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Assessing Power Distribution Resilience Hardening Effectiveness Using Combined Physics-Based and Data-Driven Modeling

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Damage Modeling and Disaster Mitigation Lab - DM2L

Outline

Background & Motivation → Model development → Model application → Results & Discussion → Summary & Conclusions

Motivation

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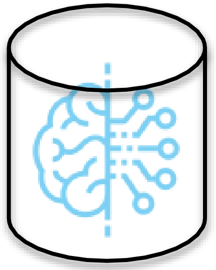
- **Problem:** To reduce storm-related power outages, utility companies invest large sums of money in grid maintenance
- It is hard to quantitatively estimate the effects *and **cost benefit analysis*** of grid hardening to inform effective actions

Methods

Solution: Create a dynamic weather damage model also sensitive to different infrastructural characteristics. Combines:

- ***Machine learning*** outage prediction models
- ***Structural analysis*** of the pole-wire system



Machine Learning

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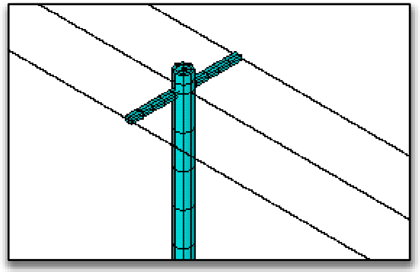

Physical Simulations

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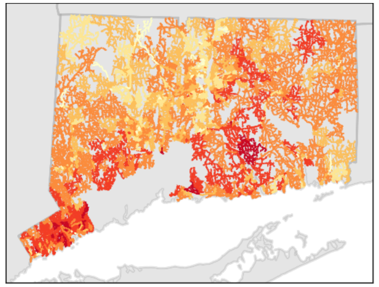
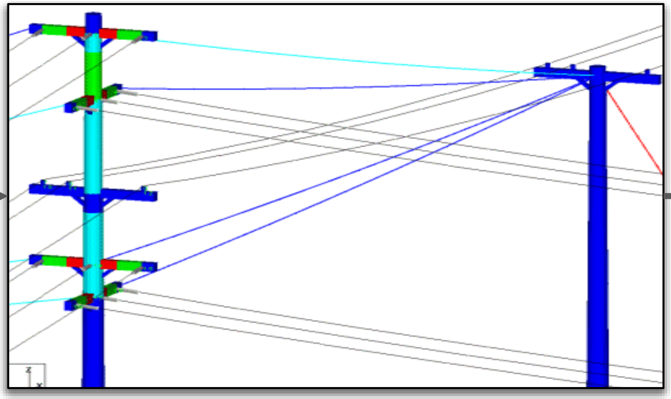
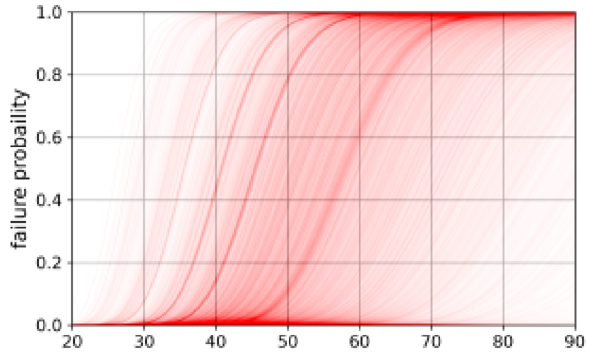


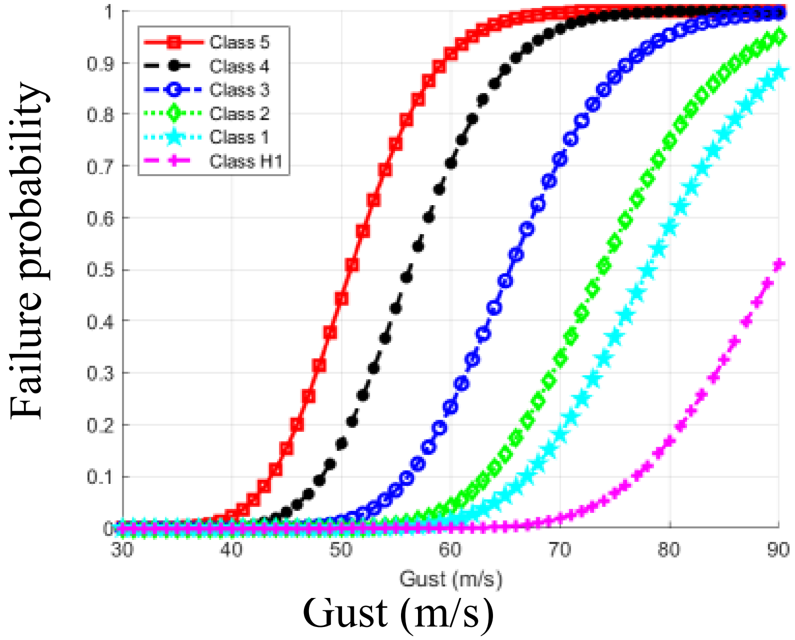
Outage predictions

Structural Modeling





- Generate ***fragility*** scores to predict pole failure probability from structural models
- Based on detailed infrastructure characteristics (age, pole class, conductor size, etc.)



