Simulating and Analyzing Wildland Fire Spread

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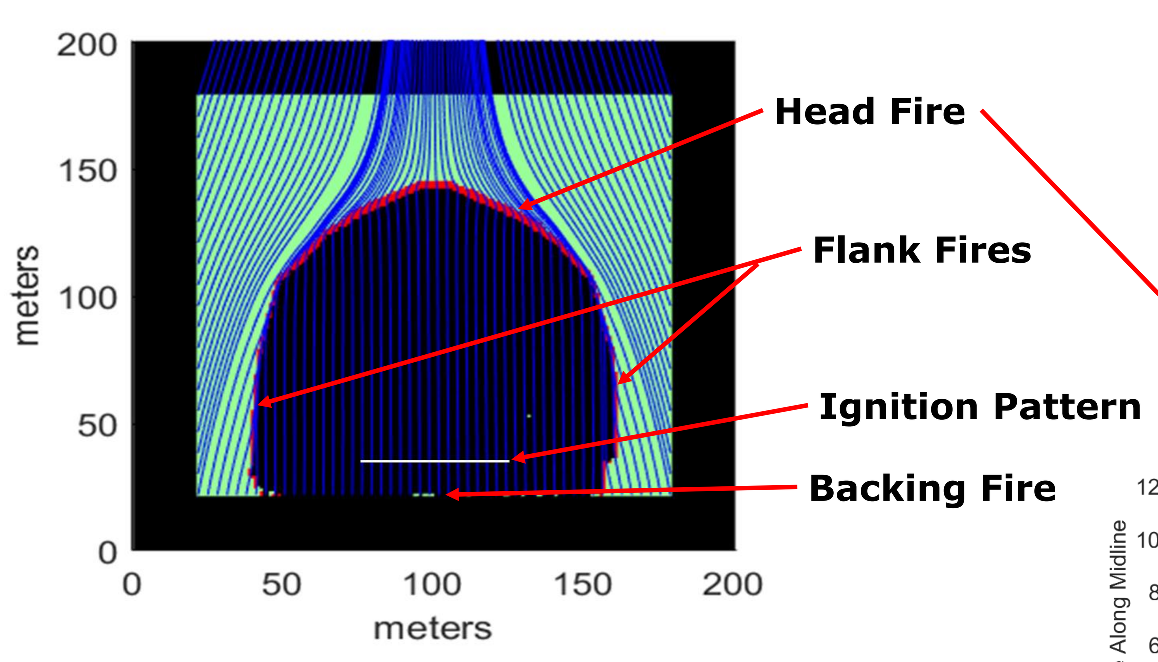
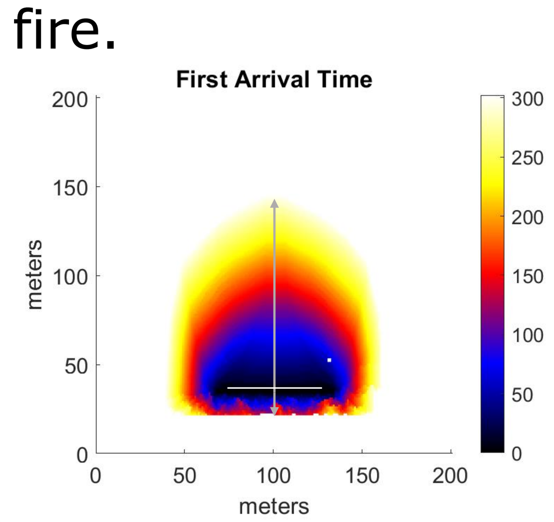
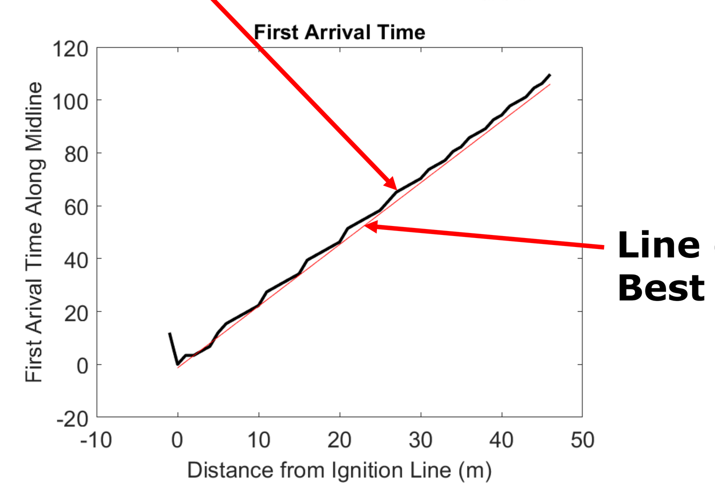
Background

Wildland fires are a complex multiphysics problem, integrating elements of meteorology, fluid mechanics, combustion, and ecology. Numerous interconnected factors affect the spread of wildland fires, including atmospheric conditions, fire intensity, fuel structure, and topography. Understanding their dynamics is crucial, not only for comprehending large wildfires but also for informing policies aimed at fire managers who use prescribed fire as a tool to meet ecological objectives.

This project uses computational tools to simulate wildland fire spread. The code accounts for multiple parameters including the background wind speed and direction, the burn time of the fuels, the fire-induced weather, and stochastic turbulence effects. By systematically adjusting each variable, I determine each parameter's effect on the rate of spread of the fire.







