Using RADAR in Real-Time Response for Restoration of Electric Utility Systems

NYSERDA Project 41310

April 14, 2016

BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

U.S. DEPARTMENT OF ENERGY | Office of Science

Background

- Utility grid systems are particularly vulnerable to severe weather events.
- Currently available tools for preparation and recovery from severe weather events have limited capability.
  - Long term planning: Severe weather impacts usually are not considered
  - Recovery: Outage management systems (OMSs) are passive and suffer from the untimely and inaccurate outage reported and a lack of analytic capabilities for predicting weather impacts and dispatching repair crews in a preemptive manner.
- High-resolution **weather radar** data is readily available and can be used to improve outage predictions

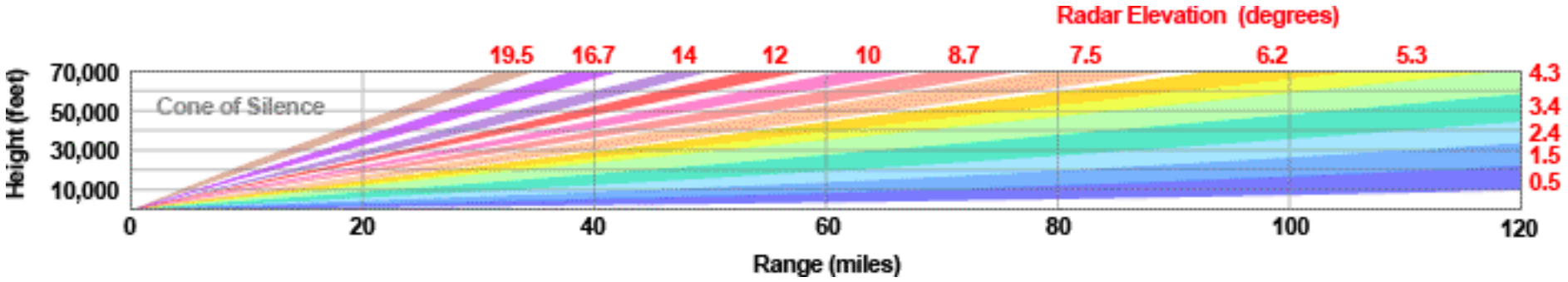
Proposed Solution

- Use high-resolution (time and space) weather radar observations to build statistical-predictive models of weather-related outages for different grid components.
- Develop an innovative Bayesian update approach to synthesizing the statistical outage prediction model and the known outage numbers to better predict the outages
- Focus on summertime convective storms for local utility partners (O&R, CHGE).
- Demonstrate applications for outage forecasting, targeted resource deployment and system hardening.

Weather Radar Observation – The Basics

http://www.crh.noaa.gov/

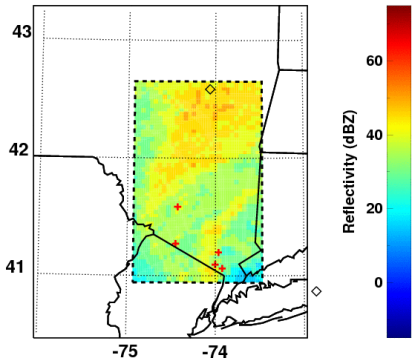
- Transmit a pulse of electromagnetic energy (10 cm)
- Scattered by targets (raindrops, snowflakes, hail, birds, bugs)
- Small amount of energy is scattered back to radar
- Measure power, time, frequency, polarization
- Scans a 3-D volume of atmosphere



