OUTLINE

Brief Overview of Argonne

What is HEADOUT?

How is HEADOUT Used?

How does HEADOUT Work?

Puerto Rico And Hawaii

HEADOUT User Feedback

Argonne
NATIONAL LABORATORY

BRIEF OVERVIEW OF ARGONNE

- Part of the U.S. Department of Energy (DOE) laboratory complex of 17 National Laboratories
- Managed by UChicago Argonne, LLC
- Main site: 1500-acre site in Illinois, southwest of Chicago
- Diverse basic and applied research portfolio

$750M

OPERATING BUDGET IN 2017

3,200+

EMPLOYEES IN 2017

8,300+

EXTERNAL USERS OF RESEARCH FACILITIES

WHAT IS HEADOUT?

HURRICANE ELECTRICAL ASSESSMENT DAMAGE OUTAGE TOOL (HEADOUT) OVERVIEW

- HEADOUT originally developed in 2013 as quick turn-around tool for DOE to estimate number of electric customers at-risk of electric outage by Census Tract, County, and State from tropical cyclones

- Typically applied 3 days before landfall

- Recently peer-reviewed as part of DOE's Grid Modernization Initiative and down-selected as **DOE's ONLY** hurricane impact model

- Future versions will identify bulk assets at-risk (electric, oil and gas, communications) and cover other hazards and threats

U.S. DEPARTMENT OF ENERGY | Infrastructure Security & Energy Restoration
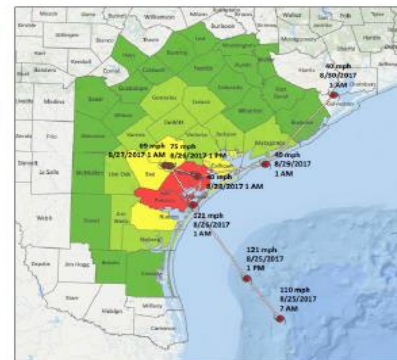
Hurricane Harvey
Situation Report (Report #1)

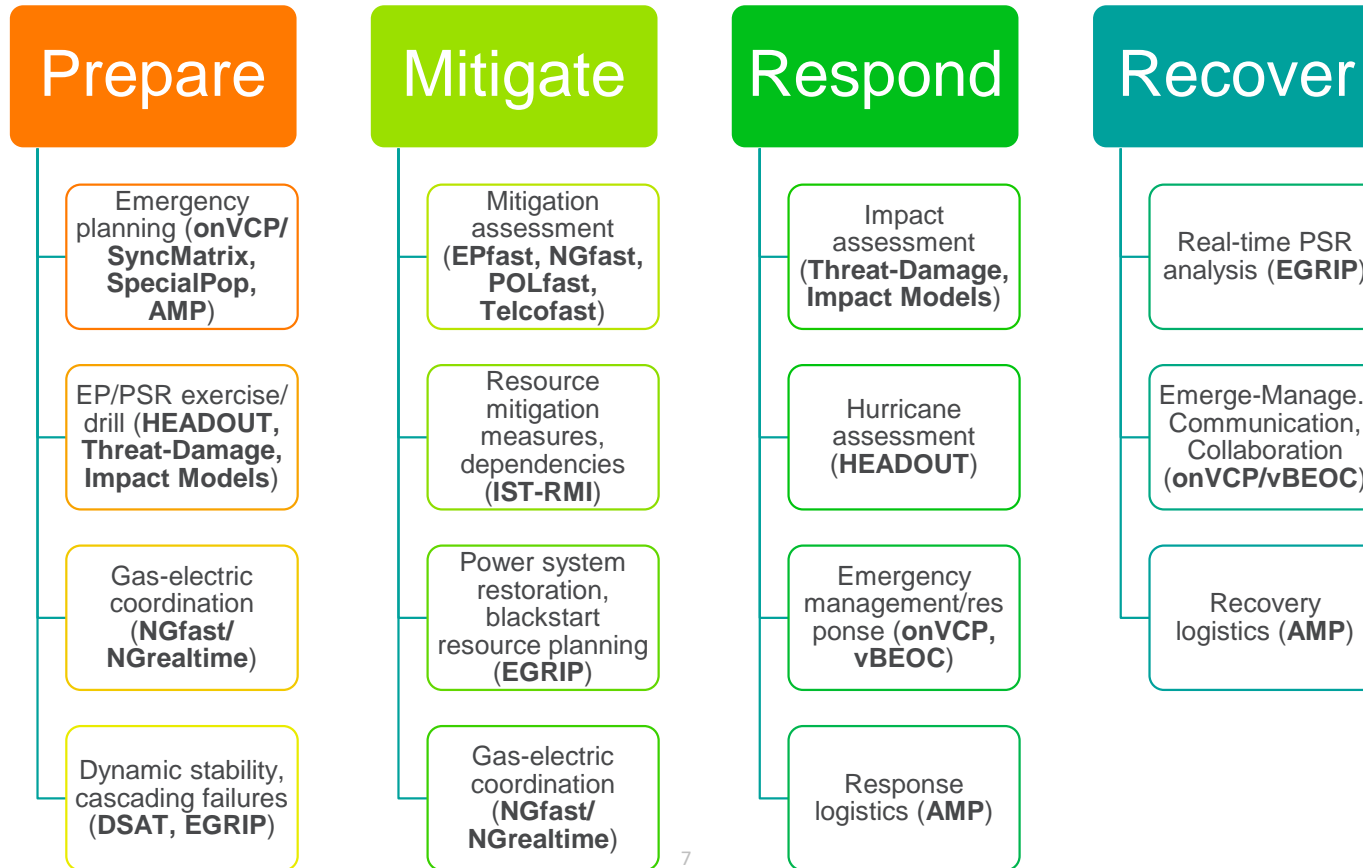| REPORT TIME & DATE: | 8:30 AM EDT | Friday, August 25, 2017 |
INCIDENT START DATE:	Friday, August 25, 2017
ISER POC:	Matthew Tarduogno (202-586-2892 // Matthew.Tarduogno@hq.doe.gov)
PRIMARY LOCATION(S):	Gulf Coast (Texas and Louisiana)
THROUGH:	Deputy Assistant Secretary Devon Streit
REPORT DISTRIBUTION:	DOE, Federal, and State

EXECUTIVE SUMMARY
The Gulf Coast of Texas and portions of Louisiana are preparing for impacts from Hurricane Harvey, a Category 2 storm, forecast to make landfall late Friday or early Saturday evening. Electric utilities in the projected impacted area have initiated preparedness efforts and are expecting power outages across the affected area. As of Wednesday afternoon 9.6% of the oil production 14.7% of the natural gas production in Gulf of Mexico are shut-in as a precaution in anticipation of the storm. The five main refineries in the Corpus Christi area also reported they were in the process of shutting down in advance of Harvey.

