Modeling and Analysis of Wildfire Behavior in New England Using FARSITE

Grant Proposal

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Abstract (RQ)

Wildfire risk in the Northeastern United States has historically received less attention than in the West, yet recent evidence shows that large wildfires in eastern forests are increasing in frequency and severity. New England presents a distinct fire regime characterized by humid climates, deciduous-dominated fuels, strong seasonal variability, and dense wildland–urban interfaces, conditions that are poorly represented in existing wildfire spread models developed for Western ecosystems. This project seeks to develop a regionally calibrated wildfire prediction framework for Massachusetts by validating and adapting FARSITE simulations using locally relevant fuel models, high-resolution meteorological data, and documented wildfire events. The study will evaluate model accuracy against observed fire perimeters, identify seasonal and climatic conditions that most strongly influence wildfire spread, and quantify the sensitivity of modeled fire behavior to key environmental parameters such as wind speed, fuel moisture, and canopy structure. The expected outcome is a validated, reproducible modeling framework that improves confidence in wildfire risk assessments and supports early-warning and mitigation planning for emerging fire-prone regions in New England.

Keywords: wildfire modeling; FARSITE; FlamMap; Northeastern United States; New England forests; fuel behavior fuel models; seasonal fire risk; climate variability; wildfire spread simulation; fire behavior sensitivity analysis

Developing a Wildfire Prediction Framework in the New England Region

Wildfire activity in the eastern United States has historically received less research attention than in the West, yet recent evidence indicates that fire risk in eastern forests is increasing (Donovan et al., 2023). Unlike the climate-driven megafires typical of the West, eastern wildfires occur in more humid environments with dense human populations and historically smaller fire sizes, making their dynamics distinct and less understood. A 36-year analysis shows that large fires in the eastern U.S. are growing in both size and frequency, underscoring the need to better understand the drivers of wildfire intensity in eastern ecosystems.

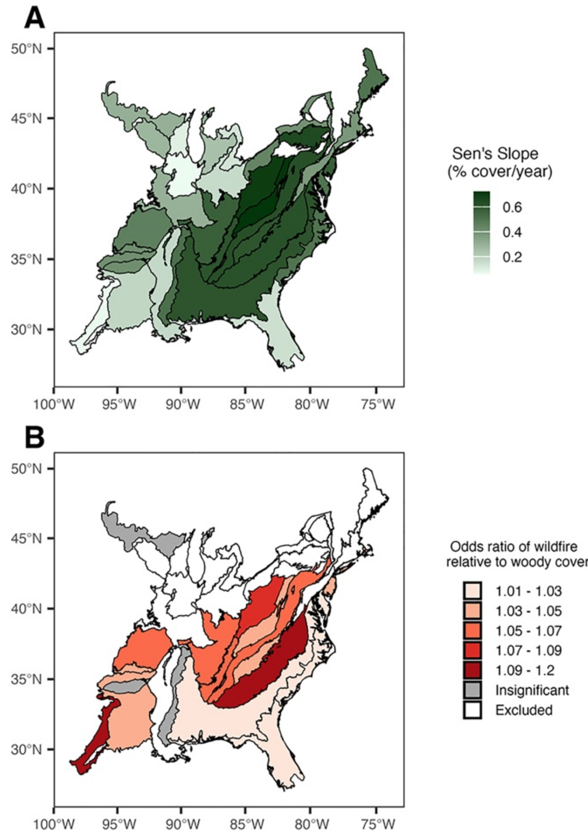

Figure 1: Trends in Woody Vegetation Cover and Associated Wildfire Risk Across the Eastern United States. (a) Geographic depiction of woody cover increases. A darkening green color represents ecoregions with greater rates of increase in woody cover per year. (b) The change in the odds of large wildfire occurrence relative to woody cover. A darkening red color indicates higher odds of wildfire with each 1% increase in woody cover. Regions that showed insignificant results are depicted in gray. Regions excluded due to insufficient fire numbers are depicted in white (Ivey et al., 2024).

