Combustion physics of wildland fire: What is SERDP research telling us?

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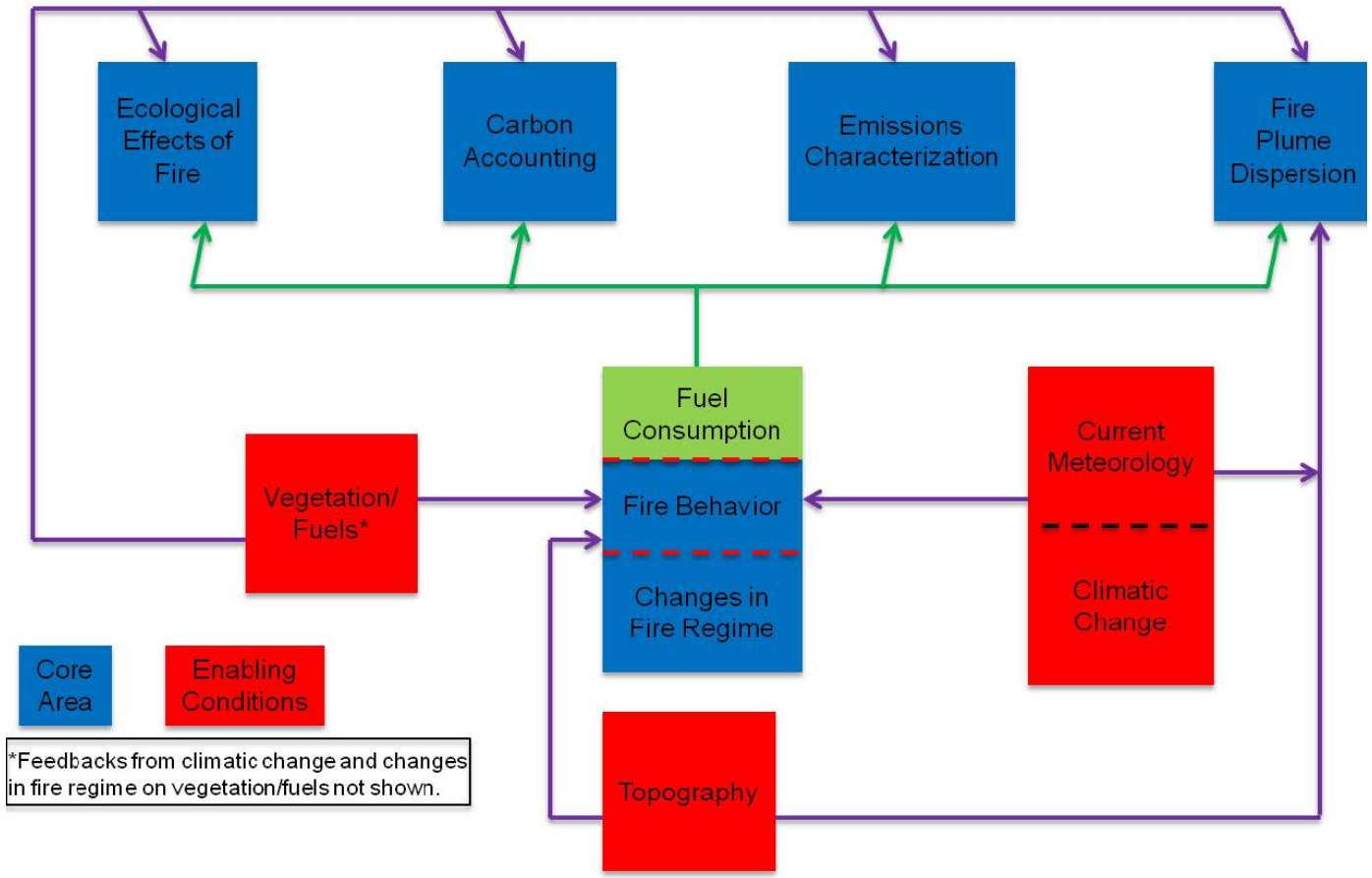
2018 | Enhancing DoD's Mission Effectiveness

SERDP Fire Science Strategy

"Fire behavior is a core fire science topic area that serves as the foundation of future investments…."

"…is critical for advancing modeling and understanding of fire behavior and ultimately its effects."

– From the 2014 SERDP Fire Science Strategy



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RCSON- 16-02: Improved understanding of wildland fire combustion processes for Department of Defense managed ecosystems

1. **Open combustion processes** at fine to landscape scales with a focus on the flaming and short-term (hours) smoldering phases.
2. **Fire spread across heterogeneous fuels** through either particle-scale or fuel-bed scale type combustion processes.
3. **Role of fuel characteristics** in the combustion process, including the burning of live fuels (as distinct from dead fuels), and how this affects fuel consumption.
4. Measured or modeled physics of heat transfer and fire propagation as a **coupled fire- atmospheric dynamic**.

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RCSON- 16-02: Funded Projects

RC-2643	Improving Parameterization of Combustion Processes in Coupled Fire-Atmosphere Models through Infrared Remote Sensing	Dr. Scott Goodrick USDA Forest Service, Southern Research Station
RC-2640	Fundamental Measurements and Modeling of Prescribed Fire Behavior in the Naturally Heterogeneous Fuel Beds of Southern Pine Forests	Dr. David Weise USDA Forest Service, Pacific Southwest Research Station
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Technical background - Goodrick

Representing wildfires using physics-based models:

- Interaction between physical processes described by complex set of governing equations
- Computational grids to approximate the solution of governing equations
  - Phenomena larger than grid cells are explicitly resolved
  - Phenomena smaller than grid cells (subgrid) must be modeled with stochastic methods.

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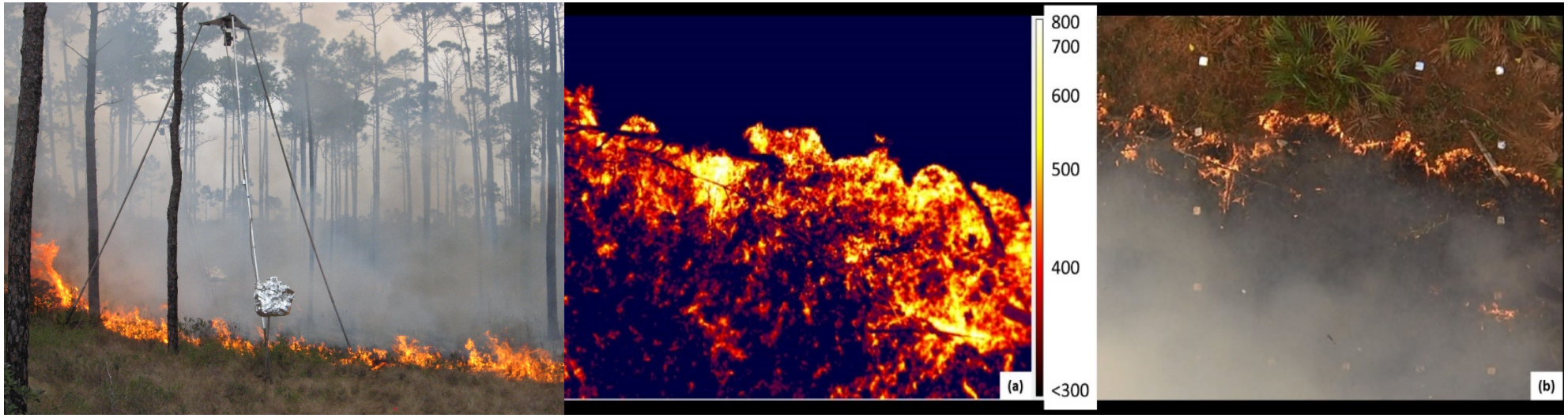
Technical approach - Goodrick

