Field Experiments and Modeling for the Assessment of Fuel Treatment Effectiveness in Reducing Wildfire Intensity and Spread Rate

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Outline

- Background
- Study site
- Experimental measurement protocol
  - Fire behavior
  - Fuel consumption
- Experimental results
  - Year 1 – detailed
  - Year 2 – overview
- Modeling challenges
- Conclusions
3-year goal – To study the effectiveness of fuel treatment
- $5.6 billion (USD) spent in the past 10 years for hazardous fuel reduction in the United States
- “The agencies, for example, still lack a measure of the effectiveness of fuel reduction treatments and therefore lack information needed to ensure that fuel reduction funds are directed to the areas where they can best minimize risk to communities and natural and cultural resources” - Government Accountability Office, 2009

Long-term goal – Improved understanding of wildland fire behavior

Goals addressed through a combined experimental and numerical approach
- 2 field experiments
- Detailed physical Computational Fluid Dynamics (CFD) modeling
  - Wildland-urban interface Fire Dynamics Simulator (WFDS)
Study Site

- New Jersey Pinelands National Reserve
  - 1.1 million acres ~23% of NJ

- Averages 1300 wildfires per year (2003-2013)
- Large crown-fire event every 5-10 years
- High level of WUI
  - RxB conducted on 12,000 acres per year
Measurement Techniques
Fire Measurement

- Overstory towers
  - 8 K-type thermocouples
  - 1 3D Sonic Anemometer

- Understory towers
  - 5 K-type thermocouples
  - 1 vertically oriented flow sensor (pressure)
  - 1 vertically oriented dual-band radiometer
Fire Measurement

Fire behavior packages – year 1

- 3 packages developed by USDA Forest Service
- Provide measurements of:
  - Temperature
    - 1 thermocouple
  - Heat flux
    - 1 Medtherm dual heat flux gauge
    - 1 narrow angle radiometer
  - Flow
    - 1 horizontal probe
    - 1 vertical probe
Fire Measurement

Fire behavior packages – year 2

- 3 Sites
  - 4 thermocouples (at 60 cm intervals)
  - 6 thin-skin calorimeters (total heat flux)
  - 3 directions of flow velocity
Fire Measurement

Aerial imagery

- Series of stills taken using RIT’s Wildfire Airborne Sensor Program (WASP)
  - 3 bands of IR - 640x512 pixel
    - SWIR: 0.9-1.7 μm
    - MWIR: 3-5 μm
    - LWIR: 8-9.2 μm
  - Georeferenced
Fuel Measurement

- 36 pre- and post-fire clip plots (3 per understory tower)

- Fuels sampled by size class
  - Forest floor: fine, repro., 1hr, 10hr, 100hr
  - Shrub and Oak layer: 1hr, 10hr (live and dead)
Fuel Measurement

- Pre- and post-fire flights of Airborne Laser Scanning data (ALS)
  - Collected at 400 kHz, with a pulse density ca. 5.12 points m$^{-2}$

- Will provide canopy height profiles and canopy bulk densities (calibrated by upward sensing LiDAR)

- Resolution of 10 x 10 x 1 m
Year 1
Fire Front Progression

- FBPs
- Understory
- Overstory

North

Directions [°]

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300

0 20 40 60 80 100 120 140 160 180 200 [Meters]

Time [t+11:00] [minutes]

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74
- FBPs
- Understory
- Overstory

Large fuel sizes had low/sporadic distributions – only fine and 1hr fuels were considered

Fireline Intensity $I_f = ROS \cdot \Delta m \cdot h$

$\sim 500\text{-}1300 \text{ kW} \cdot \text{m}^{-1}$

Plot 10

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Mean Consumption [g·m⁻²]</th>
<th>1hr L+D Consumption [g·m⁻²]</th>
<th>Total Consumption [g·m⁻²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest floor U10</td>
<td>440.2</td>
<td>131.3</td>
<td>571.5</td>
</tr>
<tr>
<td>Shrubs and Oaks U10</td>
<td>154.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Un-calibrated LiDAR

Plot 10

Pre-Fire Bulk Density

% Consumption

- P3: 63.18
- P4: 65.89
- P5: 68.46
- P6: 71.01

15% Consumption

Courtesy of Wikimedia Commons
Fireline Intensity $I_f = ROS \cdot \Delta m \cdot h$

U5: ~1500-4100 kW·m⁻¹

U11: ~4700-6000 kW·m⁻¹

Plot 5 & 11

Forest floor – U5

<table>
<thead>
<tr>
<th></th>
<th>fine</th>
<th>wood 1hr</th>
<th>FF total</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean consumption [g·m⁻²]</td>
<td>575.7</td>
<td>-0.7</td>
<td>575.0</td>
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</tbody>
</table>

Shrubs and Oaks – U5

<table>
<thead>
<tr>
<th></th>
<th>1hr L+D</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean consumption [g·m⁻²]</td>
<td>324.0</td>
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</table>

Forest floor – U11

<table>
<thead>
<tr>
<th></th>
<th>fine</th>
<th>wood 1hr</th>
<th>FF total</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean consumption [g·m⁻²]</td>
<td>507.4</td>
<td>391.7</td>
<td>899.1</td>
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</table>

Shrubs and Oaks – U11

<table>
<thead>
<tr>
<th></th>
<th>1hr L+D</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean consumption [g·m⁻²]</td>
<td>419.7</td>
</tr>
</tbody>
</table>
Plot 5 & 11

Un-calibrated LiDAR

Pre-Fire Bulk Density

% Consumption

- P3: 63.18
- P4: 65.89
- P5: 68.46
- P6: 71.01

FBPs
- Understory
- Overstory

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Local Heat Flux

Plot 10

Plot 11

Radiative Flux
Conductive Flux
Flame Contact = 2.8 s

Radiative Flux
Conductive Flux
Flame Contact = 0.1 s
Year 2
Preliminary Visual Results
Preliminary Visual Results
Other Investigations
Future Work and Conclusions
Modeling Challenges

- Numerical simulation requires higher spatial resolution than LiDAR data provides
  - Simple subdivision vs. linear interpolation vs. other (using canopy height model)??
Conclusions

- **Experimental**
  - Valuable data collected on fire behavior in a forested environment
    - Particularly as it relates to pre-fire fuel loading
  - Much more work to be done to thoroughly analyze results from both years
    - Both fire progression/behavior and total fuel consumption

- **Numerical**
  - Still in preliminary stages
  - Biggest challenge is the specification of fuel distribution
Questions?

Thank you to JFSP and NJFSS