NEXRAD Radar Observations

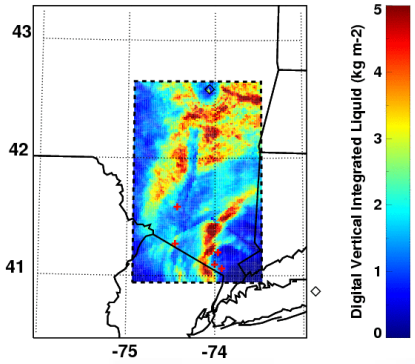
Reflectivity

Tells us about precipitation intensity



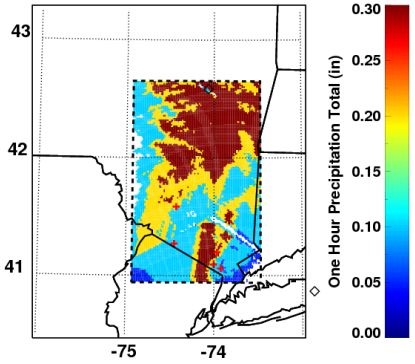
Vertically Integrated Liquid

Related to depth of storm



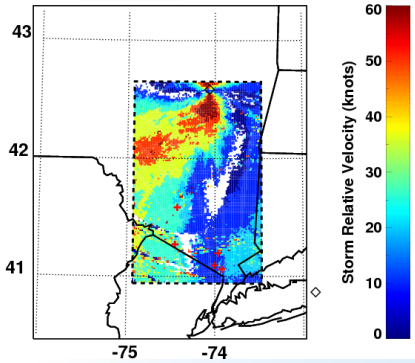
Precipitation Accumulation

Tells us about precipitation amount



Storm Velocity Mask

Tells us something about wind speed



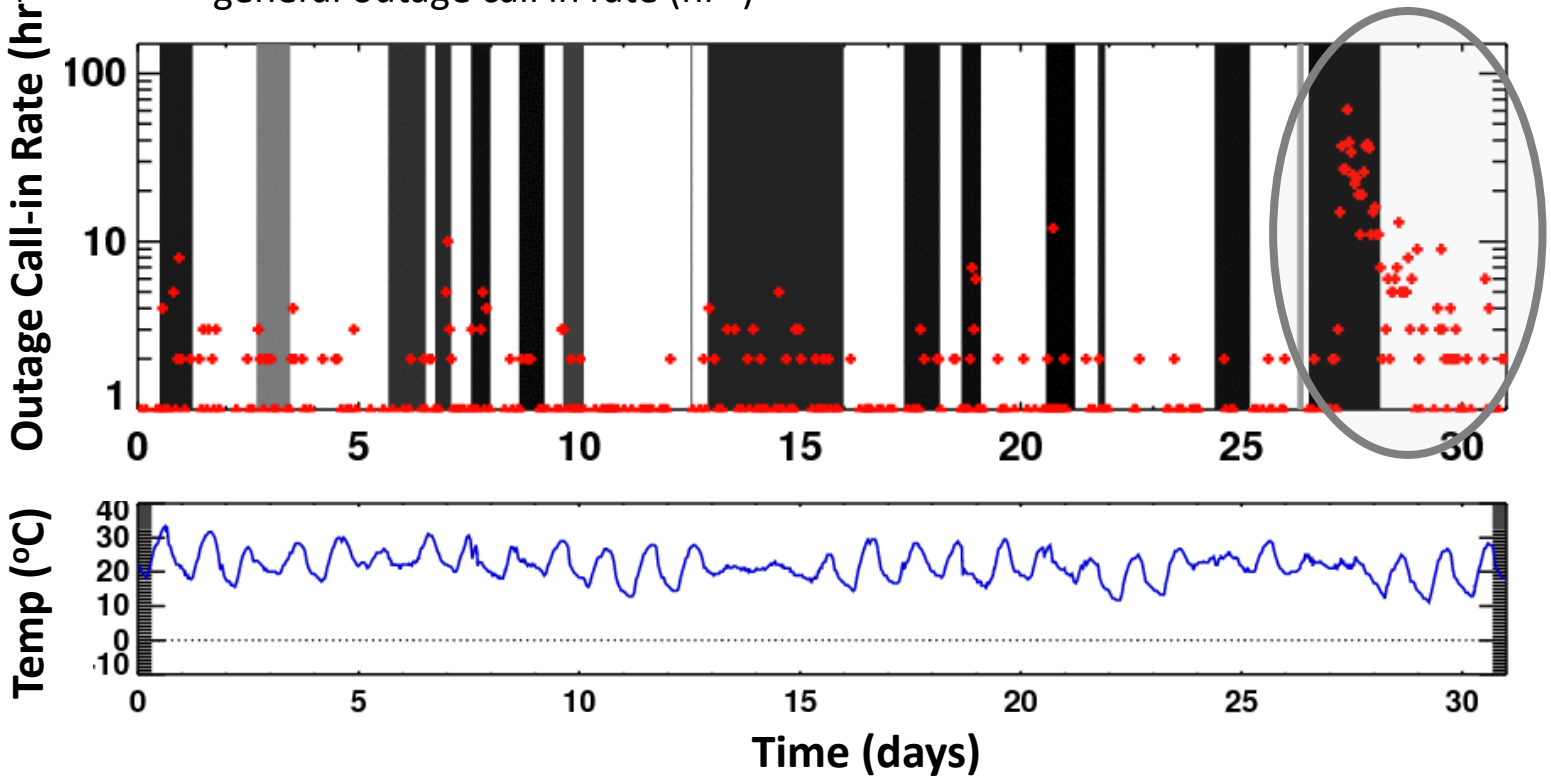
- 10 years of historical NEXRAD storm data
- ~2km spatial and ~5-min time resolution

Storm-related Utility Outages (1)

Time series of storm activity within Orange & Rockland (OR) and Central Hudson service areas along with outage data within the OR service area, for August, 2011