Use remote sensing to estimate fluxes of mass, moisture and momentum

- Flow field estimation through application of optical flow
- Mass loss rate estimation through adaptation of satellite methodology for estimating biomass combustion
- Latent heat flux through adaptation of satellite methodology



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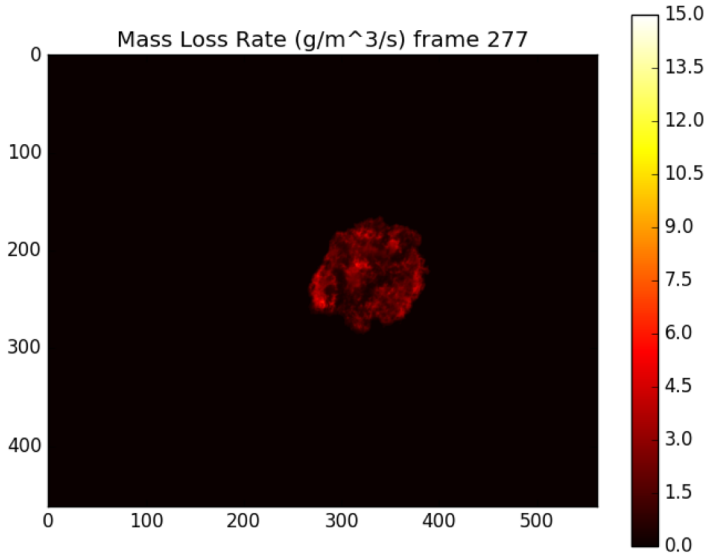
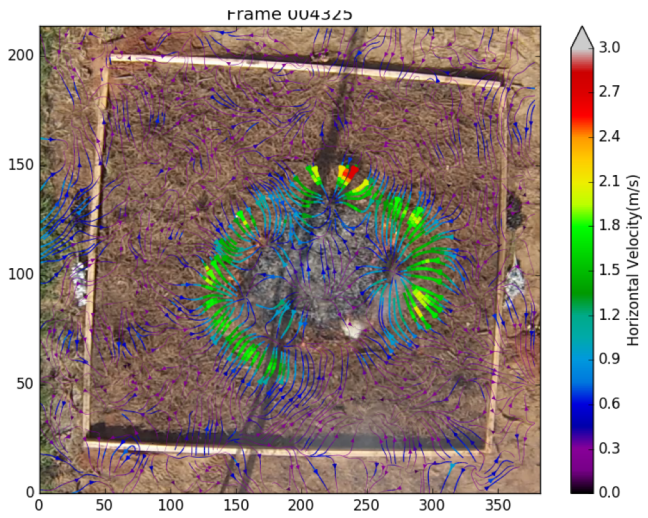
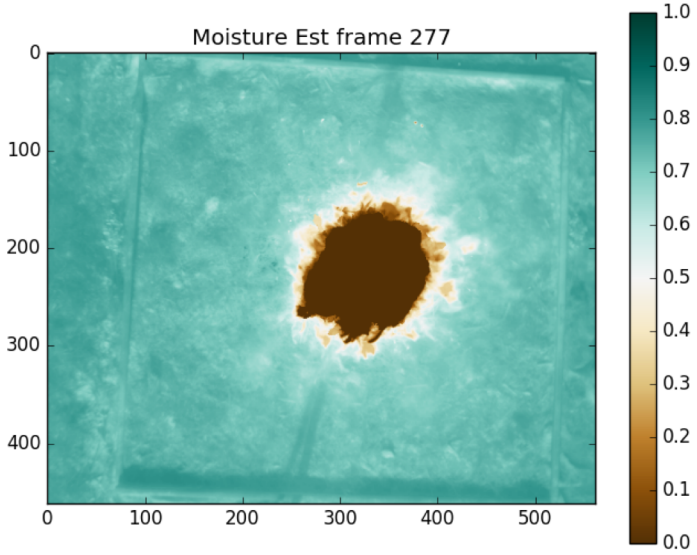
Results - Goodrick



Rate of Fuel Combustion



Airflow in, out and around the fire front.



Moisture of fuels

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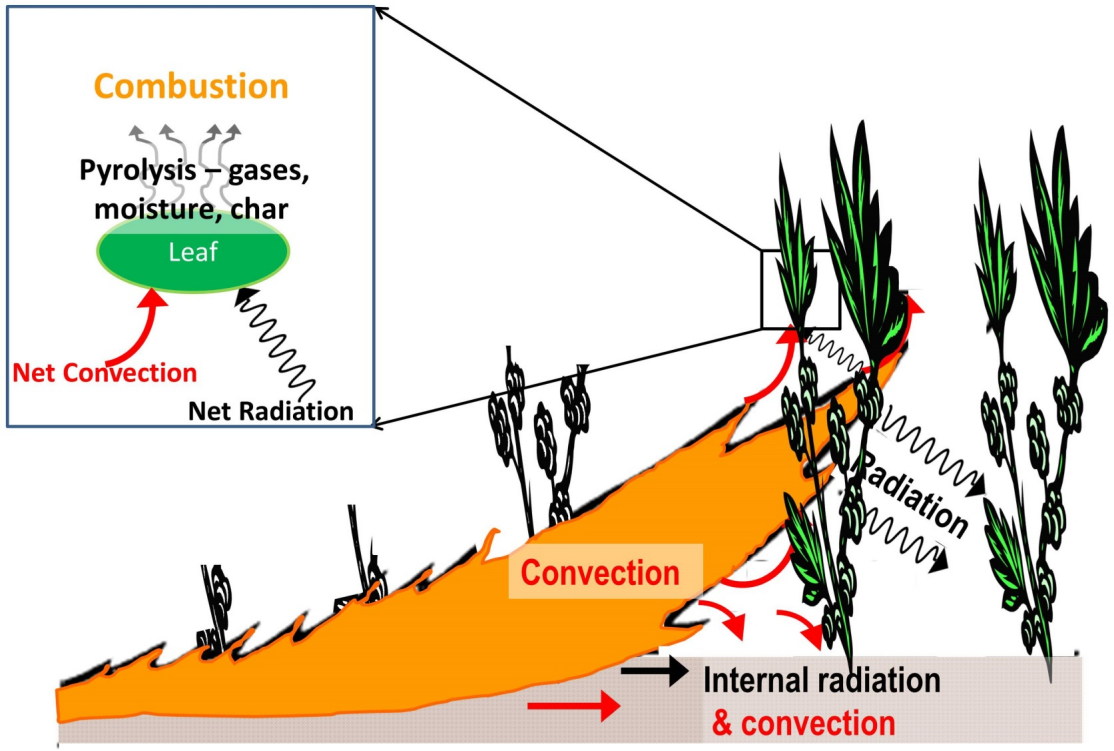
Technical Background - Weise



It's more than just wood!