At this time the DOE Argonne National Lab power outage prediction model estimates that there will be approximately 176,000 outages across Texas, with the highest percent of outages in Aransas, Refugio, San Patricio, and Nueces counties.

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HEADOUT IS PART OF ARGONNE'S SUITE OF TOOLS FOR RESILIENCE MODELING/PLANNING

Prepare

- Emergency planning (**onVCP/ SyncMatrix, SpecialPop, AMP**)
- EP/PSR exercise/ drill (**HEADOUT, Threat-Damage, Impact Models**)
- Gas-electric coordination (**NGfast/ NGrealtime**)
- Dynamic stability, cascading failures (**DSAT, EGRIP**)

Mitigate

- Mitigation assessment (**EPfast, NGfast, POLfast, Telcofast**)
- Resource mitigation measures, dependencies (**IST-RMI**)
- Power system restoration, blackstart resource planning (**EGRIP**)
- Gas-electric coordination (**NGfast/ NGrealtime**)

Respond

- Impact assessment (**Threat-Damage, Impact Models**)
- Hurricane assessment (**HEADOUT**)
- Emergency management/res ponse (**onVCP, vBEOC**)
- Response logistics (**AMP**)

Recover

- Real-time PSR analysis (**EGRIP**)
- Emerge-Manage., Communication, Collaboration (**onVCP/vBEOC**)
- Recovery logistics (**AMP**)

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HOW IS HEADOUT USED?

HOW IS HEADOUT USED?

- Real-time operational support for government agencies and electric industry

- Training and exercise support for grid operators and government

- Long-term grid planning for DOE as part of North American Resilience modeling effort

Irma Electricity Outage Predictions (as of 8:00 AM EDT Friday)

The DOE Argonne National Lab power outage prediction model estimates that there will be approximately 5,378,000 customer outages across Florida, based on the 7:00 AM EDT Forecast from the National Hurricane Center on September 8. The map shows percent of customer outages estimated by county.

U.S. DEPARTMENT OF ENERGY | Infrastructure Security & Energy Restoration
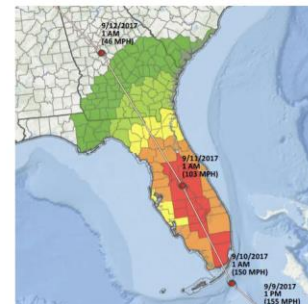
Hurricane Irma & Hurricane Harvey Recovery

Situation Report (Report #29)

| REPORT TIME & DATE: | 8:30 AM EDT | Friday, September 8, 2017 |
|---|---|
| INCIDENT START DATE: | Friday, August 25, 2017 |
| ISER POC: | Gail Miller (202-587-6843// gail.miller@hq.doe.gov) |
| PRIMARY LOCATION(S): | Irma: Leeward Islands // Harvey: Gulf Coast (Texas and Louisiana) |
| THROUGH: | Deputy Assistant Secretary Devon Streit |
| REPORT DISTRIBUTION: | DOE & Federal Agencies |

MISO powers hurricane preparedness with cutting-edge science

June 28, 2018 by Mark Brown

Partnership with Argonne National Laboratory supports realistic exercise

The official 2018 Atlantic hurricane season began June 1, and National Weather Service forecasters say it could be another active year, following a "devastating" 2017 season.

The Midcontinent Independent System Operator, with regional transmission responsibilities for much of the country's middle-section and parts of the Gulf South, invests substantially in hurricane readiness. MISO has turned to leading experts at the Department of Energy's Argonne National Laboratory to help prepare its staff to face the most trying circumstances.

MISO powers hurricane preparedness with cutting-edge science
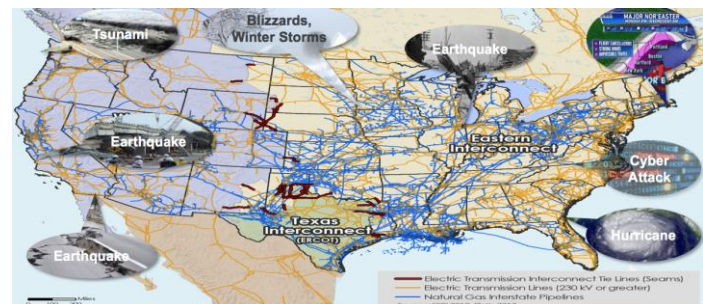
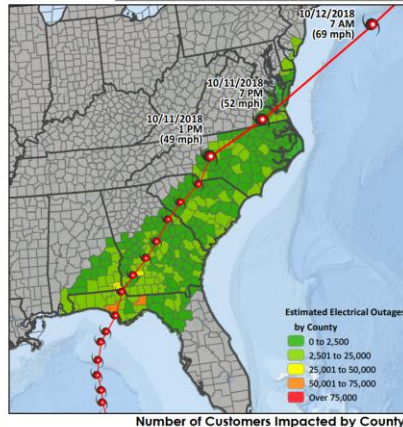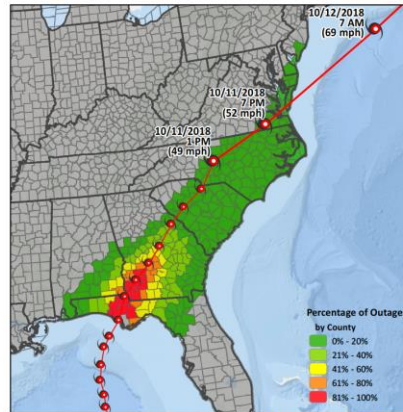# EXAMPLE OF REAL-TIME OPERATIONAL SUPPORT: 2018 HURRICANE FLORENCE/MICHAEL

