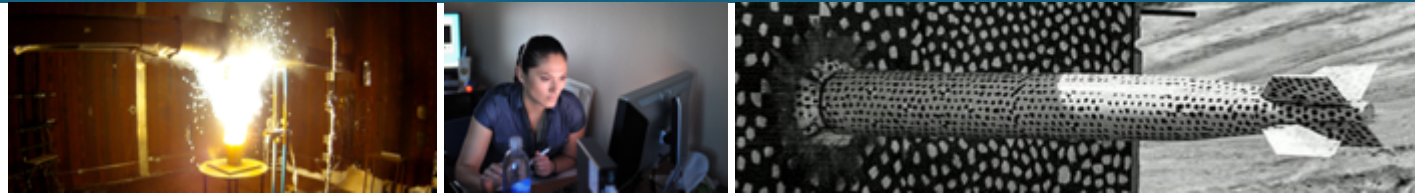


# North American Energy Resilience Model (NAERM)



*PRESENTED BY*

Andrea Staid

Collaborators: Laura Swiler, Darryl Melander, Ben Emery, Thushara Gunda, Sam Gilletly, Tom Kroeger, and many more at LLNL, NREL, INL, PNNL, LANL, ORNL, and ANL  
CIS External Review, March 30-April 1, 2021

SAND 2021XXX-XX



Sandia National Laboratories is a multission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

# NAERM aims to Assess and Improve Infrastructure Resilience

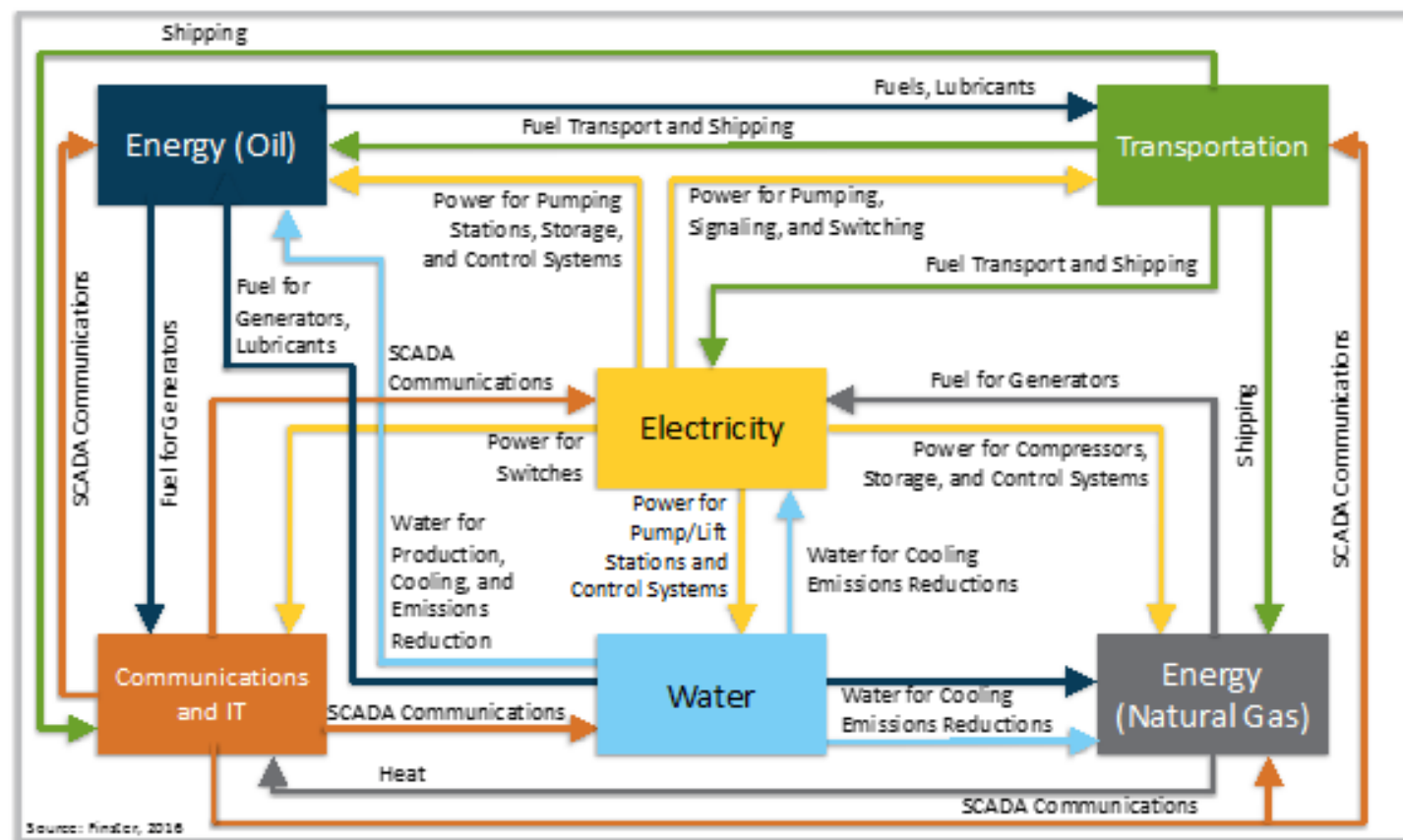


Provide DOE with visibility into the state of our energy infrastructure

- Real-time situational awareness
- Planning capabilities to assess resilience to what-if threat scenarios
- Capturing interdependencies among sectors
- **How can we provide information and analysis capabilities to improve decision-making in the face of a wide range of threats?**

End-goal: deployed software product for users at DOE and other federal agencies

- Combining established lab research tools and products, new research, and plenty of integration challenges
- Allows for national-level coordination and response
- Planning capabilities provide a testbed for threat and mitigation analysis



# Eight labs, many semi-independent efforts to eventually bring together

Currently just over two years in, TBD how many more to go

DOE funded, primarily from the Office of Electricity (OE); Smaller funding amounts have come from the office of Energy Efficiency and Renewable Energy (EERE)

- Funding has fluctuated a lot, with changes in DOE program management, project direction, and scope
- Sandia funding levels:
  - 2019 - \$2.7M, 2020 - \$740k, 2021 - \$600k+

Multi-lab project: LLNL, SNL, PNNL, LANL, NREL, ANL, ORNL, and INL

- Multiple, complex efforts all aiming towards eventual integration into a cohesive product



U.S. DEPARTMENT OF  
**ENERGY**

 **Lawrence Livermore  
National Laboratory**

 **Sandia  
National  
Laboratories**

  
**Pacific Northwest**  
NATIONAL LABORATORY

**Argonne**   
NATIONAL LABORATORY

 **OAK RIDGE**  
National Laboratory

 **NREL**  
NATIONAL RENEWABLE ENERGY LABORATORY

 **Los Alamos**  
NATIONAL LABORATORY  
EST. 1943

 **INL** Idaho National Laboratory

# NAERM Products and Lab Roles



Overall NAERM PI: John Grosh (LLNL)

Product	SNL	LLNL	PNNL	NREL	ANL	ORNL	LANL	INL
Architecture and Integration	X	X	X	X				
Bulk Electricity System			X	X		X		
Natural Gas					X		X	
Communications							X	X
Threats	X	X		X				
Real-Time Situational Awareness			X			X		
Real-Time Analytics for Grids			X	X				
VVUQ	X					X	X	

Lab Leads →

Andrea Staid  
John Collins &  
Jean-Paul Watson

Jason Fuller

Jessica Lau

Mark Petri

Teja Kuruganti

Russell Bent

Brad Nelson



# Sandia's Main Role: Threat Modeling and Analysis



Threats are the key input for resilience analysis

For select threats of interest:

1. Collect data on scope of threat severity, extent, duration, etc.
2. Develop/Integrate models to determine infrastructure impacts as a function of threat parameters
3. Pass component failures and resource impacts into infrastructure simulation models

What can we do with threat models?

