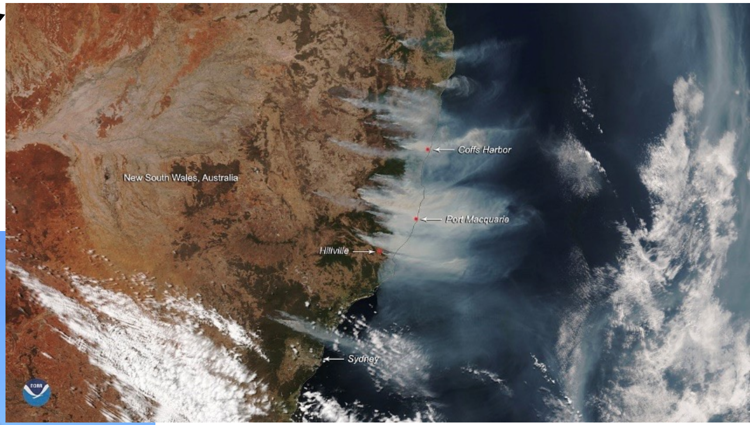
Computational Fluid Dynamics modeling of WUI fires – applications and challenges

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

Eric Victor Mueller

Motivation

For the complex problem of wildland and WUI fires…



length

time

…numerical modeling is simultaneously difficult and valuable

Motivation

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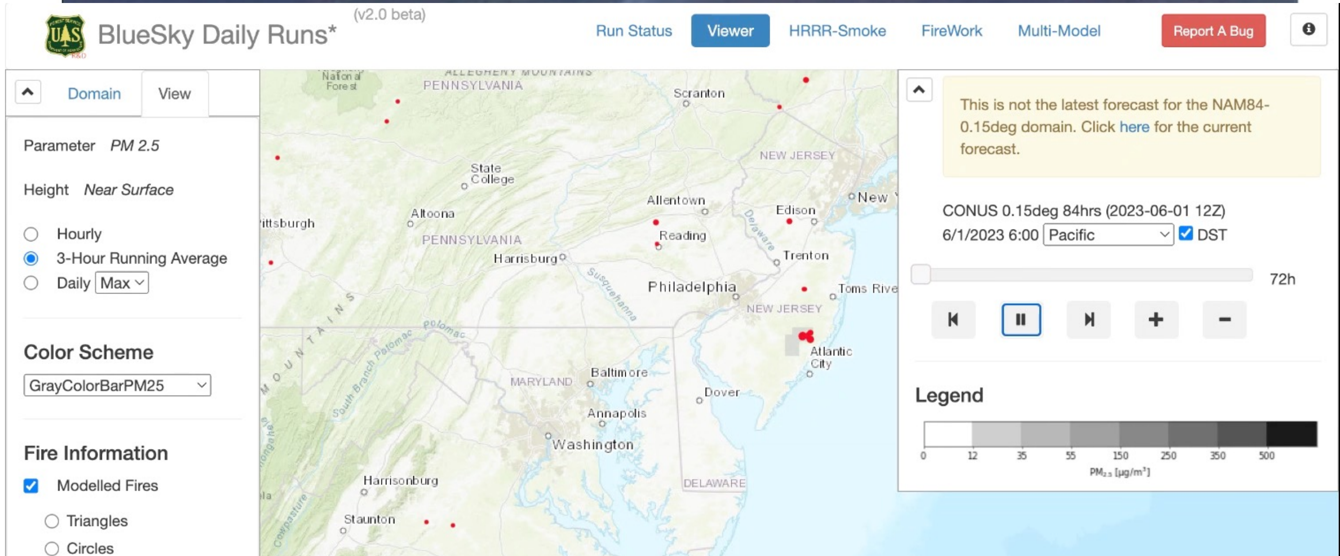
New Jersey Forest Fire Service
@njdepforestfire

WILDFIRE UPDATE: Allen Road Wildfire – Bass River State Forest

At 1:30 p.m. Saturday, June 3, the New Jersey Forest Fire Service has reached 100 percent containment of a 5,475-acre wildfire in the area of Allen Road in Bass River State Forest.

1:41 PM · Jun 3, 2023 · **13.4K** Views

https://www.fox29.com/news/allen-road-fire-uncontained-wildfire-torches-thousands-of-acres-in-nj-causes-traffic-changes



Motivation

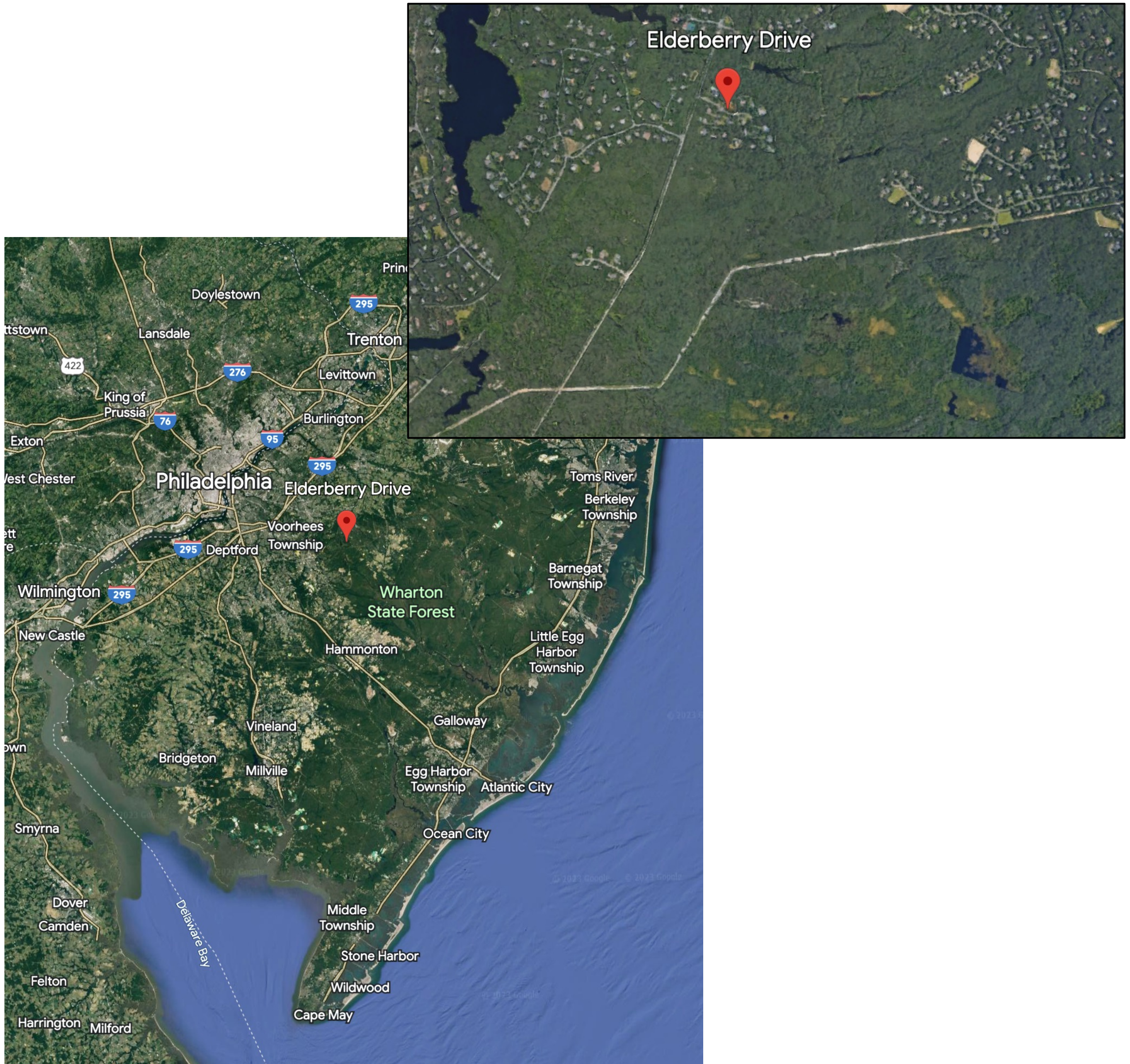
NIST ENGINEERING LABORATORY

New Jersey Forest Fire Service
@njdepforestfire

WILDFIRE UPDATE: Flatiron Wildfire – Medford, Burlington County

At 6:00 p.m. Saturday, June 3, the New Jersey Forest Fire Service has reached 100 percent containment of a 210-acre wildfire in the area of Elderberry Dr. & Jackson Rd. in Medford, Burlington County.

6:57 PM · Jun 3, 2023 · **21.9K** Views



Motivation

https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2135.pdf

Photo courtesy of TD-041, 03:20 (Nov 9). Used with permission.

Photo courtesy of TD-041, 03:22 (Nov 9). Used with permission.

https://www.businessinsider.com/santa-rosa-fire-update-diablo-winds-2017-10:
California Highway Patrol/Golden Gate Division via Reuters

What role can CFD models play?

Motivation

2018 NATIONAL PRESCRIBED FIRE USE SURVEY REPORT

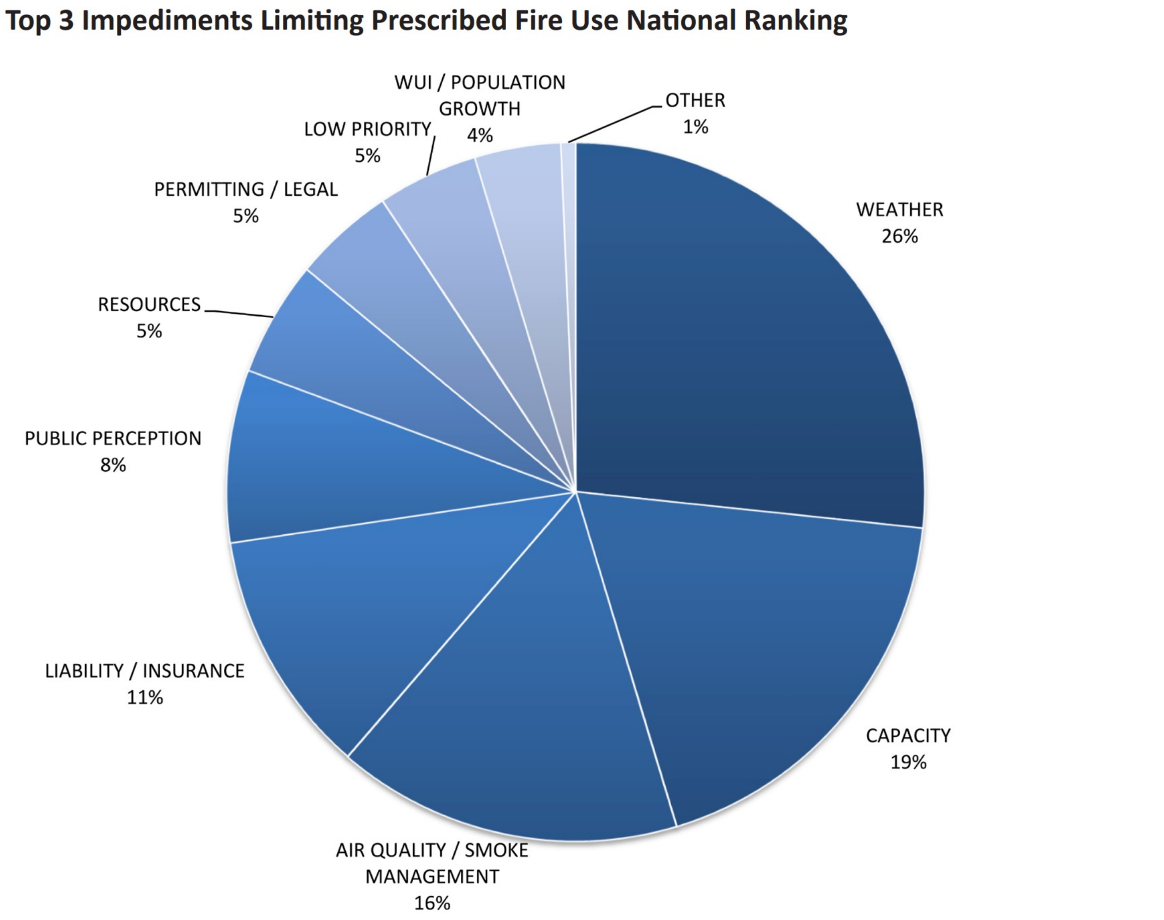


Figure 24. National summary of the top three impediments reported by states. Weather, capacity, and air quality/smoke management were the three highest ranked among all categories.

Hermits Peak/Calf Canyon fire. Source: inciweb.nwcg.gov

Motivation

NIST ENGINEERING LABORATORY

Hiers *et al. Fire Ecology* (2020) 16:11
https://doi.org/10.1186/s42408-020-0070-8

Fire Ecology

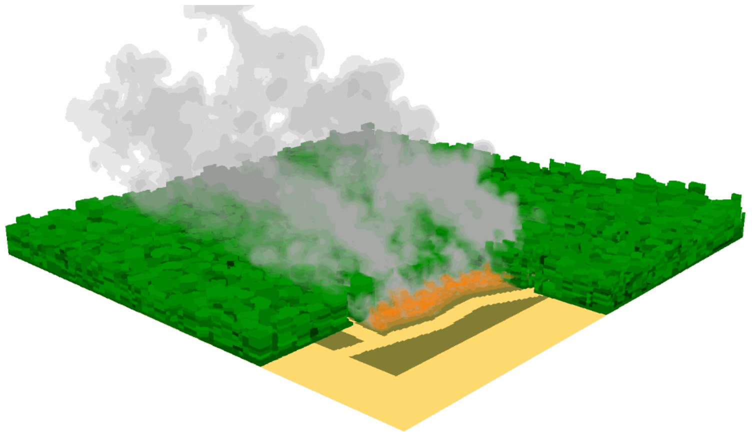
Association for Fire Ecology

FORUM **Open Access**

Prescribed fire science: the case for a refined research agenda

Check for updates

J. Kevin Hiers[1*], Joseph J. O'Brien[2], J. Morgan Varner[1,3], Bret W. Butler[4], Matthew Dickinson[5], James Furman[6], Michael Gallagher[7], David Godwin[8], Scott L. Goodrick[2], Sharon M. Hood[4], Andrew Hudak[9], Leda N. Kobziar[10], Rodman Linn[11], E. Louise Loudermilk[2], Sarah McCaffrey[12], Kevin Robertson[1], Eric M. Rowell[1], Nicholas Skowronski[13], Adam C. Watts[14] and Kara M. Yedinak[15]



"

- What spatial scale of variation in fuel influences fire behavior?
- How does ignition pattern influence interaction of firelines?
- How can we model manipulation of fire lines and other backing and flanking ignition patterns?
- What are opportunities to expand or modify prescribed burning windows to meet objectives without compromising safety?
- How do plumes differ in low-intensity, small prescribed fires in comparison to higher-intensity, larger wildfires?

"

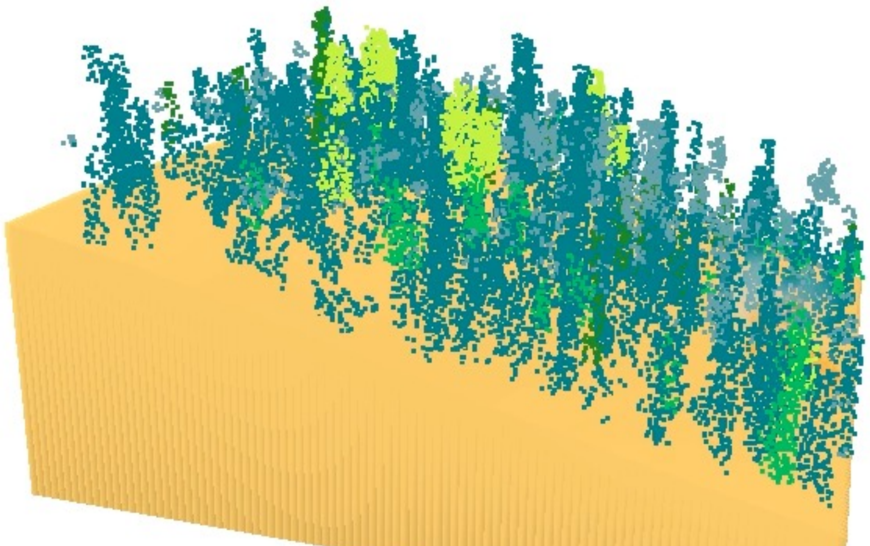
CFD in broad terms

CFD: Computational Fluid Dynamics

CFD in broad terms

	Fluid model	Fire process models	Computational cost
'fully-physical' *'detailed physical'*	-Time resolved 3D turbulent flow	-Solid phase heat transfer and decomposition -Heterogenous and homogeneous combustion -Radiation transport	-High

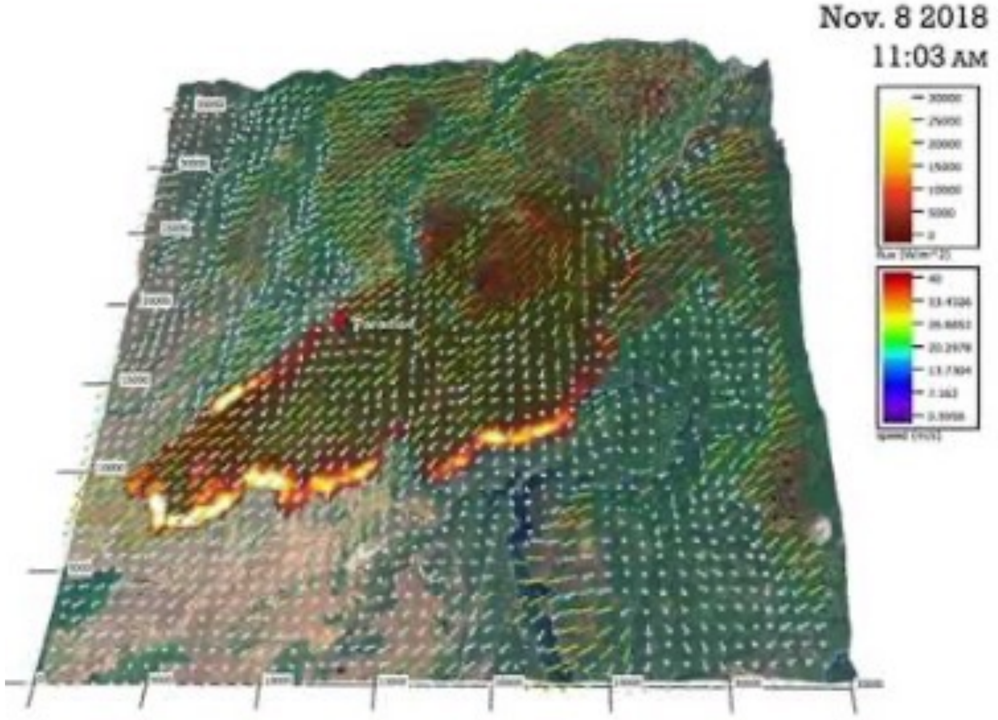
Example:
FireFOAM/ForestFireFOAM,
FIRESTAR3D, FIRETEC,
W/FDS

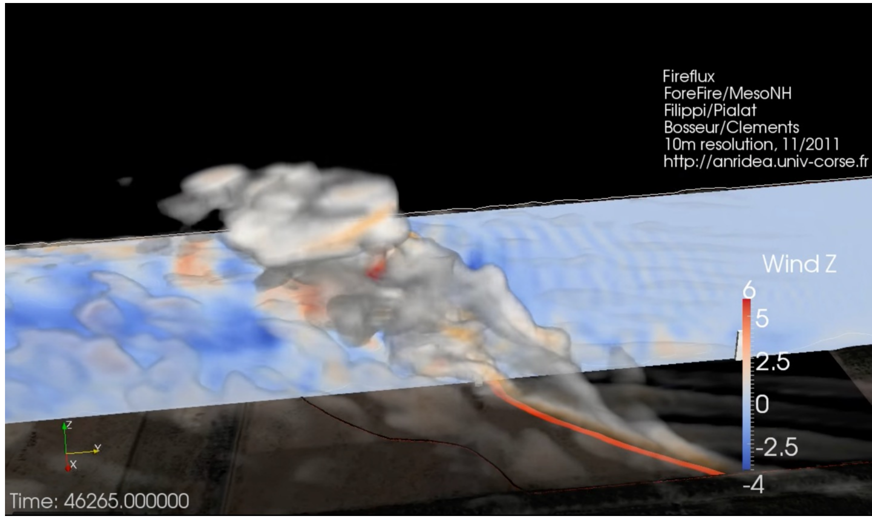


CFD in broad terms

	Fluid model	Fire process models	Computational cost
'coupled fire-atmosphere'	-Time resolved 3D turbulent flow	-Parameterized fire spread and fluxes	-Medium

Example: ARPS, CAWFEE, ForeFire/Meso-NH





https://feuxdeforet.universita.corsica/article.php?id_art=2140&id_rub=572&id_menu=0&id_cat=0&id_site=33&lang=en

CFD in broad terms

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	Fluid model	Fire process models	Computational cost
'semi-empirical' *'operational'*	-Stationary or uncoupled wind field	-Parameterized fire spread	-Low

Example: Farsite with WindNinja

https://www.firelab.org/project/flammap

A (brief) intro to ‘detailed’ CFD for vegetation fires

Solving 3D turbulent reacting flows

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Momentum

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \cdot \rho \mathbf{u}\mathbf{u} + \nabla p = \rho \mathbf{g} + \mathbf{f}_b + \nabla \cdot \tau_{ij}$$

Energy

$$\frac{\partial}{\partial t}(\rho h_s) + \nabla \cdot \rho h_s \mathbf{u} = \frac{\mathrm{D}p}{\mathrm{D}t} + \dot{q}''' - \dot{q}_b''' - \nabla \cdot \dot{\mathbf{q}}''$$

Mass

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = \dot{m}_b'''$$

Species

$$\frac{\partial}{\partial t}(\rho Y_\alpha) + \nabla \cdot \rho Y_\alpha \mathbf{u} = \nabla \cdot \rho D_\alpha \nabla Y_\alpha + \dot{m}_\alpha''' + \dot{m}_{b,\alpha}'''$$

Equation

of state

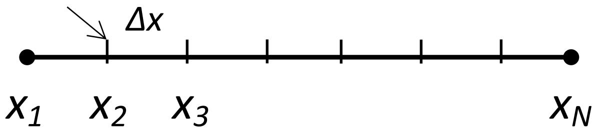
$$p = \frac{\rho \mathcal{R} T}{\overline{W}}$$

Solving 3D turbulent reacting flows

Discretization for approximation of derivatives

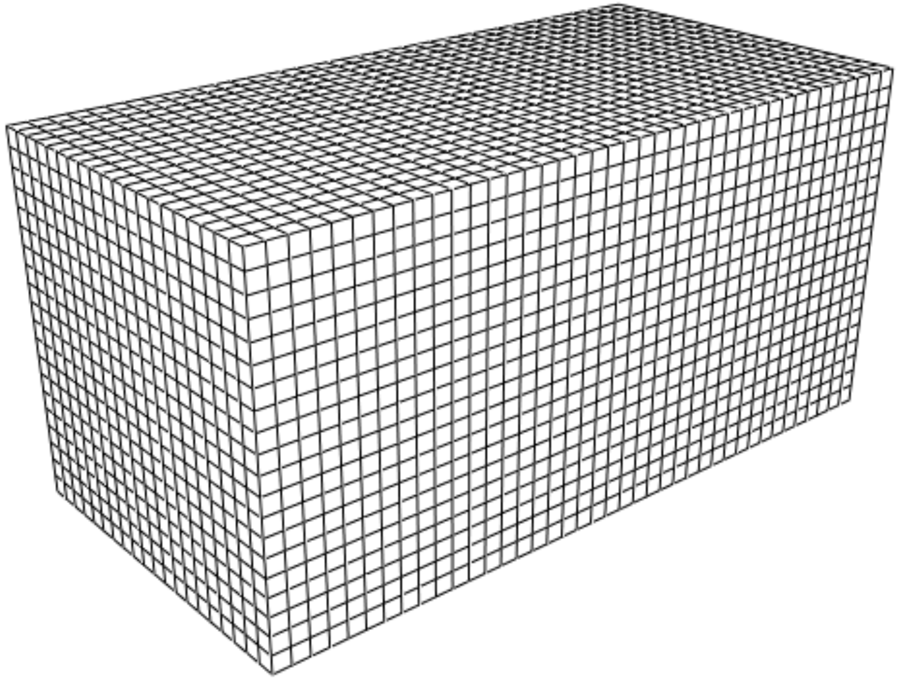
E.g.