- Provided the federal government with storm impact estimates every hurricane season since 2013; distributed to appropriate interagency, state, and industry partners (APPA/EEI/NRECA, and members via mutual aid networks)

Estimated Electrical Customer Outages

Hurricane Michael, based on Advisory #20A - Thursday, October 11, 2018 at 02 PM EDT

Total Estimated Customers Impacted: 980,680 Electrical Customers

State	Estimated Electric Customer Outages	Percent of Customers with Outages
Alabama	74,450	4.0%
Delaware	4,340	1.2%
Florida	257,680	3.5%
Georgia	346,110	9.6%
Maryland	5,180	0.2%
Massachusetts	350	0.0%
New Jersey	6,680	0.2%
North Carolina	126,590	3.3%
South Carolina	104,590	5.7%
Virginia	54,710	1.8%

Percentage of Outages by County
- 0% – 20%
- 21% – 40%
- 41% – 60%
- 61% – 80%
- 81% – 100%

Percent of Customers Impacted by County

Estimated Electrical Outages by County
- 0 to 2,500
- 2,501 to 25,000
- 25,001 to 50,000
- 50,001 to 75,000
- Over 75,000

Number of Customers Impacted by County

- Forecasted Position
- Forecasted Track

Results based on fragility curve:
Hurricane Fragility Curve, (2015)
Argonne National Laboratory.

- Electric customer outage estimates do not reflect any possible restoration efforts that may occur.
- Considers impacts from sustained wind speeds of 39 mph or greater.
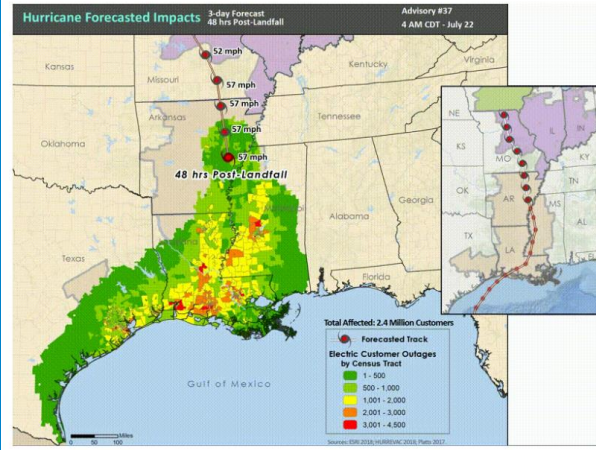
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EXAMPLE OF TRAINING/EXERCISE SUPPORT: SPRING 2018 MISO HURRICANE DRILL

EXAMPLE OF TRAINING/EXERCISE SUPPORT: SPRING 2018 MISO HURRICANE DRILL

- Argonne has supported MISO's working group for Emergency Preparedness and Power System Restoration (EP/PSR) since spring 2015 (hurricanes, gas-electric)

- Jointly prepared 2016 and 2017 spring drills on preparedness, fall drills on power system restoration

- Recently completed MISO Spring 2018 Drill (May/June) with focus on hurricane scenario and impact on various assets, including power plants, substations, transmission assets, communications assets, and natural gas supply and natural gas processing plant impacts; implemented on MISO's Dispatcher Training Simulator

- *"Your partnership with MISO on the development of the 2017 and 2016 drills were exceptional. Both in content and working with the ANL staff."* Jerry Rusin, Sr. Advisor MISO South Region Operations

EXAMPLE OF TRAINING/EXERCISE SUPPORT: FALL 2017 PJM HURRICANE DRILL

PJM Fall 2017 Operator Training for Hurricane Preparedness
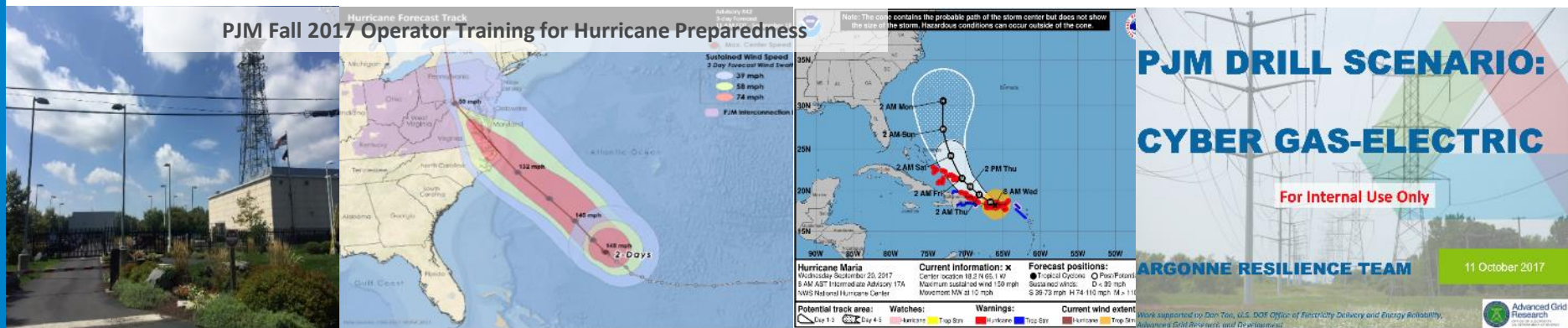
- Developed hurricane scenario for October 2017 PJM Operator Training Cycle and Gas-Electric Cyber scenario for January/February 2018 Operator Training Cycle

- Scenario was implemented in PJM's Dispatcher Training Simulator (DTS) at Alternate Control Room Facility

- Trained 6 full PJM operator shifts in responding to extreme weather event during Sep/Oct-2017 *("The timing of this training could not have been better given the active hurricane season" Glen Boyle, Manager, Operator Training; "The support and customer service PJM experienced from the planning process all the way through the final debrief session was nothing short of first rate." Mike Lawruk, Lead Trainer)*

- PJM plans to look at other large-scale threat scenarios for multi-RTO/ISO training exercises

EXAMPLE OF TRAINING/EXERCISE SUPPORT: 2018 NATIONAL LEVEL EXERCISE (NLE)