Shaded areas = storm activity identified by radar reflectivity measurements

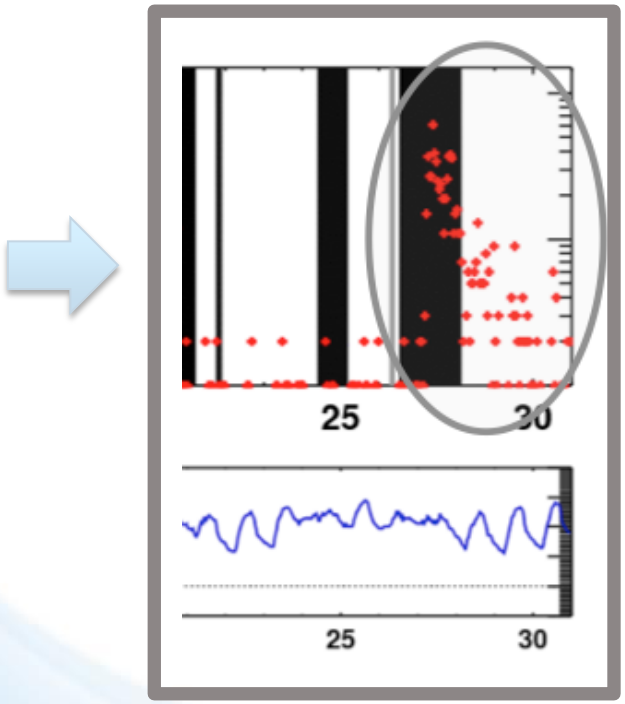
\+ = general outage call in rate (hr^{-1})



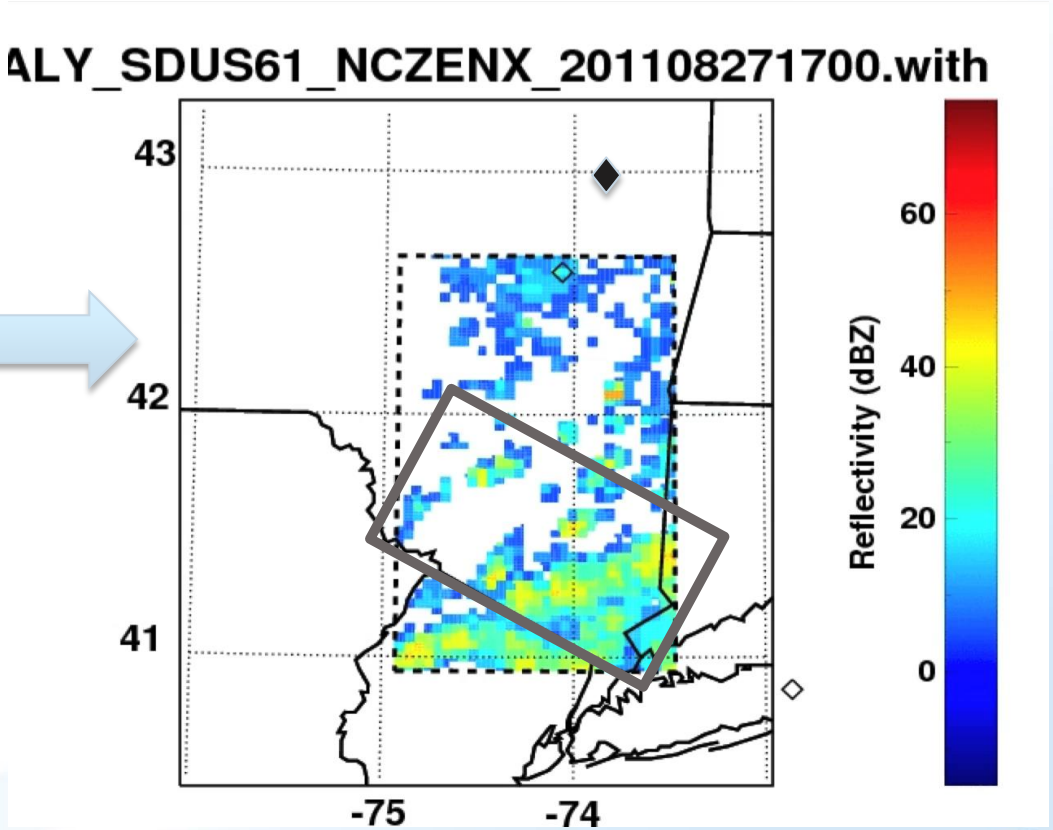
Storm-related Utility Outages (2)

Outages (+) broken out by:

