



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

**L. Treinish, A. Praino, H. Li and E. Novakovskaia**

**IBM Big Green Innovations and IBM Research**

**Yorktown Heights, NY**

**{lloydt, apraino, liho, enovako}@us.ibm.com**

**<http://www.research.ibm.com/weather/DT.html>**

**J. Mark Drexel**

**Consolidated Edison, Inc.**

**Rye, NY**

**[drexelj@coned.com](mailto:drexelj@coned.com)**



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

- **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)***



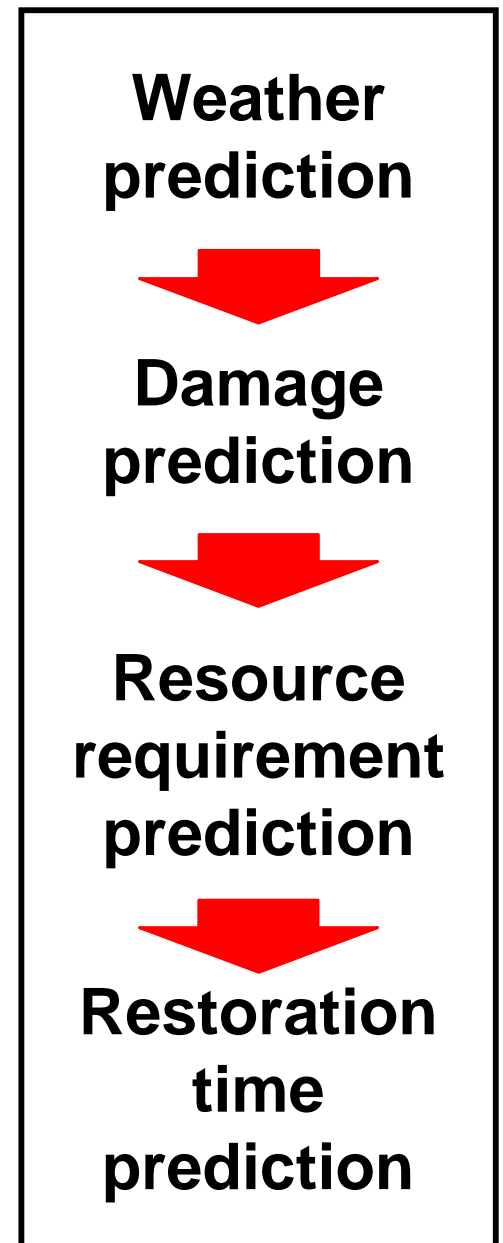
## Background and Motivation

- **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?





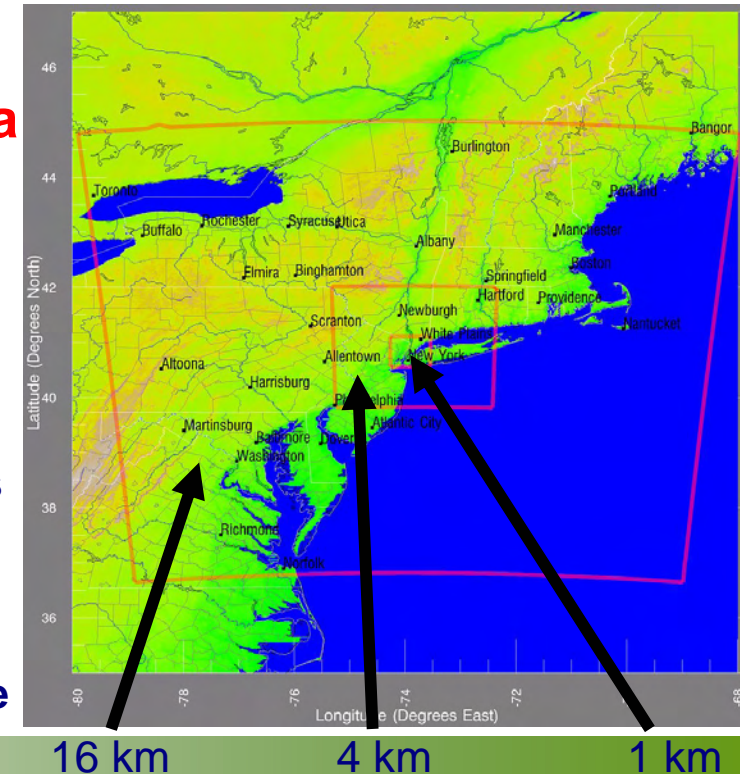
# Background and Motivation

- **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 implemented 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

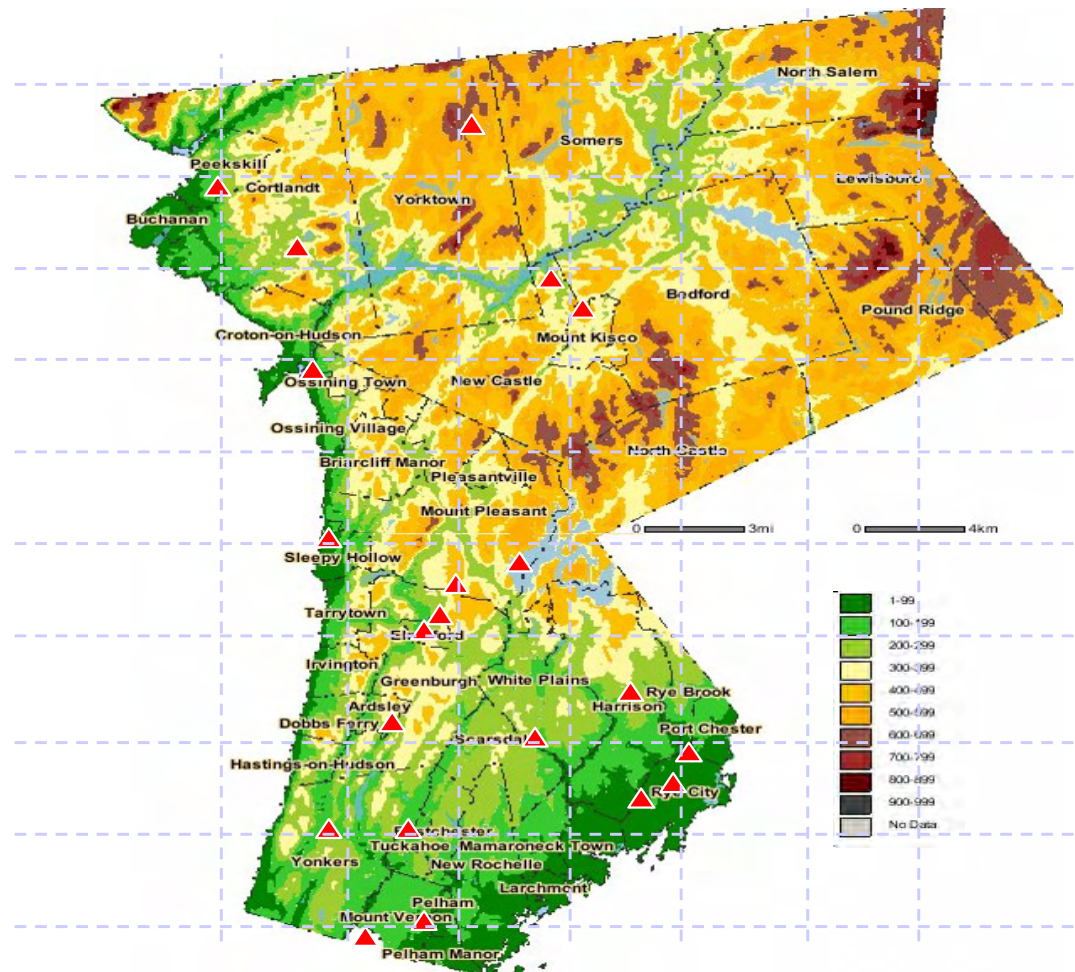
- Characterize key historical events that impact utility operations
- Use AWS/WeatherBug observing stations, anecdotal reports and public data to evaluate past forecasts and events
- Employ results to tune and improve modelling