- NLE examined the nation's ability to continue essential government functions in the event of a large hurricane impacting the National Capital Region
  - 12,000 participants, largest Government exercise
- Argonne supported the NLE18 Infrastructure Systems Working Group and provided multi-sector ground-truth on customer outages, bulk-level impacts, fuel supply, and telecom

National Exercise Program
National Level Exercise 2018

ELECTRIC OUTAGES

ELECTRIC POWER

OUTAGES

NUMBER OF CUSTOMER BY CENSUS TRA

U.S. DEPARTMENT OF ENERGY · Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

The Washington Post
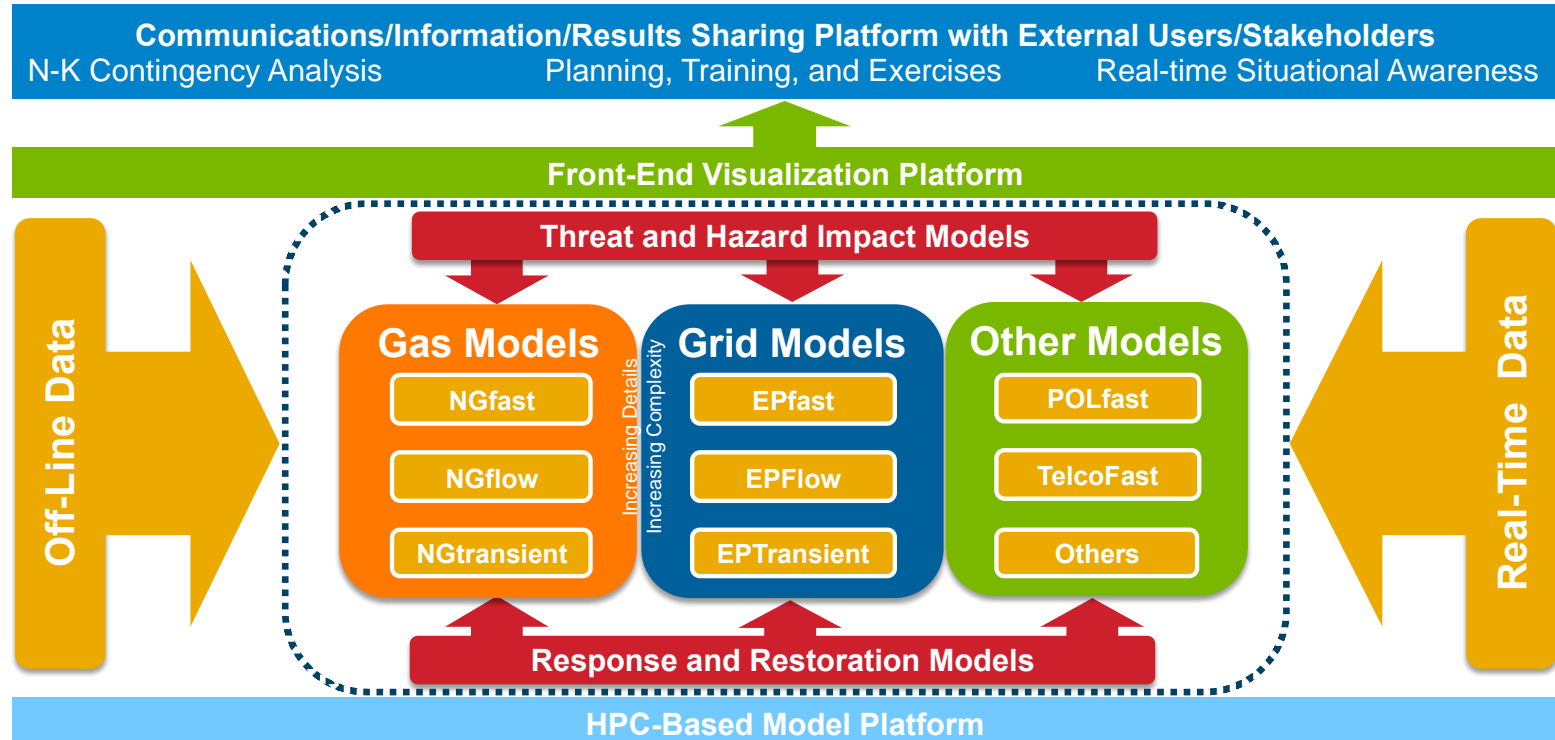*Democracy Dies in Darkness*

National

In simulation, Category 4 hurricane devastated East Coast

By Jeff Martin | AP
September 11, 2018 at 7:46 PM

EXAMPLE FOR LONG-TERM PLANNING SUPPORT: DOE NATIONAL RESILIENCE MODELING INITIATIVE

- Aimed at identifying electric/gas/telecom assets at-risk of disruption from man-made and natural events such as hurricanes


Communications/Information/Results Sharing Platform with External Users/Stakeholders
N-K Contingency Analysis   Planning, Training, and Exercises   Real-time Situational Awareness

Front-End Visualization Platform

Threat and Hazard Impact Models

Off-Line Data

Gas Models
- NGfast
- NGflow
- NGtransient

Increasing Details
Increasing Complexity

Grid Models
- EPfast
- EPFlow
- EPTransient

Other Models
- POLfast
- TelcoFast
- Others

Real-Time Data

Response and Restoration Models

HPC-Based Model Platform

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HOW DOES HEADOUT WORK?