Effect of pole class on fragility

Outage Prediction Model

- ***Machine learning model*** trained on historic storm and outage data
- Case study of state of Connecticut over past 16 years

Variables Including:

Weather
- *Wind*
- *Temperature*
- *Precipitation*

Vegetation
- *Leaf area*
- *Trimming*

Topographic
- *Elevation*
- *Soil*
- *Land cover*

Infrastructure
- *Line length*
- *Asset counts*
- *Structural fragility*

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OUTAGE PREDICTION MODEL

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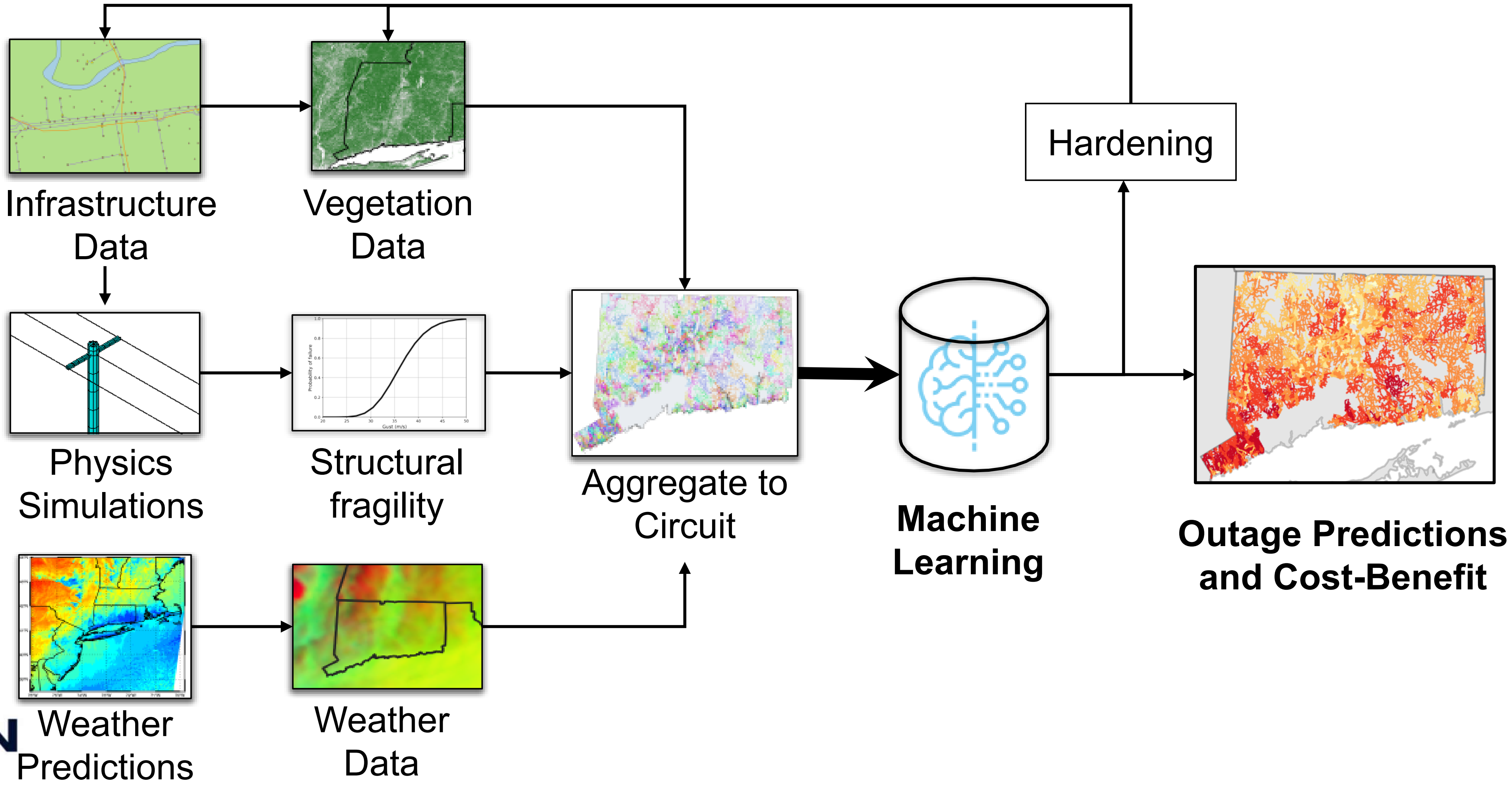
The Flow of Information



