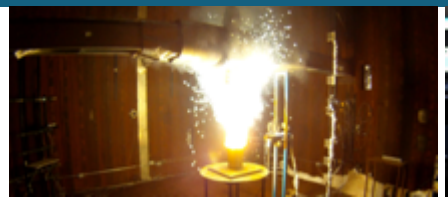
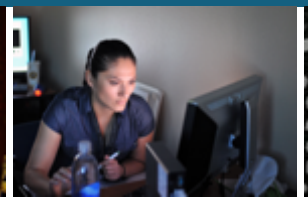
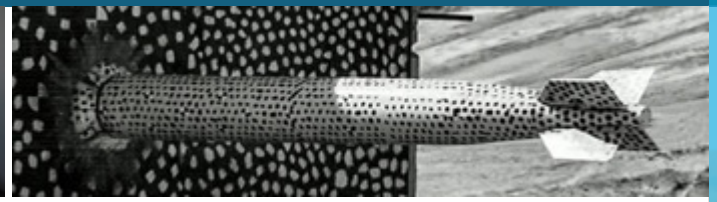
Sandia National Laboratories

SAND2021-3075PE

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 multimission 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.

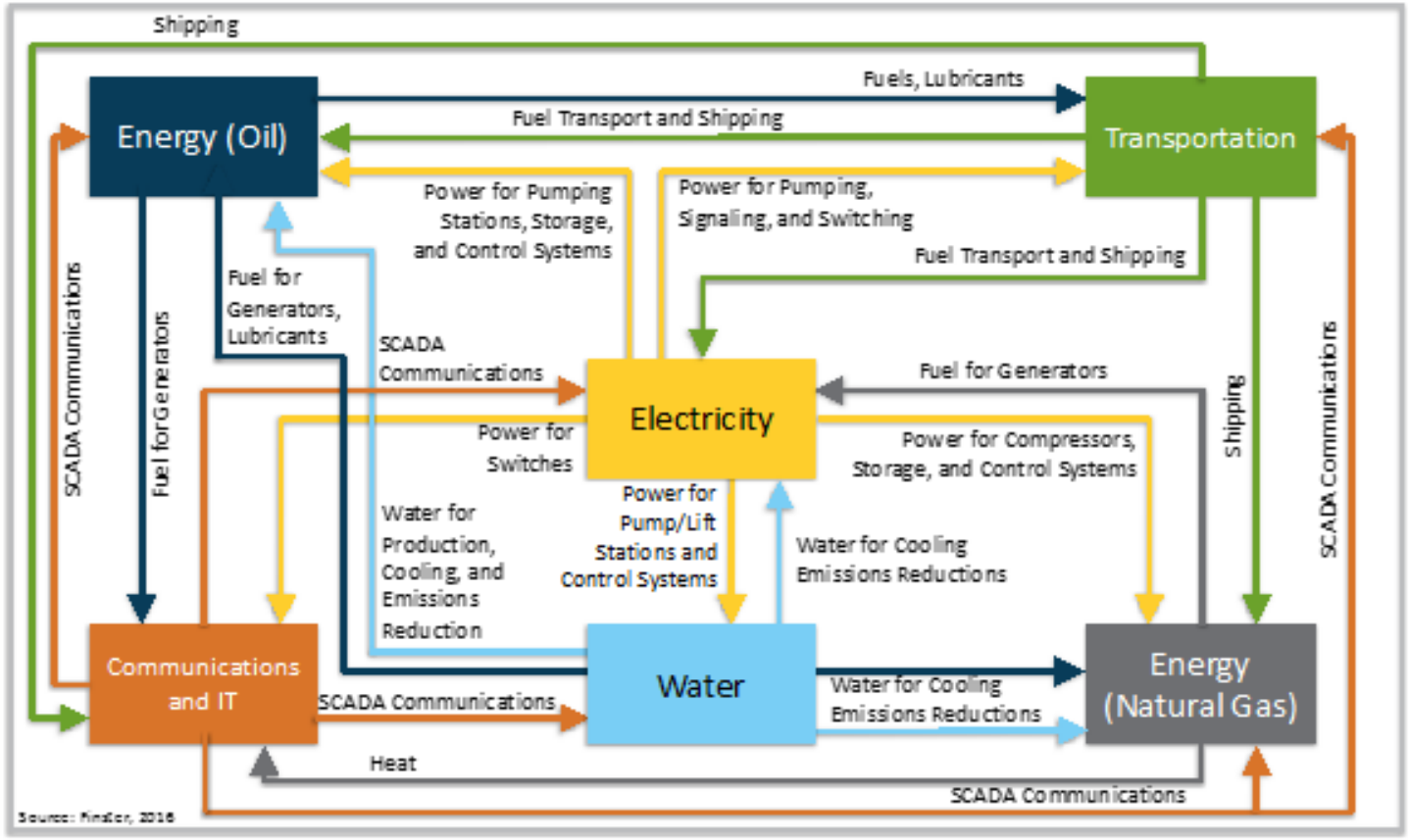
NAERM aims to Assess and Improve Infrastructure Resilience

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

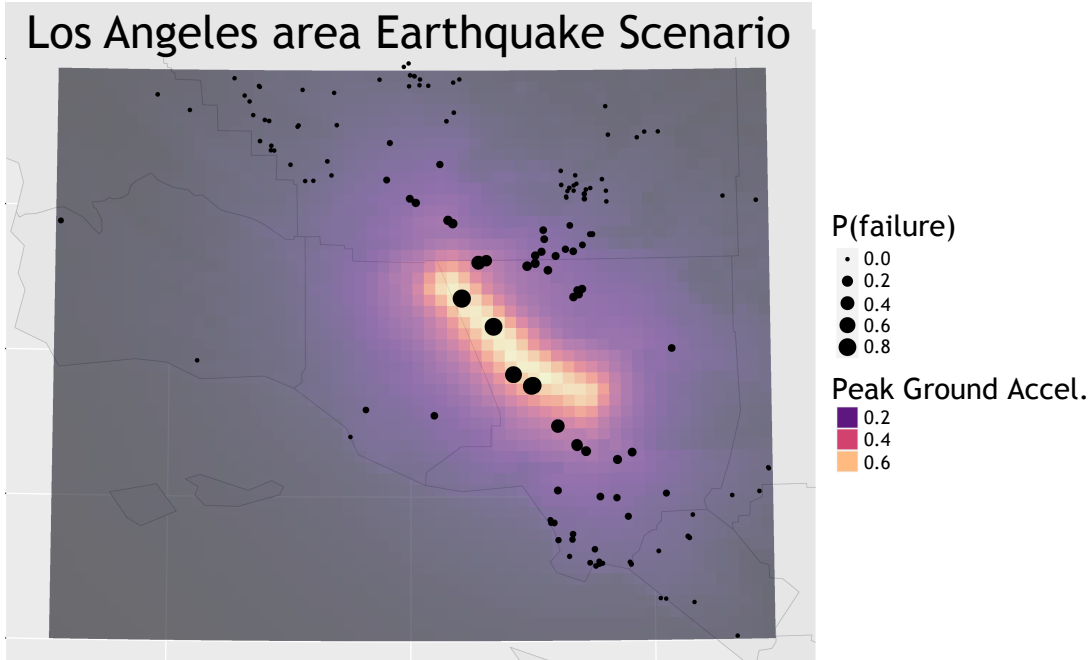
What can we do with threat models?