Fuel Load Dynamics

Fuel load, the amount of burnable live and dead vegetation, strongly influences wildfire intensity. In many eastern forests, decades of fire suppression and land-use change have allowed fuels to accumulate. Woody vegetation cover has increased by approximately 37% across the eastern U.S. over the past 30 years, largely due to agricultural abandonment and reduced fire occurrence (Ivey et al., 2024). Increased woody fuels are linked to higher wildfire risk: each 1% increase in woody cover corresponds to roughly a 3.9% increase in the odds of a large fire in parts of the East. Regions such as eastern Texas and the southern Appalachians have experienced up to a tenfold increase in large wildfire frequency over four decades as forests and understories have densified.

In contrast, the cooler and wetter Northeast has shown a weaker relationship between fuel buildup and large fires, indicating that fuel load alone does not determine fire outcomes (Ivey et al., 2024). However, heavy fuels remain a necessary condition for high-intensity fires when ignitions and favorable weather coincide. Fuel treatments such as prescribed burning and thinning are therefore critical management tools, as long-term fire suppression has been shown to exacerbate fuel accumulation and increase fire severity when fires do occur (Kreider et al., 2024).

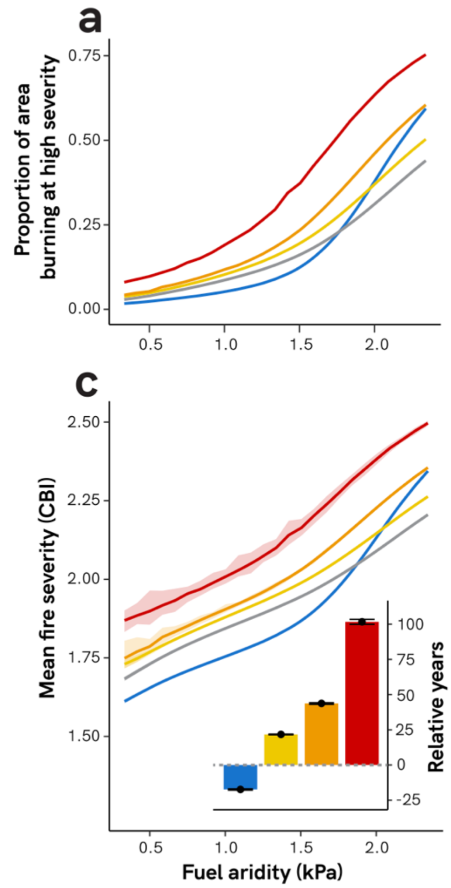

Figure 2: Relationship Between Fuel Aridity and Wildfire Severity in the Northeastern United States. Panel A shows the proportion of high-severity fire (CBI > 2.25) across a range of fuel aridity. Panel C shows mean fire

Wildfire Season

Wildfire activity in the Northeast is highly seasonal, with a pronounced peak in April and May. A climatological study of 155 Northeast wildfires (1999–2009) found that approximately 59% of large fires (≥100 acres) occurred during these two months, driven by pre-green-up conditions, rapid spring drying, and persistent high-pressure systems that produce warm, dry, and windy weather (Pollina et al., 2013). Notably, many Northeast wildfires occur without meeting traditional Red Flag Warning criteria, suggesting that fire-weather thresholds developed for western regions may not accurately capture fire risk in New England. This spring-dominated and meteorologically distinct fire season has important implications for regional fire modeling and prediction.

Climate Variables

Climate and weather strongly regulate wildfire intensity by controlling fuel moisture and ignition potential. Key variables include temperature, precipitation, and drought indices such as the Palmer Drought Severity Index and Fire Weather Index. Elevated temperatures and reduced precipitation dry fuels and increase combustion intensity, while drought indices capture prolonged moisture deficits that predispose landscapes to severe fires. In the historically wetter East, climate variability can sharply distinguish mild fire seasons from extreme ones.

