571 On-Going Utilization and Evaluation of a Coupled Weather and Outage Prediction for Electric Distribution Operations 571

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Goals

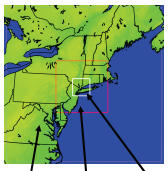
- Predict the combination of weather conditions that can disrupt the electrical distribution network of overhead lines at the level of the substation area and the characteristics of those disruptions
- Enable sufficient precision and lead time for proactive allocation and deployment of resources to minimize 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 an operational service (IBM "*Deep Thunder*") tailored for Consolidated Edison's requirements and evaluate its quality
- Quantify forecast uncertainty caused by various data sources and different modeling structures

Approach and Issues

- **Meteorological analysis to create and improve predictive models**
  - Characterize key historical events and aspects of weather that impact utility operations
  - Use Earth Networks WeatherBug observing stations, anecdotal reports and public data to evaluate forecasts and events
- **Impact analysis**
  - Characterize key historical events from the utility's perspective
  - Use Consolidated Edison's damage data, outage reports, infrastructure data, etc.
- **Uncertainty quantification of multiple data sources (not just meteorological)**
- **Wind Gusts Are a Primary Driver for Outages**
  - Storm-driven disruptions of the overhead electric distribution network (e.g., poles and wires) are caused by physical interaction of the atmosphere with that infrastructure or nearby trees
  - Reliable NWP at this turbulence scale with sufficient throughput for operational utilization is neither tractable from a computational perspective nor verifiable from observations
  - Ensemble NWP cannot capture uncertainty related to impacts
  - Therefore, outage prediction must be approached stochastically by post-processing NWP

Coupled Weather and Outage Modelling

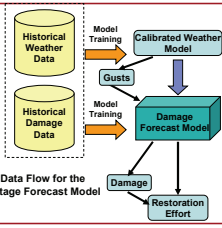
- **Meteorology: WRF-ARW 3.1.1**
  - 18/6/2 km nested (76x76x42) across extended service area for 84 hours since April 2009 twice daily (initialized at 00 and 12 UTC)
  - NAM (12km) for background and boundary conditions, and SST RTG (0.5°)
  - WSM 6-class microphysics, YSU PBL, NOAH LSM, Grell-Devenyi ensemble cumulus parameterization, urban canopy model, RRTM long-wave radiation, and Goddard short-wave radiation
- **Dissemination**
  - Tailored weather visualizations (animated maps) available via a web browser with Consolidated Edison infrastructure overlays
  - Choice of geographic views of service territory
  - Forecast plots and interactive tables at specific locations
  - Automatically updated for each forecast cycle
  - 84-hour forecasts at hourly resolution and 24-hour forecasts at 10 or 20-minute resolution



Nested Domains for WRF-ARW

Coupled Weather and Outage Modelling

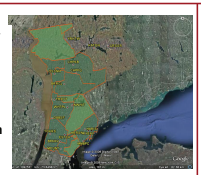
- **Damage: custom modelling for predictions of outages**
  - An outage forecast model at the area substation level was developed using historical weather and outage data as well as infrastructure and environmental data by building an hierarchical quasi-Poisson regression model
  - A daily gust maximum estimate was developed via a statistical model using time series analysis and extreme value theory based on historical wind forecasts and gust observations
  - Statistical hierarchical (Bayesian) modeling integrates various data sources in one model and allows variances or uncertainties analyzed at different levels
- **Dissemination**
  - Tailored visualizations of restoration effort for outages available via a web browser, including uncertainty
  - E-mail alerting system for outage and snow conditions

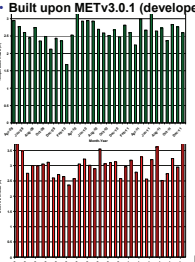


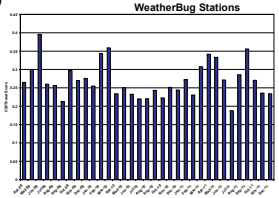
Data Flow for the Outage Forecast Model

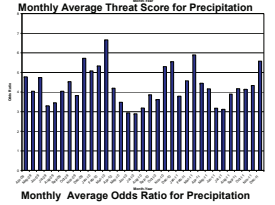
Verification of the Weather Model

- Focus on the ConEd Westchester County, NY service territory
- Compare weather model results with measurements from ~25 Earth Networks WeatherBug stations (bi-linear interpolation)
- Analyze observations and identify any issues with measurements and sensors
- Create contingency tables to evaluate rainfall results
- Utilize specific thresholds and ranges of relevance to decision makers in the verification
- Use typical methods for continuous (i.e., RMSE) and categorical data (e.g., Threat Score (Critical Success Index))
- Evaluate use of spatial methods
- Built upon METv3.0.1 (developed at NCAR DTC)


Utility Service Territory with Substation Areas and Earth Networks WeatherBug Stations


Monthly Average Forecast Statistics for Temperature, Dew Point and Wind Speed

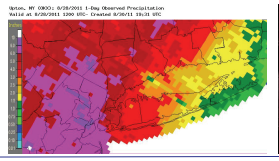

Monthly Average Threat Score for Precipitation


Monthly Average Odds Ratio for Precipitation

See Related Presentations (3.2 Energy; 10A.4 IIPS; TJ25.6 Research to Ops; 4.5 Hydrology; 3B.2 IIPS)