Technical Objectives - Weise

Measure and model pyrolysis of live and dead southern fuels to improve our ability to model fire behavior

1. **Characterize pyrolysis products and processes for live and dead fuels at multiple scales.**
2. **Determine convection and radiation heat transfer effects on pyrolysis and ignition.**
3. **Perform high-fidelity physics-based modeling of pyrolysis and ignition.**

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Results - Weise

- **Physical and chemical characteristics of foliage are different from wood** indicating the need to model pyrolysis of foliage in physically-based fire models.
- Visual assessment of results suggests **little effect of species** on proportions of light gases, tar and char from 14 southern species.
- Heating rate affects the composition of the pyrolysis products, particularly the tars.

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Technical Objectives - Hamlington

Understand and parameterize the small-scale physics of wildland fuel evaporation, pyrolysis, ignition, and combustion using advanced computational and experimental tools

1. Use Frequency Comb Laser Diagnostics (FCLD) to study fire spread at small scales, to provide data for reduced chemical mechanisms, and to provide data for validation of simulations
2. Develop and calibrate chemical models for evaporation, pyrolysis, ignition, and combustion at small scales
3. Understand and model wildland fire spread at scales from 1 m to below 1 mm using Direct Numerical Simulations (DNS) to resolve all relevant fluid and chemical processes
4. Parameterize radiative and convective heat transfer for improved subgrid-scale (SGS) models of fire spread in landscape-scale simulations

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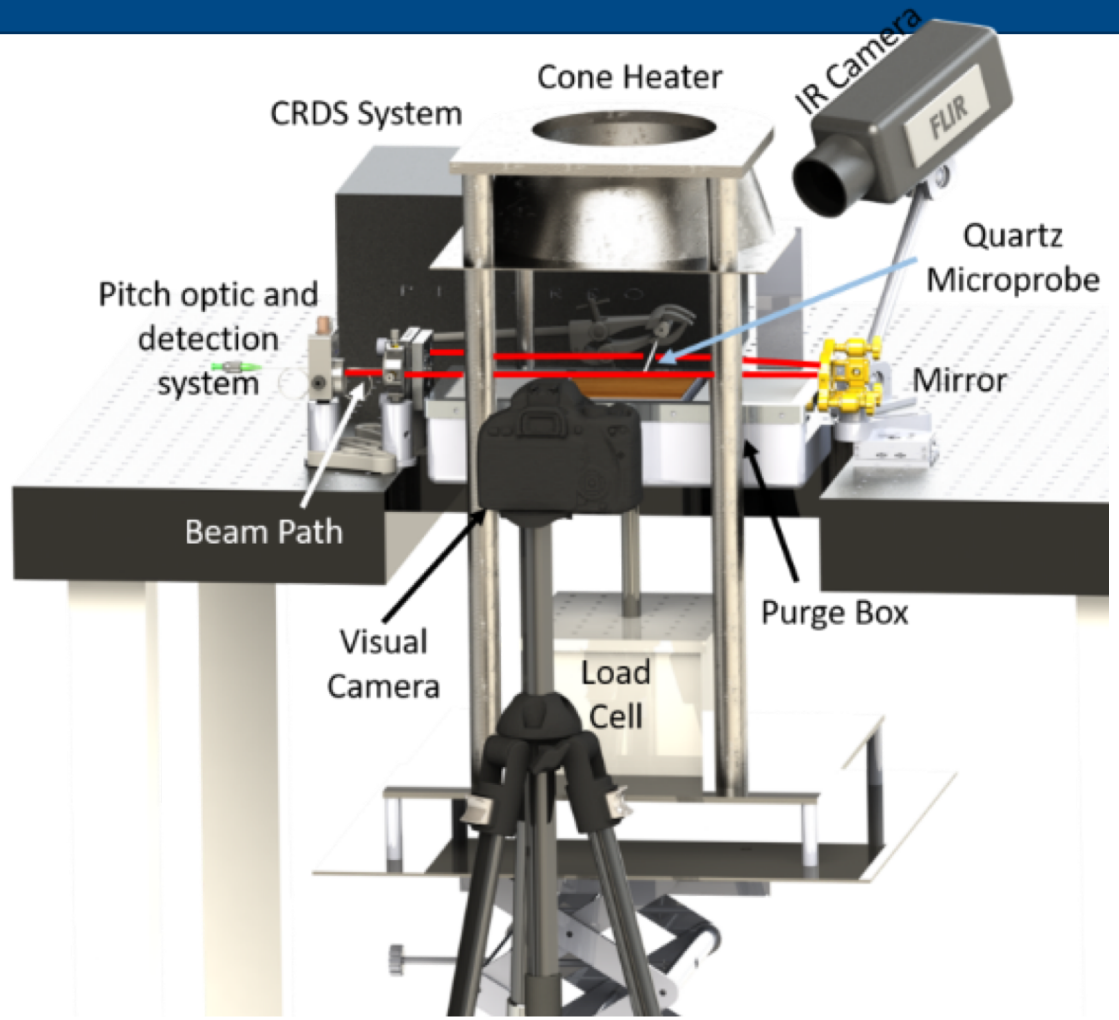
Diagnostics for Calorimeter Experiments - Hamlington

- **Dual frequency comb lasers (DCS)**
  - Gas temperature
  - Water mole fraction
  - Species mole fraction
- **Load cell**
  - Mass loss history
- **Heat flux meter**
  - Radiant energy on sample
- **Infrared camera**
  - Surface temperature
- **Visual camera**
  - Ignition time
  - Ignition type
  - Flame intensity



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Wind Tunnel Fire Spread Experiments - Hamlington

Enclosed test section:

- No entrainment, simplifies boundary conditions
- Limits dependence on air currents in room
- Allows for controlled and repeatable experiments