Computer code is used to simulate fire spread across a 200m x 200m burn unit. Each cell in the grid is burnt (black), burning (red), or has available fuel (green). The blue lines show paths that parcels of air follow. The first arrival time is the time each cell first sees fire. It can be visualized as a colormap or along a specified direction.

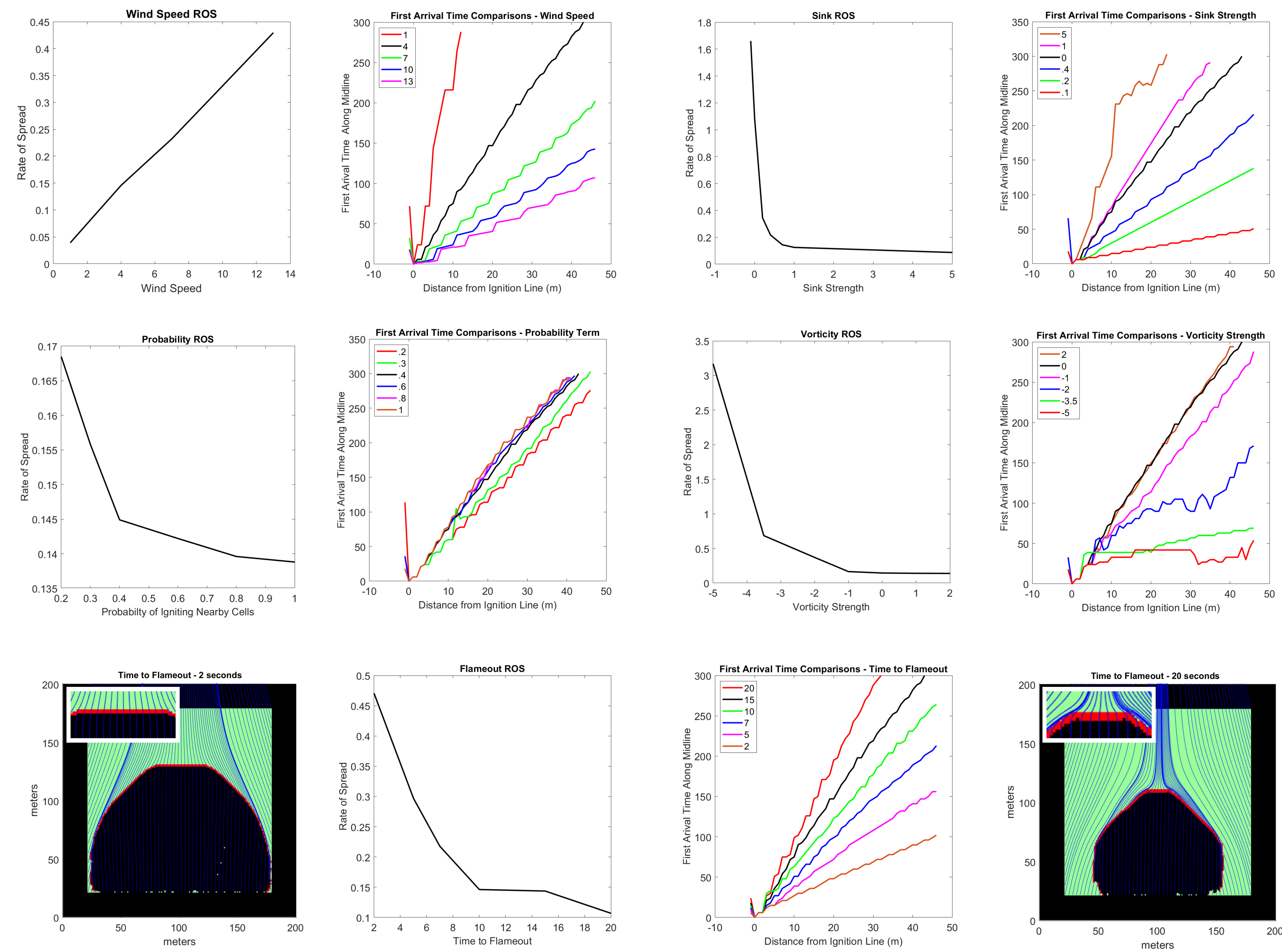
Methods

This project was completed with MATLAB code to (1) manipulate different parameters and produce fire spread simulations, (2) statistically analyze the rate of spread of those models. The parameters include wind speed, wind direction, sink strength, vorticity strength, time to flameout, and probability of a cell to ignite nearby cells. The 'random' ignition probability of nearby cells accounts for many different natural phenomena that affect a fire's ability to spread, including the types of fuels, the humidity of the environment, and the turbulence in the atmosphere.

The rate of spread (ROS) of these simulations are compared to see how the acceleration of the fire along the midline vector is changed by the parameters. The ROS on the midline is defined by the first arrival time (f).

$$ROS(y) = \frac{1}{f'(y)}$$

Results



The rates of spread and the comparisons of the first arrival times across the span of the parameters chosen.

Discussion

As expected, when the wind speed increase, the rate of spread also increases, but we see that the relationship is linear. Other parameters have a much different, nonlinear effect on the rate of spread. The effect of increasing the burnout time, vorticity strength, sink strength, and the probability of ignition of nearby cells is a decreasing rate of spread, implying that fire spreads faster as these parameters are increased.

Reference

Quaife, B.; Speer, K. A Simple Model for Wildland Fire Vortex–Sink Interactions. Atmosphere 2021, *12*, 1014. https://doi.org/10.3390/atmos12081014