$\frac{df}{dx} = ?$



$$\frac{df}{dx} = \frac{f(x_3) - f(x_1)}{2\Delta x}$$

- Can extend to 3D →



- And time

↓

$$\frac{df}{dt} = \frac{f(x)_{t+\Delta t} - f(x)_t}{\Delta t}$$

Solving 3D turbulent reacting flows

Submodels include…

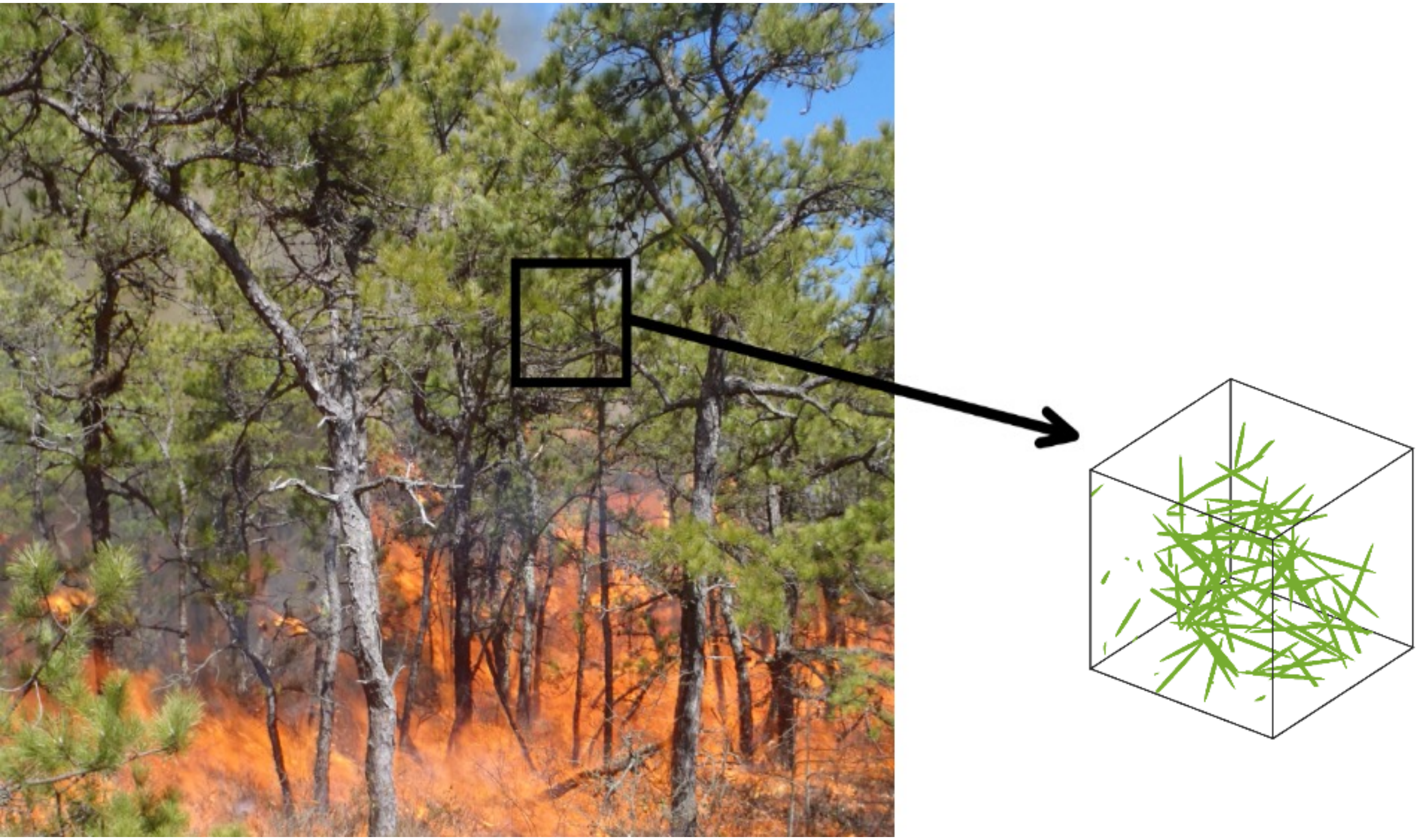
https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2135.pdf

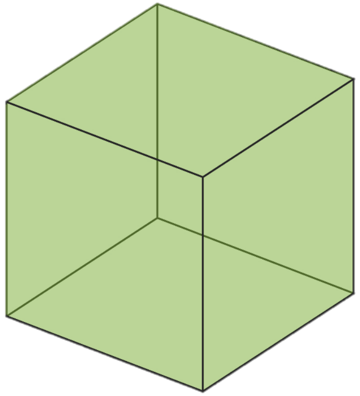
- Turbulence (e.g. Large Eddy Simulation models)
- Combustion
- Radiation
- Soot
- Wall models/Solid phase heat transfer/decomposition

Photo courtesy of TD-041, 03:22 (Nov 9). Used with permission.

Including vegetation

Multiphase model for vegetation

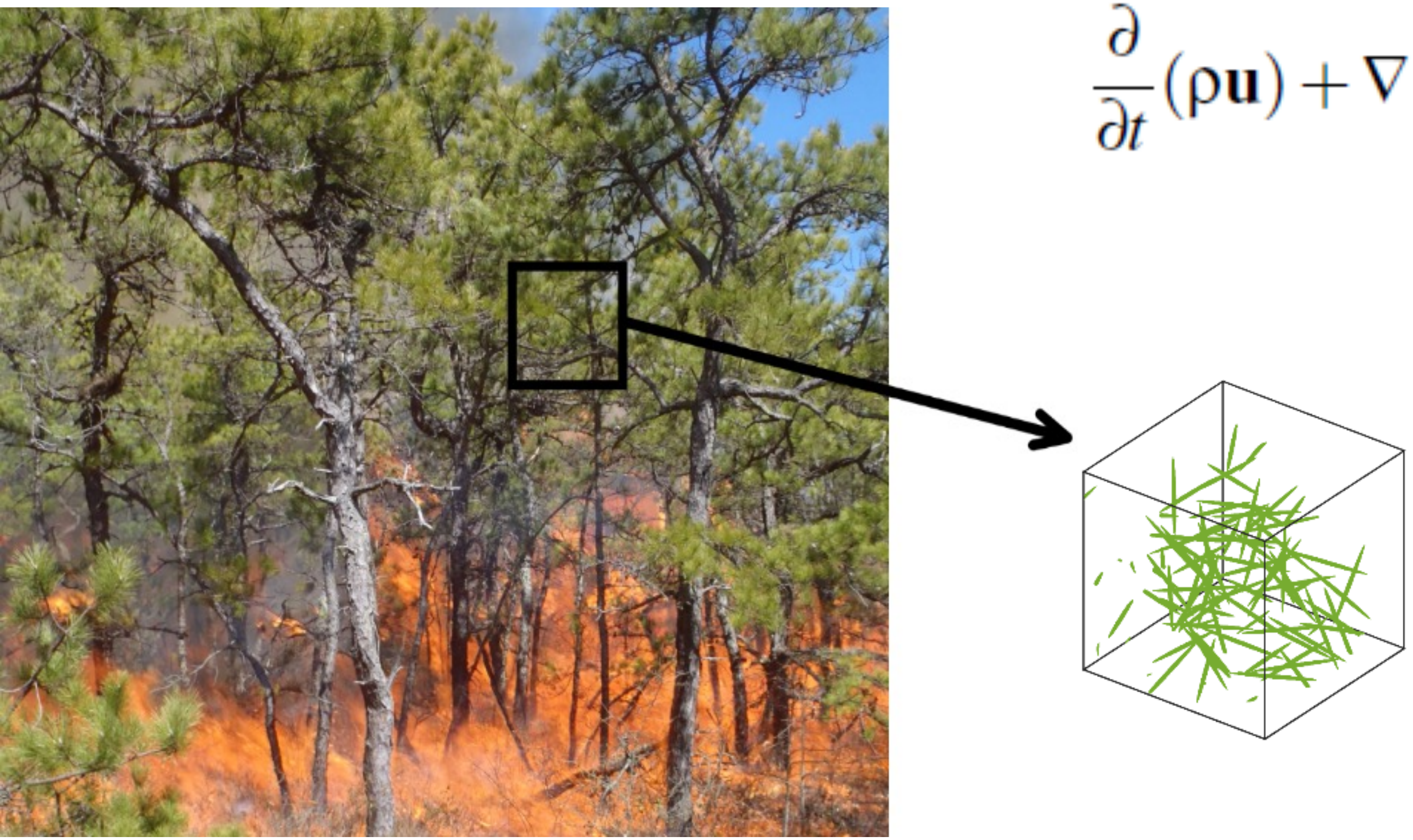


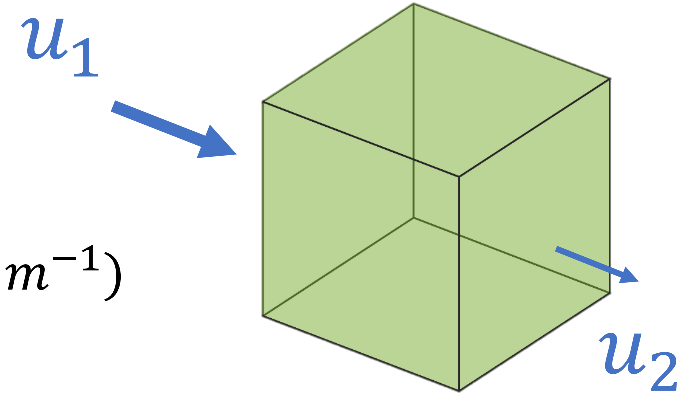


Particle surface-to-volume ratio: σ_e (m^{-1})
Fuel packing ratio: β_e $(-)$

Multiphase model for vegetation

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \cdot \rho \mathbf{u}\mathbf{u} + \nabla p = \rho \mathbf{g} + \underline{\mathbf{f}_b} + \nabla \cdot \tau_{ij}$$

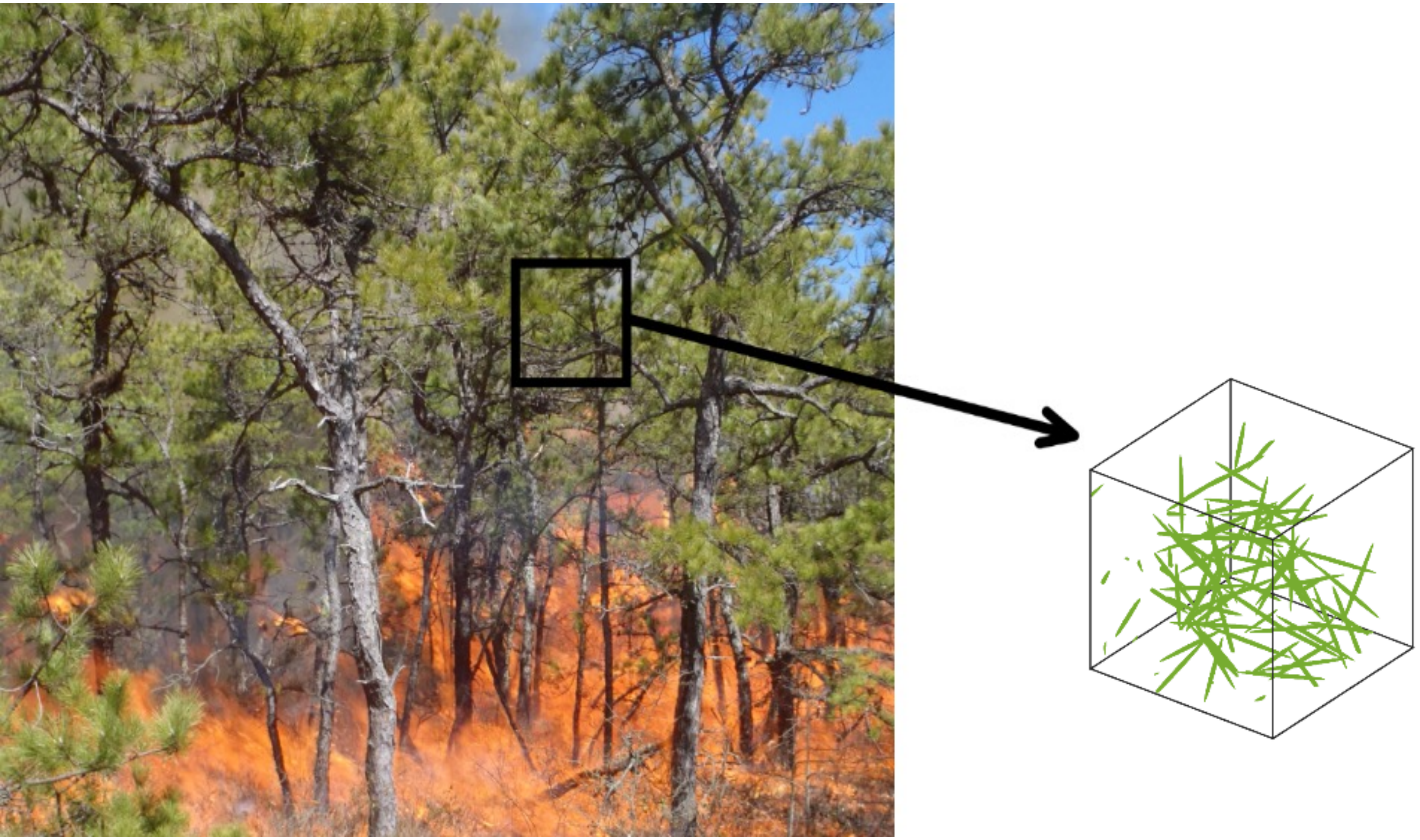


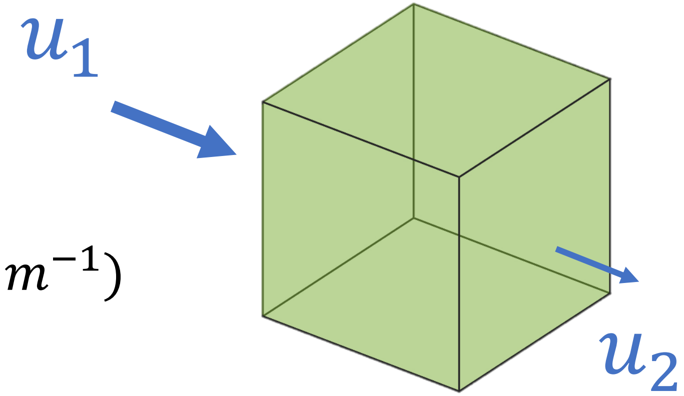


Particle surface-to-volume ratio: σ_e (m^{-1})
Fuel packing ratio: β_e $(-)$

Multiphase model for vegetation

- $F_d''' = \sigma_e \beta_e c_s c_d \rho u^2$

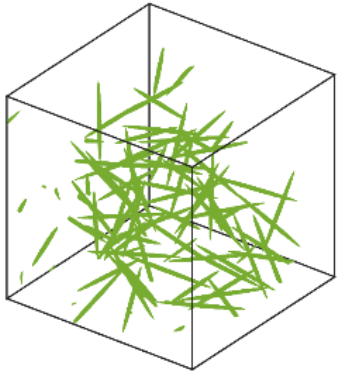


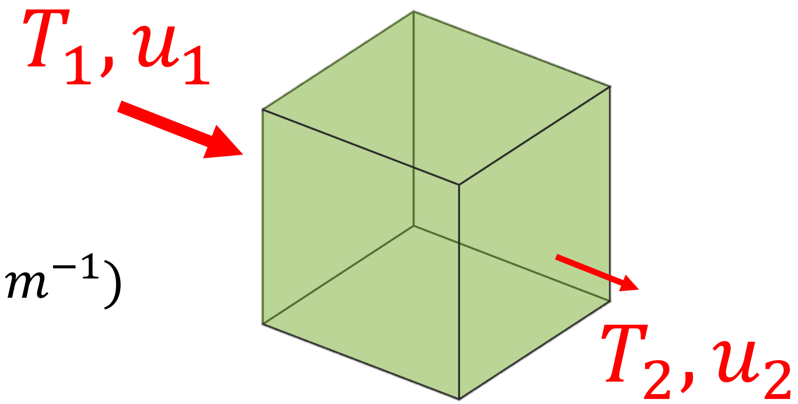


Particle surface-to-volume ratio: σ_e (m^{-1})
Fuel packing ratio: β_e $(-)$

Multiphase model for vegetation

$$\frac{\partial}{\partial t}(\rho h_s) + \nabla \cdot \rho h_s \mathbf{u} = \frac{\mathrm{D}p}{\mathrm{D}t} + \dot{q}''' - \underline{\dot{q}_b'''} - \nabla \cdot \dot{\mathbf{q}}''$$

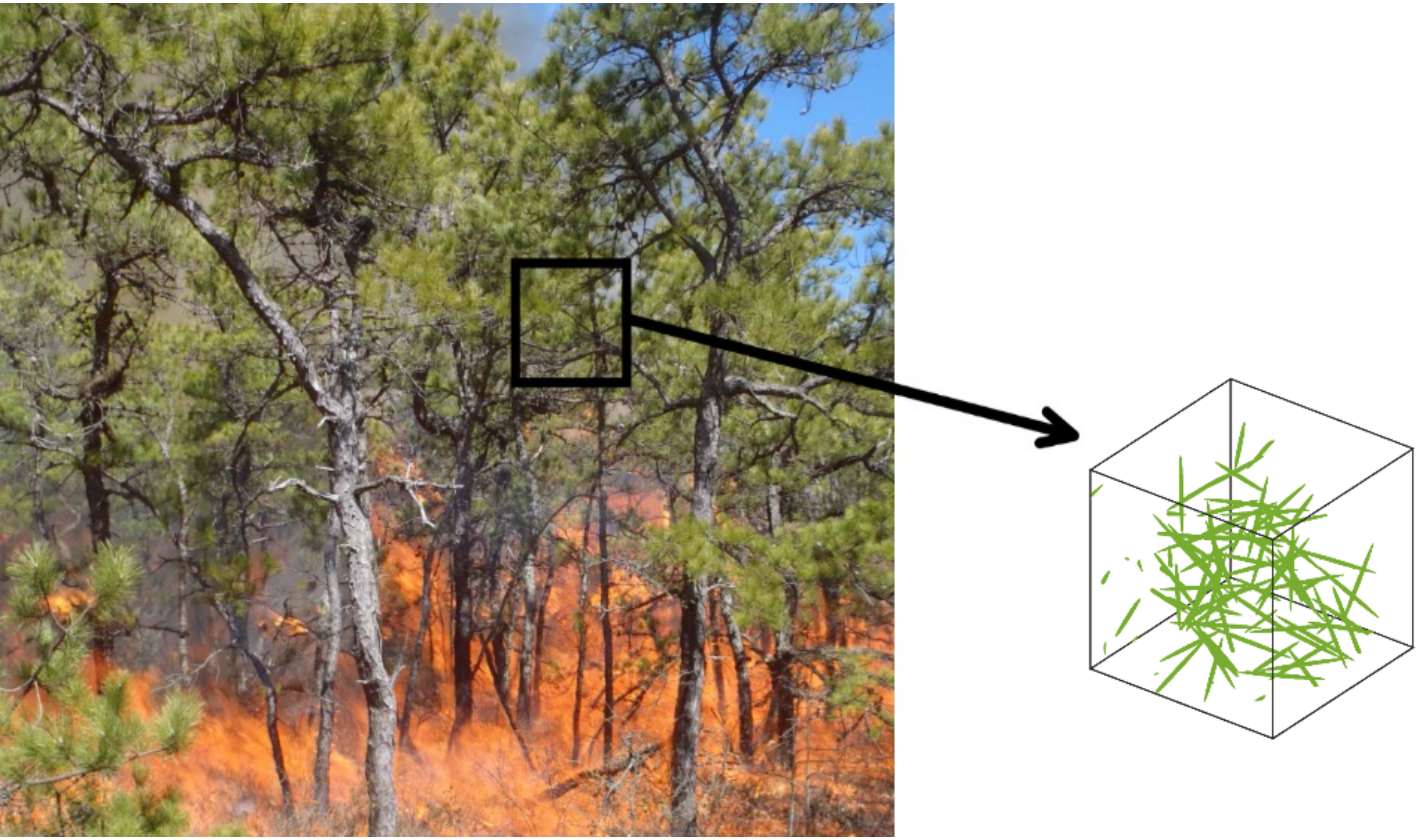


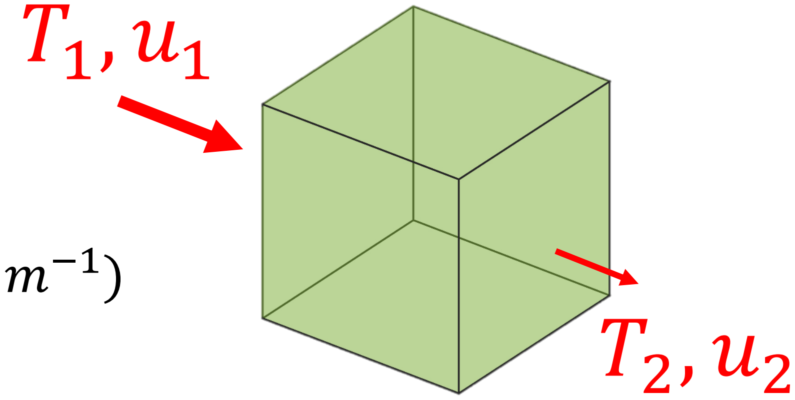


Particle surface-to-volume ratio: σ_e (m^{-1})
Fuel packing ratio: β_e $(-)$

Multiphase model for vegetation

- $F_d''' = \sigma_e \beta_e c_s c_d \rho u^2$
- $\dot{q}_c''' = \sigma_e \beta_e h_c (T_g - T_e)$

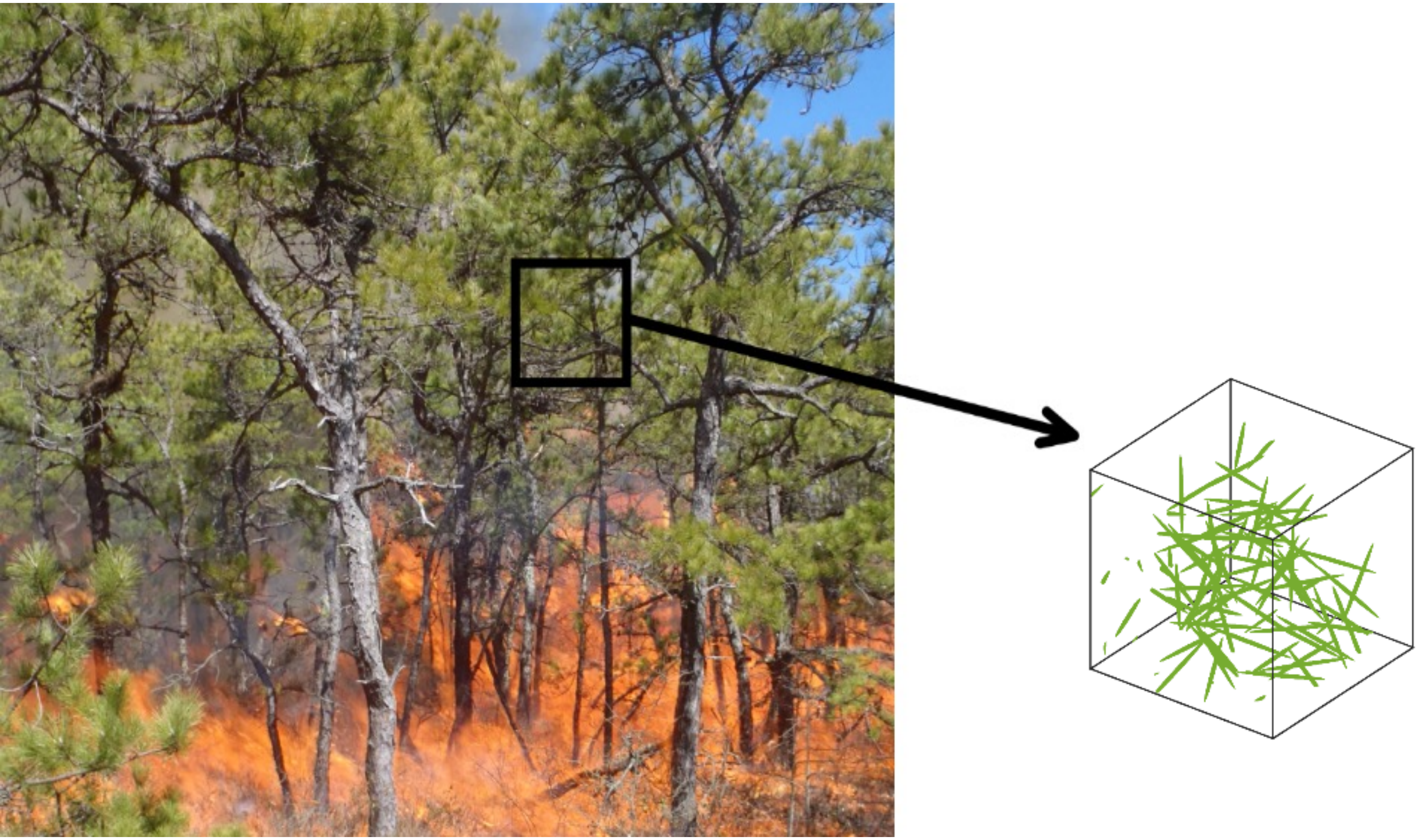


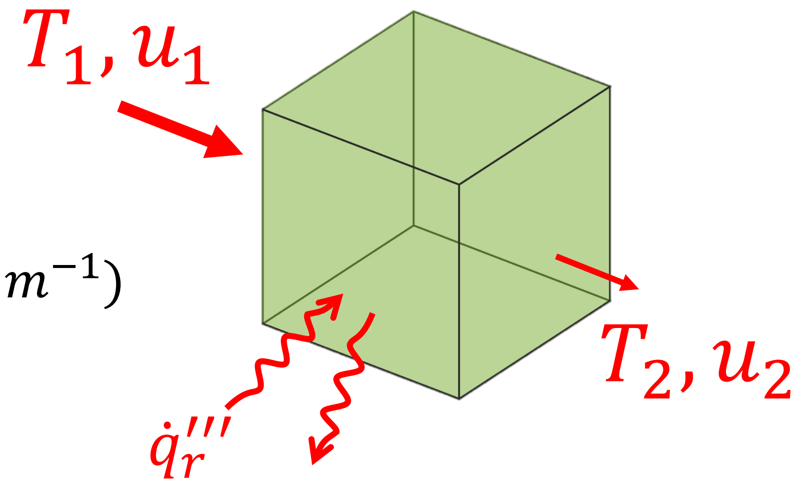


Particle surface-to-volume ratio: σ_e (m^{-1})
Fuel packing ratio: β_e $(-)$

Multiphase model for vegetation

$$\nabla \cdot \dot{\mathbf{q}}_{\mathbf{r}}'' = \kappa\,[4\pi I_b(T) - U] + \nabla \cdot \dot{\mathbf{q}}_{\mathbf{r,e}}''$$