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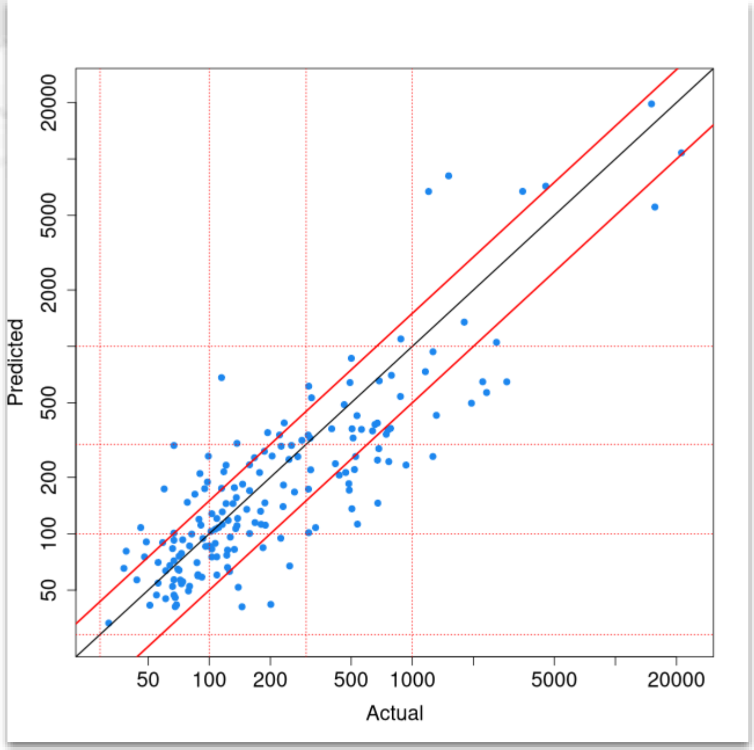
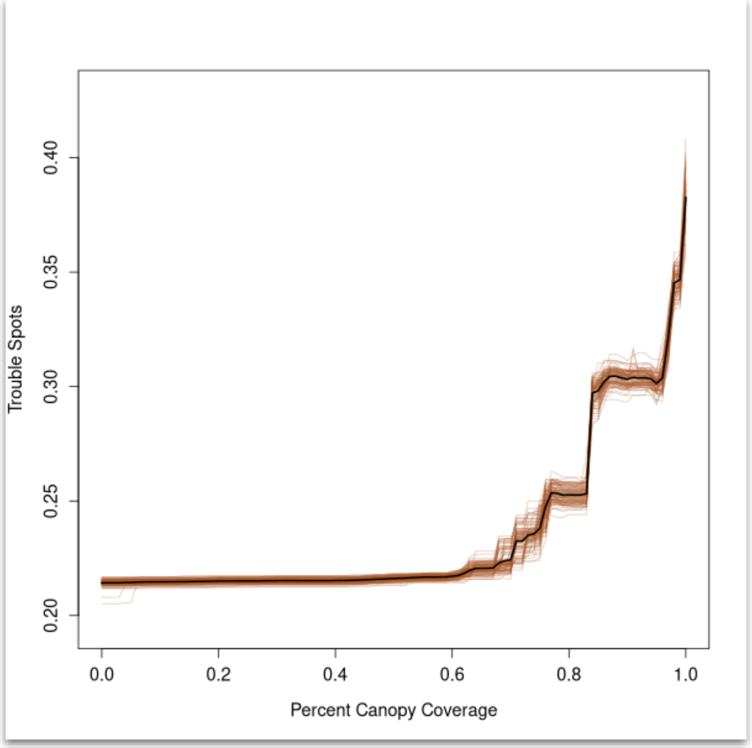
Model Results and Sensitivity