Studies in the Northeast show that large fires tend to coincide with periods of climatic water deficit (Carlson et al., 2021). The 2016 southern Appalachian fires, for example, occurred during one of the warmest and driest autumns on record, when drought and leaf litter accumulation enabled high-intensity fire behavior, including wind-driven crown fires (Reilly et al., 2022). Climate change is expected to exacerbate these conditions by lengthening fire seasons and increasing the frequency of hot, dry weather. Importantly, climate and fuel effects interact: drought can both dry existing fuels and increase dead fuel loads through vegetation stress and mortality, amplifying fire intensity once ignitions occur (Donovan et al., 2023).

Modeling Tools

Wildfire modeling tools are essential for translating relationships among fuels, climate, and fire behavior into quantitative predictions. FlamMap, a widely used U.S. Forest Service model, simulates potential fire behavior—including flame length, rate of spread, and fireline intensity—under constant environmental conditions using spatial inputs such as fuels, topography, and weather (Finney, 2006). Its Minimum Travel Time (MTT) module enables analysis of likely fire spread pathways and intensity patterns across landscapes (Conver et al., 2018). FARSITE complements FlamMap by modeling time-dependent fire growth under changing weather conditions. More advanced approaches include coupled fire-atmosphere models and scenario-based simulations, which have demonstrated how fuel management can significantly reduce fire intensity under future drought conditions (Vaz et al., 2024). Although these models have been applied primarily in western or international contexts, they offer substantial potential for eastern U.S. landscapes. By integrating fuel maps, climate data, and scenario analysis, modeling tools allow researchers to evaluate how changes in fuel accumulation or climate—

such as increased biomass or rising temperatures—may influence wildfire intensity. Applying these tools in New England will help address gaps in observational data and support more effective fire management and preparedness strategies in an under-studied region.

Section II: Specific Aims

This proposal's objective is to develop a robust, data-driven framework to model wildfire behavior in the Massachusetts, an understudied region where climate trends, increasing drought, and urban-wildland proximity are elevating risk.

Our long-term goal is to create a validated, region-adapted wildfire prediction system that can support early-warning efforts and inform community-level hazard mitigation planning. The central hypothesis of this proposal is that FARSITE simulations, when calibrated with locally relevant fuel models and historical fire data, can accurately reproduce real-world fire dynamics and reveal seasonal and climatic patterns that influence fire spread. The rationale is that existing wildfire modeling tools are optimized for Western ecosystems and required targeted calibration to accurately represent the unique fuel structures of fire regimes of the Northeast. The work we propose here will quantify these differences, adjust relevant model parameters, and systematically assess how sensitive wildfire spread is to environmental and climatic factors.

Specific Aim 1: We will simulate documented wildfires—such as the 2021 East Mountain Fire—using FARSITE and compare flame length, rate of spread, and final burn perimeters with observed outcomes. Then we will adjust fuel models and canopy parameters to better align simulated outputs with real-world burn severity, leveraging LANDFIRE data and literature-supported modifications.

Specific Aim 2: We will evaluate multi-year Open-Meteo and NOAA climatological records to identify when environmental conditions most favor rapid spread during the year. Then we can assess how wildfire spread potential has changed over time, linking seasonal peaks to temperature, humidity, drought indices, and fuel moisture trends.

Specific Aim 3: We will vary key parameters to quantify which factors most strongly influence spread rate and burn extent. Parameters we can change include wind speed/direction, fuel moisture, canopy cover, and fuel models.

The expected outcome of this work is a calibrated, regionally tailored wildfire modeling toolkit that identifies the environmental drivers of Northeastern wildfire behavior, quantifies uncertainty through sensitivity analysis, and provides reproducible workflows for future researchers and land managers. This work will ultimately contribute to improved wildfire preparedness, risk modeling, and early season hazard detection for communities in emerging fire-prone regions.

Section III: Project Goals and Methodology

Relevance/Significance

Wildfire risk in the Northeastern United States is growing due to compounding climate pressures such as extended dry periods, declining summer humidity, earlier spring thaws, and increased fuel accumulation. Yet, most fire-spread models (including FARSITE and FlamMap) are parameterized and validated almost exclusively for Western ecosystems. This mismatch creates significant uncertainty when predicting wildfire behavior in regions like Massachusetts, where deciduous-dominated fuels, lower canopy bulk density, and pronounced seasonal changes lead to unique fire dynamics. This project directly addresses that knowledge gap by validating, calibrating, and stress-testing wildfire simulation tools for Northeastern conditions. The work will generate actionable insights for emerging fire-prone communities that currently lack reliable, region-specific modeling guidance.