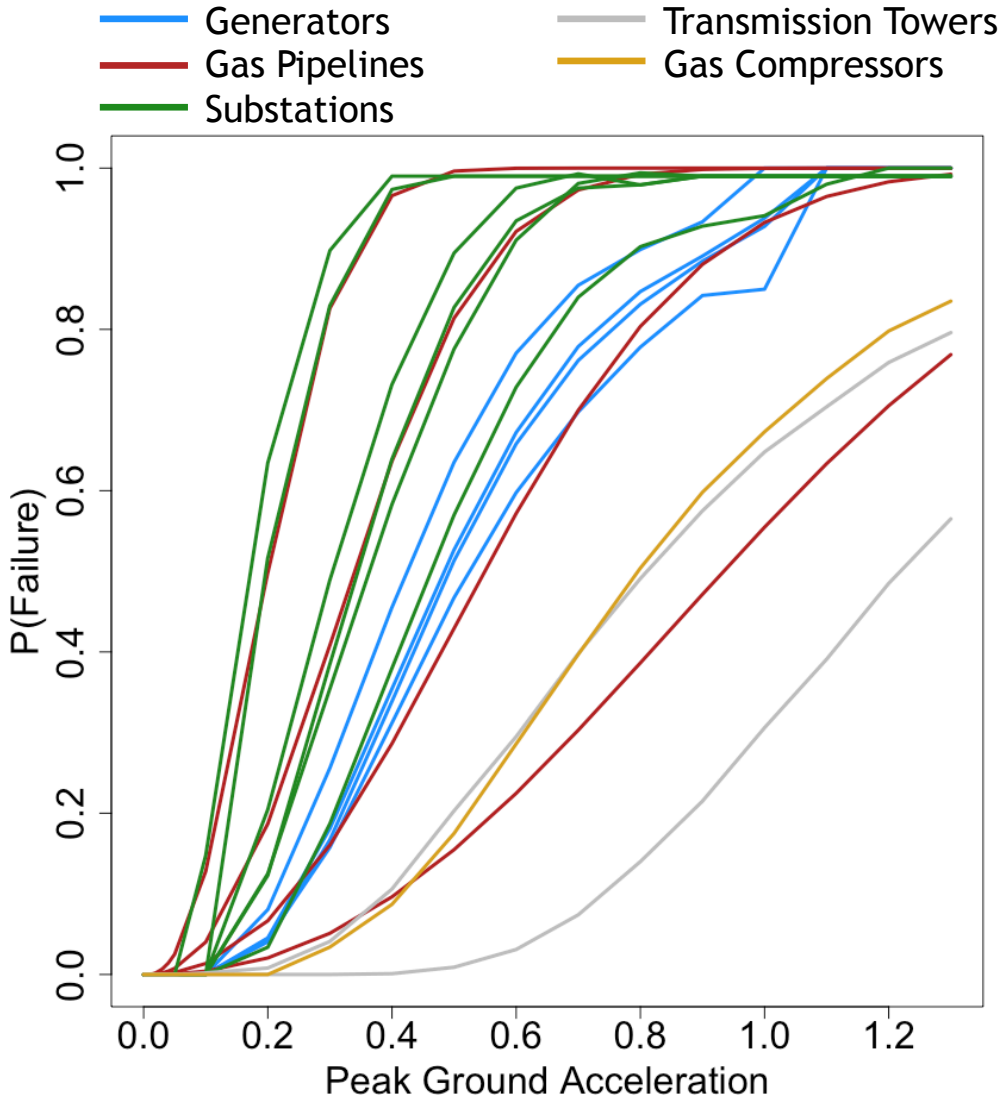
- Assess the current state of system resilience
- Quantify uncertainty in threat and impact projections
- Analyze the impact of potential investments or mitigation strategies
- Couple with real-time data streams to predict impacts based on weather forecasts

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)





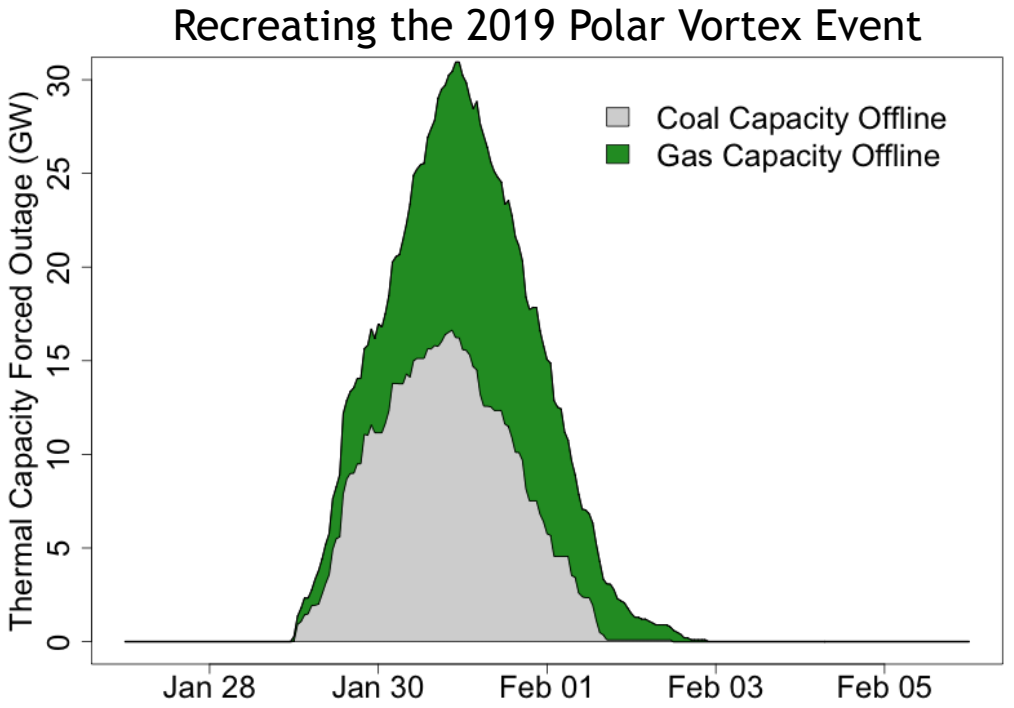
Threat Modeling Overview

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

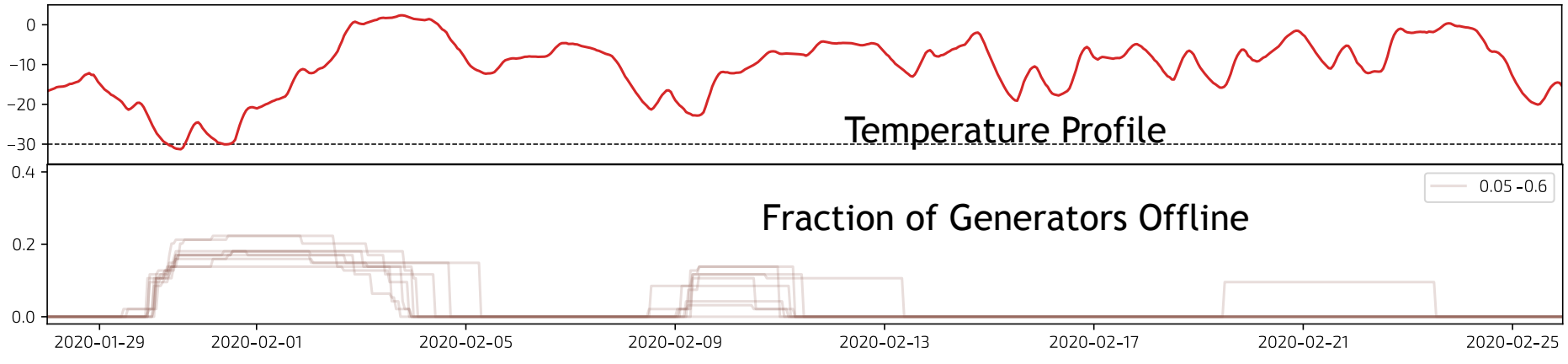
So far: earthquakes, wildfires, cold snaps (polar vortex events), and intentional physical attacks

