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# Operational Evaluation of a Mesoscale Weather and Outage Prediction Service for Electric Utility Operations

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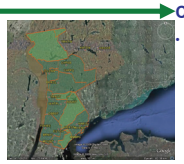
## Goals

- Predict the combination of weather conditions that can disrupt the electrical distribution network of overhead lines at the level of the substation area and the characteristics of those disruptions
- Enable sufficient precision and lead time for proactive allocation and deployment of resources to minimize time to repair
- Migrate from monitoring a storm to the ability to stage resources at the right place and time prior to the event to minimize the impact
- Implement as a service (IBM "*Deep Thunder*" or "DT") tailored for ConEd's requirements and evaluate its quality
- Quantify forecast uncertainty caused by various data sources and different modeling structures

## Initial Steps

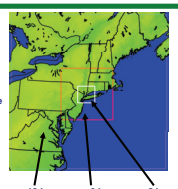
- **Meteorological analysis**
  - Characterize key historical events that impact utility operations
  - Use AWS/WeatherBug observing stations, anecdotal reports and public data to evaluate past forecasts and events
  - Employ results to tune and improve modelling
- **Impact analysis**
  - Characterize 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 Territory with Substation Areas and AWS/WeatherBug Stations

## Coupled Weather & Damage Modelling

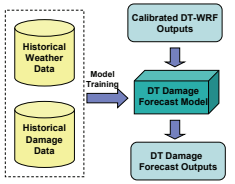
- **Meteorology: utilize WRF-ARW**
  - 18/6/2 km nested (76x76x42) at 2 km resolution across extended service area for 84 hours (i.e., at least 72 hours lead time)
  - NAM (12km) for background and boundary conditions and SST RTG (0.5°)
  - WSM 5-class microphysics, YSU PBL, NOAH LSM, Grell-Devenyi ensemble cumulus parameterization, urban canopy model, RRTM long-wave radiation, Goddard short-wave radiation
  - Assimilation of data from AWS/WeatherBug mesonet for initial conditions
  - Outages: spatial-temporal modelling to enable predictions of damage




Nested Domains for WRF-ARW

## Coupled Weather & Damage Modelling

- **Damage: custom modelling for predictions of outages**
  - A damage forecast model at the area substation level is developed using historical weather and outage data as well as infrastructure and environmental data by building a hierarchical Poisson regression model
  - DT "gust calculation" is developed via a statistical model using time series analysis based on historical wind forecasts and gust "observations"
  - Statistical hierarchical modeling integrates various data sources in one model and allows variances or uncertainties analyzed at different levels
- **Dissemination**
  - Tailored weather visualizations available via a web browser, including uncertainty
  - Automatically updated for each forecast cycle
  - Storm classification and outage estimation
  - E-mail alerting system




Data Flow for the *Deep Thunder* (DT) Damage Forecast Model

## Use of AWS/WeatherBug Mesonet

- More than 400 stations in 2km model domain that covers extended ConEd service territory – close sampling to model resolution
- Primary data include temperature, relative humidity, wind speed and direction, rainfall at 5 minute intervals
- Real-time data used for damage assessment during severe weather
- Historical data used for retrospective analysis, forecast verification and tuning
- Data also used to calibrate outage prediction model and other sensor data
- Model initialization will be improved as a future enhancement via three-dimensional variational data assimilation of near-real time data