BACKGROUND – HURRICANE TOOL

- The National Hurricane Center (NHC) monitors tropical cyclones

- Forecast/Advisories are issued on all Atlantic and eastern Pacific tropical and subtropical cyclones every six hours
  - Dataset for storm tracks in shapefile and kml/kmz formats

- HURREVAC creates 72-hour wind swath based on NOAA's Advisory Wind Fields

- NOAA provides storm surge estimates
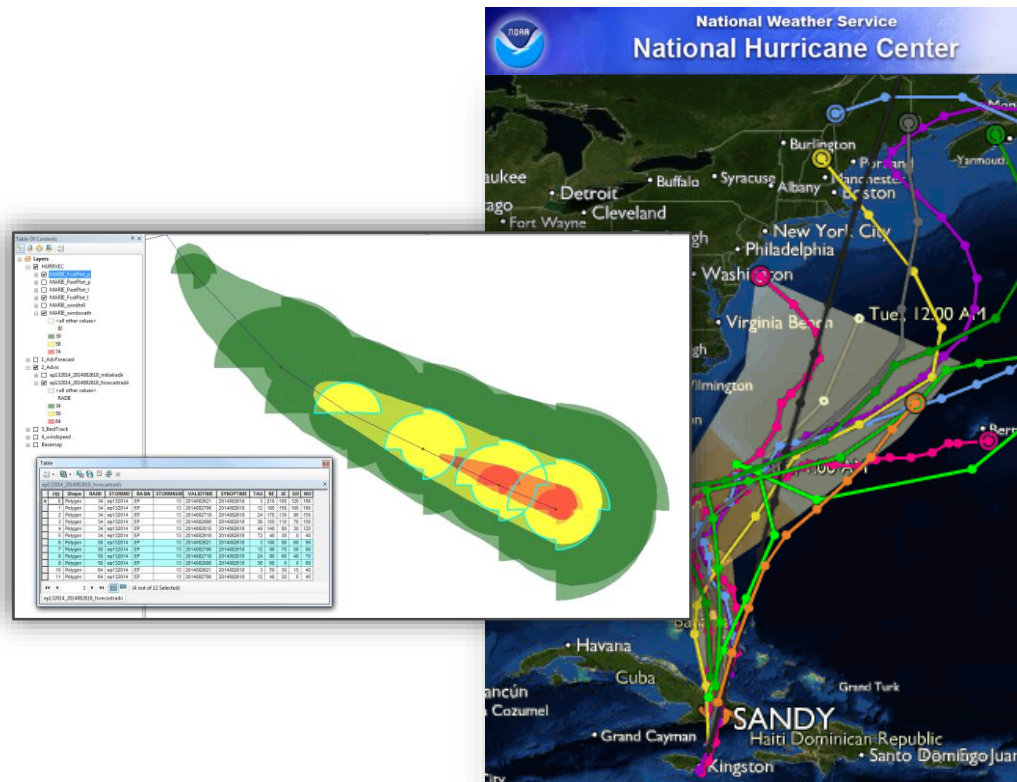
HOW DOES HEADOUT ESTIMATE ELECTRIC CUSTOMER OUTAGES?

- HEADOUT collects data from the most-recent NOAA Advisory as Tropical Cyclone near land:
  - Maximum gust wind speeds, track and 72-hour wind swath (74, 58, and 39 mph)
  - Predicted storm surge as a function of location along the coastline

- A contouring method is then applied to estimate wind speeds by interpolation
  - Spatial analyst tool provides a continuous surface for which wind contours are created using the Advisory wind swath data. Contours are created from this raster file
  - A fragility curve is applied to produce damage fraction as a function of wind speed

- The wind speed swaths are overlaid over Census population data
  - The number of electric customers are estimated for each wind swath
  - The electric customers at-risk of electric outage are estimated by multiplying the number of customers in each swath by the appropriate damage fraction

HEADOUT METHOD: WIND DAMAGE FLOW AND ESTIMATE CUSTOMERS AFFECTED

Gather Data
- NOAA's National Hurricane Center (NHC) / HURRVEC
- 72-hour projected path
- 3 wind speed intervals (74-, 58-, 39- mph)
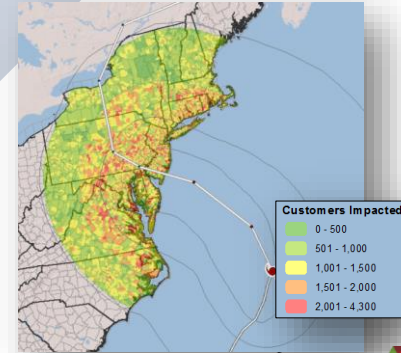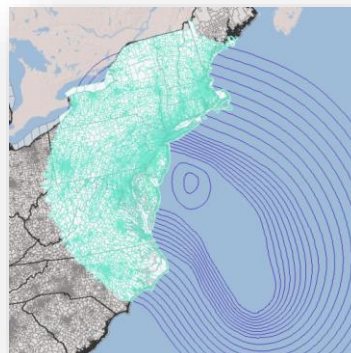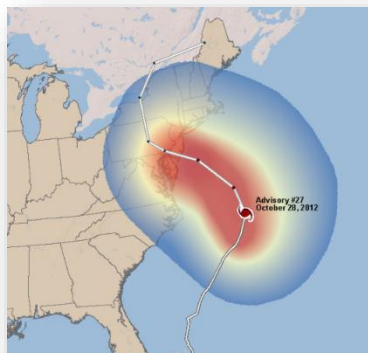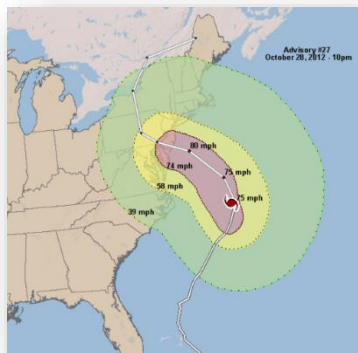- Max. center wind speed

Interpolate
- Develop continuous surface
- Natural neighbor technique

Contours and Apply Fragility Curve
- User-defined intervals
- Intervals of wind speed
- Smooth contour lines
- Join to fragility curves
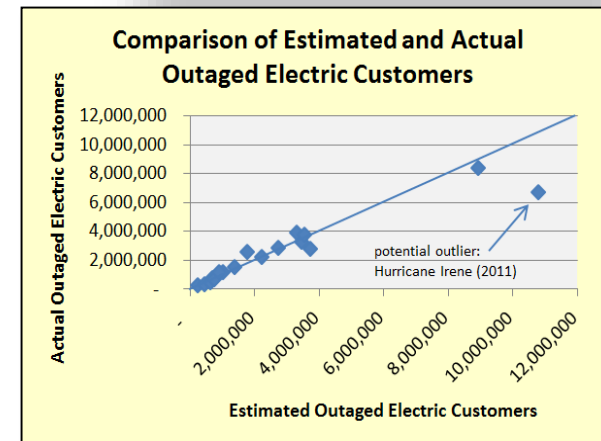- Join to areas affected by storm surge