- Priorities driven by DOE



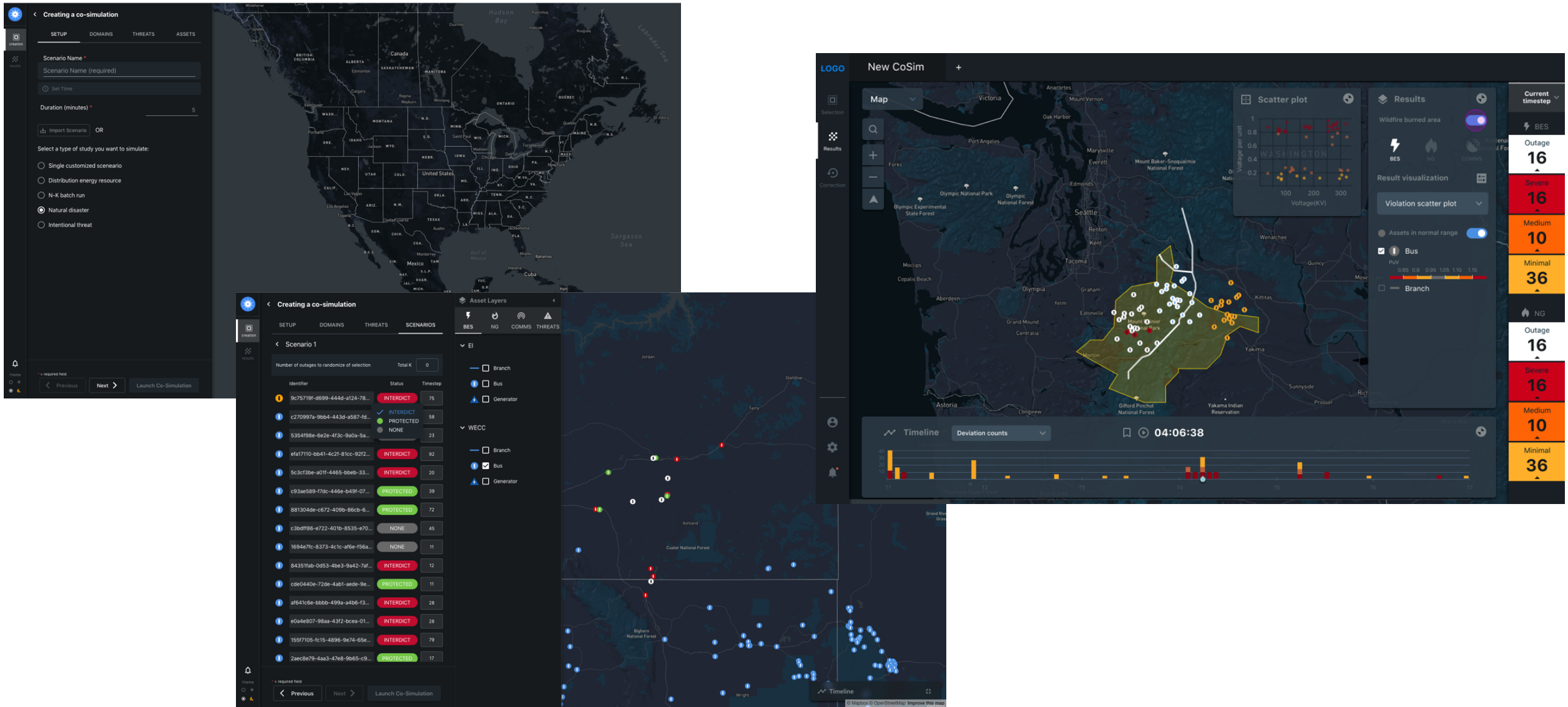
$$P(\text{thermal generator fails} \mid t, f) = \frac{\exp(\beta_0 + \beta_t t + \beta_f f)}{1 + \exp(\beta_0 + \beta_t t + \beta_f f)}$$