- Assess the current state of system resilience
- Quantify uncertainty in threat and impact projections
- Analyze the impact of potential investments or mitigation strategies
- Couple with real-time data streams to predict impacts based on weather forecasts



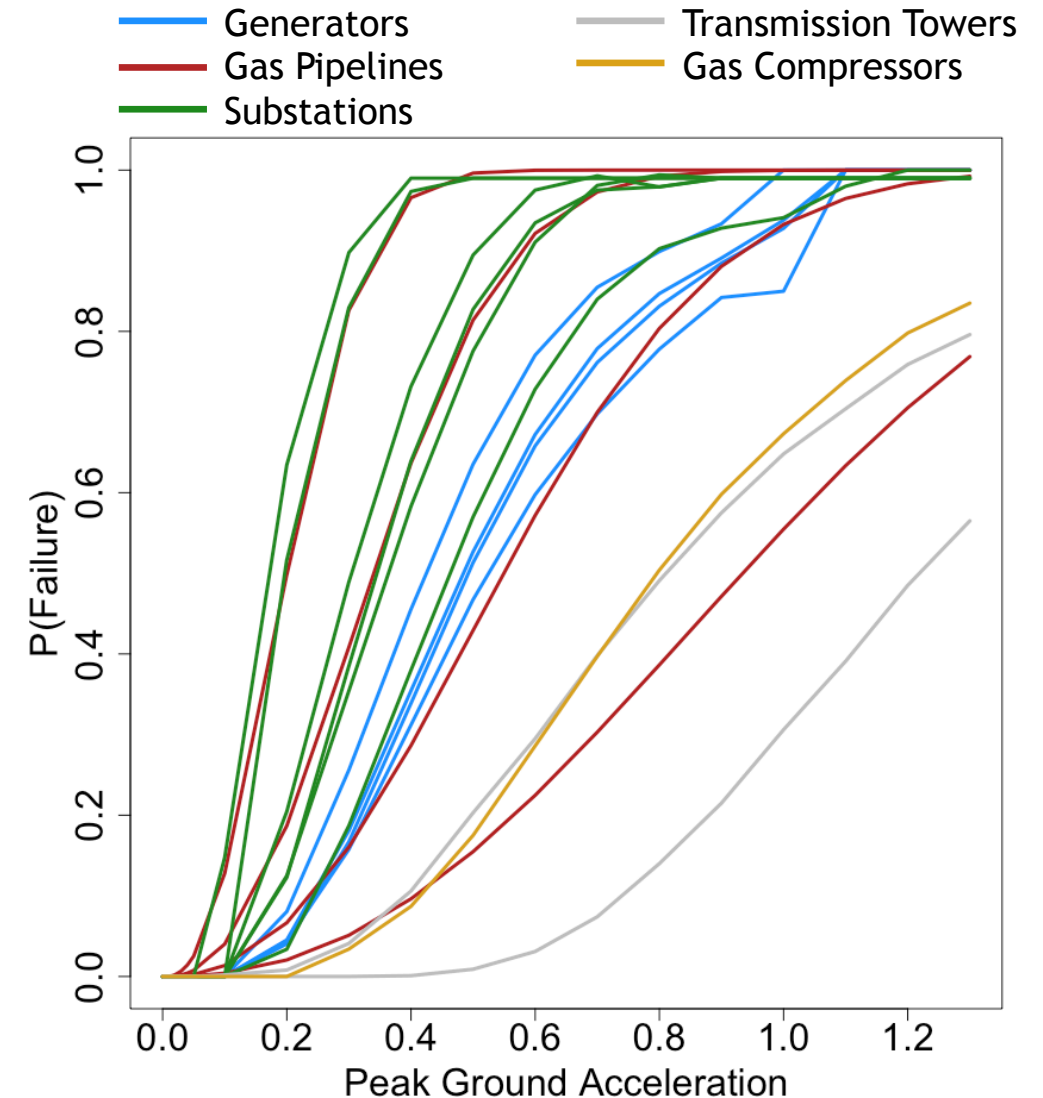
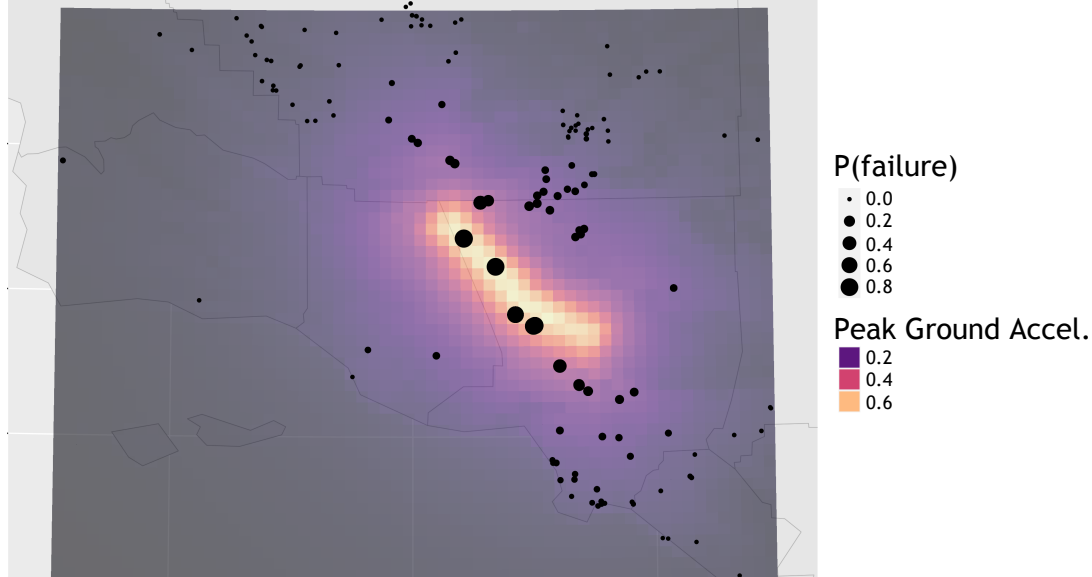
# What is new with Threat Modeling in NAERM?



Large-scale threat modeling has largely been academic in nature, without a focus on real-world infrastructure impacts

- Random scenarios are often good enough
- Realistic threat scenarios depend on detailed data, which is often proprietary
- NAERM's access to infrastructure data allows for finer granularity representations
- Coupling threat data (both open-source and proprietary) with infrastructure asset information (largely protected under CEII)

Los Angeles area Earthquake Scenario



# Threat Modeling Overview



Historical events and failure data can be used to build up representative models of infrastructure impact

- In some situations, we use HAZUS physics-based failure models
- Otherwise, develop statistical models to capture relationships
- Often have to rely on assumptions, simplifications, and proxy data to fill gaps

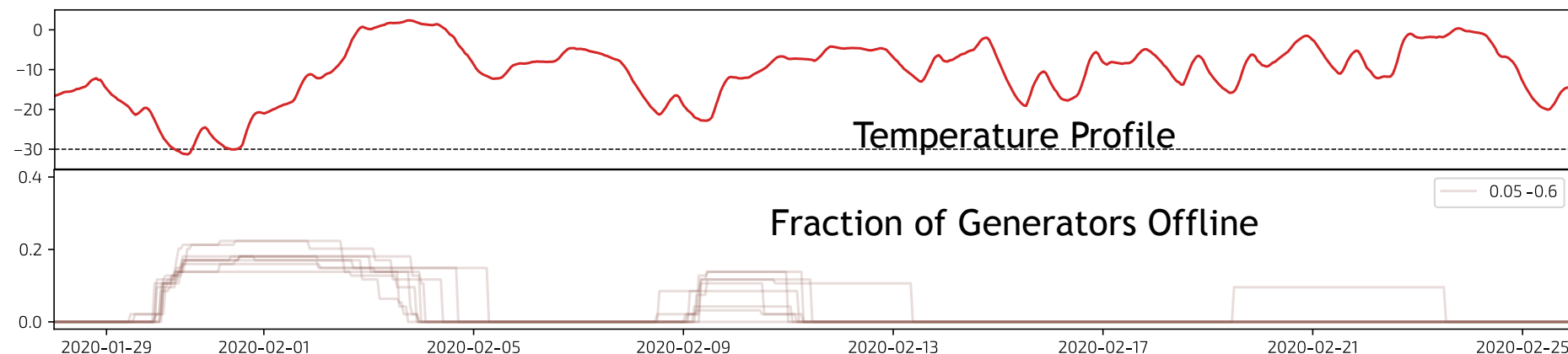
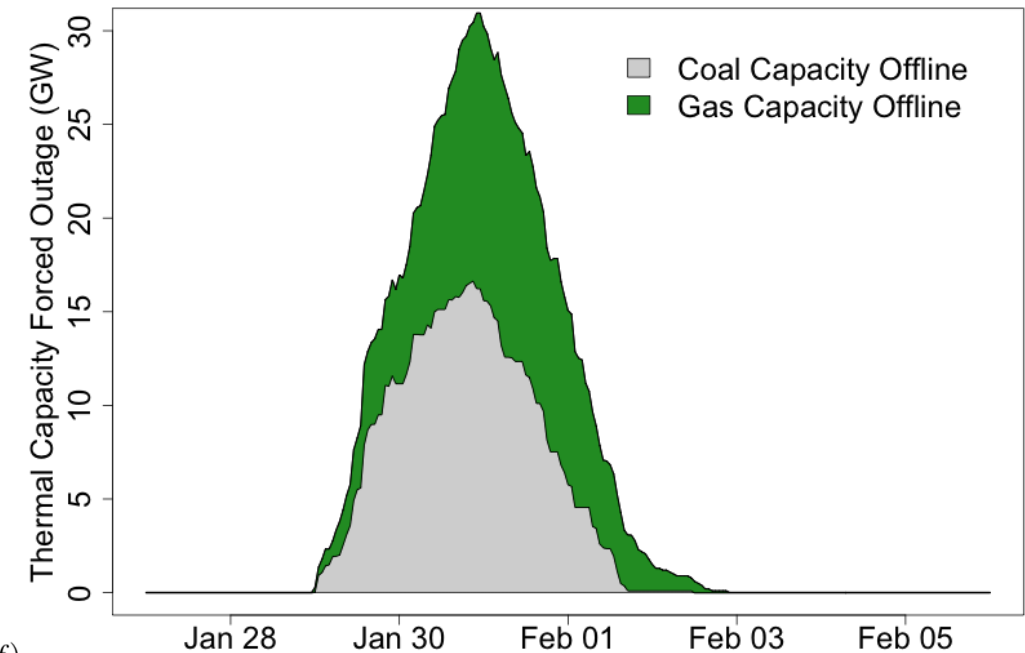
So far: earthquakes, wildfires, cold snaps (polar vortex events), and intentional physical attacks

