Identifying Source Terms of Firebrand Generation and Associated Energy Deposition

July 27, 2022

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and
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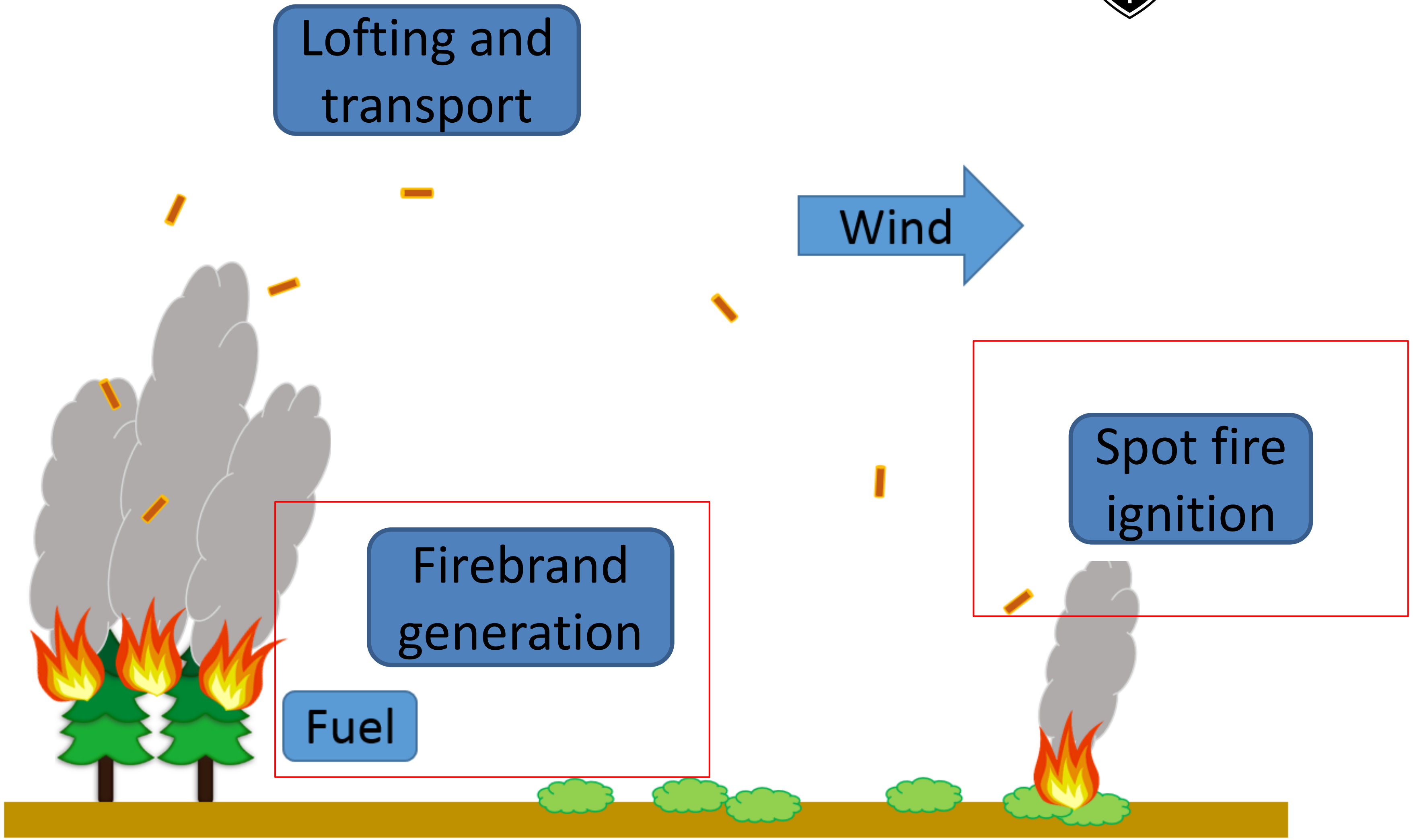
- Undergraduate students: James Chaplen, William Heffernan, Hadisen Tanoyeadi

Spot fires



Hudson, Tyler R. "Multi-scale study of ember production and transport under multiple environmental and fuel conditions." (2018).

Firebrand enumeration

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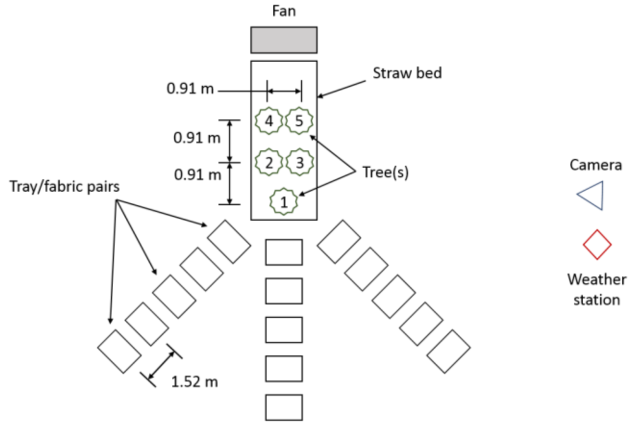
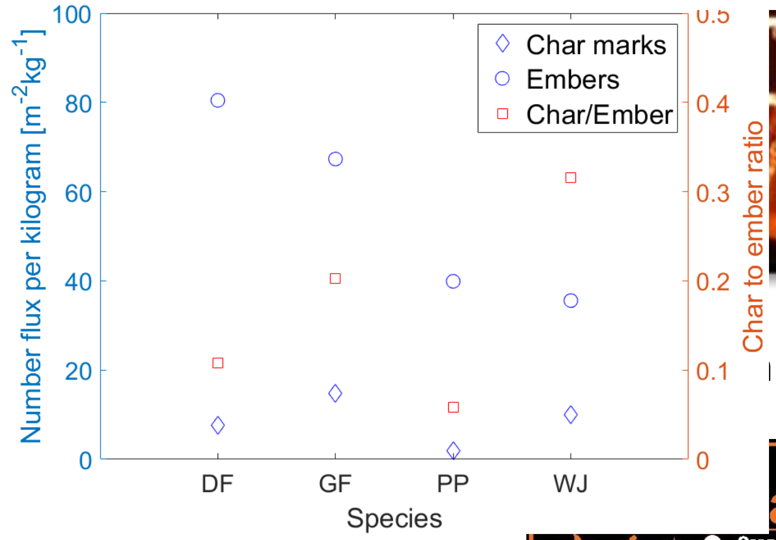
- Water tray method
  - ➢ Collects all firebrands
  - ➢ Which brands cause ignition?
- Fire-resistant fabric
  - ➢ “Hot” firebrands – higher propensity to cause ignition
  - ➢ Total firebrands vs “hot” firebrands

Simultaneous use of water tray and fire-resistant fabric employed to collect firebrands[2]





Water tr ... ds[1]

[1] F. Hedayati, B. Bahrani, A. Zhou, S.L. Quarles, D.J. Gorham, A Framework to Facilitate Firebrand Characterization, Front. Mech. Eng. 5 (2019) 1–14.
[2] T.R. Hudson, R.B. Bray, D.L. Blunck, W. Page, B. Butler, Effects of fuel morphology on ember generation characteristics at the tree scale, Int. J. Wildl. Fire. (2020).

What knowledge is needed to improve models and building codes?

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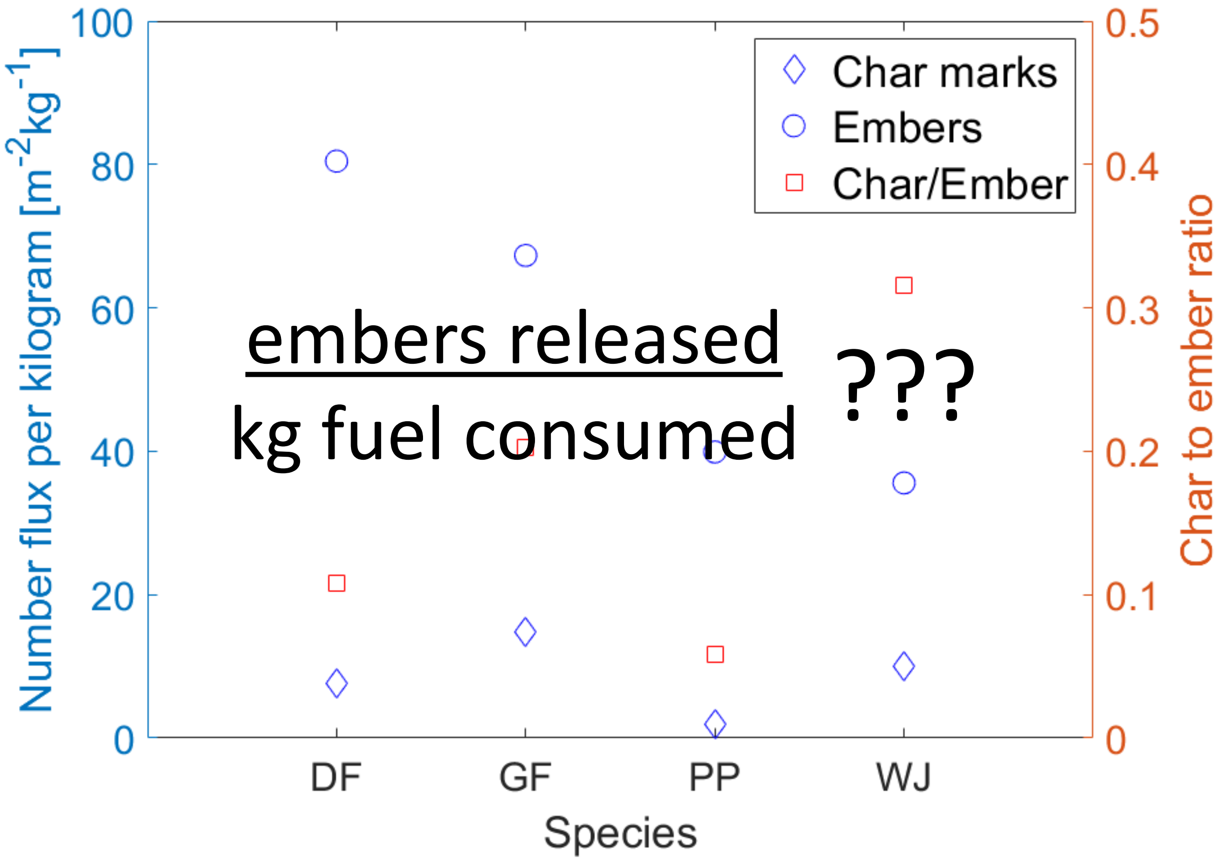
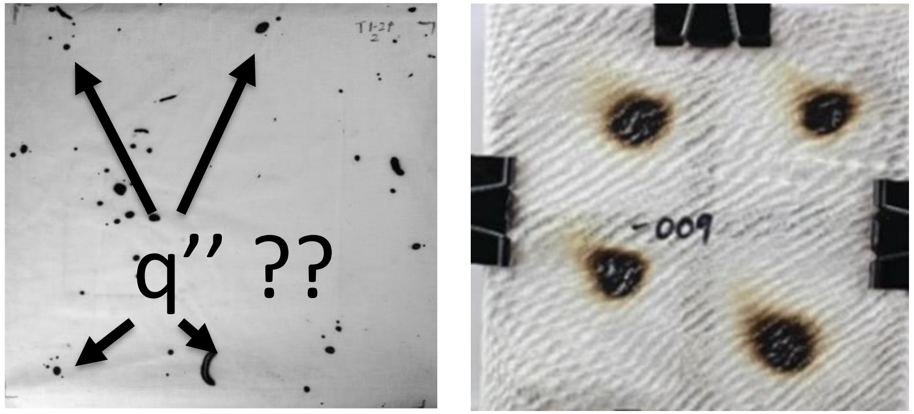


$\frac{\text{embers released}}{\text{kg fuel consumed}}$???



Char marks on fabric

1) An ability to incorporate results into models
2) Understanding of relationship between char marks and heat transfer

T.R. Hudson, R.B. Bray, D.L. Blunck, W. Page, B. Butler, Effects of fuel morphology on ember generation characteristics at the tree scale, Int. J. Wildl. Fire. (2020).

