Fine Scale, Big Scale: Wildland Fire Dynamics Research for Informed Management

NAFSE WEBINAR SERIES
Spring-Summer 2018
IMPROVED UNDERSTANDING OF WILDLAND FIRE COMBUSTION PROCESSES FOR DEPARTMENT OF DEFENSE MANAGED ECOSYSTEMS

- Given the prevalence of the use of prescribed fire by Department of Defense (DoD) managers to mimic historical, low-intensity surface fires, a primary focus is improved understanding of the processes involved in fine-fuel heat exchange, ignition, and fire spread and how they may be affected by fuel condition.
- Outcomes of proposed research should be developed in a manner that enables them to be incorporated into fire behavior models useful for predicting ecological effects and emissions responses.
SERDP Research Needs

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.
Why does this matter to us?

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- Most models were developed under the context of wildland fire suppression.
  - RxB
  - Burnouts
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- Many models were developed under the context of wildland fire suppression.
- Models were developed with outdated measurement technology and with minimal computational capacity.
  - Rothermel, 1972
A MATHEMATICAL MODEL FOR PREDICTING FIRE SPREAD IN WILDLAND FUELS

Richard C. Rothermel
(Semi) Empirical models of fire behavior

Measurements

Data Sets

Simplified Physics

Computational Model
Detailed physics-based models of fire behavior (e.g. CFD)

Fundamental Physical Principles

\[ F = m \frac{dv}{dt} = ma \]

\[ \rho \frac{Dv}{Dt} = -\nabla p + \mu \nabla^2 v + \rho g \]

\[ \Delta E^{\text{tot}} = Q + W \]

Physical Assumptions & Numerical Approximations

Computational Model
Technical objectives

1) Physical processes at multiple scales
   • Heat transfer: Radiative and convective
   • Ignition
   • Thermal degradation
   • Flaming and smoldering combustion
   • Mass consumption
   • Fire propagation particles and fuel layers scale.

2) Fuel-bed characteristics
   • Spatial variability in fuel particle type
   • Fuel moisture status
   • Bulk density
   • Arrangement of fuel components

3) Multi-scale atmospheric dynamics
   • Understanding of the effects of multi-scale atmospheric dynamics:
     • Ambient and fire- and forest overstory-induced turbulence on fire spread and convective heat transfer
1. Why are low-intensity fires important?
   ○ Management tool
   ○ Fire Suppression (long linear fire features with a wind shift)
Questions

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   - Fire Suppression (long linear fire features with a wind shift)

2. Why are they difficult for us to model?
   - Physical processes at multiple-scales (sub-grid cell)
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   - Fuel-bed characteristics
   - Multi-scale atmospheric dynamics

3. What is our approach?
Project Team

USDA Forest Service
Dr. Nicholas Skowronsni
Remote sensing and wildland fire

Dr. Warren Heilman
Boundary-layer meteorology and fire-atmospheric interactions.

Dr. Kenneth Clark
Meteorological measurements of the fire environment

Dr. William Mell
Computer modeling of wildland fire

Dr. John Hom
Smoke monitoring, fuel mapping, and fire meteorology

Dr. Joseph Charney
Computer modeling of meteorological processes in wildland fire

Dr. Michael Gallagher
Remote sensing and field measurement of fire effects

Michigan State University
Dr. Sharon Zhong
Atmospheric transport and dispersion modeling

Dr. Michael Kiefer
Atmospheric transport and dispersion modeling

University of Edinburgh
Prof. Rory Hadden
Smoldering combustion and laboratory measurements

Dr. Eric Mueller
WFDS Modeling

Worchester Polytechnic Institute
Prof. Albert Simeoni
Prof. Ali Rangwala
Bench- and large-scale fire experiments

University of Notre Dame
Prof. Seong-kyun Im
Design of laboratory flame-flow experiments

Rochester Institute of Technology
Dr. Robert Kremens
Design and engineering of sampling equipment.