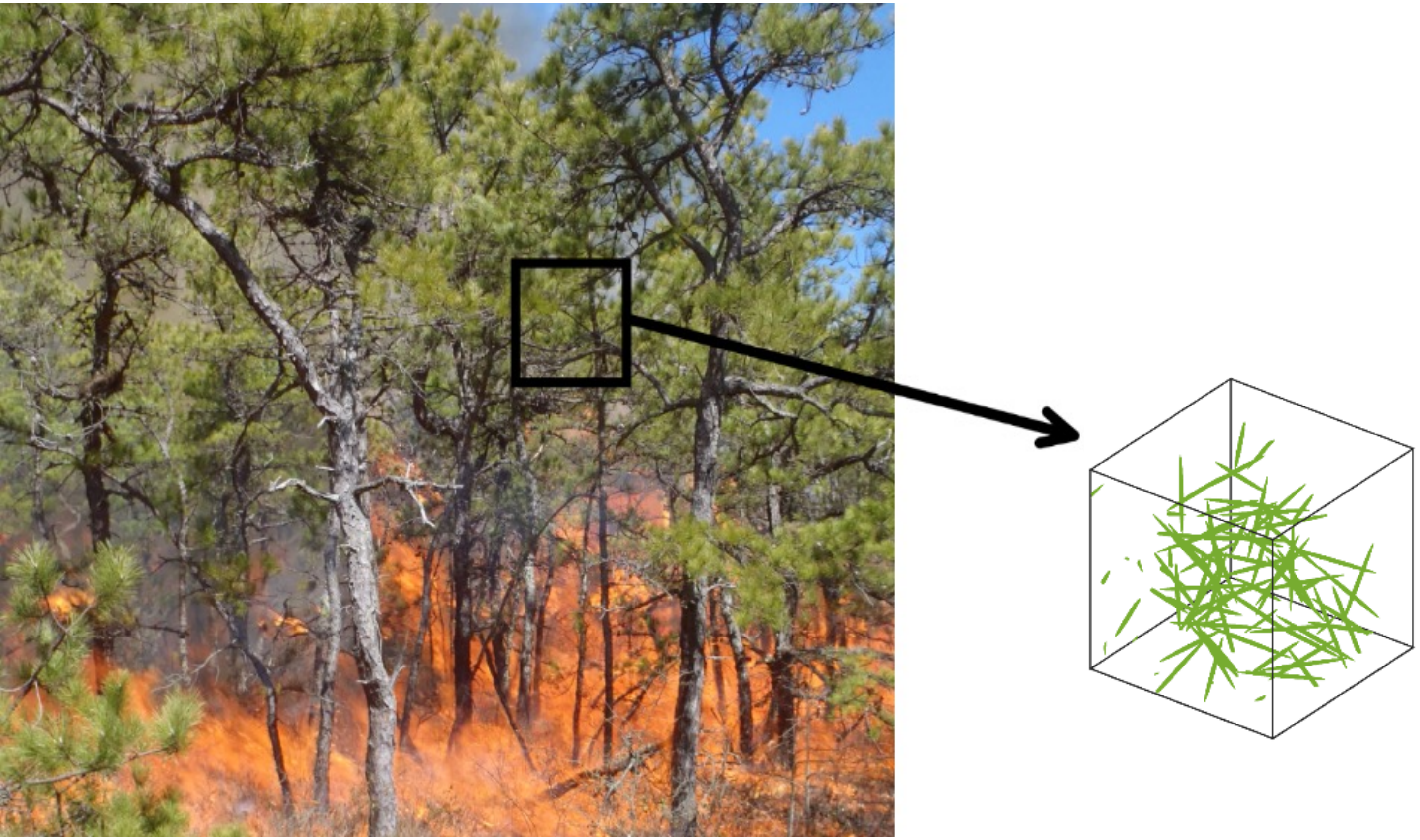




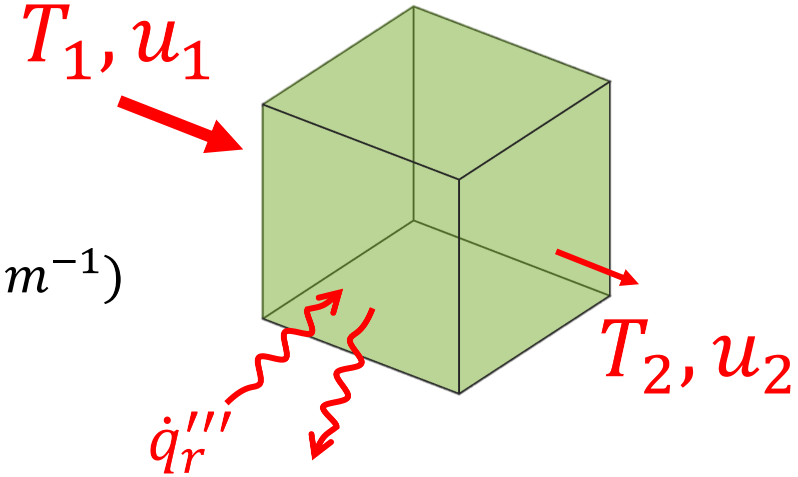
Particle surface-to-volume ratio: σ_e (m^{-1})
Fuel packing ratio: β_e $(-)$

Multiphase model for vegetation

- $F_d''' = \sigma_e \beta_e c_s c_d \rho u^2$
- $\dot{q}_c''' = \sigma_e \beta_e h_c (T_g - T_e)$
- $\nabla \cdot \dot{\boldsymbol{q}}_r'' = \varepsilon \frac{\sigma_e \beta_e}{4} (U - 4\sigma {T_e}^4)$



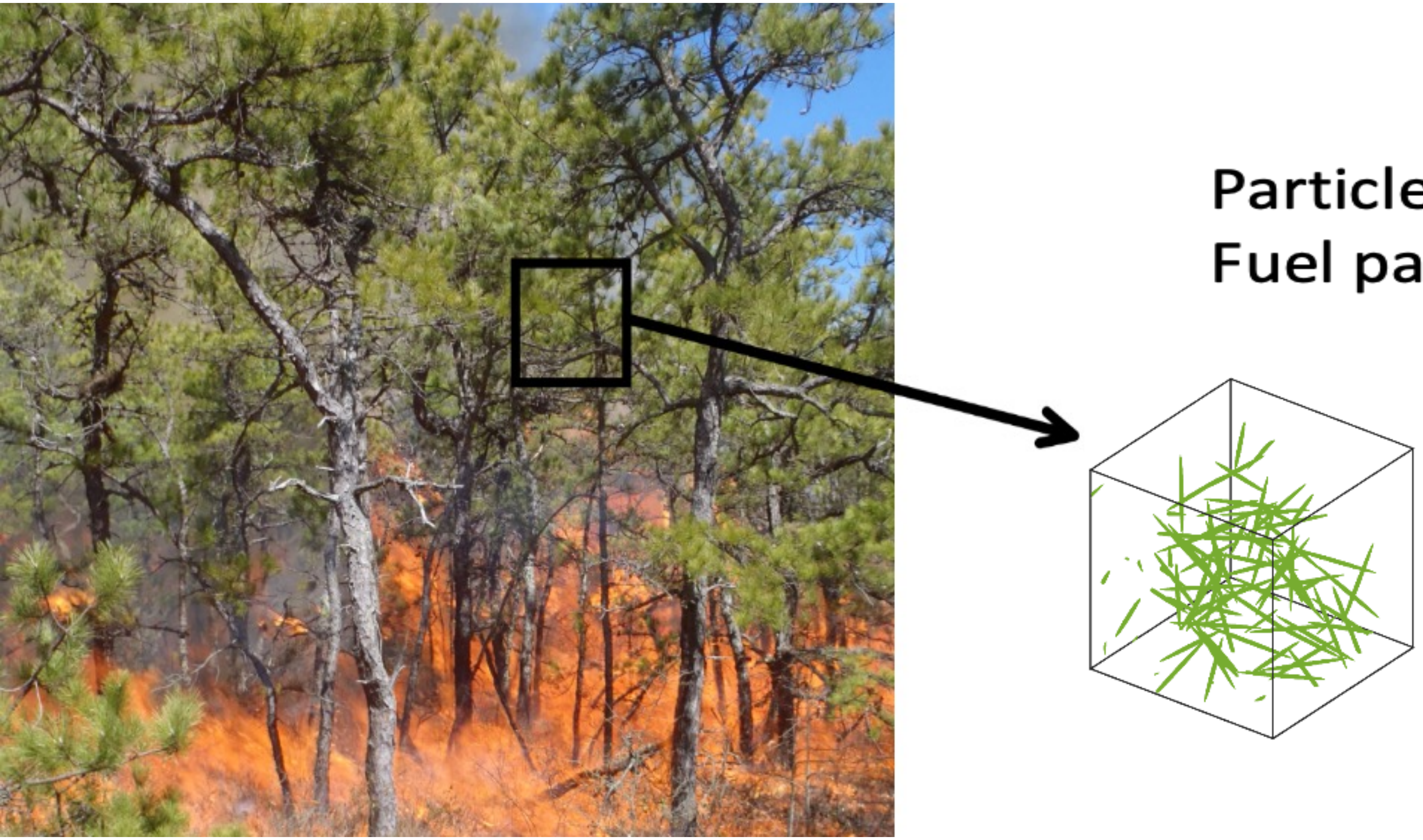
Particle surface-to-volume ratio: σ_e (m^{-1})
Fuel packing ratio: β_e $(-)$

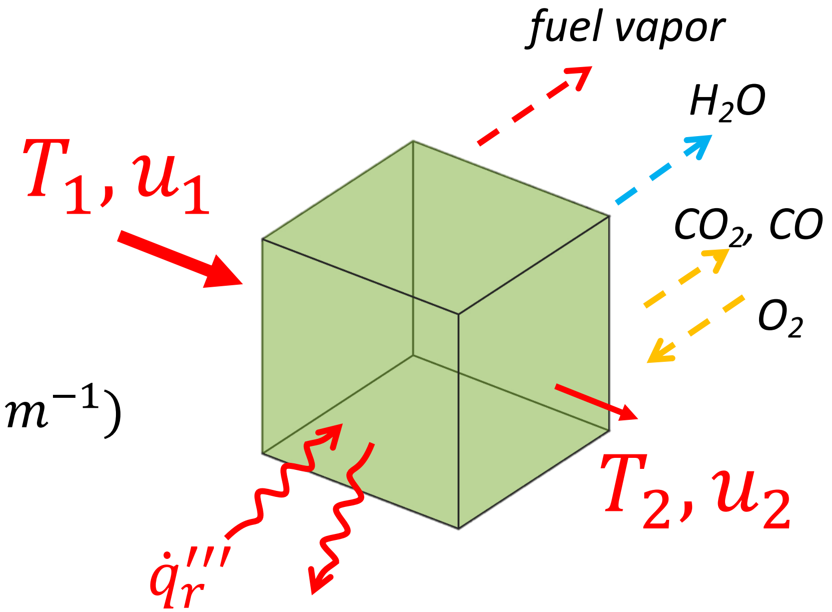


Multiphase model for vegetation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = \dot{m}_b'''$$

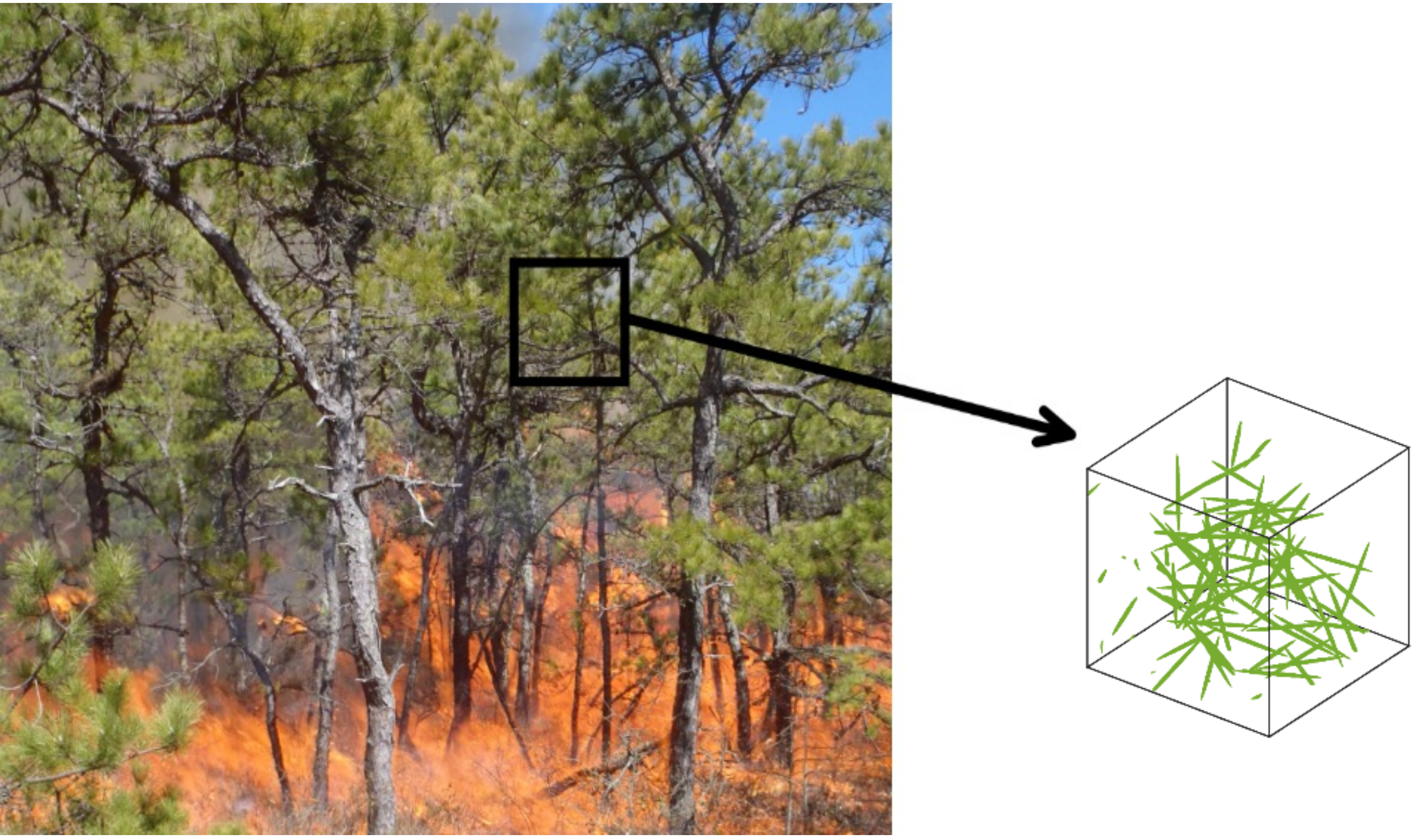
Particle surface-to-volume ratio: σ_e (m^{-1})
Fuel packing ratio: β_e $(-)$



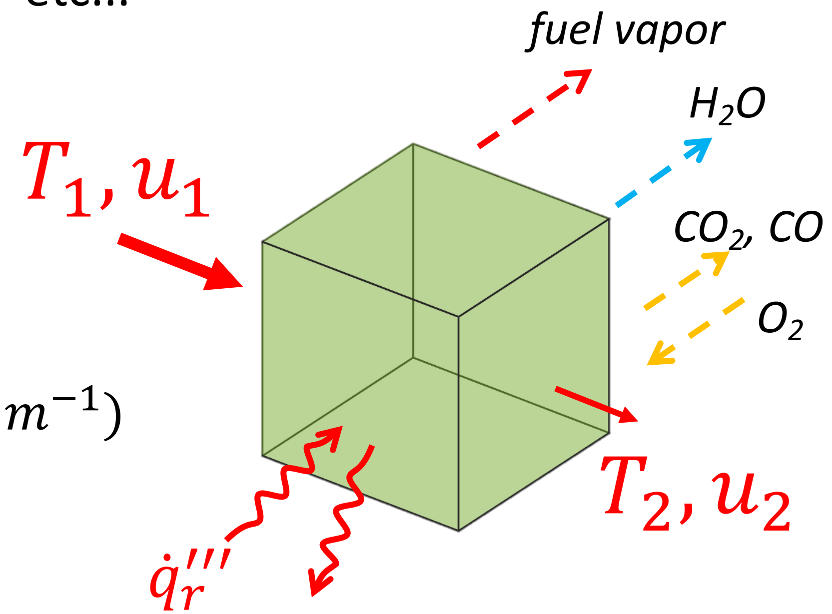


Particle surface-to-volume ratio: σ_e (m^{-1})
Fuel packing ratio: β_e $(-)$

Multiphase model for vegetation

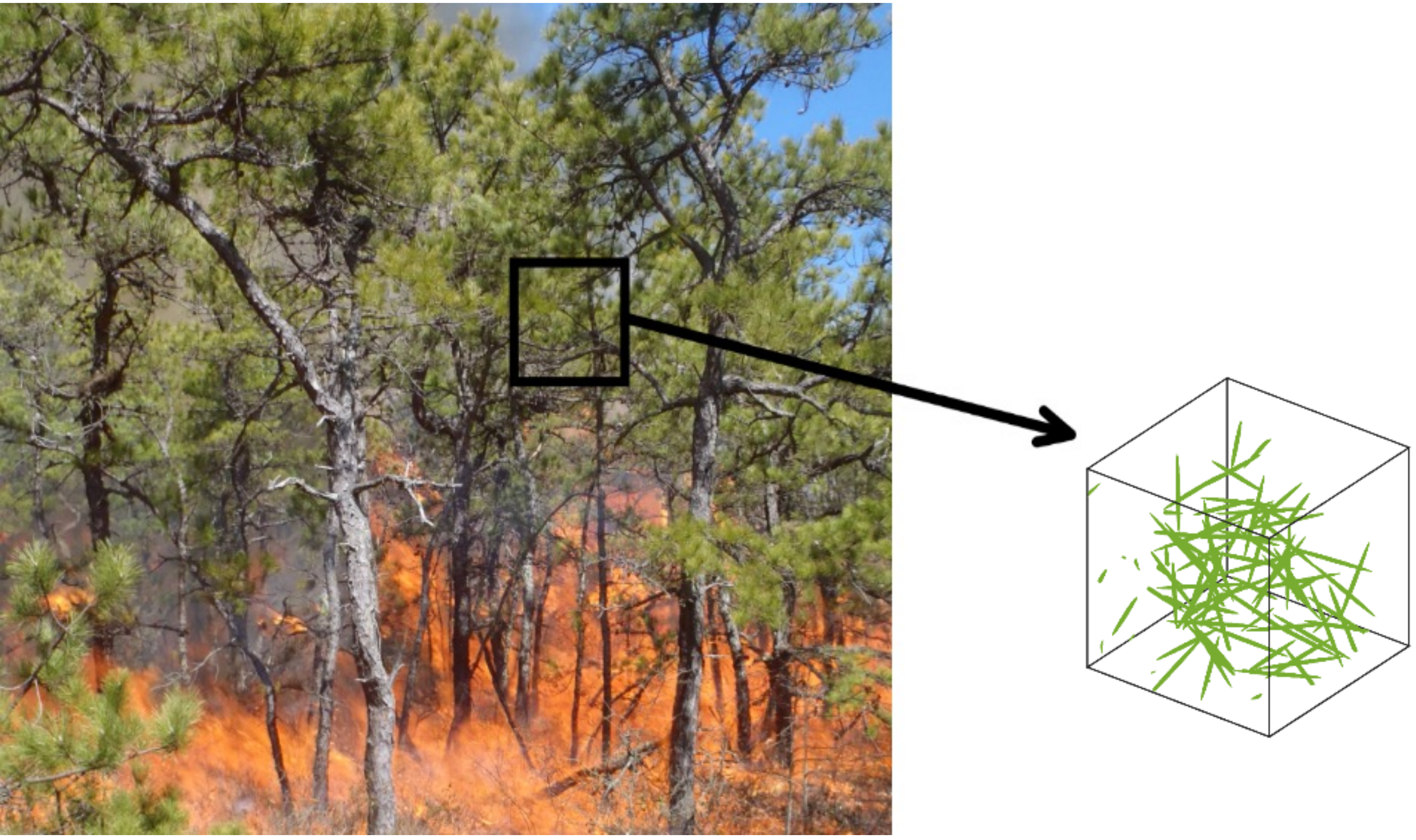


- $F_d''' = \sigma_e \beta_e c_s c_d \rho u^2$
- $\dot{q}_c''' = \sigma_e \beta_e h_c (T_g - T_e)$
- $\nabla \cdot \dot{\boldsymbol{q}}_{r,e}'' = \varepsilon \frac{\sigma_e \beta_e}{4} (U - 4\sigma {T_e}^4)$
- $r_{pyr} = \rho_{dry} A_{pyr} \exp[{}^{-E_{pyr}}/_{RT_e}]$
- etc...



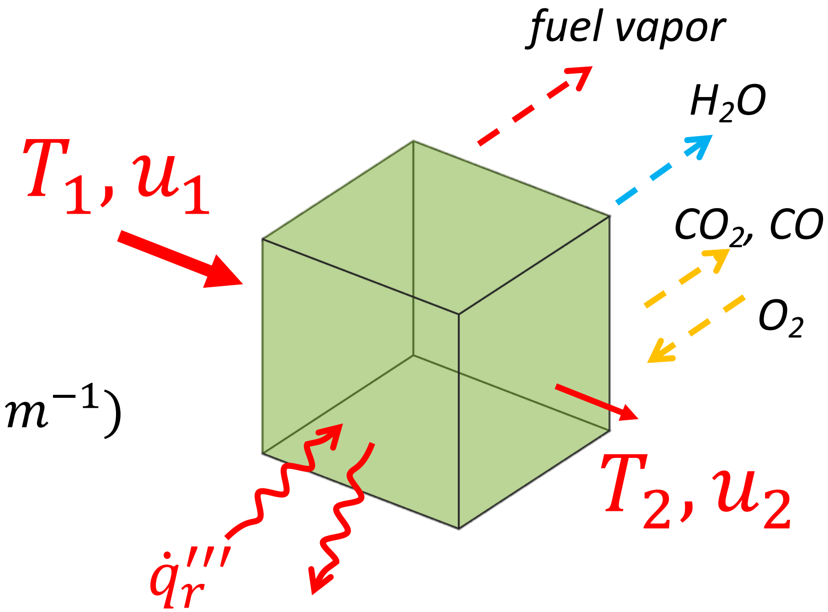
Particle surface-to-volume ratio: σ_e (m^{-1})
Fuel packing ratio: β_e $(-)$

Multiphase model for vegetation



$$\beta_e c_{p,s} \rho_s \frac{\partial T_e}{\partial t} = \dot{q}_c''' + \nabla \cdot \dot{\boldsymbol{q}}_{r,e}'' + \dot{q}_{rxn}'''$$

$$\frac{\partial \beta_e \rho_s}{\partial t} = \dot{m}_b'''$$



Particle surface-to-volume ratio: σ_e (m^{-1})
Fuel packing ratio: β_e $(-)$

Multiphase model for vegetation

Pioneers…

A.M. Grishin

Mathematical modeling of forest fires and new methods of fighting them

Translated by Marek Czuma, L. Chikina and L. Smokotina; Edited by Frank Albini

Publishing House of the Tomsk State University
Tomsk – 1996

Pergamon

Int. J. Heat Mass Transfer. Vol. 41, Nos 6–7, pp. 881–897, 1998

Printed in Great Britain
0017–9310/98 $19.00+0.00

PII: S0017–9310(97)00173–7

A multiphase formulation for fire propagation in heterogeneous combustible media

M. LARINI, F. GIROUD, B. PORTERIE and J.-C. LORAUD
Département Ecoulements Diphasiques et Réactifs, IUSTI, UMR CNRS 139, 5 rue Enrico Fermi, Technopôle de Château-Gombert, 13453, Marseille Cedex 13, France

(*Received* 2 *April* 1996 *and in final form* 4 *June* 1997)

Combustion, Explosion, and Shock Waves, Vol. 34, No. 2, 1998

Wildfire Propagation: A Two-Dimensional Multiphase Approach

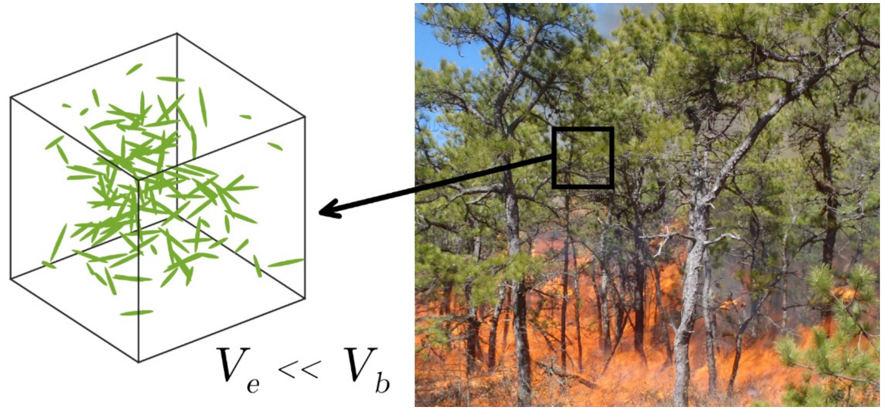
B. Porterie,[1] D. Morvan,[2] M. Larini,[1] and J. C. Loraud[1]

UDC 533.6.011.6

Translated from *Fizika Goreniya i Vzryva*, Vol. 34, No. 2, pp. 26–38, March–April, 1998.
Original article submitted July 18, 1997.

Challenge 1 – Understanding the bounds of submodels

Example 1: Drag – fuel layers/canopies



Sum up the contribution of many particles with projected area A_p

$$F_d''' = \frac{\Sigma \tfrac{1}{2} A_p c_d \rho u^2}{V_c}$$

$$F_d''' = {}^{1}/_{2}\, \sigma_e \beta_e c_s c_d \rho u^2$$

Example 1: Drag – fuel layers/canopies

H.M. Nepf, Flow and transport in regions with aquatic vegetation, Annu. Rev. Fluid Mech. 44 (2012) 123–142.