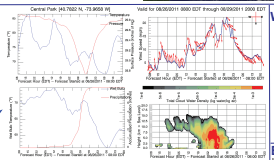
Example Operational Forecasts – Tropical Storm Irene – 28 August 2011

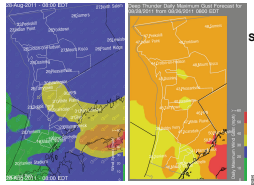
- Sustained winds 40 to 52 mph with gusting 60 to 90 mph and heavy rains (over 10" in some areas)
- Innumerable downed trees and power lines, and local flooding and evacuations
- Electricity service lost to about 1M residences and businesses (half of CT)
- Widespread disruption of transportation systems (e.g., road and bridge closures, airport and rail delays)
- Others forecasted storm as Category 1 or 2 but actually tropical storm at landfall
- Hence, expectation of much greater impacts of wind, and far less impact from heavy rainfall
- Event covered by six operational forecasts



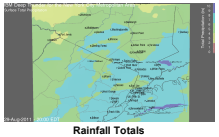
Weather and Outage Prediction Initiated with Data from 1200 UTC on 26 August 2011 (~two days lead time)

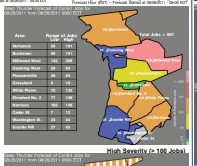
- Forecast showing tropical storm not hurricane strength at landfall
- Heavy rainfall predicted with similar distribution to reported rainfall
- Initiated with data from 0800 EDT on 8/26 with results available in the late afternoon
- Shows rainfall beginning in parts of New York City in the early morning on 8/27 and ending the afternoon of 8/28
- Sustained winds well below hurricane strength

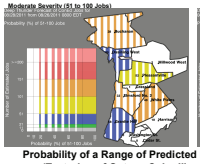

Site-Specific Forecast for Central Park


Maximum Sustained Wind

Maximum Daily Gust


Rainfall Totals

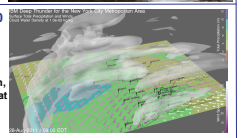

Prediction of Number of Repair Jobs per Substation Area


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

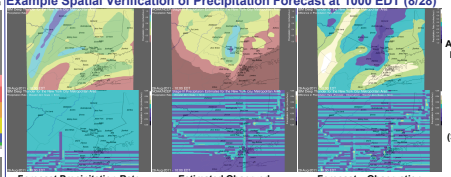
Weather and Outage Prediction Initiated with Data from 1200 UTC on 27 August 2011 (~one day lead time)

- Fourth of six operational forecasts covering the event confirming the earlier forecast of tropical storm not hurricane strength at landfall and showing the track to the north
- Shows rainfall beginning in parts of New York City in the evening on 8/27 and ending the afternoon of 8/28

Visualization of Forecasted Clouds, Wind and Precipitation, including Rain Bands at Landfall



Example Spatial Verification of Precipitation Forecast at 1000 EDT (8/28)


Actual Data

Haar Wavelet at 4km Scale (> 5mm/hour Precipitation Rate)

Forecast Precipitation Rate

Estimated Observed Precipitation Rate

Forecast – Observation Precipitation Rate

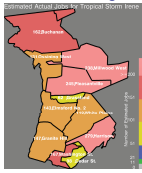
- Grid-based: assuming NCEP Stage-IV at 4.7km resolution is accurate estimate of actual precipitation, then forecast has a CSI of 0.647 and an intensity ratio of 0.771 (top row of images, above)
- Wavelet-based decomposition of precipitation intensity and spatial scale (table to the right with intensity skill scores for 12 UTC 8/27 – 12 UTC 8/28, with red ones being dominant) using Haar filter
- Examples of a dominant (5mm/hour) intensity and dominant (4km) scale (bottom row of images, above)

Wavelet Intensity Scale (mm/hour)

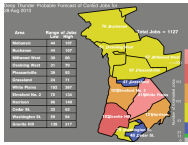
Wavelet Spatial Scale (km)	0	2.5	5	7.5	10
256	-3.30033	-1.42392	-0.85539	-0.45487	-0.24995
128	0.55117	0.23661	0.48810	0.43698	-0.04489
64	0.66926	0.25180	0.22658	0.07714	-0.11880
32	0.76660	0.65126	0.42576	0.34675	0.07081
16	0.85640	0.70255	0.58384	0.46648	0.43883
8	0.83845	0.83295	0.73974	0.65910	0.59638
4	0.61280	0.84197	0.77715	0.73530	0.66890
2	0.19934	0.29903	0.34067	0.32384	0.19304

Probable Outage Prediction and Actual Outages

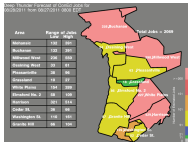
Actual Number of Repair Jobs per Substation Area (Total = 1953)

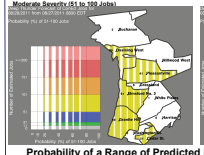


Probable Number of Repair Jobs per Substation Area Using Real-Time WeatherBug Data (Estimates are Low Due to Down Stations)



Prediction of Number of Repair Jobs per Substation Area

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