Innovation

The proposed research is innovative because it applies fire-spread simulation tools in a way that has rarely been attempted in Northeastern landscapes. Unlike prior studies that use FARSITE, this project introduces a calibration procedure that aligns fuel models and moisture inputs with actual, observed wildfire behavior. Additionally, the integration of climate records with simulation-based seasonal spread modeling directly addresses the question of whether Northeastern fire seasons are intensifying or shifting. Finally, the sensitivity analysis conducted in this project provides the first quantitative assessment of which environmental variables exert the strongest influence on wildfire spread in hardwood-dominated ecosystems. Together, these contributions extend the capabilities of existing fire modeling and provide a replicable framework for future regional studies.

Methodology

This project employs a simulation-based, data-driven approach to evaluate and adapt wildfire spread models for New England forests. High-resolution spatial inputs describing fuels, canopy structure, and topography will be assembled from LANDFIRE and related geospatial datasets and combined with hourly meteorological data from NOAA ISD stations and Open-Meteo archives. Baseline FARSITE simulations will be conducted for documented Massachusetts wildfires, and modeled fire behavior metrics, such as rate of spread, flame length, and burn perimeter, will be quantitatively compared against observed outcomes to guide calibration of fuel models and moisture parameters. Using calibrated configurations, seasonal simulations will be performed across multiple years with identical ignitions to isolate the effects of climate and fuel moisture variability. Finally, sensitivity analyses will systematically vary wind, fuel moisture, canopy characteristics, and fuel models to identify the dominant drivers of wildfire spread and quantify uncertainty in Northeastern wildfire simulations.

Specific Aim #1

The purpose of this aim is to determine how accurately FARSITE can reproduce the spread patterns of real Northeastern wildfires and to identify which model components require adjustment. The objective is to compare simulated flame length, rate of spread, and burn perimeter with documented wildfires such as the 2021 East Mountain Fire and fires recorded in Clarksburg State Forest. To accomplish this, we will construct high-resolution spatial inputs—elevation, slope, aspect, canopy structure, and LANDFIRE fuels—and combine them with hourly meteorological data derived from NOAA ISD and Open-Meteo archival datasets. These inputs will be used to run baseline simulations, after which the modeled results will be compared directly to observed fire progression and final perimeters.

The rationale for this aim is strongly supported by recent work demonstrating that FARSITE's performance is highly dependent on the accuracy of fuel model selection. In particular, the study by Price and Germino (2022) showed that when FARSITE was parameterized using unmodified LANDFIRE fuel behavior fuel models (FBFMs), the simulated fire perimeters for the 2015 Soda Wildfire had very low agreement with the observed burn area (Price & Germino, 2022) . Their results showed Sorensen's coefficient values only between 0.31–0.38 and Cohen's Kappa values between 0.29–0.36, indicating poor accuracy under default LANDFIRE conditions. In contrast, when they replaced LANDFIRE fuels with a regionally calibrated fuel-mapping approach derived from RAP satellite vegetation cover, model accuracy improved dramatically, reaching SC = 0.70 and K = 0.68. This finding establishes a critical precedent: default LANDFIRE fuel models systematically underperform in certain ecosystems, and recalibration using local vegetation structure can greatly increase FARSITE accuracy. This directly parallels the challenge in Northeastern forests, where deciduous litter, seasonal leaf-off fuel beds, and hardwood understories are poorly represented by standard Western-derived models. Thus, incorporating the approach demonstrated by Price & Germino strengthens both the feasibility and scientific justification for recalibrating FARSITE to better match regional conditions.