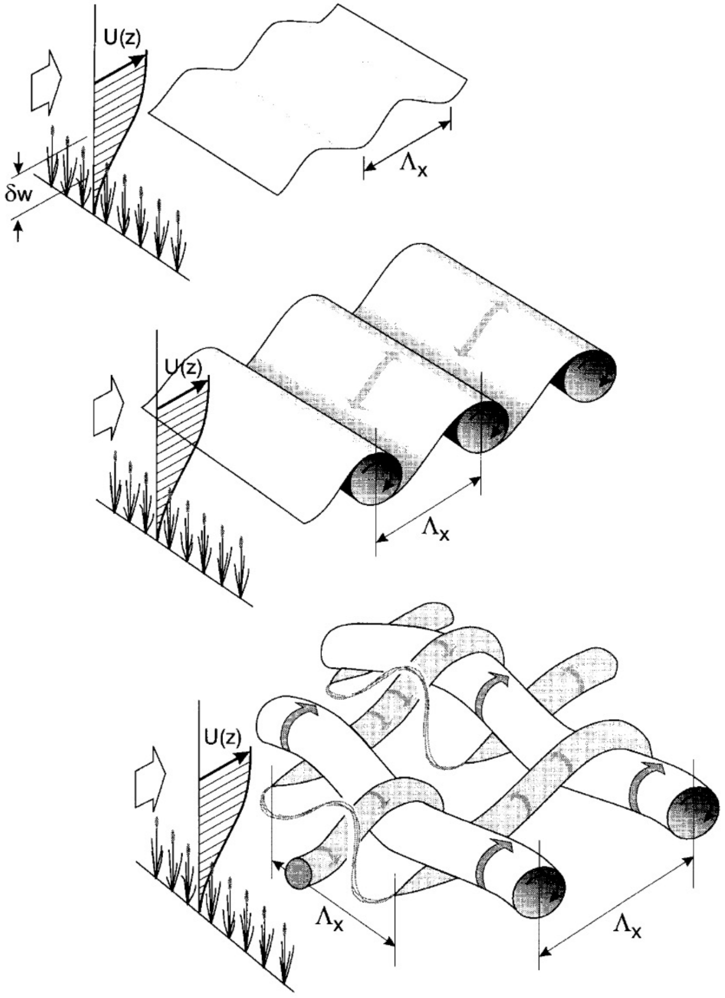
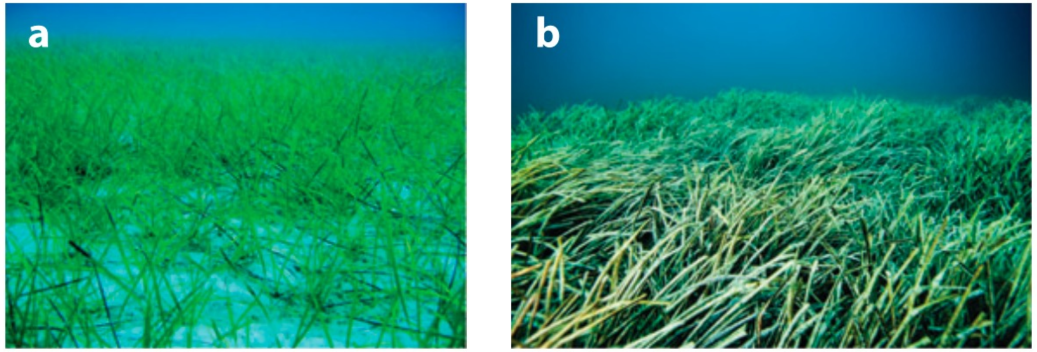
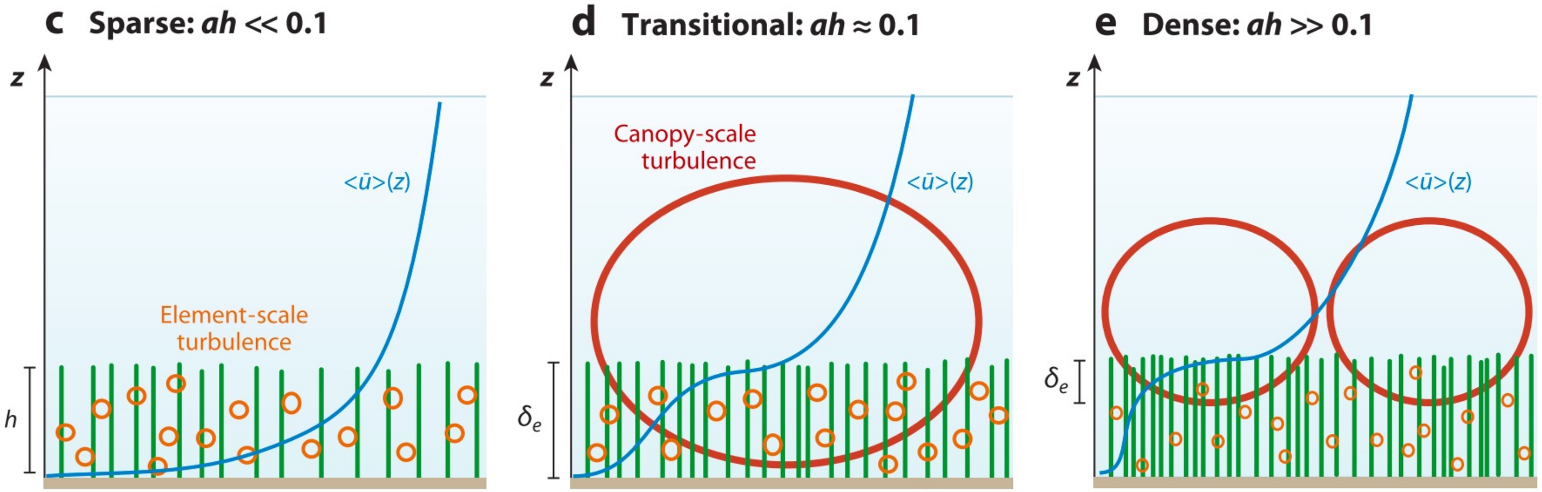


Figure 12 Schematic diagram of stages in the development of the mixing-layer type instability in the roughness sublayer.

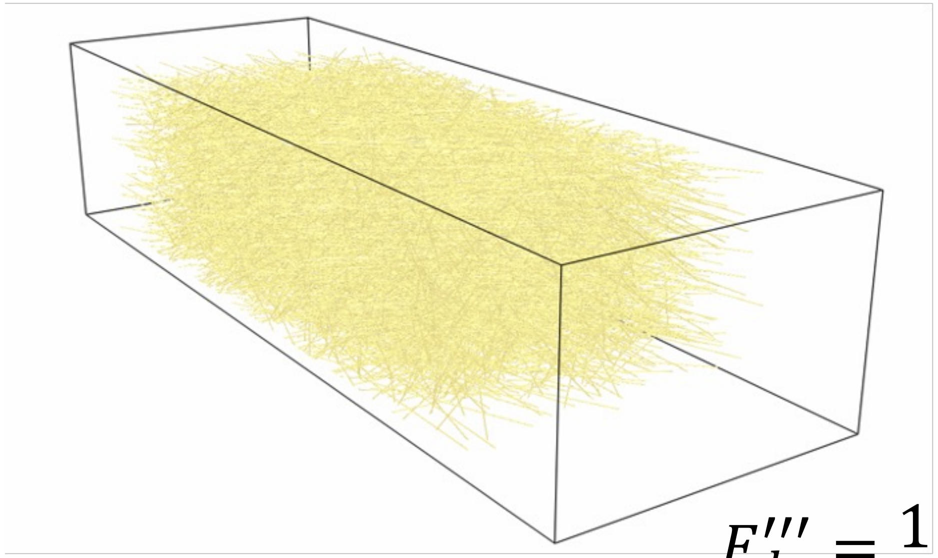


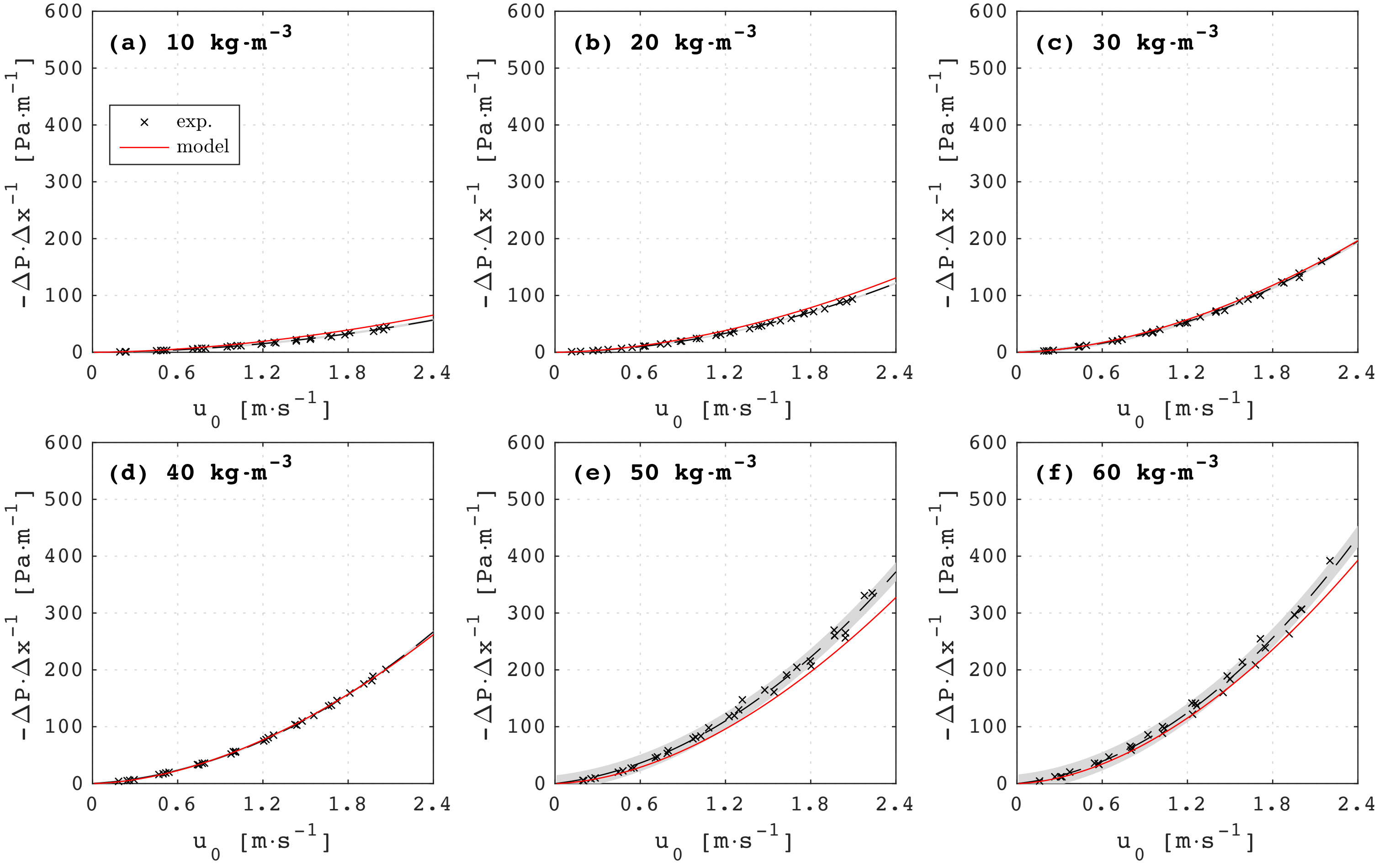


$a = \sigma_e \beta_e c_s$ (frontal area per volume)

J. Finnigan, Turbulence in plant canopies, Annu. Rev. Fluid Mech. 32 (2000) 519–571.

Example 1: Drag – fuel layers/canopies

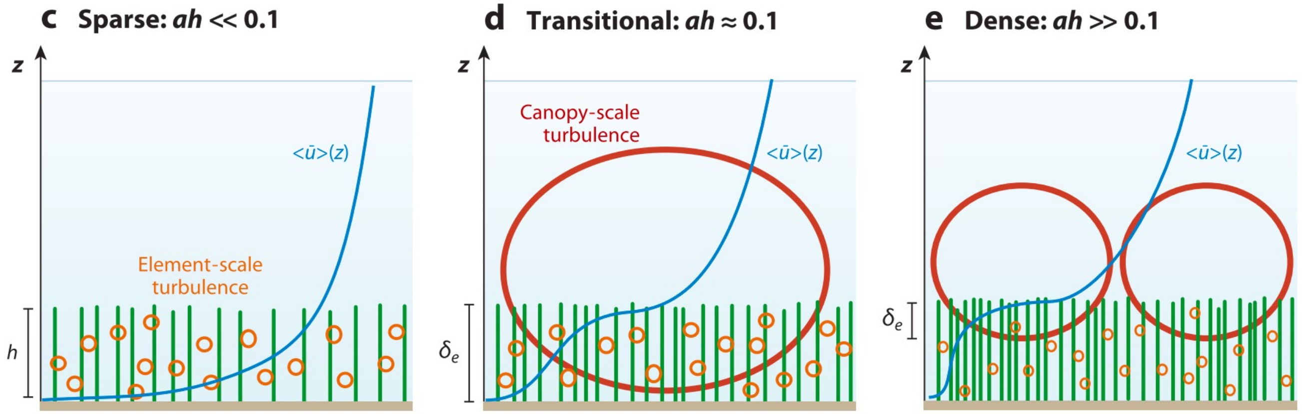


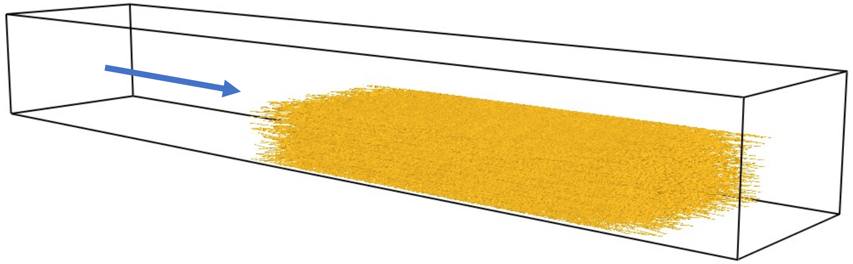


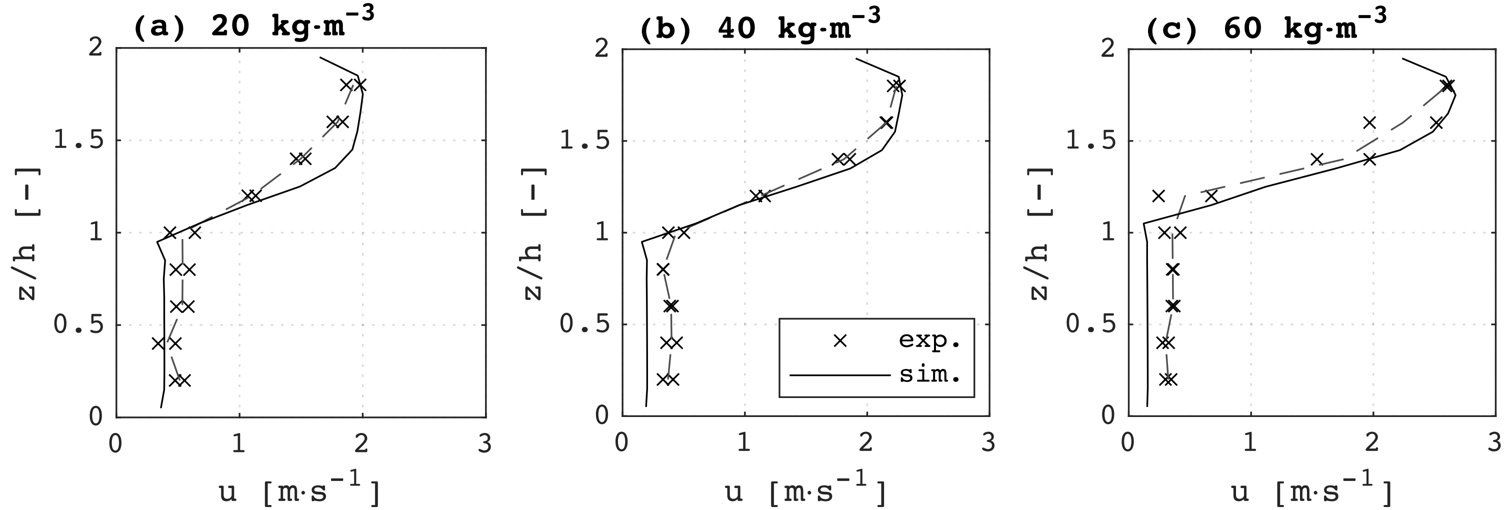
$$F_d''' = {}^1\!/_2\, \sigma_e \beta_e c_s c_d \rho u^2 \qquad c_d = \frac{10}{Re}(0.6 + 0.4Re^{0.8}) \qquad \boldsymbol{c_s = 0.16}$$

Example 1: Drag – fuel layers/canopies

H.M. Nepf, Flow and transport in regions with aquatic vegetation, Annu. Rev. Fluid Mech. 44 (2012) 123–142.







E. V. Mueller, M.R. Gallagher, N. Skowronski, R.M. Hadden, Approaches to Modeling Bed Drag in Pine Forest Litter for Wildland Fire Applications, Transp. Porous Media. 138 (2021) 637–660.

Example 1: Drag – discrete fuels

Figure 8. White Fir (WT8) Mounted on Truck

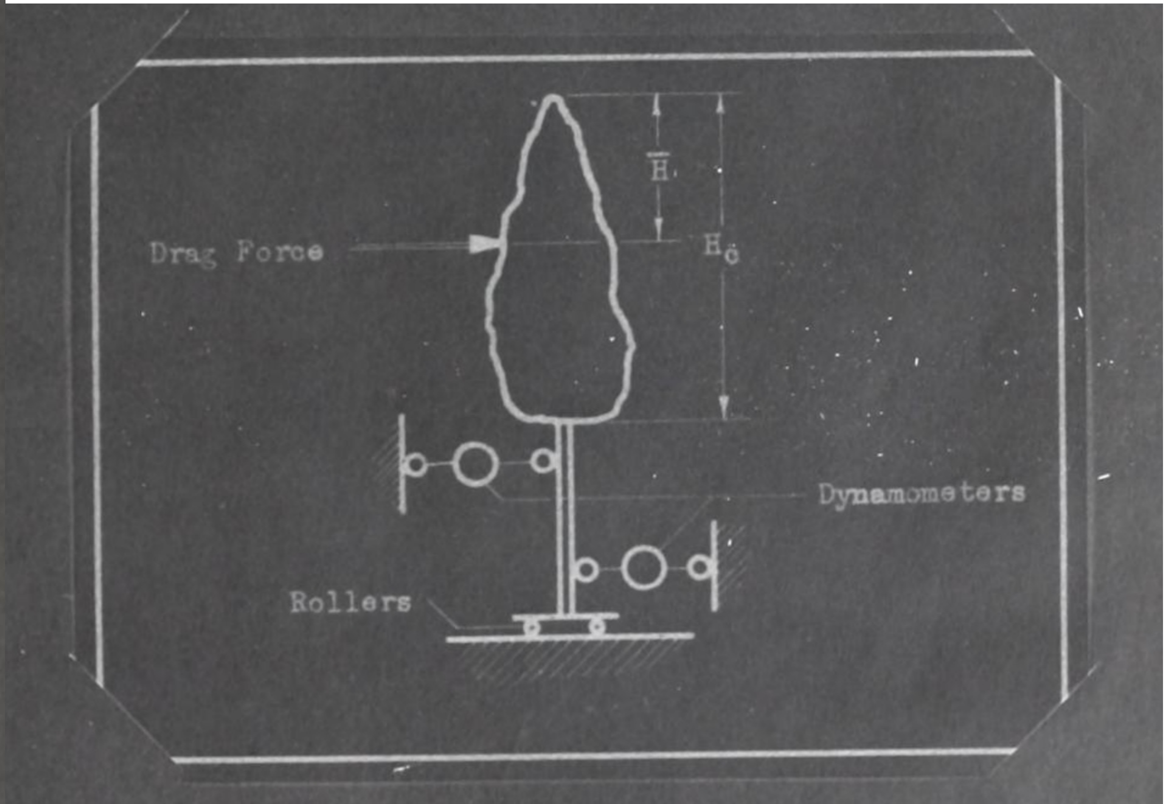
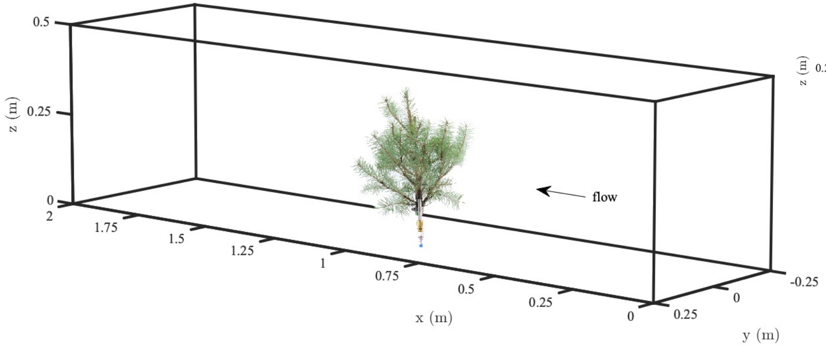


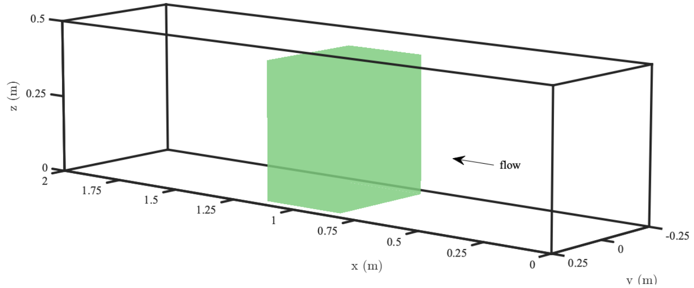
Figure 5. Schematic Diagram of the Drag-Force Measuring System Mounted on Truck Bed

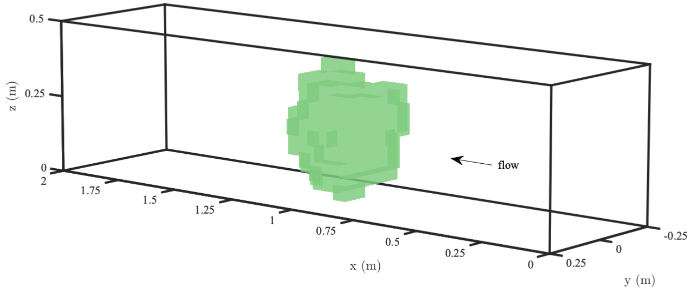
F.M. Sauer, W.L. Fons, K. Arnold, Experimental investigation of aerodynamic drag in tree crowns exposed to steady wind: conifers, Phase Rep. Oper. Res. Off. Johns Hopkins Univ., USDA For. Serv., Washington, DC. 18 (1951).

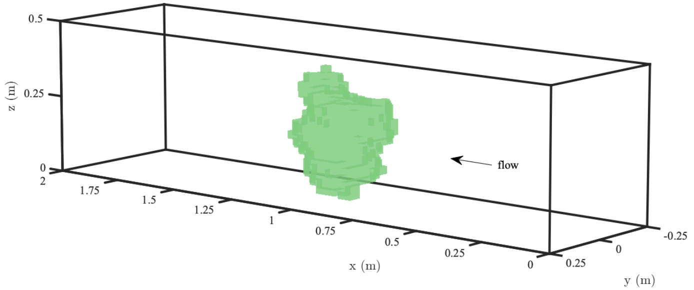
Example 1: Drag – discrete fuels



$$F_d''' = {}^1\!/_2\, \sigma_e \beta_e c_s c_d \rho u^2$$

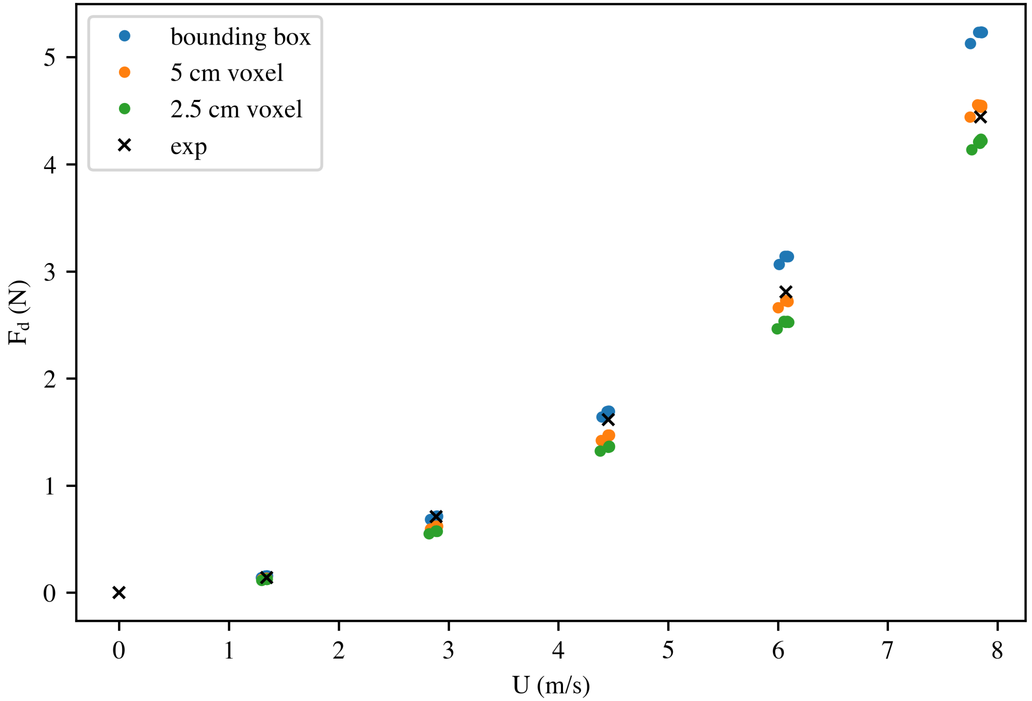






↑ β_e

total volume ↓



Example 1: Drag – additional complexity?