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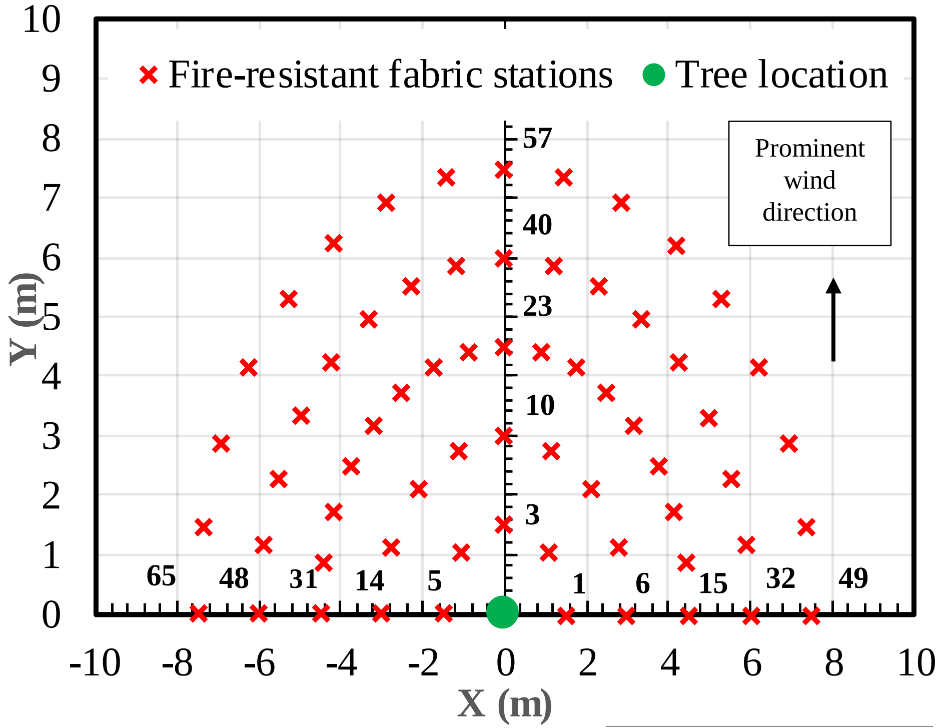
Tree scale burns

- 65+ locations of fire-resistant fabric
- 40+ trees per species: Douglas-fir, ponderosa pine and sagebrush, chamise
- Heights of samples: 1-7 m
- Moisture content: dried to ~living
- Wind speeds measured, but not controlled (typical average velocity < 1 m/s)
- Several parameters varied



3. S. Adusumilli, J.E. Chaplen, D.L. Blunck, Firebrand Generation Rates at the Source for Trees and a Shrub, Front. Mech. Eng. 7 (2021).

Example burns

multiple juniper trees

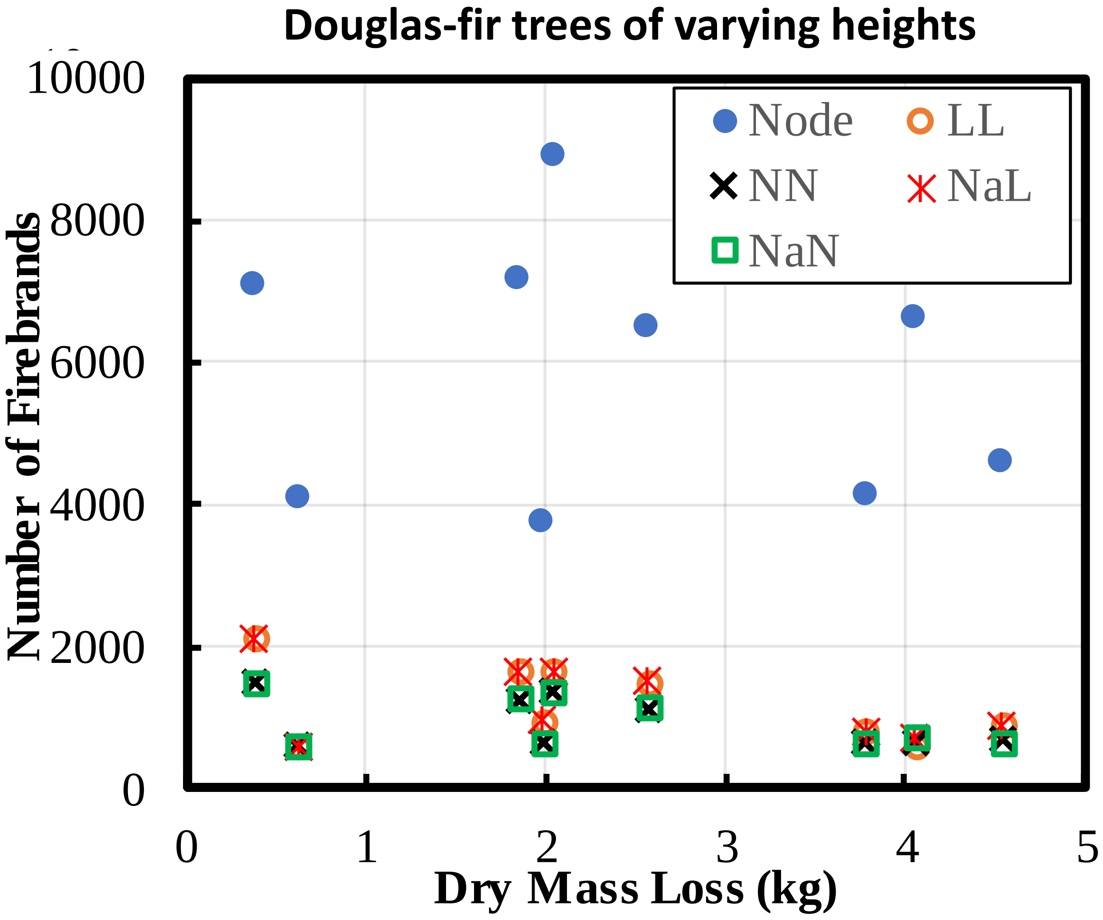
Total firebrand enumeration

Several approaches

- ➢ Node method
- ➢ Integration approaches

Integration methods

- ➢ Linear interpolation and linear extrapolation (LL)
- ➢ Nearest neighbor interpolation and extrapolation (NN)
- ➢ Natural neighbor interpolation and linear extrapolation (NaL)
- ➢ Natural neighbor interpolation and nearest neighbor extrapolation (NaN)



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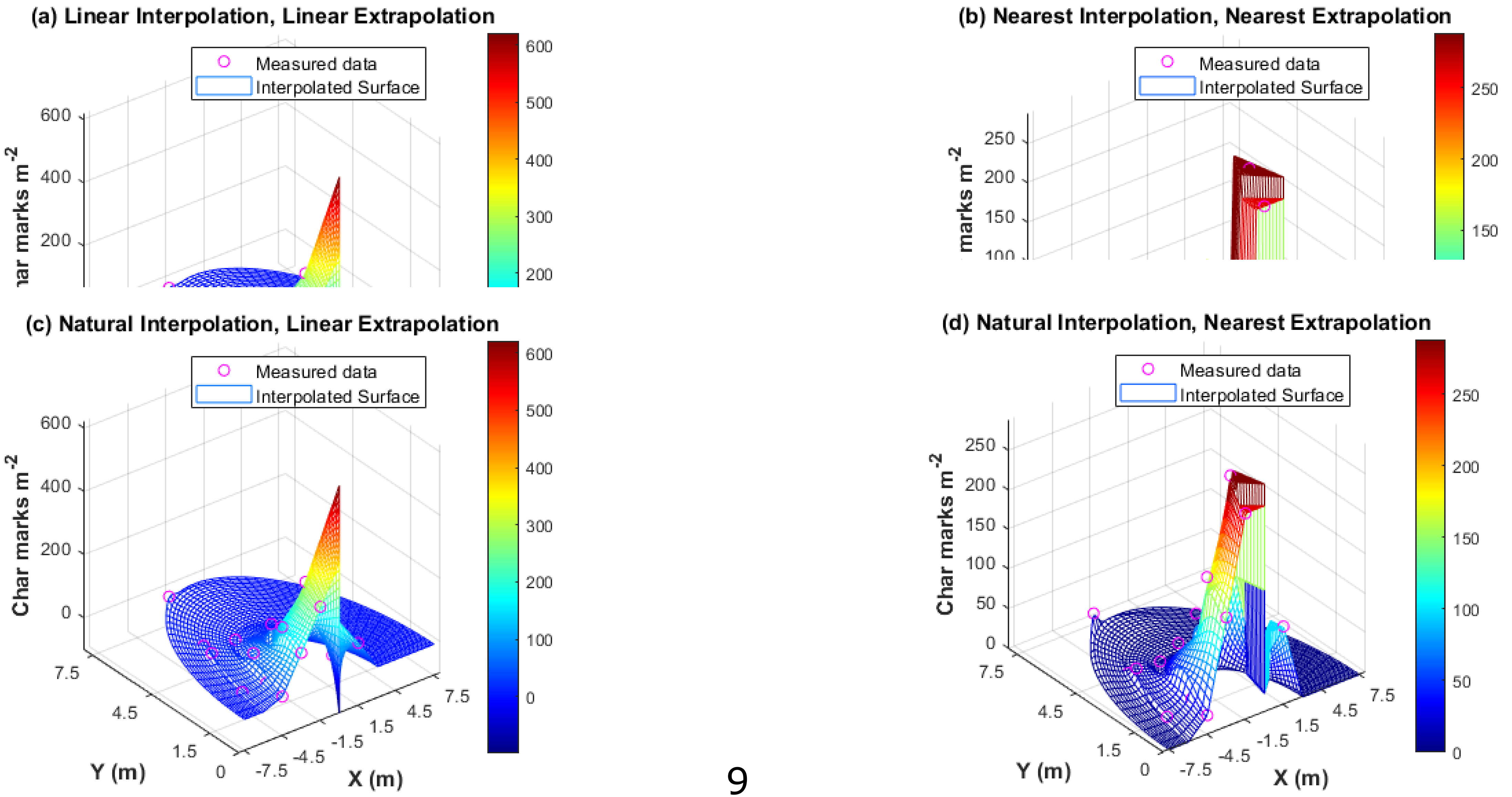
Integration methods

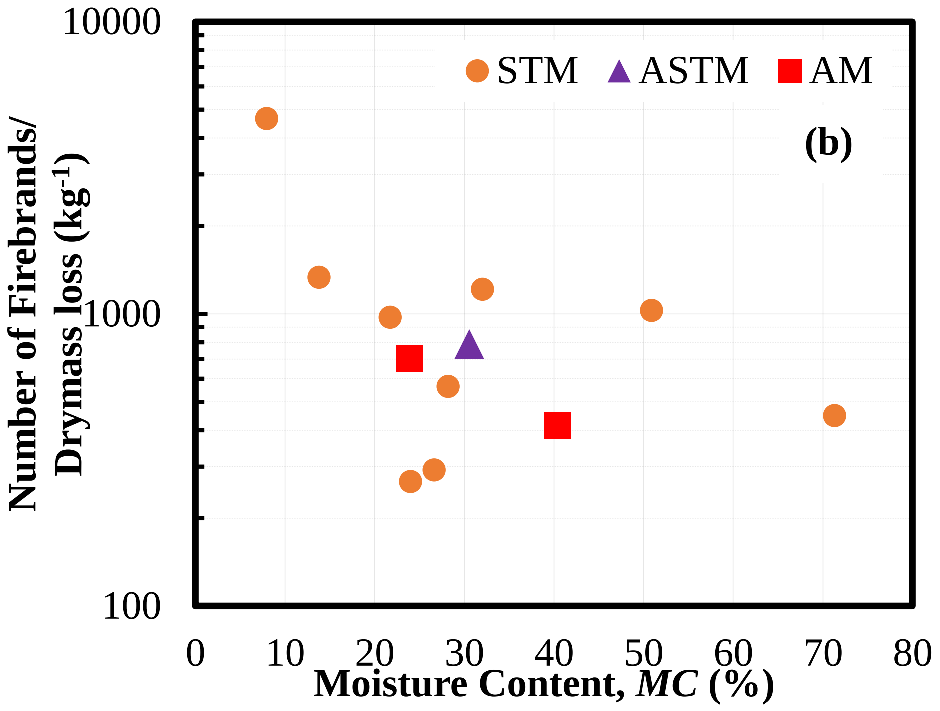


3. S. Adusumilli, J.E. Chaplen, D.L. Blunck, Firebrand Generation Rates at the Source for Trees and a Shrub, Front. Mech. Eng. 7 (2021).

Single Tree Method (STM) vs Accumulation method (AM)

- Two different approaches
  - ➢ Single Tree Method (STM)
  - ➢ Accumulation Method (AM)
- Advantages/ Disadvantages
  - ➢ AM easier to conduct
  - ➢ STM provides granular data
  - ➢ AM usually used
- Firebrand production increases exponentially with decreasing moisture content

Adusumilli et al.[3]



For Douglas-fir trees

3. S. Adusumilli, J.E. Chaplen, D.L. Blunck, Firebrand Generation Rates at the Source for Trees and a Shrub, Front. Mech. Eng. 7 (2021).