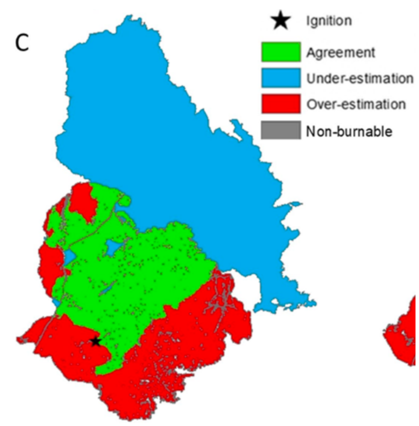

Figure 3: Agreement between FARSITE simulated fire spread and the observed area burned in the 2015 Soda fire using Anderson's 13 FBFMs as input.

Justification and Feasibility. Existing fuel behavior fuel models, including those embedded in LANDFIRE were primarily developed and validated for Western coniferous systems, and as a result, they might mischaracterize the dynamics typical of New England. This aim is feasible because of the open-source high-resolution spatial layers available for the region. Meteorological data is also available for hourly weather data given any time period. A unique challenge in the Northeast is the limited number of documented wildfires large enough to serve as robust validation cases. Fires such as the 2021 East Mountain Fire and historical fires in Clarksburg State Forest represent rare opportunities for quantitative comparison, but the overall dataset is sparse compared to the dozens of large, well-documented fires available for Western validation studies. Rather than undermining the feasibility of the project, this limitation increases its importance. In regions with few large fires, it is especially critical to understand whether modeling tools can generalize accurately from a small number of calibration events. Demonstrating that FARSITE either succeeds or requires systematic adjustment will help define the confidence bounds for future research that relies on simulation-based risk estimation in the Northeast.

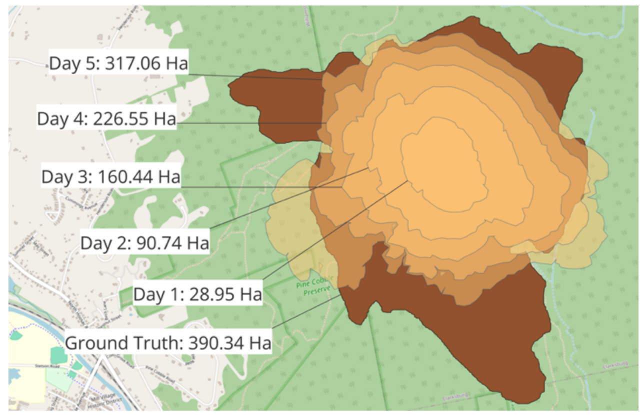

Figure 4: Daily burn perimeters generated by FARSITE for the 2021 East Mountain Fire compared against the mapped ground-truth perimeter (brown). The simulation captures the general outward expansion pattern but underestimates the total area burned and shows spat.

Summary of Preliminary Data. Preliminary FARSITE simulations of the 2021 East Mountain Fire show a substantial mismatch between modeled and observed burned area (Figure 4). Overlay analysis shows 13 ha of overestimation and 127 ha of underestimation. These discrepancies suggest issues with either LANDFIRE fuel models or other model inputs.

Expected Outcomes. The overall outcome of this aim is a quantitative evaluation of FARSITE's accuracy in Northeastern ecosystems. In addition, we can determine which model components require recalibration. By systematically varying inputs, we will be able to test whether specific adjustments meaningfully improve agreement with observed fire progression. The ultimate outcome will be a set of evidence-based recommendations for how FARSITE should be configured or modified to perform reliably in New England forests. This knowledge will be used to inform Aim 2 and Aim 3 and will help establish realistic confidence bounds for using FARSITE in future fire-risk assessments in New England.

Potential Pitfalls and Alternative Strategies. A potential pitfall is the limited number of real Northeastern wildfires available for validation. To address this, the project will expand the dataset by incorporating smaller but well-mapped fires. Although these events are smaller in scale, they still provide valuable perimeter-growth patterns that can be used for calibration and help strengthen the robustness of the validation process.

Specific Aim #2:

Justification and Feasibility. Wildfire spread in Massachusetts is strongly influenced by seasonal fuel and climate dynamics that differ from Western fire regimes. Deciduous forests experience pronounced spring leaf-off and autumn leaf-drop periods that alter fuel moisture and continuity, yet these transitions are rarely captured in wildfire risk models. This aim is justified by the need to identify when during the year wildfire spread potential is highest and which environmental factors drive these seasonal peaks.