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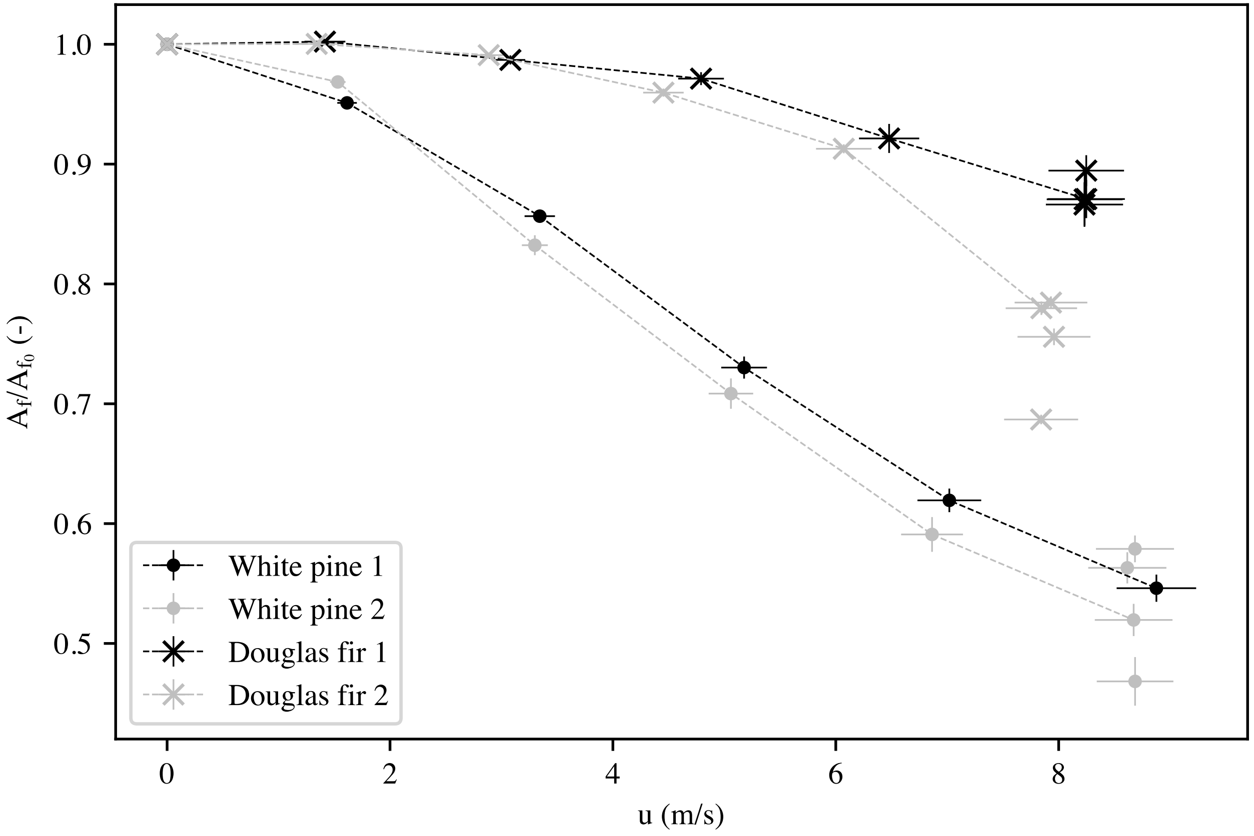


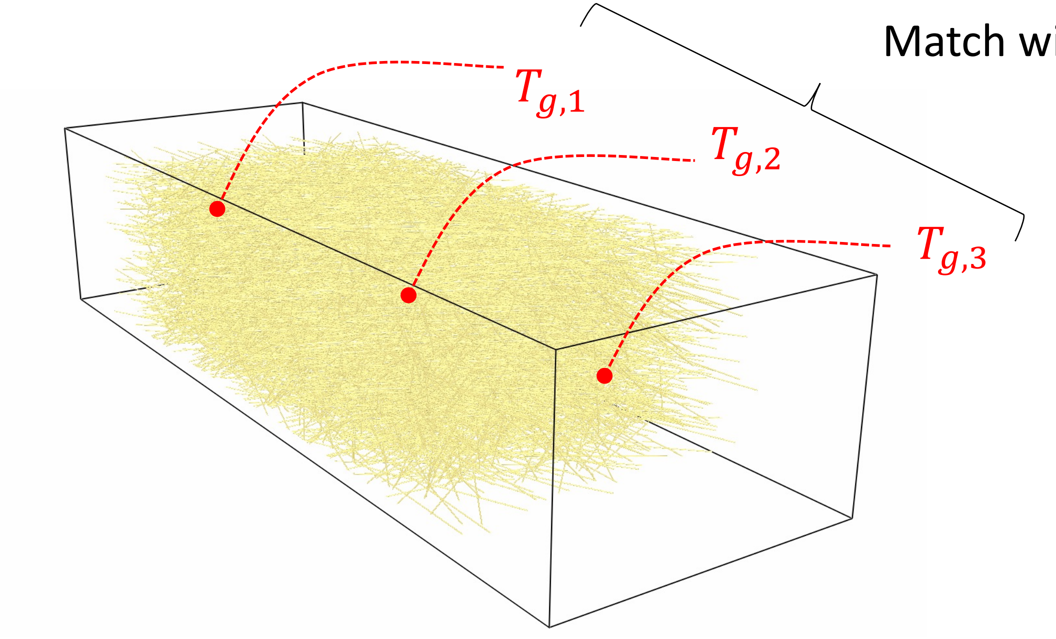
M. Rudnicki, S.J. Mitchell, M.D. Novak, Wind tunnel measurements of crown streamlining and drag relationships for three conifer species, Can. J. For. Res. 34 (2004) 666–676.

Example 2: Convective heat transfer

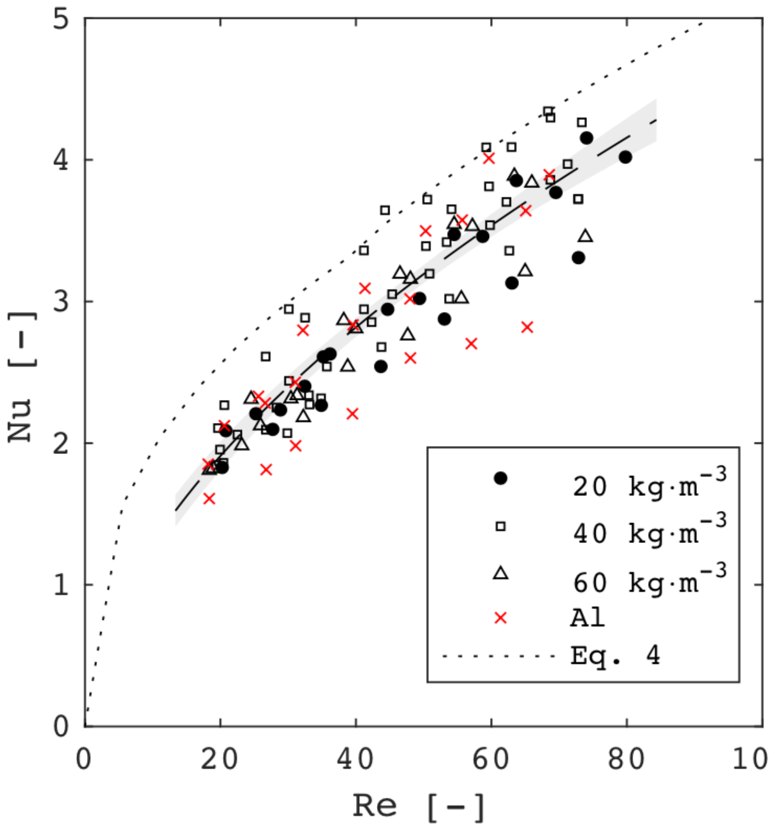
$$\dot{q}_c''' = \sigma_e \beta_e h_c (T_g - T_e)$$

$$\epsilon \rho_g c_{p_g} \frac{\partial T_g}{\partial t} + u \rho_g c_{p_g} \frac{\partial T_g}{\partial x} = \epsilon k_g \frac{\partial^2 T_g}{\partial x^2} + \sigma \beta h_c (T_s - T_g)$$

Match with 1D model optimization



$$Nu = \frac{h_c l}{k} = 0.37 Re^{0.553}$$



Example 2: Convective heat transfer

$$\dot{q}_c''' = \sigma_e \beta_e h_c (T_g - T_e)$$

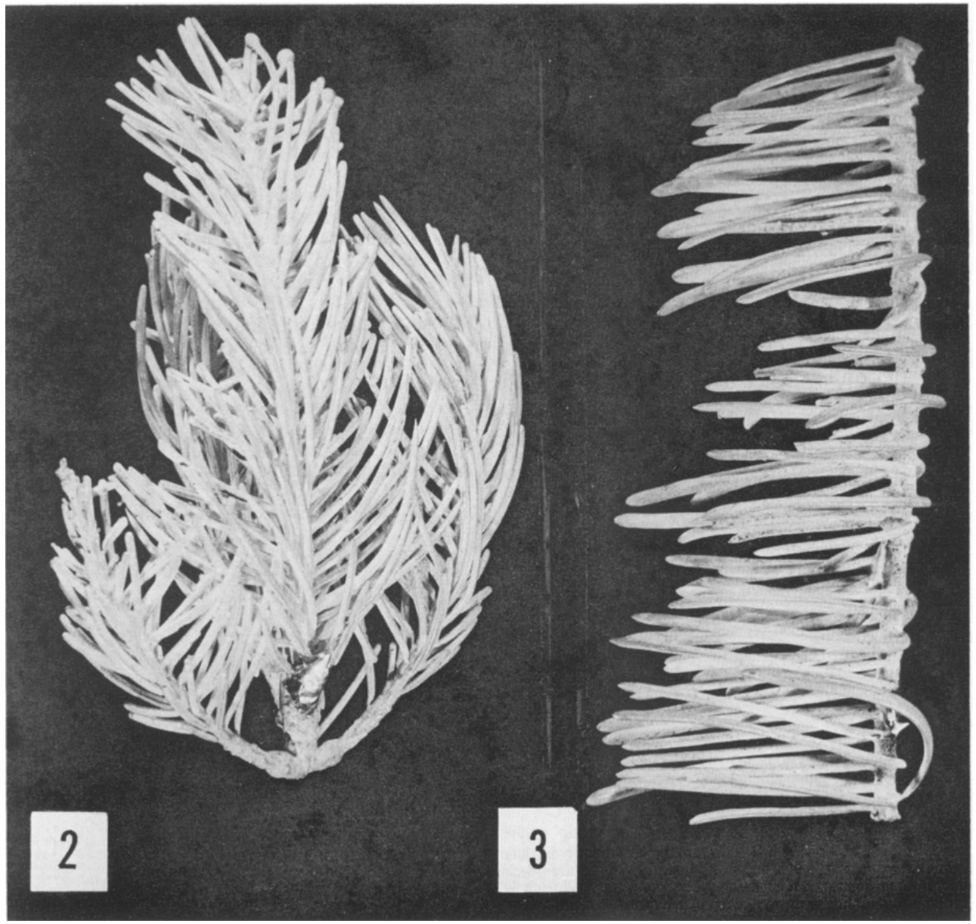
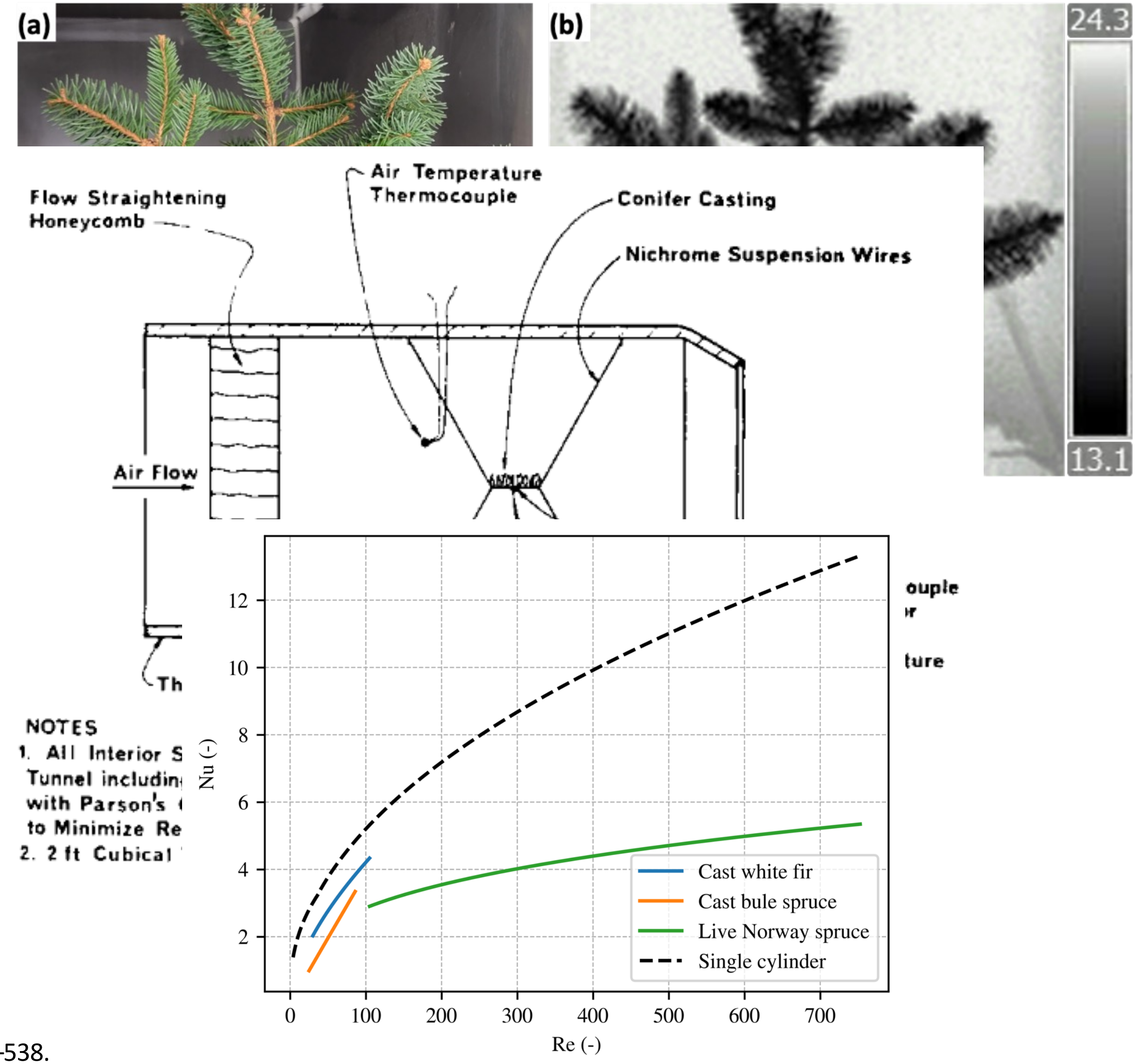


Fig. 2–3. Silver casting of part of a branch of: Fig. 2. Blue spruce.—Fig. 3. White fir.

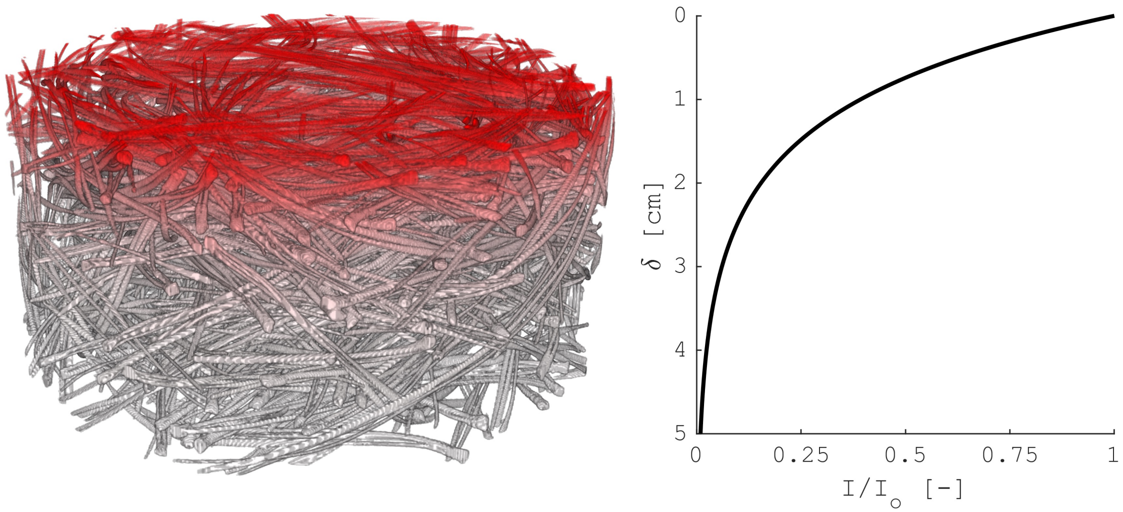


E.C. Tibbals, E.K. Carr, D.M. Gates, F. Kreith, Radiation and Convection in Conifers, Am. J. Bot. 51 (1964) 529–538.

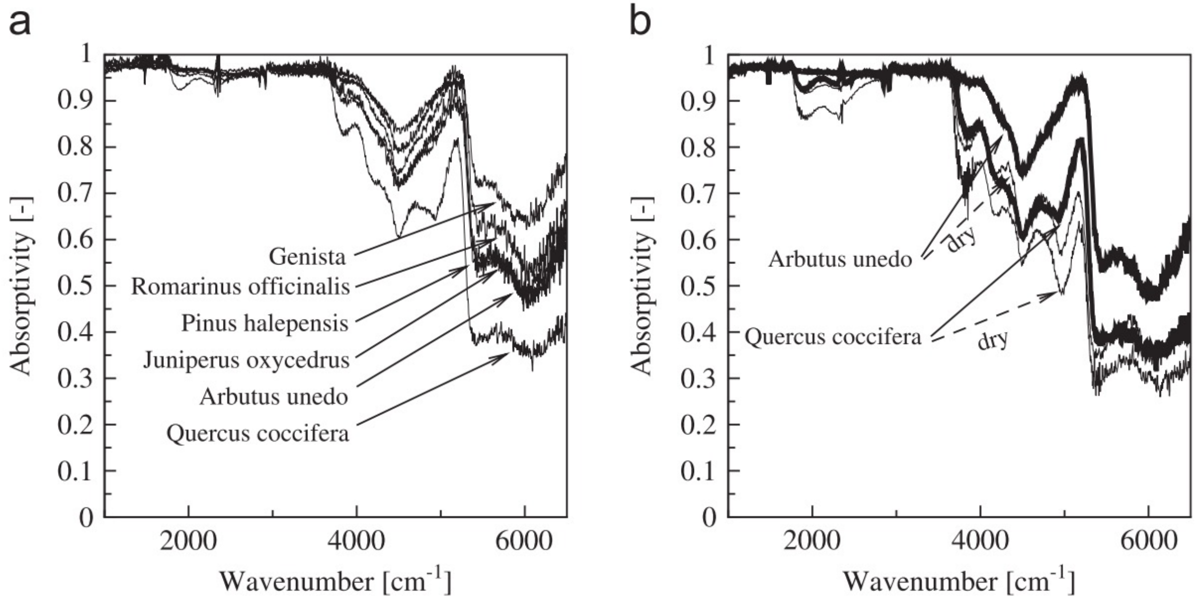
Example 3: Radiative heat transfer

$$\nabla \cdot \dot{\boldsymbol{q}}_r'' = \boxed{\varepsilon}\,\boxed{\frac{\sigma_e \beta_e}{4}}\left(U - 4\sigma {T_e}^4\right)$$

B. Monod, A. Collin, G. Parent, P. Boulet, Infrared radiative properties of vegetation involved in forest fires, Fire Saf. J. 44 (2009) 88–95.



Attenuation coefficient



Absorption coefficient

Example 4: Thermal decomposition

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Fire Safety Journal 137 (2023) 103762

Contents lists available at ScienceDirect

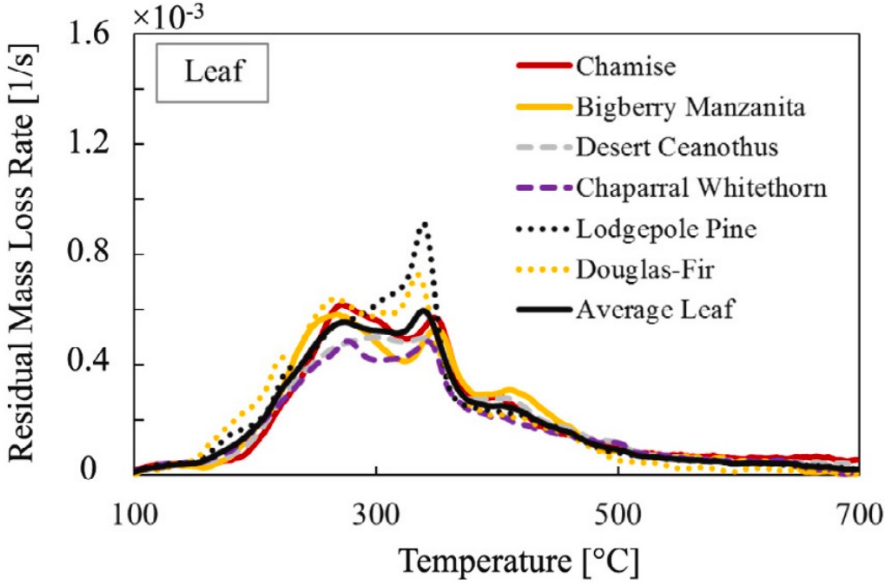
Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

Check for updates

Thermal decomposition of vegetative fuels and the impact of measured variations on simulations of wildfire spread

Isaac T. Leventon [a,*], Jiuling Yang [a], Morgan C. Bruns [b]



One possibility…

Single step model (kinetic)

dry material → ν_{char} Char + (1 -ν_{char}) Volatile

$$r = \rho_{dry} A \exp[{-E}/{RT_e}]$$

A? E? ν_{char}?

Example 4: Thermal decomposition

Fire Safety Journal 137 (2023) 103762

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

Thermal decomposition of vegetative fuels and the impact of measured variations on simulations of wildfire spread

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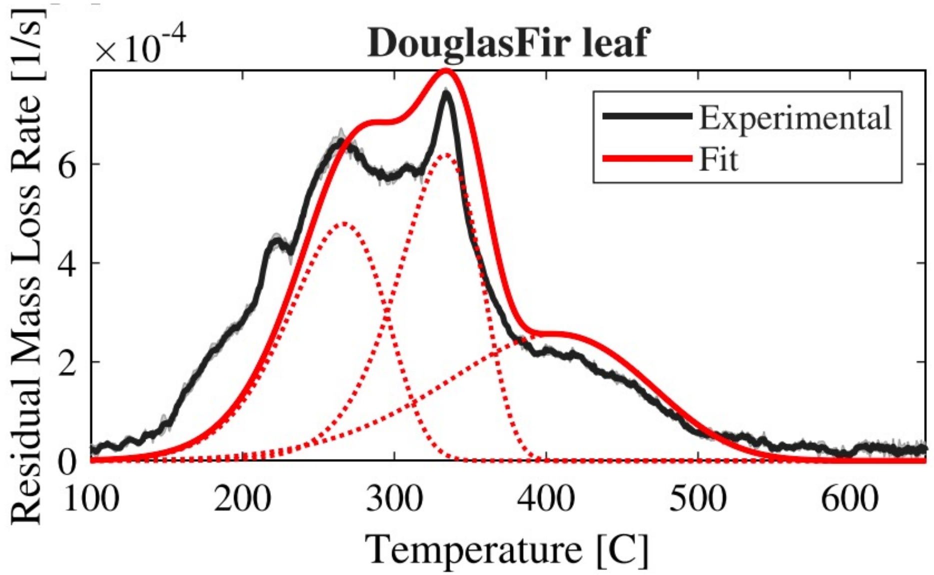


Another possibility…

Multi- step model (kinetic)

dry material 1 → $\nu_{char,1}$ Char + (1 -$\nu_{char,1}$) Volatile

dry material 2 → $\nu_{char,2}$ Char + (1 -$\nu_{char,2}$) Volatile

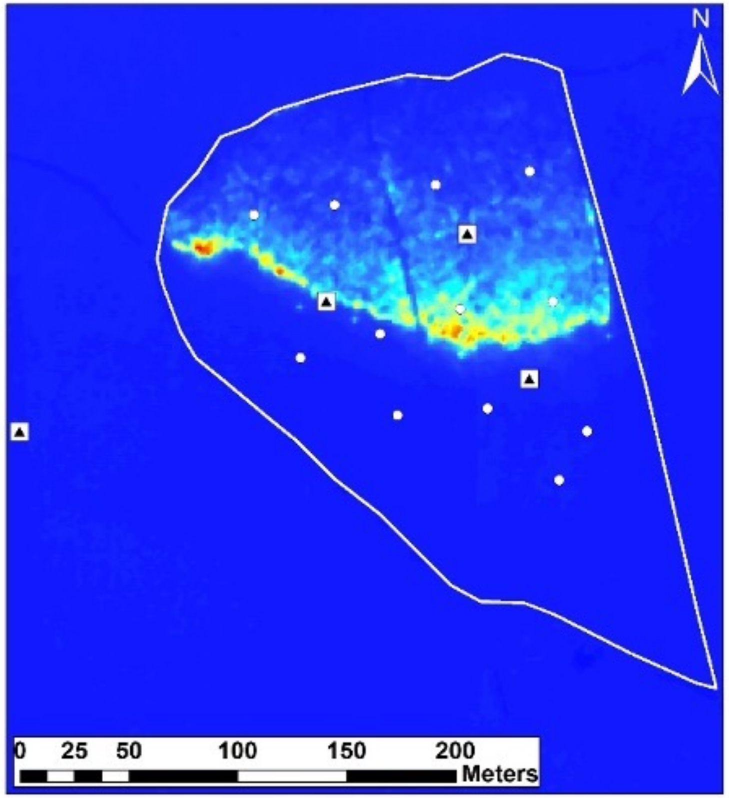
.
.
.