- Priorities driven by DOE

Given the assumptions in place, uncertainty quantification is crucial to understanding the impact of our modeling decisions

$$P(\text{thermal generator fails} \mid t, f) = \frac{\exp(\beta_0 + \beta_t t + \beta_f f)}{1 + \exp(\beta_0 + \beta_t t + \beta_f f)}$$

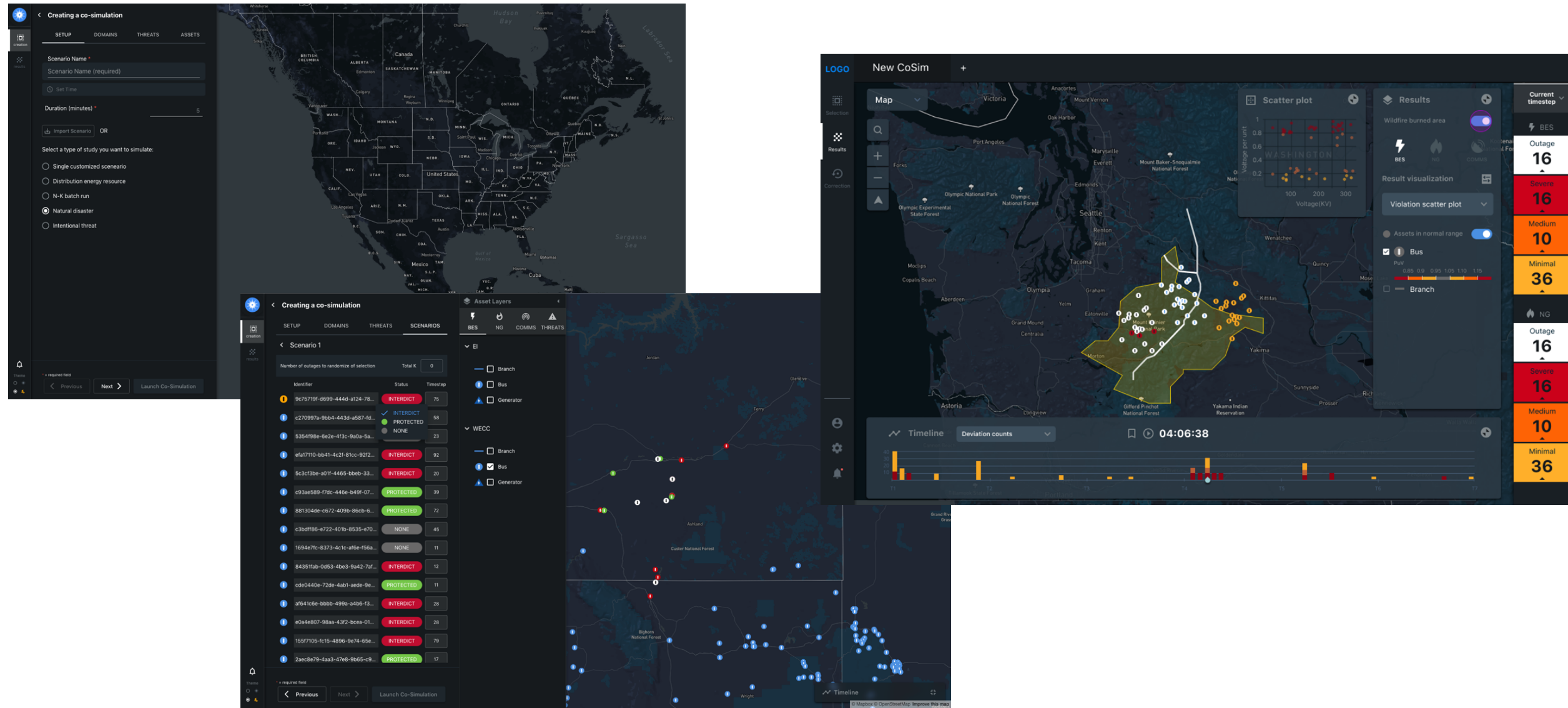
Recreating the 2019 Polar Vortex Event




# All models aim for integration to the User Interface





The planning tool and real-time situational awareness tool are deployed with limited user access














creation

results

Theme

< Creating a co-simulation

SETUPDOMAINSTHREATSASSETS

Domains

Bulk Electric System

☒ Eastern Interconnect (EI)

Select Case

☒ Western Electricity Coordinating Council (WECC)

Select Case

Natural Gas

☒ Natural Gas

Select Case

Load from NAERM

Communications

☒ Communications

Select Case

Simulators

Bulk Electric System

Eastern Interconnect (EI)

☒ Steady-State

Static

☐ DCAT

Dynamic

Western Electricity Coordinating Council (WECC)

☒ Steady-State

Static

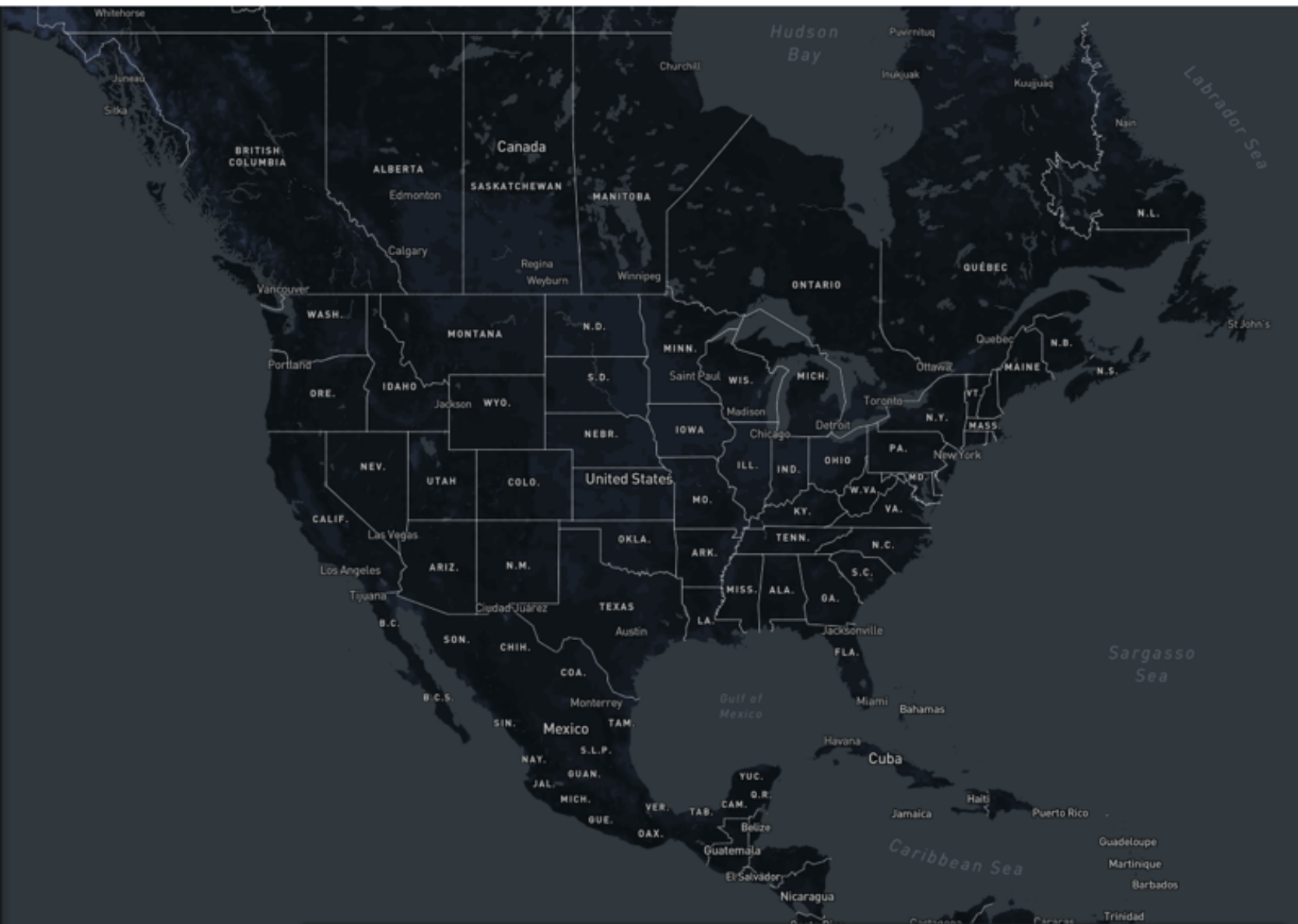
☐ Automatic Generator Controller (Nevada only)


