Data Collection for Wildland Fire: Isolating Fire and Plume Behavior

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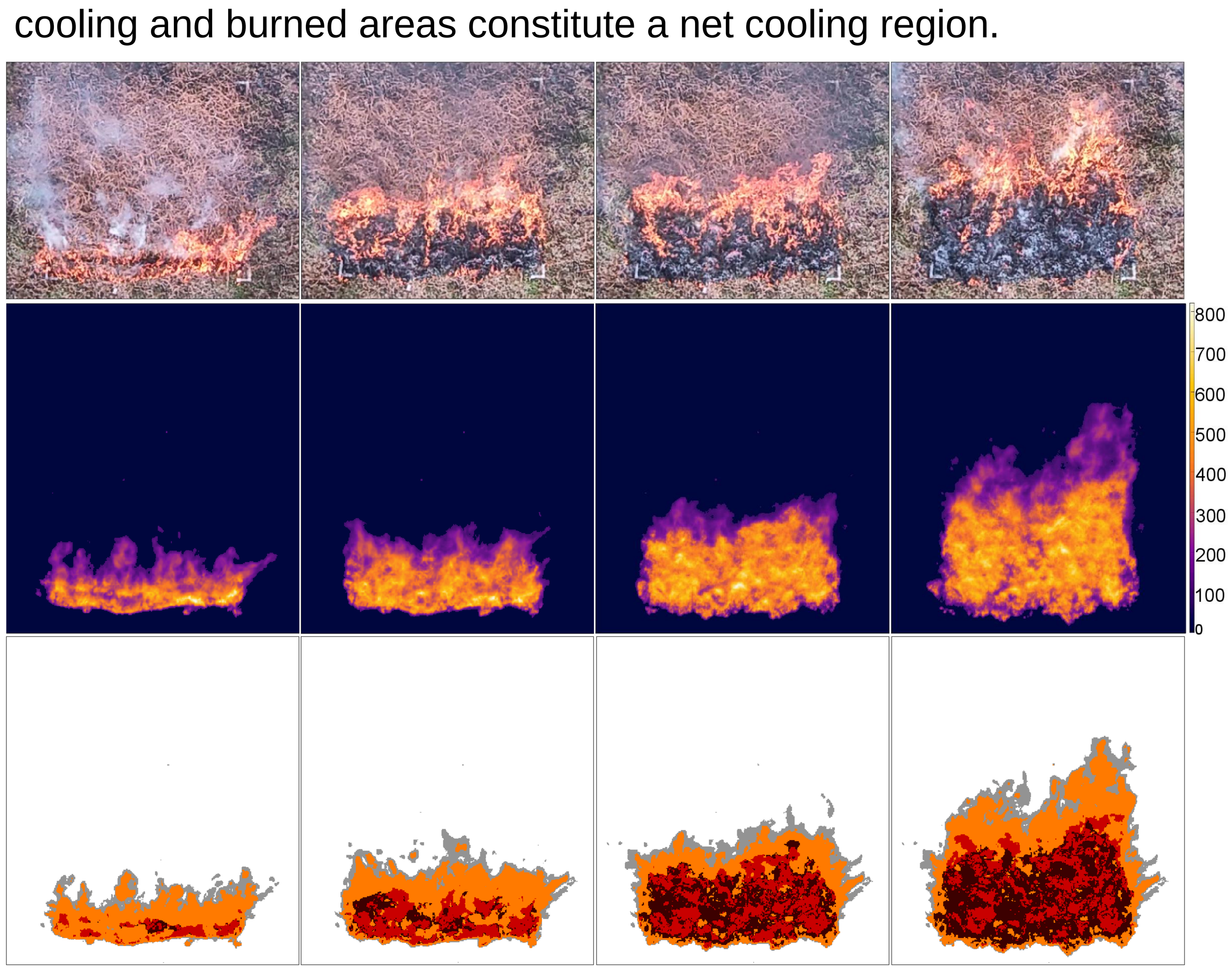
Abstract

When fire propagates through a fuel bed, there are a variety of structures and behaviors we wish to better understand. Though fire occurs in diverse environments and may look significantly different depending on geographical region, the physical laws that underlie fire behavior remain consistent. As such, we study fire spread and plume behavior using data from a selection of fire scenarios. Two examples of fire scenarios that are generalizable to multiple regions are (1) small-scale fire spread through a porous pine straw bed, which is common in nature, and (2) large-scale interactions between the fire, plume, forest canopy, and atmosphere. I have developed techniques that combine computer vision and graph theory to track these behaviors. The visual and infrared image data sets demonstrating my methodology on this poster are obtained via ground-based cameras and small unmanned aerial vehicles (UAVs). Due to the turbulent nature of fire, data is analyzed through a statistical approach. This analysis reveals patterns behind the behavior of the fire and plume dynamics, heat transport, and fire-atmosphere coupling.