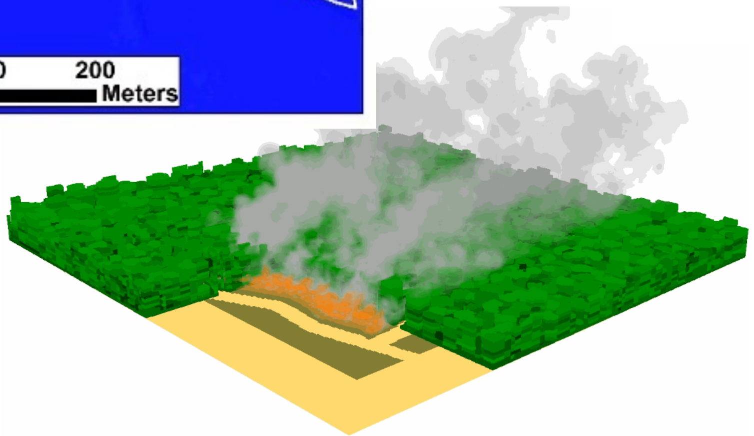
$$r_1 = \rho_{dry} A_1 \exp[{}^{-E_1}/_{RT_e}]$$

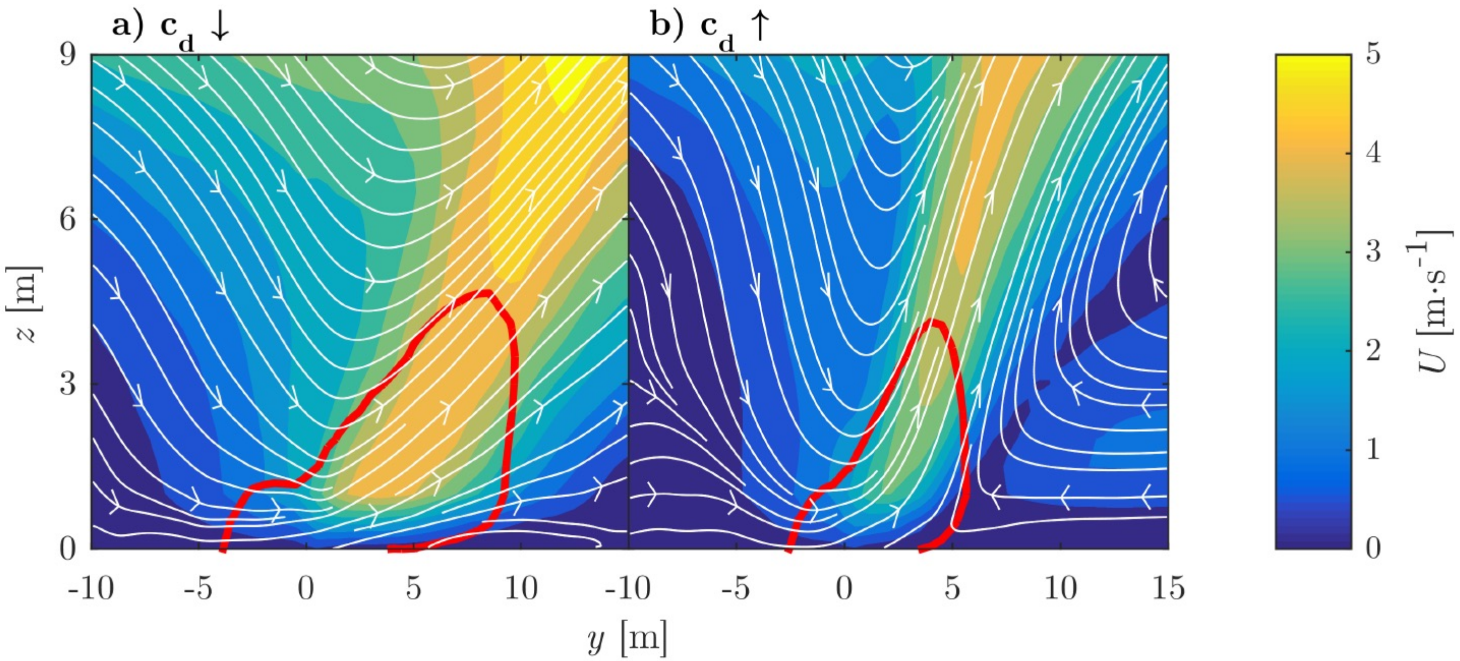
$$r_2 = \rho_{dry} A_2 \exp[{}^{-E_2}/_{RT_e}]$$

$A_1, A_2, \ldots ?$ $E_1, E_2 \ldots ?$ $\nu_{char,1}, \nu_{char,2}, \ldots ?$

How does it matter?







Challenge 2 – Ensuring the relevant processes are accounted for

Example at laboratory scale

www.publish.csiro.au/journals/ijwf International Journal of Wildland Fire 2010, 19, 163–170

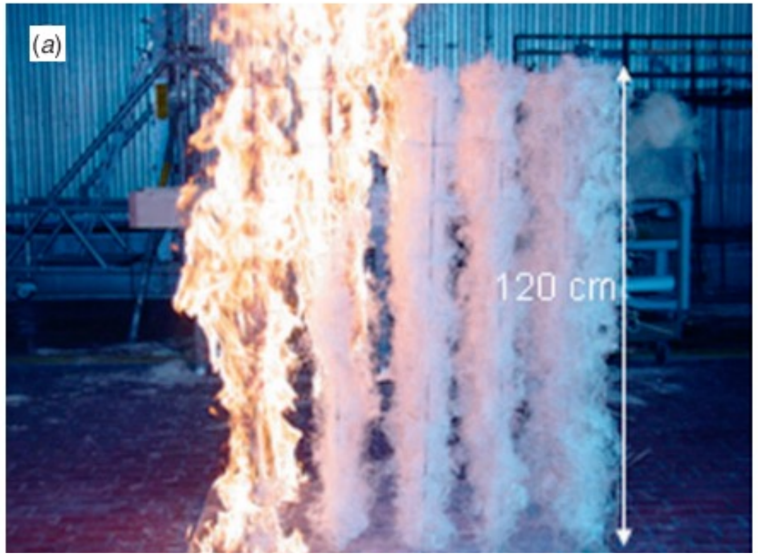
An examination of fire spread thresholds in discontinuous fuel beds[A]

Mark A. Finney[A,B], Jack D. Cohen[A], Isaac C. Grenfell[A] and Kara M. Yedinak[A]

www.publish.csiro.au/journals/ijwf International Journal of Wildland Fire 2010, 19, 171–178

An examination of flame shape related to convection heat transfer in deep-fuel beds

Kara M. Yedinak[A,B,*], Jack D. Cohen[A,C,*], Jason M. Forthofer[A] and Mark A. Finney[A]



Can we even reproduce the behavior of just one?

Example at laboratory scale

Drag model? Convection model?

$$F_d''' = {}^1\!/_2\, \sigma_e \beta_e c_s c_d \rho u^2 \qquad c_d = \frac{10}{Re}\left(0.6 + 0.4 Re^{0.8}\right) \qquad c_s = 0.16$$

$$h_c = \frac{k\sigma}{4} \cdot 0.37 Re^{0.553}$$

Example at laboratory scale

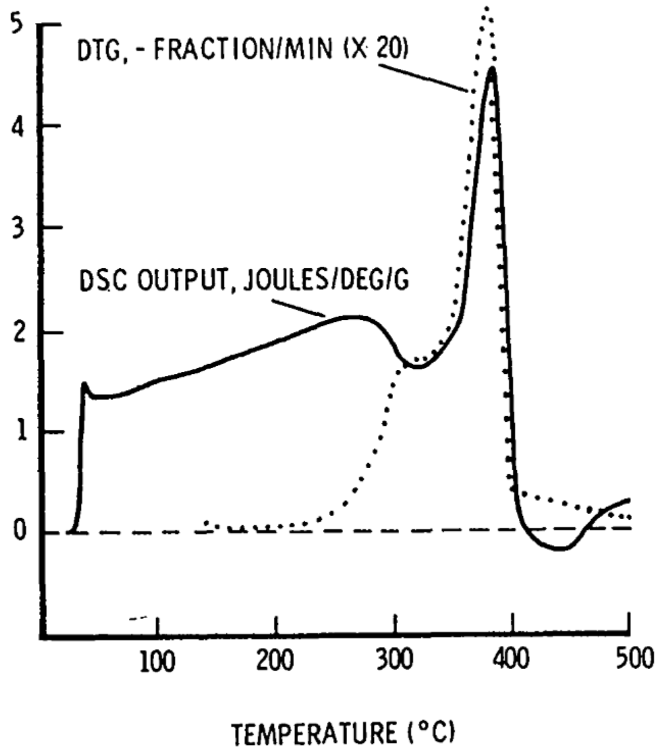


FIGURE 1. DSC and DTG curves for excelsior.

TABLE 3. Heats of combustion for fuels, chars, and volatiles.

Component and sample number[a]	Char yield (percent)	Heat of combustion, MJ/kg[b]			
				Distribution at 500°C	
		Fuel	Char	Volatiles[c]	Char[c]
Wood					
18	22.1	20.57	33.18	13.24	7.33
19	20.7	20.25	32.00	13.63	6.62
20	15.4	19.60	32.37	14.60	5.00
21	20.7	19.83	32.29	13.15	6.69
22	23.7	20.22	32.15	12.61	7.60
23	19.5	20.82	32.85	14.41	6.41
24	20.3	20.97	32.82	14.31	6.65
25	20.1	20.25	31.90	13.84	6.41
26	22.2	20.09	31.94	13.01	7.08

R.A. Susott, Characterization of the thermal properties of forest fuels by combustible gas analysis, For. Sci. 28 (1982) 404–420.

R. Susott, Differential Scanning Calorimetry of Forest Fuels, For. Sci. 28 (1982) 839–851.

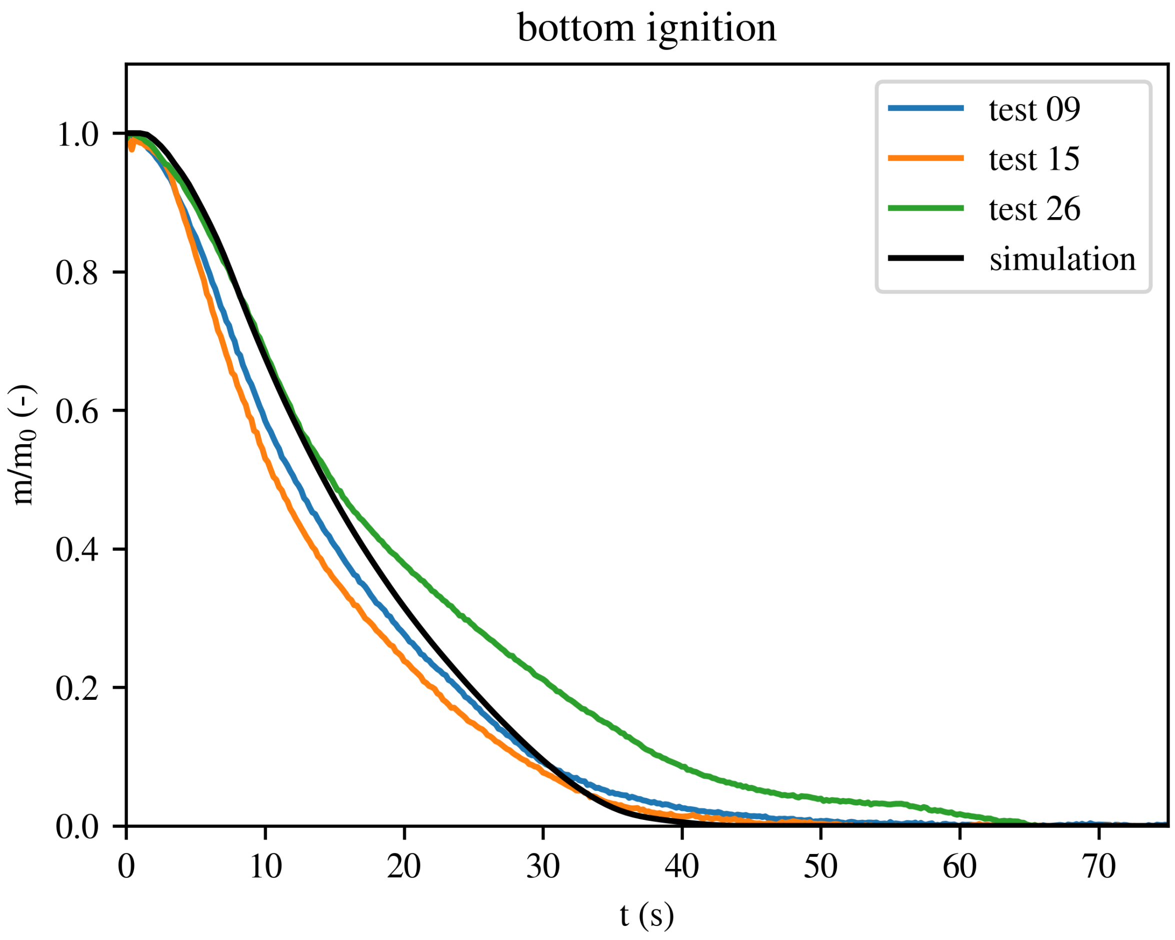
Example at laboratory scale

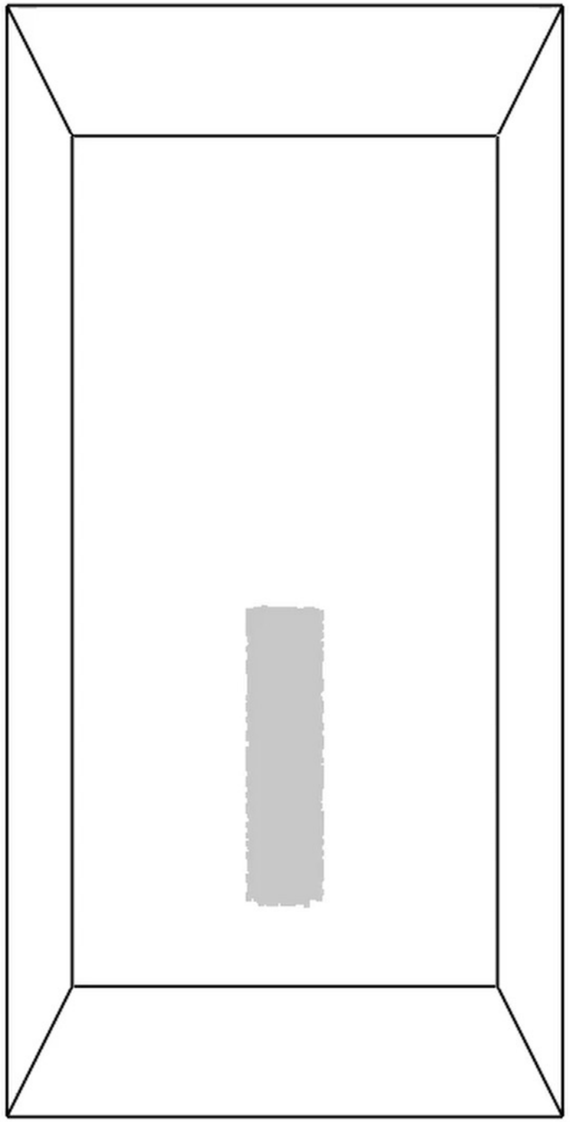
Modeling framework is FDS:

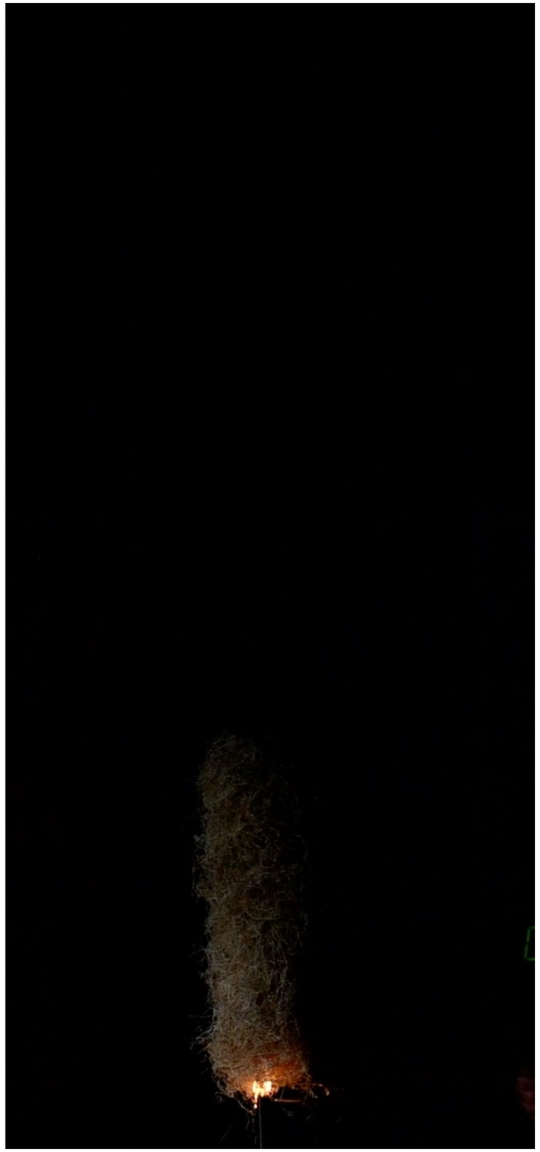
- LES, Deardorff eddy viscosity turbulence model
- Infinitely fast chemistry
- Gray gas radiation model (effective absorption coefficient)
- Prescribed radiant fraction (0.35)
- $\Delta x = 1.25\ cm$

- 60 cm x 15.25 cm
- 150 g

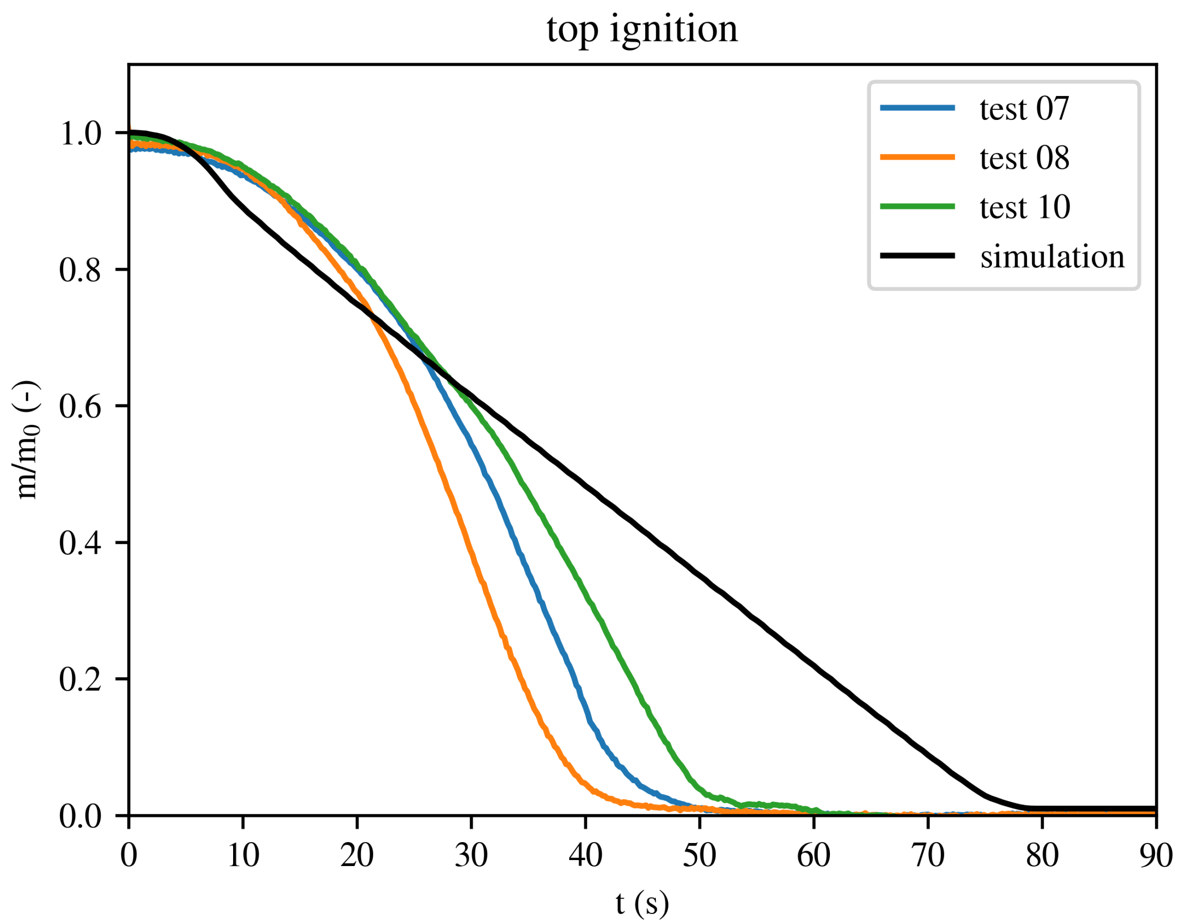
Example at laboratory scale

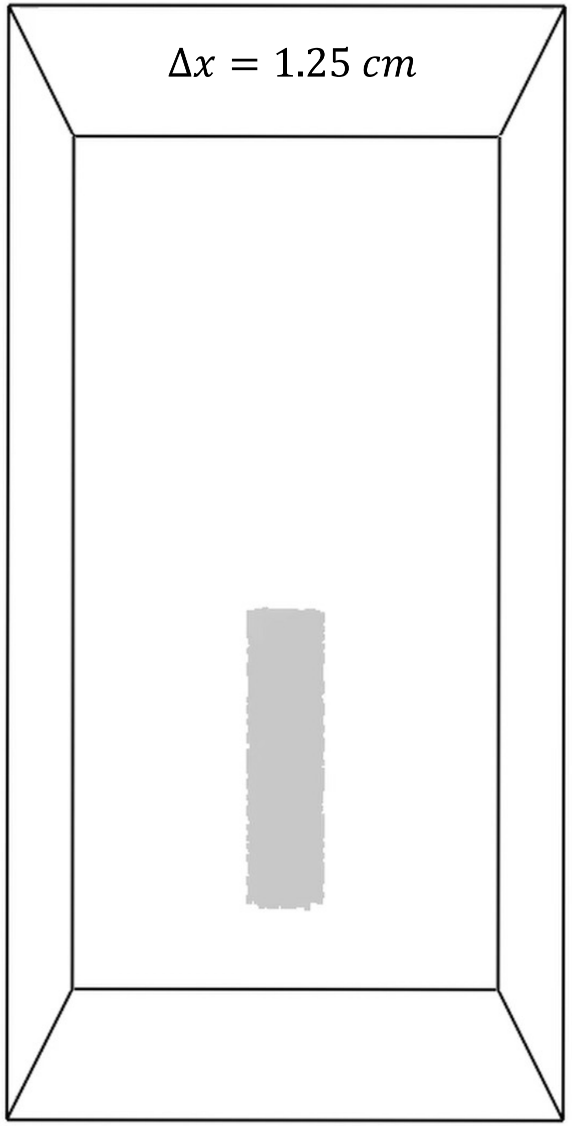




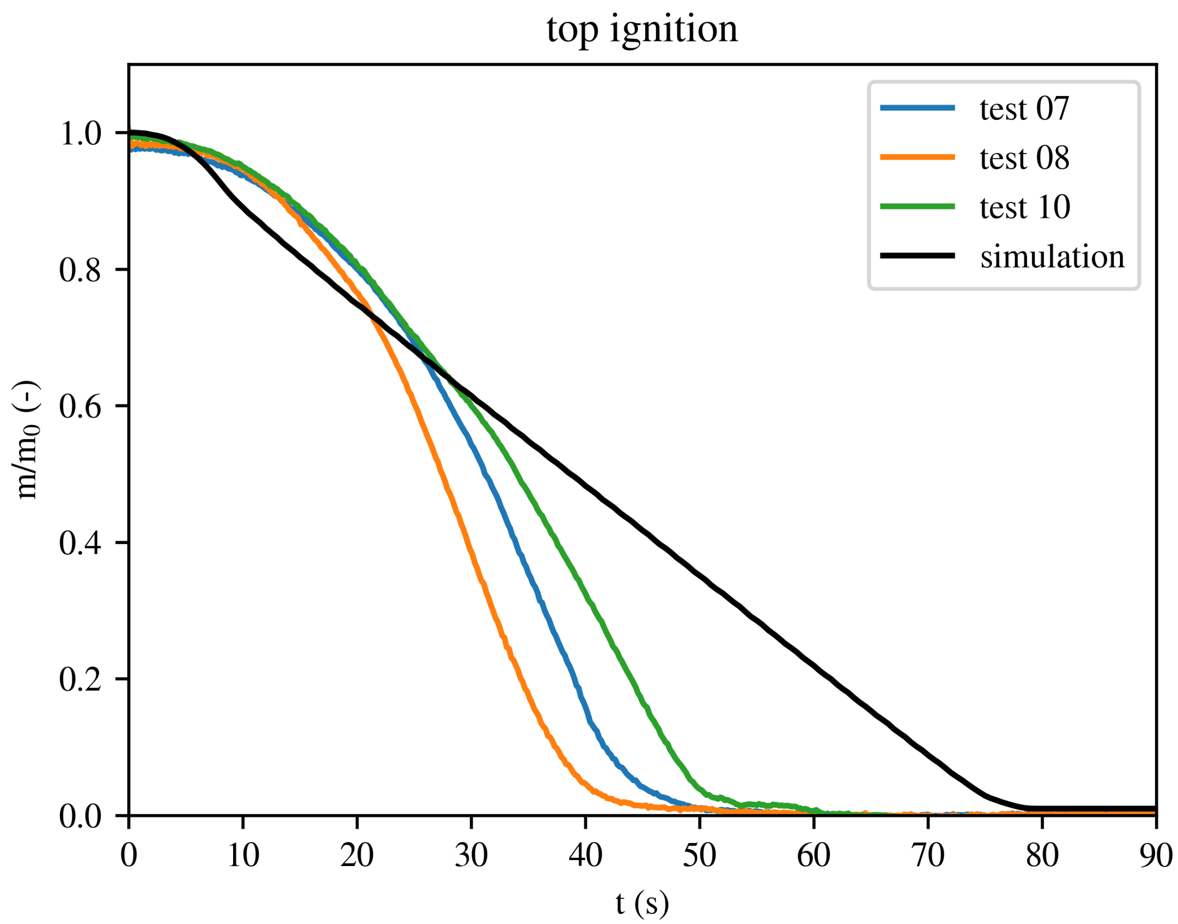


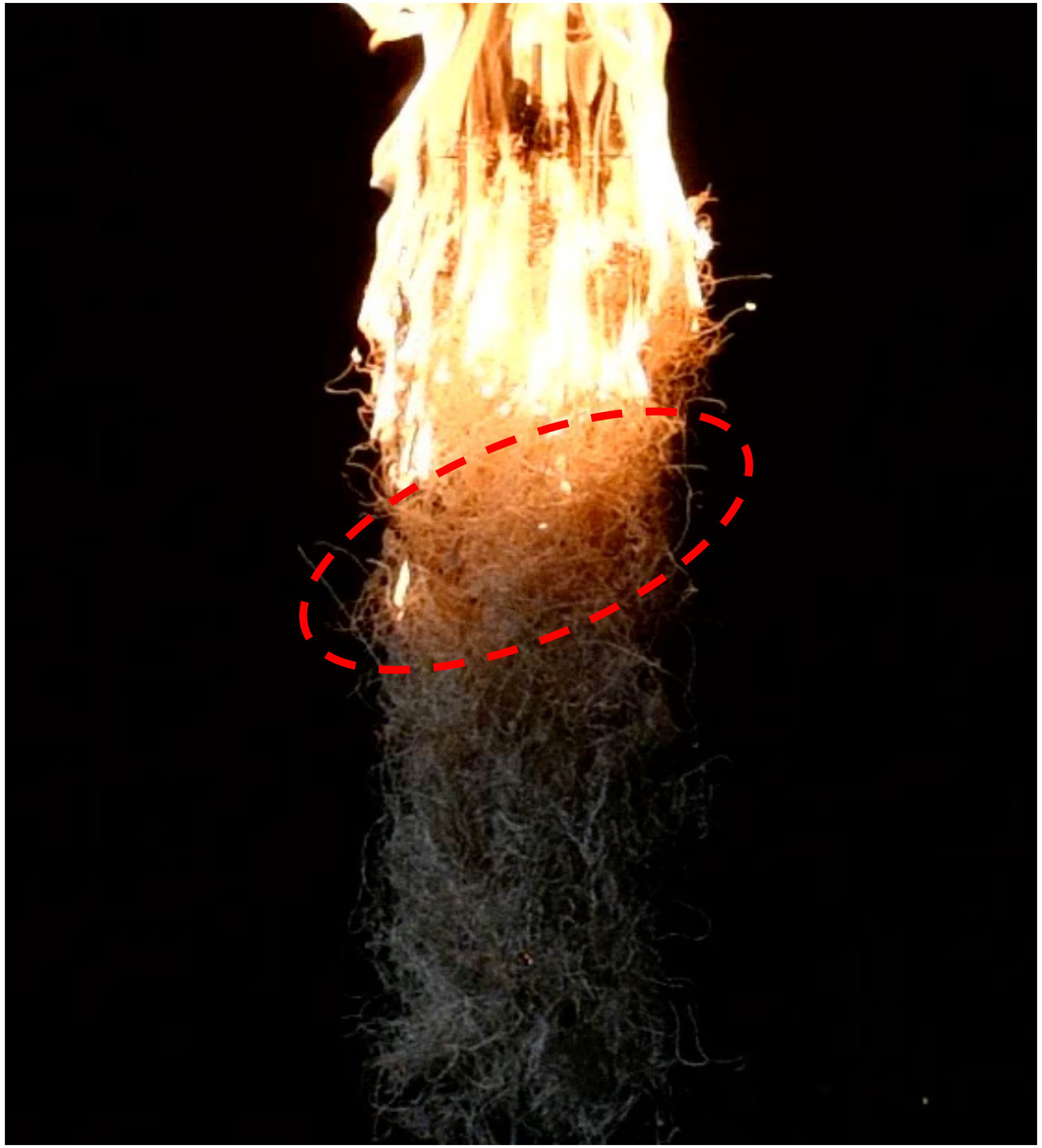
Example at laboratory scale





Example at laboratory scale





Live versus dead fuel

$r_{H_2O} = \rho_{H_2O} A\exp[{}^{-E}/_{RT_e}]$?