< Previous

Next >


Launch Co-Simulation

\* required field



 Timeline


<






>

0

All Selected Assets



© Mapbox © OpenStreetMap Improve this map



## Creating a co-simulation

SETUPDOMAINSTHREATSASSETS

Earthquake

Total 798 results

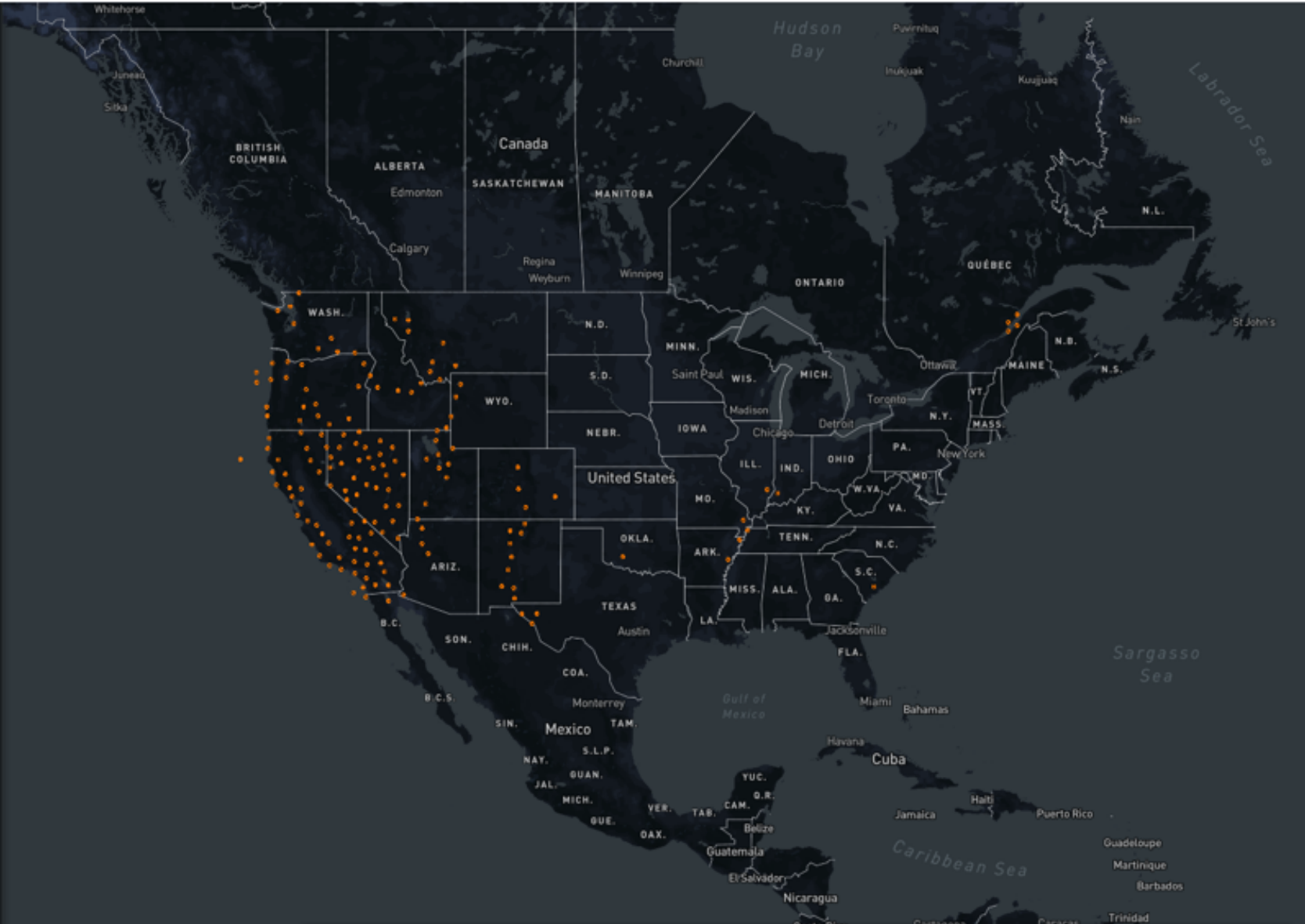
Earthquake TypeMagnitude Range

<input type="radio"/>	Wasatch fault, Salt La...	M 4.4	08:14 PM 05/12/2017
<input type="radio"/>	Quien Sabe	M 5.61	02:32 PM 05/16/2017
<input type="radio"/>	Spanish Springs Peak...	M 6	08:14 PM 05/12/2017
<input type="radio"/>	Acala fault	M 6.09	08:14 PM 05/12/2017
<input type="radio"/>	Brawley (Seismic Zon...	M 6.1	02:31 PM 05/16/2017
<input type="radio"/>	Brawley (Seismic Zon...	M 6.11	02:31 PM 05/16/2017
<input type="radio"/>	Scodie Lineament	M 6.11	02:31 PM 05/16/2017
<input type="radio"/>	Indian Hill fault	M 6.13	08:14 PM 05/12/2017
<input type="radio"/>	Kickapoo	M 6.13	02:31 PM 05/16/2017
<input type="radio"/>	Yaquina faults	M 6.14	08:14 PM 05/12/2017
<input type="radio"/>	Sawyer Canyon fault	M 6.15	08:14 PM 05/12/2017
<input type="radio"/>	Black Hills fault	M 6.18	08:14 PM 05/12/2017
<input type="radio"/>	Hayward (So) extensi...	M 6.18	02:32 PM 05/16/2017
<input type="radio"/>	Bolton fault	M 6.19	08:14 PM 05/12/2017
<input type="radio"/>	Oak Ridge (Offshore)...	M 6.2	02:31 PM 05/16/2017
<input type="radio"/>	Grant Butte fault	M 6.21	08:14 PM 05/12/2017
<input type="radio"/>	Thompson Valley fault	M 6.22	08:14 PM 05/12/2017
<input type="radio"/>	Wasatch fault, Salt I a...	M 6.23	08:14 PM 05/12/2017

Theme

\* required field

PreviousNextLaunch Co-Simulation



Timeline

<▶>0


All Selected Assets


© Mapbox © OpenStreetMap. Improve this map.





# Setting up an Earthquake Simulation

11









## < Creating a co-simulation

SETUP

DOMAINS

THREATS

ASSETS

Earthquake

Total 798 results

Earthquake Type

☒ Seattle fault zone-mi...

M 7.2

08:14 PM 05/12/2017

☐ Seattle fault zone-so...

