North American Energy Resilience Model (NAERM) Program

Ali Ghassemian (DOE Office of Electricity), John Grosh (Lawrence Livermore National Laboratory),
JP Watson (Lawrence Livermore National Laboratory), Russell Bent (Los Alamos National Laboratory)

February 15, 2023

Agenda

⇨ **Introduction to NAERM (Ali Ghassemian – DOE OE)**

Current State of NAERM (John Grosh – LLNL)

Wildfire Use Case (JP Watson – LLNL)

Cold Wave Use Case (Russell Bent – LANL)

Q&A

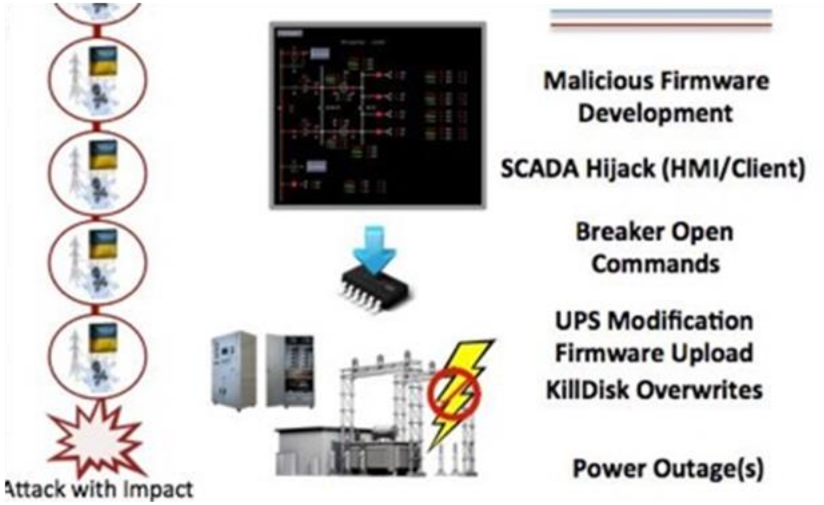
The U.S. energy infrastructure faces many threats

Extreme Weather

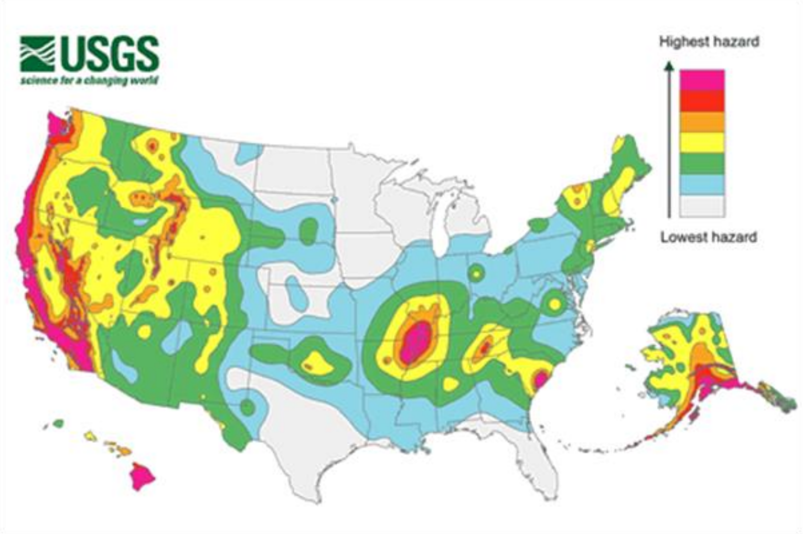
Hurricane Maria

Winter Storm Uri

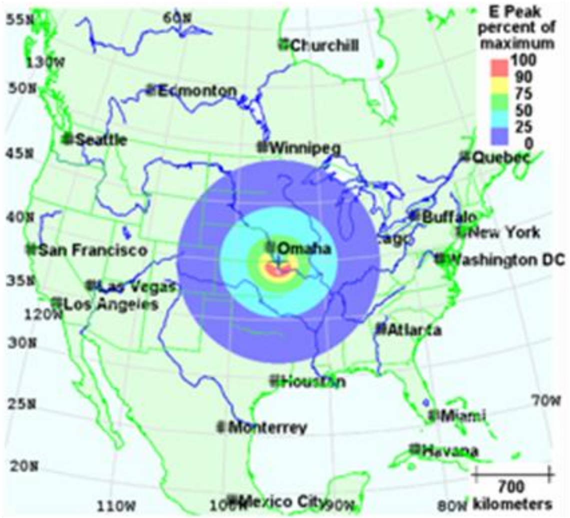
Cyber Attack



Earthquakes



EMP

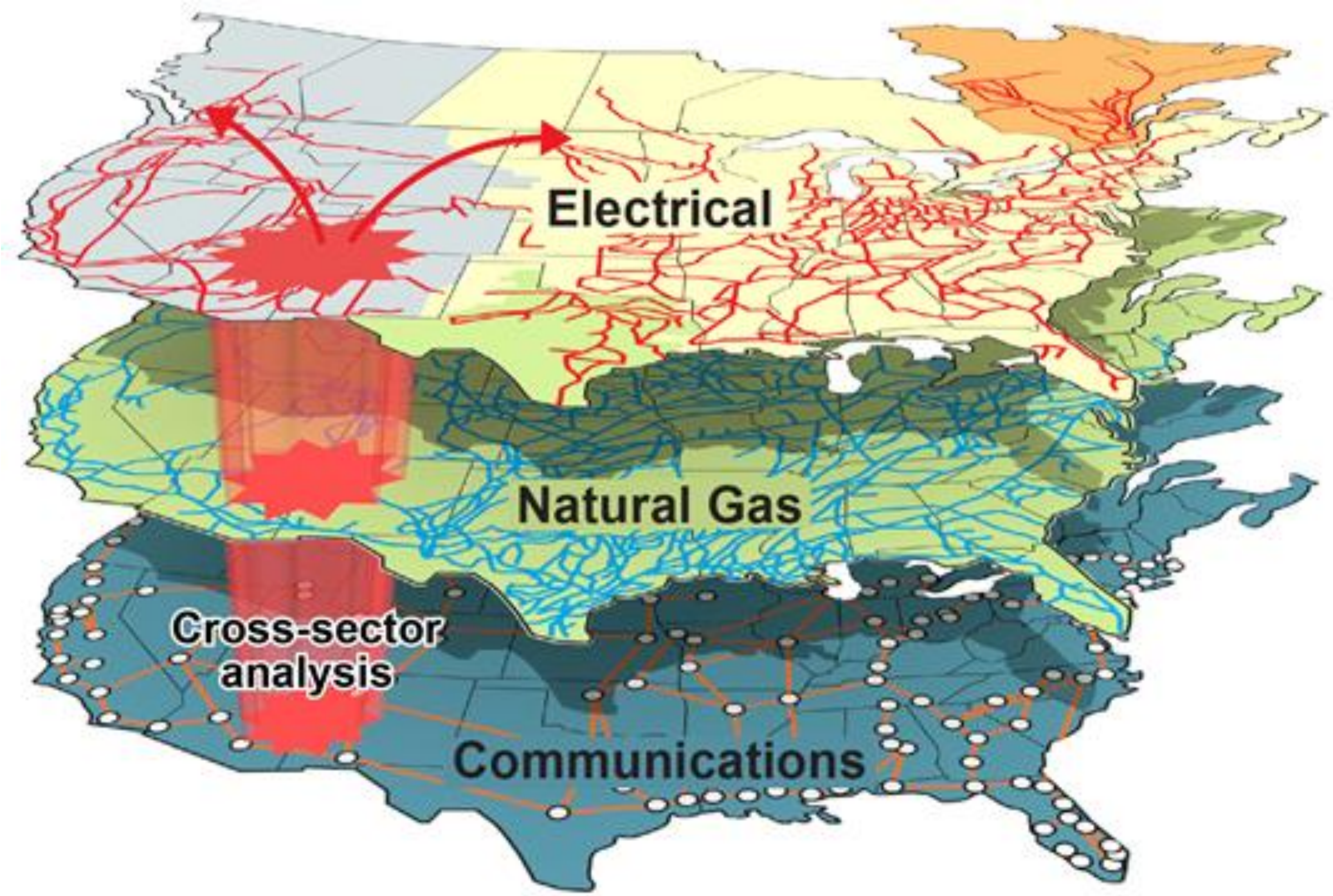


North American Energy Resilience Model (NAERM)

Vision: Rapidly predict energy system interdependencies, consequences, and responses to reduce risk of extreme events at a national scale

Mission: Develop and deploy engineering-class modeling system for planning and near real-time resilience analysis

Key Objective: Catalyze partnerships with industry, national labs, states/communities, and other federal agencies to enhance coordination to support energy resilience



Team: DOE, LLNL, PNNL, ORNL, LANL, ANL, SNL, NREL, INL

National Labs Contributing to NAERM

Idaho National Laboratory

Sandia National Laboratories

Oak Ridge National Laboratory

Argonne National Laboratory

Pacific Northwest National Laboratory

NREL National Renewable Energy Laboratory

Los Alamos National Laboratory

Lawrence Livermore National Laboratory

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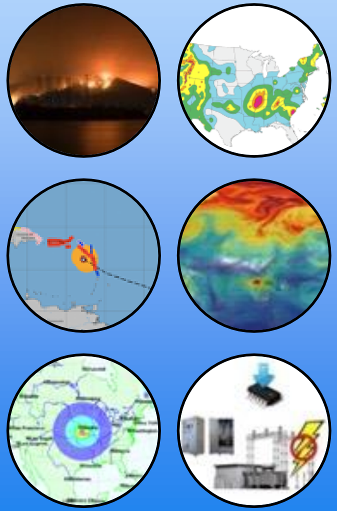
Q&A

NAERM workflow

Threat and Hazard Models and Data



Integrated Modeling & Analysis Environment

- Electric Grid Models
- Pipeline System Models
- Communications Systems Models

HELICS Code Coupling / Adv. Contingency Tools / …
Front-Ends / Computing / Archives / Security

Data Infrastructure

- Model DBs
- Gen and Loads
- Infra-structure
- Asset Info
- Weather / Climate
- Sensor Data

Outputs

- Predict Outages & Other Impacts
- Post-event Analysis
- Operational Planning Options
- Resilience Investments

NAERM is organized around three major capabilities

Multi-Infrastructure Planning Modeling

Analyze options to affect energy resilience, improve rapid restoration and recovery, and enable risk-informed planning and coordination to mitigate large-scale energy disruptions (e.g. earthquakes, wildfires).

Data and Analytics

Store and analyze wide range of data to support resilience analysis. Data layers include modeling databases for bulk electric system, generation, natural gas pipelines; cell, fiber communications; weather forecasts, icing; hospitals, roads. Analytics include graph analysis and machine learning (ML).

Software and Computing Architecture

Enable a complex, multi-component software system focused on security, integration, scalability, and open architecture that leverages existing commercial and open-source software and commercial and government cloud services.

NAERM builds on 50+ projects / technologies from DOE, government agencies, and industry

Sponsors

- DOE OE
- DOE EERE
- DOE GMI
- DOE CESER
- DOE FE
- DOE NNSA
- DOE LDRD
- DOE GDO
- DHS
- ARPA-E
- DARPA
- DOS

Labs

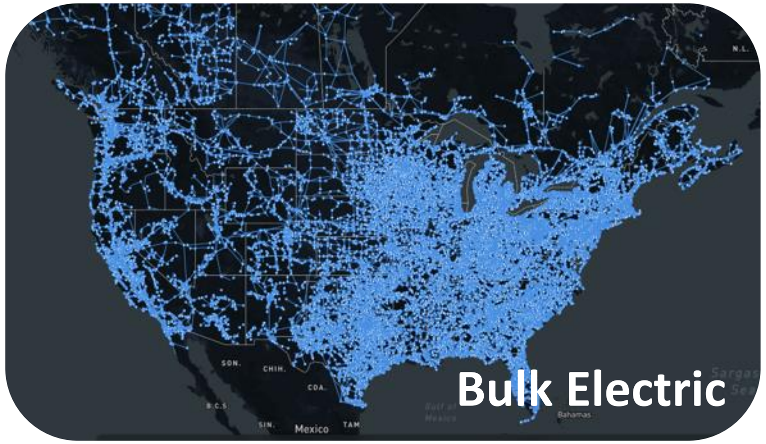
- ANL
- INL
- LLNL
- LANL
- NREL
- ORNL
- PNNL
- Sandia
- Vendors

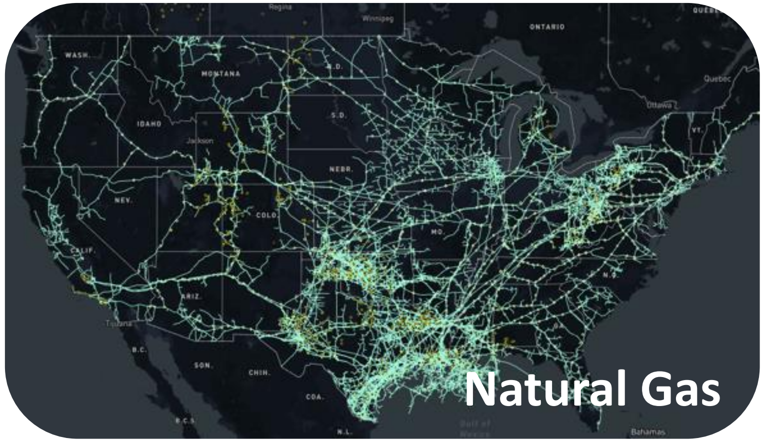
Partial List of Tech Contributions to NAERM

- HELICS co-simulation framework
- Extreme events modeling
- Solar, wind, and load forecasting
- Modeling distributed energy resources
- Communications modeling
- Natural gas pipeline modeling
- Dynamic and worst-case contingency analysis tools
- Situational awareness tools
- Validation, verification, and UQ
- Commercial power flow solvers

Infrastructure Modeling

Integrated





Under Development

Bulk Electric System Modeling

Commercial and lab tools:

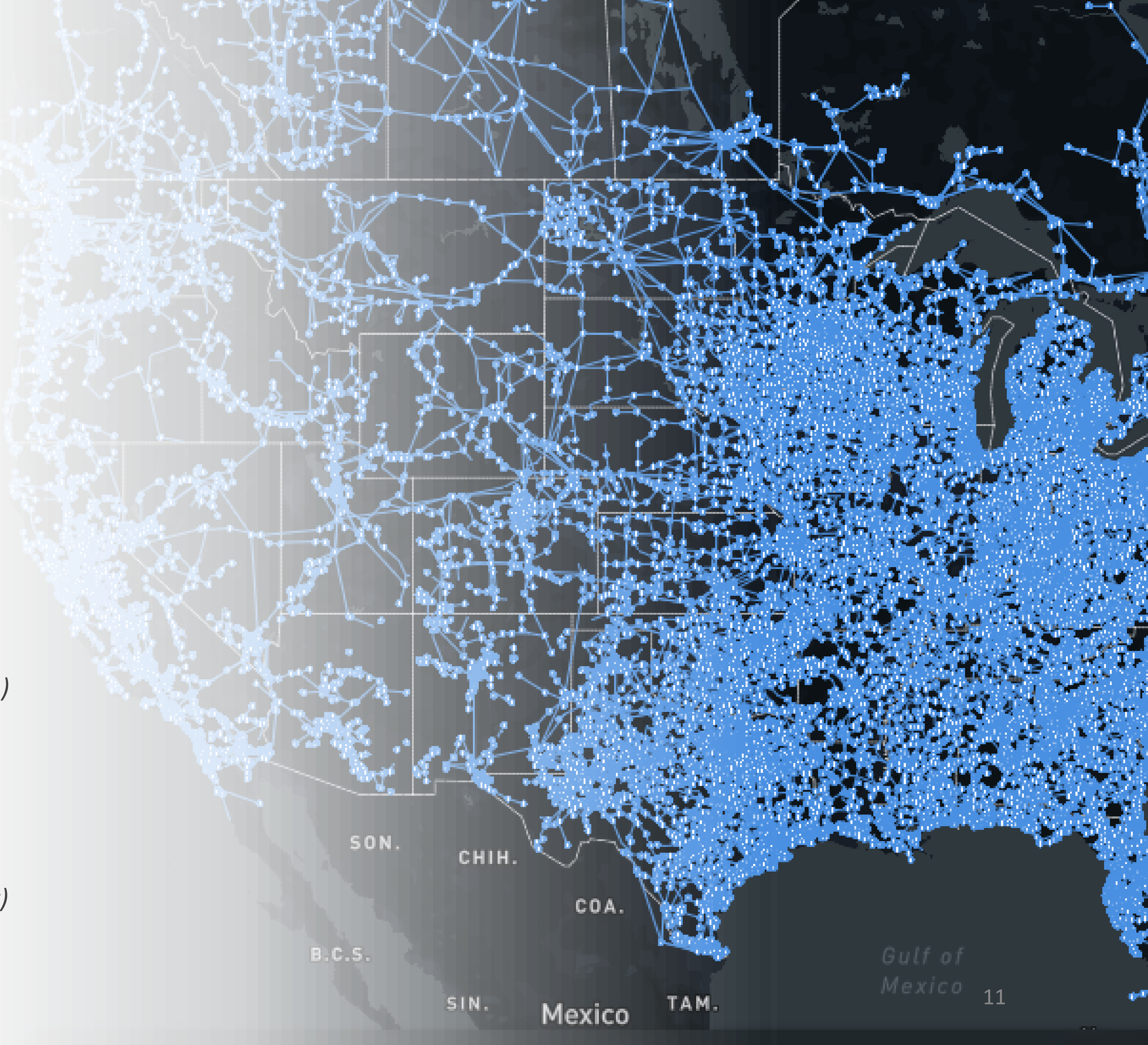
- PowerWorld
- PSS/E
- Dynamic Contingency Analysis Tool *(initial integration)*

Modeling capabilities:

- Steady-state
- Transient *(for limited use cases)*
- Commitment and dispatch modeling *(initial integration)*
- High-k N-k contingency analysis *(prototype)*
- AGC *(prototype)*

Example of Data Layers Used:

- WECC, ERAG, and ERCOT planning models
- Real-time EMS and telemetry data *(under development)*



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Natural Gas Modeling

Lab Modeling Tools:

- NGFast
- NGTransient
- GasModels

Modeling Capabilities:

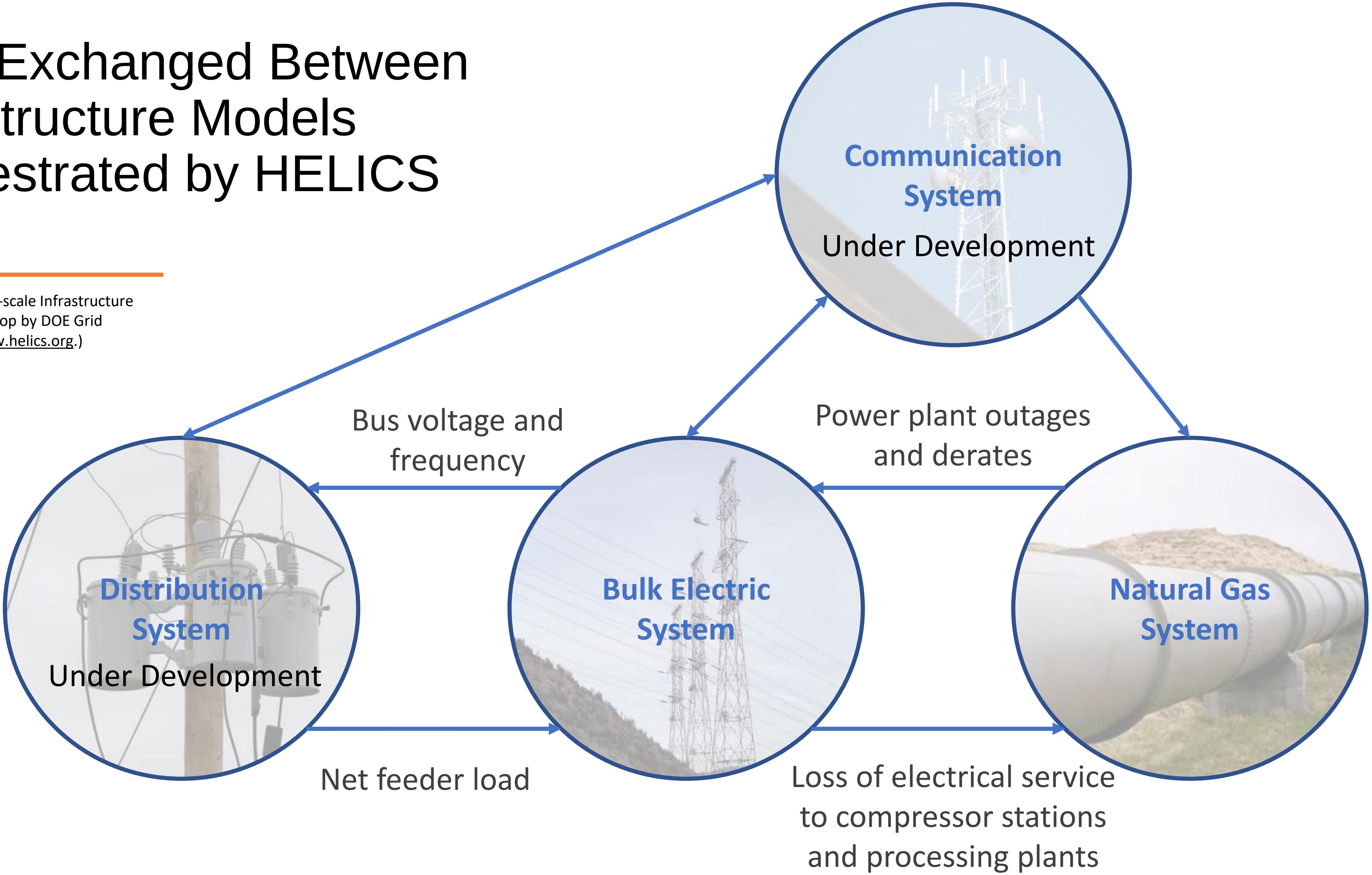
- National Steady-state models
- Regional Transient models

Example of Data Layers Used:

- DHS HIFLD
- Genscape

Data Exchanged Between Infrastructure Models Orchestrated by HELICS

Hierarchical Engine for Large-scale Infrastructure Co-Simulation (HELICS) develop by DOE Grid Laboratory Consortium (www.helics.org.)



Datasets

Electric System

- Bus
- Branch
- Generator
- DC Transmission Lines
- HIFLD Substations
- HIFLD Power Plants
- HIFLD Transmission Lines
- HIFLD Electric Service Areas
- Balancing Authorities
- Load/Generation By BA
- Forecasted Load
- Forecasted Solar Generation
- Forecasted Wind Generation

Natural Gas

Natural Gas Model

NGFAST

- Power Plants
- Compressor Stations
- Processing Plants
- Border Points
- Underground Storage
- Interstate Pipelines
- Receipt Delivery Points
- HIFLD Natural Gas Receipt Delivery Points

Communications

Communication Model

NAESCCM

- Cellular Sites
- Central Offices
- Microwave Sites
- Control Centers
- Fiber Regen
- Fiber
- Fiber Routes

Weather / Natural Hazards

- NIFC Active Wildfires
- Pyregence Forecasted Wildfires
- USGS Earthquakes
- USFS Fire Potential Index
- NWS Flood Monitor
- NWS Storm Surge
- NWS Ice Accumulation
- NWS Drought Monitor
- NWS Radar Precipitation
- NWS Day 1 Convective Outlook
- NWS Temperature
- NWS Weather Warnings
- NWS Windspeed
- NWS Tornado
- NASA FIRMS Wildfires
- NWS 5-Day Outlook
- NOAA GOES-16
- NWS Cyclone Tracks
- EPA Smoke
- SPIA
- SPIA Ice Accumulation
- SPIA Precipitation
- SPIA Snowfall
- SPIA Temperature
- SPIA Wind Direction
- SPIA Wind Speed

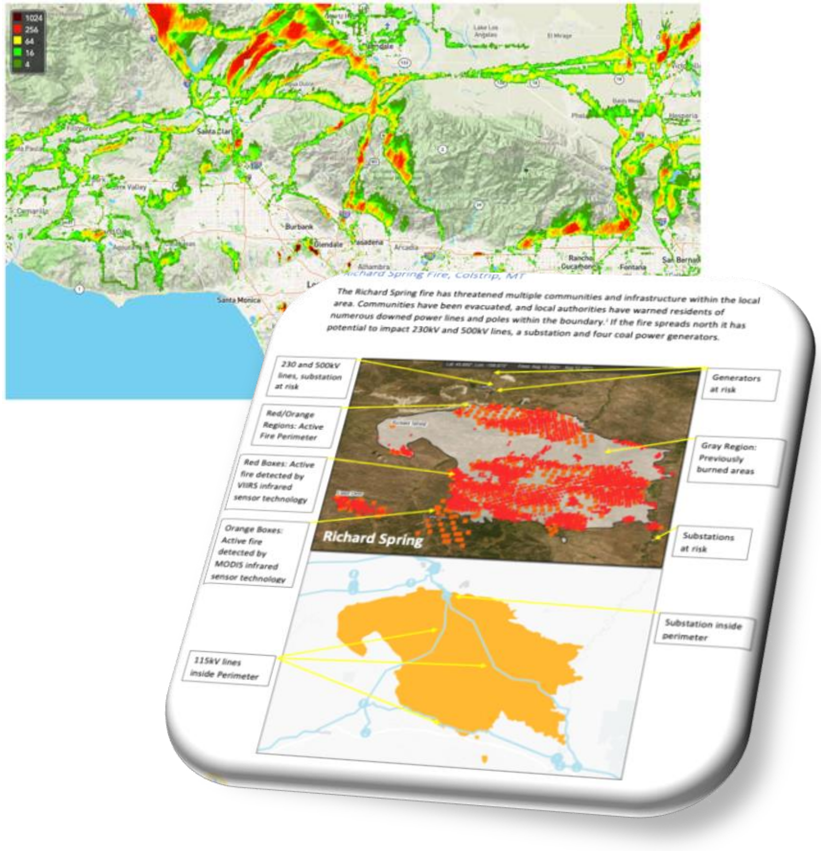
Reference

- Roads
- Rails
- Hurricane Evacuation Routes
- Protected Areas: Designation
- Protected Areas: Easement
- Protected Areas: Fee
- Protected Areas: Marine
- Protected Areas: Proclamation
- Ethanol Plants
- FDIC Insured Banks
- Fire Stations
- Hospitals
- Law Enforcement Locations
- Military Bases
- NCUA Insured Credit Unions
- Oil Refineries
- Petroleum Terminals
- Wastewater Treatment Plants

NAERM team is developing capabilities at the National Level

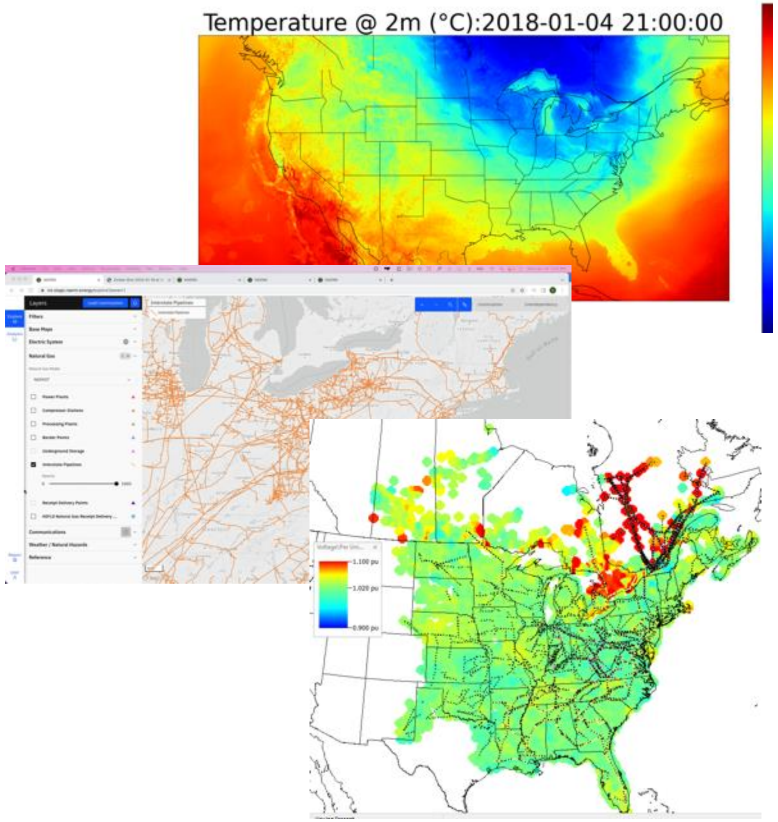
- Demonstrate how modeling and analytics can be used to support transformational resilience investments
- Rapidly demonstrate the type of studies, metrics, and threats that can be analyzed, then engage stakeholders to improve outcomes
- Focus on regional use cases that can be extended to other parts of the country
- Coordinate with other DOE R&D to extend analysis capabilities (e.g., energy equity)

Technical assistance use cases briefed today



Western Wildfire

JP Watson, LLNL
Kaarthik Sundar, LANL



Northeastern Cold Wave

Greg Brinkman, NREL
Russell Bent, LANL

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Wildfire Threat Analytics: Impacts Projection and Mitigation

Approach:

- Wildfires are amplifying in intensity, frequency, and extent of wildfires in the US
- Changes in the above metrics will impact the benefits associated with various proposed mitigation options
- Critical to focus on how wildfire threats are *going* to manifest, rather than how they manifest presently
- Climate-impacted (future) weather data is required for high-fidelity modeling

Benefits:

- Quantification of future wildfire impacts on Western Interconnect infrastructure
- Maximize resilience benefit of hardening investments and other mitigation options