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

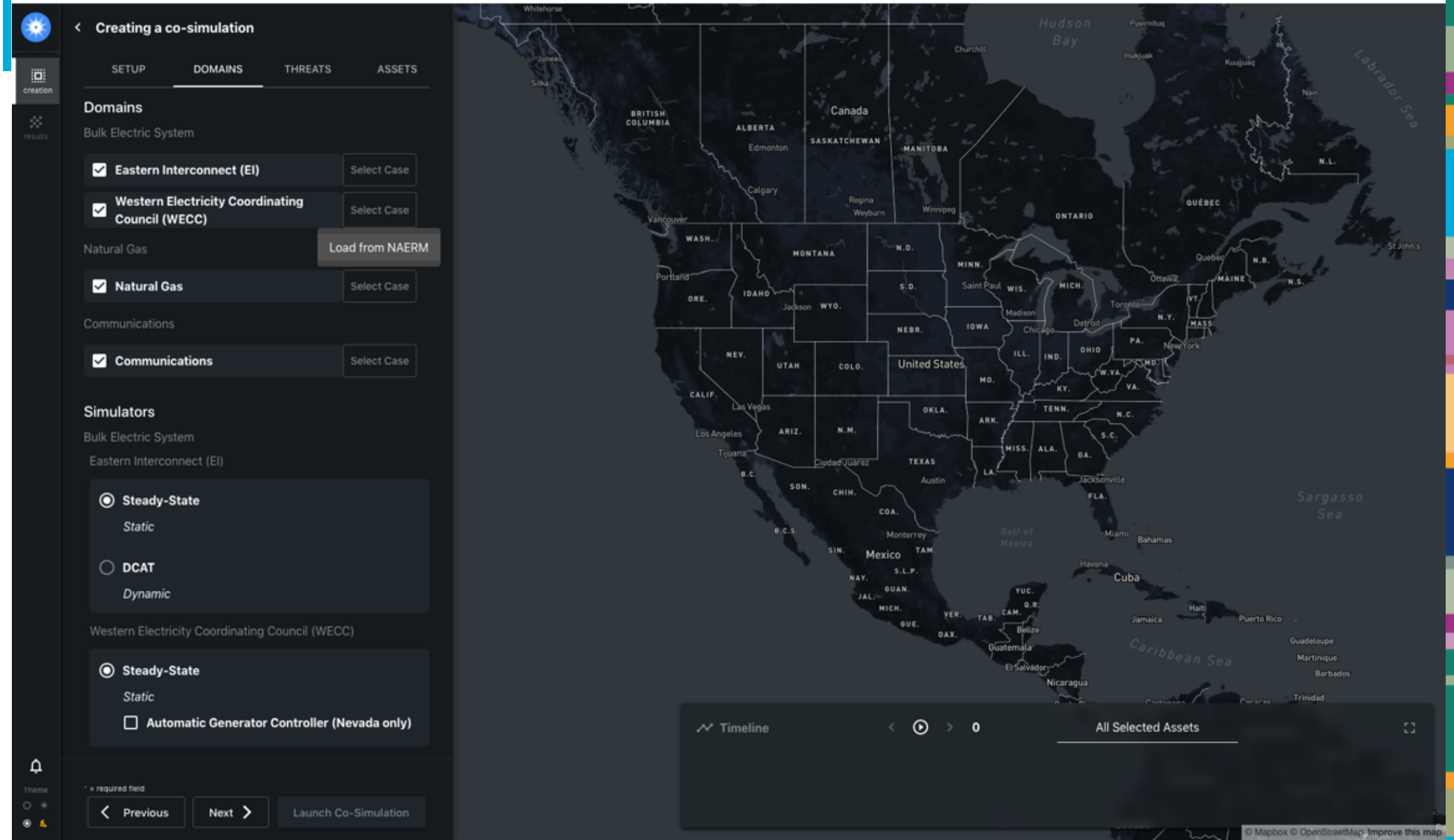


All models aim for integration to the User Interface

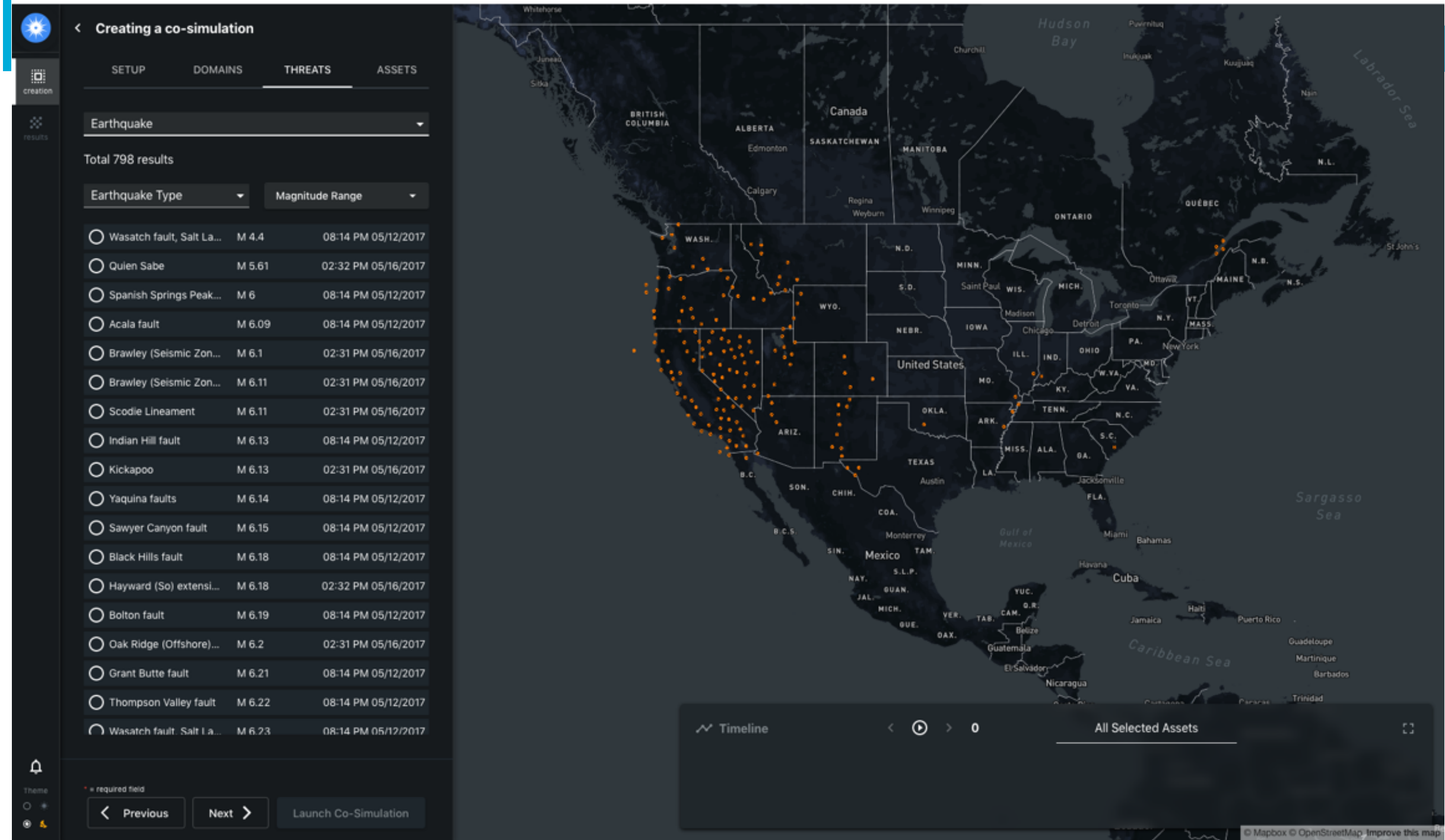
The planning tool and real-time situational awareness tool are deployed with limited user access