Test section: 35cm x 35cm x 70cm

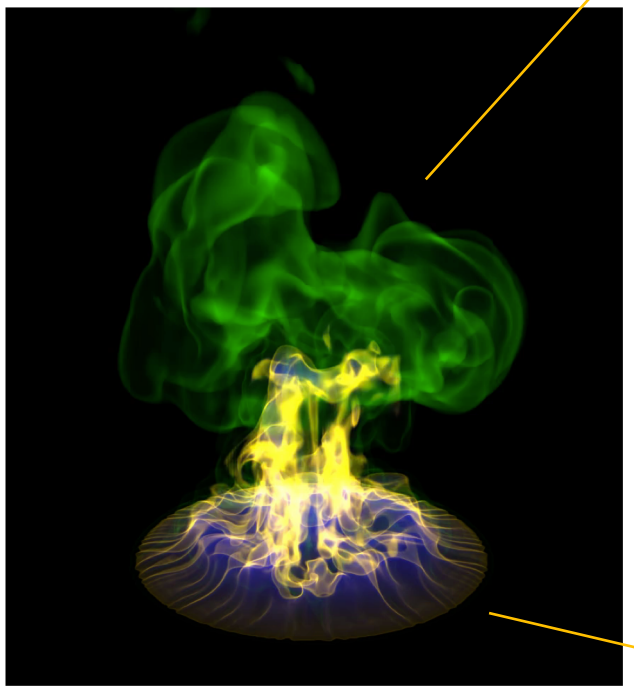
Maximum operating velocity: 12 m/s

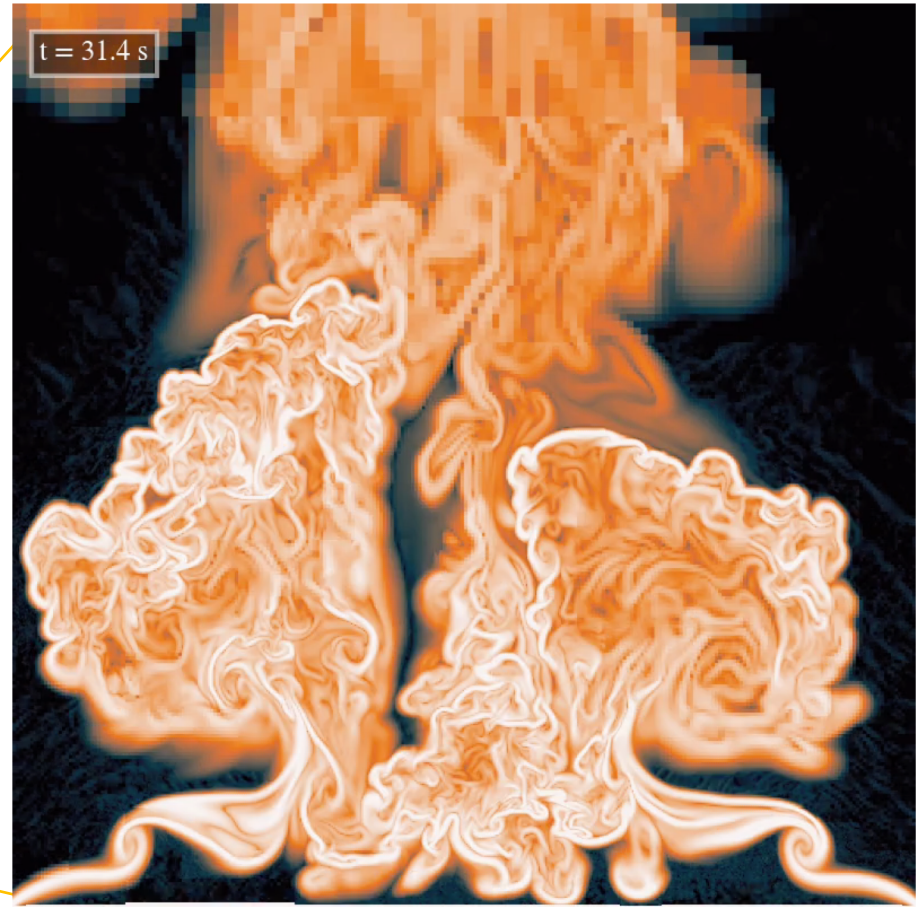
Fire spread wind tunnel with model human for scale

Gas temperature: FCLD
Spread rate: Visual camera
Qualitative heat transfer: FLIR camera
Flow velocity: Pitot tube/Hot wire anemometer
Qualitative flame structure: Visual camera
Species Mass Fractions H_2O, CO_2: FCLD
Quantitative heat transfer: FLIR, Thermocouples
Turbulence intensity: Hot wire anemometer

Helium Plume Simulation - Hamlington

- Represents similar geometry and physics as a pool fire
- Uses adaptive mesh refinement (AMR) to achieve computational savings





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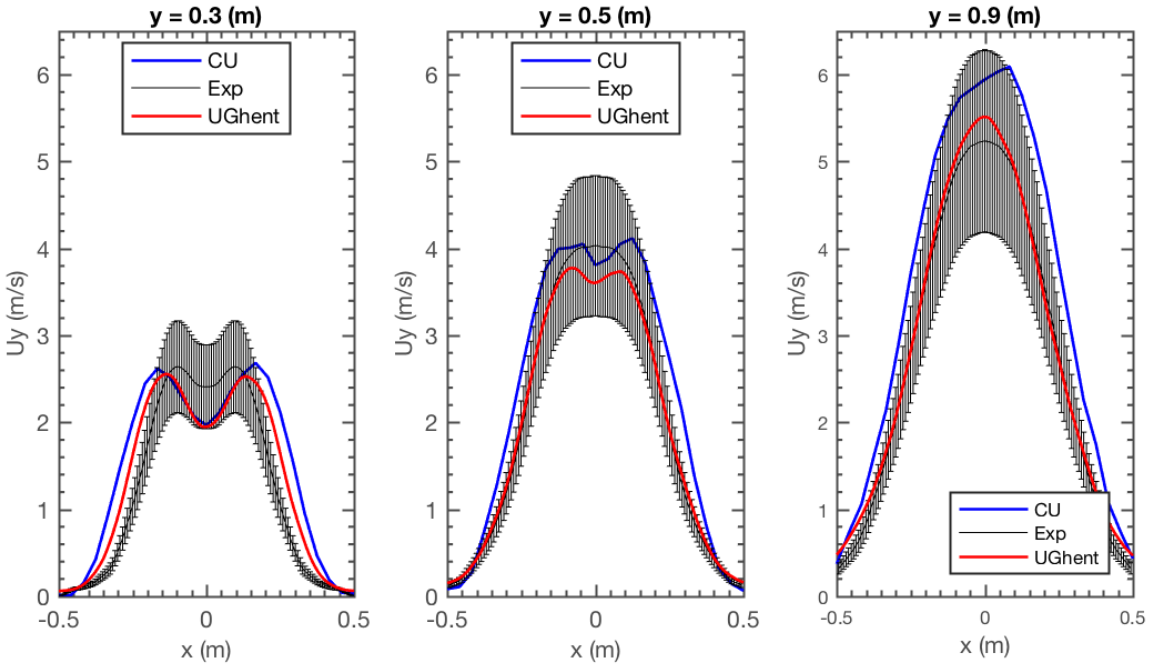
Methane Pool Fire Simulations - Hamlington

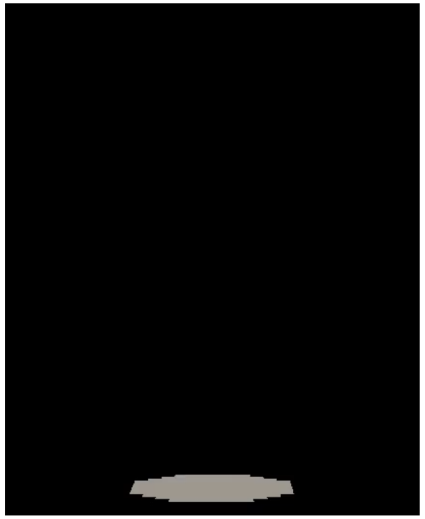
Computational Savings:

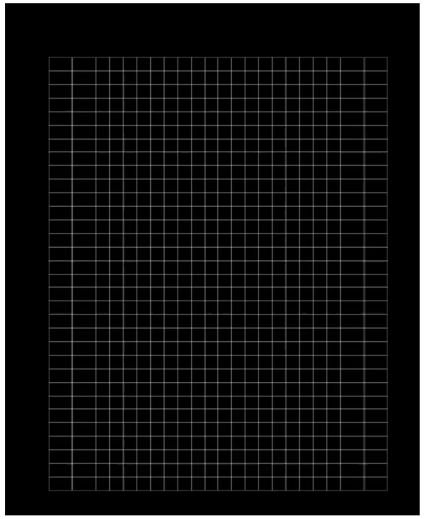
- Ran on 6 processors and ~300,000 cells
  - Koo et. al. (2017) used 1.6M cells
  - Univ. Ghent (2017) used 2.38M cells

Agreement:

- Velocity profiles compare well with experimental and computational data







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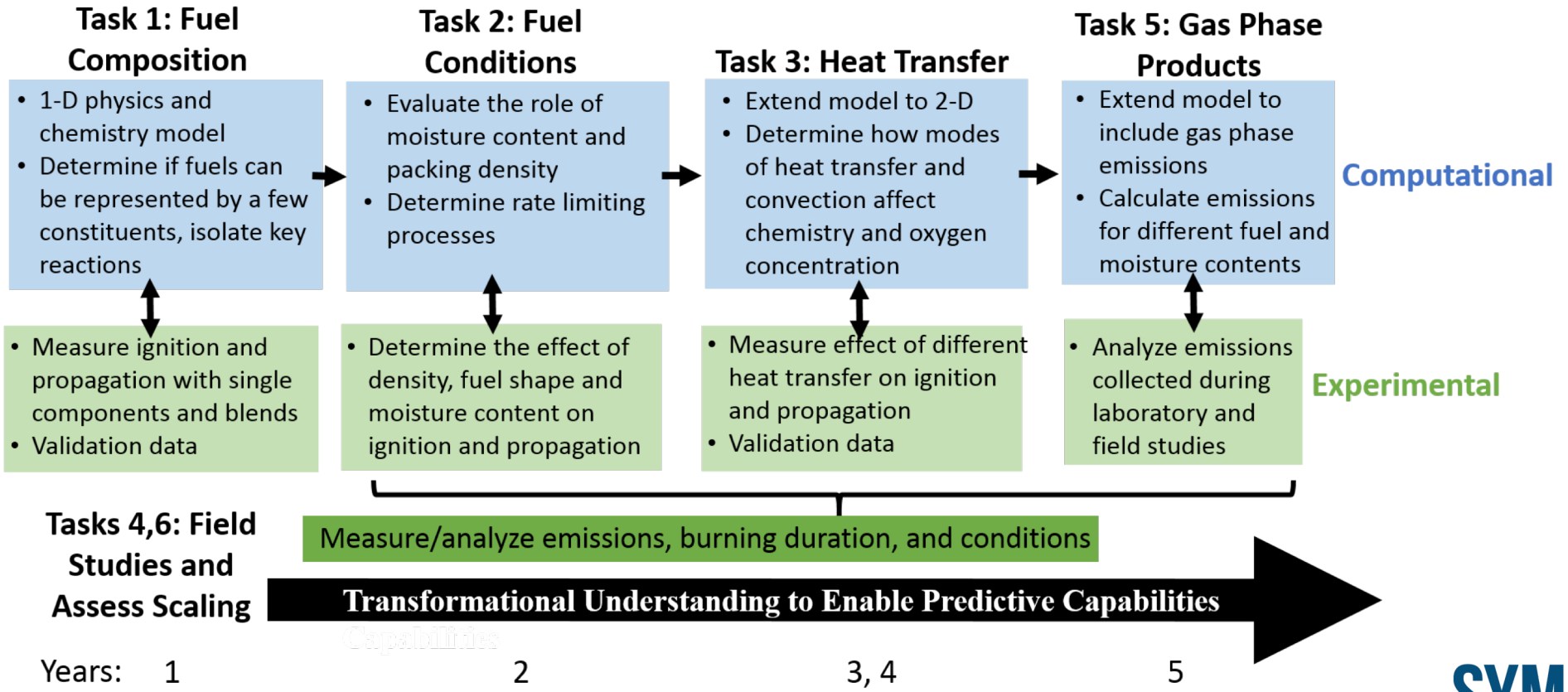
Objective and Approach – Blunck

Develop the scientific knowledge needed to understand ignition, spread, and emissions of smoldering combustion



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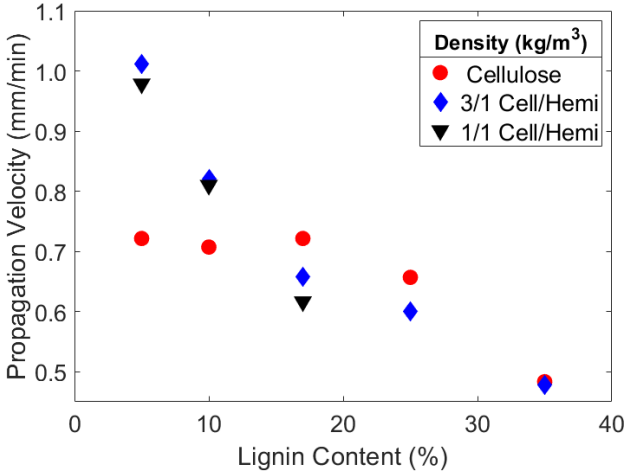
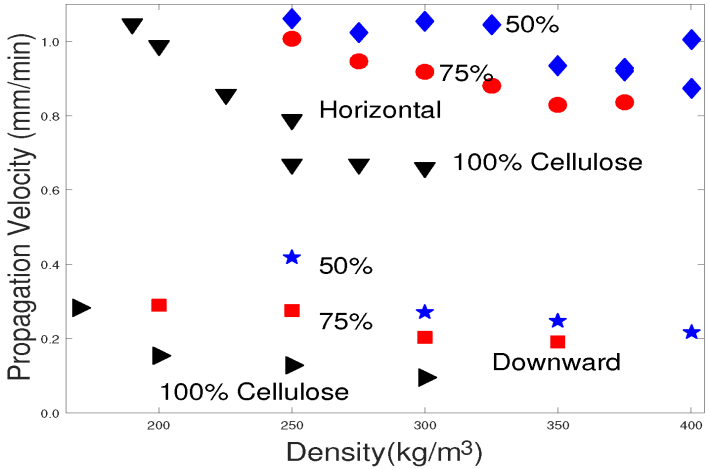
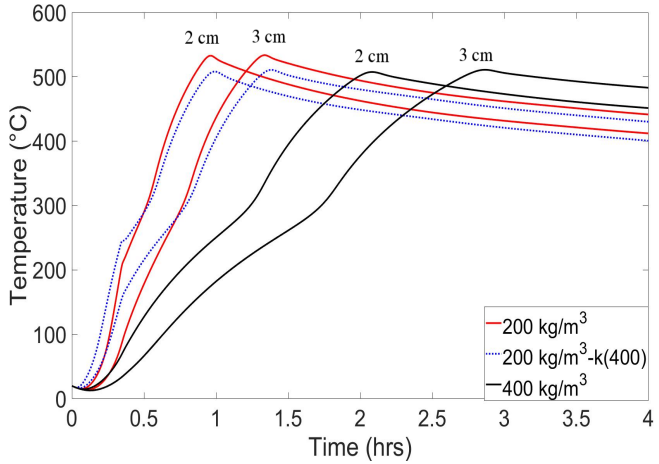
Laboratory and computational results - Blunck

- The concentration of lignin, hemiceullose, and cellulose and the density of the mixture all influence smoldering burning rate and temperature.