Sensitivity of generation to: species and height

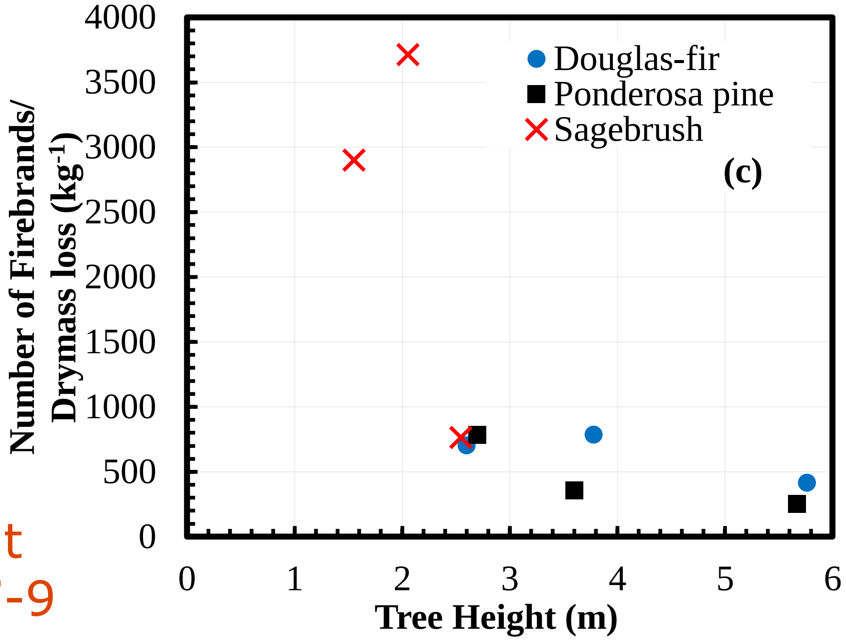
- Specific number of firebrands decreases with increase in tree height for Douglas-fir and ponderosa pine trees

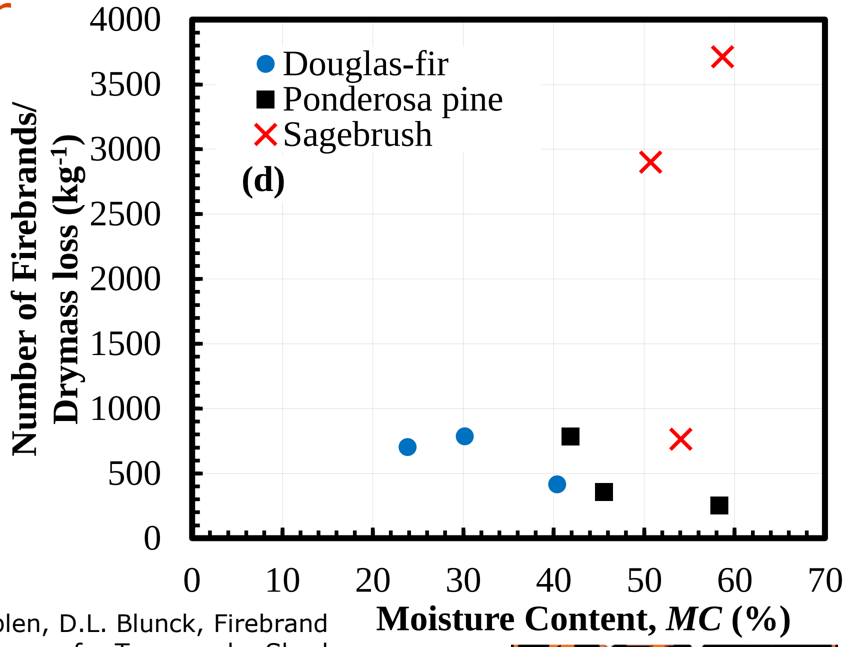
- Opposite is true for sagebrush

- Similar trends in variation with moisture content

- Working theory – type of burning is different for tallest sagebrush

Each data point is average of 7-9 trees of similar height





3. S. Adusumilli, J.E. Chaplen, D.L. Blunck, Firebrand Generation Rates at the Source for Trees and a Shrub, Front. Mech. Eng. 7 (2021).

Sensitivity of generation terms to: ground fire heat release

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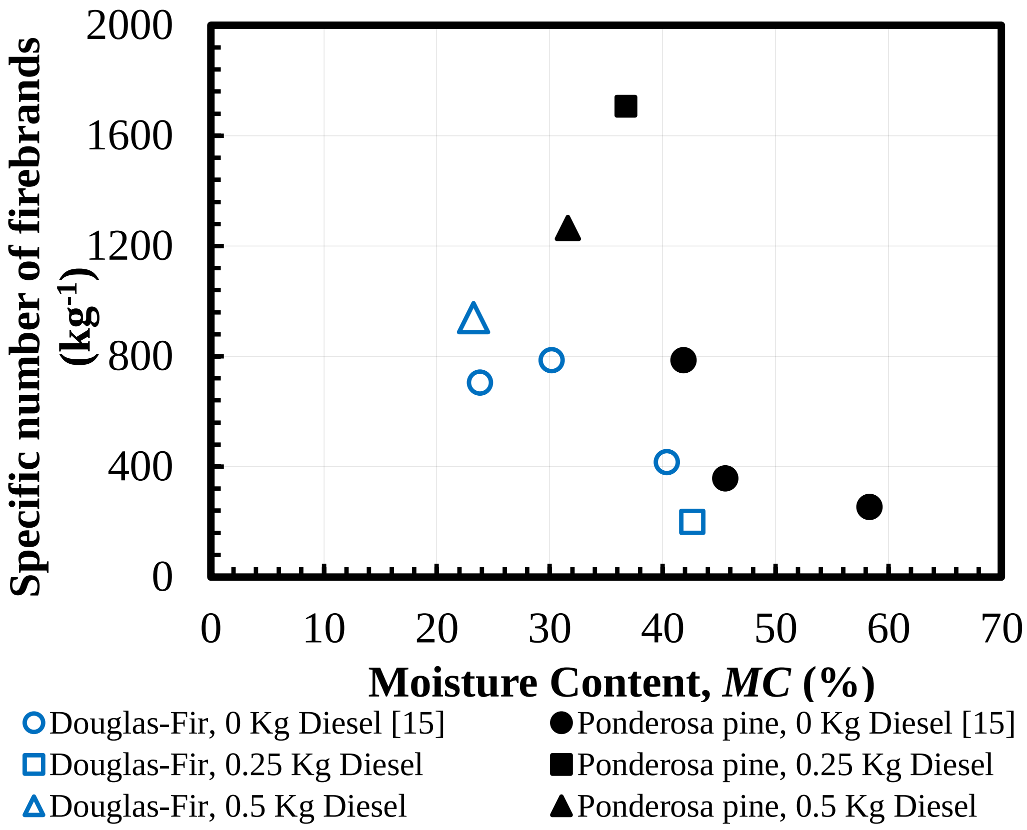
- Diesel addition to straw bed
- Specific number of firebrands produced not impacted
- Consistent with moisture content sensitivity



S. Adusumilli D.L. Blunck, in Preparation

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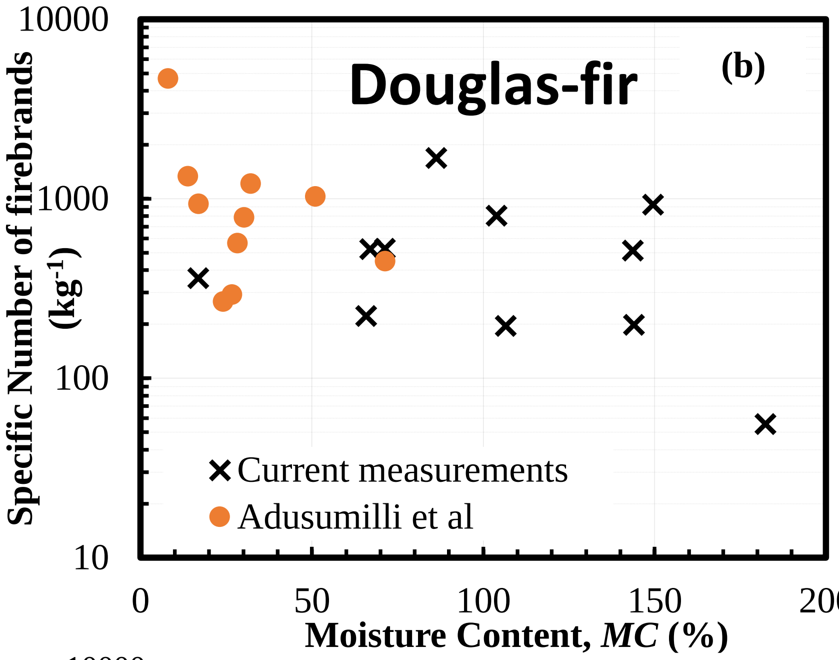
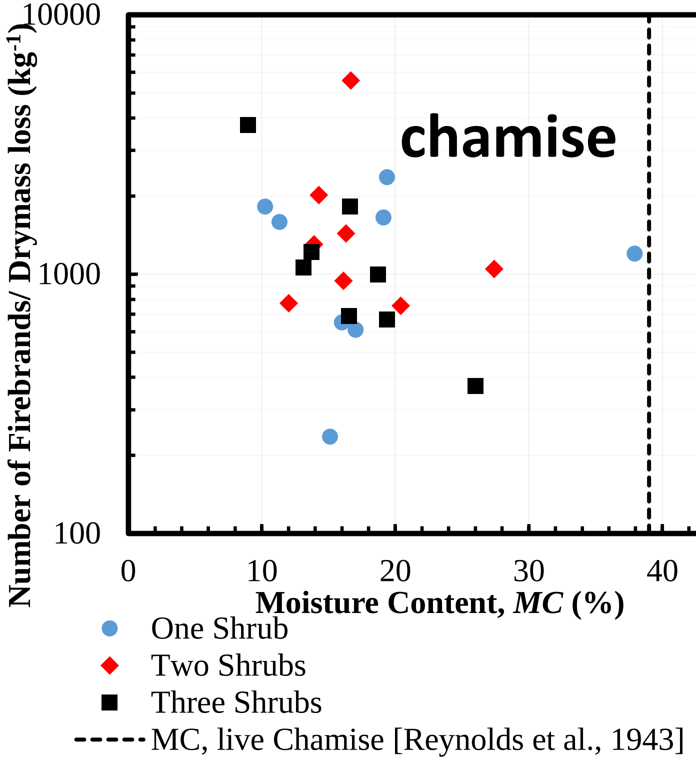
Firebrands from chamise

- Studying impact of fuel packing
- Firebrand production seems to not depend on fuel packing
- Sensitivity to live shrub moisture content
- Douglas-fir vs Chamise
  - ➢ Similar values
  - ➢ Steeper drop off for Douglas-fir with rise in MC





S. Adusumilli D.L. Blunck, in Preparation

Key Finding/Results

1. New methodology established to enumerate total number of firebrands, source terms can be provided for implementation in models and ready comparison
2. Firebrand production negatively correlated with moisture content
3. Relative amount of firebrands produced decreases with height of the tree
4. Increasing the total heat release of the surface fuels does not increase relative amounts of firebrands

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Firebrand Heat Flux Estimation

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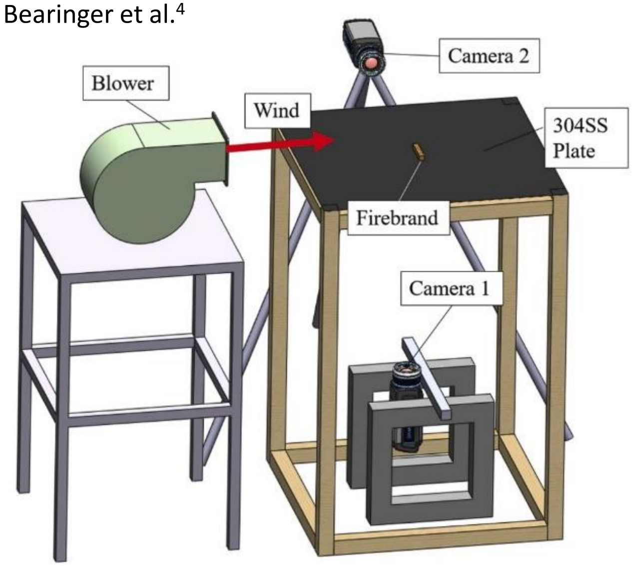
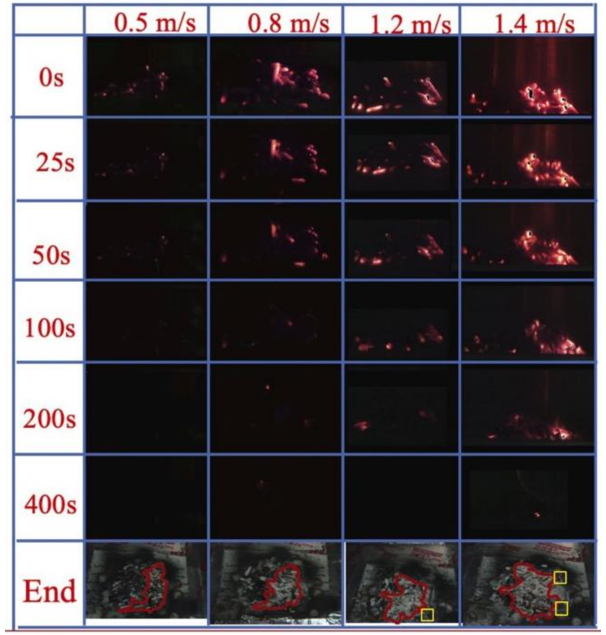
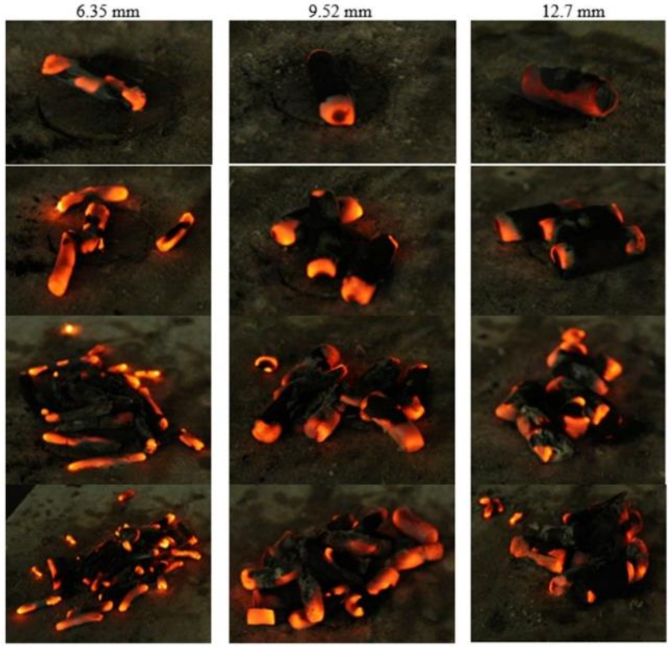
Research review