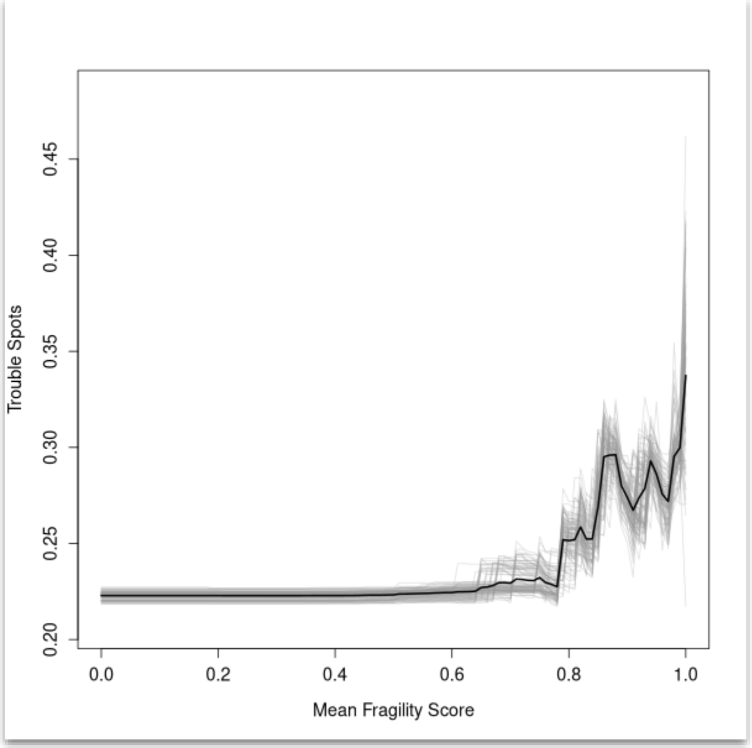
Cross Validation Results



Canopy Coverage



Structural Fragility



Model has Reasonable Accuracy

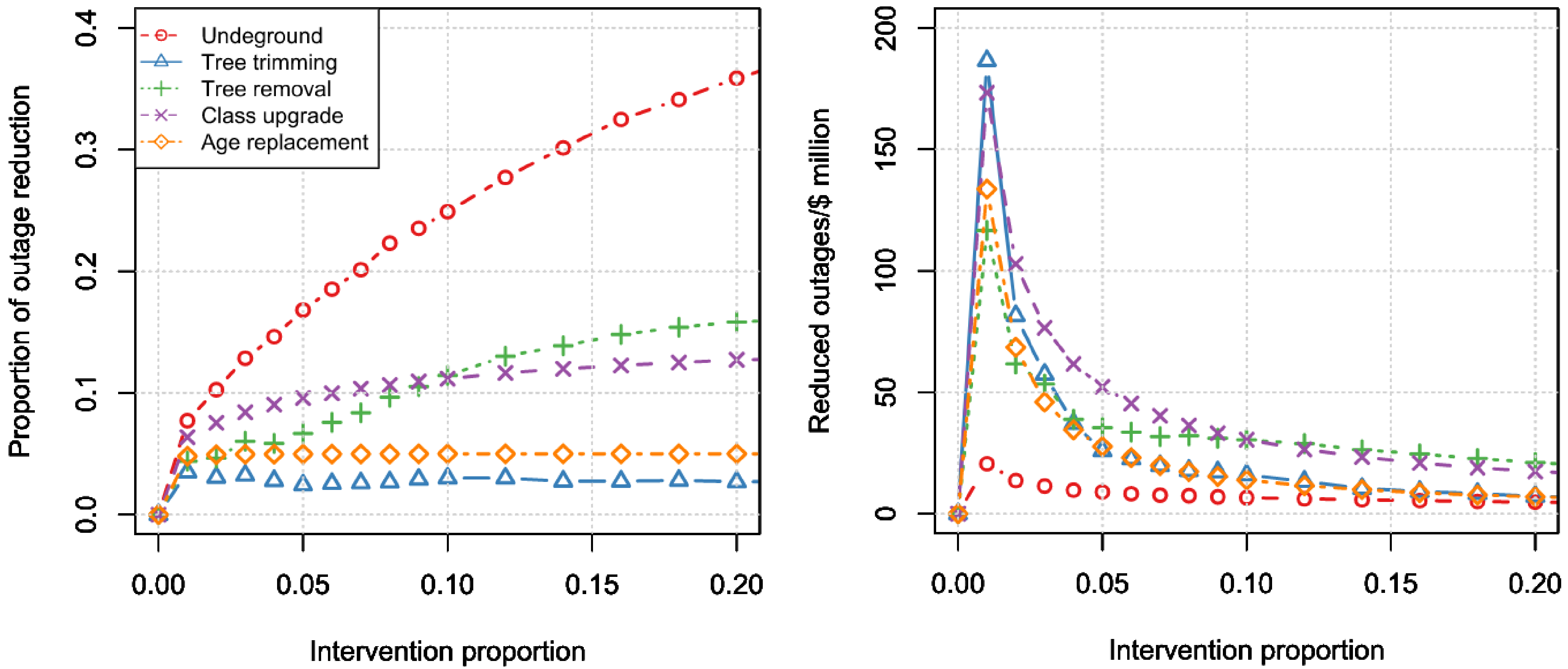
Predicts outages within 50% error

The Variables have Intuitive Dynamics

We can force the model with representative hardening scenarios