AWS/WeatherBug Stations within the 2km WRF-ARW Nest

| RMSE | TEMP DAY 1 | TEMP DAY 2 | TEMP DAY 3 | WIND DAY 1 | WIND DAY 2 | WIND DAY 3 |
|---|---|---|---|---|---|---|
| BRNNY | 3.926 | 4.727 | 5.063 | 1.770 | 1.810 | 1.929 |
| CHPPQ | 3.471 | 4.146 | 4.661 | 1.194 | 1.173 | 1.216 |
| CHPSB | 4.433 | 5.296 | 5.549 | 1.834 | 1.869 | 1.907 |
| CRSSR | 3.676 | 4.450 | 4.675 | 1.442 | 1.451 | 1.516 |
| HARIS | 3.700 | 4.245 | 4.435 | 1.551 | 1.557 | 1.626 |
| HRRSN | 4.101 | 4.943 | 5.149 | 2.047 | 2.036 | 2.067 |
| MMBPC | 4.357 | 7.166 | 6.889 | 2.804 | 3.096 | 3.233 |
| MOUNT | 4.883 | 5.738 | 6.073 | 2.886 | 2.911 | 2.933 |
| RYENY | 3.697 | 4.392 | 4.587 | 2.218 | 2.158 | 2.233 |
| RYWSE | 4.612 | 5.142 | 5.182 | 2.114 | 2.050 | 2.112 |
| TRRYT | 3.936 | 4.470 | 4.716 | 2.048 | 1.992 | 1.996 |
| WHITPL | 4.536 | 4.620 | 4.369 | 1.671 | 1.723 | 1.726 |
| YORKS | 4.473 | 5.852 | 5.705 | 2.013 | 2.037 | 2.087 |
| YORTW | 4.121 | 7.894 | 7.389 | 1.223 | 1.462 | 1.353 |

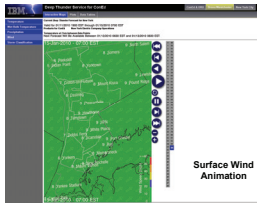
Example Monthly Forecast Statistics for DT (August 2009) vs. WeatherBug Observations

| RMSE | TEMP DAY 1 | TEMP DAY 2 | TEMP DAY 3 | WIND DAY 1 | WIND DAY 2 | WIND DAY 3 |
|---|---|---|---|---|---|---|
| BRNNY | 6.95 | 6.82 | 6.68 | 5.82 | 5.46 | 5.94 |
| CHPPQ | 7.95 | 7.78 | 7.59 | 5.66 | 5.37 | 5.91 |
| CHPSB | 8.24 | 8.04 | 8.14 | 4.99 | 4.86 | 5.16 |
| CRSSR | 7.94 | 7.8 | 7.79 | 5.49 | 5.18 | 5.66 |
| HARIS | 7.59 | 7.43 | 7.47 | 6.1 | 5.81 | 6.24 |
| HRRSN | 7.3 | 7.2 | 7.19 | 5.23 | 4.95 | 5.34 |
| MMBPC | 5.6 | 5.86 | 5.89 | 6.6 | 6.74 | 6.24 |
| MOUNT | 6.59 | 6.57 | 6.12 | 4.74 | 4.49 | 4.66 |
| RYENY | 7.22 | 7.06 | 6.98 | 5.26 | 4.96 | 5.4 |
| RYWSE | 6.79 | 6.77 | 6.61 | 5.52 | 5.19 | 5.63 |
| TRRYT | 7.03 | 7.01 | 6.83 | 4.98 | 4.72 | 5.13 |
| WHITPL | 7.05 | 6.78 | 6.75 | 5.18 | 4.94 | 5.46 |
| YORKS | 6.51 | 6.42 | 6.18 | 5.2 | 4.95 | 5.44 |
| YORTW | 8.03 | 8.02 | 8.41 | 4.91 | 5.02 | 5.22 |

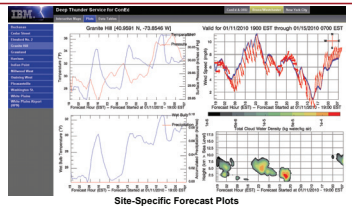
Example Monthly Forecast Statistics for 12km NAM (August 2009) vs. WeatherBug Observations

## Web-Based Dissemination

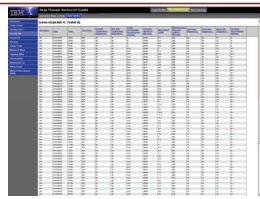
- Customized visualizations with ConEd infrastructure overlays
- Choice of geographic views of service territory
- Forecast plots and interactive tables at specific locations
- Alerts for outage and snow conditions with additional visualizations
- 84-hour forecast at hourly resolution and 24-hour forecasts at 10 or 20-minute resolution