Bearinger et al.[4]



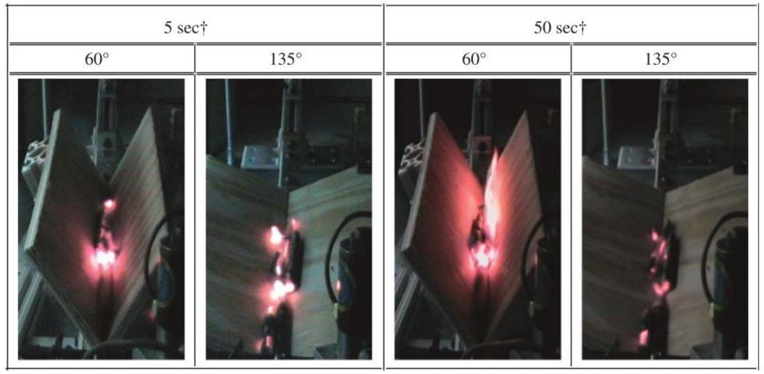
Tao et al.[5]





Hakes et al.[6]

Manzello et al.[7]



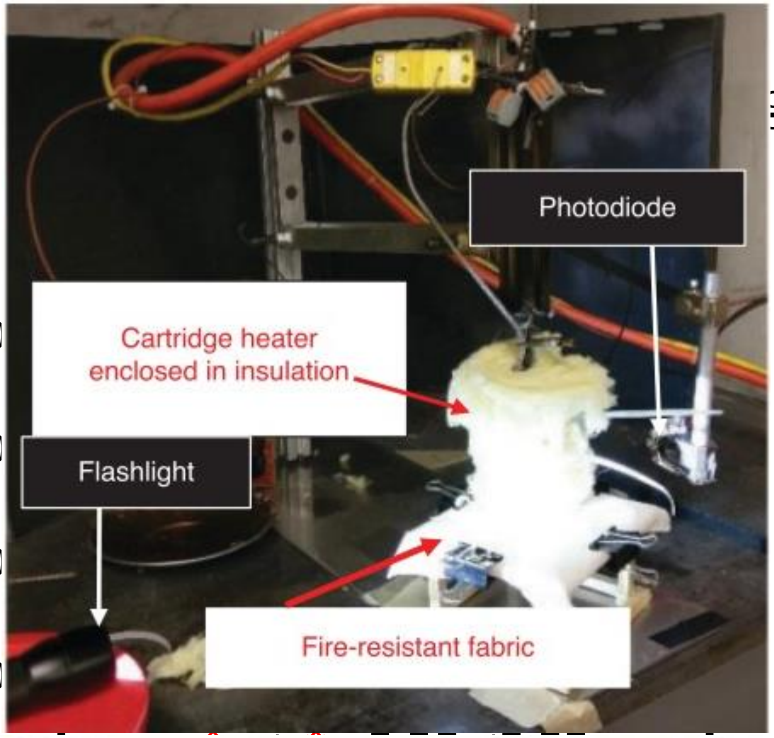
Knowledge Gap

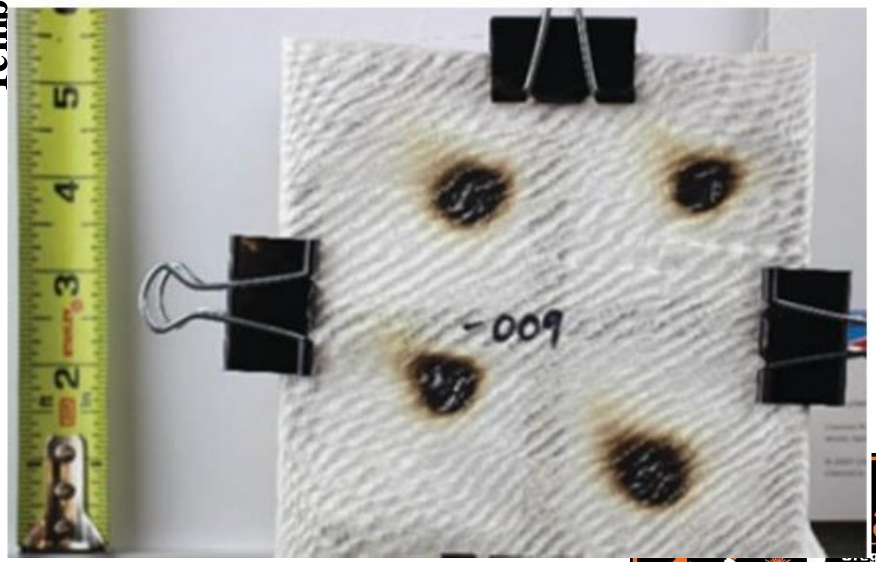
- Energy deposited by firebrands from real fires remains unknown

4. E.D. Bearinger, J.L. Hodges, F. Yang, C.M. Rippe, B.Y. Lattimer, Localized heat transfer from firebrands to surfaces, Fire Saf. J. 120 (2021) 103037
5. Z. Tao, B. Bathras, B. Kwon, B. Biallas, M.J. Gollner, R. Yang, Effect of firebrand size and geometry on heating from a smoldering pile under wind, Fire Saf. J. 120 (2021) 103031.
6. R.S.P. Hakes, H. Salehizadeh, M.J. Weston-Dawkes, M.J. Gollner, Thermal characterization of firebrand piles, Fire Saf. J. 104 (2019) 34–42.
7. S.L. Manzello, S.-H. Park, T.G. Cleary, Investigation on the ability of glowing firebrands deposited within crevices to ignite common building materials, Fire Saf. J. 44 (2009) 894–900.

Fabric characterization

- Lab-scale tests using cartridge heater
- Constant temperature tests
- Minimum temperature was found to be 300℃ based on edge detection methodologies





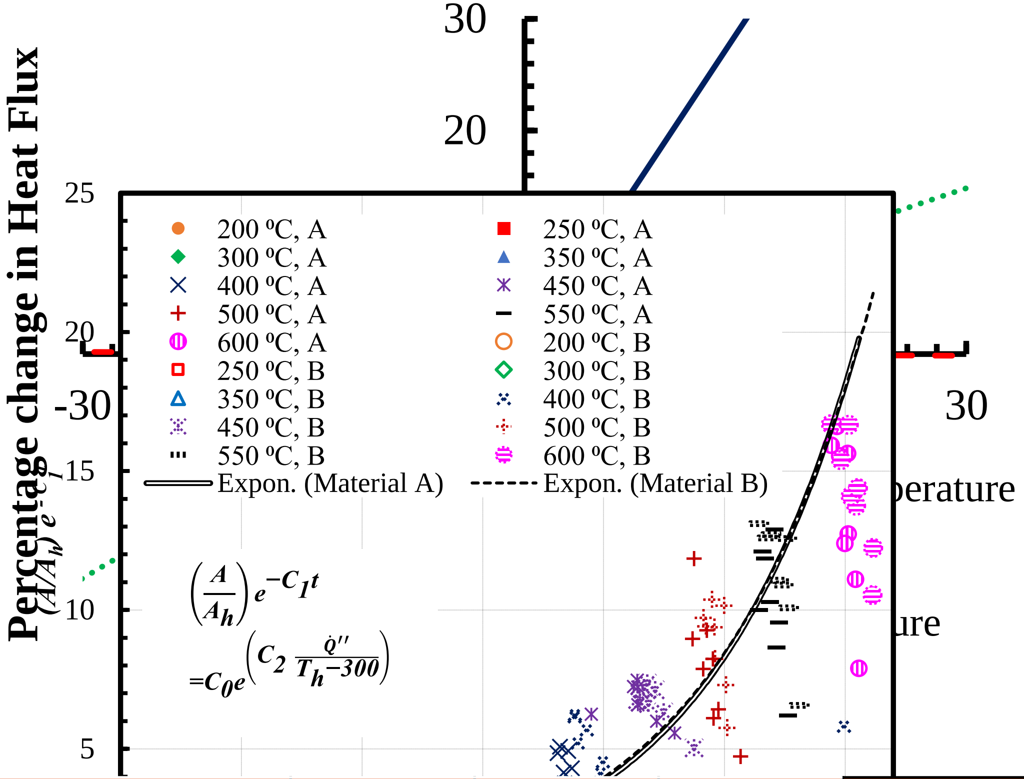
8. S. Adusumilli, T. Hudson, N. Gardner, D.L. Blunck, Quantifying production of hot firebrands using a fire-resistant fabric, Int. J. Wildl. Fire. 30 (2021) 154.

Char marks and heat flux

- Curve fit between normalized area, exposed time, heat flux and heater temperatures

- Can be used to characterize several different fire-resistant fabrics

- Will use the curve fit to estimate heat flux by firebrands



Coefficients⟶ ↓Material	C_0	C_1	C_2	R^2
A	0.1689	0.0001	0.0156	0.7647
B	0.1935	0.0001	0.0151	0.8326

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Determining heat flux

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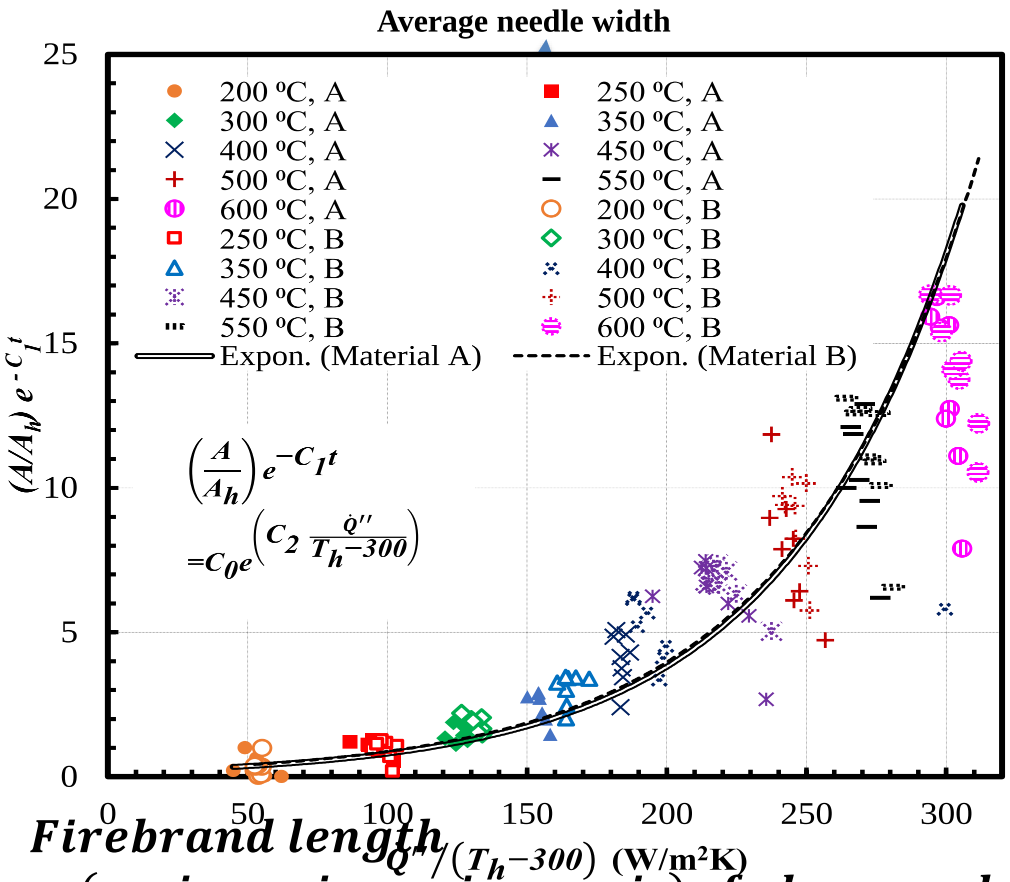
- $\dot{Q}'' = \frac{(T_h - 300)}{c_2} \ln\left(\frac{1}{c_0}\frac{A}{A_h}e^{-c_1 t}\right)$