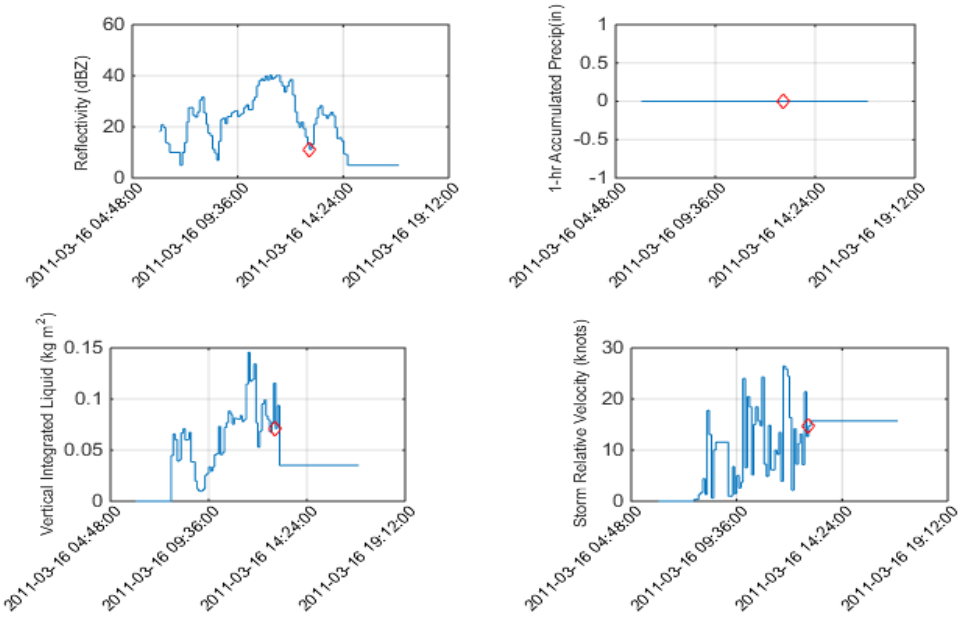
- **geographical location**
- **component type**
- **storm intensity**



Storm and Outages
August 27, 2011 17:00 UTC –
August 28, 2011 23:59 UTC



Regression Model



- The radar covered area was divided into 100 small areas and radar measurement was extracted for each of the small areas along the timeline of the storm development.

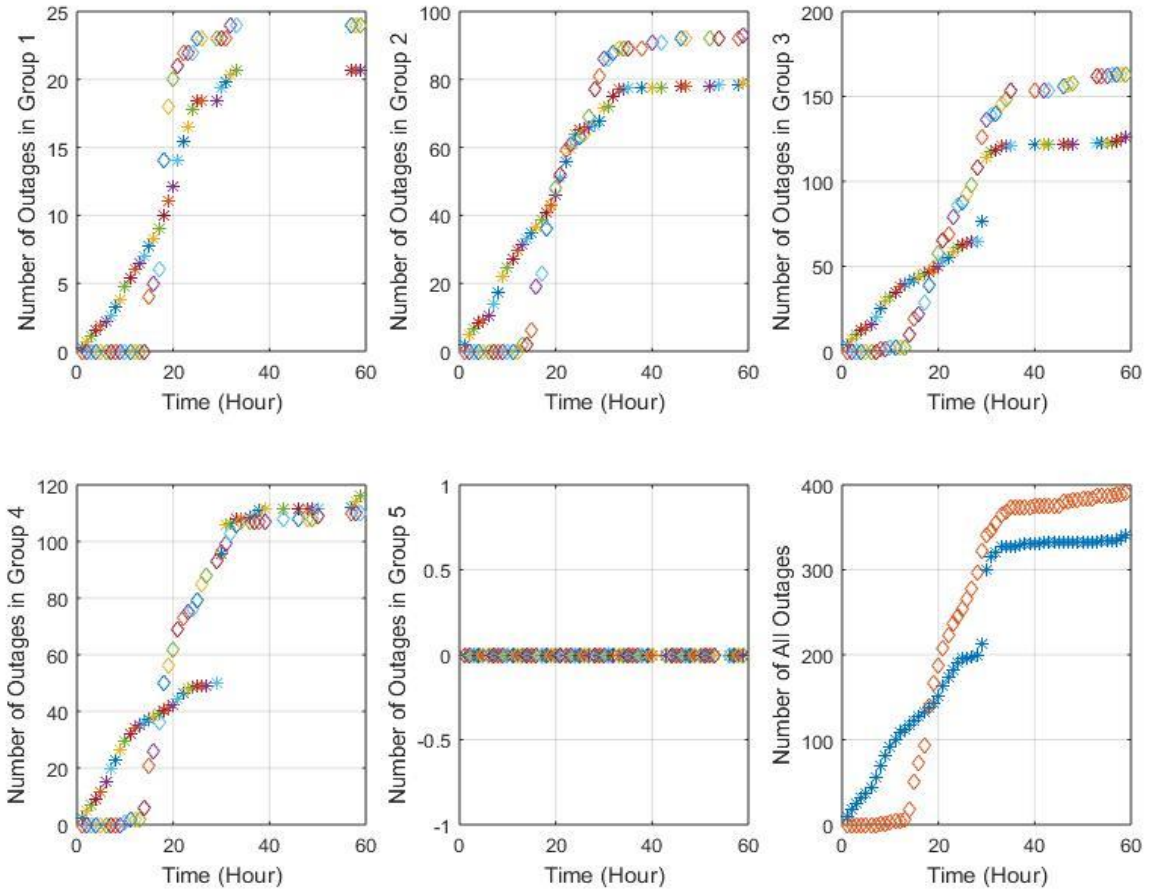
- Regression models were developed for different types of components:

$$\log \lambda_i = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4$$

λ_i =Type i component failure rate, X_1=Reflectivity, X_2=Total Precipitation, X_3=Doppler velocity, X_4=Temperature.