Data

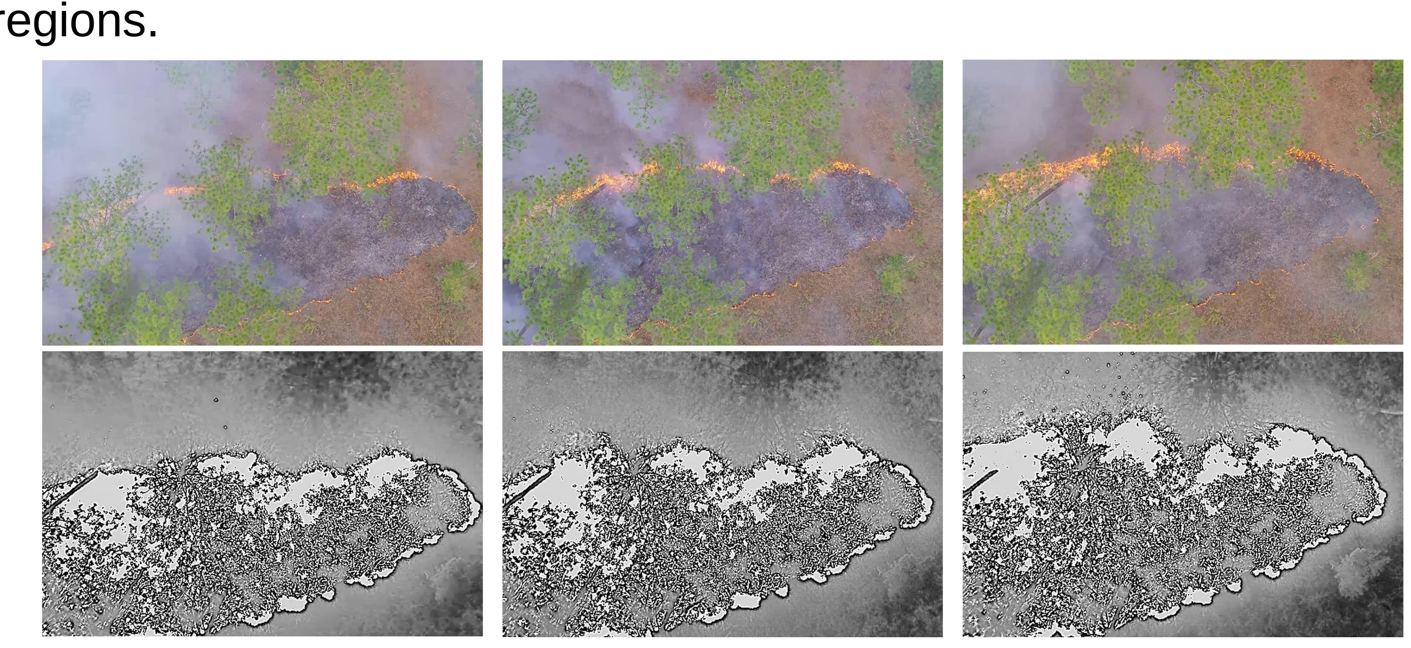
Data Set 1: Small-Scale Fire Spread [1]

The top row displays visual frames of a head fire spreading across a 2m x 2m plot of pine straw, sampled 10s apart and with 8.7mm resolution. The middle row contains corresponding infrared images with temperature given in ºC. The bottom row visualizes this infrared data as segments according to temperature region: heating (gray), combusting (orange), cooling (red), and burned (brown). The heating and combusting areas constitute a net heating region, whereas the cooling and burned areas constitute a net cooling region.



Data Set 2: Meso-Scale Fire Spread

Images in the top row are visual frames of a head fire spreading across a 70m x 38m region of longleaf pine forest, sampled 17s apart and with 3.2cm resolution. The bottom row visualizes infrared data from the same area segmented into combusting and non-combusting regions.