## ■ 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





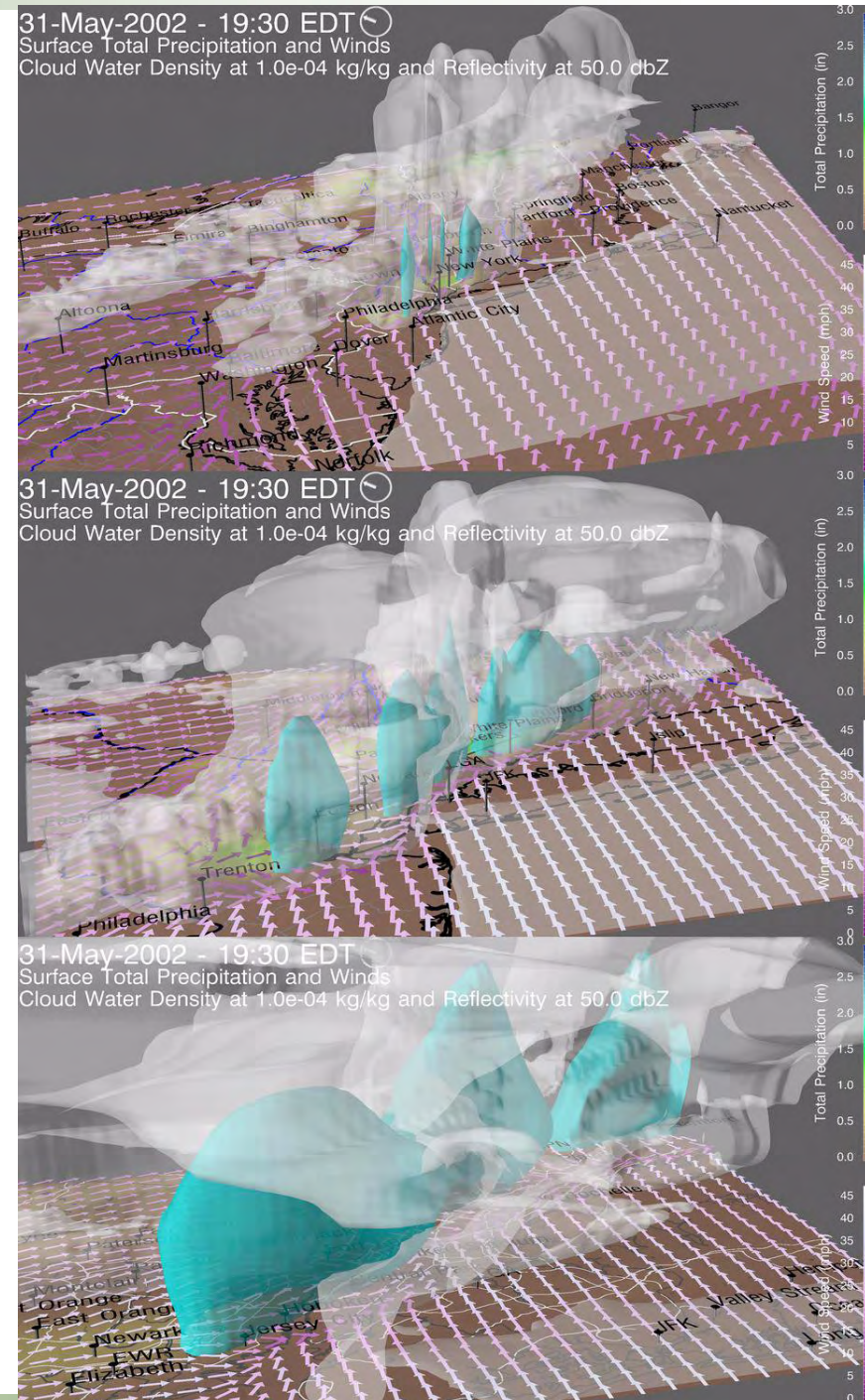
# Key Steps

## ■ 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

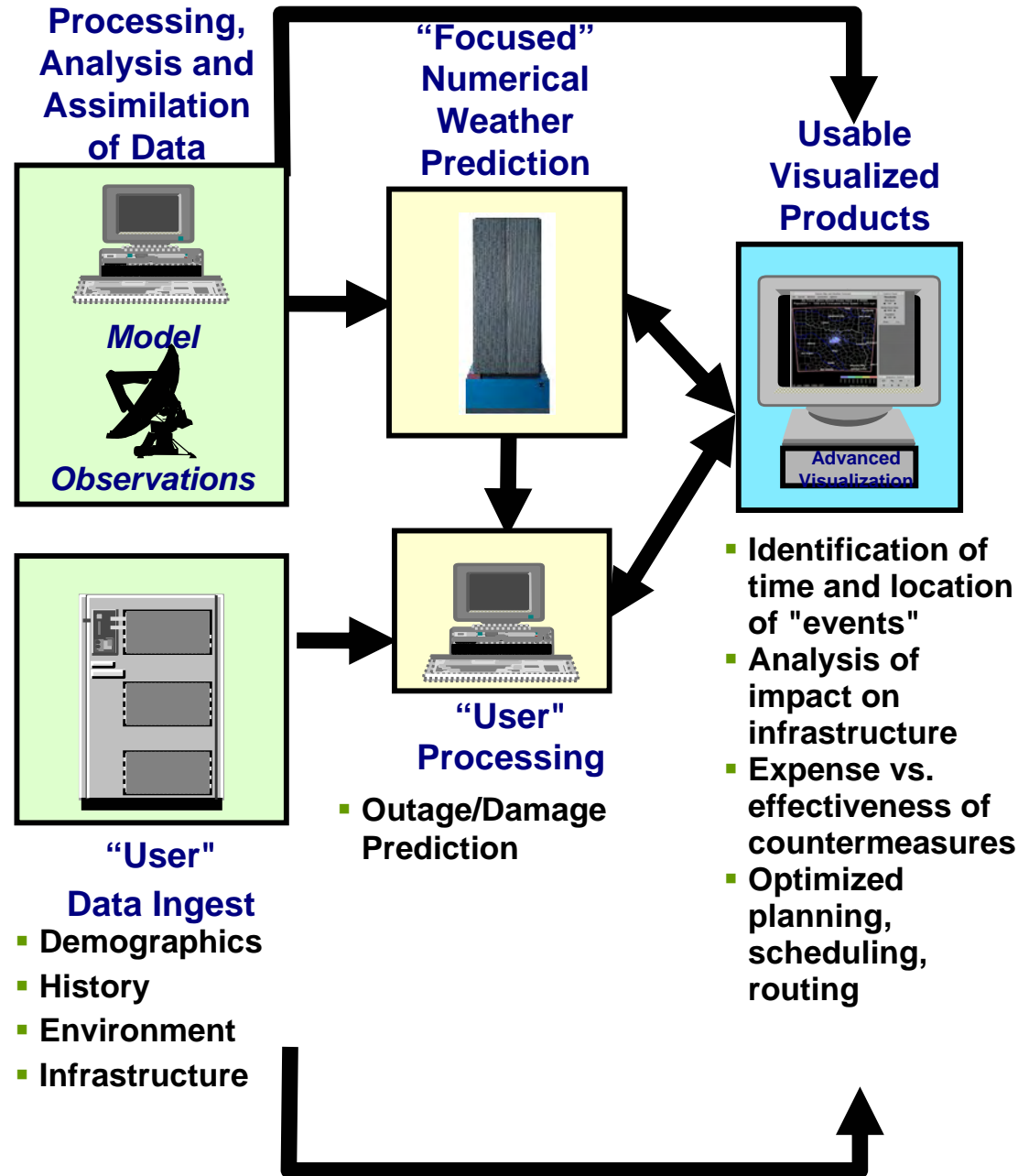