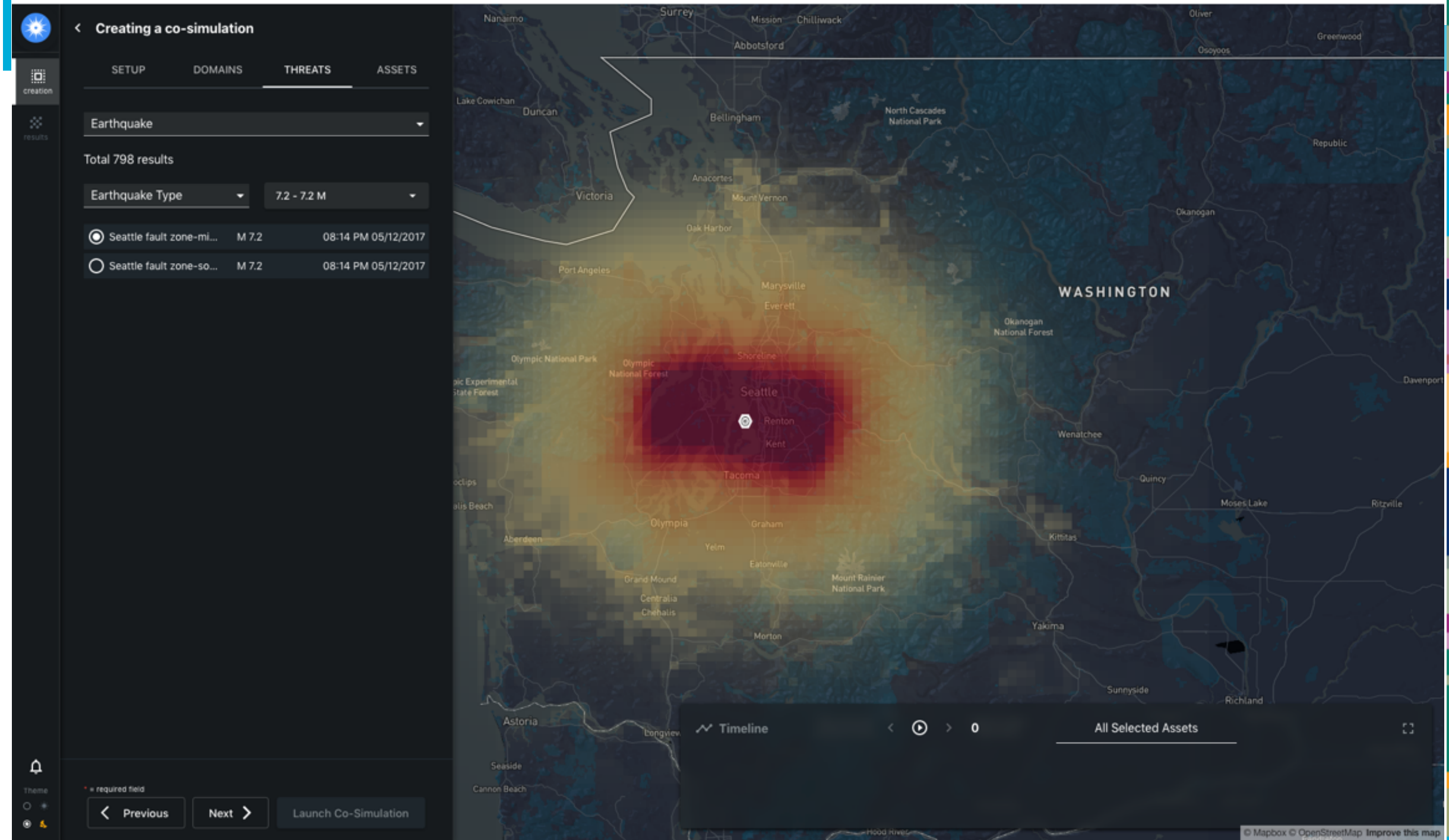
Setting up an Earthquake Simulation



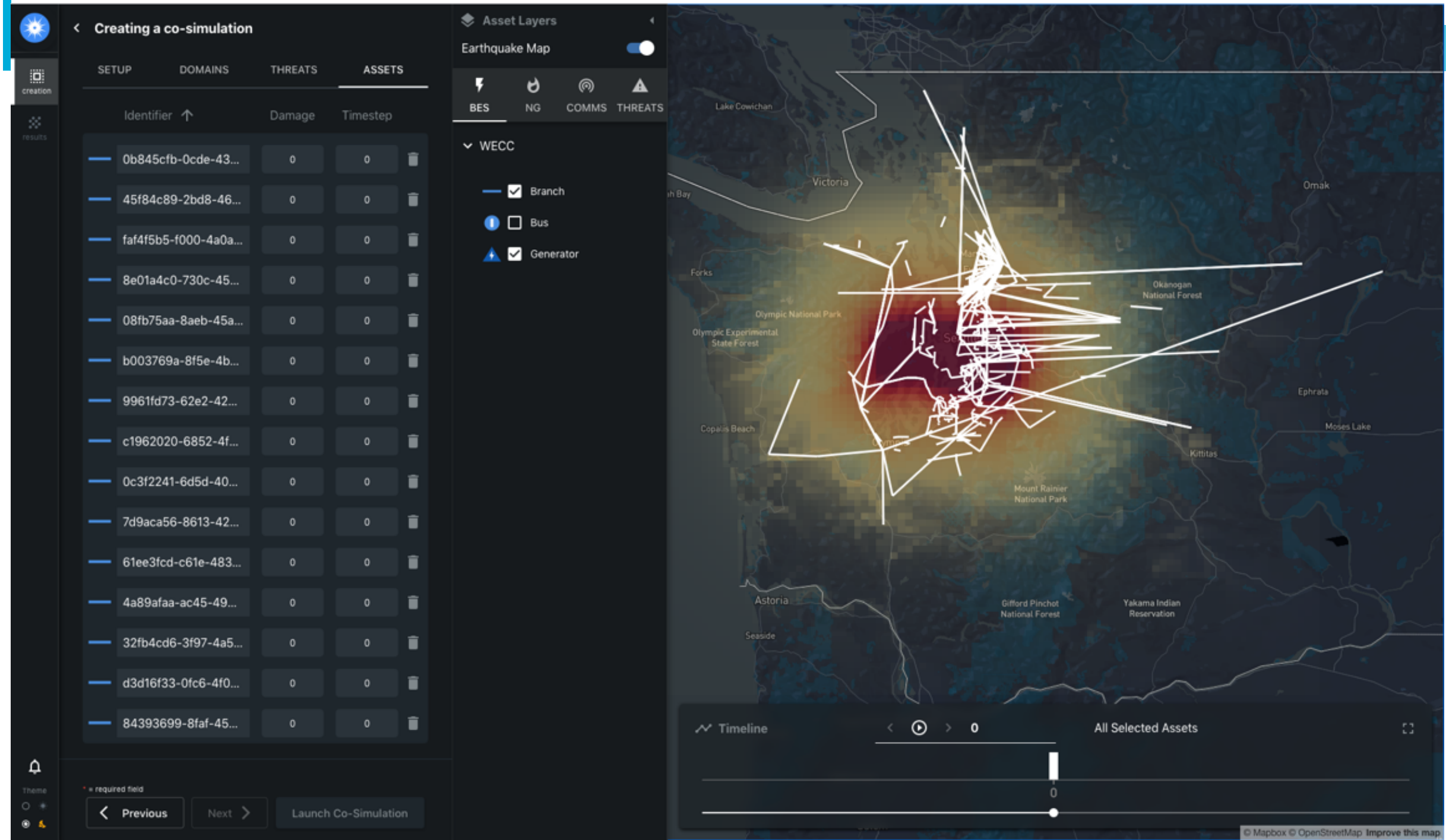
Setting up an Earthquake Simulation



Setting up an Earthquake Simulation



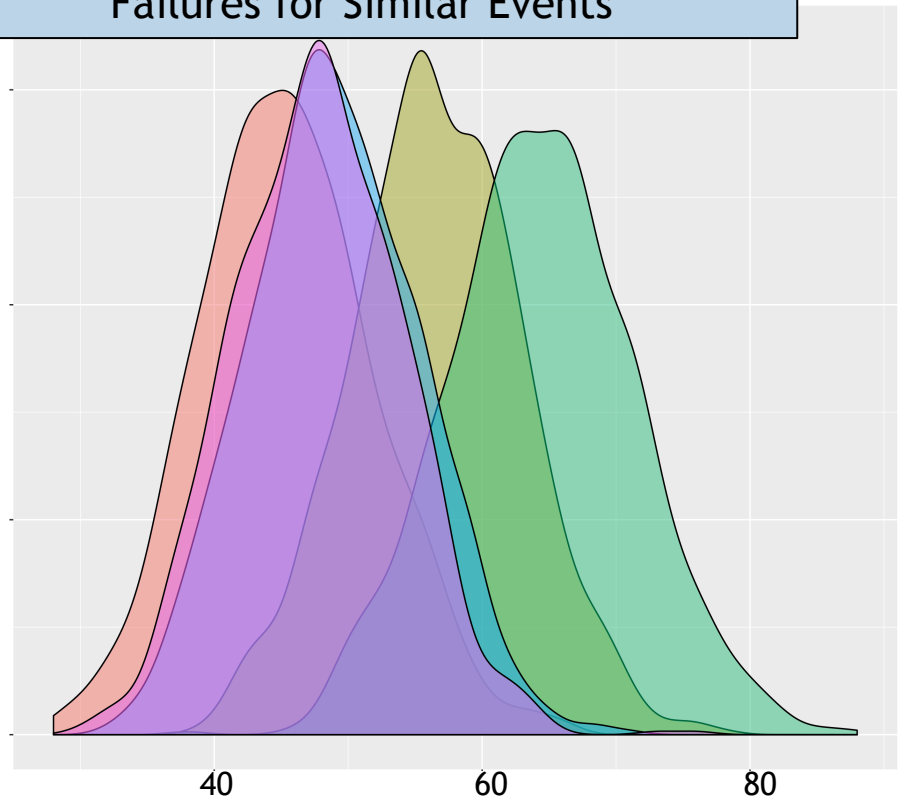