M 7.2

08:14 PM 05/12/2017

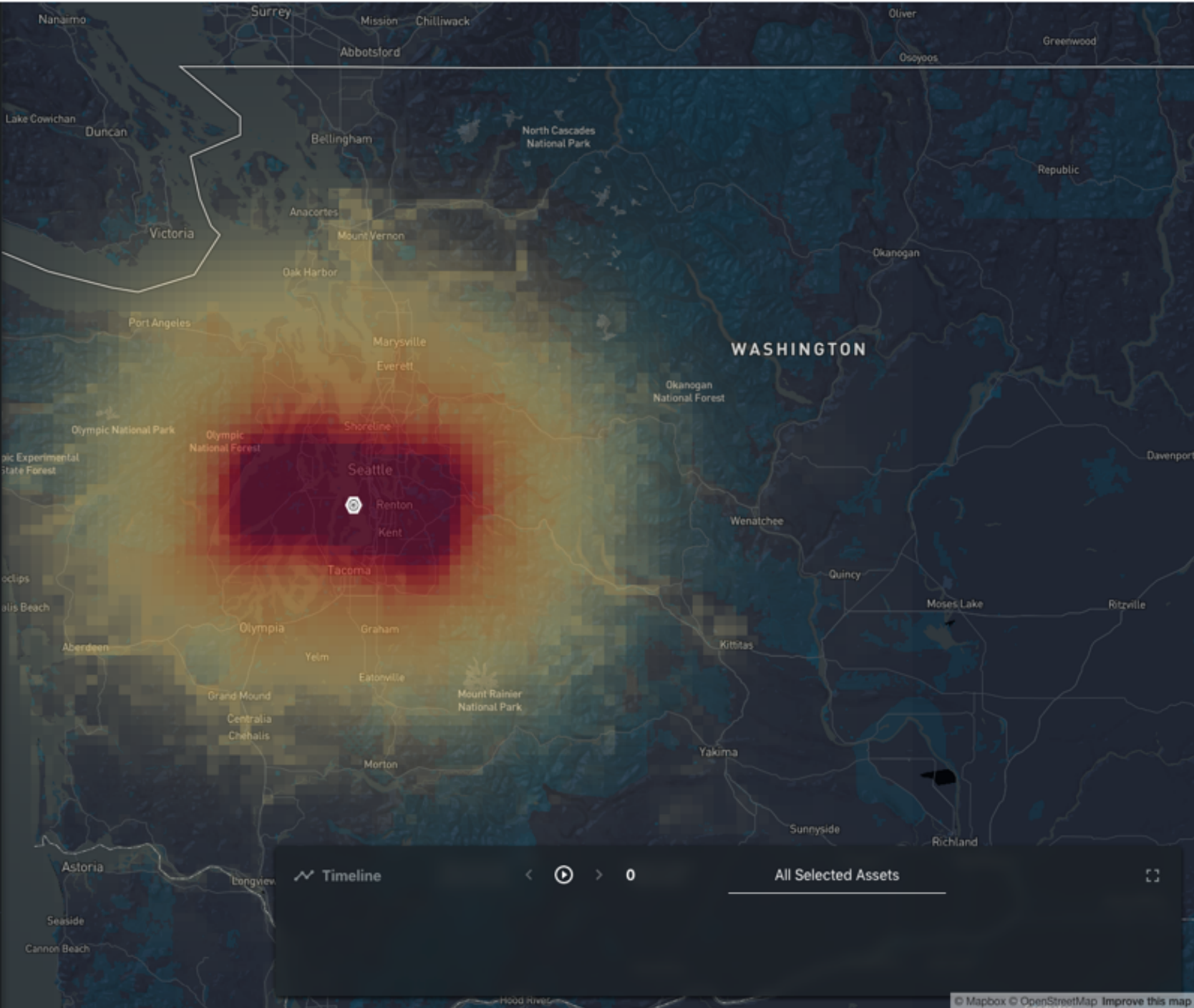
Theme


\* required field

< Previous


Next >

Launch Co-Simulation



 Timeline


<



>

0


All Selected Assets





© Mapbox © OpenStreetMap Improve this map


# Setting up an Earthquake Simulation

12
























## < Creating a co-simulation

SETUP


DOMAINS


THREATS


ASSETS


Identifier ↑	Damage	Timestep	
0b845cfb-0cde-43...	0	0	
45f84c89-2bd8-46...	0	0	
faf4f5b5-f000-4a0a...	0	0	
8e01a4c0-730c-45...	0	0	
08fb75aa-8aeb-45a...	0	0	
b003769a-8f5e-4b...	0	0	
9961fd73-62e2-42...	0	0	
c1962020-6852-4f...	0	0	
0c3f2241-6d5d-40...	0	0	
7d9aca56-8613-42...	0	0	
61ee3fcd-c61e-483...	0	0	
4a89afaa-ac45-49...	0	0	
32fb4cd6-3f97-4a5...	0	0	
d3d16f33-0fc6-4f0...	0	0	
84393699-8faf-45...	0	0	