## ■ Dissemination

- 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**



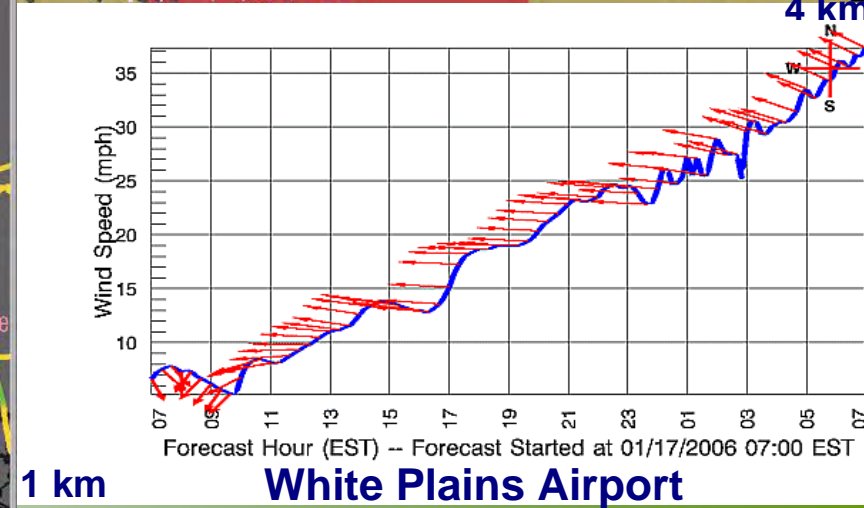
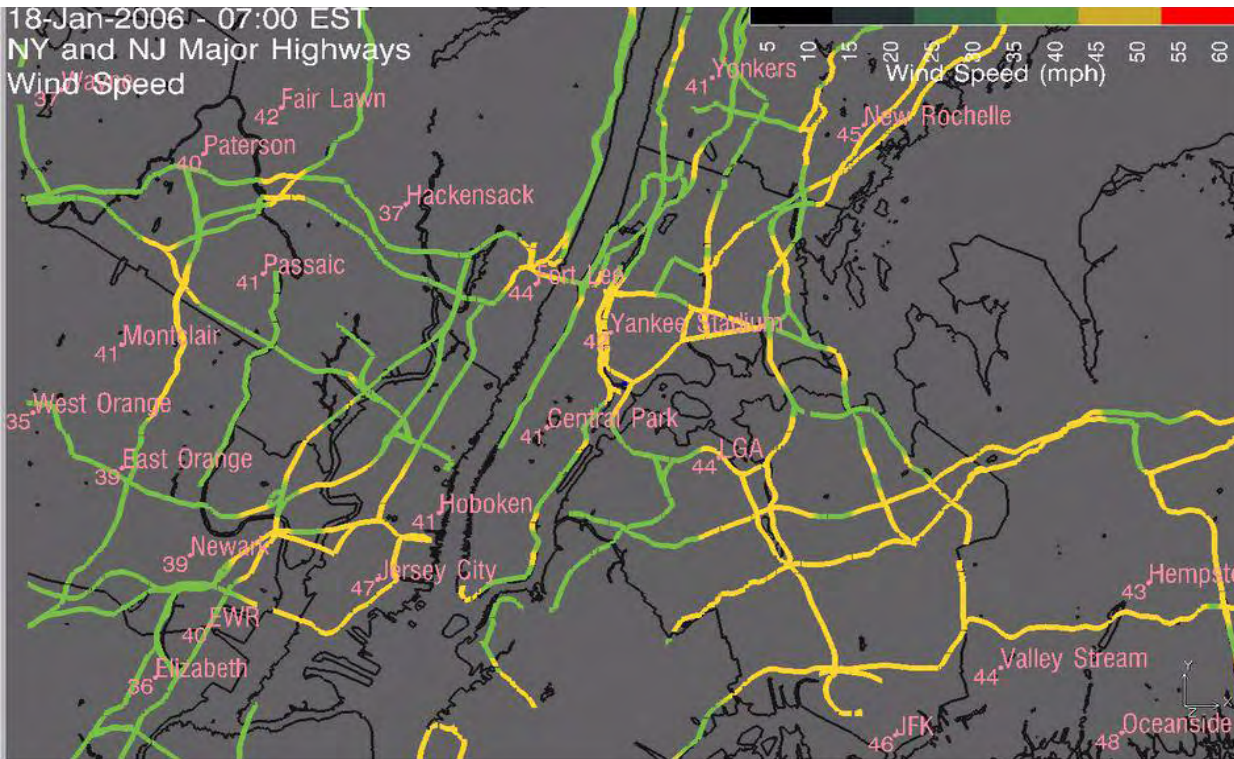