Setting up an Earthquake Simulation



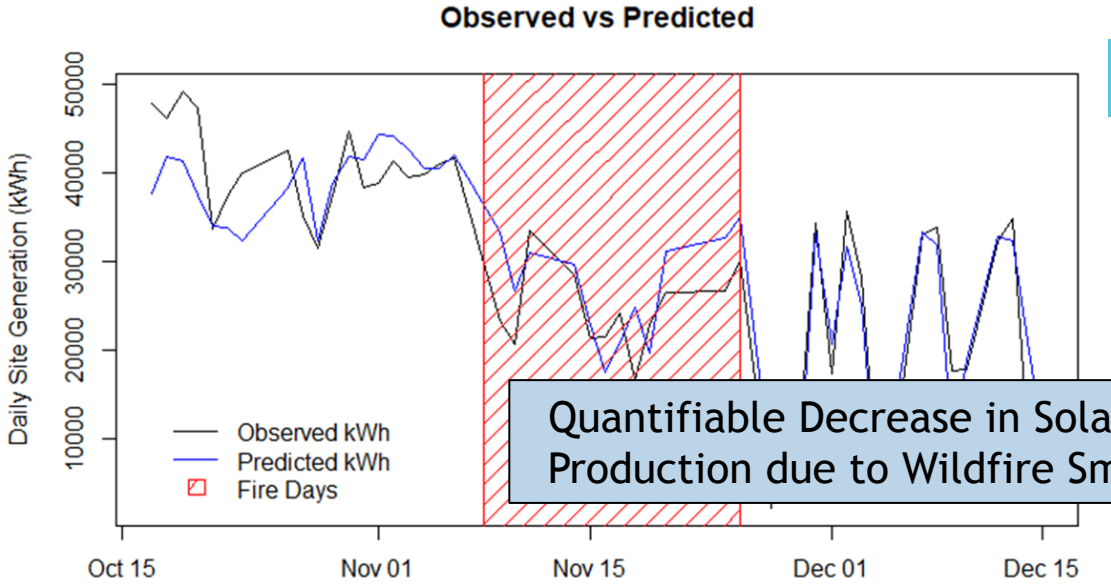
Sample Results: Threat Analysis

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

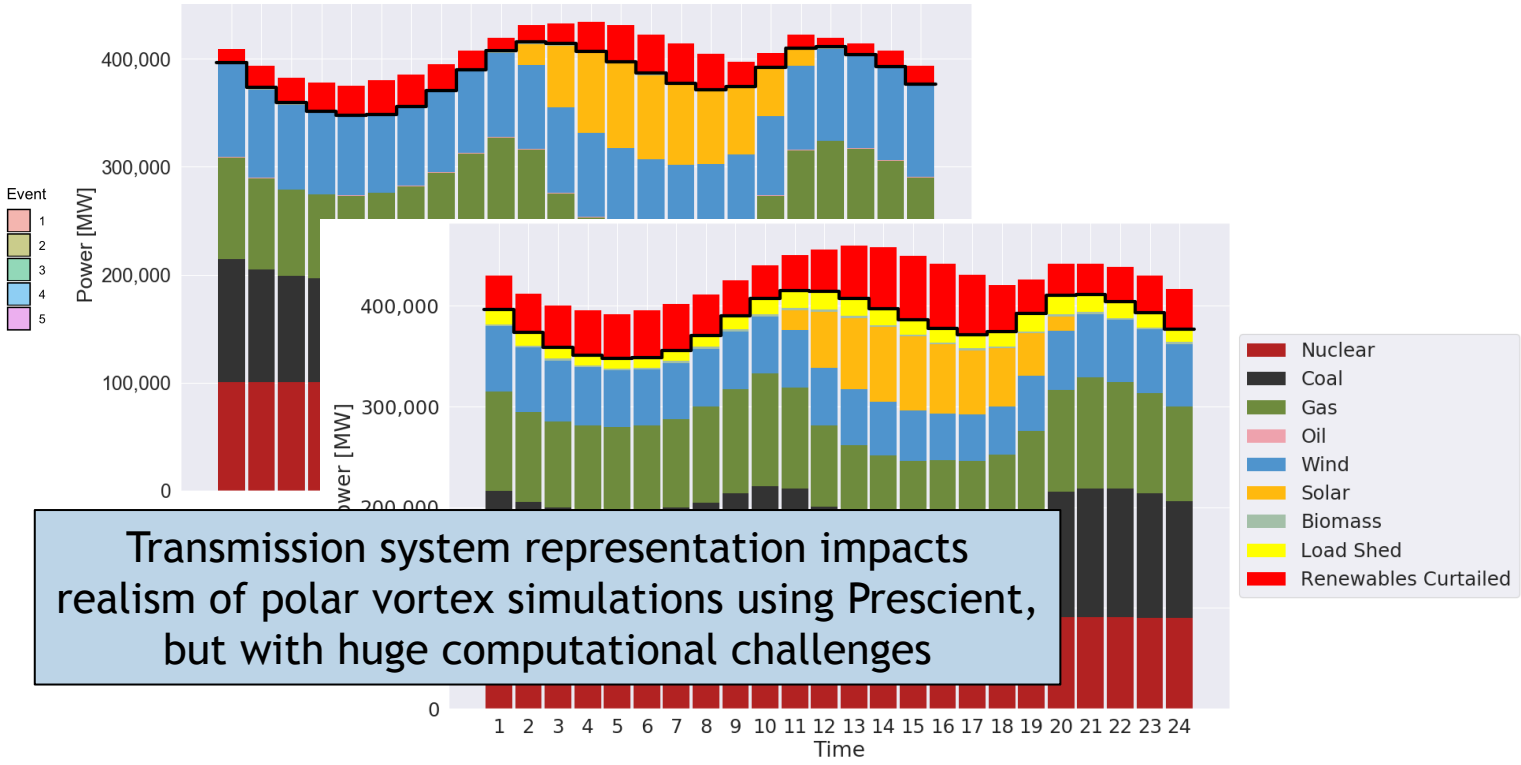
Wide Variability in Sampled Earthquake Failures for Similar Events



