Raleigh,
North Carolina,
February 18 -22,
2013

Semi-empirical Fire Spread Simulator for Utah Juniper and Chamise Shrubs

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IAWF
4th Fire Behavior
and Fuels Conference
Raleigh, NC
Feb 18-21, 2013

Background

- The ability to predict the spread of wildland fires is paramount in protecting life, property, and natural resources.
- Current operational models predict overall fire behavior well for dead fuel beds but not as well for live bushes or trees with high moisture.
- Therefore, a semi-empirical model was developed as an attempt to bridge the scale gap between full simulations and empirical correlations.
- Ignition and flame characteristics of fuel segments (3 – 6 cm lengths) burned in a laboratory flat-flame burner system were used in a semi-empirical multi-element fire spread simulator for chamise (Adenostoma fasciculatum) and Utah juniper (Juniperus osteosperma) shrubs.
- The objective is to develop modeling technology for describing fire initiation and propagation in vegetation with low canopy bulk density:
  - Measure fire behavior of fuel elements (leaves, stems, segments)
  - Represent shrub geometry using Lindenmayer systems
  - Model fire propagation semi-empirically
  - Compare model based on fuel elements to shrub scale burns

Flame propagation measurements

- Fuel samples are heated above a flat-flame burner producing 10 mol% O_2 and 1000°C post-flame gases.
- Mass, flame and temperature are recorded
- Fuel properties (size, moisture, mass) are correlated to flame and mass loss results
- Flame correlations trace flame profile. (see Figure 2)
  - Time to ignition, max flame, burn out
  - Max flame height and width

Figure 1. Flaming sample held on a mass balance cantilever above a glass-enclosed flat flame burner.

Wind tunnel experiments

- Experiments were performed at the PSW Research Station to measure shrub-scale fire propagation.
- The effects of wind speed, fuel arrangement and moisture content on fire spread were investigated for for chamise (see Figure 3, Table 1).

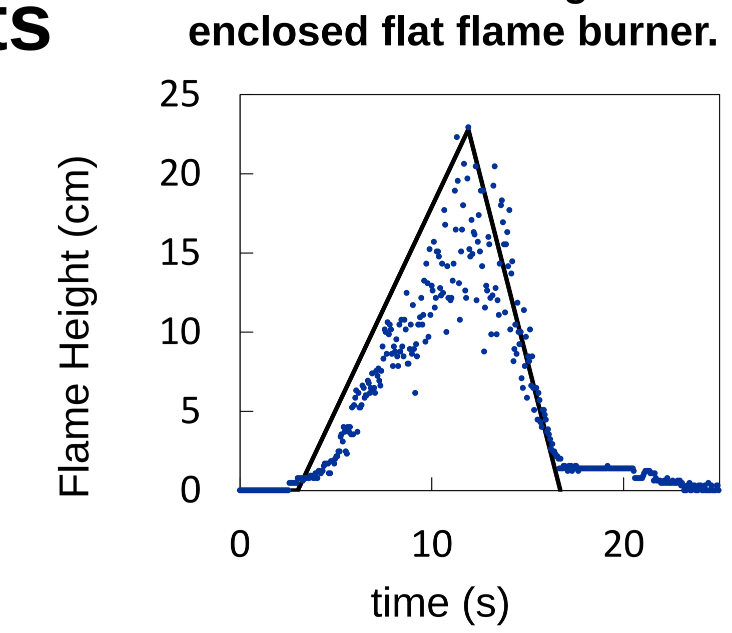

Figure 2. Example flame profile overlaid on one experiment.

Figure 3. Wind tunnel chamise experiment

Table 1. Summary of wind tunnel experiments

Run	MC %	Mass (g)	L-W-H (cm)	U (m/s)
1	6.7	3040	91-91-92	0.7
2	13.2	1311	109-92-94	0.0
3	13.2	1338	77-87-100	1.1

Special thanks to David Weise, Joey Chong and Gloria Burke of the Forest Fire Laboratory, Pacific Southwest Research Station, USDA Forest Service, Riverside, CA for advice and for collecting and shipping live samples from California to Brigham Young University.