# 18 January 2006 Windstorm

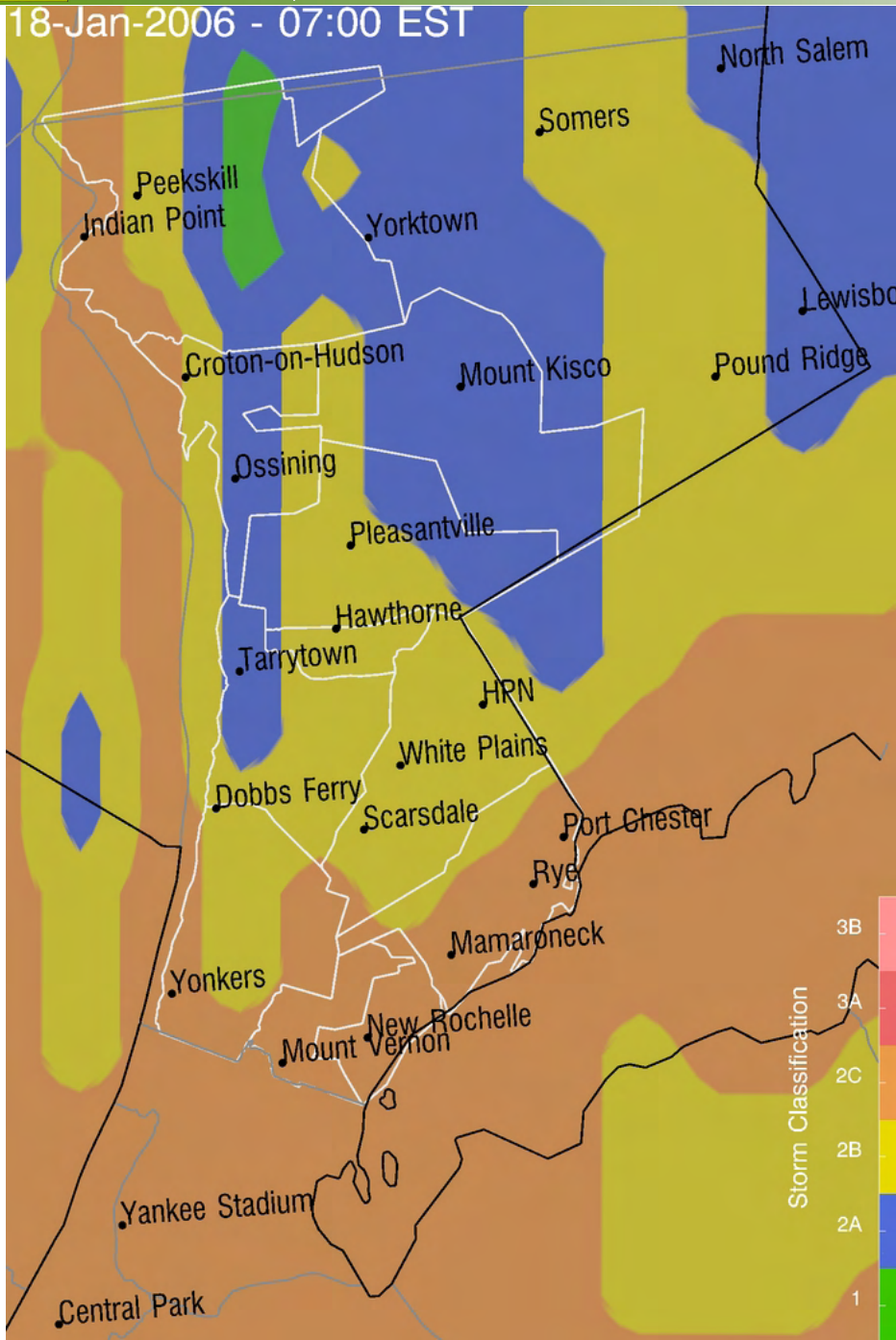
## Operational *Deep Thunder* Forecast

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



18-Jan-2006 - 07:00 EST



# 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

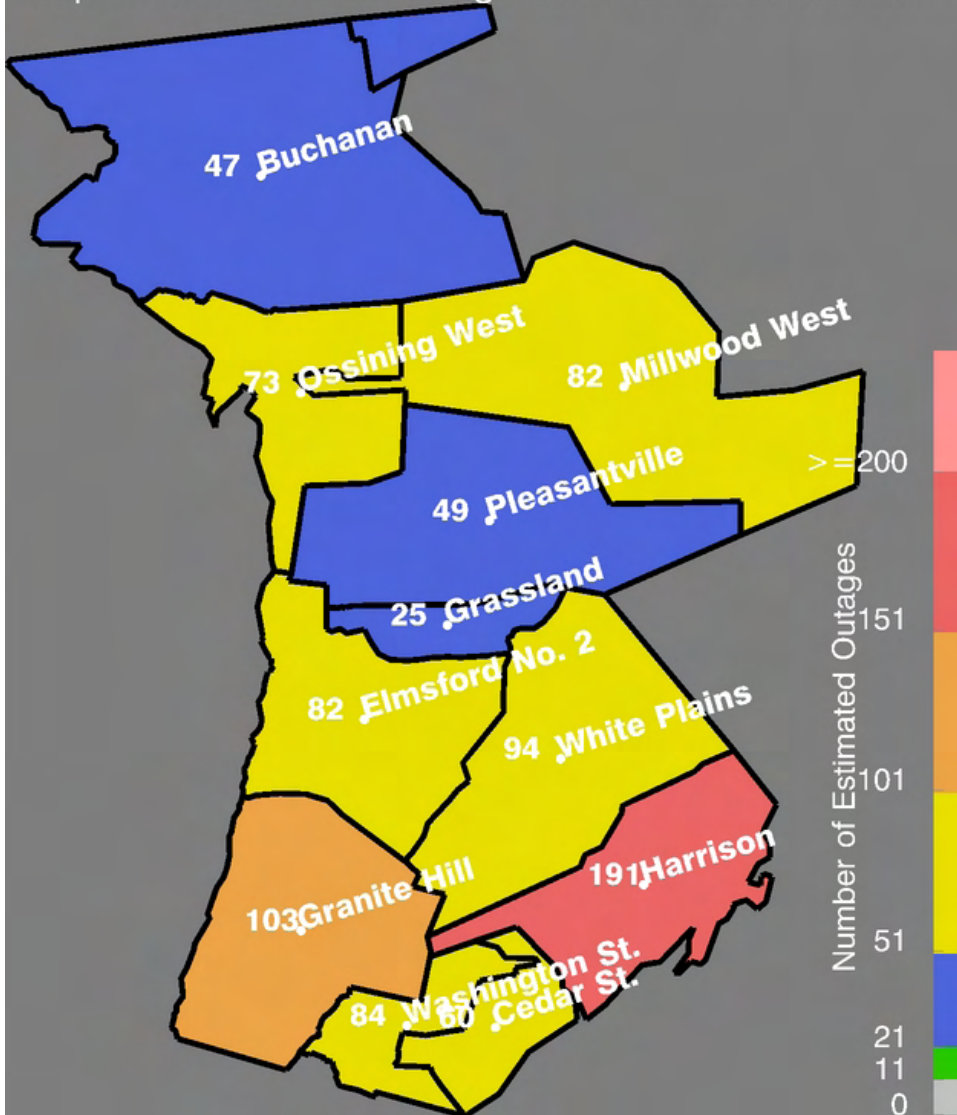




# Deep Thunder Damage Prediction -- 18 January 2006

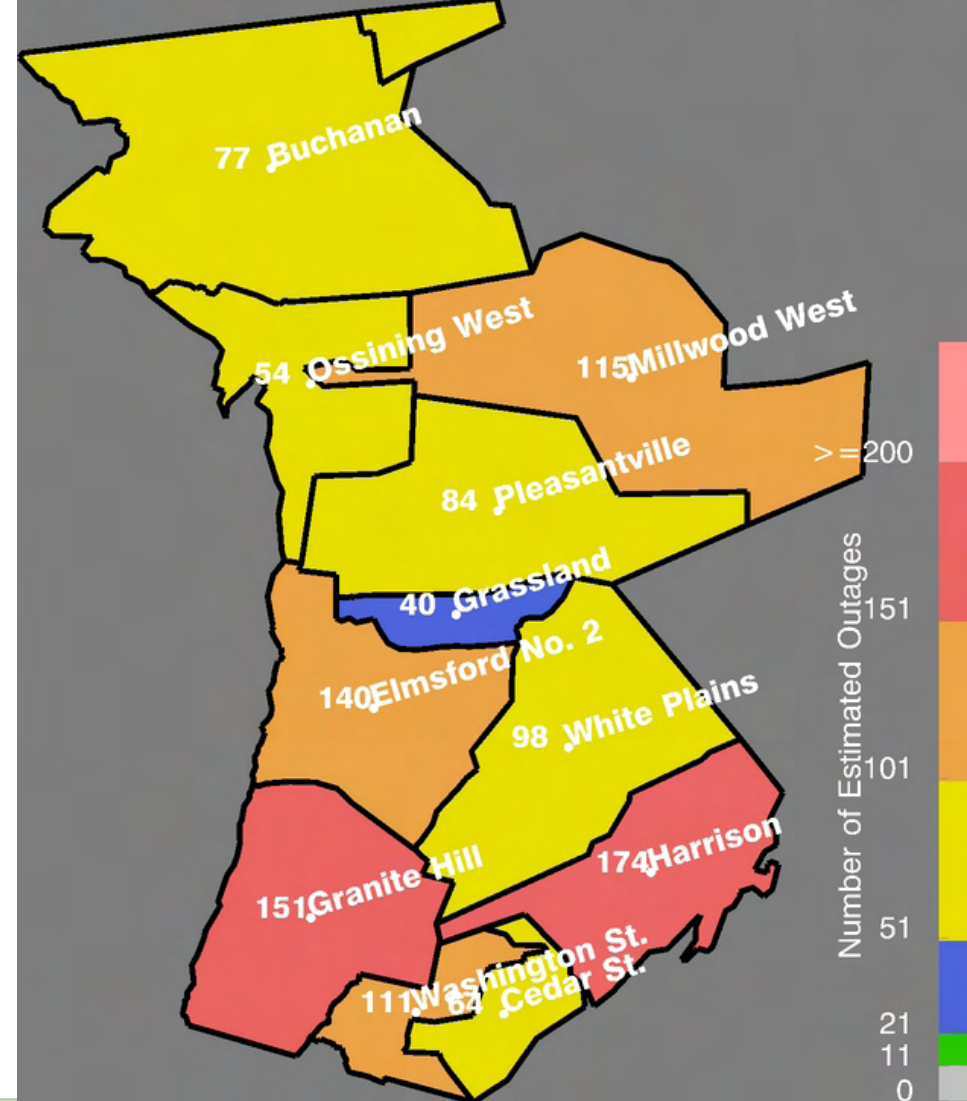