Number of Sampled Generator Outages Across 5 Similar Earthquake Events



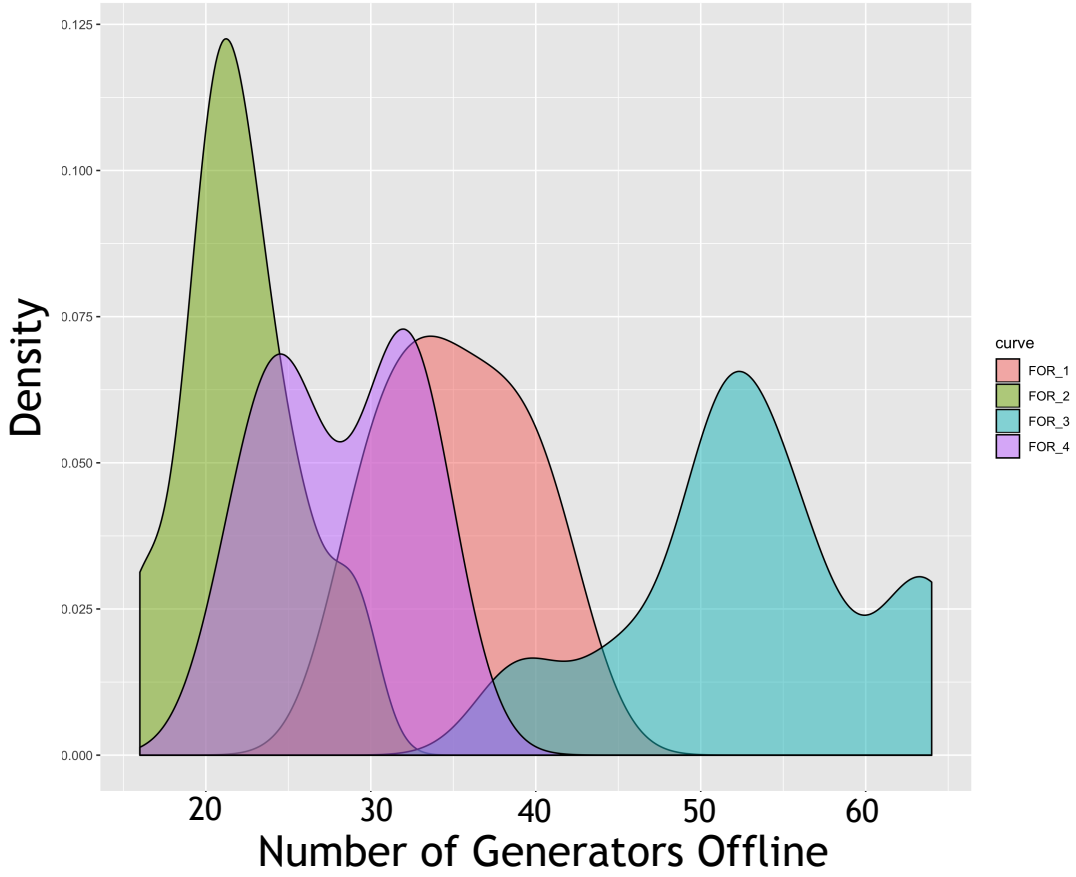
Quantifiable Decrease in Solar PV Production due to Wildfire Smoke

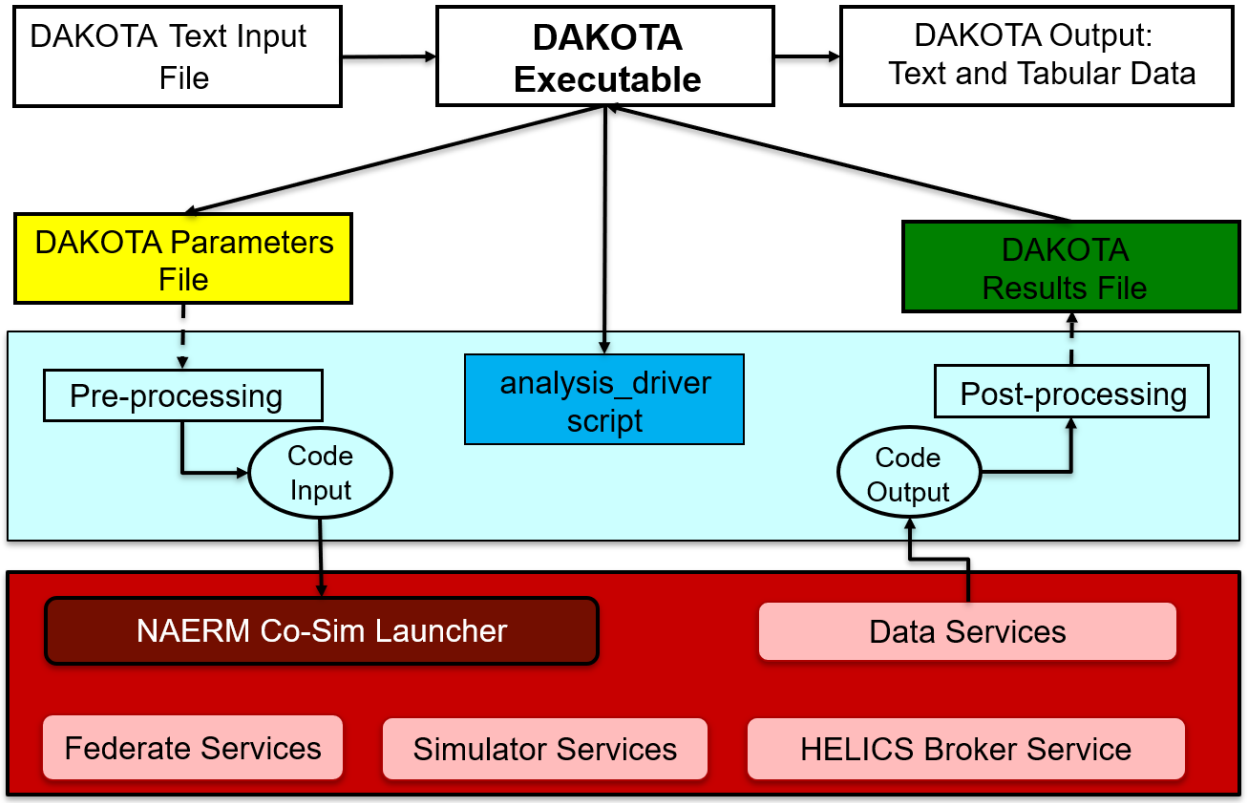


Transmission system representation impacts realism of polar vortex simulations using Prescient, but with huge computational challenges