Grid Hardening

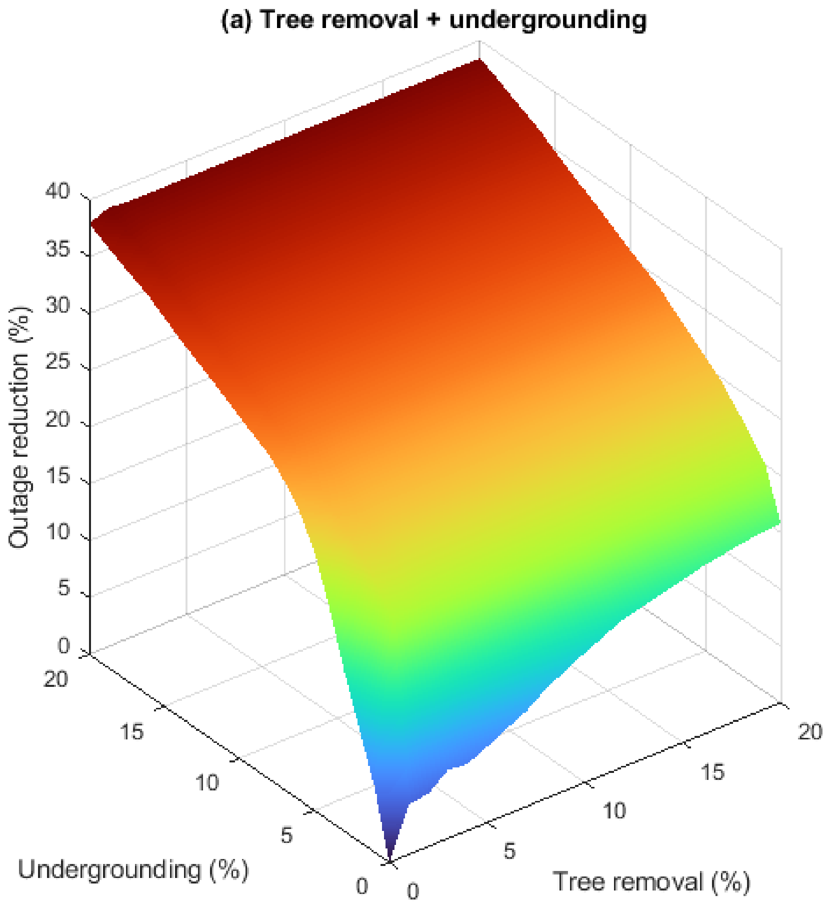
- ***Simulate hardening scenarios*** by altering related variables

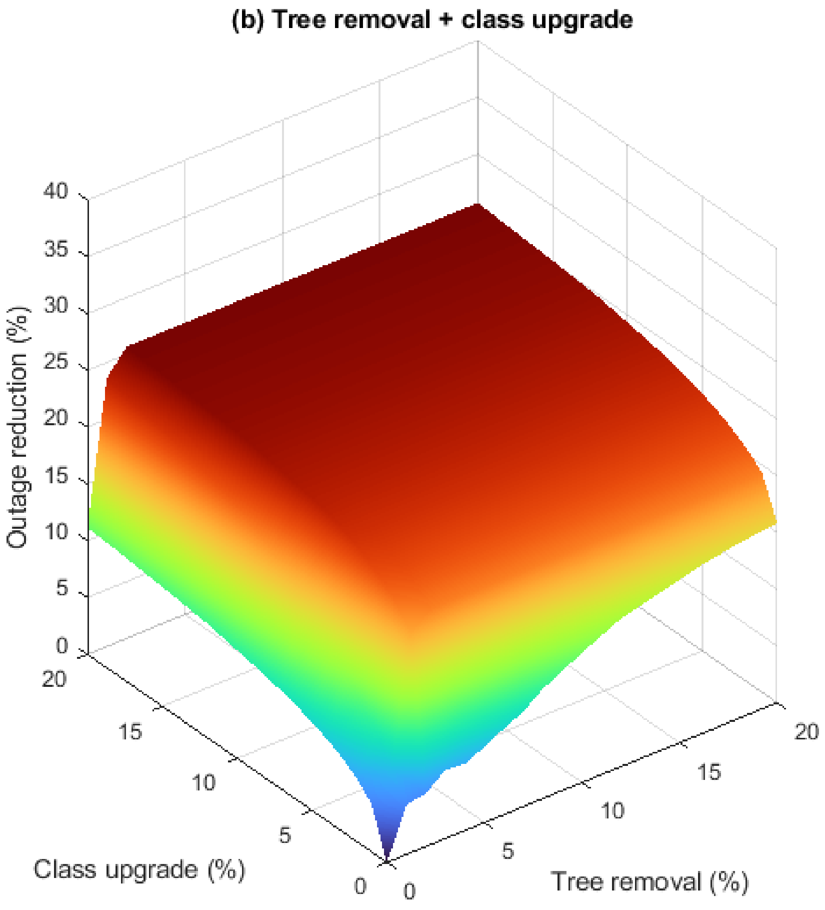


Percent outage reduction (left) and reductions per investment (right) for different strategies