- T_h and A_h can be considered as firebrand temperature and surface area respectively



$\textbf{Firebrand length} = (\textbf{major axis} - \textbf{minor axis})\,\textbf{of char mark} + \textbf{average needle width}$

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Estimating temperature of brands

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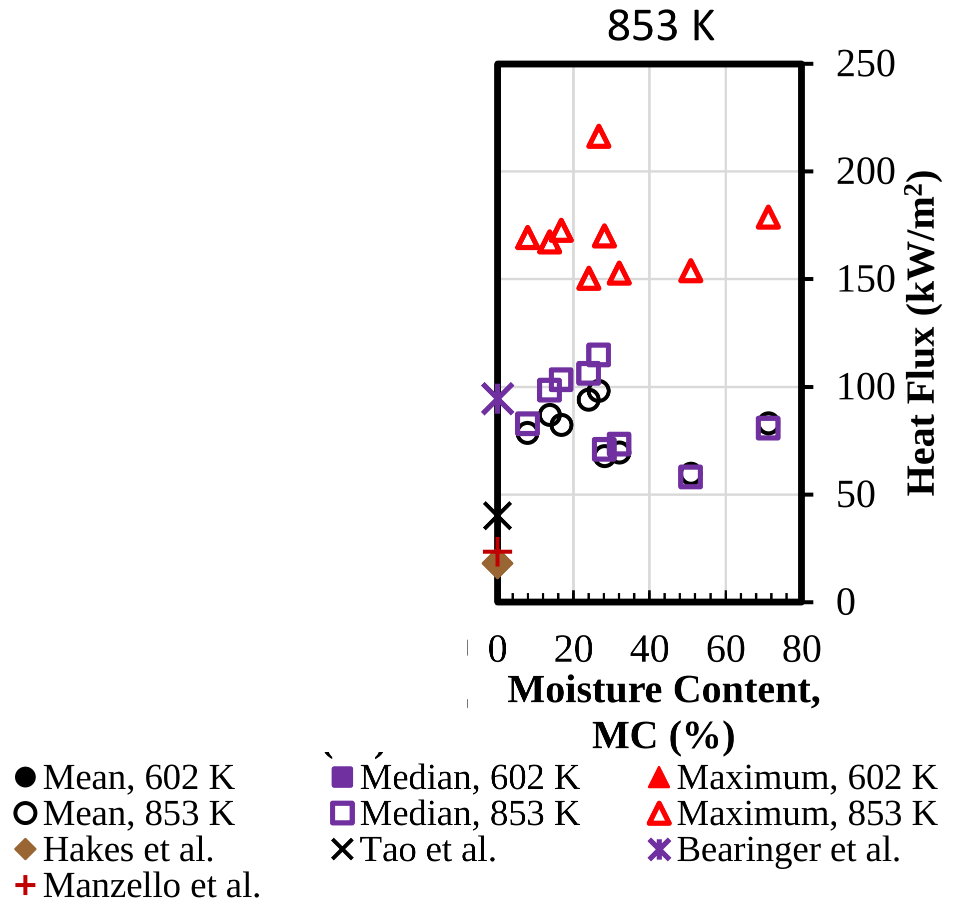
- Two temperatures evaluated
  - 853 K (burning firebrands)
  - 602 K (glowing firebrands)
- Trend at MC < 27%
- Constant for MC > 27%



For Douglas-fir trees

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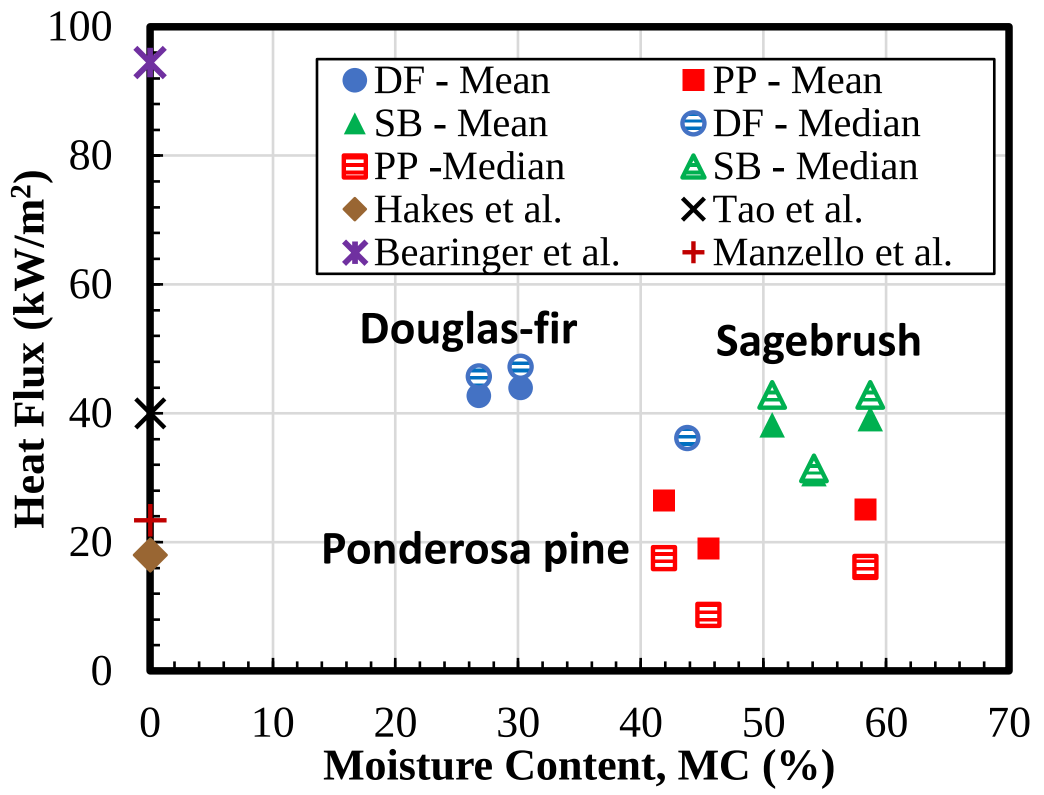
Species dependence of flux

- SB and DF have similar median and mean q’’
- PP firebrand have smaller heat fluxes



Distribution of q” from firebrands

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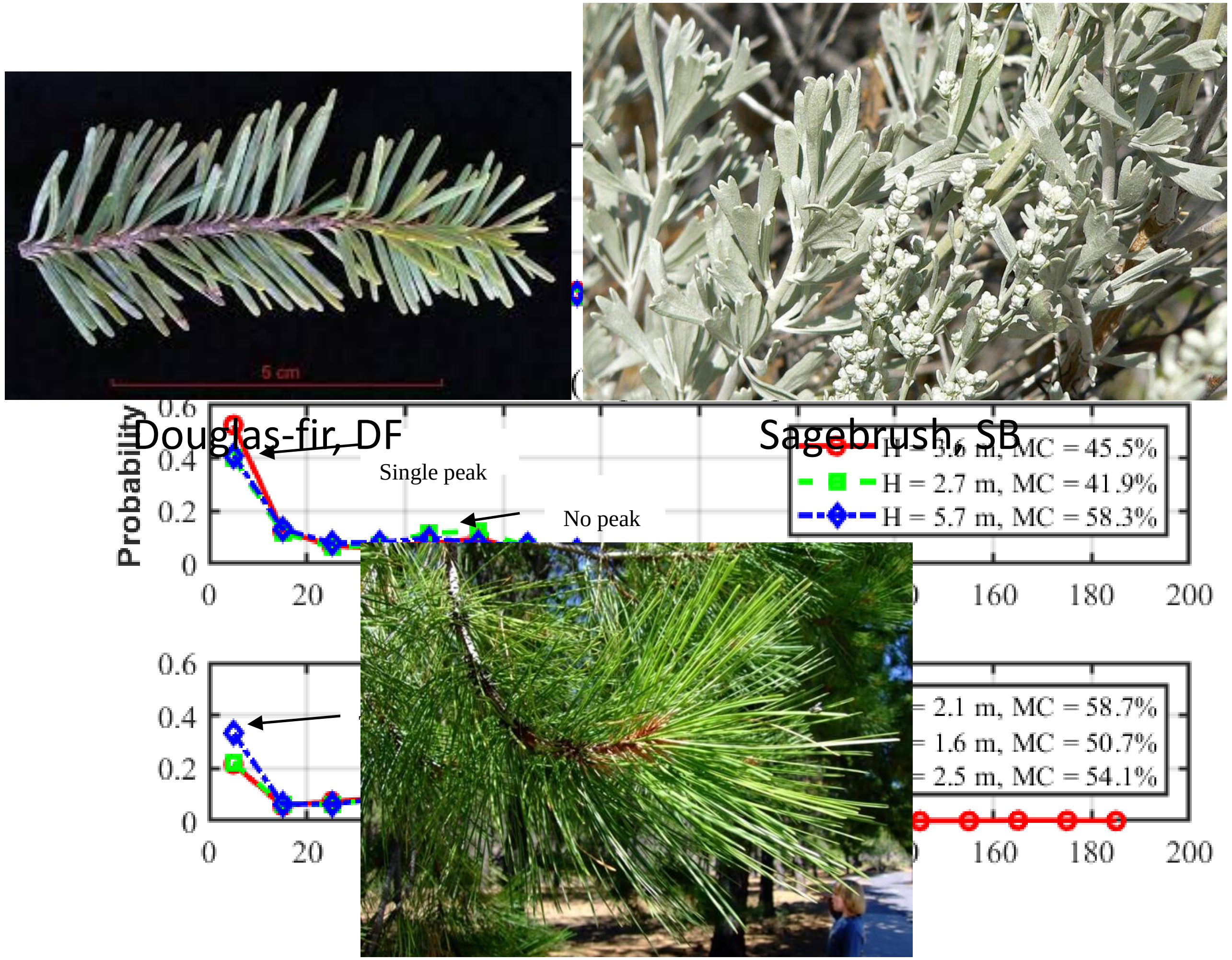
- Distribution most similar for Douglas-fir and sagebrush

- Foliage
  - Short needles – DF, SB
  - Long needles – PP

- Chemical composition?



Ponderosa pine, PP

Photos obtain from internet

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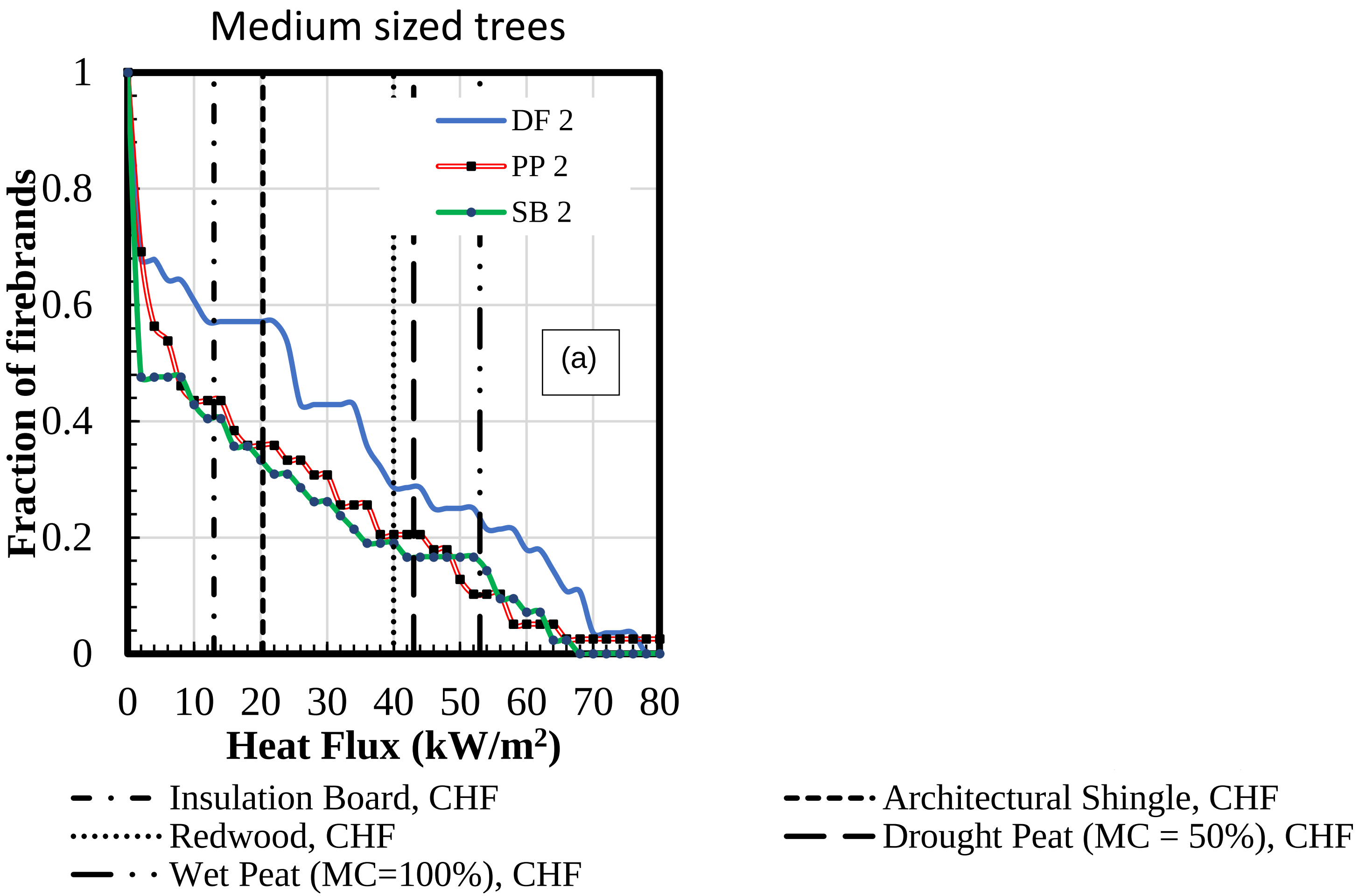
Critical heat flux (CHF)