Theme














Asset Layers

Earthquake Map 


 BES


 NG


 COMMS


 THREATS

WECC


 ☒ Branch

 ☐ Bus

 ☒ Generator

 Timeline

<

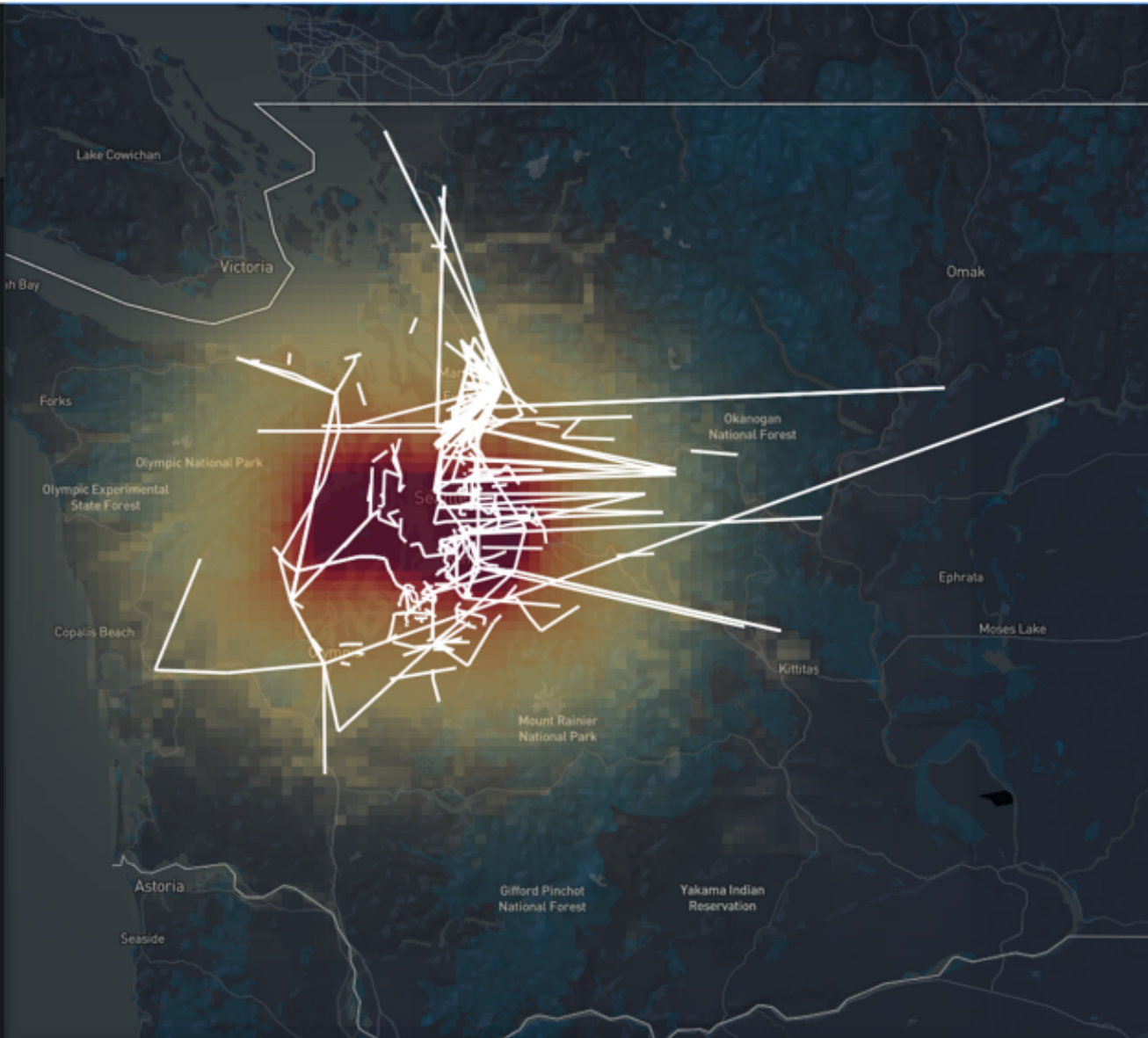


>

0

All Selected Assets

0



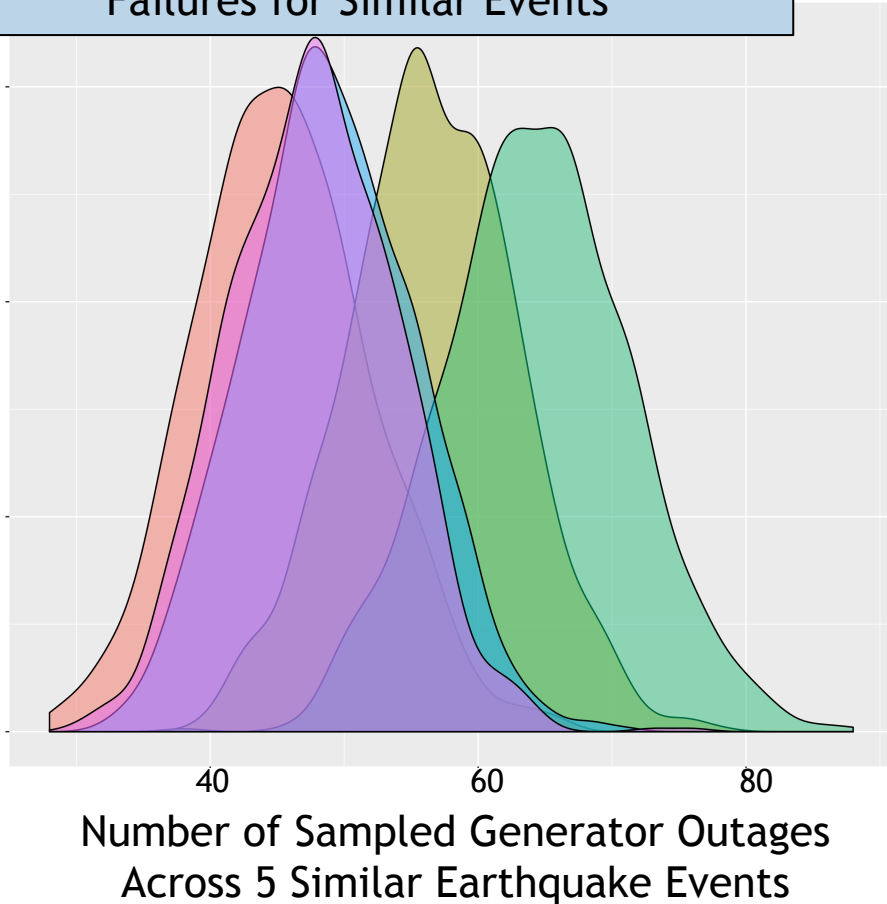
Map showing the state of Washington with various geographical features and locations labeled. The map is overlaid with a network of white lines representing the power grid. A red and yellow heatmap indicates the intensity of the earthquake simulation, with the highest intensity (red) concentrated in the central part of the state, near the coast. The map includes labels for Lake Cowichan, Victoria, Omak, Ephrata, Moses Lake, Kititas, Mount Rainier National Park, Gifford Pinchot National Forest, Yakama Indian Reservation, Astoria, Seaside, Copalis Beach, Forks, Olympic National Park, Olympic Experimental State Forest, and Okanogan National Forest.

© Mapbox © OpenStreetMap Improve this map

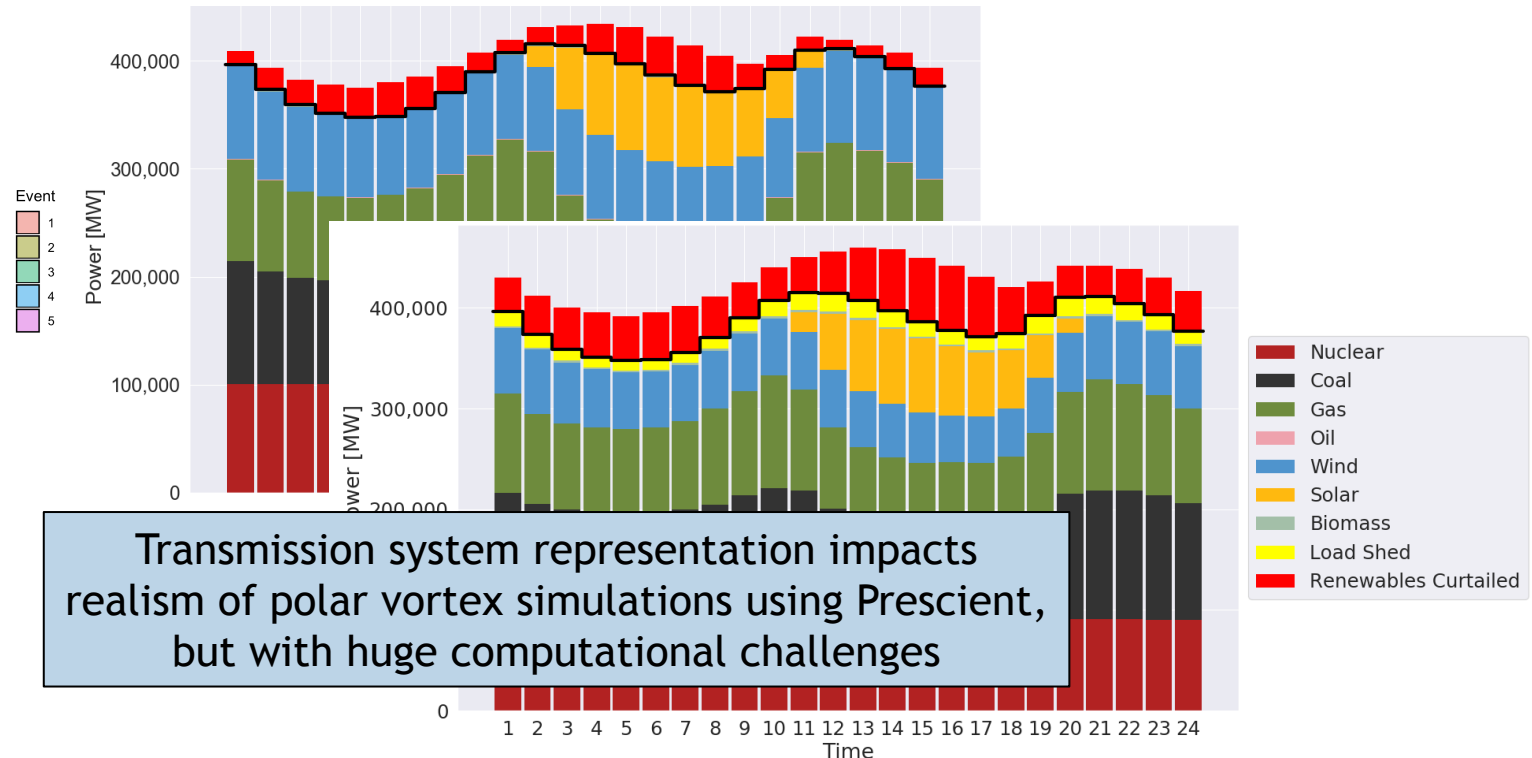
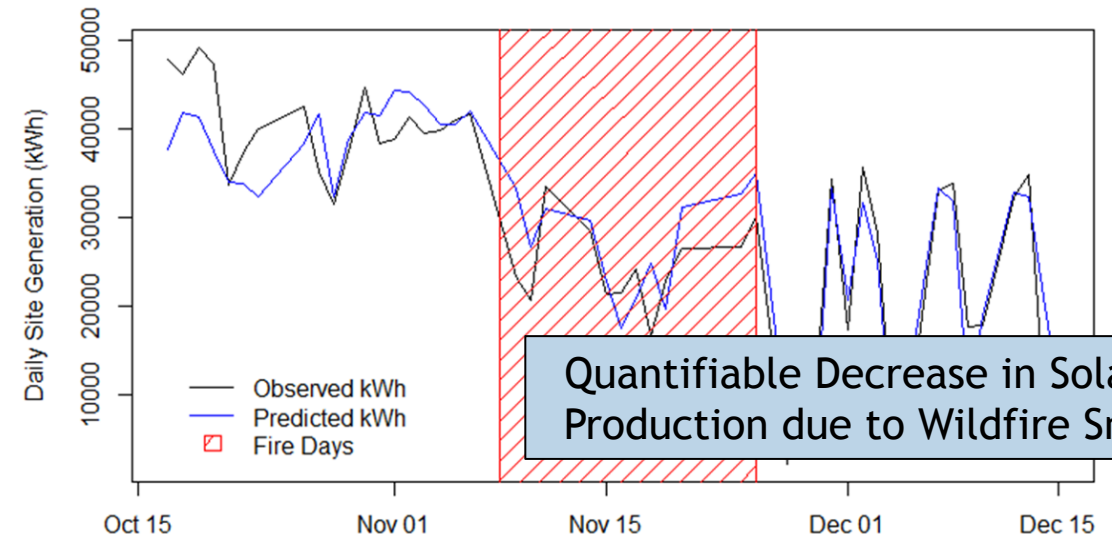
# Sample Results: Threat Analysis