Flame propagation modeling

- Fuel segments with representative distributions of physical properties are given locations in the shrub according to L-systems models.
- Each fuel segment is assigned a flame profile (Figure 2) which is correlated to its unique properties.
- A set of fuel elements is ignited to initiate propagation.
- Ignited fuel elements produce a flame volume which overlaps unreacted elements which then heat to ignition, and so on.
- Flames overlapping other flames are scaled according to a flame coalescence model.
- The model determines a flame height, spread rate, burn path, flame angle, and amount consumed.

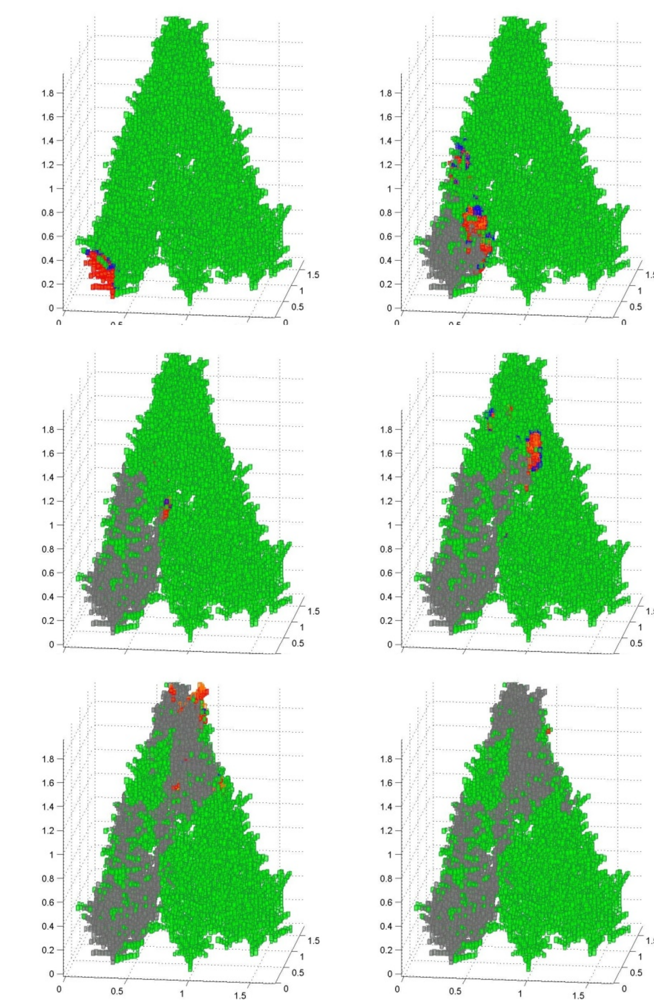

Figure 4. Time sequence visualizing model of fire spread through a juniper shrub.

Utah juniper results

- Fuel structure was well-represented by L-systems approach (Figure 5).

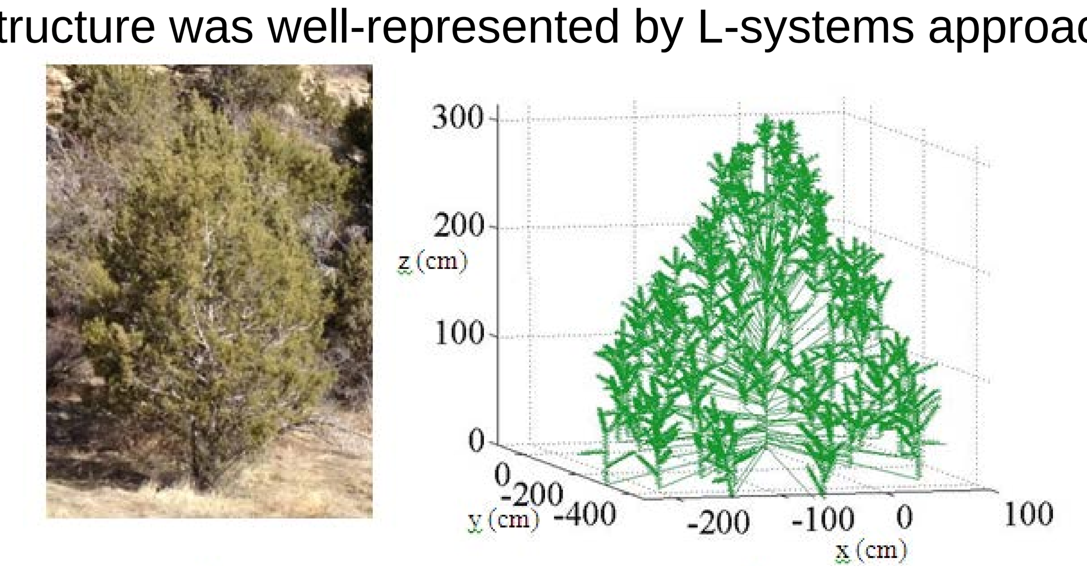

Figure 5. Utah juniper shrub (left) and simulated structure (right).