- The failure rate model, based on the very high resolution radar data, take into account the “dynamics” of the weather condition variation

Outage Calculation Using Radar Measurement Data: Failure Rate Model Only



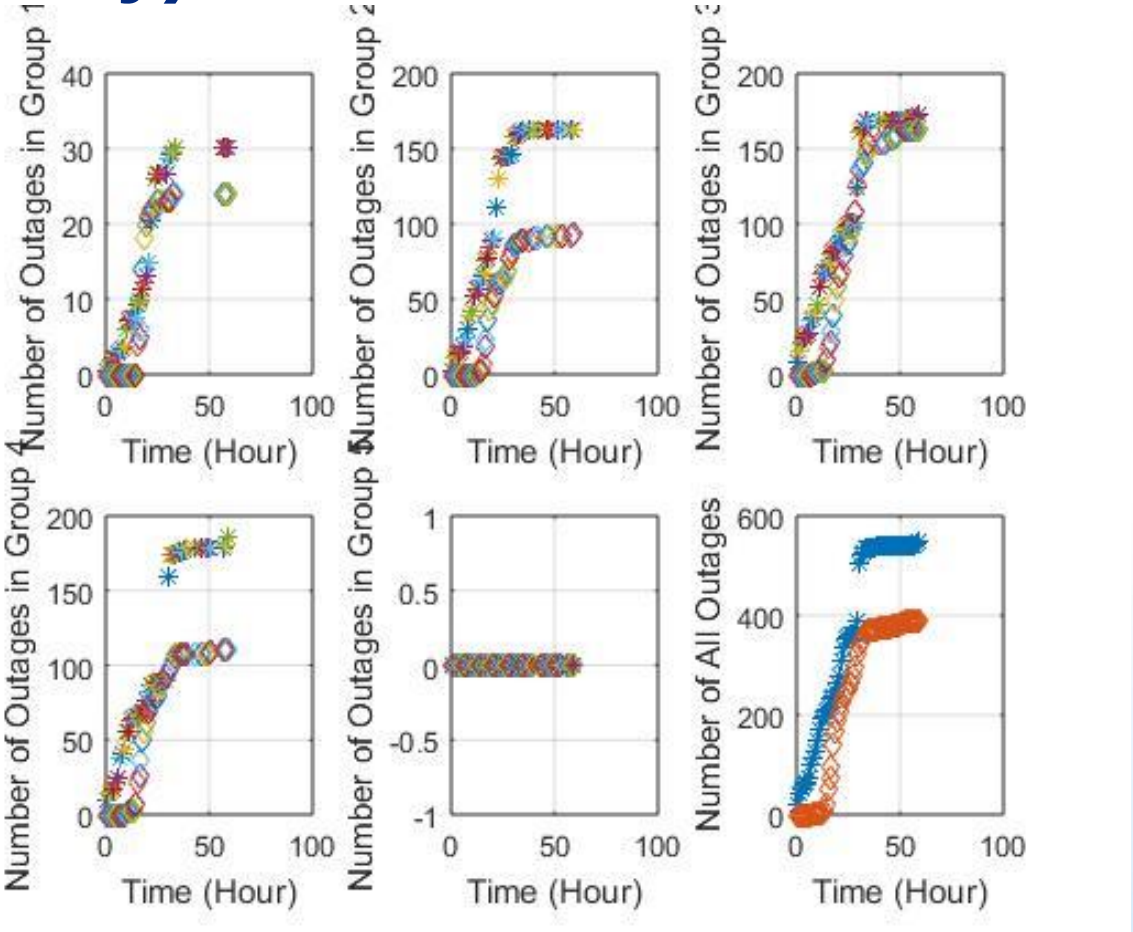
OH Cable Outage Hourly Estimation in a Storm in August, 2011: Diamonds for Actual Outages and Stars for Calculated Outages

- The total number of outages exceeds 400 and most of the outages are OH cable related;
- The outage prediction was performed for five areas of the utility service territory;
  - Inputs: Hourly weather condition data and utility's component inventory.
  - Output: Hourly evolution of OH outages in different areas.

Issues with Using Failure Rate Model Only

- Works better for severe storms that may cause a large number of outages and longer term prediction due to its statistical nature
  - Error of outage prediction can be fairly large for mild storms that cause very few outages
- Does not deal with the inherent uncertainties with data of weather forecasting
- Does not make use of known outages when predicting the outages within the next forecasting window

Outage Prediction Using Pseudo Weather Forecasting Data (Up to ±50% Uncertainty): Failure Rate Model Only



OH Cable Outage Hourly Estimation in a Storm in August, 2011 : Diamonds for Actual Outages and Stars for Predicted Outages

A Bayesian Update

- In short-term forecasting, known outages can provide valuable information about the status.
  - Care must be taken when using this knowledge: the reported outages can be significantly different from what actually occurred due to untimely and inaccurate reporting of outages and “nested outages” that is unique to distribution systems
- A Bayesian approach is developed for better predicting outage numbers within the short forecasting time window using both failure rates and known outage numbers
  - This approach is capable of accounting for confidence levels or belief on both types of uncertainties.