Results

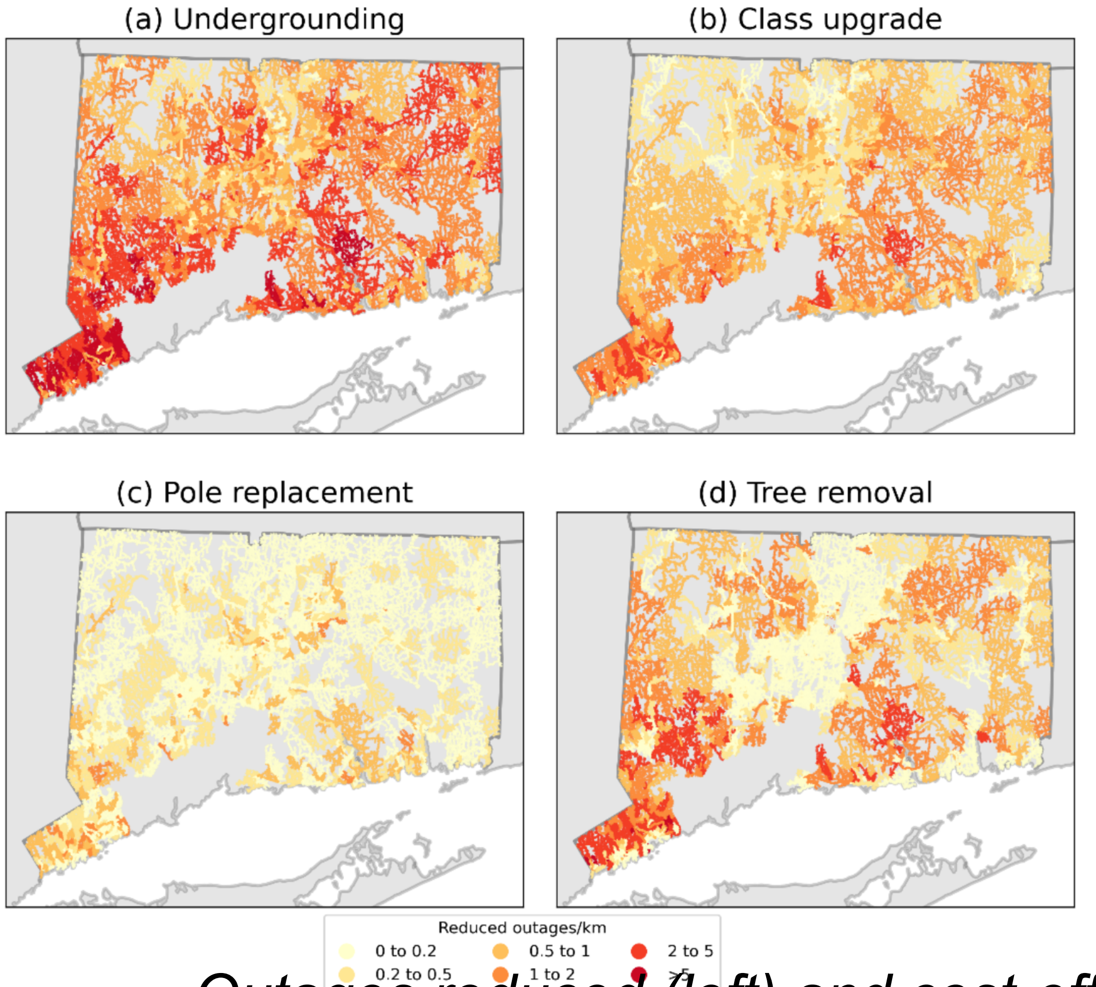
- Interactions between and effectiveness of different strategy combinations