Calculate Customer Outages
Apply damage curve to estimate electric customers without power Census Tracts shapefiles contain 2016 data (assumes equally dispersed distribution of customers through census tract)

Customers Impacted
- 0 - 500
- 501 - 1,000
- 1,001 - 1,500
- 1,501 - 2,000
- 2,001 - 4,300

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HEADOUT FRAGILITY FUNCTIONS/CURVES

- Fragility curves are the cumulative distribution function of the capacity of the asset to resist a particular undesirable event, or rather the probability that an uncertain quantity will be less than or equal to a given value, as a function of that value

- Fragility curve was originally tested for 17 of the 21 events which SitReports were available
  - Nine Gulf Coast storms,
  - Four Atlantic Coastal; and
  - Four impacting the State of Florida

- Largest discrepancy produced for Irene, partially due to variances in the forecast
  - The intensity decreased as it moved up along the Atlantic Coast; sustained max wind speeds of 75 mph opposed to the 90 mph wind predictions by NHC

Comparison of Estimated and Actual Outaged Electric Customers

potential outlier:
Hurricane Irene (2011)

PUERTO RICO AND HAWAII

PUERTO RICO RESILIENCE STUDY

▪ Five DOE National Laboratories are combining their skills and capabilities to:
  – Develop and execute a plan for advanced grid modeling in Puerto Rico.
  – Translate existing DOE models into tools for Puerto Rico's needs.

▪ DOE has selected Argonne to lead Phase 1 of the program.

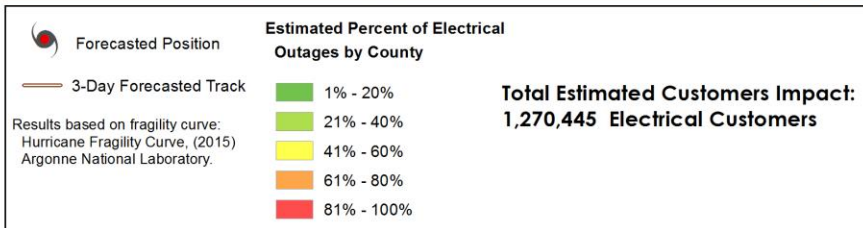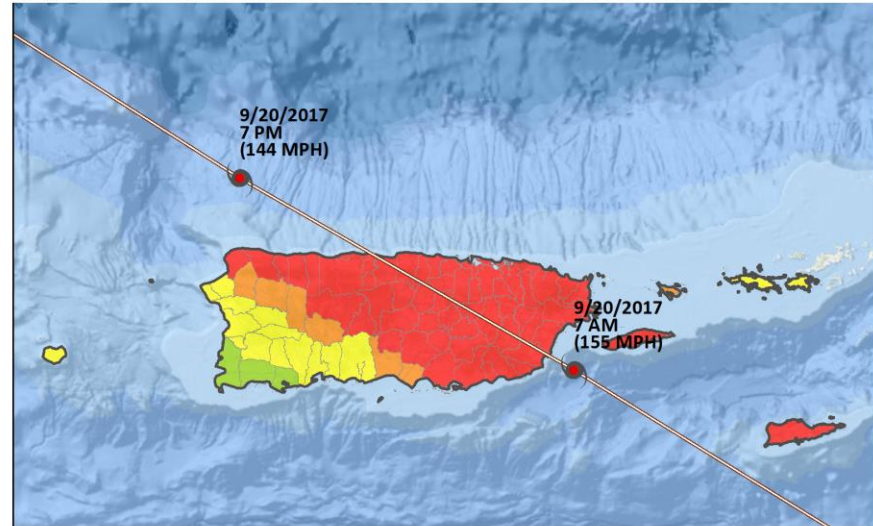| PHASE 1	PHASE 2
▪ **Develop and deploy resilient grid operation and planning models.** ▪ **Support DOE's recommendations to U.S. Department of Housing and Urban Development, the Federal Emergency Management Agency and Puerto Rico.**	▪ **Use lab models to provide information needed by stakeholders to make investment decisions.** ▪ **Provide training and user support to Puerto Rico stakeholders.**

THE HEADOUT RESULTS - PUERTO RICO

- A Near Real-Time Analysis of Hurricane Maria
  - Use of HEADOUT enabled DOE to kept the White House aware of the storm's impact on electric outage occurrences in near real-time.
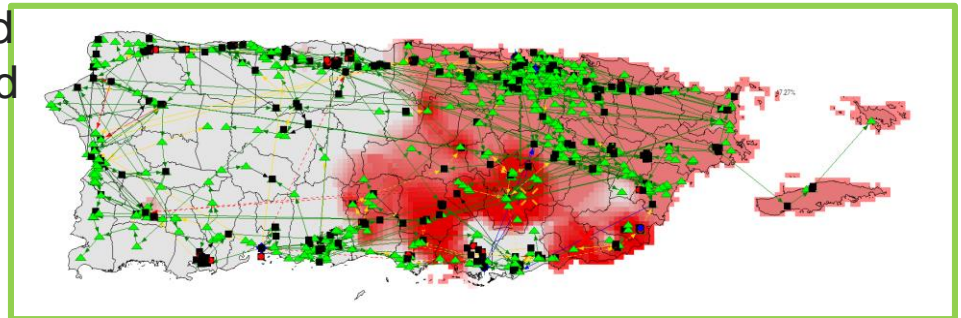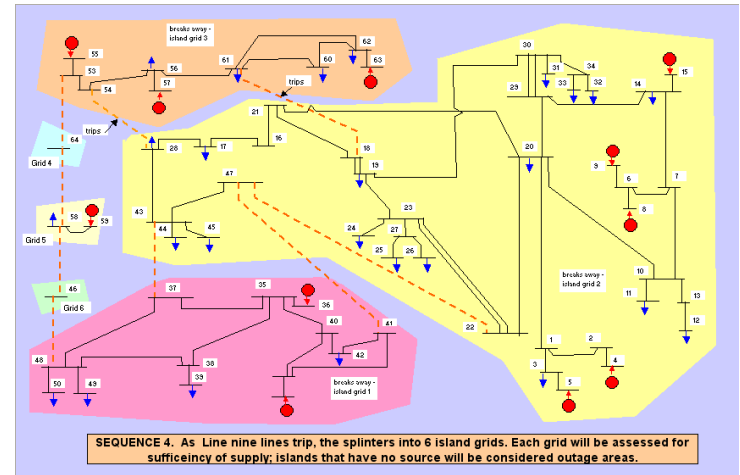
Estimated Electrical Customer Outages

Hurricane Maria based on Advisory #14 – Tuesday, September 19, 2017 at 11am EDT

9/20/2017
7 PM
(144 MPH)

9/20/2017
7 AM
(155 MPH)

Forecasted Position

3-Day Forecasted Track

Results based on fragility curve:
Hurricane Fragility Curve, (2015)
Argonne National Laboratory.