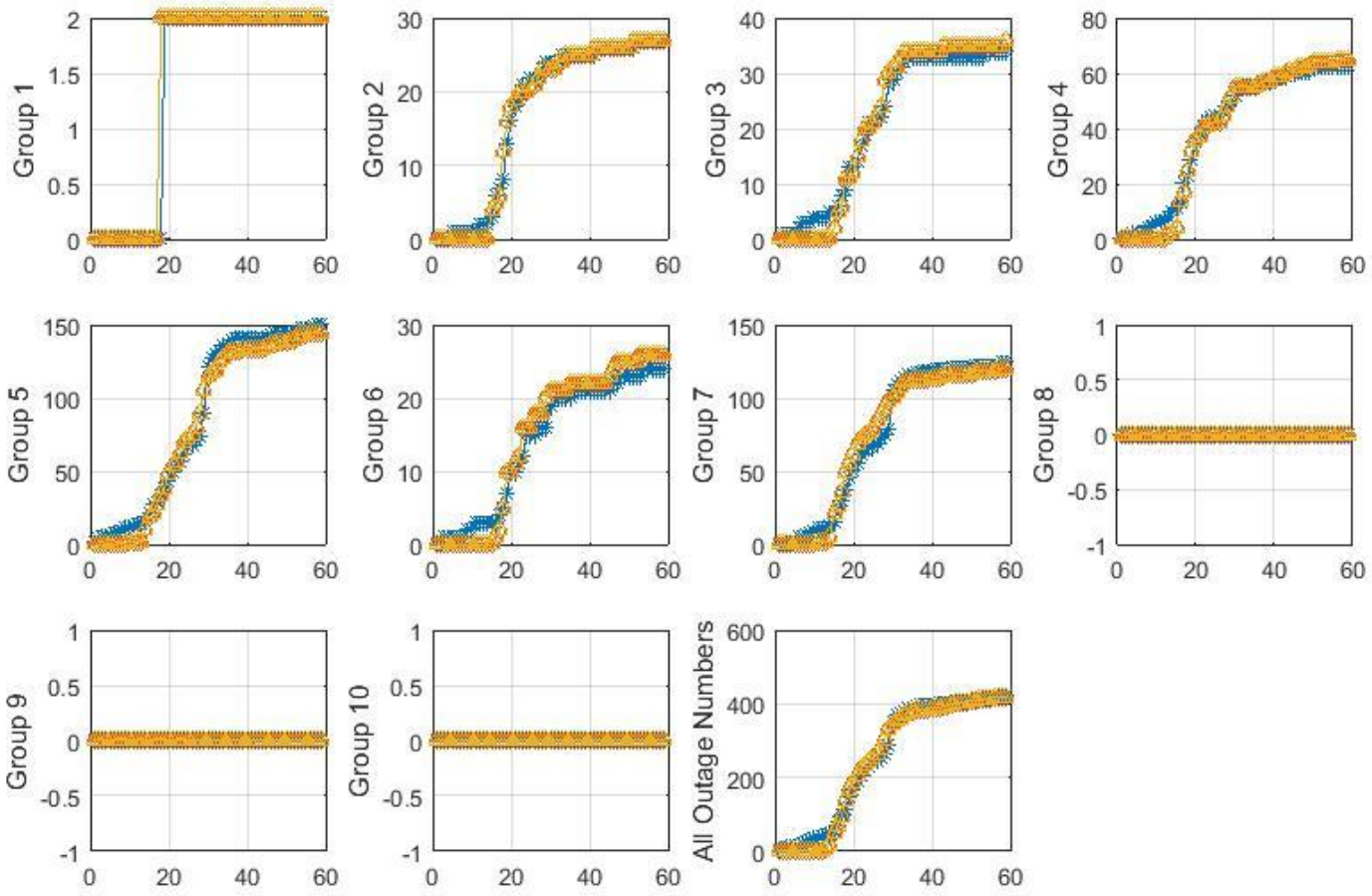
A Bayesian Update (cont'd)

- A Bayesian update approach consists of three steps
  - the selection of prior distributions
  - construction of likelihood functions, and
  - estimation of the posterior distributions using Bayes' theorem.

$$f_{post}(\lambda(t)) \propto likelihood(\lambda(t)) \times f_{prior}(\lambda(t))$$