West Virginia University
Prof. Charles Yuill
Remote sensing scientist linking active and optical methods.
A. Numerical Modeling

B. Small-scale laboratory experiments

C. Mid-scale laboratory experiments

D. Small-scale field experiments

E. Operational burn observations
A. Numerical modeling (Theory)

- Low-intensity fires + large scale + detailed physics-based models =

- High sensitivity to small-scale phenomena which have not been adequately described/characterized and are under-resolved

Already demonstrated for moderate- to high-intensity fires…

E.g.: roughly ±40% change in spread rate due to uncertainty in drag coefficient ($c_d$)
B. Small-Scale laboratory experiments
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Mass loss (left) and mass loss rate (right) based on different sidewall heights
A. Numerical modeling
C. Large-Scale laboratory experiments
Flow Characterization

- Pitot probe array
- 7 pitot probes connected to differential pressure transducers
- Evenly spaced across exit to test section

\[
p_t = p_s + \left( \frac{\rho u^2}{2} \right)
\]

\[
u = \sqrt{\frac{2(p_t - p_s)}{\rho}}
\]
Flow Characterization

○ Current flow field
□ 2 Honeycombs
□ 1 screen
D. Small-scale field experiments
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D. Small-scale field experiments: Modeling

Initialization and testing of model for experiments in Silas Little plantation
E. Large-scale field experiments

○ Need to link small-scale laboratory test conditions to realistic field conditions

□ *Flow, heat flux, and temperature in the litter:*

○ Autonomous and robust integrated sensor package
E. Large-scale field experiments

○ Need to link small-scale laboratory test conditions to realistic field conditions
○ *Spread rate, residence time, front depth:*
○ GPS-enabled thermocouple loggers (‘Fire Trackers’)

![Image of small-scale laboratory test conditions]

![Image of large-scale field experiments]
Idealized ARPS-simulated vertical wind speeds, potential temperatures, and turbulent kinetic energy in response to a surface fire.
Upcoming Webinars

• 3-D Fuels – Dr. Mike Gallagher – May 16th
• Next Generation Fire Environment Measurements – Dr. Bob Kremens – May 29th
• Small-scale Instrumented Burns – Dr. Ken Clark – June 12th
• Lab-Scale Burning Experiments – Dr. Rory Hadden – June 27th
• Wind-Tunnel Experiments – Dr. Seong-kyun Im and Dr. Albert Simeoni (split presentation) – July 11th
• Numerical Simulations of Fire Dynamics – Dr. Eric Mueller – July 25th
• Numerical Simulations of Atmospheric Turbulence – Dr. Mike Kiefer – August 8th
Joint Fire Science Program awards:

10-1-02-04: Assessment of Canopy Fuel Loading Across a Heterogeneous Landscape Using LiDAR

DoD Strategic Research and Development Program award:

RC-2641: Multi-Scale Analyses of Wildland Fire Combustion Processes in Open-Canopied Forests Using Coupled and Iteratively Informed Laboratory-, Field-, and Model-Based Approaches
Upcoming Webinars

• “From Rothermel’s models to 3D scanners - getting a closer look fuel properties and their role in prescribed fire dynamics” – Dr. Mike Gallagher – May 16th
• “Progress towards precision measurements of radiant and convective flows in wildland fires: History and current state of the art” – Dr. Bob Kremens - May 29th
• “Small-scale fire behavior measurements in the field: Bridging the gap between the laboratory and management-scale prescribed fires” – Dr. Ken Clark – June 12th
• “Measurement of Fire Spread Phenomena at the Laboratory Scale.” – Dr. Rory Hadden – June 27th
• “Developing a mid-scale portable wind tunnel for laboratory and field experiments”.– Dr. Seong-kyun Im and Dr. Albert Simeoni (split presentation) – July 11th
• “High resolution simulation of low-intensity and backing fires: a multi-scale model development exercise” – Dr. Eric Mueller – July 25th
• “Management-scale atmospheric modeling: Exploring fire-induced turbulent flows in forested environments” – Dr. Mike Kiefer – August 8th

NAFSE site for the full schedule