Fraction of firebrands at 7.5 m from the burn with energy greater than CHF

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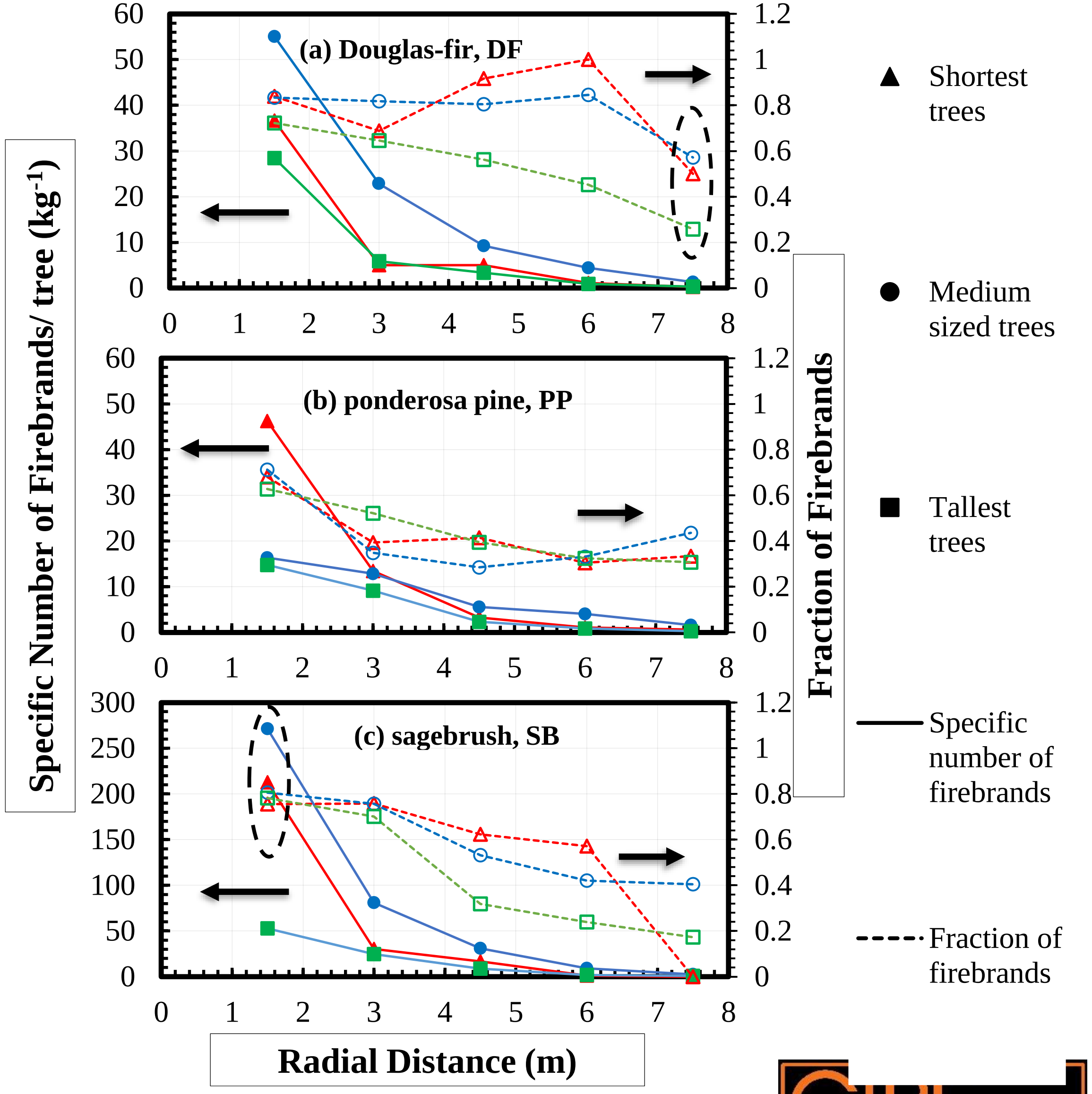
Threat from firebrands

- CHF is the minimum heat flux required for flaming ignition
- CHF measured using ASTM E1354
- SB higher threat at 1.5 m – immediate fire propagation
- DF higher threat (by fraction) at 7.5 m – spot fires



CHF = 13 kW/m^2

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Char mark sizes

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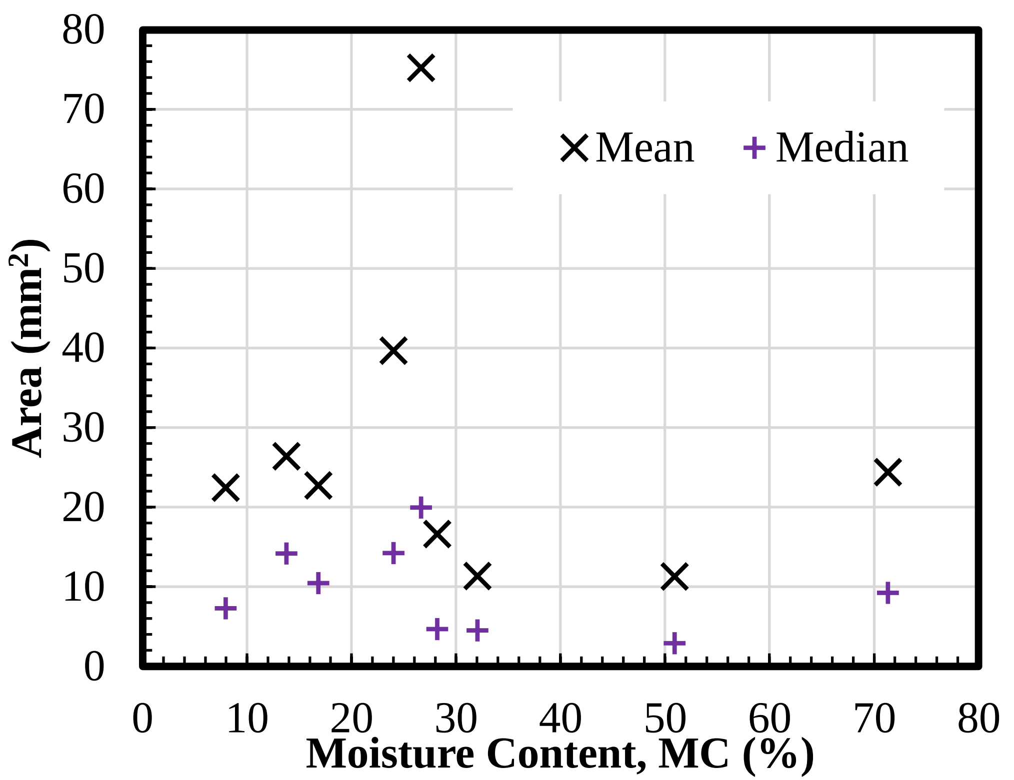

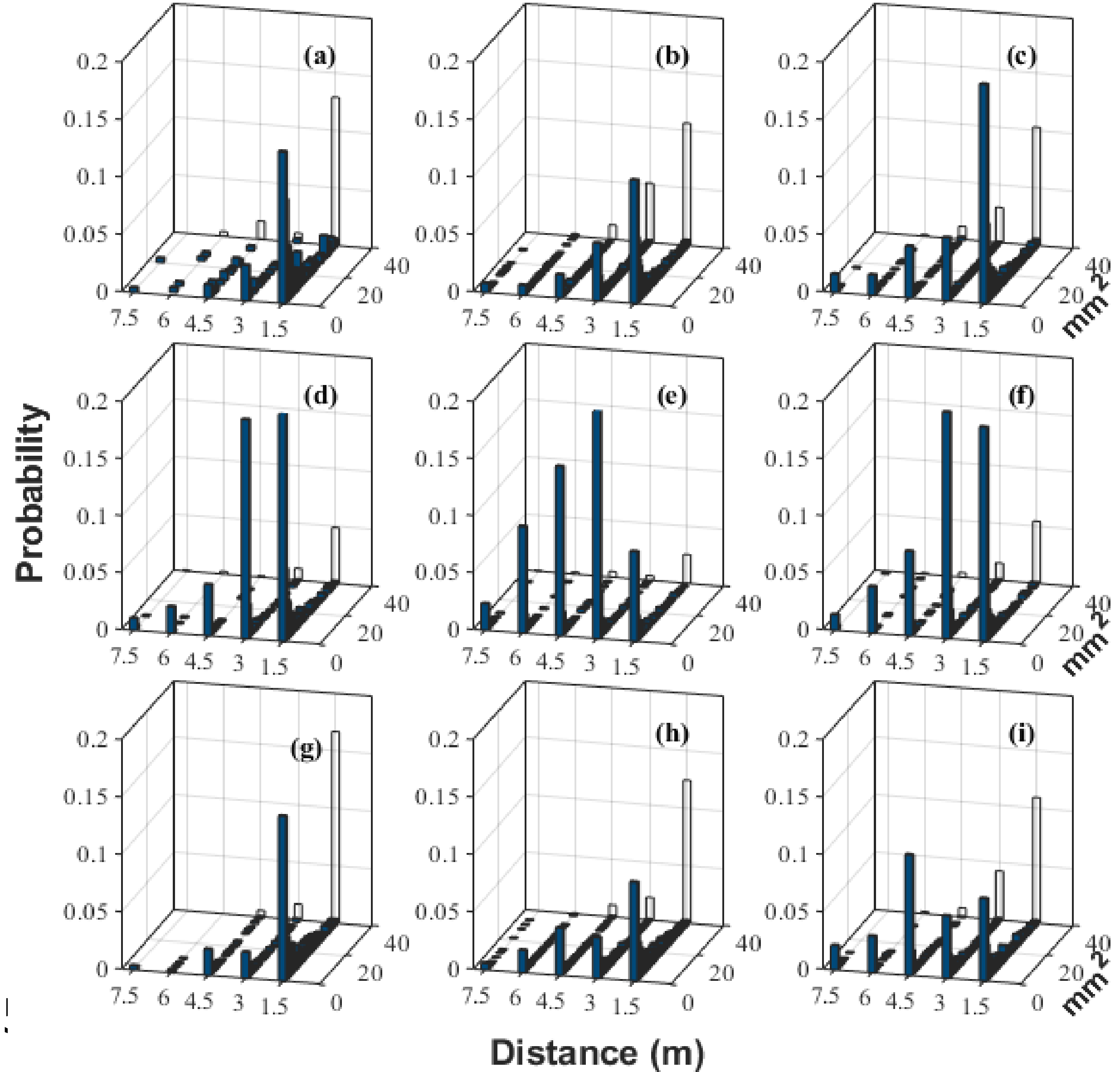

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Key Finding/Results

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1. New methodology established for estimating heat fluxes from firebrands
   - 1000’s of measurements collected
   - Potential to apply to field burns
   - Specific numbers of firebrands that are actually a threat are being measured
2. Douglas-fir firebrands tend to produce the highest average heat fluxes, sagebrush creates highest peak fluxes
3. Sagebrush generates the largest specific number of firebrands that produce critical heat fluxes
4. Not all firebrands are similar in threat/risk

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Expected impact

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1) Source terms available for models considering firebrand generation (conversations on-going)
2) Firebrand energy data can better inform risk assessment and building codes
3) Testing methodology can be extended to structural fires
4) Species sensitivities quantified

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Limitations (and opportunities)

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- Sensitivities to wind not considered
- Methodology does not generate “large” firebrands like bark or cones
- Changes in heat release rate from ladder fuels not considered
- Temperatures of firebrands only approximated, limits confidence

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Thank you

Questions?