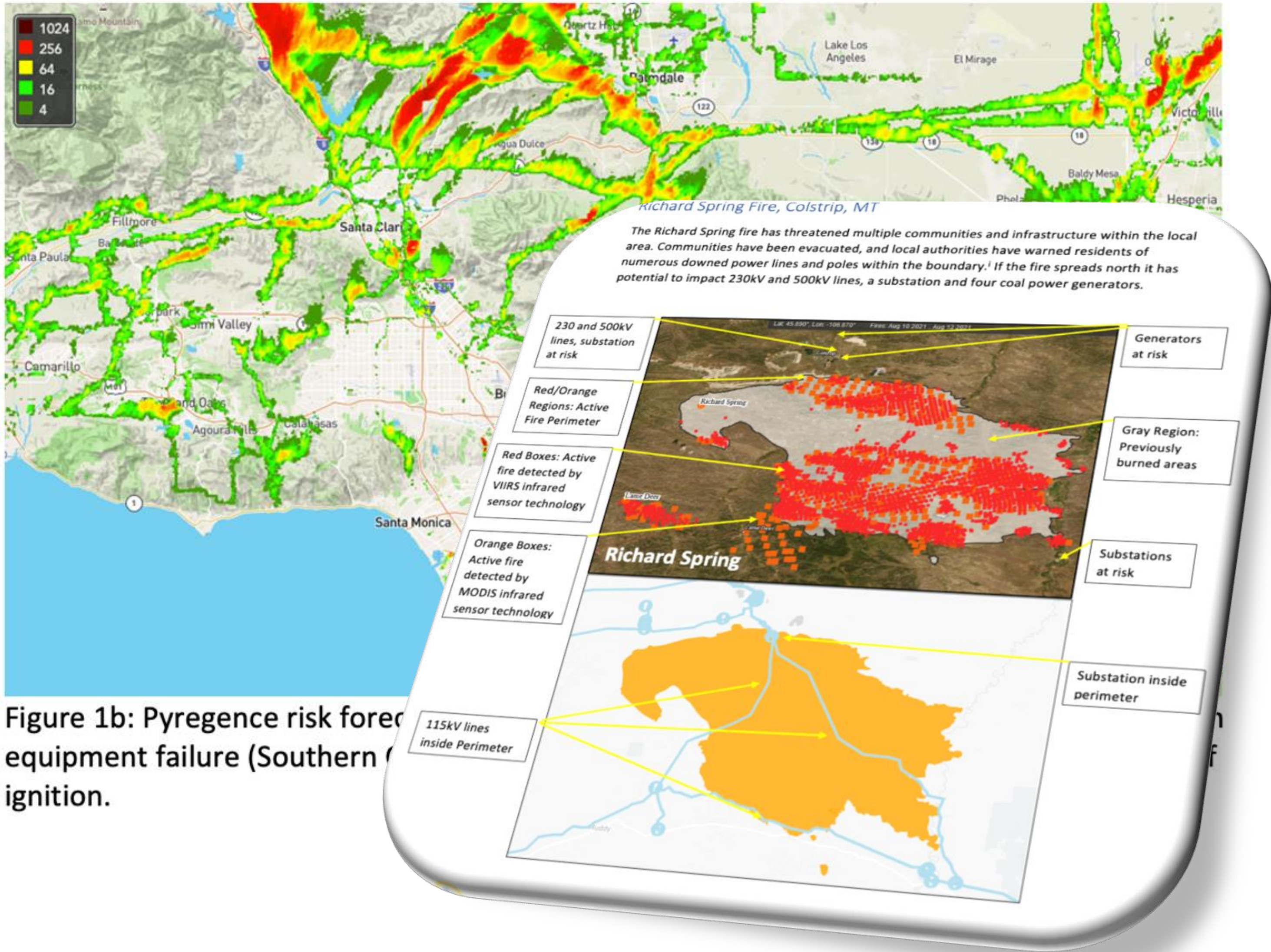
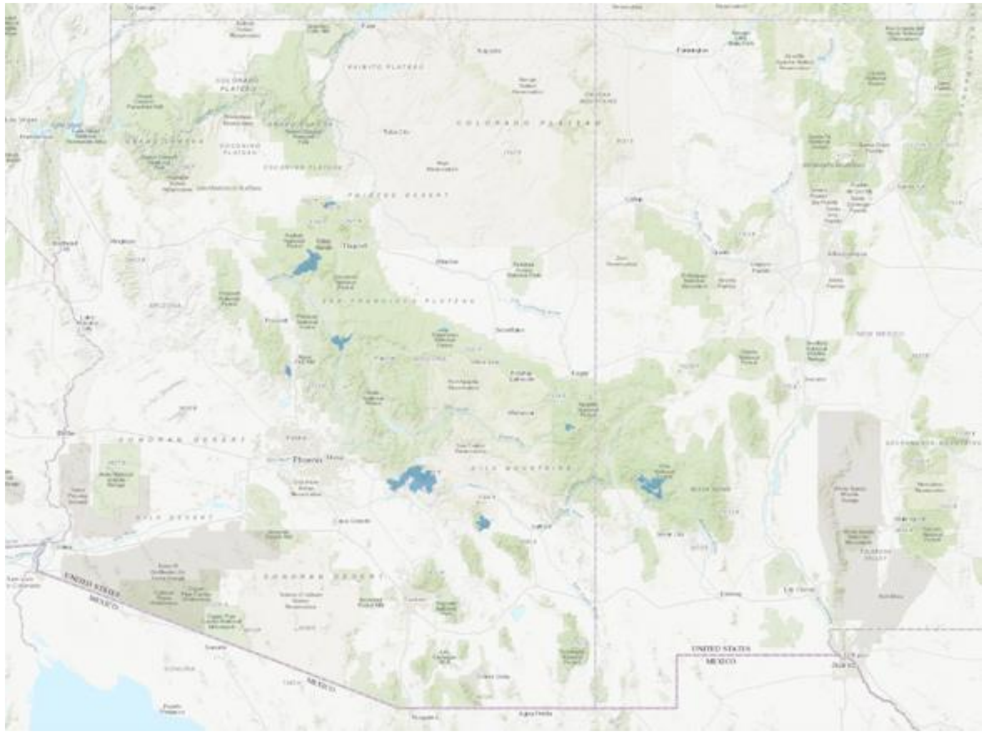


Figure 1b: Pyregence risk forec
equipment failure (Southern (
ignition.

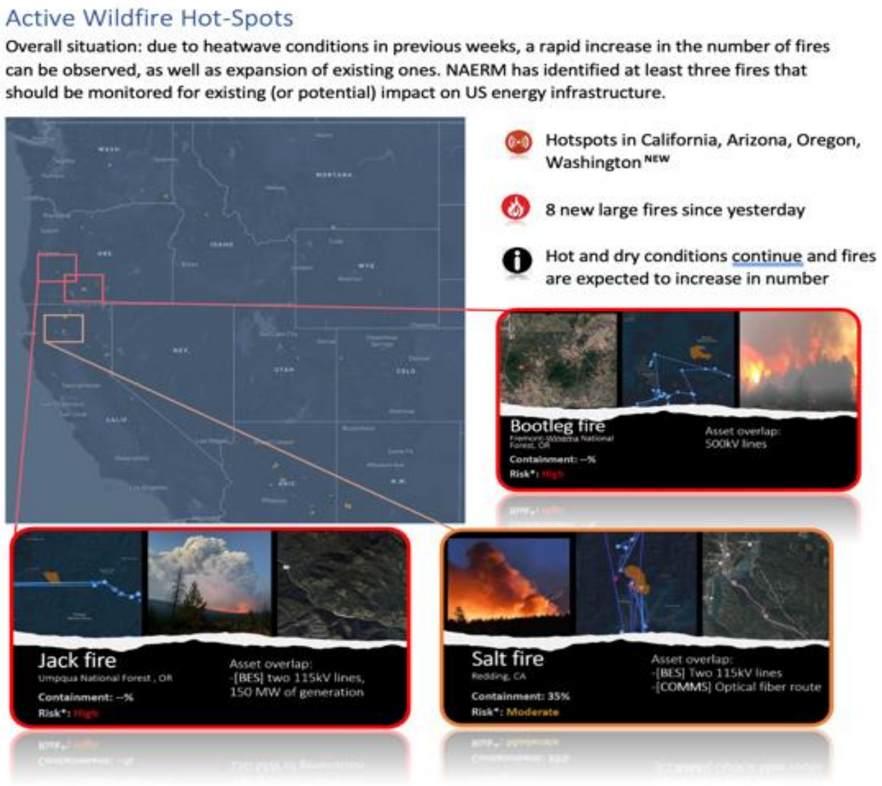
Background: Short-Term Predictive Wildfire Impacts Analysis with NAERM (1)

Snapshot from NAERM UI, visualizing NIFC data



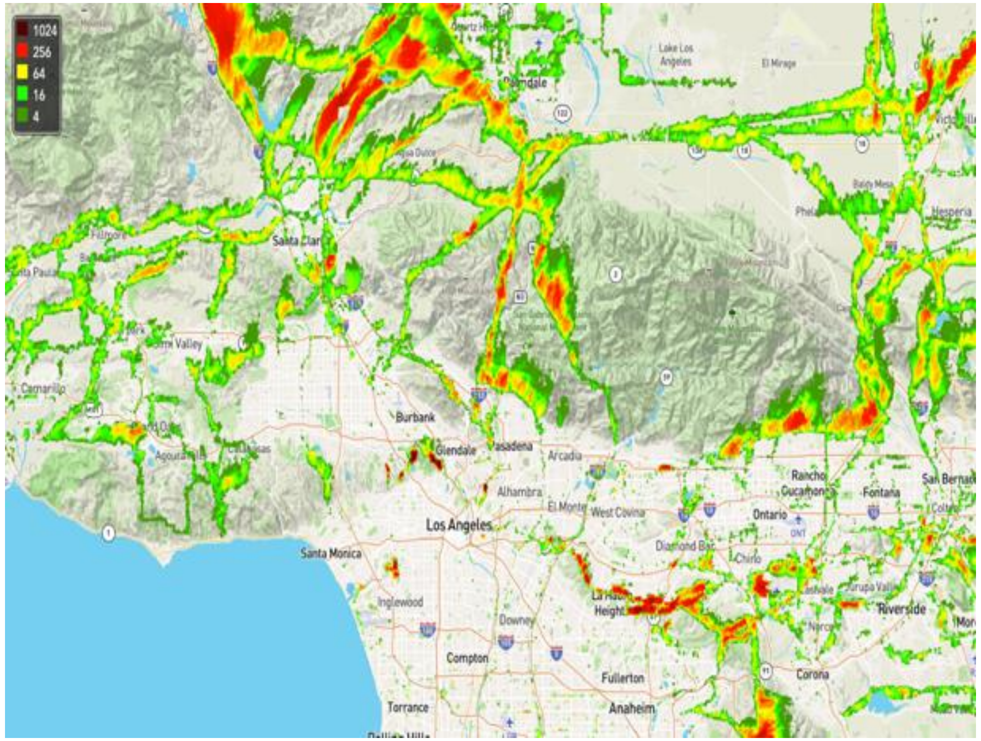
Active wildfire perimeters in the southwestern US on July 7, 2021

NAERM leveraged active wildfire perimeters from NIFC and growth projections from Pyregence to identify infrastructure at risk and estimate impacts



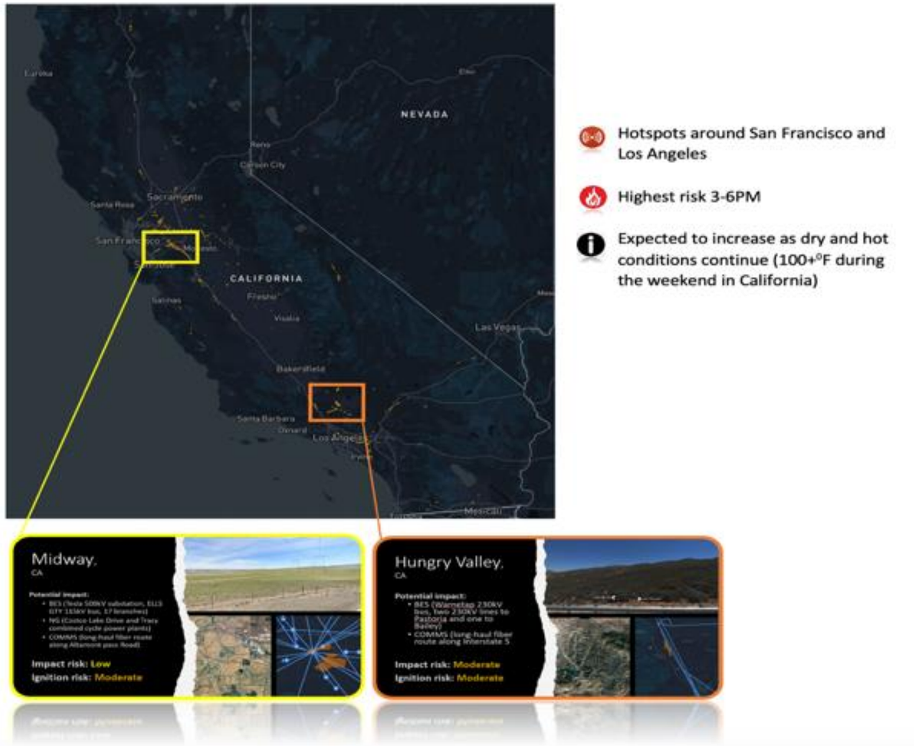
Background: Short-Term Predictive Wildfire Impacts Analysis with NAERM (2)

Snapshot from https://pyregence.org



Pyregence risk forecast on 06/17/2021 UTC 20:00 for wildfires due to bulk transmission equipment (Southern California)

Identical impacts quantification tools were leveraged by NAERM team to identify infrastructure at risk from and impacts associated with potential wildfires



Forecasted Wildfires Hotspots

California

Overall situation: Provided transmission fault caused fire risk forecast is for 6th of July and covers the state of California. With the dry conditions the risk of ignition continues to rise. NAERM has identified potential high-impact regions from energy infrastructure perspective.