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

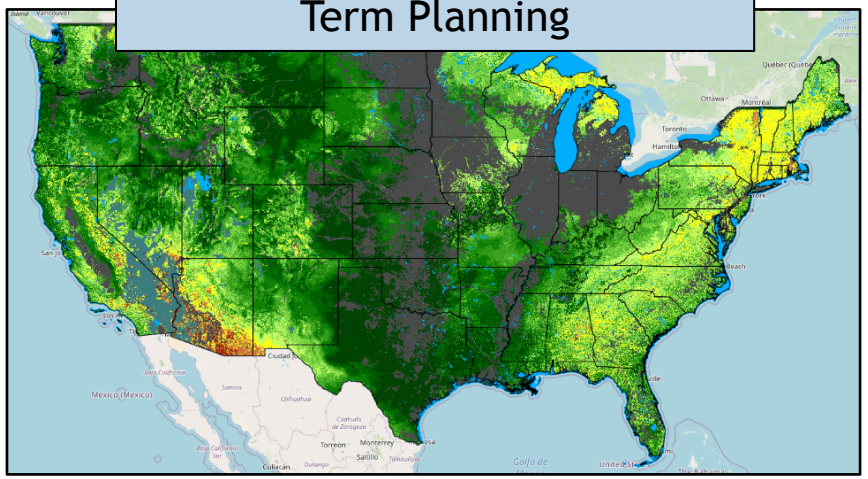
- Incorporating dispatch and commitment models into the NAERM platform to enable more realistic system response to threats

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

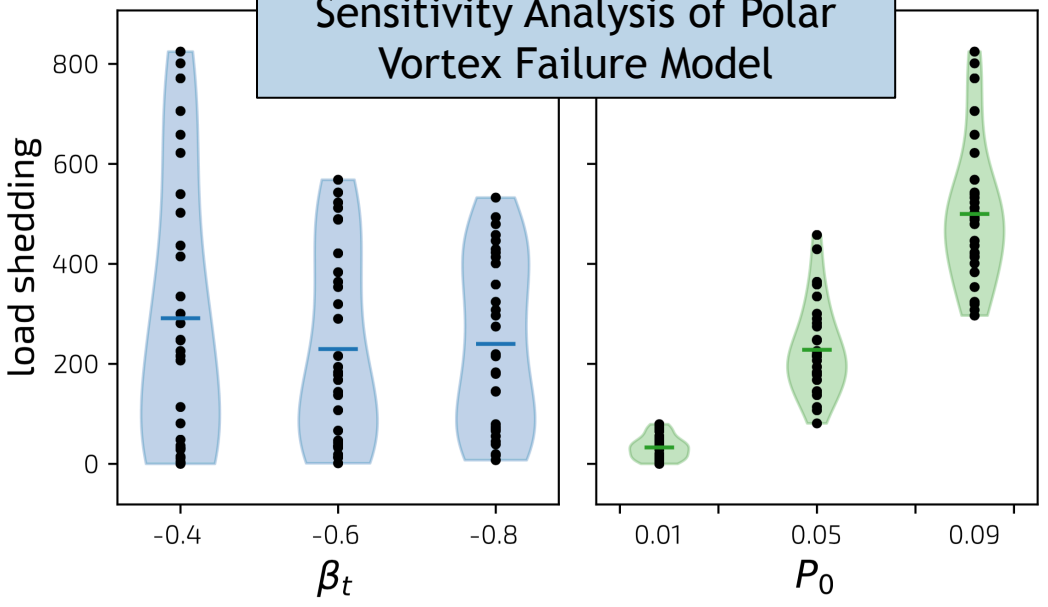
- Focus on metrics that provide value for decision-making in the face of threats
- How to convey uncertainty to support resilience

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



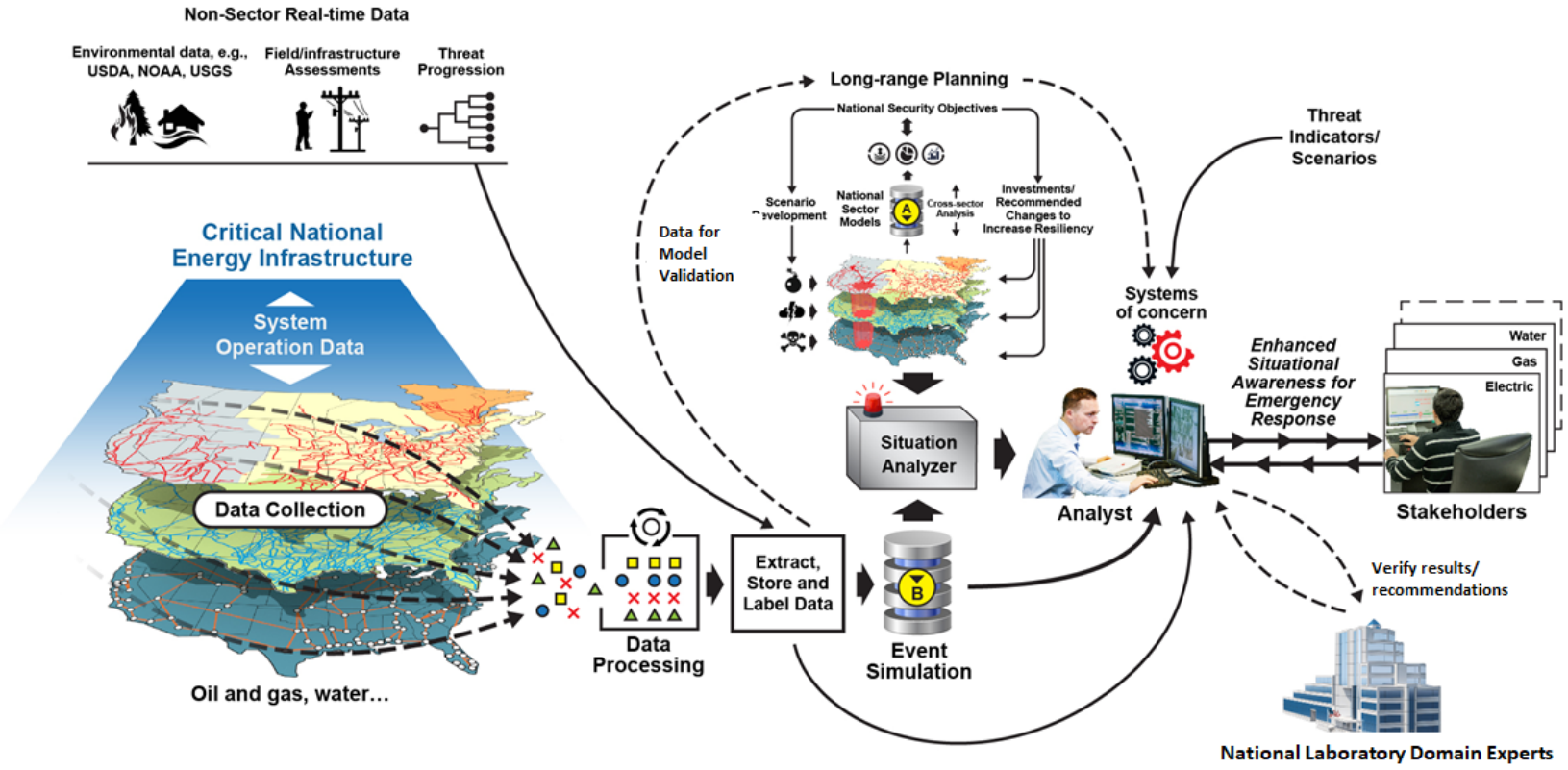
NAERM is big, complex, and highly customer-driven

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

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.