Tree-scale burns

- ~ 40 trees per species (Currently Douglas-fir, ponderosa pine, sagebrush and chamise).
- Up to 79 locations of fire-resistant fabric
- Wind data recorded (typical average wind velocity < 1 m/s)
- Water tray tests provide total number of embers, but too cumbersome for so many test locations.
- Characteristics of fire-resistant fabric are unknown.

Suggestions from previous meetings with NIST researchers

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- Understand the impact of surface fire intensity on firebrand production

- Fuels native to Southern California (Chapparal species)

- LIDAR information of the fuel before and after burns

- Collect mass information of the firebrands

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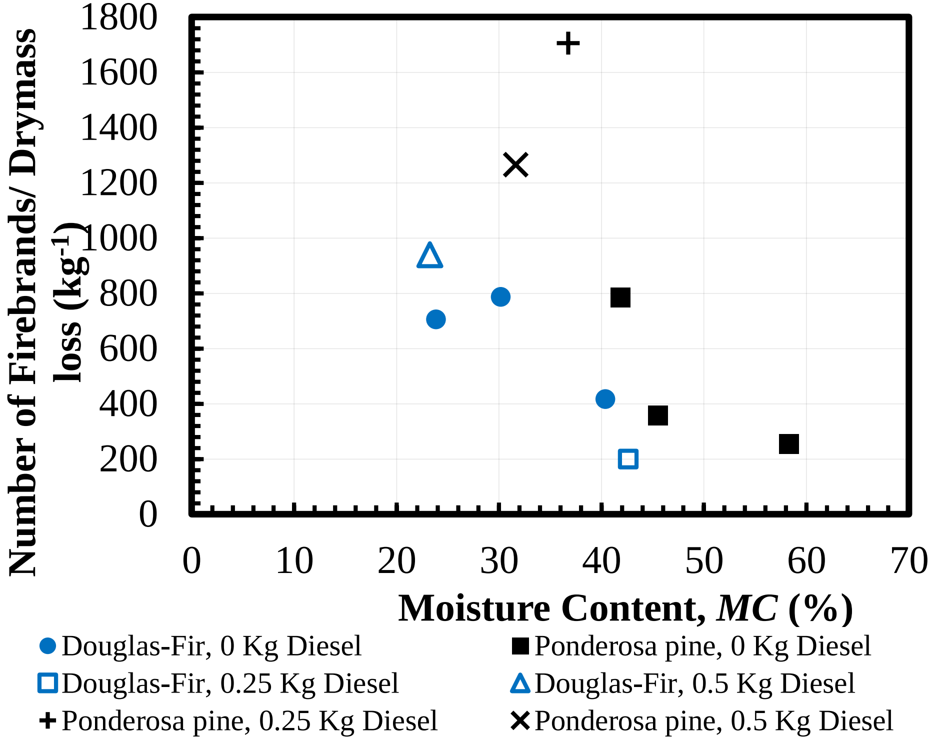
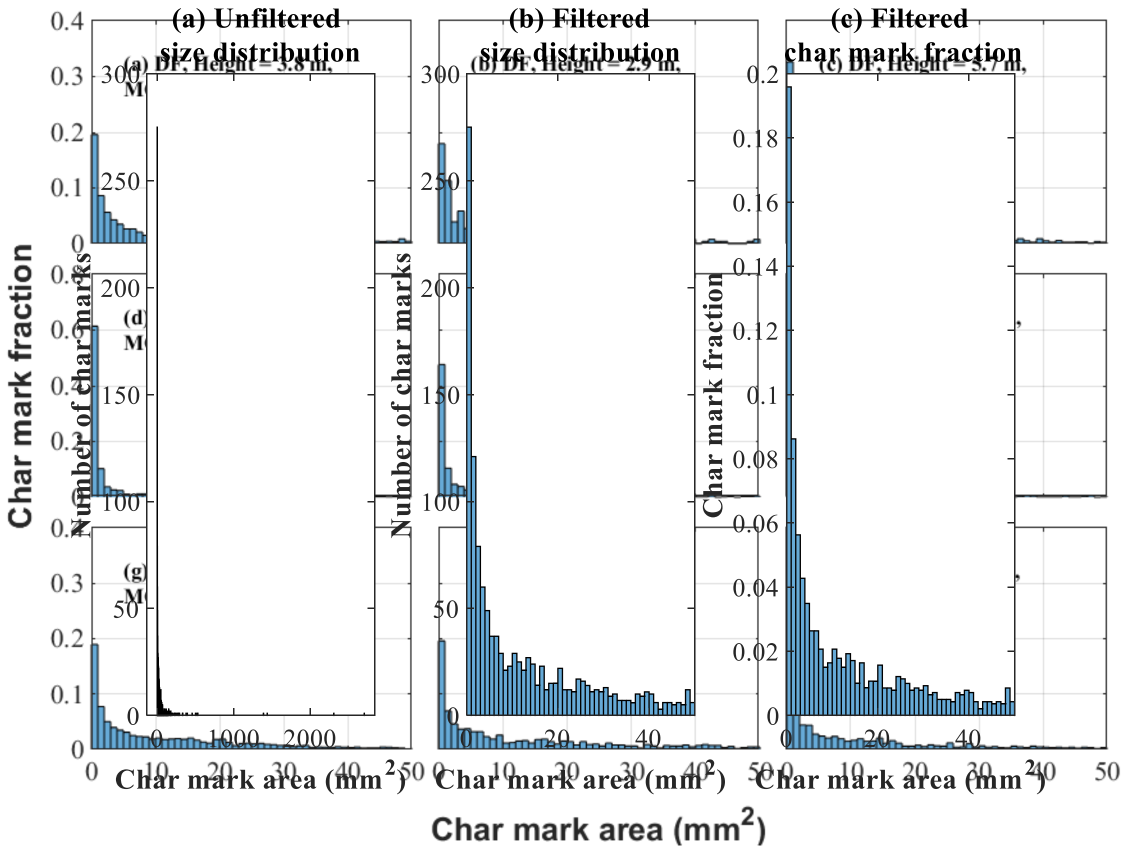
Impact of ground fire

- Diesel addition to straw bed
- Specific number of firebrands produced not impacted
- Fits with moisture content curve



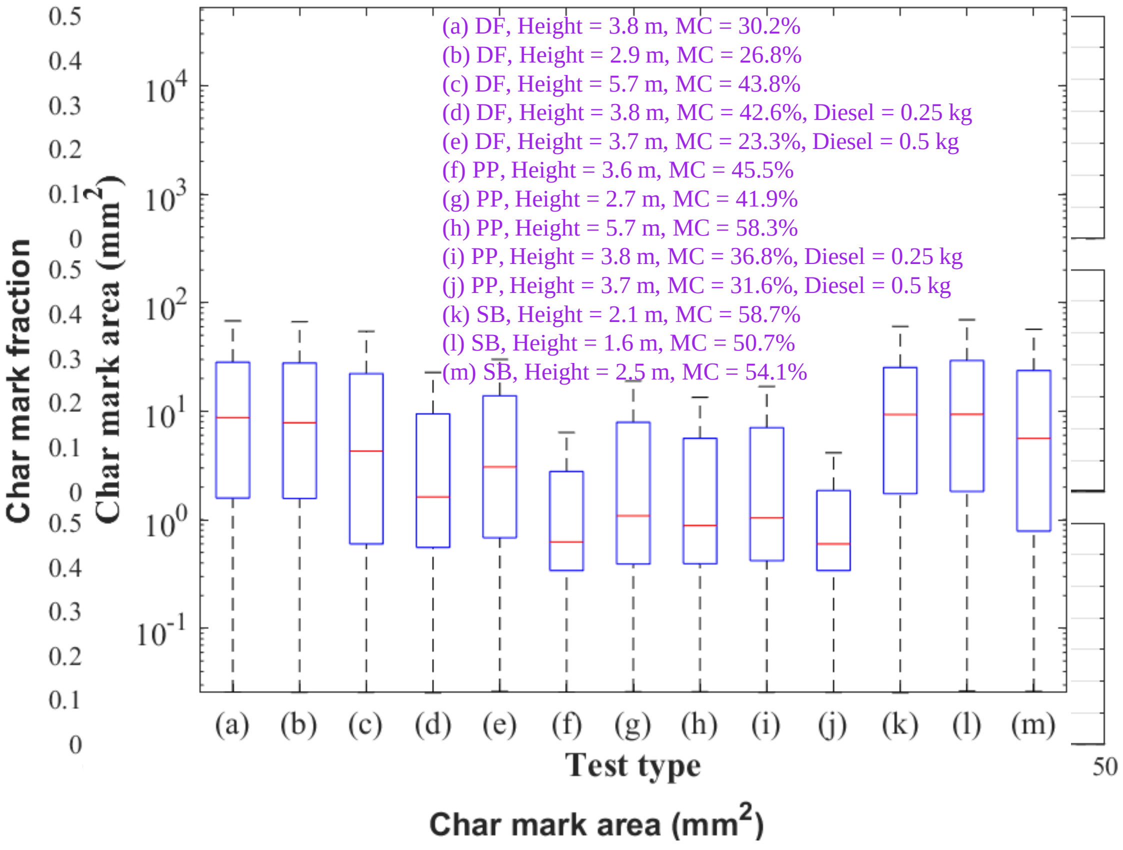
Char mark area statistics

- Char mark area vs firebrand area
- Char mark fraction – allows to compare between different tests
- Majority (>95%) within 50 mm^2
- Ponderosa pine produces smaller (median area) firebrands when compared to other species
  - ➢ Type of foliage burning



Char mark area statistics

- Number of char marks < 1 mm^2 increased for Douglas-fir with diesel addition
- No clear trend evident for ponderosa pine
- Box plots
  - ➢ Median area for Douglas-fir decreases
  - ➢ Ponderosa pine unclear
  - ➢ Sagebrush and Douglas-fir similar median area



Progress regarding previous discussions with NIST researchers

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- Understand the impact of surface fire intensity on firebrand production
- Minimal impact for Douglas-fir and ponderosa pine species

- Fuels native to Southern California (Chapparal species)
- Measured firebrand production for chamise

- LIDAR information of the fuel before and after burns
- Collected LIDAR information for live Douglas-fir trees – Data processing ongoing

- Collect mass information of the firebrands
- Unable to collect mass information for firebrands – brainstorming alternative ideas

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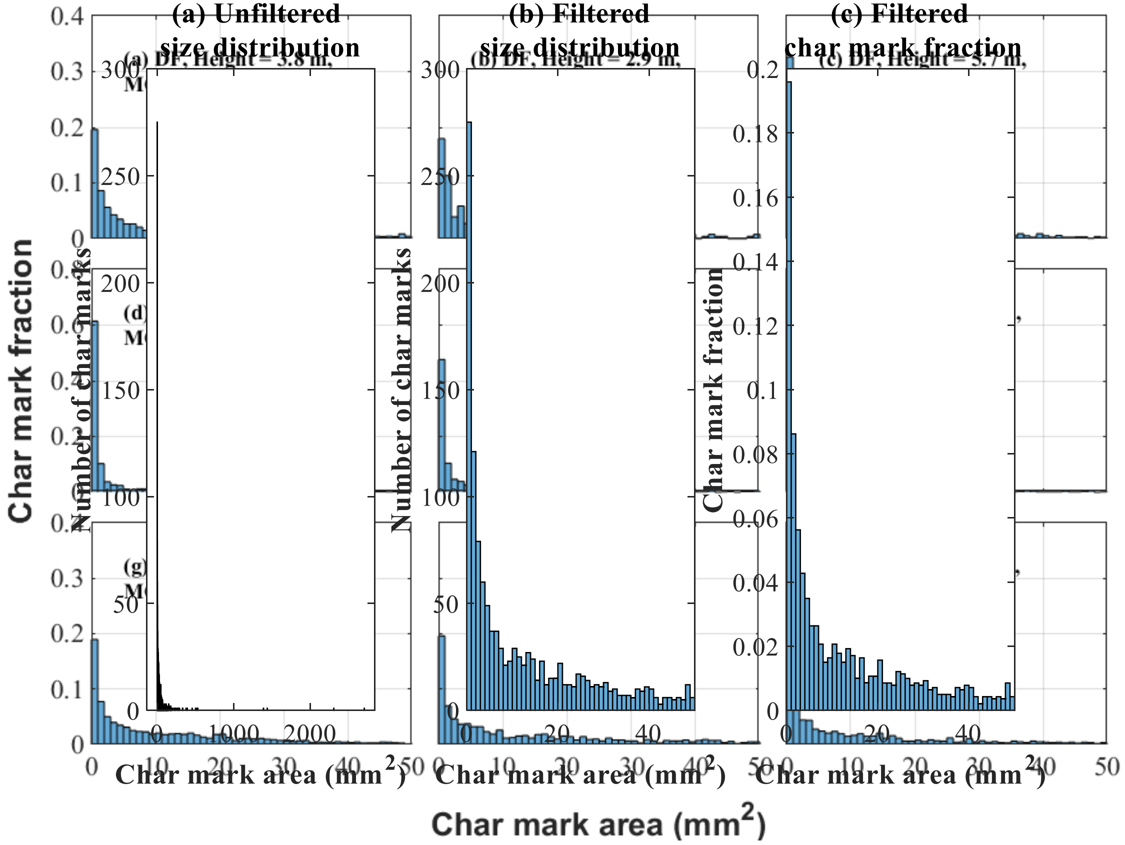