Estimated Percent of Electrical Outages by County

- 1% - 20%
- 21% - 40%
- 41% - 60%
- 61% - 80%
- 81% - 100%

Total Estimated Customers Impact:
1,270,445 Electrical Customers

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EPFAST RESULTS - PUERTO RICO

- Impact analysis tool:
  - Linear model, employing DC load flow.
  - Assesses impacts of single and multiple line and substation outages.

- Performs traditional load flow analysis, contingency studies, islanding analysis, and outage area estimation:
  - Ability to track cascading line outages.
  - Ability to track successive island grid formation until stable supply-demand balance is reached.
  - Ability to estimate magnitude (MW loss) and spatial extent of power outages.

SEQUENCE 4. As Line nine lines trip, the splinters into 6 island grids. Each grid will be assessed for sufficeincy of supply; islands that have no source will be considered outage areas.

HEADOUT - HAWAII

- Tropical Strom Olivia and Hurricane Lane
  - Data availability is limited
  - Forecasting results seem reasonable (26k vs. 39k and 15k vs. 12k)

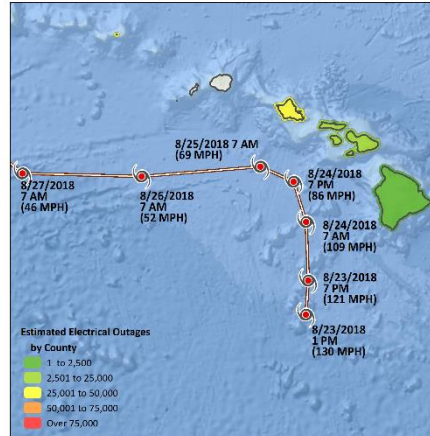**Estimated Electrical Customer Outages**

Hurricane Lane, based on Advisory #36A - Thursday, August 23, 2018 at 2 PM ET

Total Estimated Customers Impacted: 39,210 Electrical Customers

State	County	Estimated Electric Customer Outages	Percent of Customer with Outages
Hawaii	Hawaii	2,400	3.6%
Hawaii	Honolulu	31,900	10.3%
Hawaii	Kalawao	10	9.1%
Hawaii	Maui	4,900	9.1%
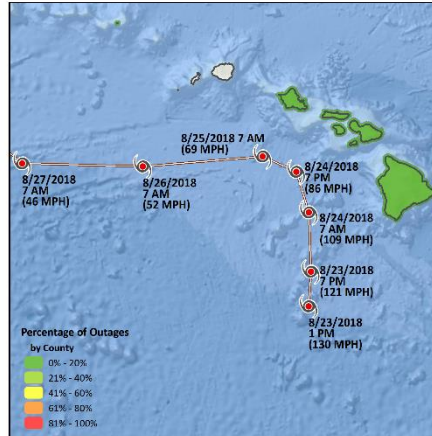
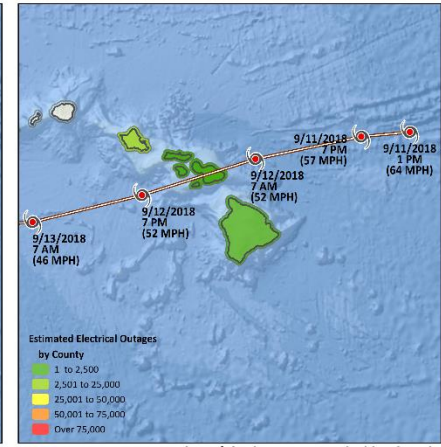**Estimated Electrical Customer Outages**

Tropical Storm Olivia, based on Advisory #44A - Tuesday, September 11, 2018 at 02 PM ET