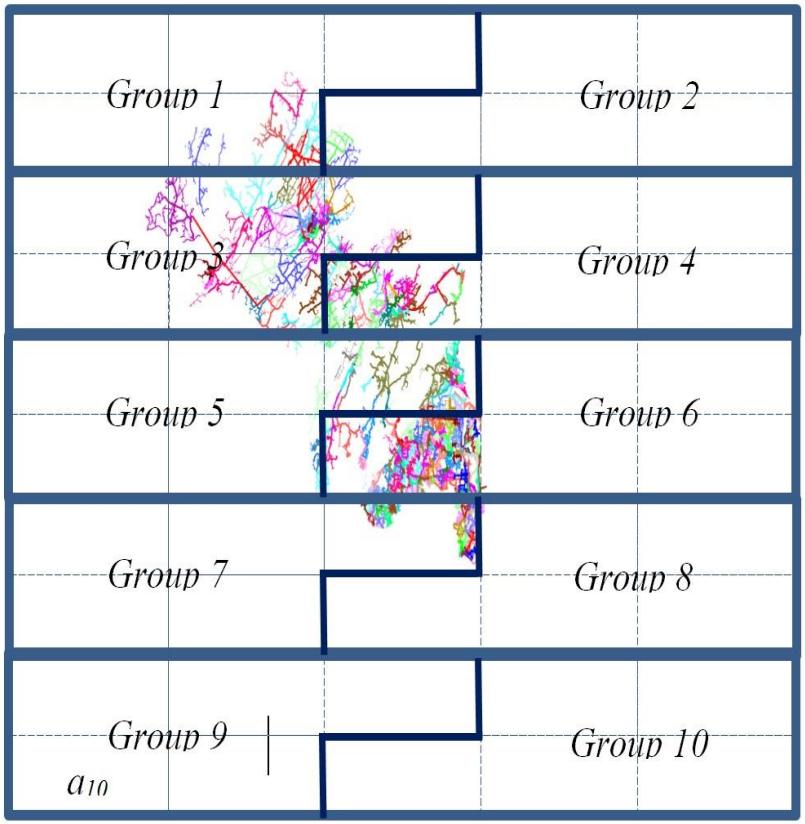
- Assuming the process of failure occurrences can be described by a non-homogeneous Poisson process (NHPP), i.e., the rate of failure occurrence changes with time
  - Using the known outage data to update the failure rate for prediction in next forecasting time window

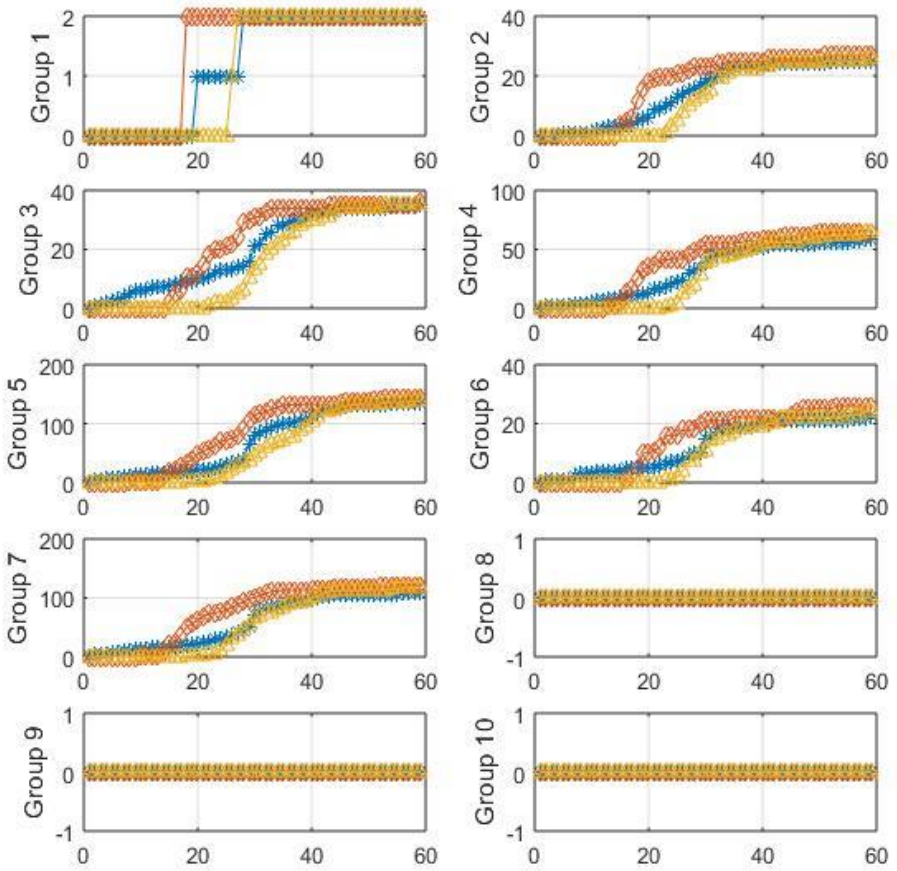
Bayesian Outage Prediction Using Pseudo Weather Forecasting Data (Up to ±30% Uncertainty)