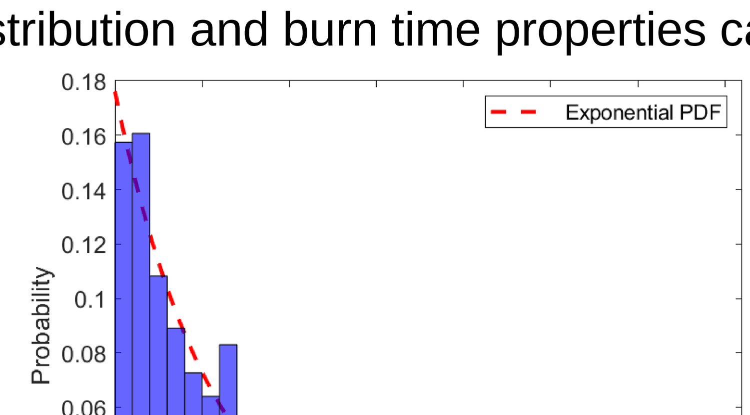


Data Set 3: Meso-Scale Flame-Atmosphere Interactions [2]

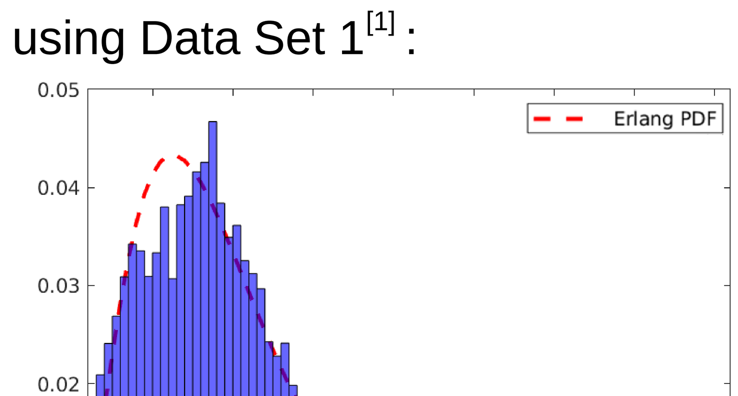
Infrared images of fire front progression through a canopy, sampled 1s apart and with 1.15cm resolution. The use of low-temperature infrared causes the fire to appear as a solid body of heat despite containing a range of temperatures. However, this also allows details of heat movement within the plume to be distinguishable.

Results

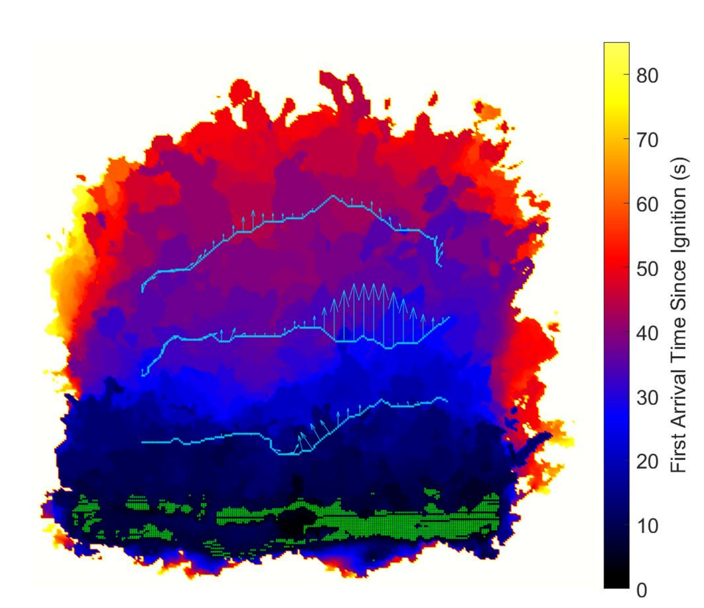
Analysis of the images in Data Sets 1 and 2 yield information about transverse and longitudinal velocity components of the fires' spread, spatially- and temporally-varying forward rates of spread, fuel consumption, and first arrival time rates of spread. Both scenarios are comprised of a head fire spreading through a pine straw bed, so the resulting velocity distributions have similar shapes with different scales. Looking at the forward spread distribution and burn time properties calculated using Data Set 1[1]:



Forward rates of spread fit with an exponential distribution. Suggests that small-scale fire behavior can be modeled as a random, memoryless process.