- Detailed modeling has shown that these changes occur because of differences in thermal conductivity, changes in oxygen availability, and differences in the reaction rates for the fuels.







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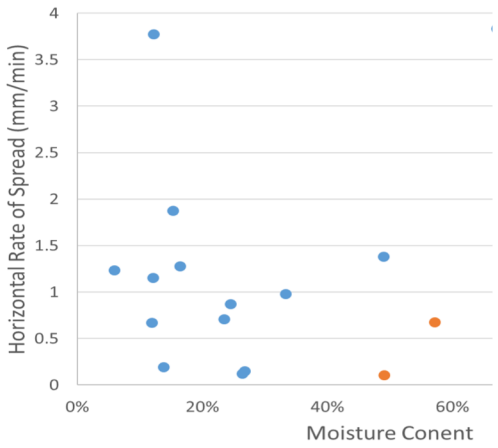
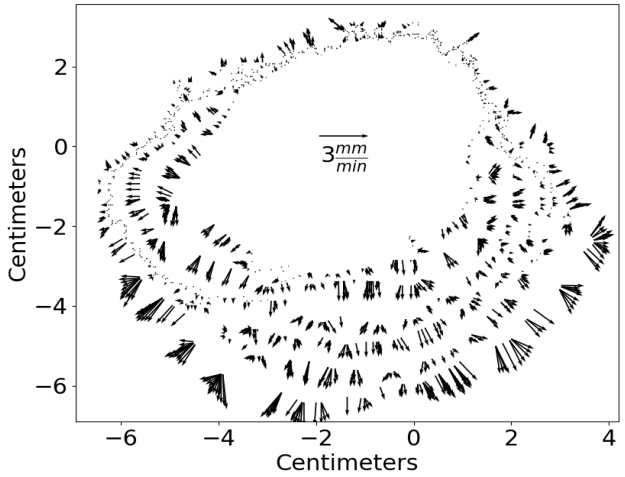
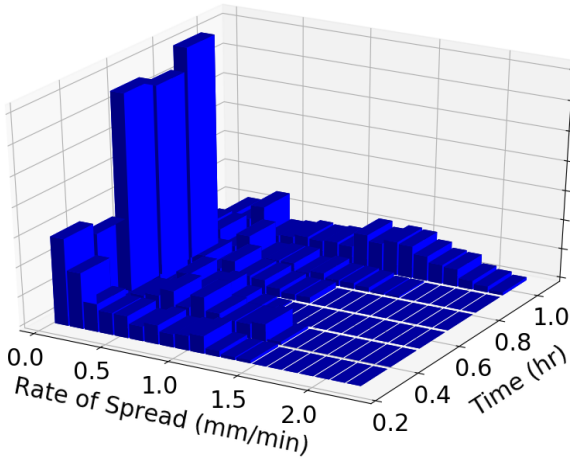
Field study results - Blunck







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Technical Approach - Skowronski