## Forecasted Outages

Deep Thunder ConEd Outage Estimate for 18 Jan 2006



## Actual Outages

Deep Thunder ConEd Outage Estimate for 18 Jan 2006



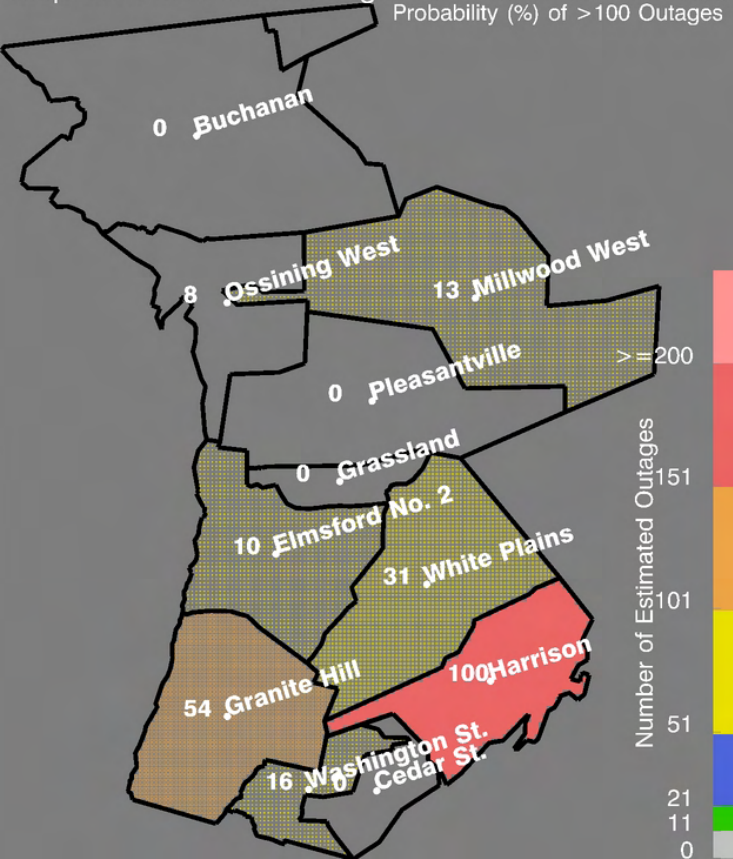




# Uncertainty in Damage Prediction -- 18 January 2006

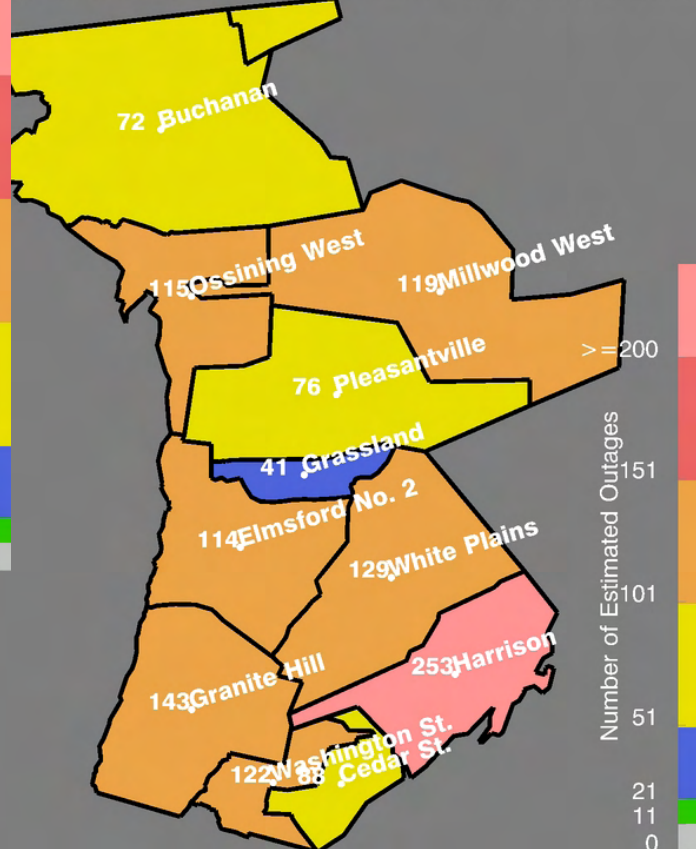
## Forecasted Outages with Probability Exceeding 100 Outages

Deep Thunder ConEd Outage Estimate for 18 Jan 2006  
Probability (%) of >100 Outages