Surface Wind Animation



Site-Specific Forecast Plots



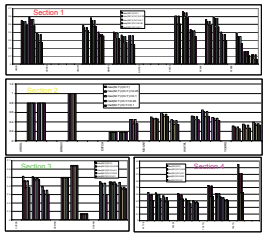
Interactive Site-Specific Forecast Table

## Verification of the Weather Model

- Focus on the ConEd Westchester County, NY service territory
- Compare weather model results with measurements from WeatherBug stations
- Analyze observations and identify any issues with measurements and sensors
- Use typical methods (i.e., RMSE to compare 84-hour WRF-ARW and NAM results with observations
- Create contingency tables to evaluate rainfall results within subsections of the service territory
- Utilize specific thresholds and ranges of relevance to decision makers in the verification
- Evaluate methods for potential application to verification of the outage prediction model

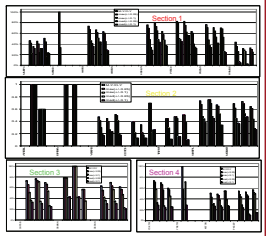

AWS/WeatherBug Stations and Subsections of the Service Territory

- Hourly rainfall data used to compute statistics
- Ratio of rain events when forecast time exactly matches observed time divided by all observed rain events within 2km
- HITS/(HITS+MISSES)




Example Daily Rainfall Subsection Statistics for October 2009 within 2 km of Each WeatherBug Station and Exact Timing of the Observed Event

- Hourly rainfall data used to compute statistics
- Ratio of rain events when forecast time is within three hours of the observed time divided by all observed rain events
- HITS/(HITS+MISSES)

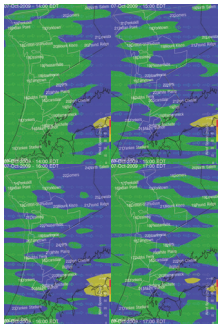



Example Daily Rainfall Subsection Statistics for October 2009 for the Location of Each WeatherBug Station and within 3 Hours of the Observed Event

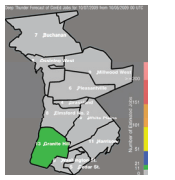
**See Related Presentations (Poster 521 Probability and Statistics; J11.3 Energy; J6.1 Socio-Economic)**

## Example Operational Forecast – 07 October 2009 Wind Event

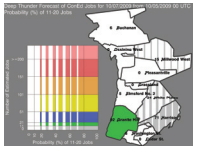
**Forecast and Outage Prediction Initiated with Data from 0000 UTC on 05 October 2009 (~60 hours lead time)**



Wind Forecast for Service Territory

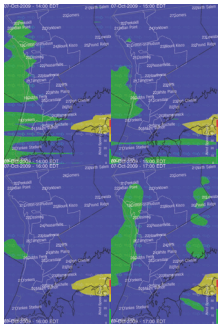


Prediction of Number of Repair Jobs per Substation Area

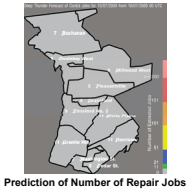


Probability of Number of Predicted Repair Jobs per Substation Area (Texturing of Outage Color Illustrates Probability with Value)

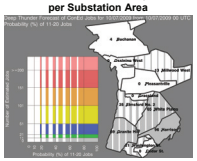
**Forecast and Outage Prediction Initiated with Data from 0000 UTC on 07 October 2009 (~12 hours lead time)**



Wind Forecast for Service Territory

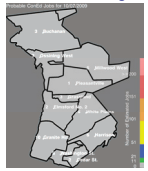


Prediction of Number of Repair Jobs per Substation Area

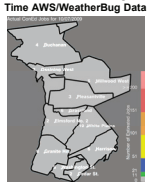


Probability of Number of Predicted Repair Jobs per Substation Area (Texturing of Outage Color Illustrates Probability with Value)

**Probable Outage Prediction and Actual Outages**



Probable Number of Repair Jobs per Substation Area Using Real-Time AWS/WeatherBug Data



Actual Number of Repair Jobs per Substation Area