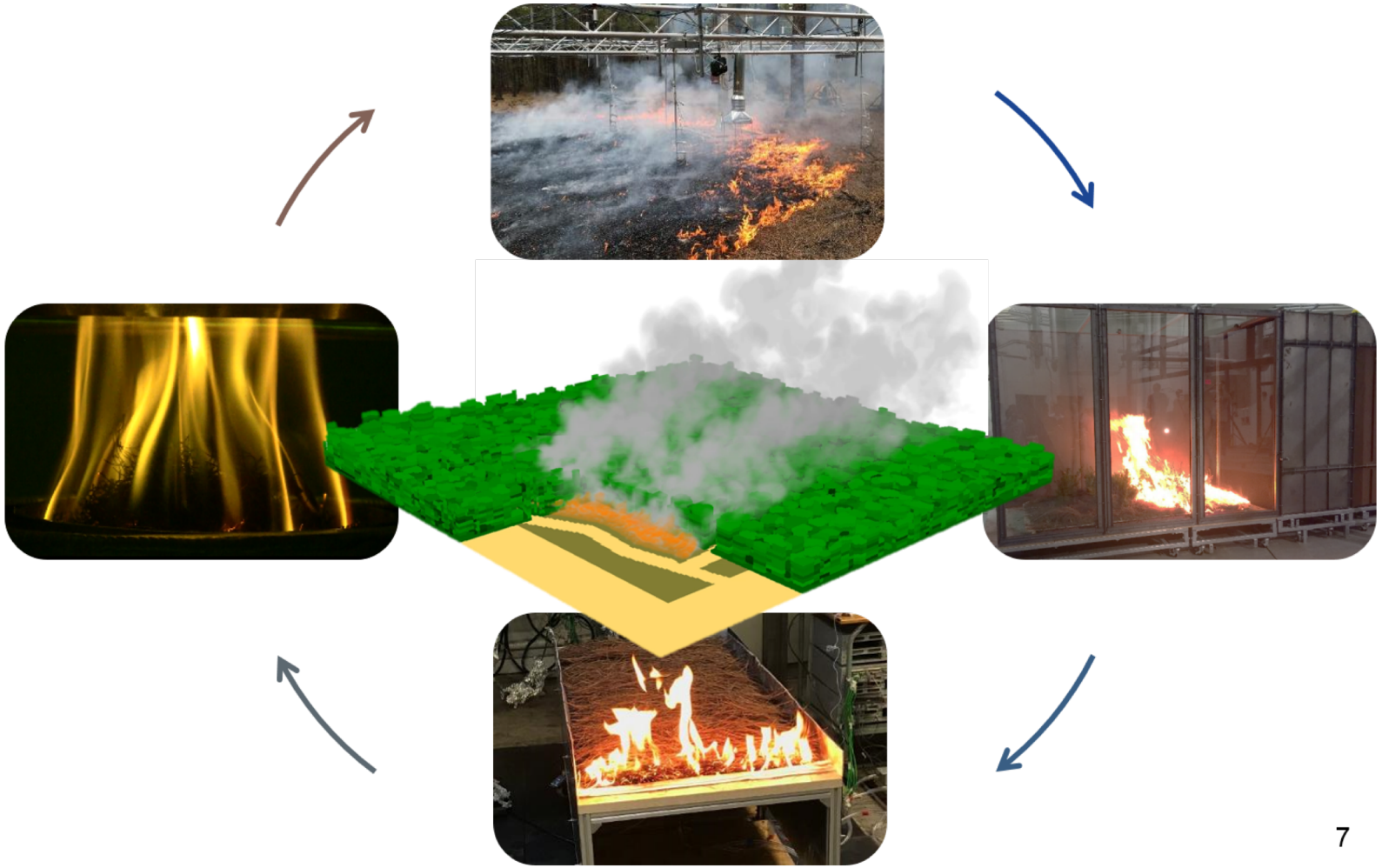

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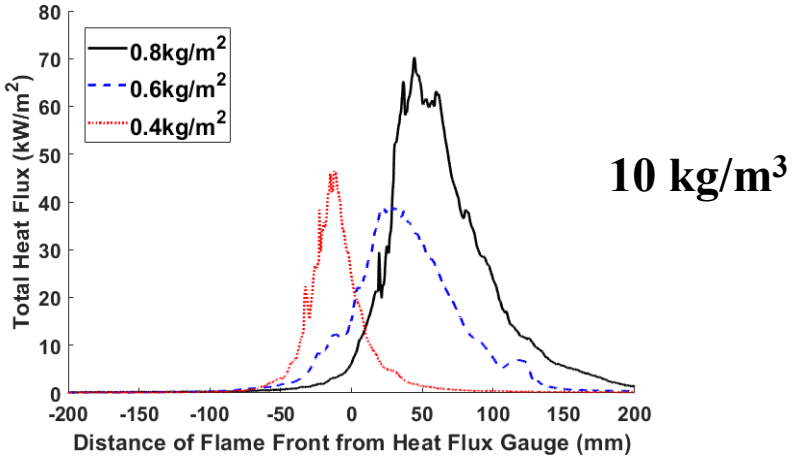
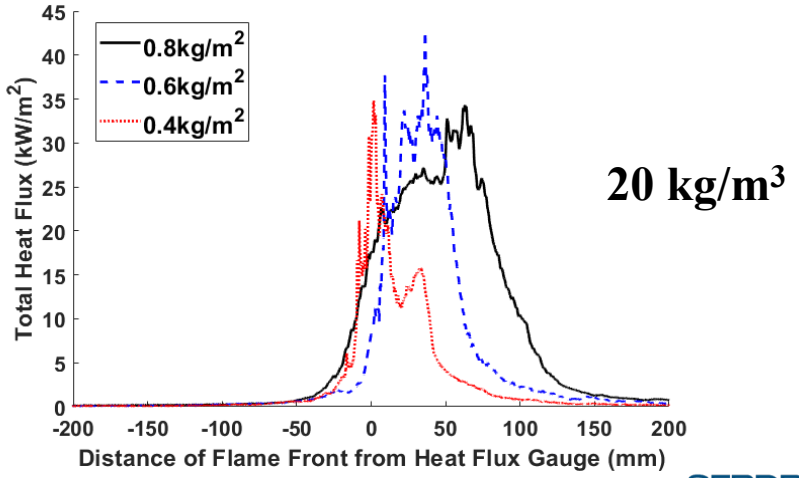
Table results - Skowronski

Time = 45 Seconds Flame Height = 0.9m HRR = 50 kW Fuel Loading = 1.6kg/m²	Time = 121 Seconds Flame Height = 0.6m HRR = 39 kW Fuel Loading = 0.8kg/m²	Time = 255 Seconds Flame Height = 0.3m HRR = 16 kW Fuel Loading = 0.4kg/m²	Time = 432 Seconds Flame Height = 0.05m HRR = 6kW Fuel Loading = 0.2kg/m²





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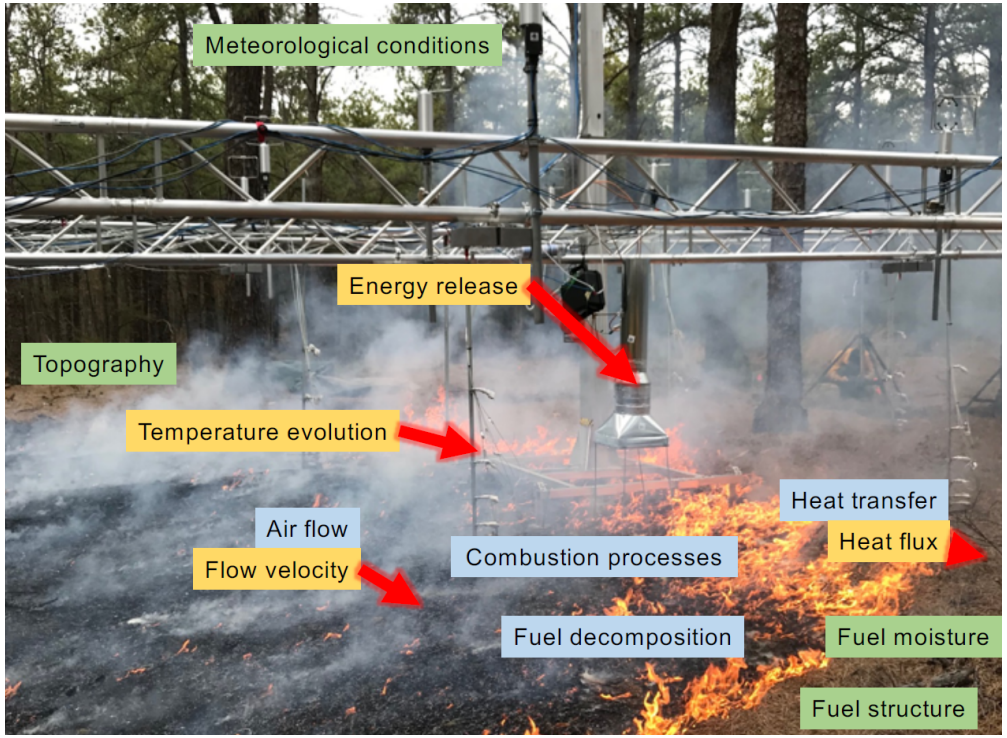
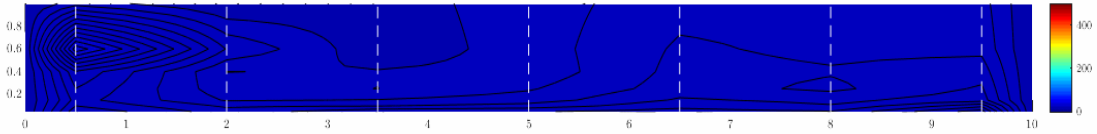
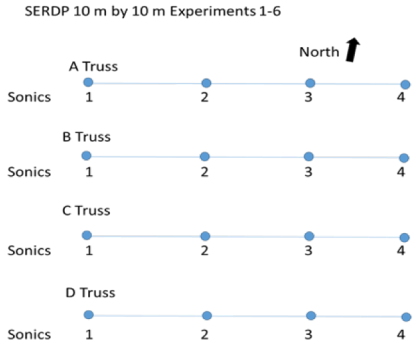
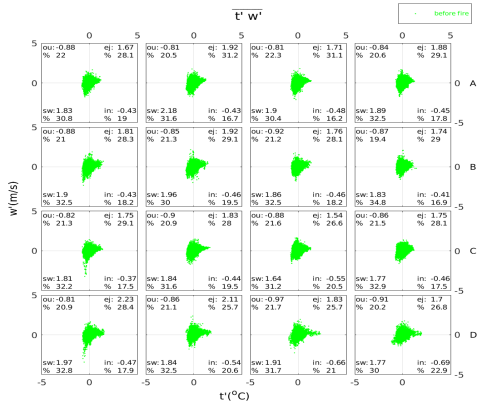
Field results heat flux - Skowronski