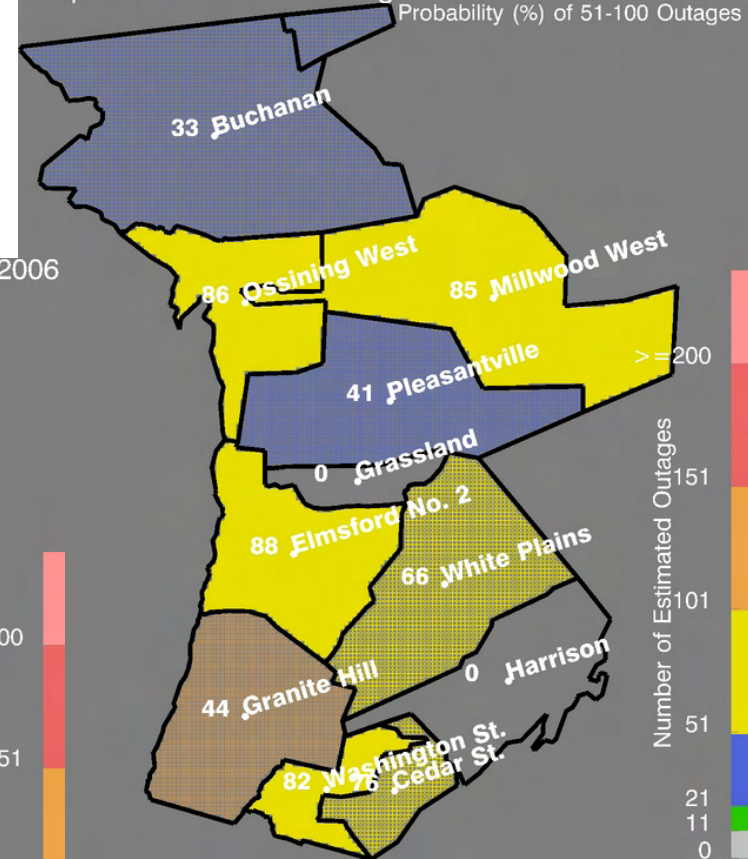
## Upper Bounds of Outage Estimates

Deep Thunder ConEd Outage Estimate for 18 Jan 2006



## Forecasted Outages with Probability of 51 to 100 Outages

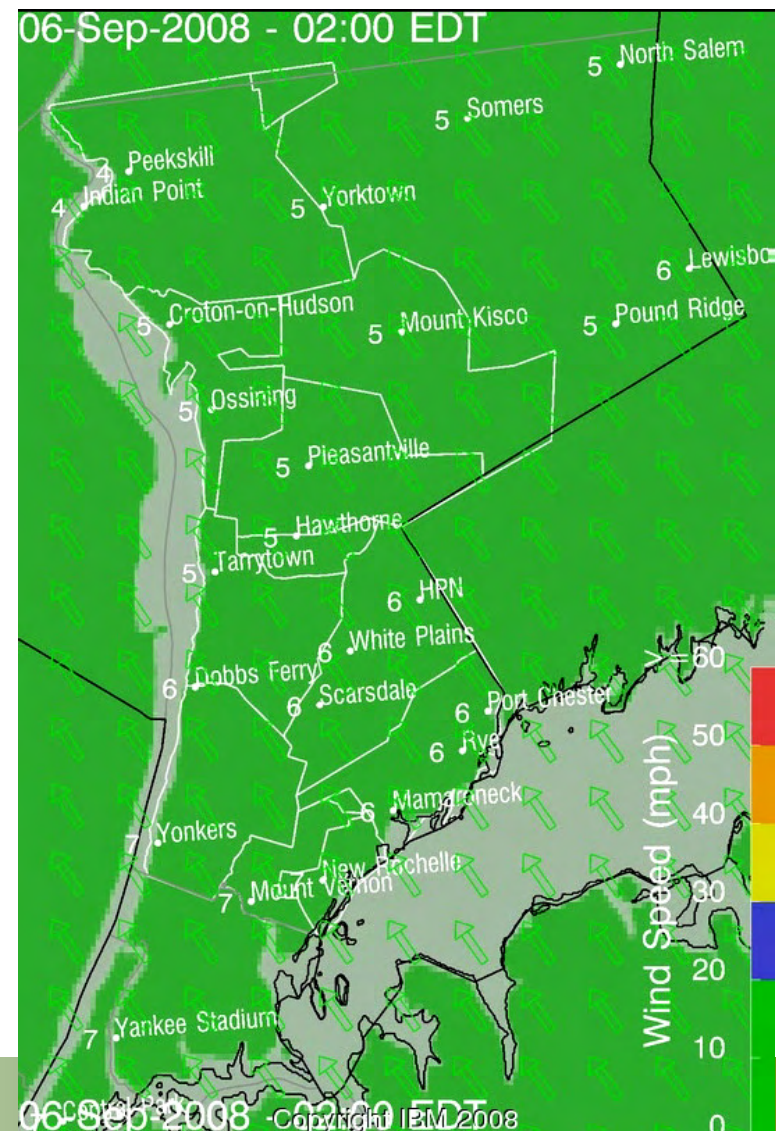
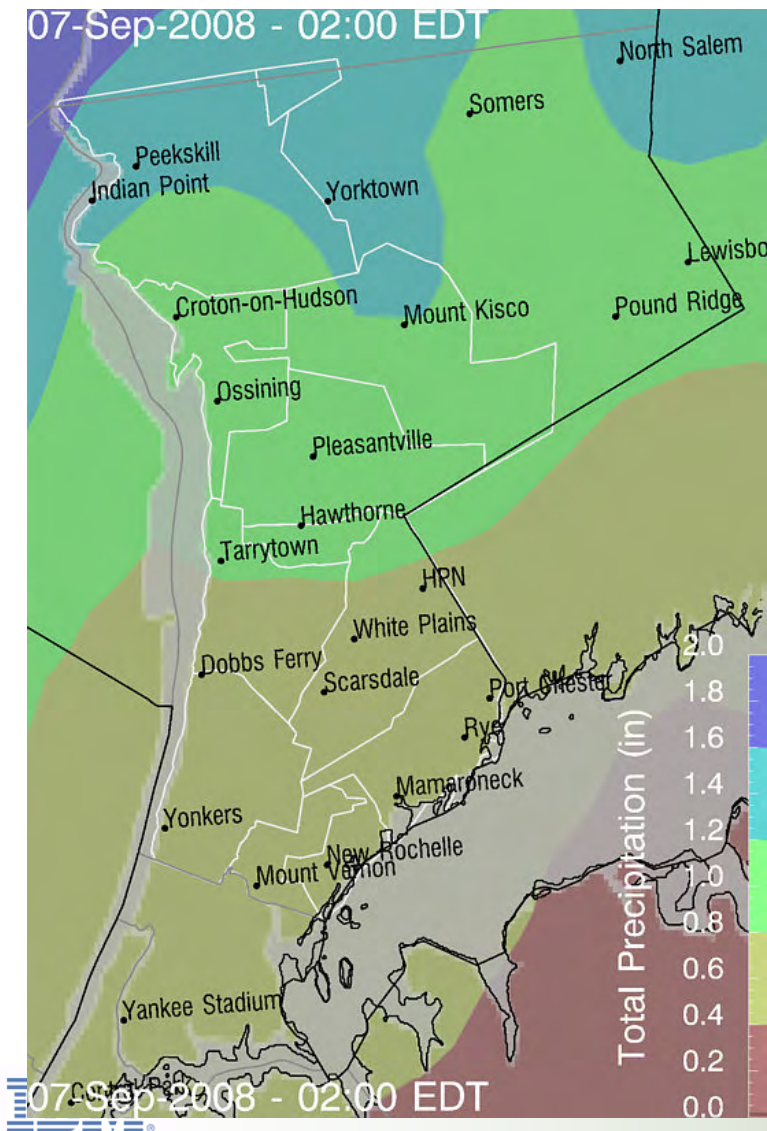
Deep Thunder ConEd Outage Estimate for 18 Jan 2006  
Probability (%) of 51-100 Outages