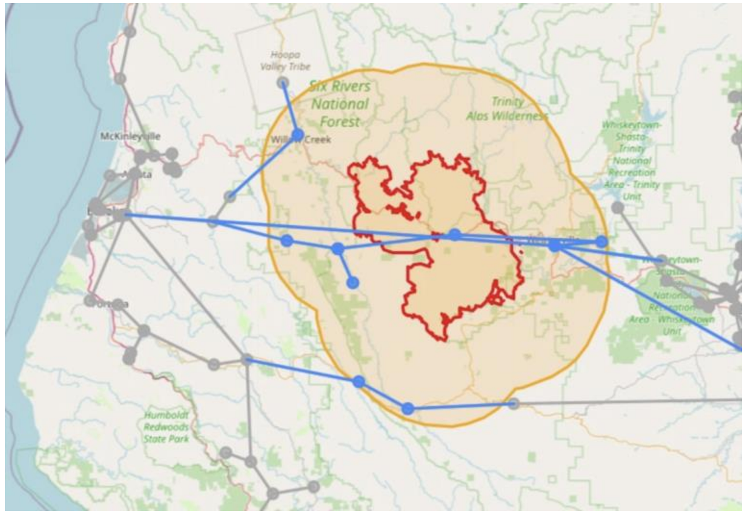
Enabling Capabilities	Analytic Outputs

• Ingestion of wildfire risk sources
  • Historical, forecasted, climate-impacted
  • Vegetation density
• High-impact contingency identification within high-risk areas
• Co-simulation (time-stepped) of BES and NG to determine cascades and quantify impacts
• Customizable Jupyter notebooks leveraging extensive NAERM back-end
	• Impact metrics
	  • Load lost
	  • Voltage violation
	  • Transmission rating violation
	  • Generator trips / re-dispatch
	  • Generation headroom
	• Investment recommendations
	  • Optimal allocation of limited resources for hardening, e.g., lines to underground
	  • Characterization of cost vs. impact-reduction trade-off curve

Risk = Relative Likelihood of Event Occurrence

Capability Demonstration: Monument Wildfire (1)

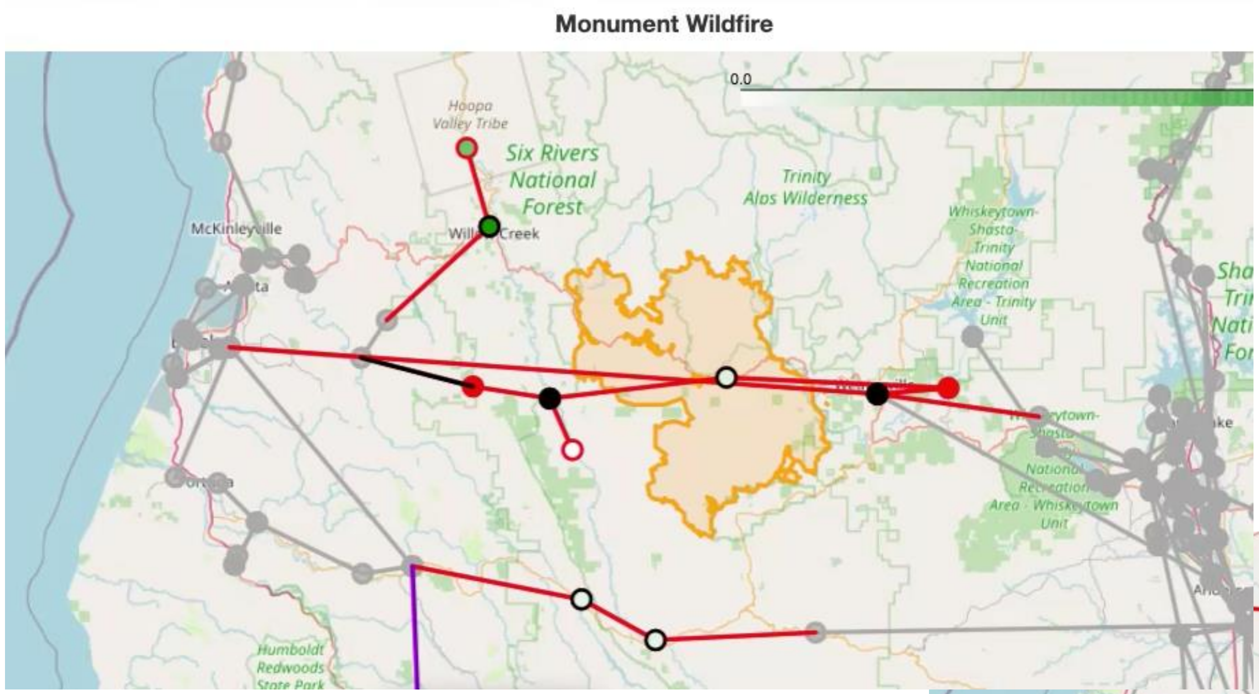
Identification and analysis of high-impact contingencies associated with wildfires ultimately supports optimal allocation of infrastructure hardening budgets

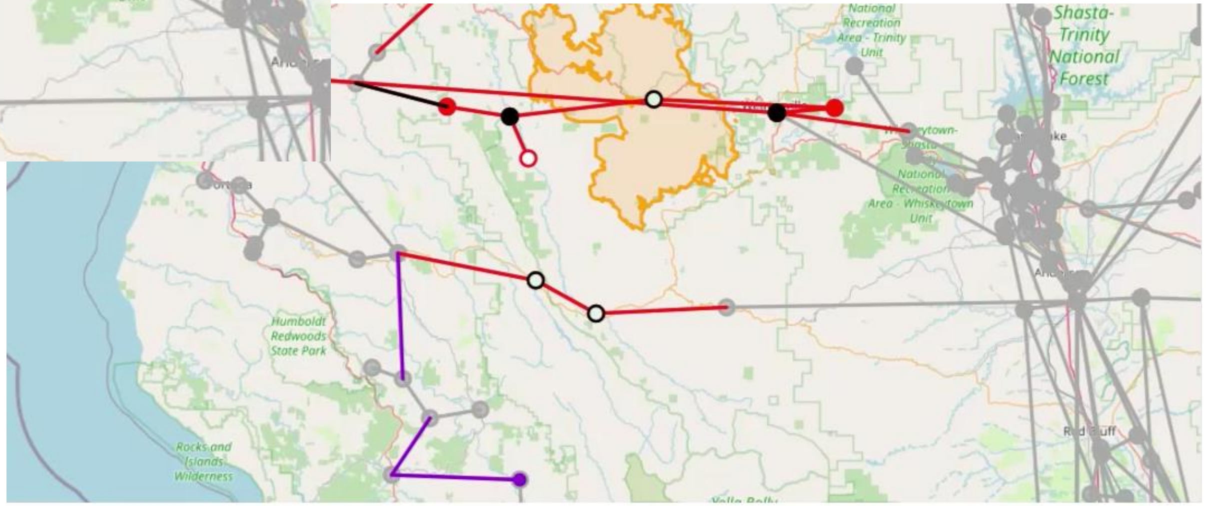


- *Limited impacts on BES and NG infrastructure…*
- *… but exhibits full spectrum of impacts*
- *Enable straightforward verification and validation*

Monument is a wildfire in Northern California, started in July 30 2021 (due to lightening strike)

Capability Demonstration: Monument Wildfire (2)





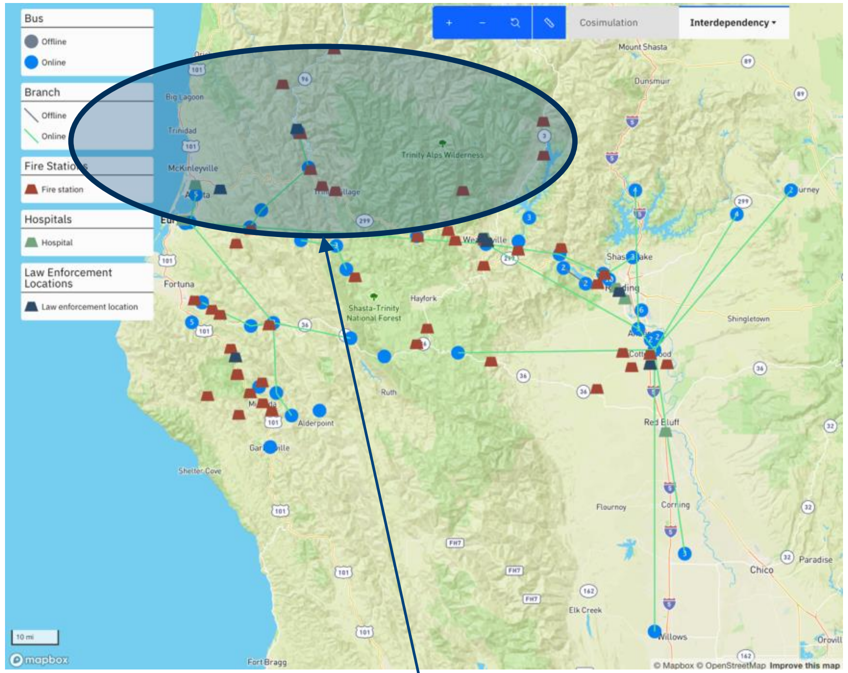
NAERM focuses on analysis of extreme events, which yield contingencies with high “k"

Ensures simulation in contexts with k >> 10 outaged components

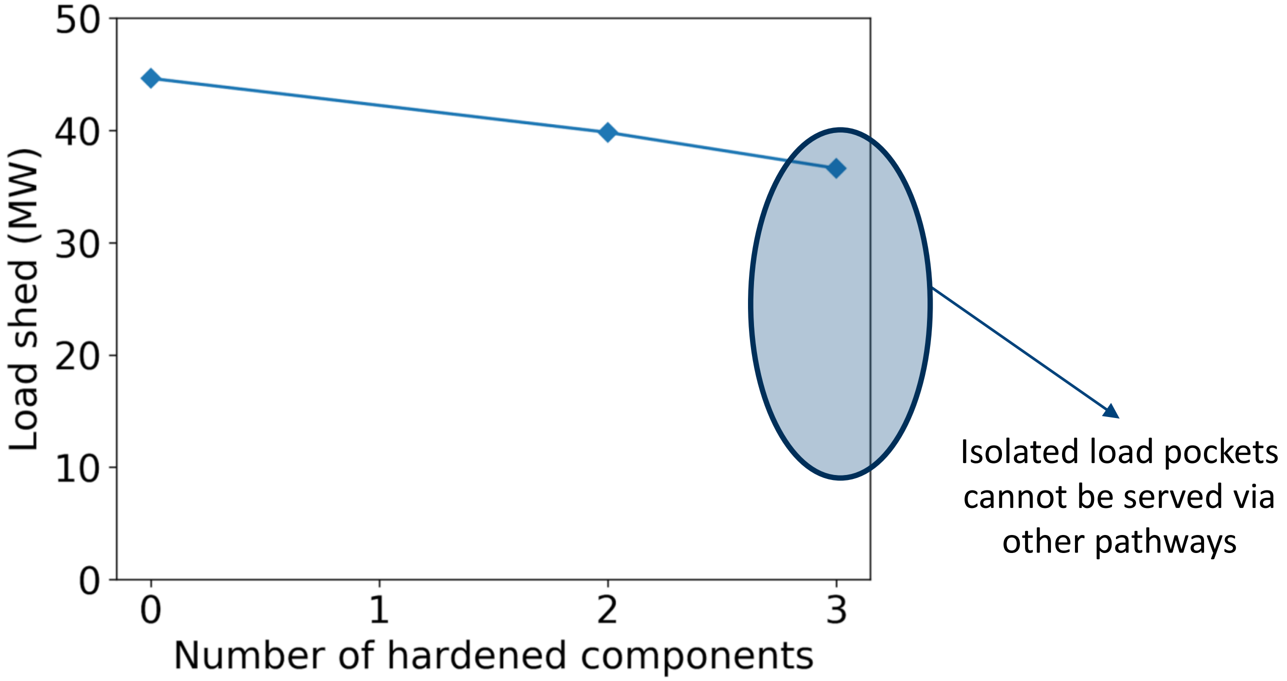
Legend:

- Black: direct outage
- Red: cascade outage
- Green: load lost
- Purple: violations

Capability Demonstration: Monument Wildfire (3)



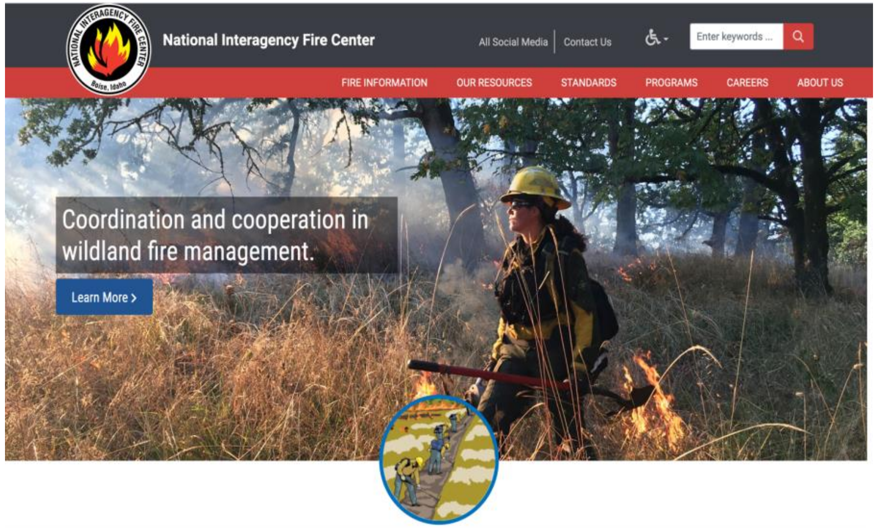
Significant fire and emergency facilities directly impacted by the wildfire, and many potentially impacted in surrounding area



Investment optimization algorithms indicate a limit to benefits of hardening *existing* assets

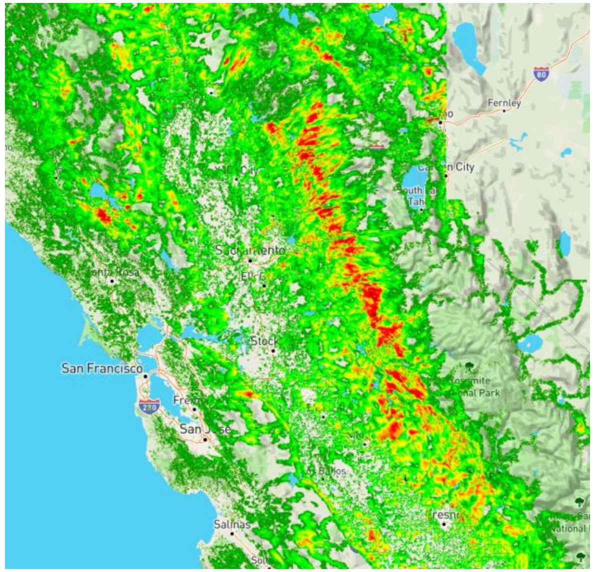
Key Wildfire Data Sources

https://www.nifc.gov



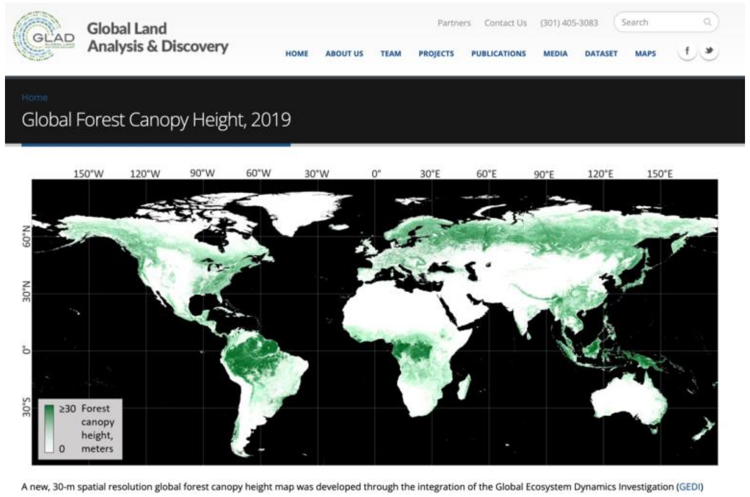
NIFC – historical wildfire perimeter archive

https://pyrecast.org



Forecasted wildfire risk sources (USGS, Pyregence, and numerous others)