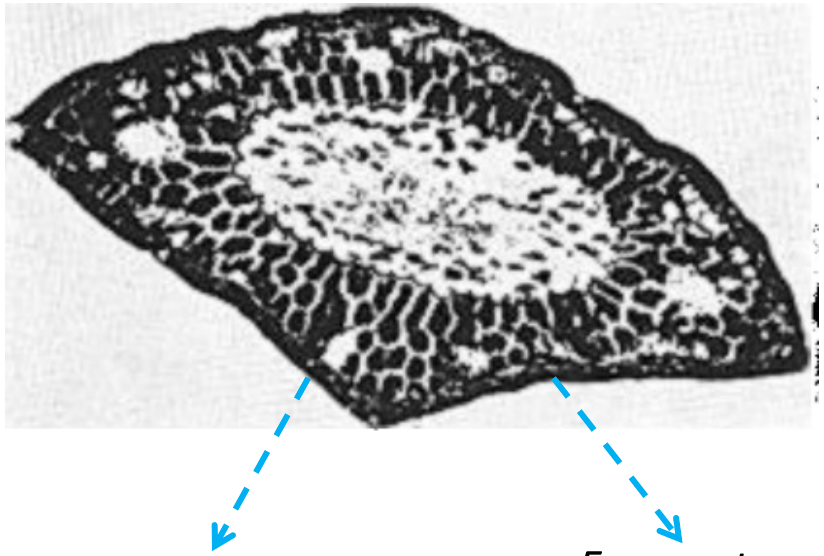
From bench scale tests of dead fuel?

COMBUSTION SCIENCE AND TECHNOLOGY
2017, VOL. 189, NO. 9, 1551–1570
https://doi.org/10.1080/00102202.2017.1308357
Taylor & Francis
Taylor & Francis Group
Check for updates

Physics-Based Modeling of Live Wildland Fuel Ignition Experiments in the Forced Ignition and Flame Spread Test Apparatus

C. Anand[a], B. Shotorban[a], S. Mahalingam[a], S. McAllister[b], and D. R. Weise[c]

One possibility… separation of water into two independent drying steps



Going beyond thin fuel

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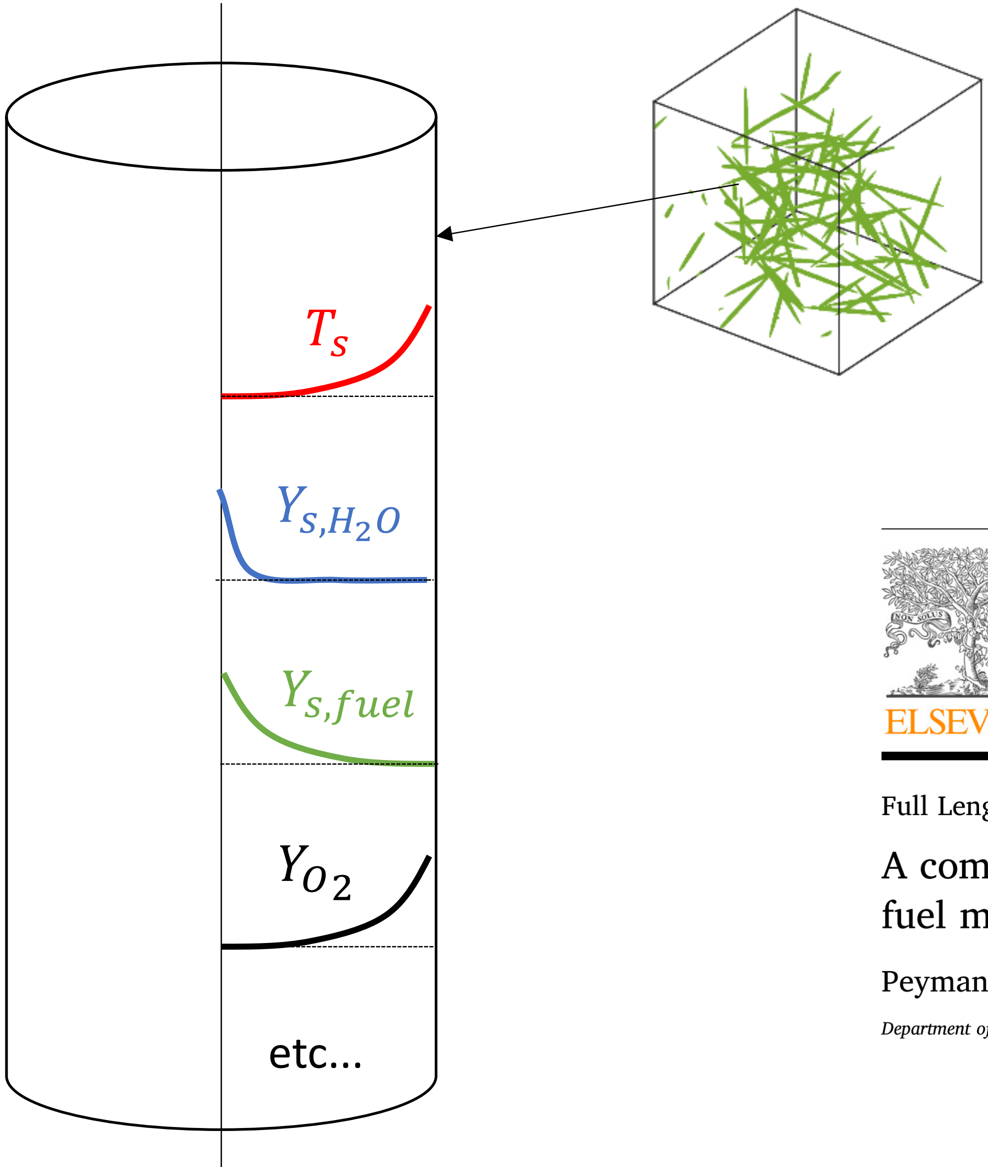


Multiphase within the multiphase…

Fuel 276 (2020) 118030

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

ELSEVIER

Full Length Article

A computational study of burning of vertically oriented leaves with various fuel moisture contents by upward convective heating

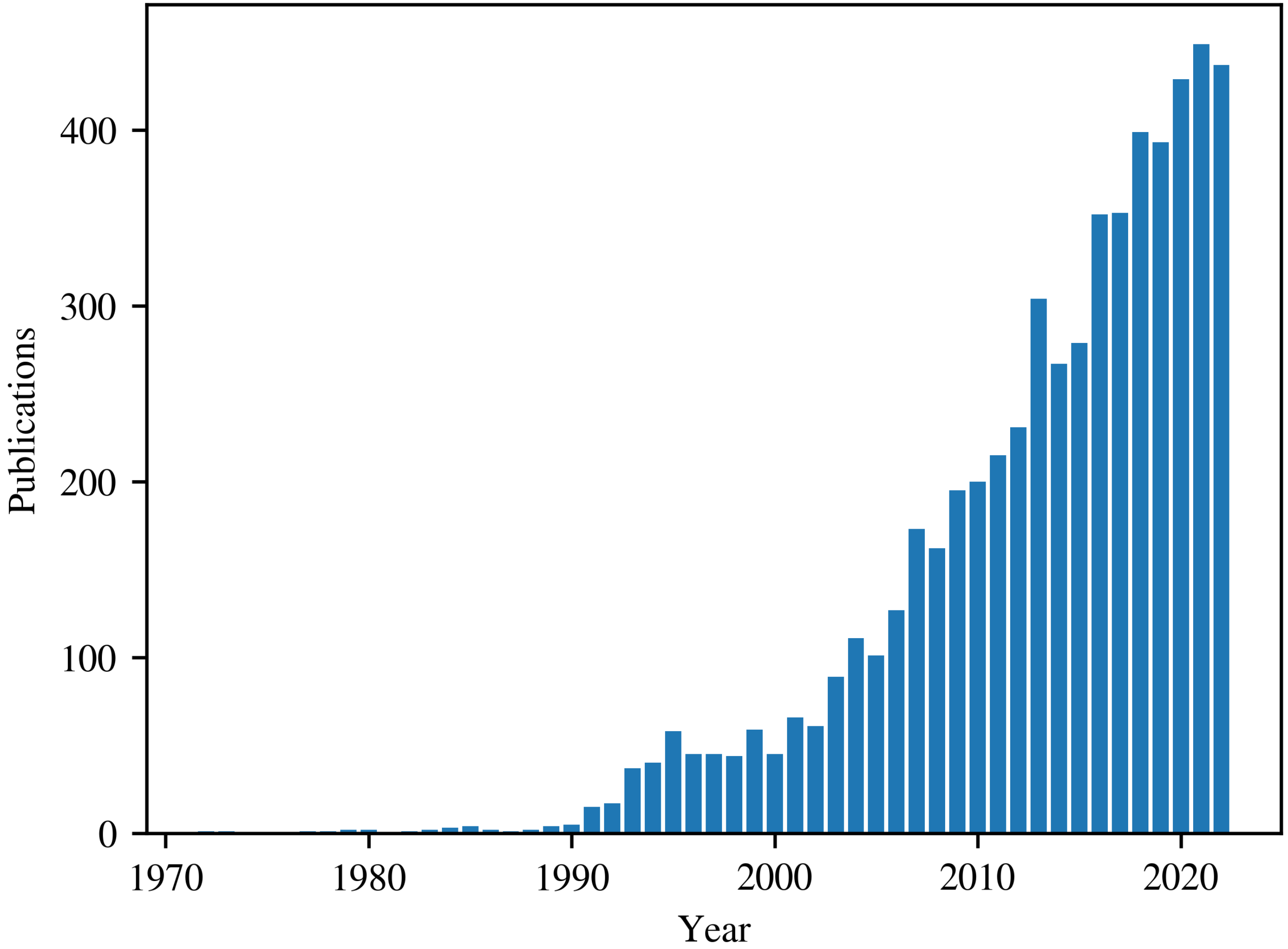
Peyman Rahimi Borujerdi, Babak Shotorban*, Shankar Mahalingam

Department of Mechanical and Aerospace Engineering, The University of Alabama in Huntsville, Huntsville, AL 35899, USA

(future) application of CFD for WUI fires

Increased use of CFD

webofscience.com: References including ‘CFD’ and ‘wildfire’/’wildland fire’



International Conference on Forest Fire Research:

- 2010: 2 papers
- 2018: 6 papers
- 2022: 12 papers

Example 1: Firebrands

Transport

Review
CSIRO PUBLISHING
International Journal of Wildland Fire **2010**, *19*, 818–843
www.publish.csiro.au/journals/ijwf

Firebrands and spotting ignition in large-scale fires

Eunmo Koo[A,E], *Patrick J. Pagni*[B], *David R. Weise*[C] *and John P. Woycheese*[D]

Fire Safety Journal 134 (2022) 103674
Contents lists available at ScienceDirect
Fire Safety Journal
journal homepage: www.elsevier.com/locate/firesaf
ELSEVIER

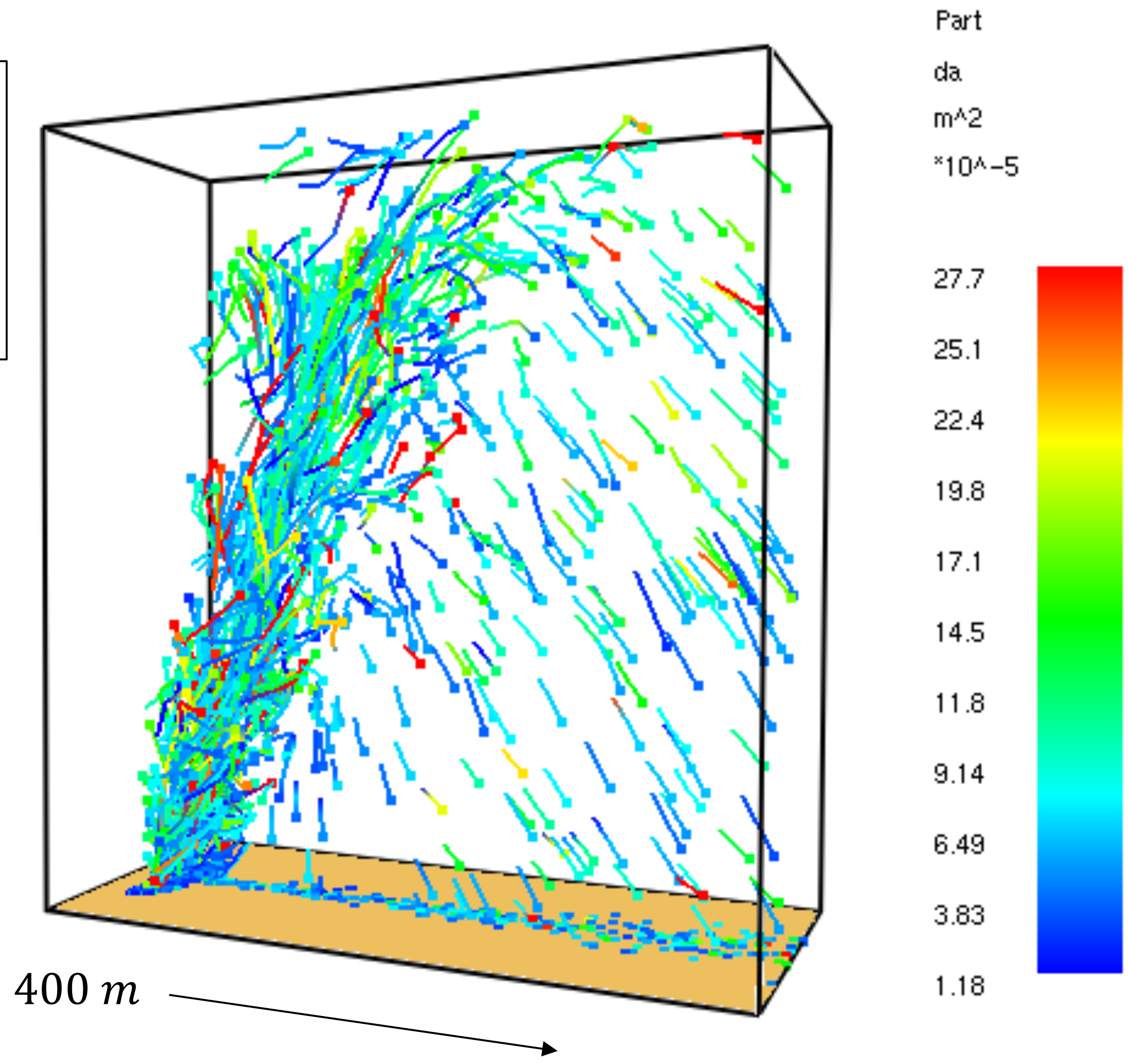
A review of firebrand studies on generation and transport

Rahul Wadhwani[a,b], Catherine Sullivan[c], Amila Wickramasinghe[a,b], Matthew Kyng[a,b], Nazmul Khan[a,b], Khalid Moinuddin[a,b,*]

Prog Energy Combust Sci. 2020 ; 76: . doi:10.1016/j.pecs.2019.100801.

Role of Firebrand Combustion in Large Outdoor Fire Spread

Samuel L. Manzello[1], **Sayaka Suzuki**[2], **Michael J. Gollner**[3], **A. Carlos Fernandez-Pello**[4]



Example 1: Firebrands

Ignition

International Journal of Wildland Fire **2018**, *27*, 550–561
https://doi.org/10.1071/WF17083

Simulation of fuel bed ignition by wildland firebrands

O. V. Matvienko[A,B], *D. P. Kasymov*[A], *A. I. Filkov*[C,D], *O. I. Daneyko*[B] and *D. A. Gorbatov*[A]

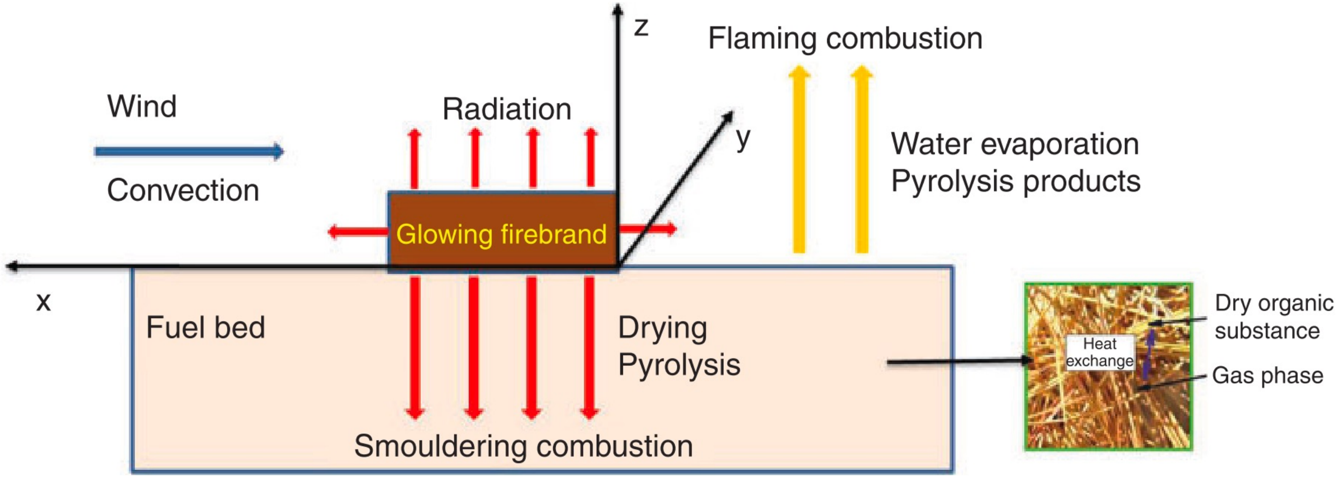


Fig. 2. Physical problem, initial and boundary conditions. Figure shows schematic representation of stated problem.

Example 1: Firebrands

Generation??

Available online at www.sciencedirect.com
SciVerse ScienceDirect
Proceedings of the Combustion Institute 34 (2013) 2649–2656
Proceedings of the Combustion Institute
www.elsevier.com/locate/proci

Thermo-mechanical modeling of firebrand breakage on a fractal tree

B.W. Barr, O.A. Ezekoye *

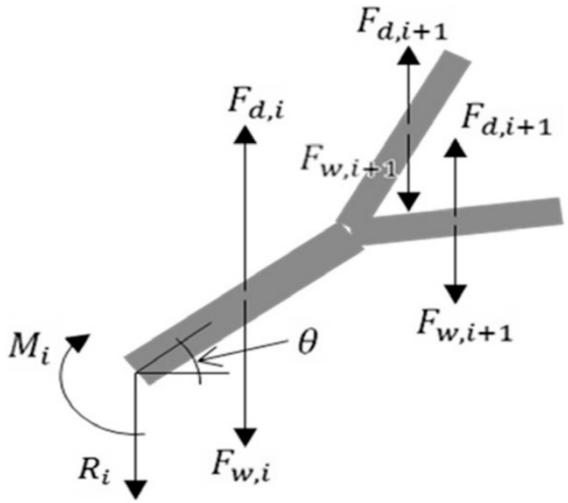


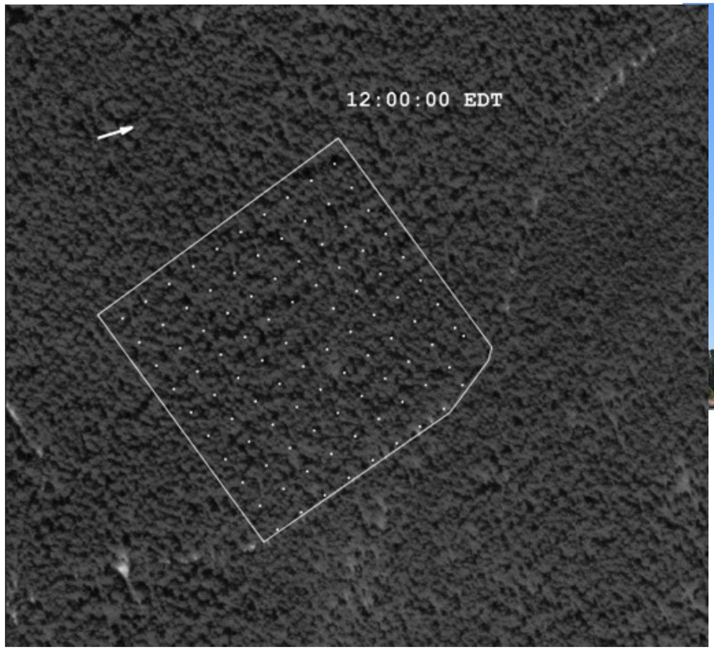
Fig. 2. Overall force distribution on branch *i*.

fire
MDPI
Article

Determining Firebrand Generation Rate Using Physics-Based Modelling from Experimental Studies through Inverse Analysis

Amila Wickramasinghe, Nazmul Khan and Khalid Moinuddin *

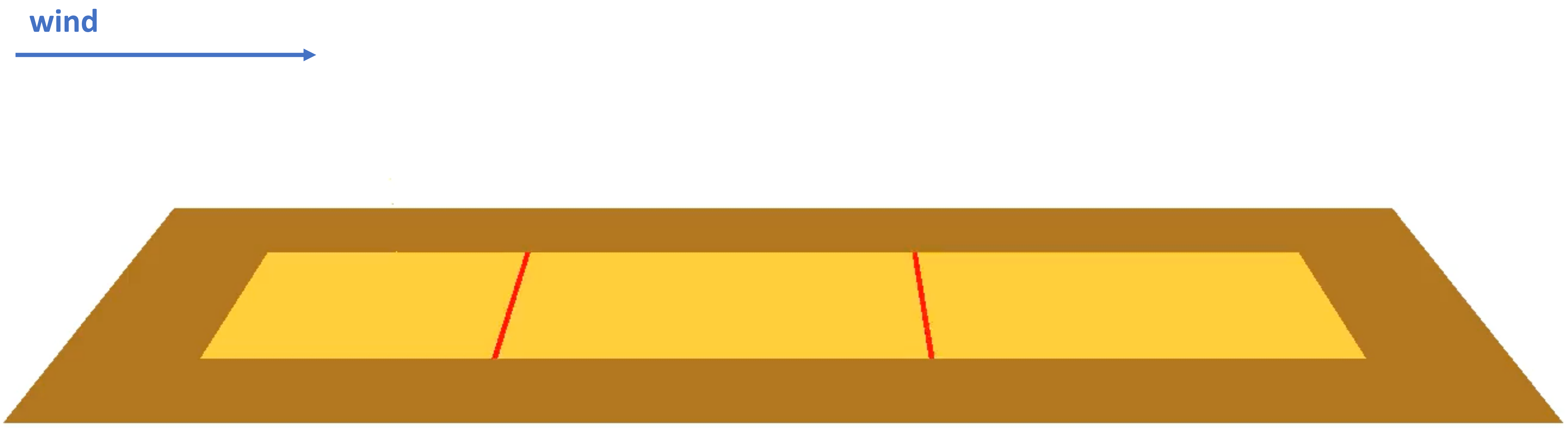
Fire **2022**, *5*, 6



Example 2: Prescribed fire

Parameterized fire spread model ($\Delta x = 0.2\ m$):

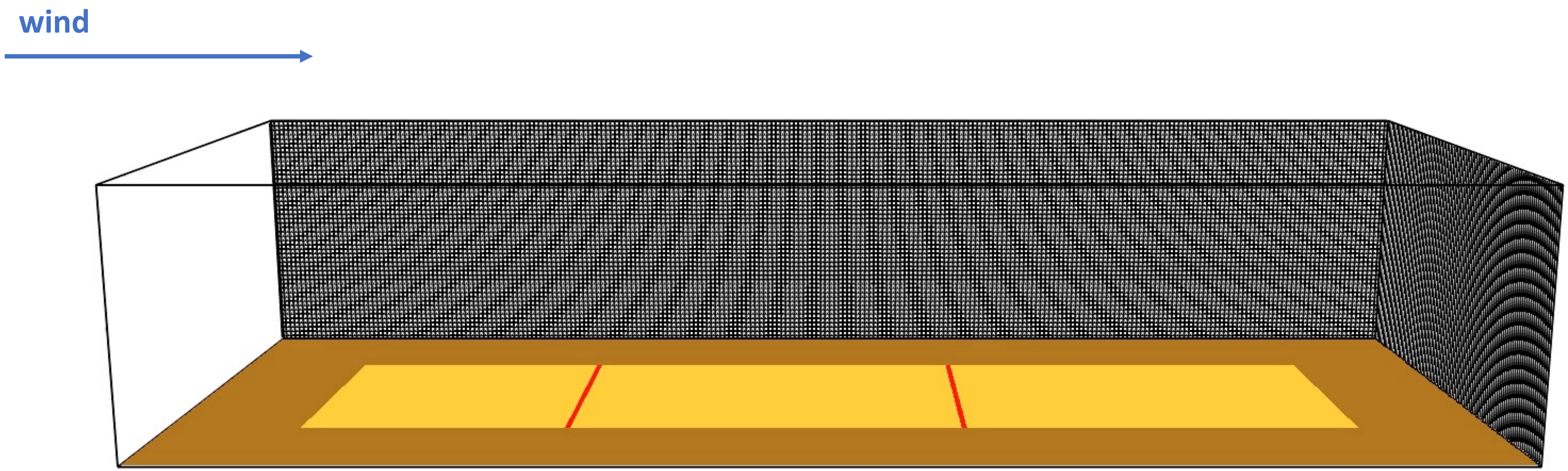
- Idealized fuel bed, no energy release ($R_0 = 0.5\ cm/s$)
- Background wind of 1 m/s, frozen
- Rothermel wind speed function: $R = R_0\left(1 + aU^b\right)$