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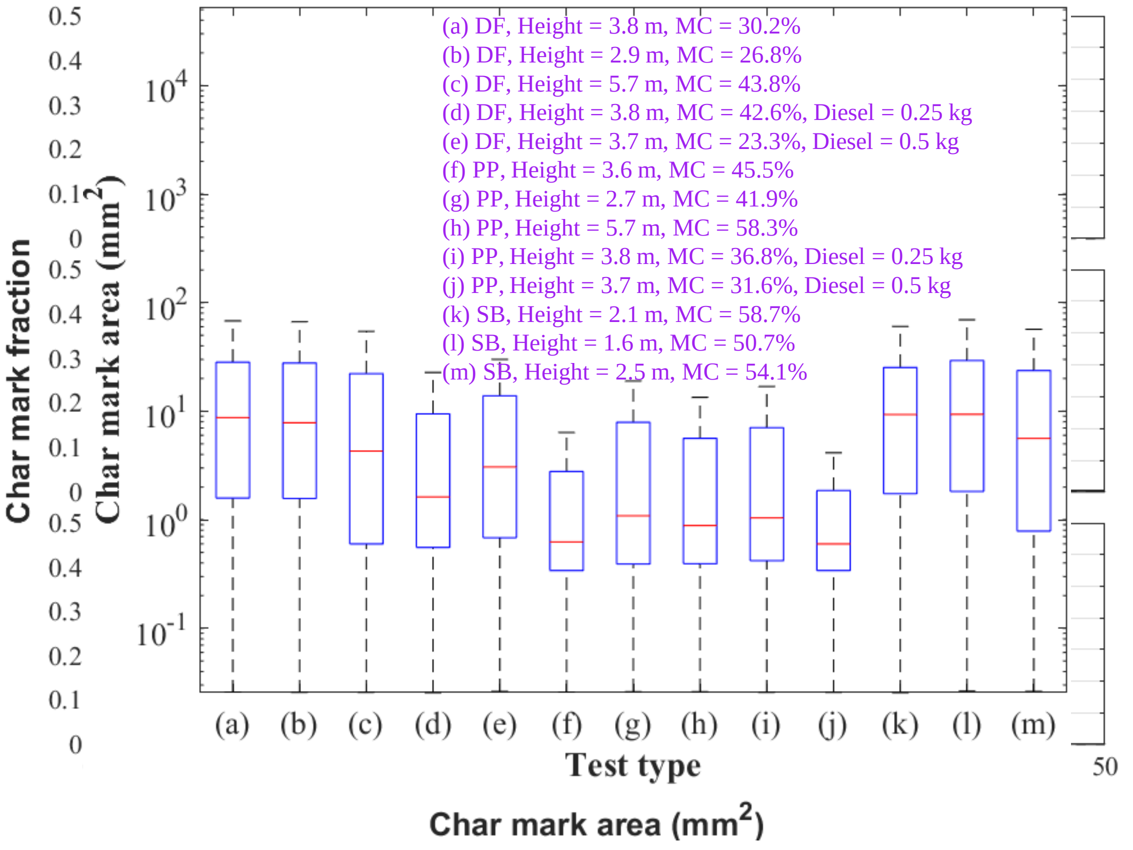
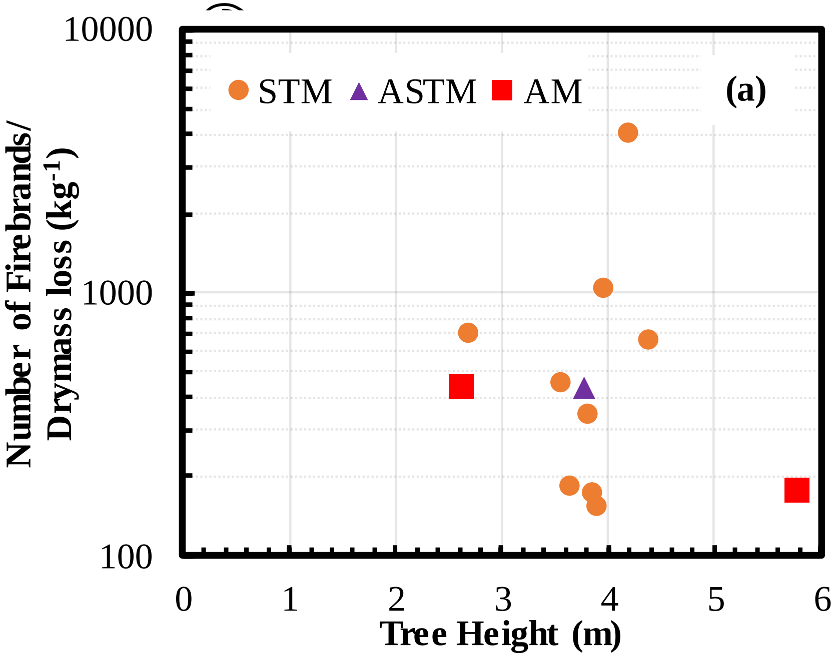
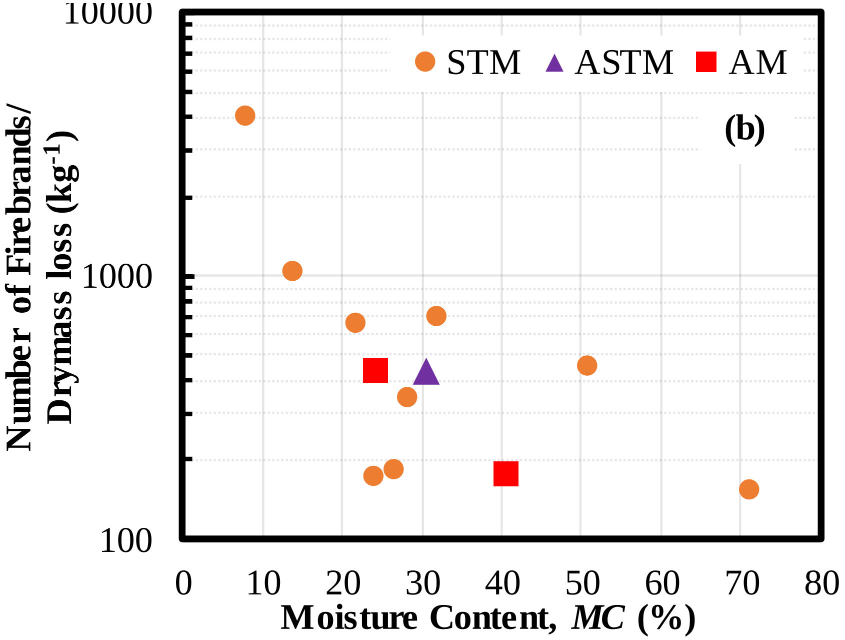


Single Tree Method (STM) vs Accumulation method (AM)

- Two different approaches
  - Single Tree Method (STM)
  - Accumulation Method (AM)
- Advantages/ Disadvantages
  - AM easier to conduct
  - STM provides granular data
  - AM is used in current study
- Ember production increases exponentially with decreasing moisture content

For Douglas-fir trees of varying heights



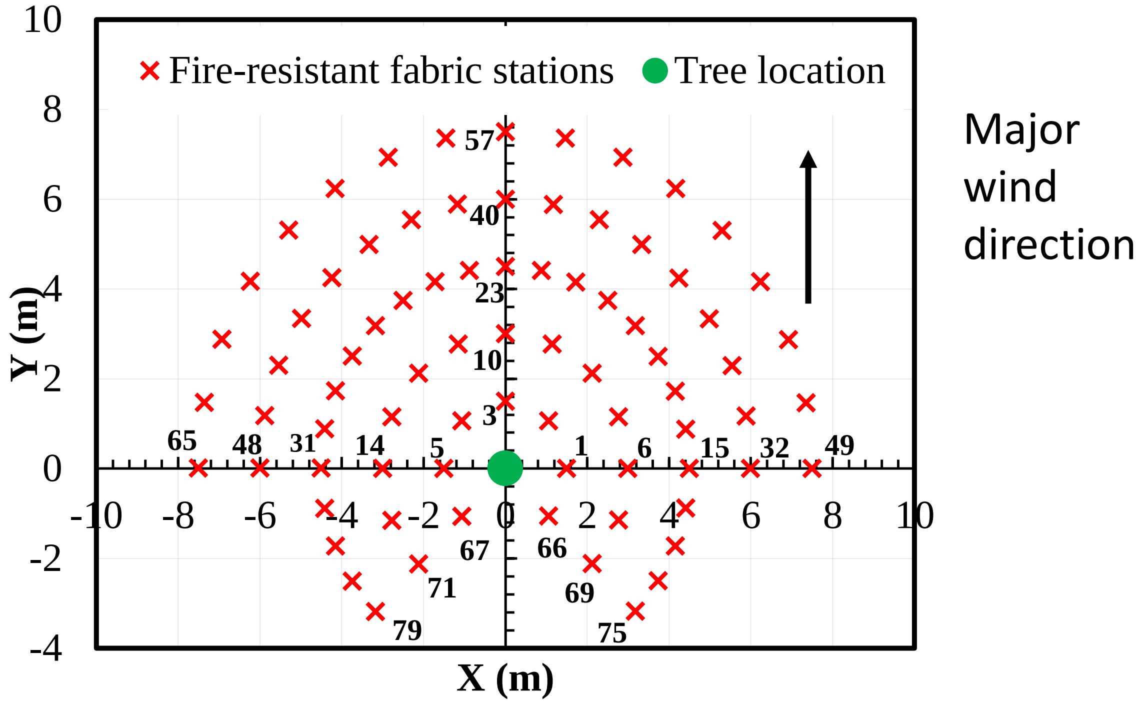


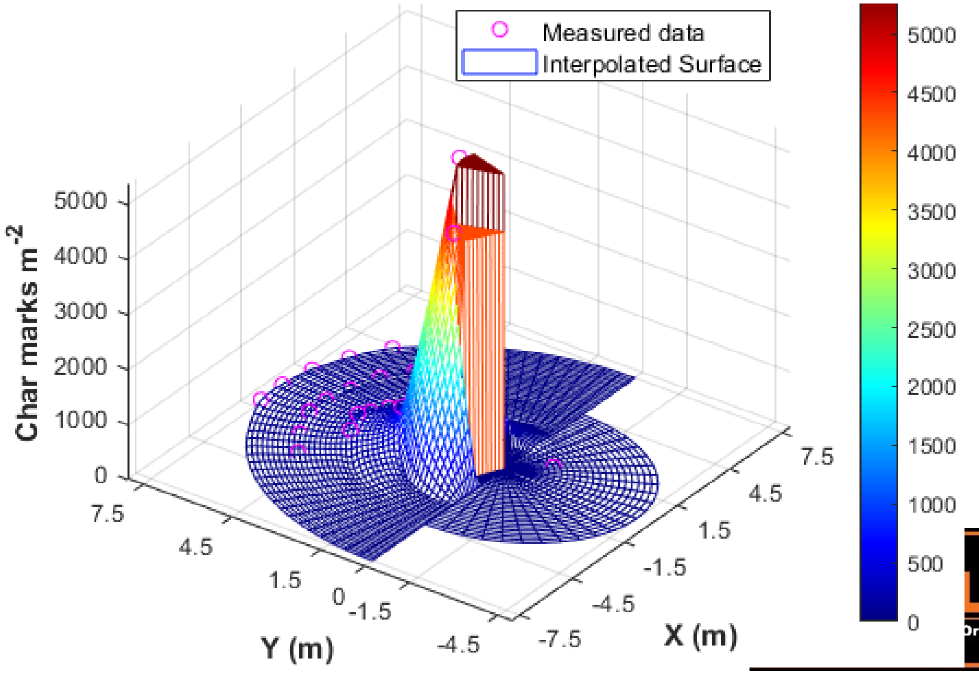
Potential areas of collaboration

1. Tree scale firebrand data sharing
2. Ways to use source terms in simulations
3. Potential simulations of tree scale burning
4. Moving to larger scale tests and simulations

Updated Grid

- Added 14 more stations in the non-predominant wind direction
- Provides a corroboration for wind direction
- No. of firebrands down wind direction > firebrands up wind direction





Char marks

- Firebrand enumeration ("hot" firebrands)

- Advantages/ disadvantages

  - How to estimate the total number of firebrands?
  - How to estimate the energy from the char marks?