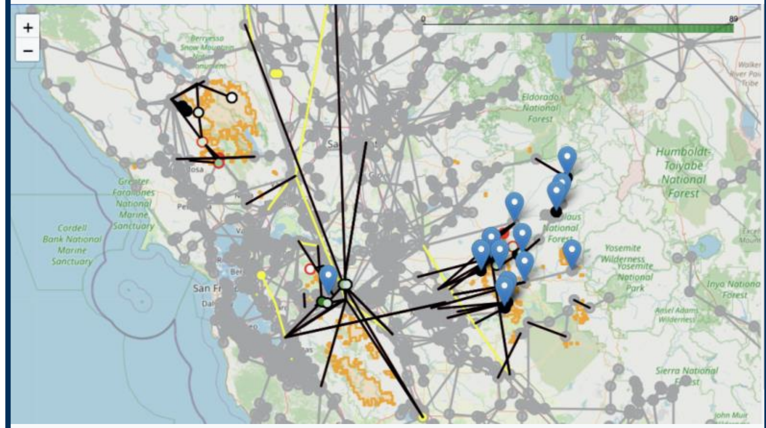
https://glad.umd.edu/dataset/gedi/



Vegetation density layers to inform fragility curve development (NASA/GEDI)

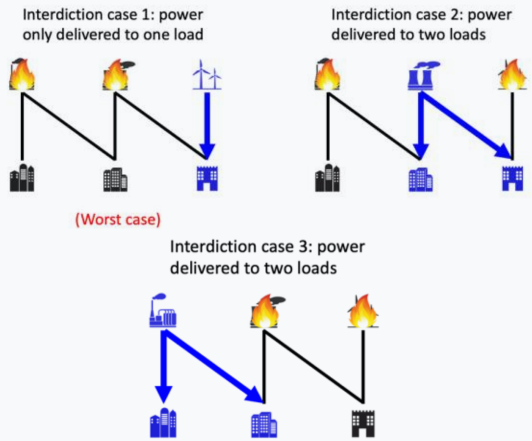
High-Impact Contingency Identification Analytics

Number of BES and NG components in high-risk wildfire regions is significant



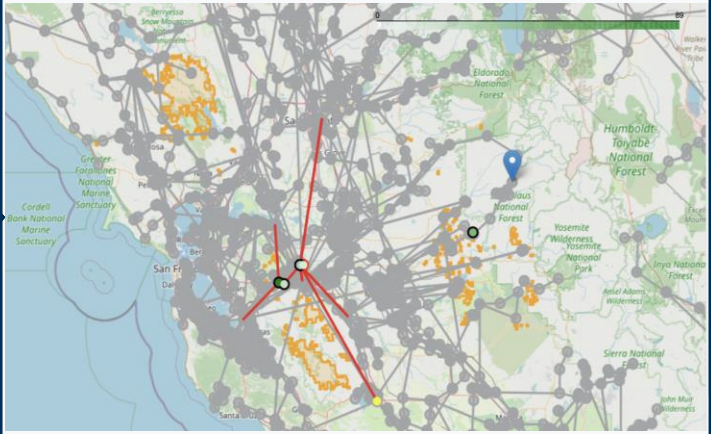
Hardening everything in a high-risk region is cost-prohibitive

Use rigorous optimization analytics to identify subsets of *critical* components



Combinatorics prevents naïve critical component identification approaches from working

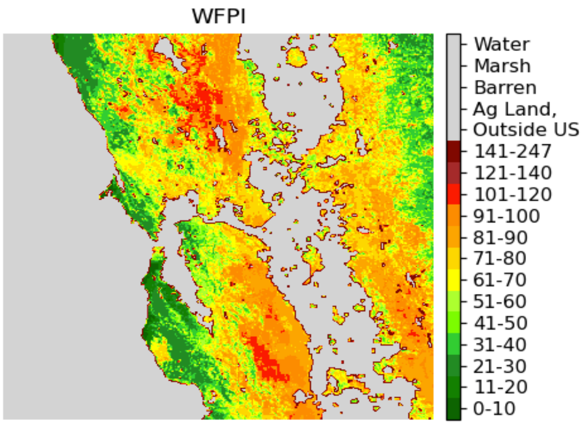
Outaging a small subset of components in a high-risk region often leads to large-scale impacts

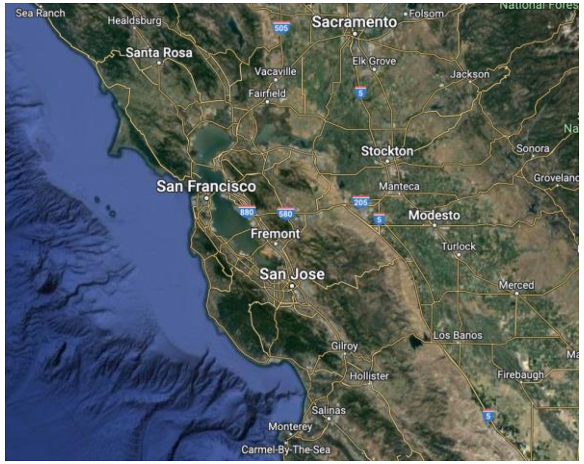


Critical component identification forms the basis for optimal investment / hardening

Capability Demonstration: Bay Area (1)

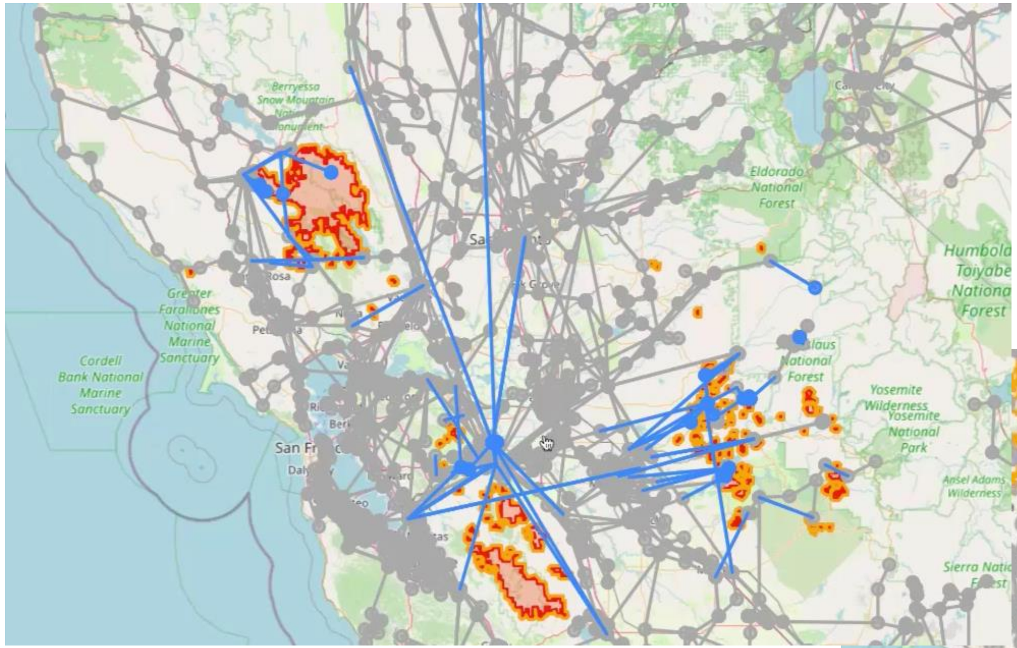
Consideration of wildfire risk maps in impacts analytics enables (1) consideration of larger high-risk wildfire regions and (2) inclusion of climate impacts



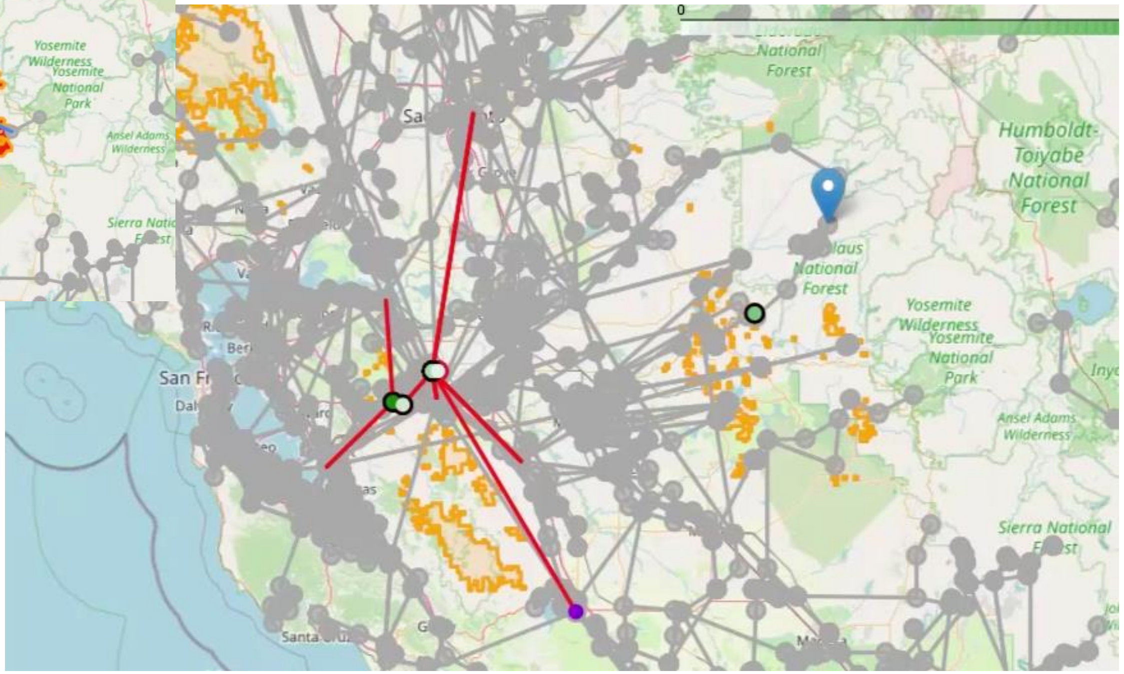


- *Demonstrates use of wildfire risk maps…*
- *… as opposed to historical impacts*
- *Broader impacts on BES and NG infrastructure*

Capability Demonstration: Bay Area (2)



Significant infrastructure in the bay area is at high risk from potential wildfires

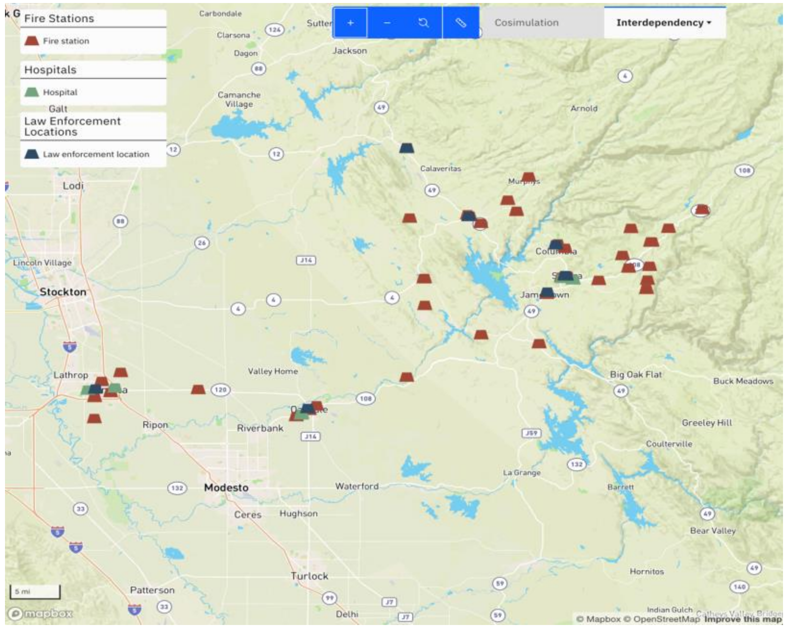


Legend:

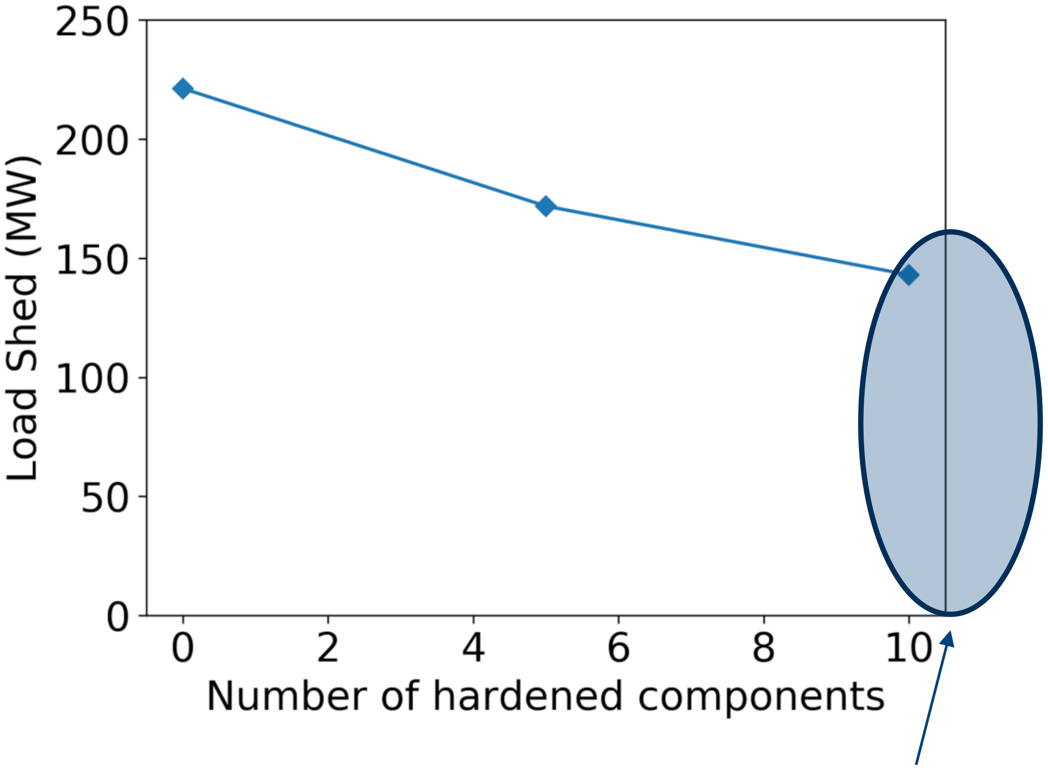
- Black: direct outage
- Red: cascade outage
- Green: load lost
- Purple: violations

But a handful of components dictate the overall impact

Capability Demonstration: Bay Area (3)



Interdependency analysis provides a "picture beyond MW demand" relating to what functionality may be lost during a contingency