- Other results focus on refinement of individual models, extensions for second-order impacts, and studies to quantify uncertainty throughout the NAERM platform

## Wide Variability in Sampled Earthquake Failures for Similar Events

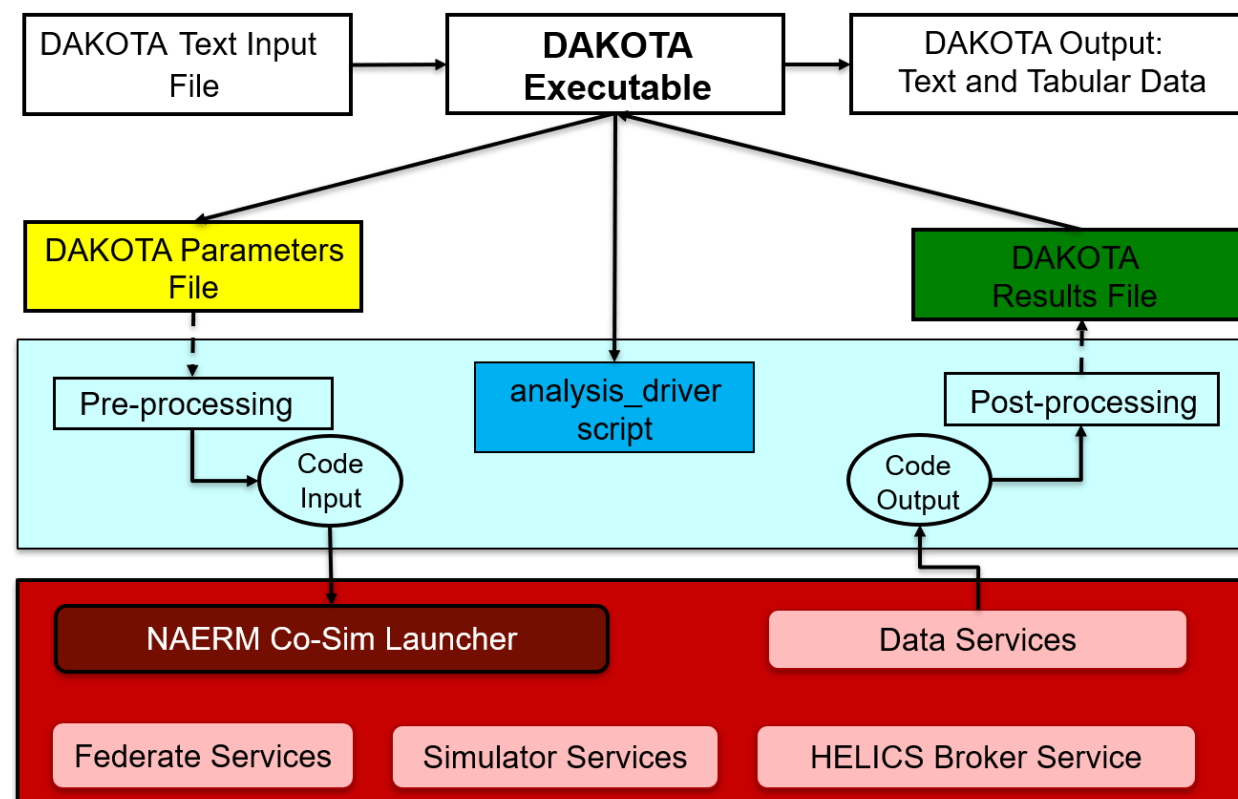
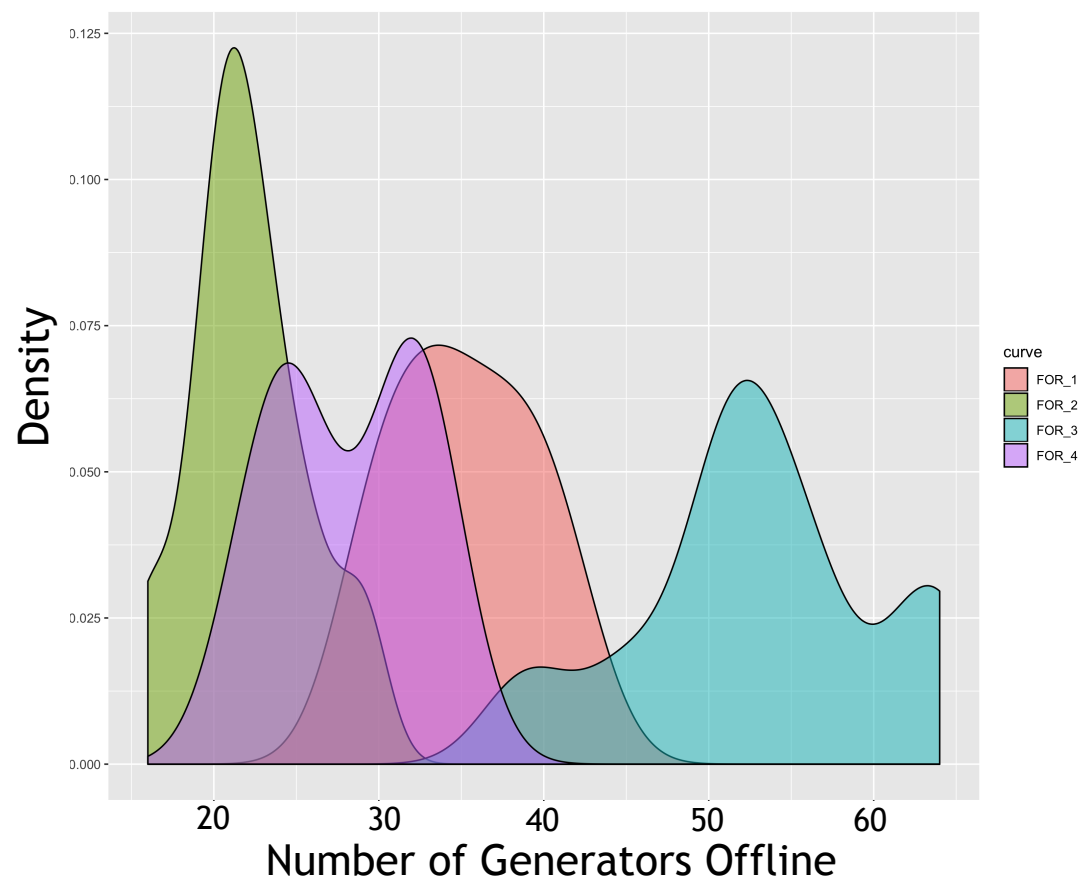


## Observed vs Predicted



# Dakota Integration for Threat Sensitivity

- We demonstrated the ability to integrate Dakota with the NAERM platform to advance our uncertainty quantification and sensitivity analysis capabilities



Generator		Fragility 1	Fragility 2	Fragility 3	Fragility 4
Gen. 29454	Probability of failure	0.251	0.164	0.378	0.158
	Number failed (out of 10)	3	2	4	1
Gen. 29490	Probability of failure	0.021	0.011	0.032	0.027
	Number failed (out of 10)	0	0	0	1



# Future work to improve threat representation



## Advancements in threat and impact representation

- Integrating additional data sources for increased accuracy
- Extending threat models to account for communications infrastructure assets