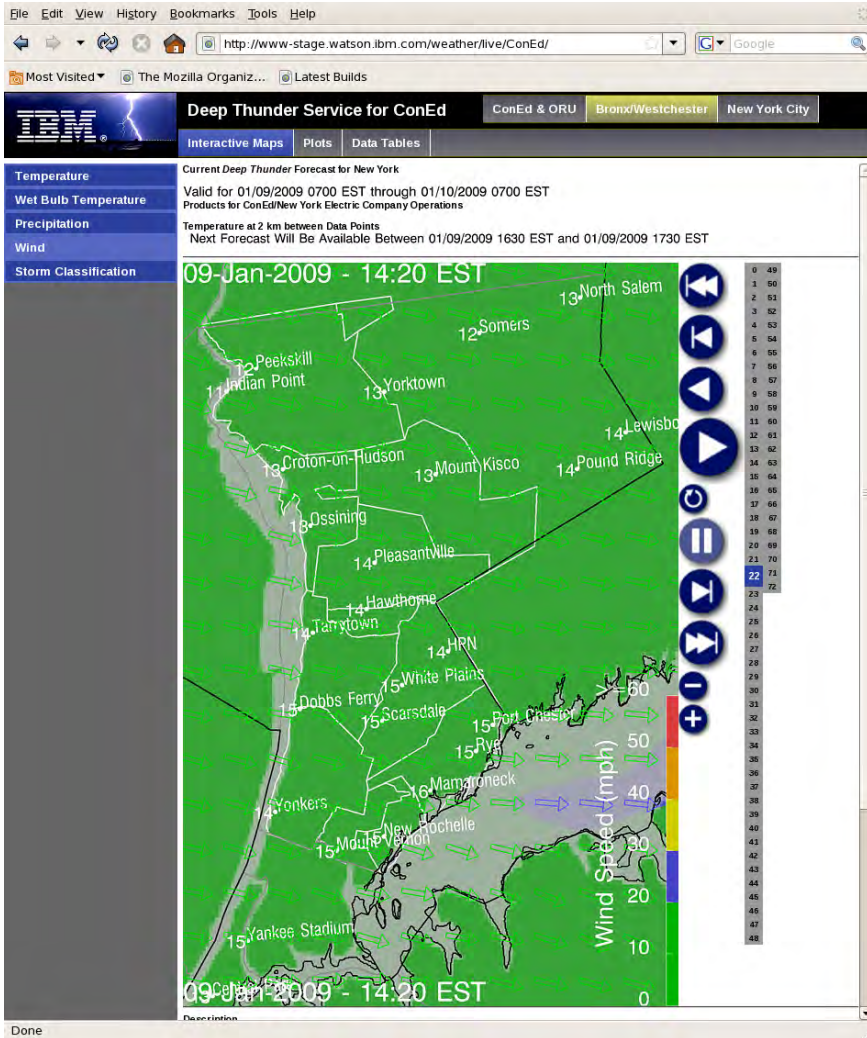
## Other Example Visualizations

- 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

W. 110th St. [40.8024 N, -73.9630 W]

Site Name	Dry Bulb Temperature (Degrees F)	Wet Bulb Temperature (Degrees F)	Liquid Precipitation Accumulation (Inches)	Pressure (Inches of Mercury)	Wind Speed (mph)	Dew Point (Degrees F)	Heat Index (Degrees F)	Wind Chill (Degrees F)	Dry Snow Accumulation (Inches)	Date	Time	Zone
Bensonhurst	26.73932	14.03272	0	29.70257	17.42631	13.64096	26.73932	13.94024	0	01/09/2009	07:00	EST
Buchanan	27.35475	13.77461	0	29.75072	15.2084	13.35778	27.35475	15.3007	0	01/09/2009	07:10	EST
Cedar Street	27.22388	13.42824	0	29.7729	14.13848	12.99206	27.22388	15.81927	0	01/09/2009	07:20	EST
Central Park	27.37249	13.22412	0	29.7965	12.48763	12.77285	27.37249	16.73393	0	01/09/2009	07:30	EST
Elmsford No. 2	27.4139	13.00243	0	29.81127	11.37563	12.53838	27.4139	17.31677	0	01/09/2009	07:40	EST
Farragut	27.55349	12.77677	0	29.82673	10.66765	12.29643	27.55349	17.85587	0	01/09/2009	07:50	EST
Fresh Kills	27.84459	12.62015	0	29.84633	11.05649	12.12337	27.84459	18.01847	0	01/09/2009	08:00	EST
Granite Hill	27.89112	12.62889	0	29.85029	11.58224	12.13012	27.89112	17.81551	0	01/09/2009	08:10	EST
Harrison	28.1356	12.70087	0	29.86305	12.31149	12.19842	28.1356	17.77748	0	01/09/2009	08:20	EST
Grassland	28.32257	12.75619	0	29.86841	12.96716	12.25103	28.32257	17.7186	0	01/09/2009	08:30	EST
Hillburn	28.5922	12.94841	0	29.87656	13.6397	12.4454	28.5922	17.77188	0	01/09/2009	08:40	EST
Indian Point	28.9133	13.19644	0	29.8852	13.78622	12.69702	28.9133	18.11917	0	01/09/2009	08:50	EST
JFK Airport (JFK)	29.20935	13.43262	0	29.88885	13.85872	12.93697	29.20935	18.46604	0	01/09/2009	09:00	EST
Jamaica	29.58043	13.76677	0	29.89549	14.22063	13.27772	29.58043	18.79282	0	01/09/2009	09:10	EST
LaGuardia Airport (LGA)	29.86506	14.14556	0	29.89824	14.37754	13.66667	29.86506	19.09404	0	01/09/2009	09:20	EST
Millwood West	30.17372	14.47929	0	29.90152	14.35894	14.00953	30.17372	19.49525	0	01/09/2009	09:30	EST
Newark Airport (EWR)	30.53071	14.75817	0	29.9051	14.34073	14.29235	30.53071	19.95791	0	01/09/2009	09:40	EST
Newburgh Airport (SWF)	30.87024	14.93625	0	29.90641	14.39248	14.46996	30.87024	20.37129	0	01/09/2009	09:50	EST
Ossining West	31.18676	15.14568	0	29.90788	14.61599	14.68111	31.18676	20.69053	0	01/09/2009	10:00	EST
Palisades	31.45263	15.41336	0	29.90701	14.88765	14.95462	31.45263	20.92925	0	01/09/2009	10:10	EST
Pleasantville	31.74243	15.72833	0	29.90862	14.98588	15.27691	31.74243	21.26431	0	01/09/2009	10:20	EST
Ramapo	32.02716	16.02941	0	29.90994	14.75776	15.58468	32.02716	21.71228	0	01/09/2009	10:30	EST
Sterling Forest	32.34953	16.30442	0	29.90778	14.55985	15.86419	32.34953	22.19749	0	01/09/2009	10:40	EST
Washington St.	32.6357	16.50289	0	29.90545	14.21209	16.06458	32.6357	22.69223	0	01/09/2009	10:50	EST
West 19th Street	32.90689	16.71198	0	29.90336	14.10013	16.27642	32.90689	23.07996	0	01/09/2009	11:00	EST
White Plains	33.1864	16.9568	0	29.90174	14.03074	16.52534	33.1864	23.46213	0	01/09/2009	11:10	EST
White Plains Airport (HPN)	33.50427	17.38287	0	29.90018	13.87227	16.75375	33.50427	23.92453	0	01/09/2009	11:20	EST
Yonkers	33.79549	17.36381	0	29.89857	13.82852	16.93569	33.79549	24.31343	0	01/09/2009	11:30	EST
Yonkers Stadium	34.07693	17.55641	0	29.89673	14.01818	17.13005	34.07693	24.60155	0	01/09/2009	11:40	EST
Yonkers Stadium	34.32995	17.73184	0	29.89477	14.1009	17.30716	34.32995	24.89315	0	01/09/2009	11:50	EST
Yonkers Stadium	34.55473	17.86035	0	29.89299	13.98614	17.436	34.55473	25.2178	0	01/09/2009	12:00	EST
Yonkers Stadium	34.78872	17.96585	0	29.89128	13.80827	17.54068	34.78872	25.58459	0	01/09/2009	12:10	EST
Yonkers Stadium	35.00965	18.05579	0	29.88943	13.66092	17.62945	35.00965	25.9159	0	01/09/2009	12:20	EST
Yonkers Stadium	35.206	18.12746	0	29.8877	13.58872	17.69976	35.206	26.19613	0	01/09/2009	12:30	EST
Yonkers Stadium	35.40472	18.18116	0	29.88576	13.55662	17.75131	35.40472	26.46045	0	01/09/2009	12:40	EST
Yonkers Stadium	35.60435	18.20238	0	29.88399	13.5748	17.76903	35.60435	26.70735	0	01/09/2009	12:50	EST
Yonkers Stadium	35.7744	18.18831	0	29.88236	13.64528	17.75062	35.7744	26.89764	0	01/09/2009	13:00	EST
Yonkers Stadium	35.91548	18.12927	0	29.87926	13.4893	17.686	35.91548	27.13387	0	01/09/2009	13:10	EST
Yonkers Stadium	36.10075	18.0559	0	29.87896	13.44984	17.60541	36.10075	27.38357	0	01/09/2009	13:20	EST
Yonkers Stadium	36.23728	17.96876	0	29.87774	13.59433	17.51151	36.23728	27.50434	0	01/09/2009	13:30	EST
Yonkers Stadium	36.33008	17.8503	0	29.87584	13.77521	17.38589	36.33008	27.55725	0	01/09/2009	13:40	EST
Yonkers Stadium	36.39177	17.74849	0	29.87363	13.79269	17.27828	36.39177	27.62948	0	01/09/2009	13:50	EST
Yonkers Stadium	36.42992	17.67133	0	29.87191	13.80742	17.19691	36.42992	27.67278	0	01/09/2009	14:00	EST
Yonkers Stadium	36.45201	17.59844	0	29.87037	13.71149	17.12032	36.45201	27.7351	0	01/09/2009	14:10	EST
Yonkers Stadium	36.45573	17.5443	0	29.86856	13.54967	17.06371	36.45573	27.79801	0	01/09/2009	14:20	EST
Yonkers Stadium	36.45409	17.51048	0	29.8671	13.33699	17.02844	36.45409	27.87328	0	01/09/2009	14:30	EST
Yonkers Stadium	36.44188	17.49884	0	29.8654	13.063	17.01658	36.44188	27.95802	0	01/09/2009	14:40	EST
Yonkers Stadium	36.41719	17.50963	0	29.86372	12.79695	17.02844	36.41719	28.02784	0	01/09/2009	14:50	EST
Yonkers Stadium	36.38223	17.53004	0	29.86246	12.60377	17.05056	36.38223	28.05744	0	01/09/2009	15:00	EST
Yonkers Stadium	36.33226	17.56227	0	29.86151	12.46244	17.08535	36.33226	28.04902	0	01/09/2009	15:10	EST
Yonkers Stadium	36.26385	17.60529	0	29.86059	12.30456	17.13182	36.26385	28.02448	0	01/09/2009	15:20	EST