This aim is feasible due to the availability of long-term, high-resolution meteorological data. These datasets provide hourly temperature, humidity, wind, and precipitation inputs that can be translated into fuel moisture parameters for FARSITE. Because this analysis relies on controlled simulations rather than large historical fires, it is not limited by the scarcity of documented Northeastern wildfire events.

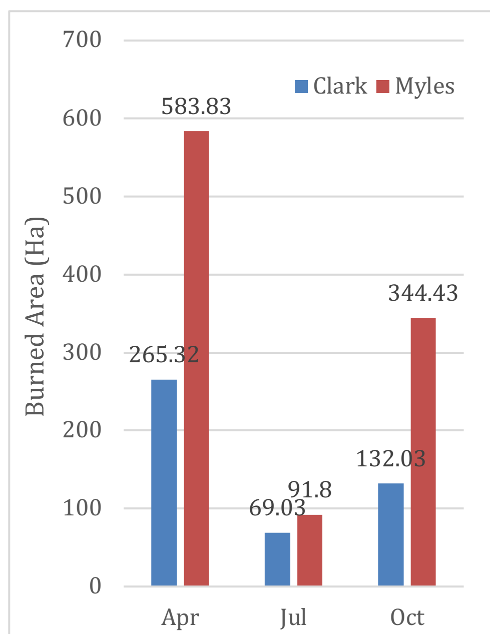

Figure 5: Seasonal burned area (ha) for two simulated fires in Myles Standish and Clarksburg using 2024 weather and the same ignition as Figure 1. Myles Standish contains more flammable TL3, TL5, and TU1 fuels, while Clarksburg has moister TL1, TL2, and TL6 hard.

Summary of Preliminary Data. Preliminary seasonal simulations using identical ignitions and 2024 weather show consistent seasonal patterns across sites (Figure 5). Both Myles Standish and Clarksburg exhibit maximum burned area in April, a secondary peak in October, and minimal spread in July. These trends persist despite differences in fuel composition, indicating that seasonal fuel moisture dynamics—rather than fuel type alone—are the dominant control on spread potential. April fires coincide with low moisture before green-up, October fires with leaf-drop, and July fires with wetter growing-season fuels.

Expected Outcomes. This aim will identify seasonal windows of elevated wildfire spread risk in Massachusetts and quantify which climatic variables (e.g., temperature, relative humidity, drought indicators, inferred fuel moisture) most strongly influence fire growth. Results will establish whether seasonal wildfire risk has shifted over time and will provide calibrated seasonal baselines to support sensitivity analysis in Aim #3 and region-specific early-warning strategies.

Potential Pitfalls and Alternative Strategies. Fuel moisture estimates derived from weather data may introduce uncertainty. To address this, multiple moisture parameterizations will be tested to bracket realistic conditions. If interannual climate variability obscures trends, additional historical years will be incorporated. These strategies ensure robust identification of seasonal wildfire risk patterns despite data limitations.

Specific Aim #3:

Justification and Feasibility. Wildfire spread models such as FARSITE rely on numerous interacting inputs—including wind speed and direction, fuel moisture, canopy structure, and fuel model selection—yet the relative influence of these parameters in Northeastern ecosystems remains poorly quantified. This aim is justified by the need to determine which variables most strongly control modeled fire behavior in Massachusetts and to identify where uncertainty in inputs most affects predictive reliability. Understanding parameter sensitivity is essential for interpreting simulation results and prioritizing data accuracy in operational and research applications.

This aim is feasible because FARSITE allows controlled, systematic variation of individual inputs while holding others constant. Using the calibrated configurations developed in Aims #1 and #2, we will perform sensitivity experiments across realistic parameter ranges derived from observed weather variability and fuel conditions in Massachusetts.