## Data collection and model development to characterize the time-evolution of threats

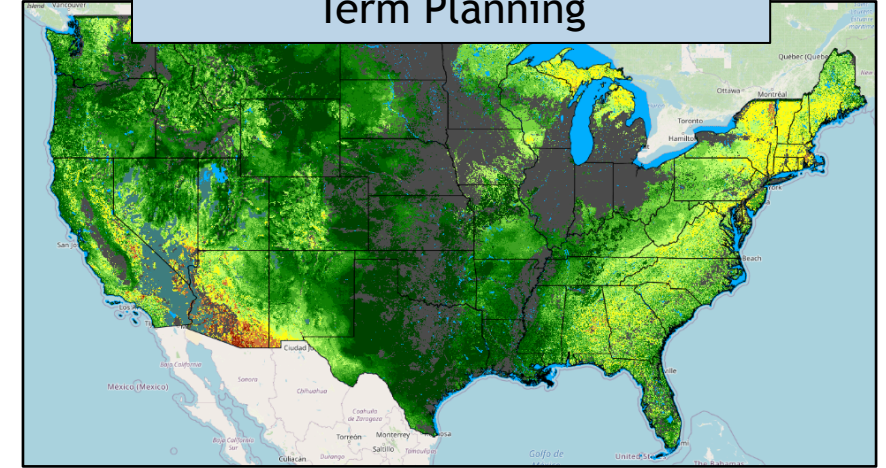
- Incorporating dispatch and commitment models into the NAERM platform to enable more realistic system response to threats

## Analysis of uncertainty propagation and resilience metrics given threat-specific impacts

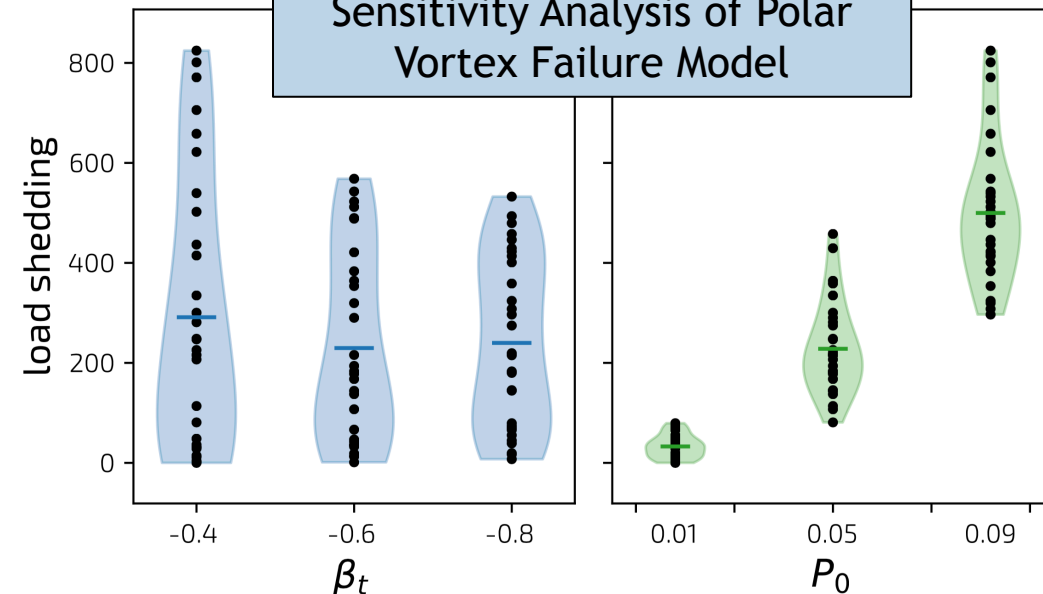
- Focus on metrics that provide value for decision-making in the face of threats
- How to convey uncertainty to support resilience

**Eventual vision: couple with climate projections for long-term hazard assessment and investment planning**

Wildfire Risk Map for Near-Term Planning



Sensitivity Analysis of Polar Vortex Failure Model



# NAERM is big, complex, and highly customer-driven

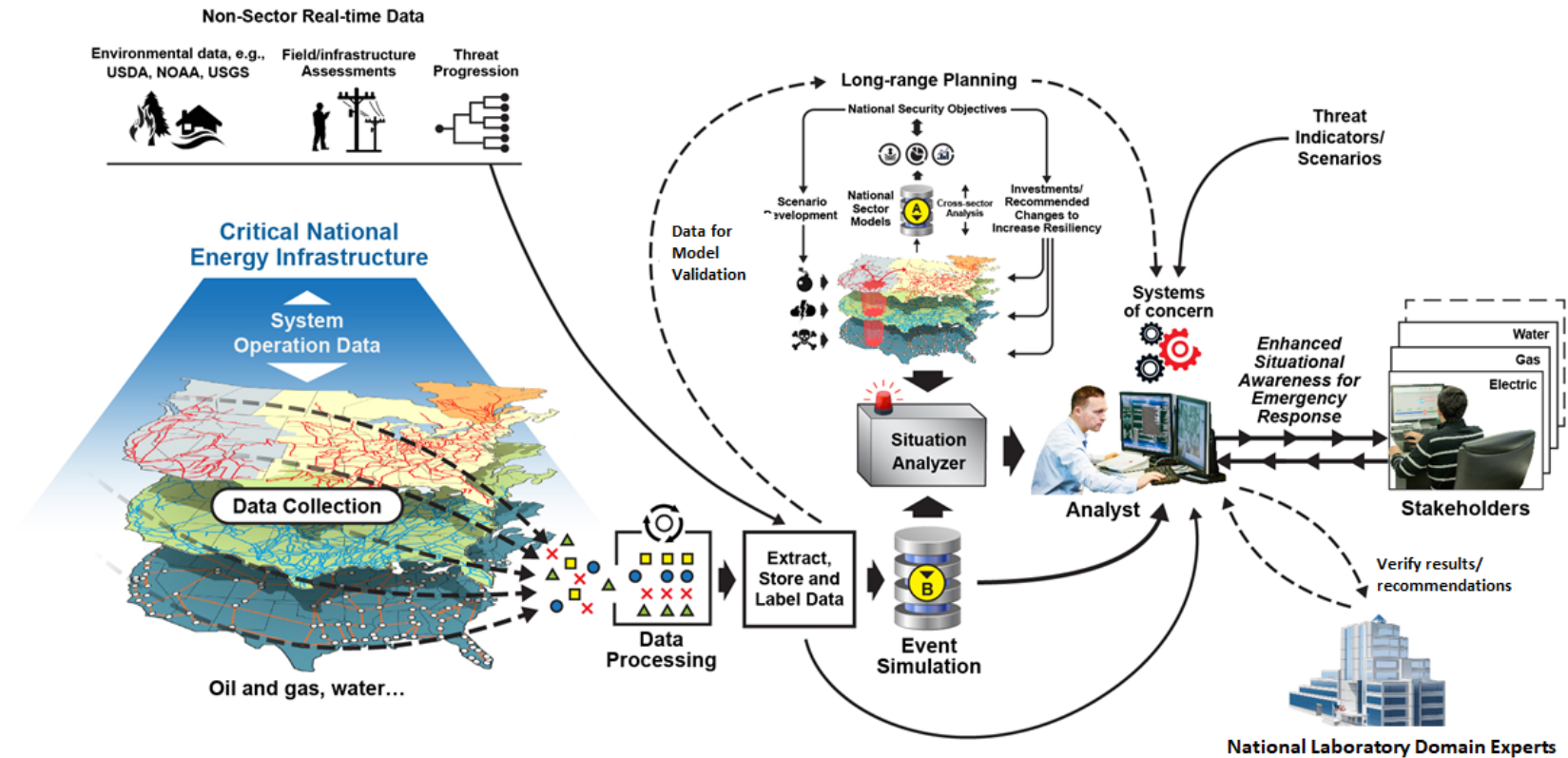


NAERM is focused on getting a tool into the hands of users

- Much of the research needed to improve the tool will happen under other projects and funding sources

Basic functionality deployed – allowing DOE to show off the potential

- Much more research, development, and integration needed to reach the promised state of full resilience analysis
- Sorting out long-term vision of user roles/capabilities and where the labs fit in for technical support and detailed analysis





# Questions?



## Contact Information:

- Andrea Staid, [astaid@sandia.gov](mailto:astaid@sandia.gov)

## Publications:

- Laura P. Swiler, Sarah Newman, Andrea Staid, and Emily Barrett. “Dakota-NAERM Integration.” SAND Report, 2020.
- Benjamin F. Emery, Andrea Staid, and Laura Swiler. “Sensitivity and Uncertainty Analysis of Generator Failures under Extreme Temperature Scenarios in Power Systems.” SAND Report, 2020.
- Anya Castillo, Robert Jeffers, Katherine Jones, Andrea Staid, Vanessa Vargas, Bernard Knueven, Sean Ericson, Jessica Lau, Caitlin Murphy, Jean-Paul Watson, and Mercy B. DeMenno. “Resilience Metrics for Informing Decisions Associated with the Planning and Operation of the North American Energy System.” SAND Report, 2020.