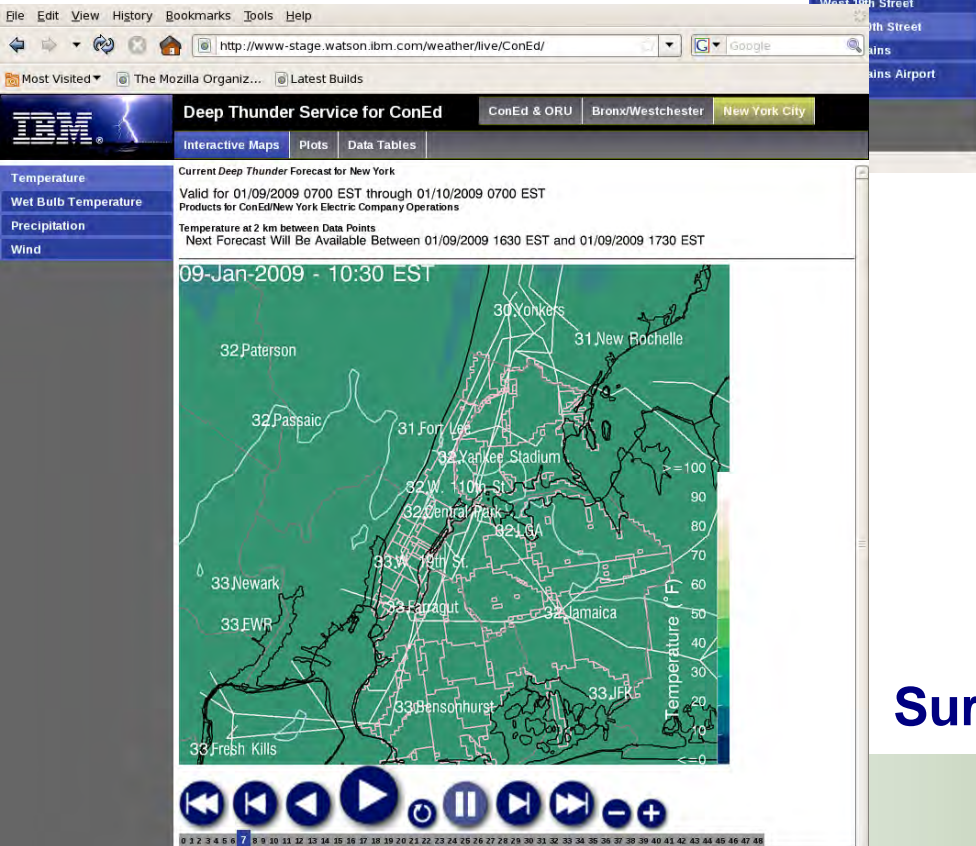
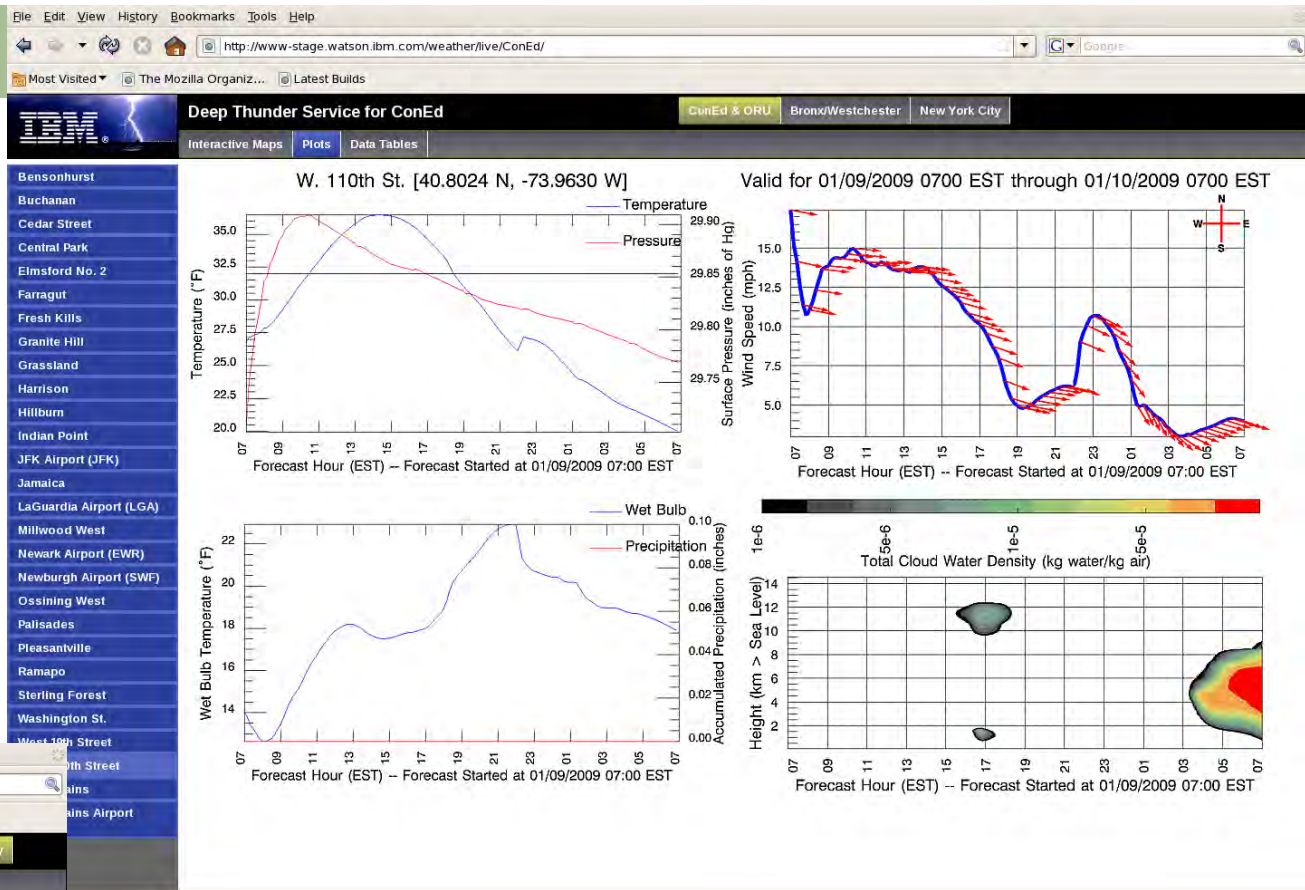
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Interactive Site-Specific Forecast Table





# 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