Hardening a modest number of components yields significant reductions in impacts – but tens of components must be hardened to mitigate *all* impacts

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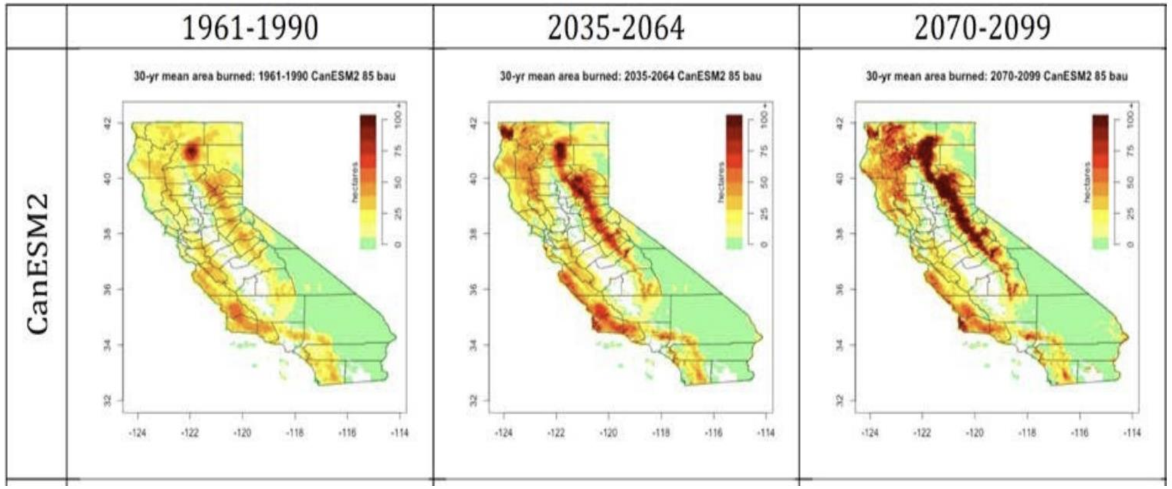
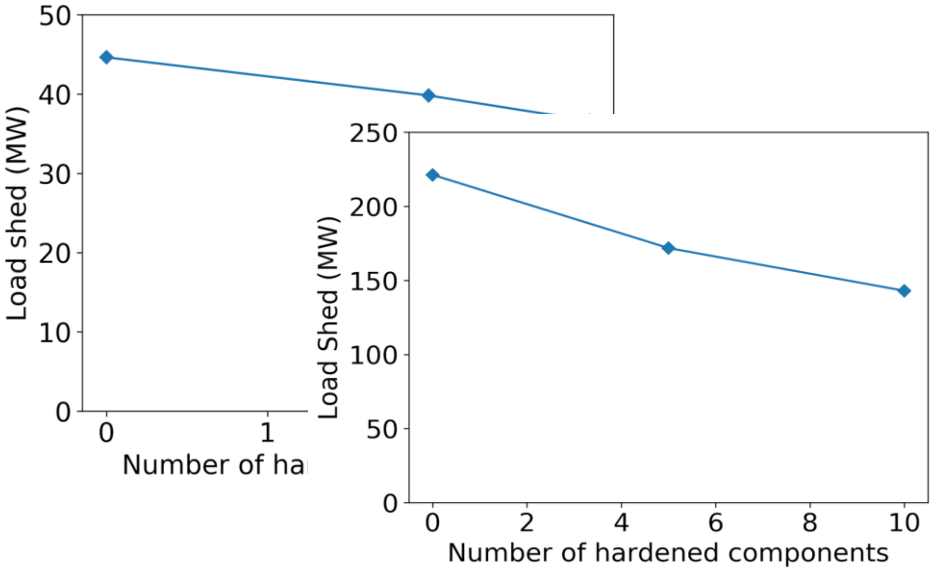
In-Progress: Climate Impacts and Hardening Recommendations

Climate is projected to significantly impact wildfire risk – due to shifts in both intensity and location



Through the Pyregence consortium, we will be acquiring and analyzing climate-impacted wildfire risk maps for 2030 and beyond

Investment planning is driven by understanding and analysis of cost-versus-risk tradeoffs



Algorithms underlying NAERM high-impact contingency identification analytics will provide recommendations for hardening investments

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New England Cold Wave
Co-simulation of Electric Power and Natural Gas

Need:

- New England has experienced several cold weather events over the last decade that have caused tight generation and gas supplies
- Assess the resilience (N-k) of combined electric power and natural gas systems during extreme cold weather
- Evaluate the resilience benefits of mitigation and investment options

Benefits:

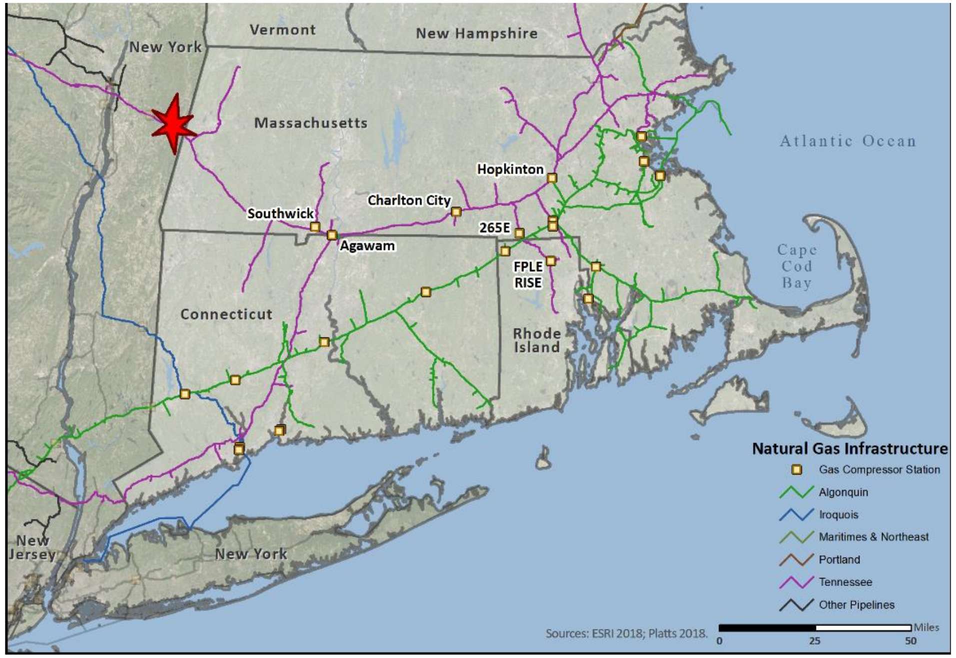
- Inform energy planners on compounding risk of cold weather impacts to generation infrastructure, increased demand, and guide mitigation strategies for these scenarios

Approach:

- Regional focus on Northeastern United States
  - Generalize to other parts of the country
- Identify cold weather events over the last decade that have impacted actual system
- Identify candidate N-k contingencies that would have exacerbated capacity limitations during the collected cold weather events
- Perform co-simulation of the electric power and natural gas system
- Work with stakeholders to assess proposed mitigation investments, inclusive of:
  - Dual fuel units
  - Wind turbine winterization
  - Increased LNG capacity
  - Electrification and demand flexibility

Use Case Summary

- Cold Weather Event: Winter Storm Grayson (early January 2018)
- Co-simulate what could have happened during Grayson had additional failures occurred
  - Natural gas pipeline failure scenarios
  - Scenarios of power plant outages due to winter weather and gas unavailability
- Use case highlights how NAERM's natural gas pipeline and bulk electric system co-simulation capabilities can be used
- In progress: Evaluation of mitigation options.
- Talk Focus: Underlying technical approach to support such analysis with specific results omitted



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Analysis Workflow

Data Inputs

- System models for Electric Power Transmission and Natural Gas Interstate Pipelines
- Characterization of cold weather event

Co-simulation

- Sequence of steady-state simulation (NGFast and Powerworld)
- Generator redispatch
- Curtailment of gas supplies to generators
- Compressor outages
- Transient natural gas simulation codes available

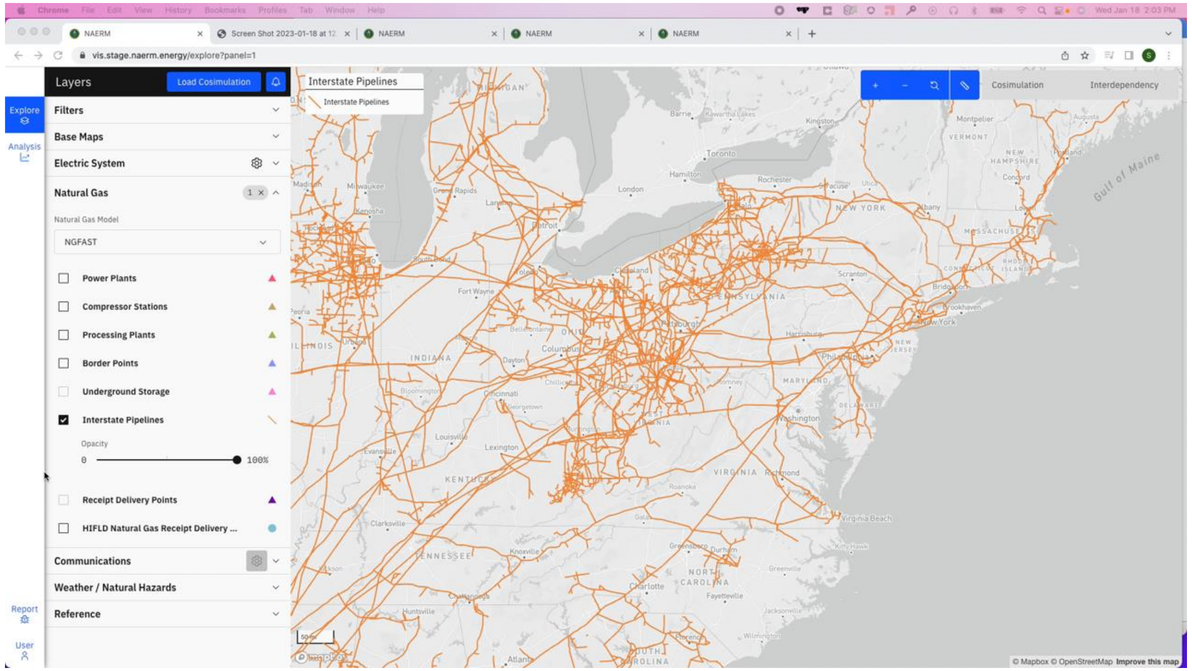
Resilience Evaluation

- Analyze outages induced by pipeline failures during cold weather events

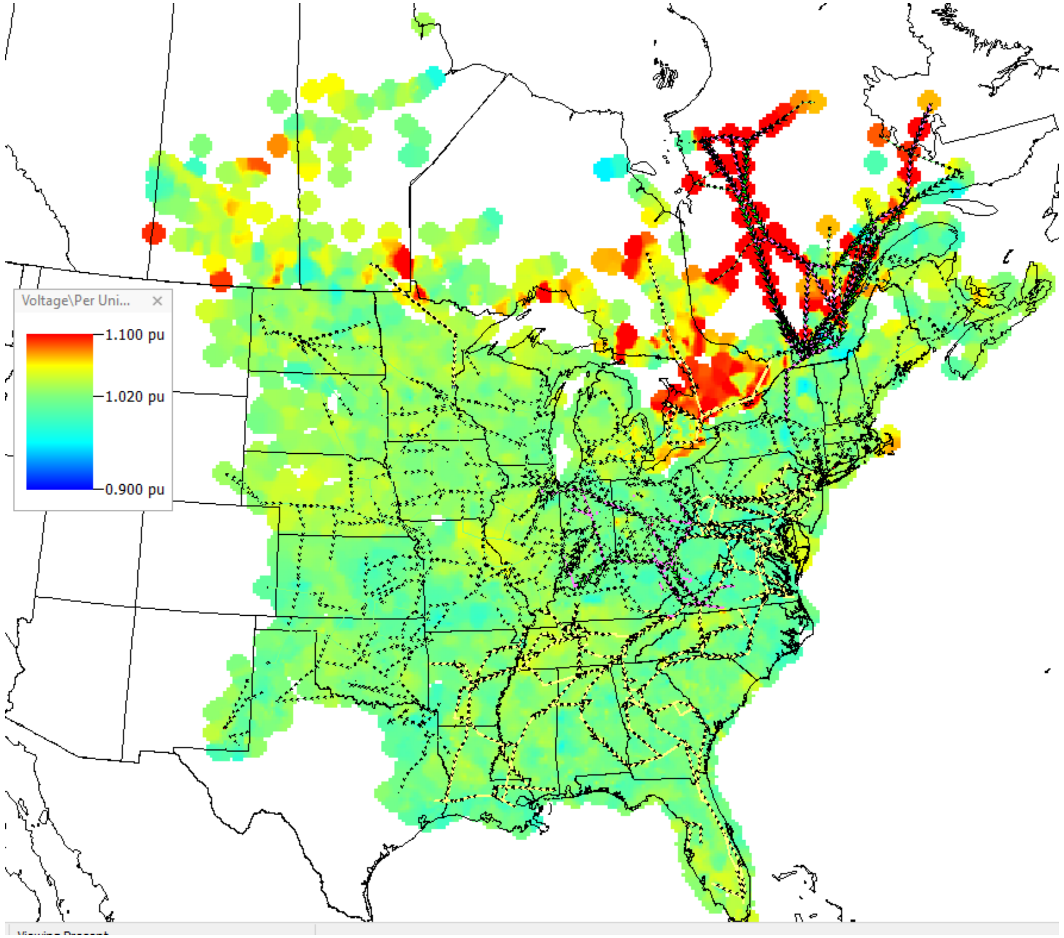
Mitigation Evaluation

- LNG and pipeline capacity
- Wind turbine winterization
- Energy storage
- Electrification
- Dynamic line ratings
- …