Summary of Preliminary Data. Preliminary sensitivity analysis demonstrates a strong dependence of modeled burn extent on wind speed (Figure 6). Increasing wind magnitude from 40% to 160% of default conditions produces a monotonic increase in final burned area, from approximately 300 ha to over 365 ha. This result highlights wind speed as a dominant driver of fire growth and underscores the importance of accurate meteorological inputs when applying FARSITE in the Northeast.

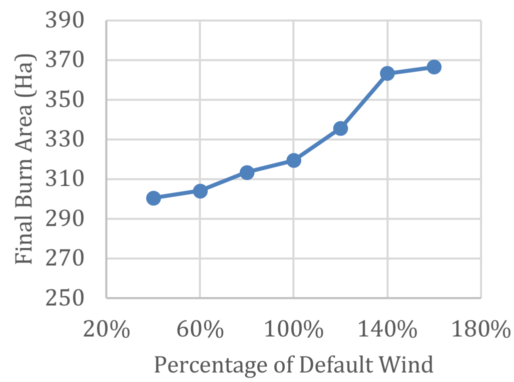

Figure 6: Final burn area produced under different wind-speed multipliers (40–160% of default conditions). Increasing wind speed consistently increases total area burned, demonstrating strong sensitivity of FARSITE outputs to wind magnitude and the importance of accurate meteorological inputs.

Expected Outcomes. This aim will quantify the relative sensitivity of wildfire spread to wind speed, fuel moisture, canopy cover, and fuel model selection. The results will identify which parameters exert first-order control on burn area and rate of spread and which contribute comparatively less uncertainty. These findings will establish confidence bounds for simulation-based risk assessments and provide guidance on which inputs must be most carefully constrained for reliable Northeastern wildfire modeling.

Potential Pitfalls and Alternative Strategies. A key limitation of this aim is the computational cost associated with running large numbers of FARSITE simulations, as each individual run requires nontrivial processing time. Systematically varying multiple parameters across realistic ranges can therefore become time-intensive and limit the total size of the sensitivity dataset. To address this, the analysis will prioritize one-at-a-time parameter perturbations to identify first-order sensitivities before exploring limited multi-parameter combinations. Parameter ranges will be constrained to climatologically realistic bounds informed by observational data, reducing unnecessary simulations. If runtime remains restrictive, sensitivity analysis will be performed on representative subsets of scenarios and sites rather than exhaustive combinations. These strategies ensure that meaningful sensitivity rankings can be obtained while remaining computationally feasible.

Section IV: Resources/Equipment

This project integrates open-source geospatial datasets with a suite of computational tools to support wildfire modeling and analysis. Core datasets include fuel and vegetation characteristics, climate and drought variables, historical fire occurrence, and topographic information. Fuel, vegetation, and topography are sourced from LANDFIRE, while fire occurrence and burn perimeters are obtained from the Monitoring Trends in Burn Severity (MTBS) dataset. Weather and climate data are retrieved through the Open-Meteo API. All datasets used in this study are publicly available. Analysis and simulation are performed using specialized fire behavior models such as FlamMap and FARSITE, complemented by GIS platforms including QGIS and ArcGIS Pro. Python, with relevant scientific and geospatial libraries, is employed for data processing, modeling, and visualization within Jupyter notebooks, while Git/GitHub is used for version control and project management. Excel supports preliminary data organization, validation, and summary analysis.

Section V: Ethical Considerations

This research uses only publicly available datasets and simulation tools. Ethical responsibility in this project centers on transparent modeling practices and responsible communication of wildfire risk, particularly given the limited number of large document wildfire in the Northeast. The findings are intended solely for long-term risk assessment and research purposes, not for operational decision-making during active wildfire events.

Section VI: Timeline

Oct 20 – Nov 3	Setup & Scoping	Finalize RQ, variables, region, datasets, and model setup
Nov 4 – Nov 24	Data Assembly	Collect and clean data, align to grid
Nov 25 – Dec 8	Baseline Simulations	Run baseline FlamMap scenarios and validate
Dec 9 – Jan 12	Scenario Modeling	Run modeling simulations, test sensitivity
Jan 13 – Feb 2	Statistical/ML Analysis	Fit regression models, compute effects, SHAP plots

Section VIII: References

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