- According to the measurements in the field, a correlation was developed to predict total Utah juniper bush dry weight (W_{dry}) by crown diameter (D_{crown}), which was also embedded in the bush model.

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- Different parametric runs were performed to study the effects of bush size, bush shape, fuel density, and wind.

Table 2. Selected parametric runs. (X_x is fraction burned)

Run #	Crown Diameter (cm)	Height (cm)	segment number	ρ_{bulk} (leaves/m³)	*MC* (%)	*U* (m/s)	X_s	$t_{brn,bush}$ (s)
1	170	244	27,268	4,924	90	0	44.2%	534
2	170	244	27,268	4,924	70	0	45.8%	579
3	170	244	27,268	4,924	110	0	42.0%	605
4	170	244	27,268	4,924	90	1	44.2%	534
5	170	244	15,805	8,007	90	3	41.1%	413

- When *MC* decreased, fraction burned increased as expected.
- At high wind speeds, the predicted flame propagation was diminished. This trend is being examined and will be improved.

Chamise results

- Fuel structure simulation using L-systems (Figure 6).

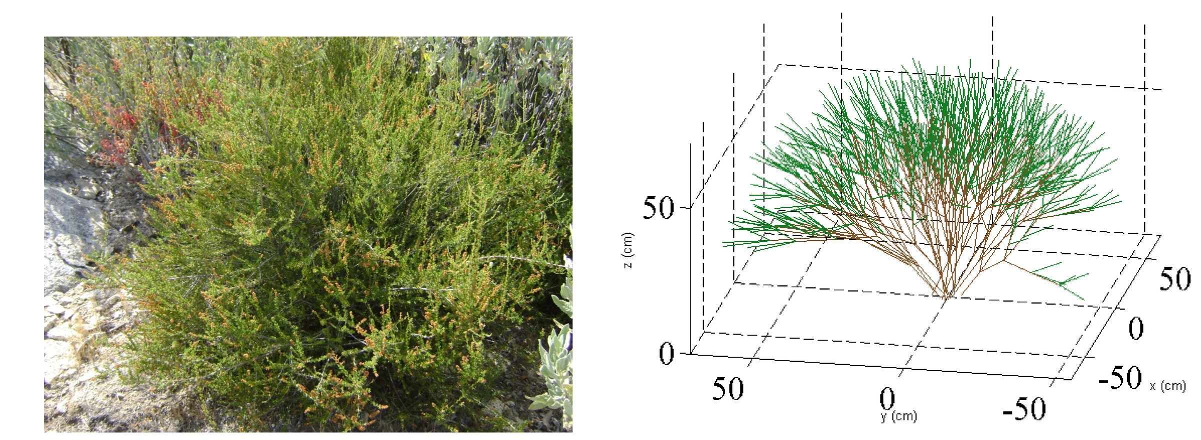

Figure 6. Chamise shrub (left) and simulated structure (right).

- Burn time increased then slightly decreased with increased wind speed.
- Burn time decreased slightly with loading because fuels were closer together, creating larger flames resulting in faster fire spread.
- Wind increased fire spread rate and fraction burned, as did increased loading. Higher moisture content resulted in less burned, as expected.
- Flame height above the top of the shrub demonstrated a similar response to wind, loading and MC as did fraction burned. This illustrates the correlation between larger flames and more fuel consumption.
- A simulation of wind tunnel experiment 1 (Table 1) was attempted. While most of the shrub actually burned, the simulation only predicted marginal burning.
- The discrepancy between wind tunnel experiments and model predictions will be investigated and resolved. The remainder of the experiments will then be simulated.