Data Inputs: Natural Gas and Electric Power System Models



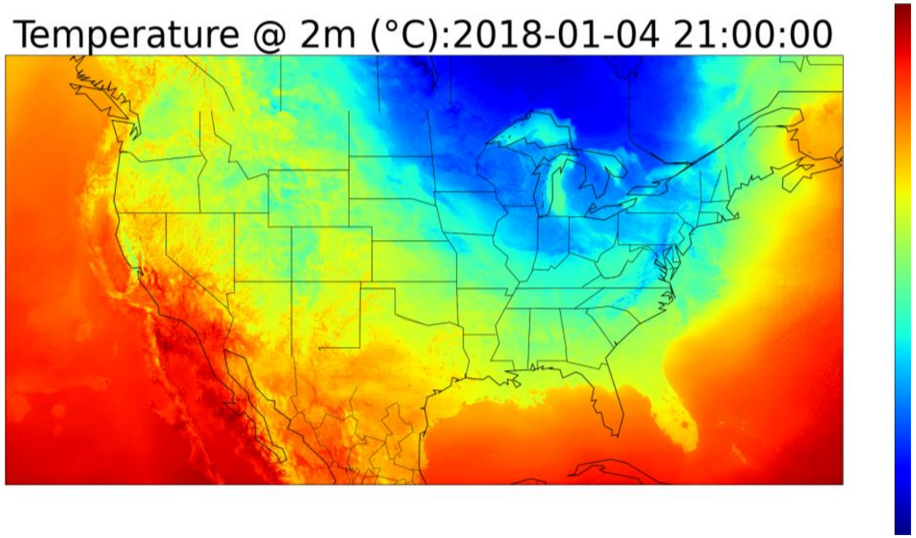
Interstate Pipelines



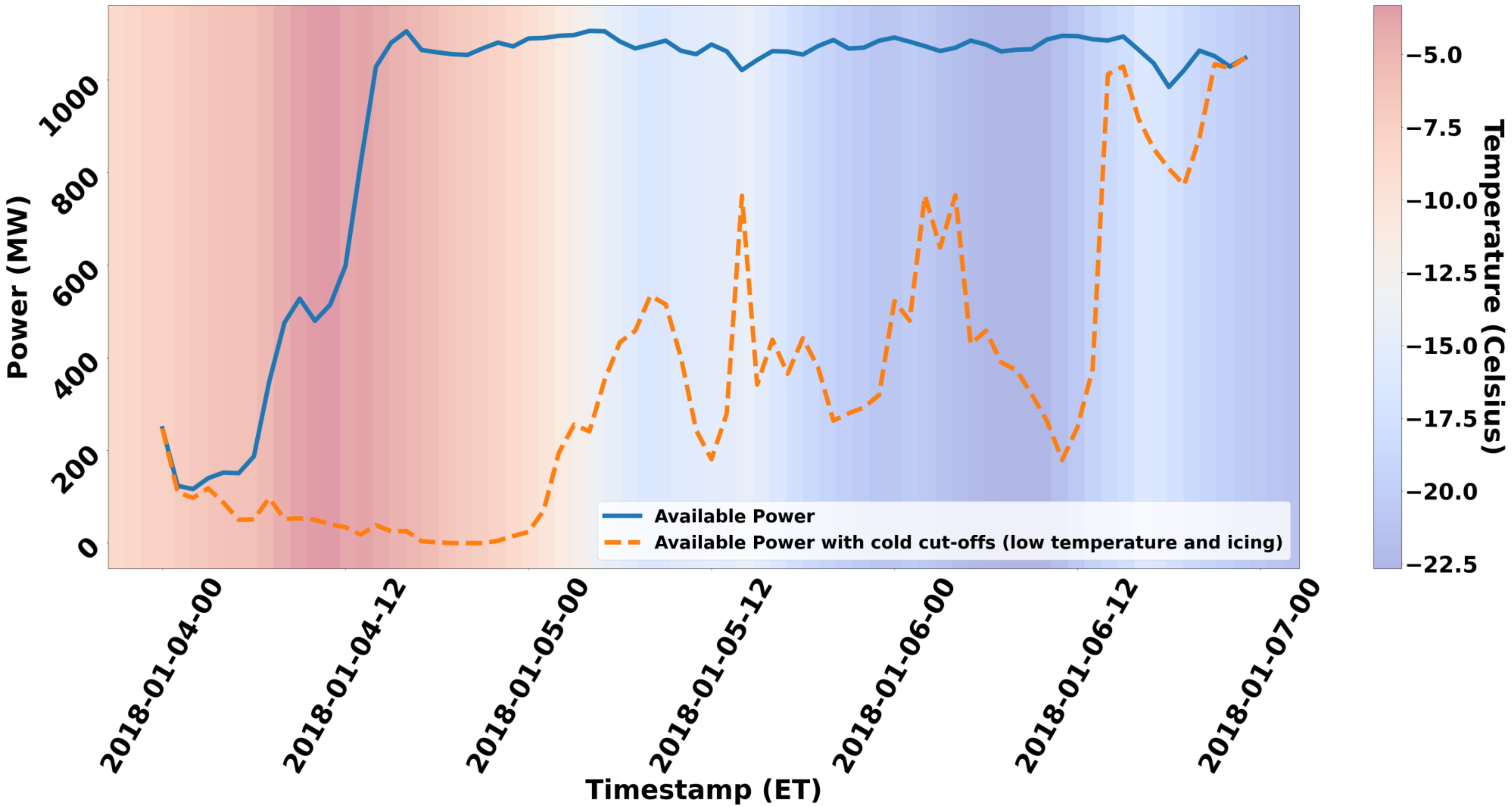
Transmission Planning Models

Data Inputs: Cold Weather Characterization

- Select cold weather event
  - Winter Storm Grayson (early January 2018)
- NAERM utilizes wind, solar, demand, and meteorological data from the event
  - Temperature, icing, snow
- NAERM uses actual generator outages from the event OR hypothetical cold weather outages generated from fragility curves



Data Inputs: Cold Weather Characterization

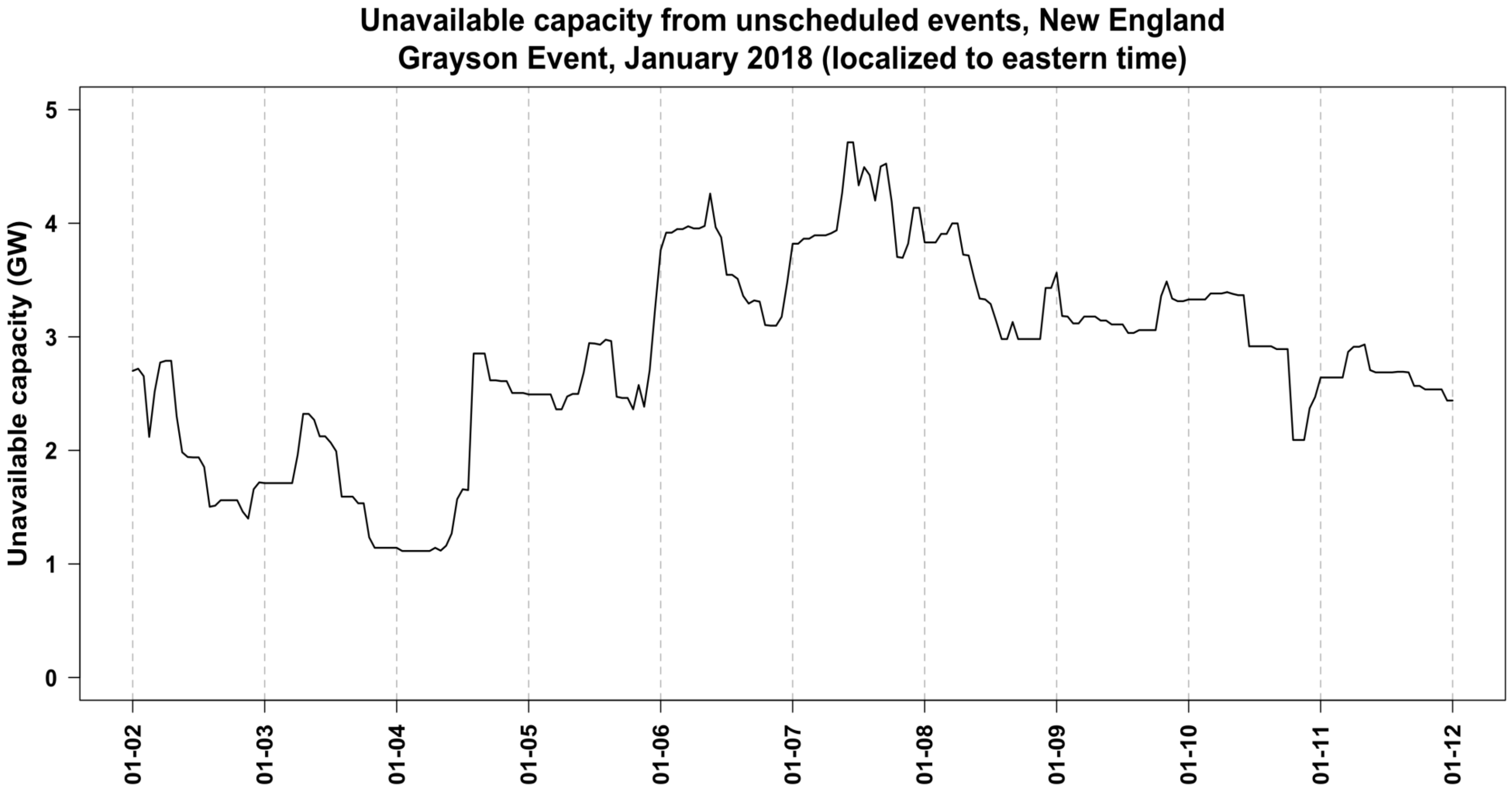


Example: Wind Generation Profiles

Comparison of available capacity and reduced capacity due to cold temperature cutoffs

Mitigation Teaser: Basis for evaluated the potential benefits of winterizing turbines

Data Inputs: Cold Weather Characterization

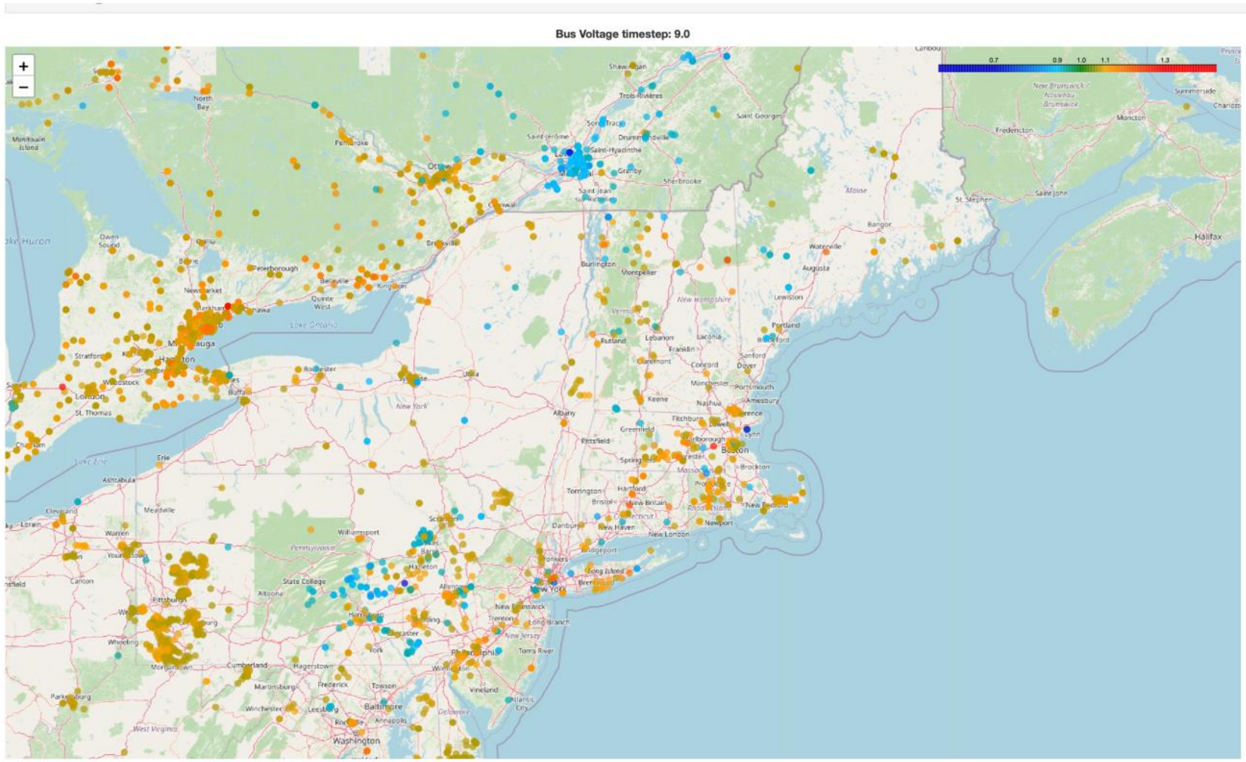


Example: Available generator capacity

Capacity that was unavailable due to cold weather

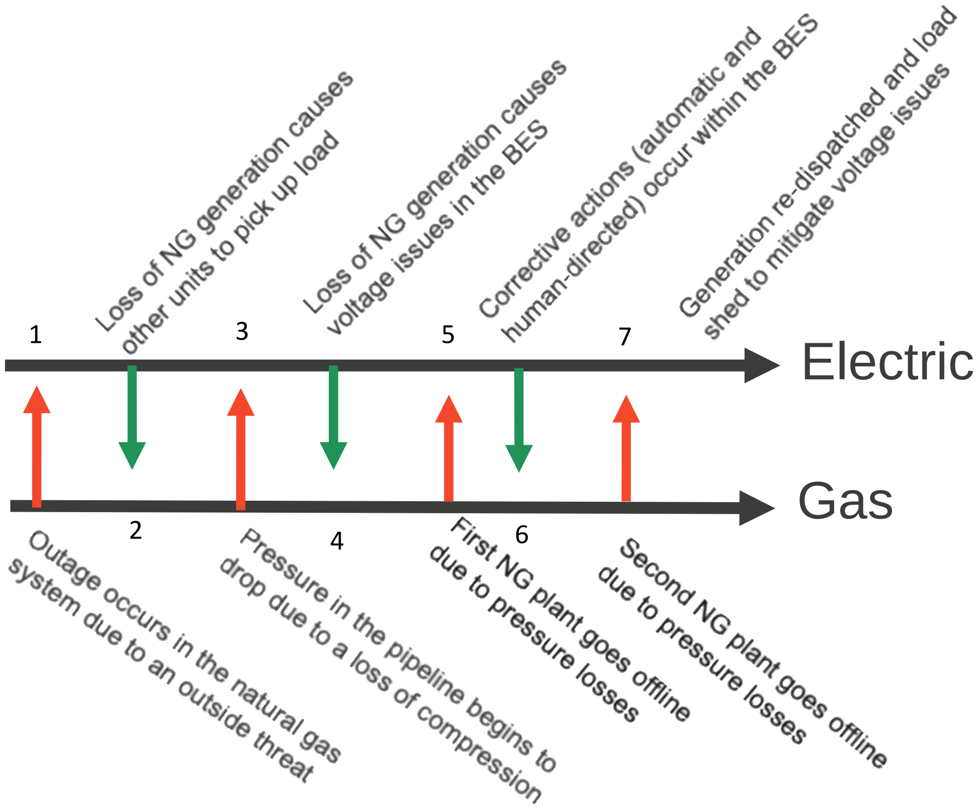
Mitigation Teaser: Utilize winter weather fragility curves to explore benefits of hardening technologies

Co-Simulation: Procedure



Bus voltage violation change map

NAERM Interface



Simulation Schematic

Co-Simulation: Power Flow Modeling

Power flow software: Powerworld, PSLF, PSEE

NAERM developed (semi) automated redispatch and load shedding

timestep: 49.0

	voltage	category	counts
0	BusPUVolt < .9	severe violation	65
1	.9 <= BusPUVolt < .95	violation	591
2	.95 <= BusPUVolt < 1.05	nominal	77036
3	1.05 <= BusPUVolt < 1.1	violation	4022
4	1.1 <= BusPUVolt	severe violation	710

timestep: 59.0

	voltage	category	counts
0	BusPUVolt < .9	severe violation	67
1	.9 <= BusPUVolt < .95	violation	599
2	.95 <= BusPUVolt < 1.05	nominal	77008
3	1.05 <= BusPUVolt < 1.1	violation	4041
4			