Total Estimated Customers Impacted: 12,130 Electrical Customers
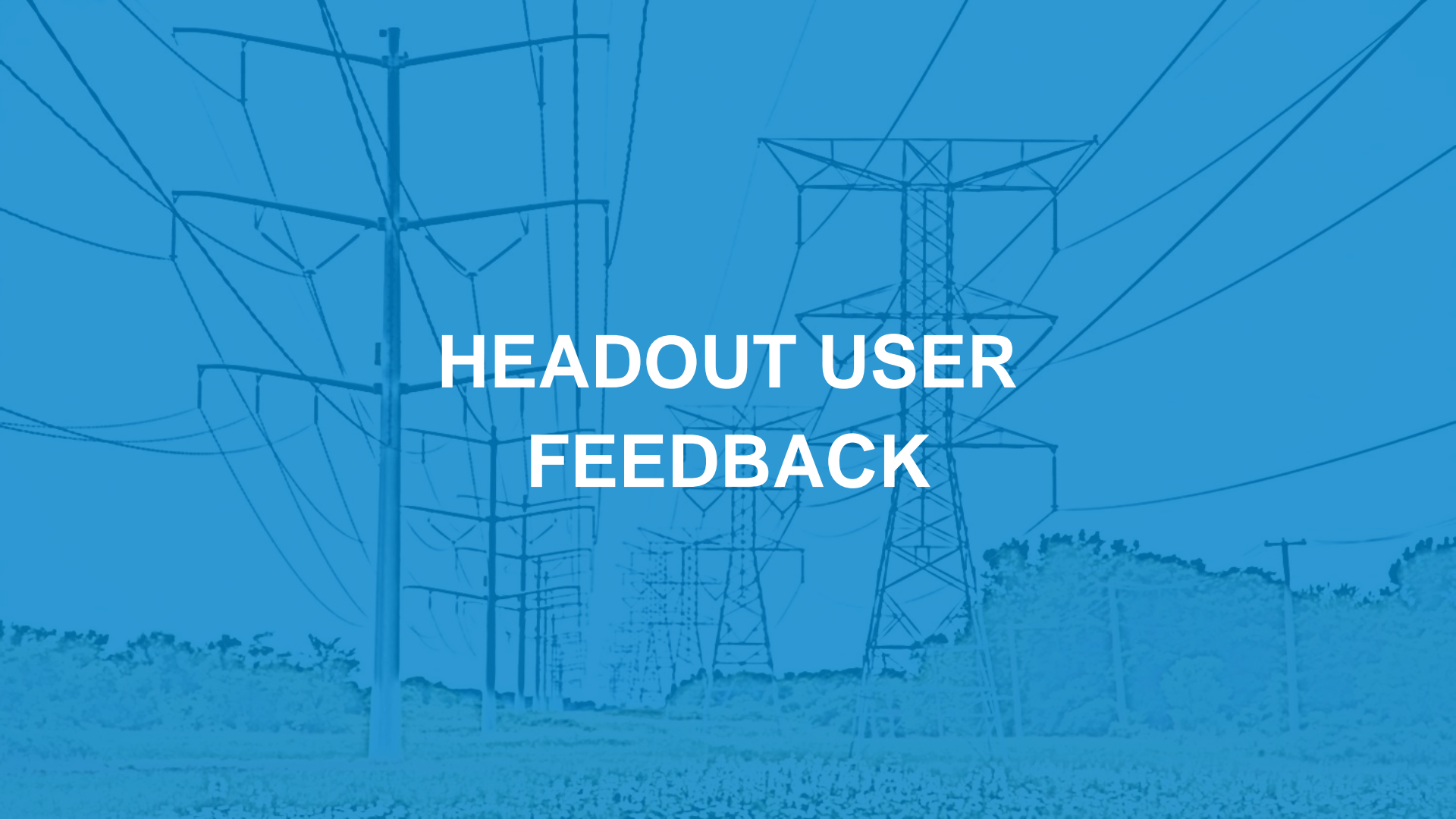
State	County	Estimated Electric Customer Outages	Percent of Customer with Outages
Hawaii	Hawaii	100	>0.1%
Hawaii	Honolulu	9,625	0.3%
Hawaii	Kalawao	5	7.0%
Hawaii	Maui	2,400	3.4%
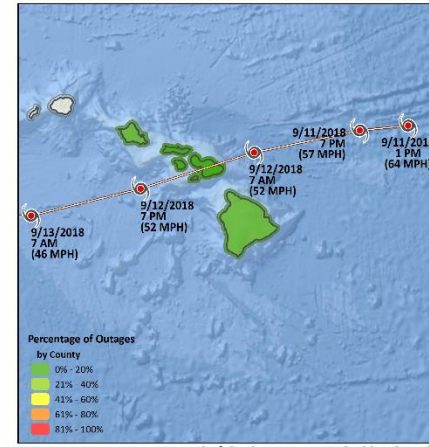
HEADOUT USER FEEDBACK

HOW WELL ARE WE DOING? OUR INDUSTRY STAKEHOLDERS SAY IT BEST

- "The support and customer service PJM experienced from the planning process all the way through the final debrief session was nothing short of first rate." Mike Lawruk, Lead Trainer, 10/17/2017

- "The operators have really embraced this scenario after some refining and it's lead to very good discussions." (Mike Lawruk, PJM Senior System Operator Trainer, 1/31/18): Feedback on Argonne's Gas Cyber Scenario which PJM implemented on its Digital Training Simulator for its current 6-week Jan/Feb-2018 operator training cycle designed for operations during extreme events

- "The timing of this training could not have been better given the active hurricane season." (Glen Boyle, Manager, Operator Training, 10/17/17): Feedback on Argonne's Hurricane Scenario prepared for PJM's Fall-2017 6-week operator training cycle designed for operations during extreme events

- "I am writing to request the assistance of Argonne National Laboratory to help in the creation of the scenario/storyline. Your partnership with MISO on the development of the 2017 and 2016 drills were exceptional. Both in content and working with the ANL staff." (Jerry Rusin, MISO South Region Operations, 12/20/17): Requesting assistance for 2018 Spring Drill to help design and implement a Harvey-like Hurricane scenario on MISO's digital simulator

- "I received your contact information from Glen Boyle, the Operations Training Manager at PJM. He had mentioned during one of our recent ISO/RTO Operations Training Meetings that you and the folks at Argonne had developed a hurricane simulation for their use in some recent Operator Training Simulations. What he described sounded like quite a valuable training tool, and I was hoping to get some information on whether you could do something similar for us at some point in the future." Stephen George, Manager Operational Performance and Training ISO-NE, 2/16/2018

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HOW WELL ARE WE DOING? OUR INDUSTRY STAKEHOLDERS SAY IT BEST

- "This is great information and intel." Feedback from Byron Letcher, Exelon Team Lead for Business Continuity and Crisis Management in response to receiving Hurricane Florence updates, 9/11/2018

- "My name is Alex Shestopal and I work for SERC region as part of Situational Awareness team. During Florence last week, Brian from RF was kind enough to share customer outage predictions from ANL which we found very helpful and accurate. Is there any chance SERC can be added to the report distribution list? If so, our email address is SAEA@serc1.org. Thank you." Feedback in response to receiving Hurricane Florence updates, 9/17/2018

- "My name is Darrell Moore of the North American Electric Reliability Corporation. I work in Bulk Power System Awareness (BPSA) group, we have contacts across the industry with Reliability Coordinators, and the NERC Regions, we have forwarded your projected outage information to the impacted NERC regions so that they can share this information with the registered entities that will potentially be impacted by Hurricane Michael as requested. Mr. Bill Graham of my NERC BPSA have also reached out to you to get our group included in the outage emails at SystemAwareness@NERC.net." Feedback in response to receiving Hurricane Michael updates, 10/9/2018

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QUESTIONS AND DISCUSSION