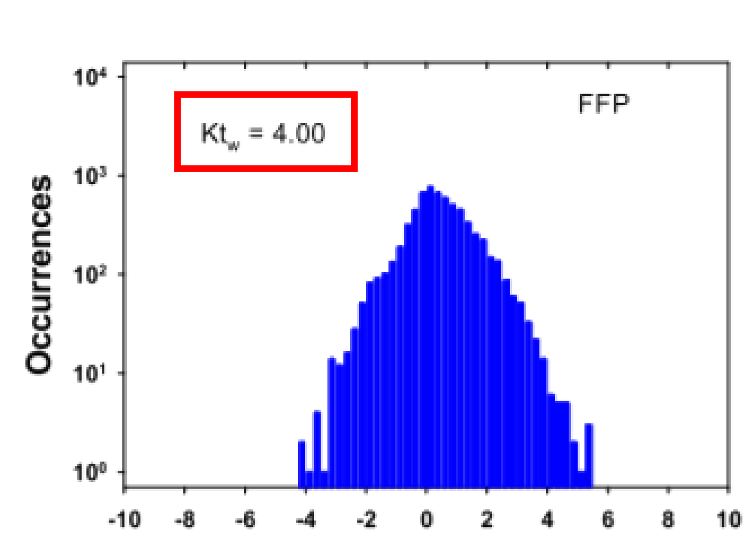


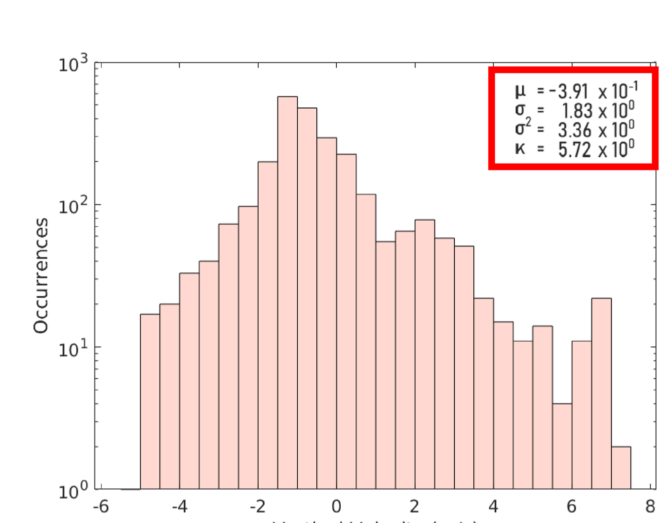
Pixel burn times fit with an Erlang distribution. Implies that burn time relies on multiple exponential factors, like spread rate.

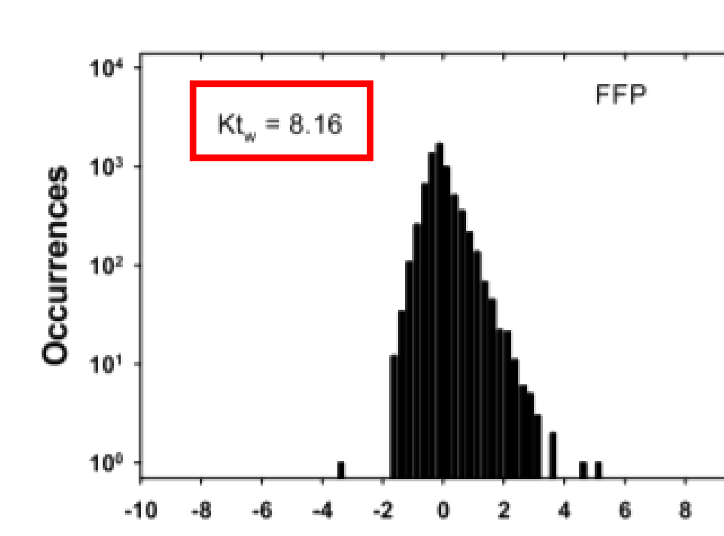


Map of the time each pixel exceeds ignition temperature with initial ignition pattern in green and sample isotherms in blue.

Isolation, tracking, and analysis of the flame-atmosphere boundary in Data Set 3[2] yields vertical velocity results that are consistent with results for similar scenarios found in literature and validated by anemometer wind speed recordings[3]:







Distribution shape and kurtosis value calculated with my method (center) are consistent with those found in literature.

References

[1] Sagel, D., Speer, K., Pokswinski, S., & Quaife, B. (2021). Fine-Scale Fire Spread in Pine Straw. *Fire*, *4*(4), 69.

[2] Sagel, D. (2020). A new way to look at fire: Computer vision applied to fire dynamics. The Florida State University.

[3] Heilman, W. E., Bian, X., Clark, K. L., Skowronski, N. S., Hom, J. L., & Gallagher, M. R. (2017). Atmospheric turbulence observations in the vicinity of surface fires in forested environments. Journal of Applied Meteorology and Climatology, 56(12), 3133-3150.