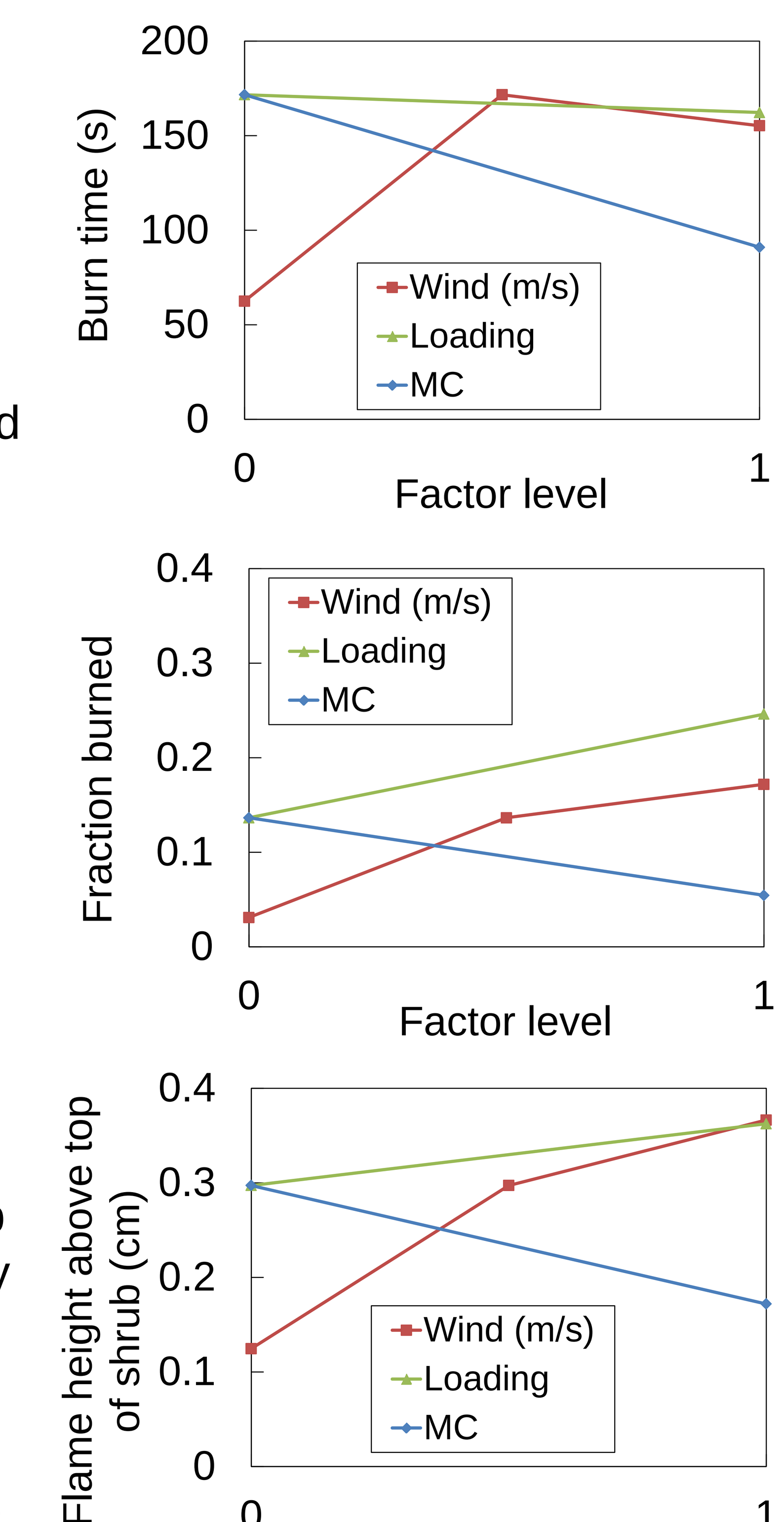

Figure 7. Results of parametric study. Factor levels were: wind [0, 1, 2] m/s, Loading [14, 18] branches, MC [10, 30] %. Baseline was 1 m/s, 14 branches and 10% for wind, loading and MC, respectively.

Conclusion

- The burning bush model shows the ability to capture basic flame spread behavior at low wind speeds in sparse arrays of fuel.
- Comparisons with experiments show the need for improvement, but will guide further development.
- The placement of fuels has a critical impact on fire propagation and will be improved for chamise in future work.
- Future work will improve the accuracy and applicability of the model, ultimately resulting in a fast model for fires in sparse, live vegetation.