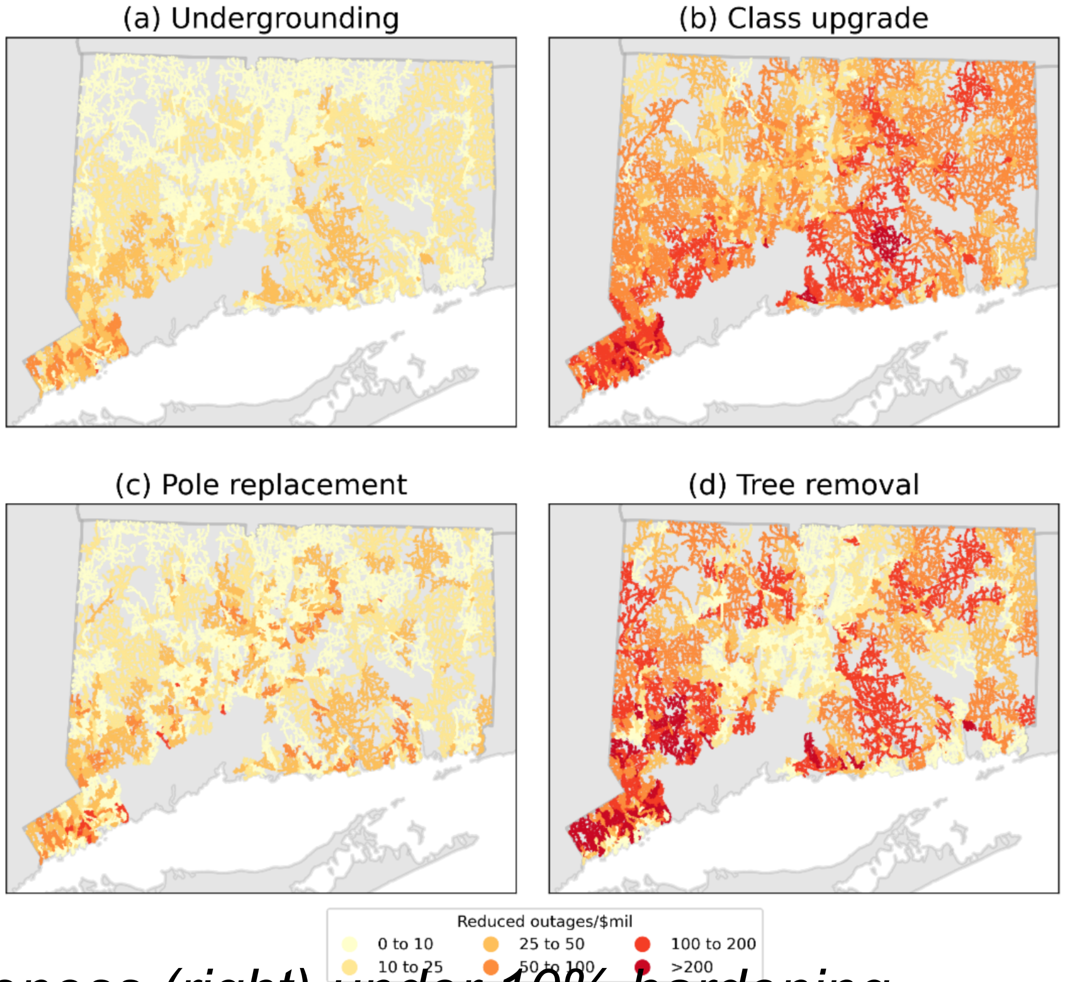




Spatial Effects

- Reveal ***differential benefits*** and highlight ***vulnerable regions***

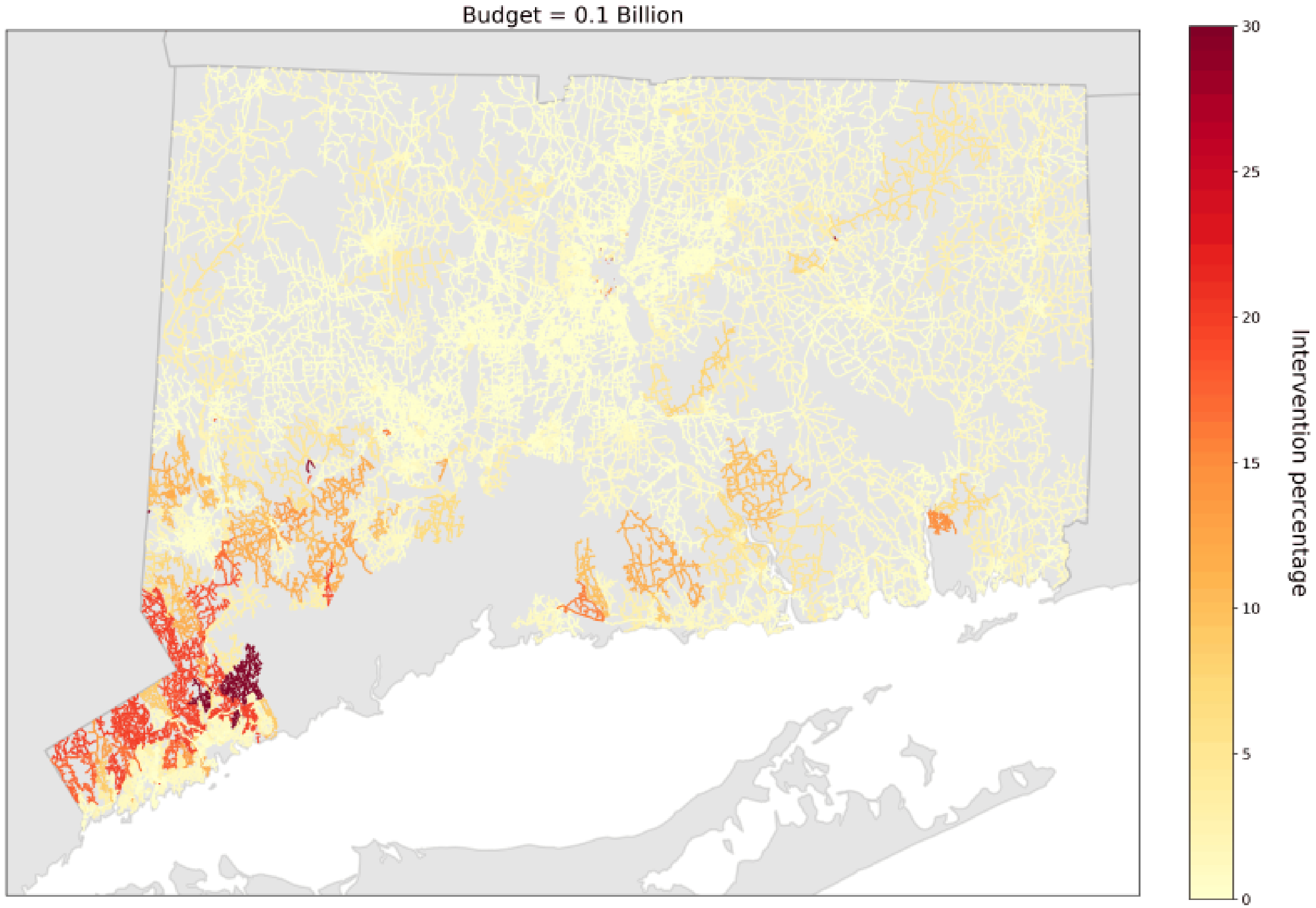




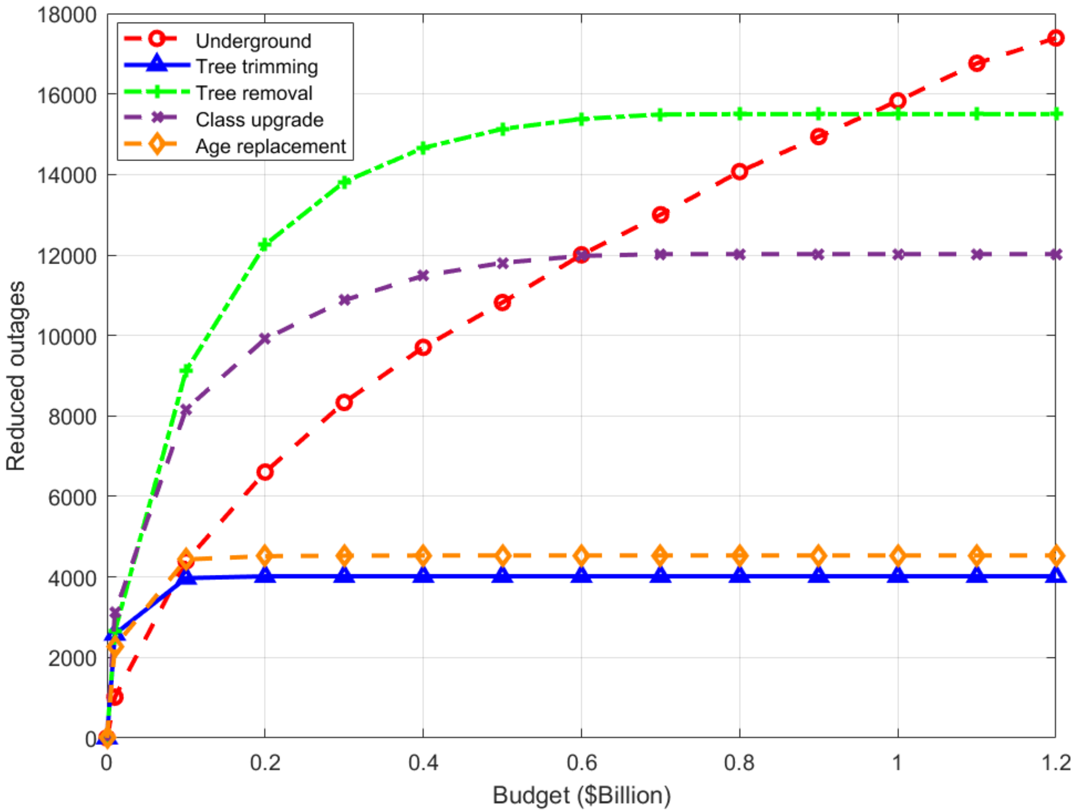
Outages reduced (left) and cost-effectiveness (right) under 10% hardening

Prioritization

- ***Prioritize*** investments under ***constrained budgets***



Optimal spending for tree removal under varying budget



Reduced outages against budget

Summary and Conclusions

- ***Outage prediction model*** developed combining physics-based and machine learning models for resilience assessment
- Model demonstrates reasonable accuracy and variable sensitivities
- ***Grid hardening benefits*** are simulated to develop prioritized under limited budgets
- Future efforts can extend to include outage durations and affected customers considering different social and economic consequences
- Provisional patent in works for commercialization and utility use

Thank you!

Questions?

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