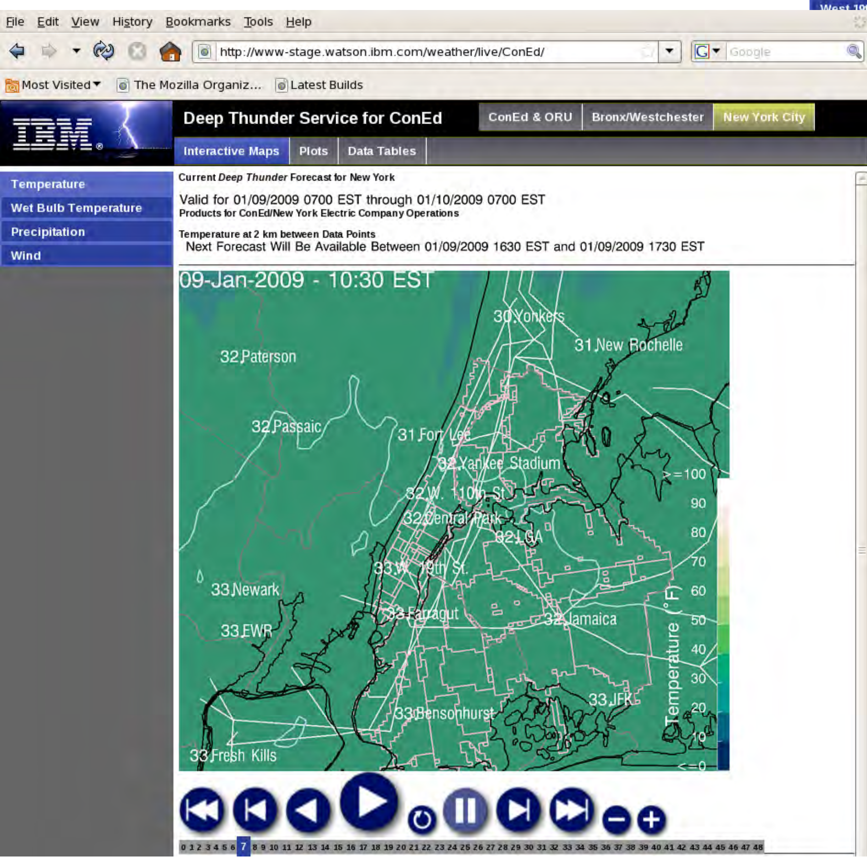


Interactive Site-Specific Forecast Table

Web Interface for Consolidated Edison



Site-Specific Forecast Plots



Surface Temperature Animation

Discussion

- **Enabled an operational capability useful for overhead distribution network emergency management**
- **Collaborative and diverse team critical to success**
- **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**
- **Better than expected results for 72-hour WRF-ARW runs**
  - **Original plan was to continue to produce 24-hour high-resolution (e.g., 2 km) and add 72-hour (4 to 6 km) runs**
  - **Assimilation of AWS/WeatherBug data and effective model configuration with retrospective and quasi-operational runs with 2 km nests**
  - **Computationally and meteorologically viable for two high-resolution 72-hour runs per day**
- **Work is on-going given continuing challenges**
  - **Outage and NWP calibration and uncertainty estimation**
  - **Effective visualization and dissemination at ConEd**

Future Work

- Outage forecast disseminated operationally
  - –Enhance with likely type of damage
  - –Integration into resource planning tools
- Continue to improve calibration of weather and outage models, and characterization of uncertainties
  - –Operational statistics
  - –Retrospective analysis and tuning of new events with impact
- Deploy real-time outage estimate using AWS data
- Develop additional specialized visualizations (e.g., frozen precipitation, wind gusts)
- WRF-ARW for core model becomes operational
  - –Two 84-hour runs per day (0 and 12 UTC)
  - –Replace content for current 24-hour weather visualizations and add new visualizations for up to 72-hour lead time
  - –Develop daily outage estimate per day of model output