OH Cable Outage Hourly Estimation in a Storm in August, 2011 : Diamonds for Actual Outages (and Reported Outages) and Stars for Predicted Outages

Bayesian Outage Prediction Using Pseudo Weather Forecasting Data (Up to ±30% Uncertainty) and Inaccurate Outages Reported





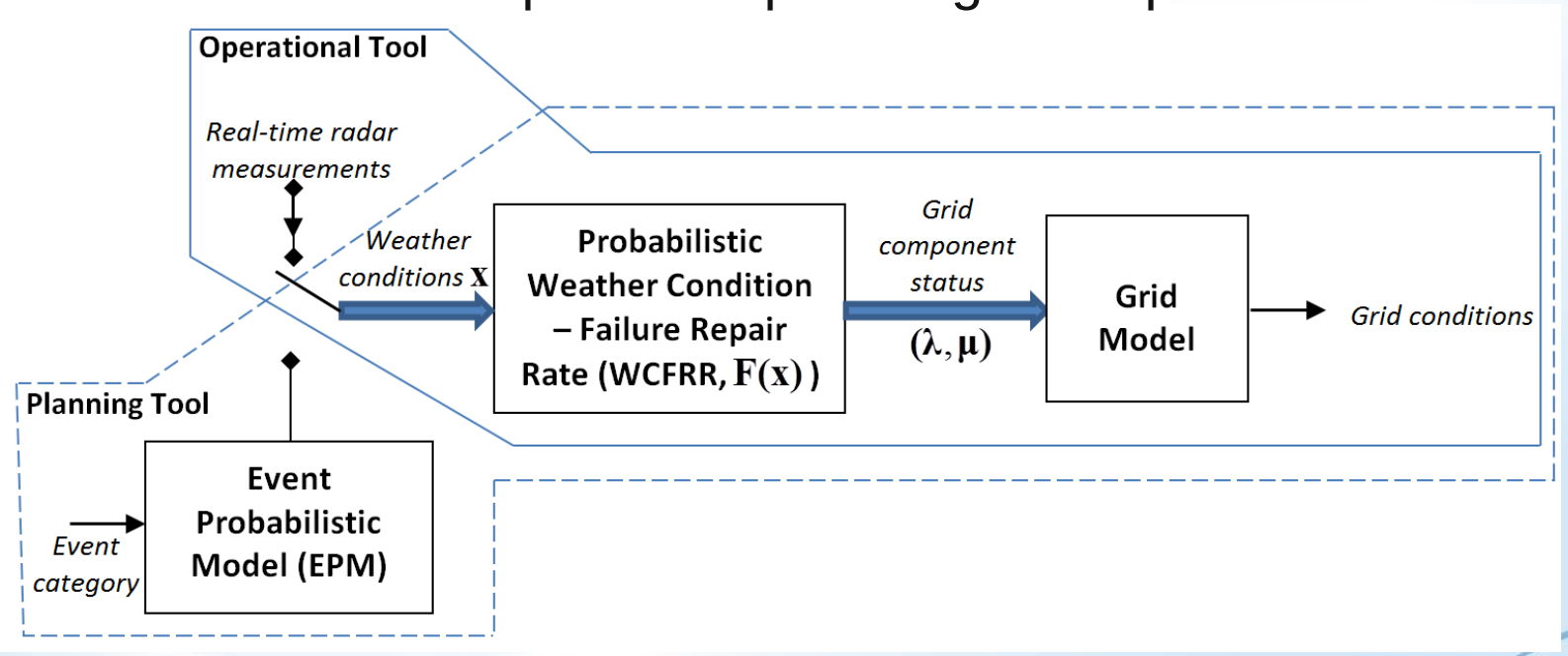
OH Cable Outage Hourly Estimation in a Storm in August, 2011 : Diamonds for Actual Outages, Triangles for Reported Outages, and Stars for Predicted Outages

Sample Results

- The number of outages is determined by both the total number of components and the weather conditions in different areas of the service territory.
- Northeastern storms can cost utilities approximately $120,000 per hour in restoration and may involve 100 or more crews.
- The storm-induce outage prediction scheme can
  - give a better picture of the outage distribution in the system within the forecasting time window and
  - enable the strategic positioning of the crews and reduce the storm restoration time and cost.

Next Steps in Future Program

- Develop algorithms to reduce the uncertainty of outage reporting using available measurements from, e.g., SCADA, AMI, μPMUs et al
- The weather dependent failure rate models can be used in a framework for development of planning and operational tools



Summary

- Need for improved tools for the prediction of storm-related utility outages for restoration and resiliency.
- BNL developed a process to use high-resolution (time and space) radar observations to predict grid component outages.
- The outage predictions can be used by utility operators to improve restoration times and reduce cost
- Preliminary results indicate improved outage forecasting can be obtained using radar observations as input.
- Operational and planning tools can be built based on the outage prediction scheme.
- Accuracy of short-term weather forecasting will be further investigated.