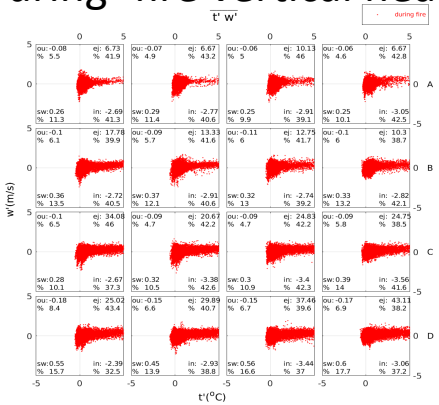




Pre- fire vertical heat flux



During- fire vertical heat flux



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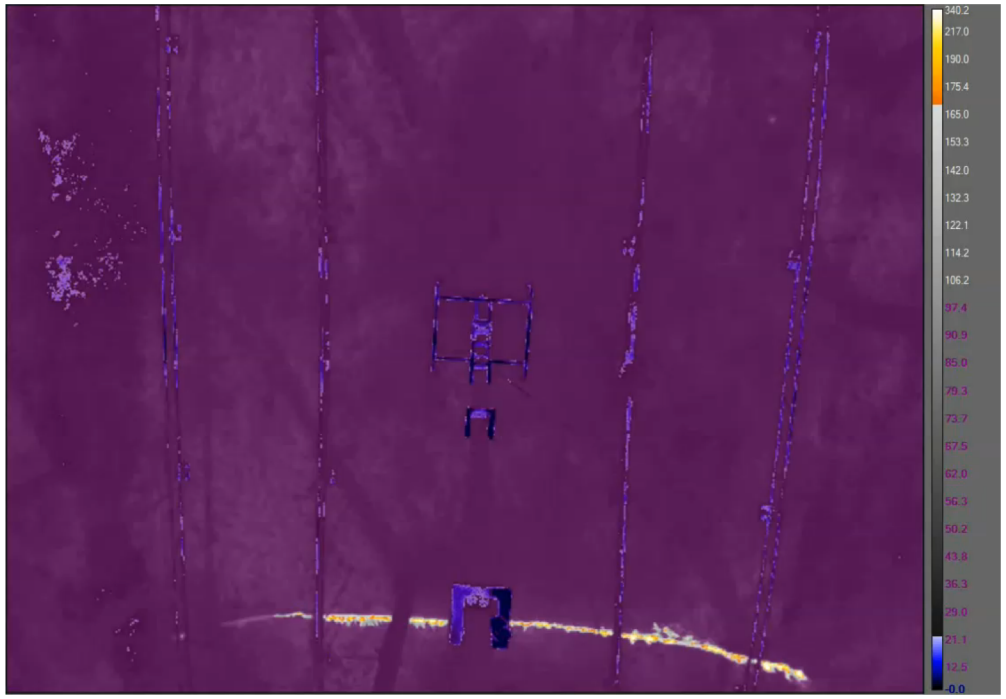
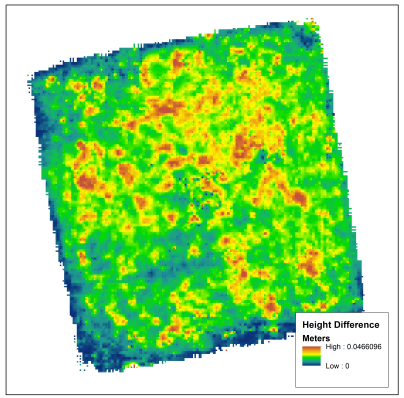
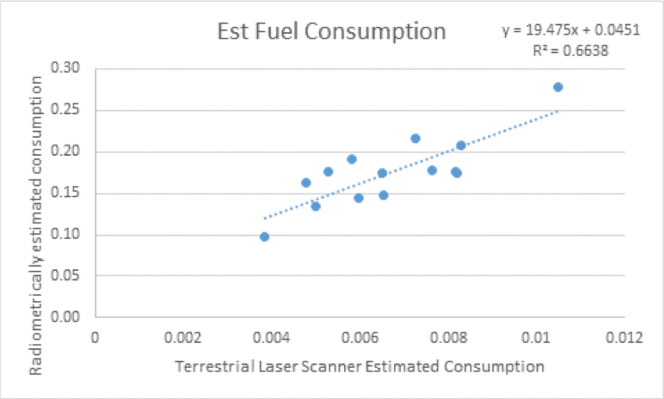
Field results fuels - Skowronski







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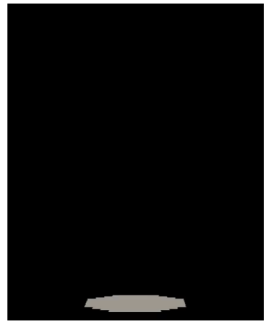
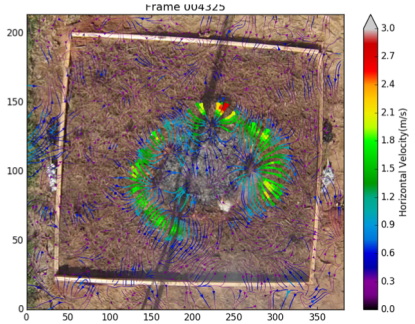
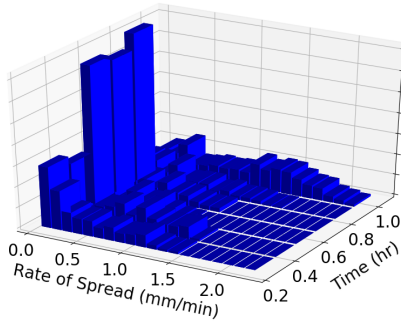
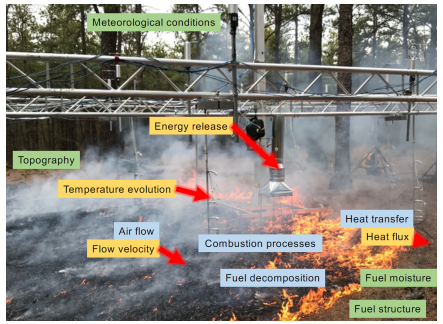
Conclusions

- Stay tuned for a wave of publications from these projects.
- These multi-disciplinary teams are key to pushing the science of fire behavior.
- Technological innovations are changing how we can approach these problems.









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