Before redispatch: Many severe violations at 109 minutes, diverging powerflow after 109 minutes

timestep: 109.0

	voltage	category	counts
0	BusPUVolt < .9	severe violation	221
1	.9 <= BusPUVolt < .95	violation	772
2	.95 <= BusPUVolt < 1.05	nominal	76889
3	1.05 <= BusPUVolt < 1.1	violation	3848
4	1.1 <= BusPUVolt	severe violation	694

timestep: -99999

	voltage	category	counts
0	BusPUVolt < .9	severe violation	0
1	.9 <= BusPUVolt < .95	violation	0
2	.95 <= BusPUVolt < 1.05	nominal	20
3	1.05 <= BusPUVolt < 1.1	violation	1
4	1.1 <= BusPUVolt	severe violation	0

	voltage	category	counts
1	.9 <= BusPUVolt < .95	violation	554
2	.95 <= BusPUVolt < 1.05	nominal	76814
3	1.05 <= BusPUVolt < 1.1	violation	4268
4	1.1 <= BusPUVolt	severe violation	719

timestep: 59.0

	voltage	category	counts
0	BusPUVolt < .9	severe violation	68

Before redispatch: Converging powerflow through the simulation, with voltage violations similar to beginning of simulation.

timestep: 109.0

	voltage	category	counts
0	BusPUVolt < .9	severe violation	66
1	.9 <= BusPUVolt < .95	violation	554
2	.95 <= BusPUVolt < 1.05	nominal	76998
3	1.05 <= BusPUVolt < 1.1	violation	4092
4	1.1 <= BusPUVolt	severe violation	714

timestep: 119.0

	voltage	category	counts
0	BusPUVolt < .9	severe violation	66
1	.9 <= BusPUVolt < .95	violation	584
2	.95 <= BusPUVolt < 1.05	nominal	77030
3	1.05 <= BusPUVolt < 1.1	violation	4033
4	1.1 <= BusPUVolt	severe violation	711

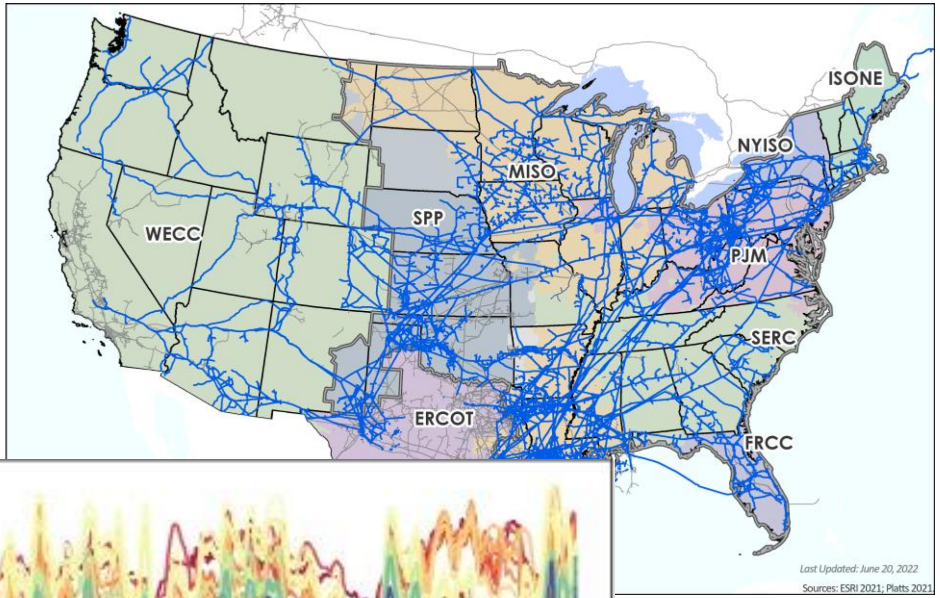
timestep: 120.0

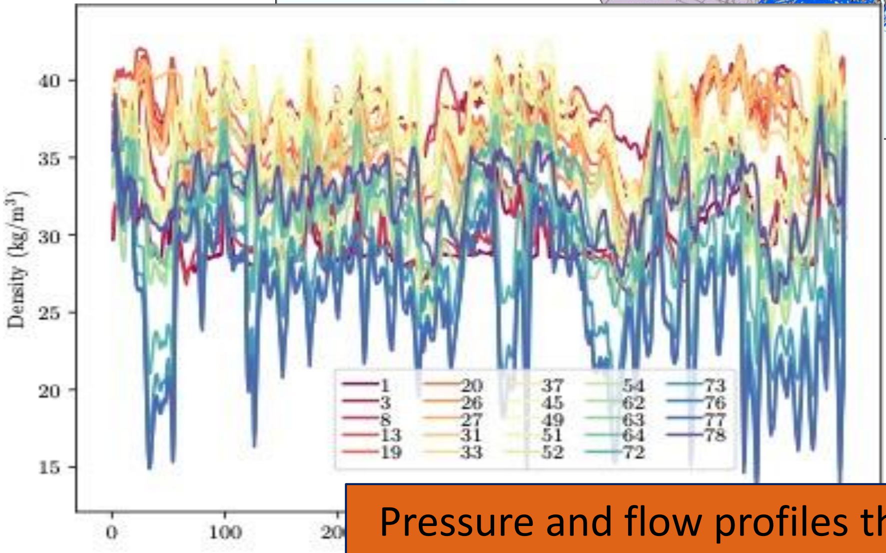
	voltage	category	counts
0	BusPUVolt < .9	severe violation	66
1	.9 <= BusPUVolt < .95	violation	584
2	.95 <= BusPUVolt < 1.05	nominal	77030

Co-Simulation: Natural Gas Modeling

<u>Natural gas software: Lab developed software</u>

- Steady-state (NG Fast)
  - National-scale, computationally efficient screening tool to identify events of interest and concern
- Transient-state (GasModels, NGTransient)
  - Physics-based, high fidelity model of the dynamics of gas flow in pipelines to calculate the spatio-temporal evolution of disruptions and key physical quantities like pipeline pressure





Pressure and flow profiles that track system evolution and impacts over time

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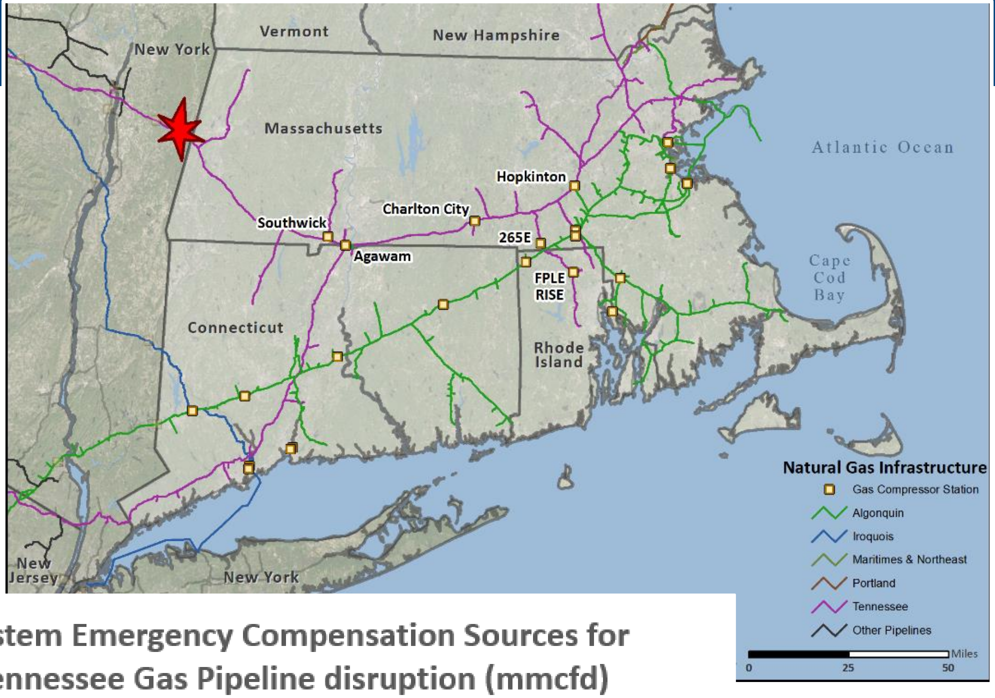
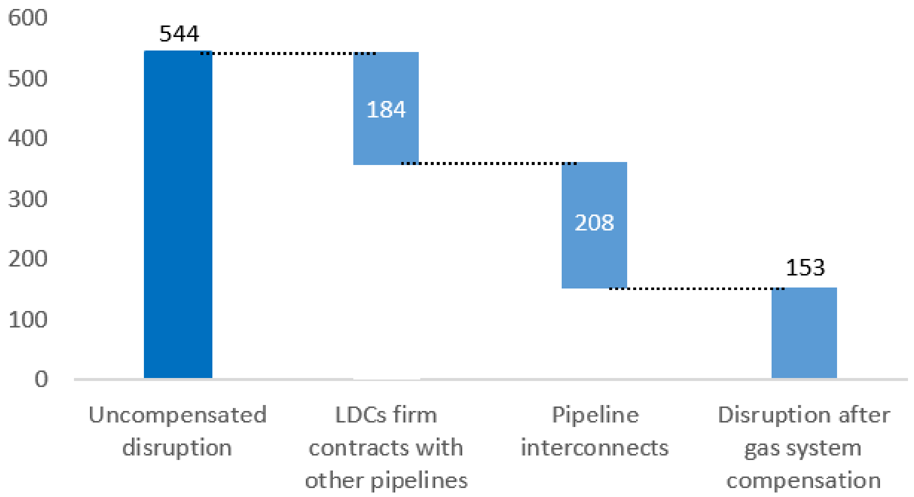
Resilience Evaluation



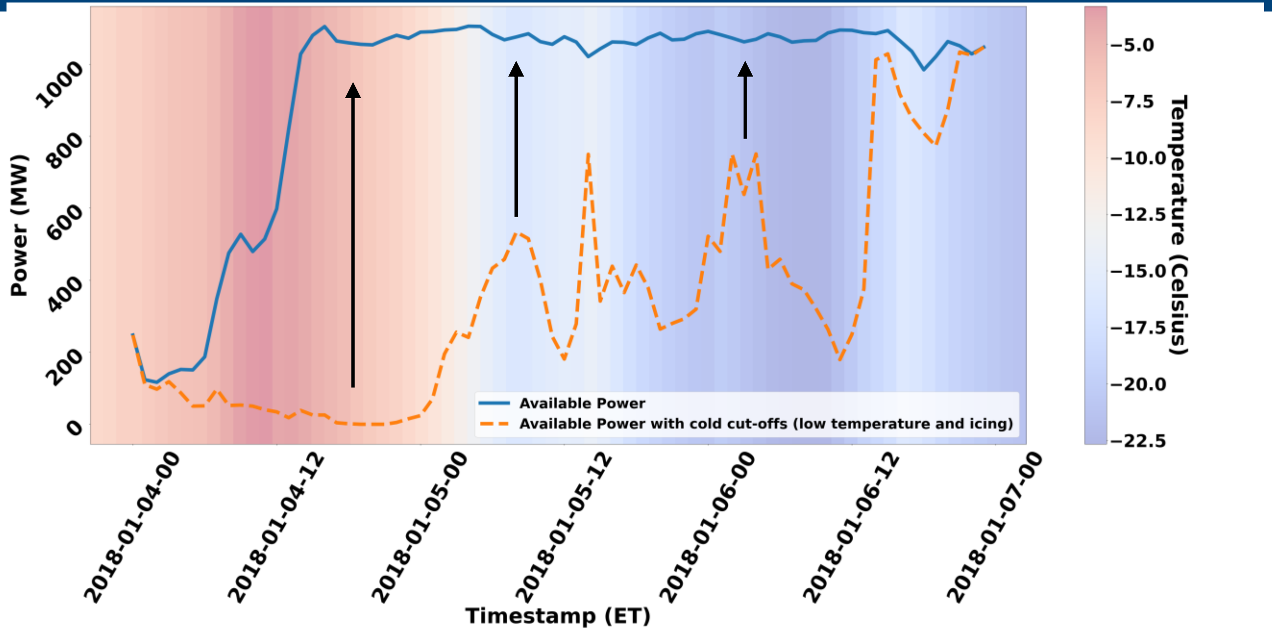
<u>Develop contingency scenarios and evaluate impacts through co-simulation</u>

- To-date, we have evaluated
  - Generator outages that occurred during Grayson with…
  - Two pipeline outage scenarios, one on the Tennessee pipeline and one on the Iroquois pipeline

Gas System Emergency Compensation Sources for the Tennessee Gas Pipeline disruption (mmcfd)



Mitigation and Investment Evaluation

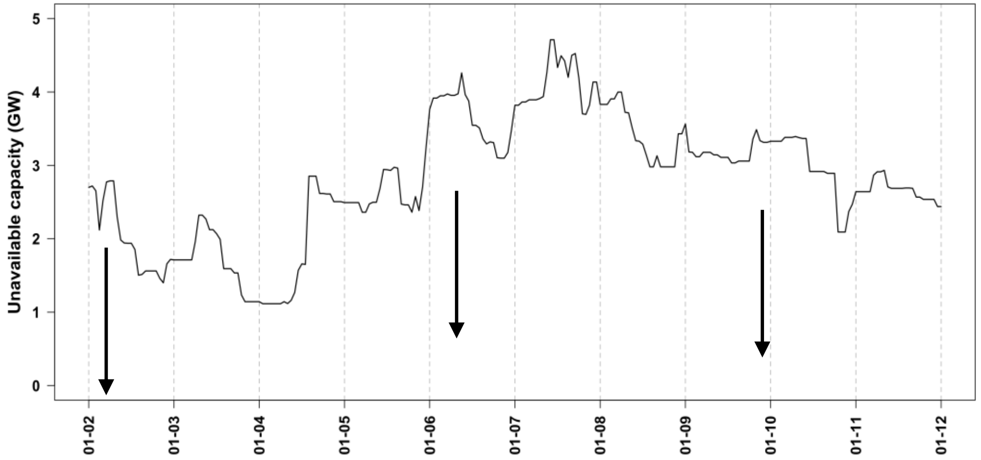


<u>Forthcoming…</u>

In combination with plans for the future of energy delivery in New England

- Evaluate conversion to dual fuel units
- Evaluate wind turbine winterization
- Evaluate Increased LNG capacity
- Evaluate Electrification and demand flexibility
- Other stakeholder priorities…

Unavailable capacity from unscheduled events, New England
Grayson Event, January 2018 (localized to eastern time)



Agenda

Introduction to NAERM (Ali Ghassemian – DOE OE)

Current State of NAERM (John Grosh – LLNL)

Wildfire Use Case (JP Watson – LLNL)

Cold Wave Use Case (Russell Bent – LANL)

⇨ Q&A