Example 2: Prescribed fire

LES flow field, parameterized fire spread model:

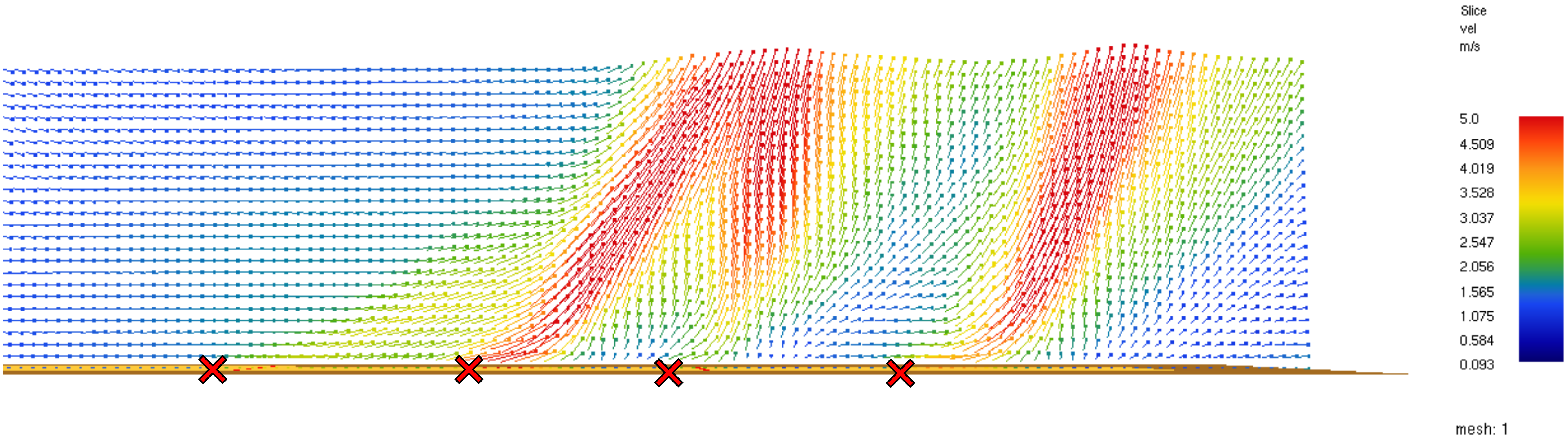
- Idealized fuel bed ($R_0 = 0.5\, cm/s$; $t_{burnout} \approx 20\ s$; $Q'' \approx 16\ MJ/m^2$)
- Background wind of 1 m/s, applied with pressure gradient
- Rothermel wind speed function: $R = R_0\left(1 + aU^b\right)$



Example 2: Prescribed fire

LES flow field, parameterized fire spread model:

- Pine needle fuel bed ($R_0 = 0.01\ m/s;\quad t_{burnout} \approx 20\ s;\ q'' \approx 700\ kW/m^2$)
- Background wind of 1 m/s
- Rothermel wind speed function: $R = R_0\left(1 + aU^b\right)$



Example 2: Prescribed fire

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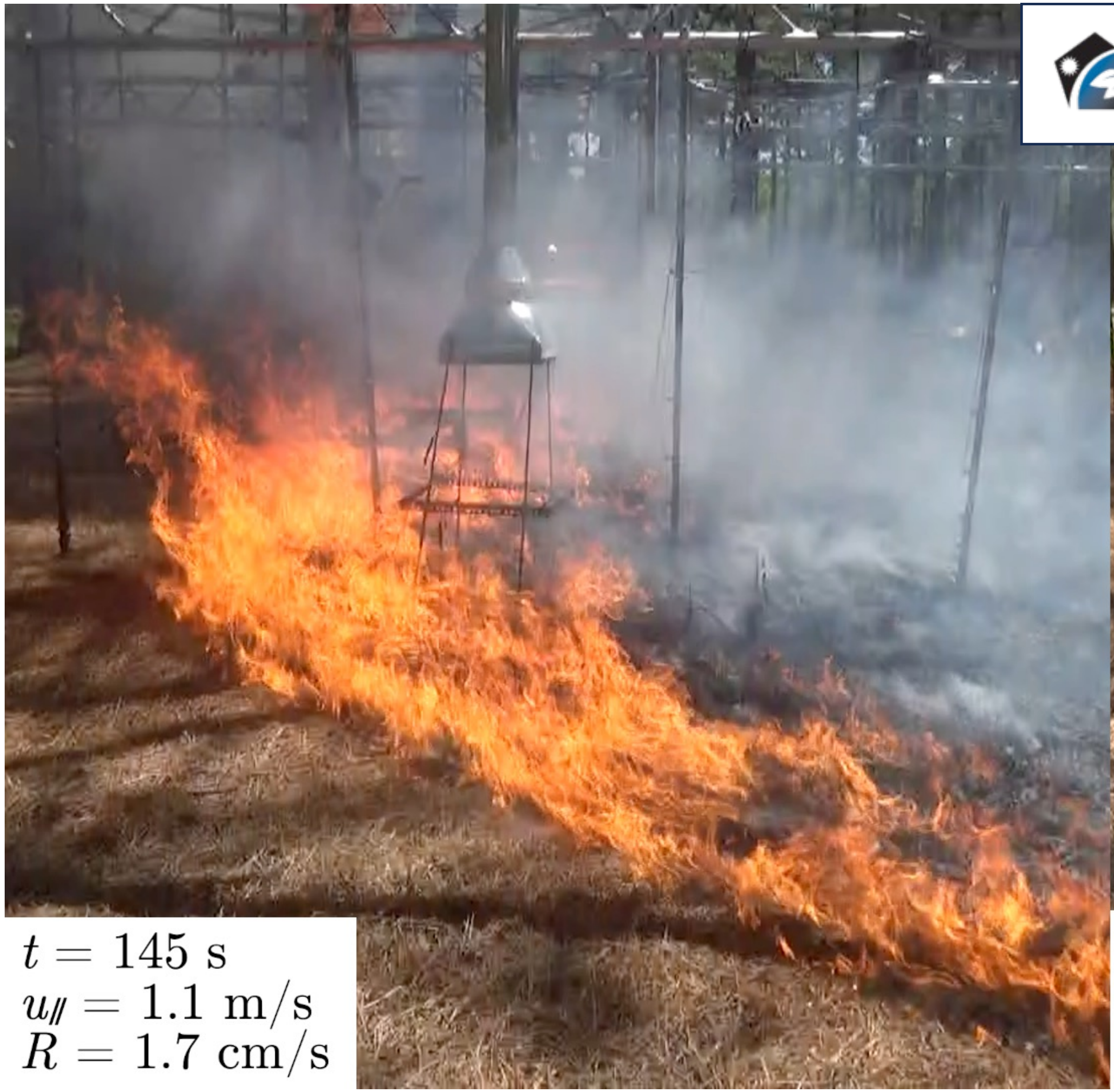
THE UNIVERSITY of EDINBURGH School of Engineering



Example 2: Prescribed fire

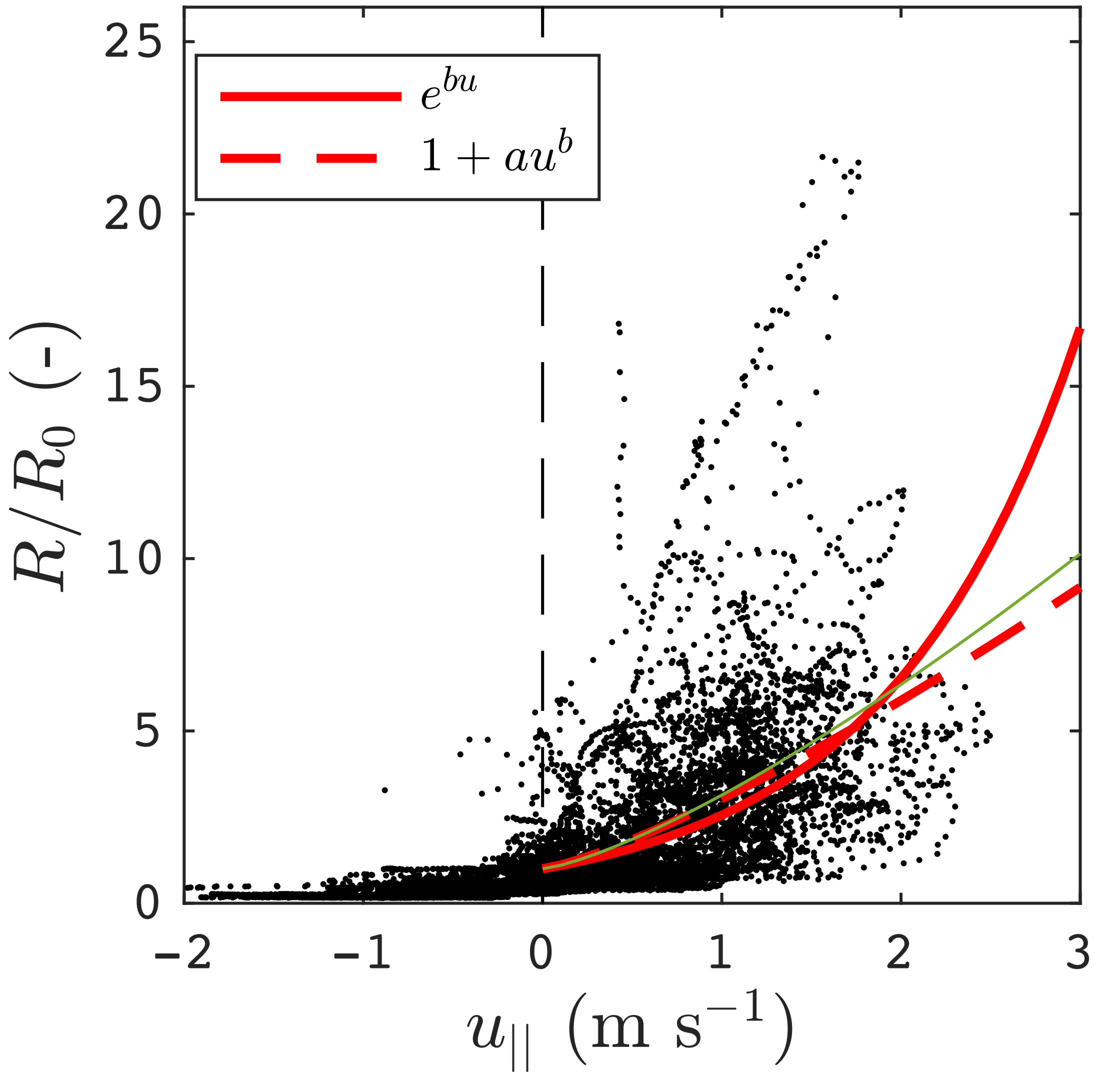
Normalize against no-wind spread (R_0) in an attempt to account for fuel variables: loading, structure, moisture…

$$R = R_0 \emptyset_w$$

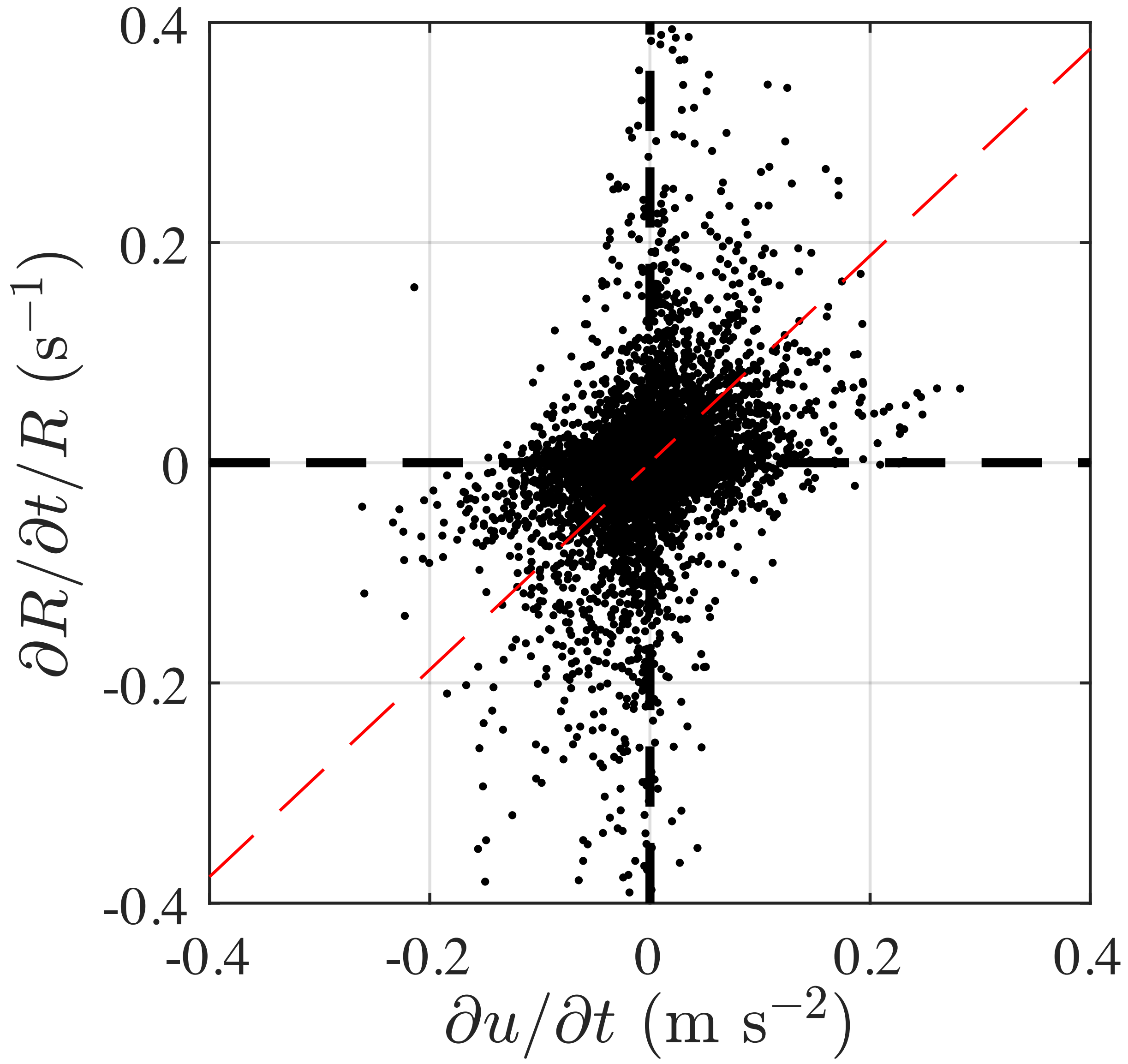
$$\vdots$$

$$R = R_0 e^{bu}$$

$$R = R_0 \left(1 + aU^b\right)$$



Example 2: Prescribed fire



$$R = R_0 e^{bu}$$

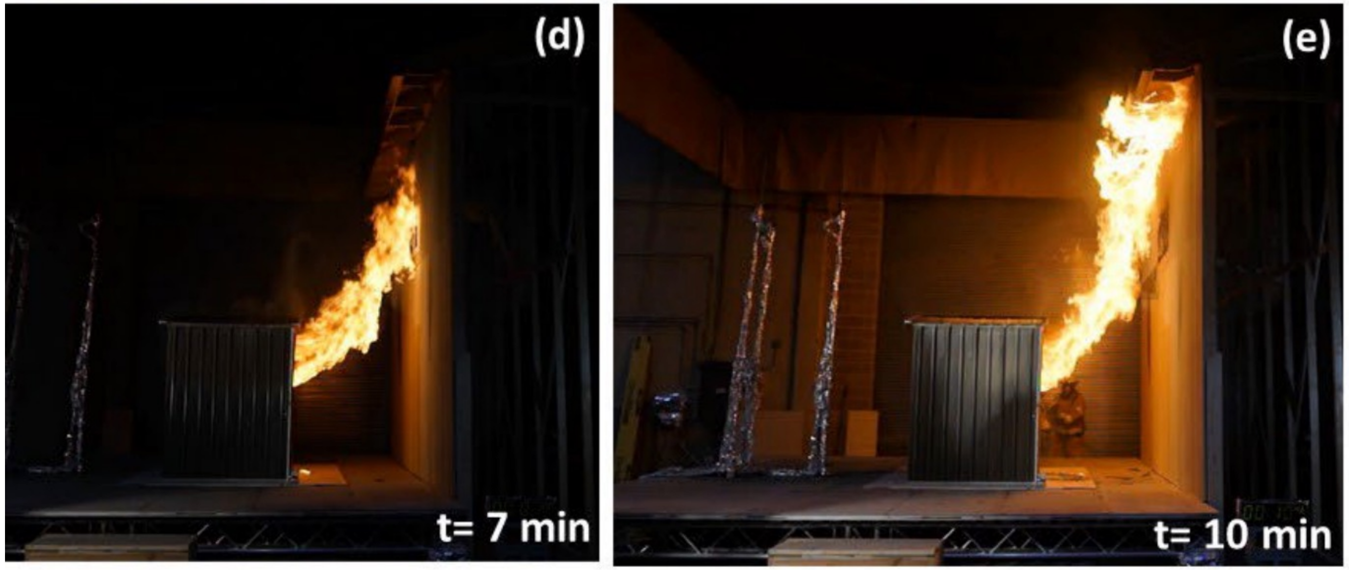
$$\frac{1}{R}\frac{\partial R}{\partial t} = b\frac{\partial u}{\partial t}$$

Example 3: Structure exposure

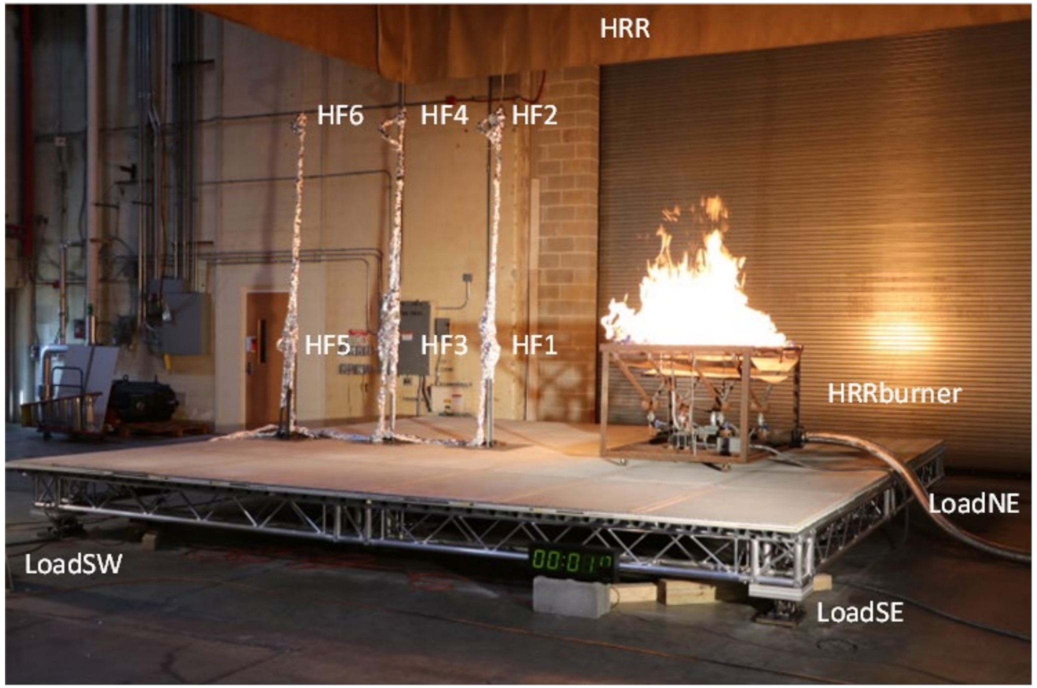
NIST Technical Note
NIST TN 2235

Structure Separation Experiments: Shed Burns without Wind

Maranghides A, Nazare S, Link E, Hoehler M, Bundy M, Hedayati F, Gorham D, Monroy X, Morrison M, Mell W, Bova A, Milac T, McNamara D, Hawks S, Bigelow F, Raymer B, Frievalt F, Walton W

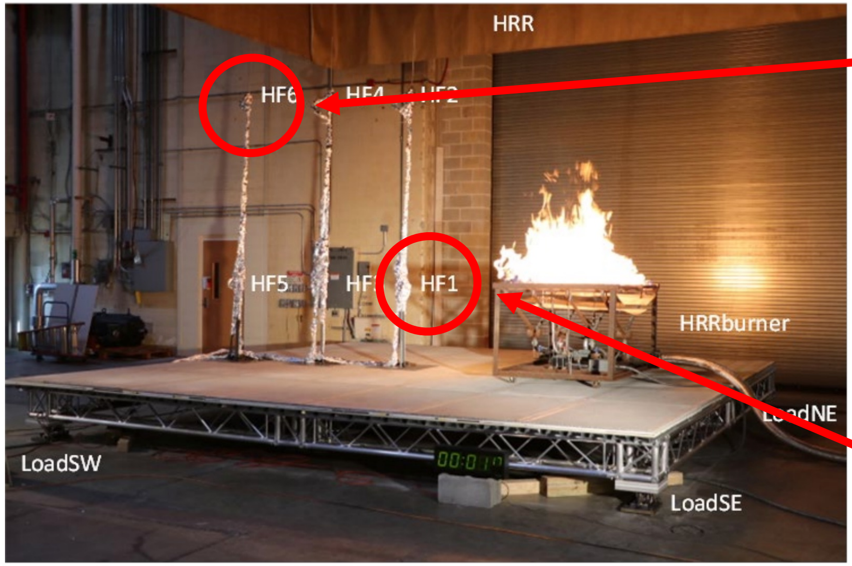


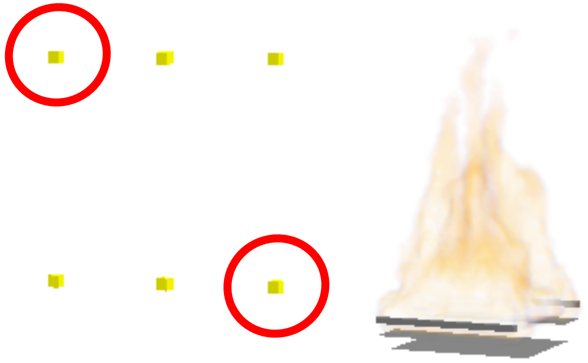
Calibration

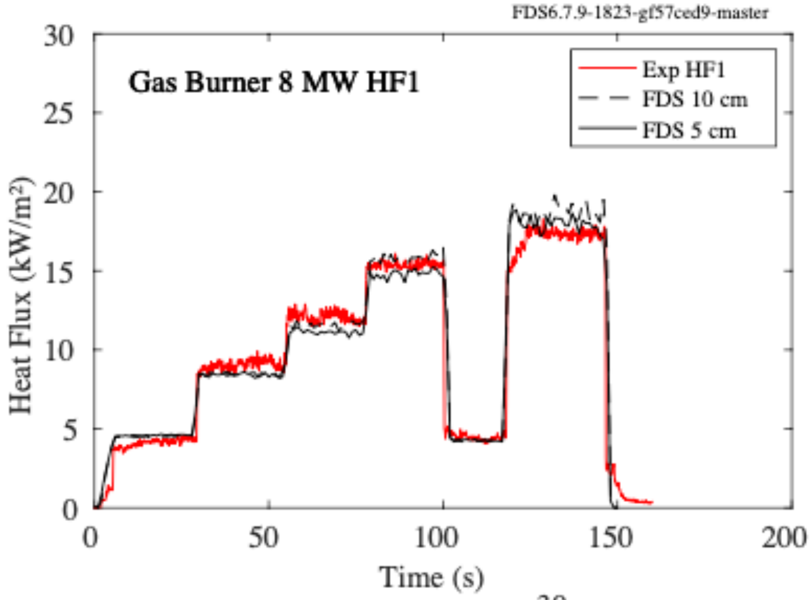


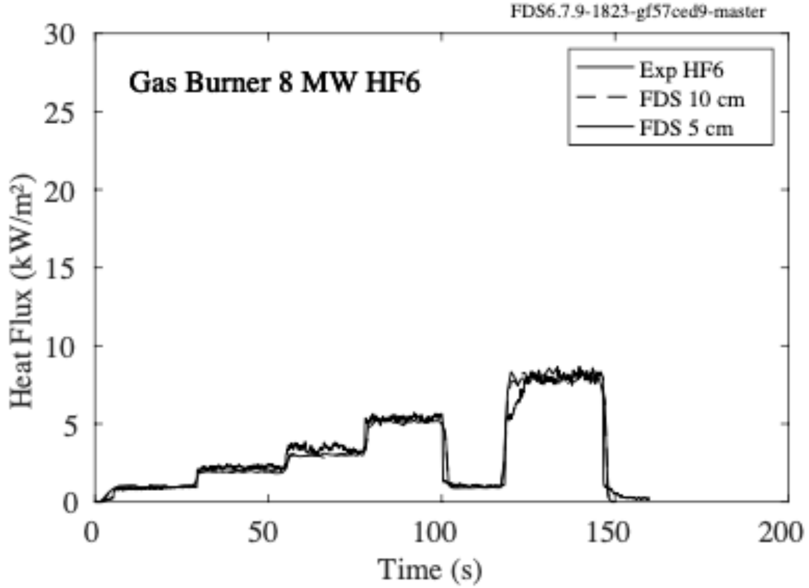
Example 3: Structure exposure

Calibration

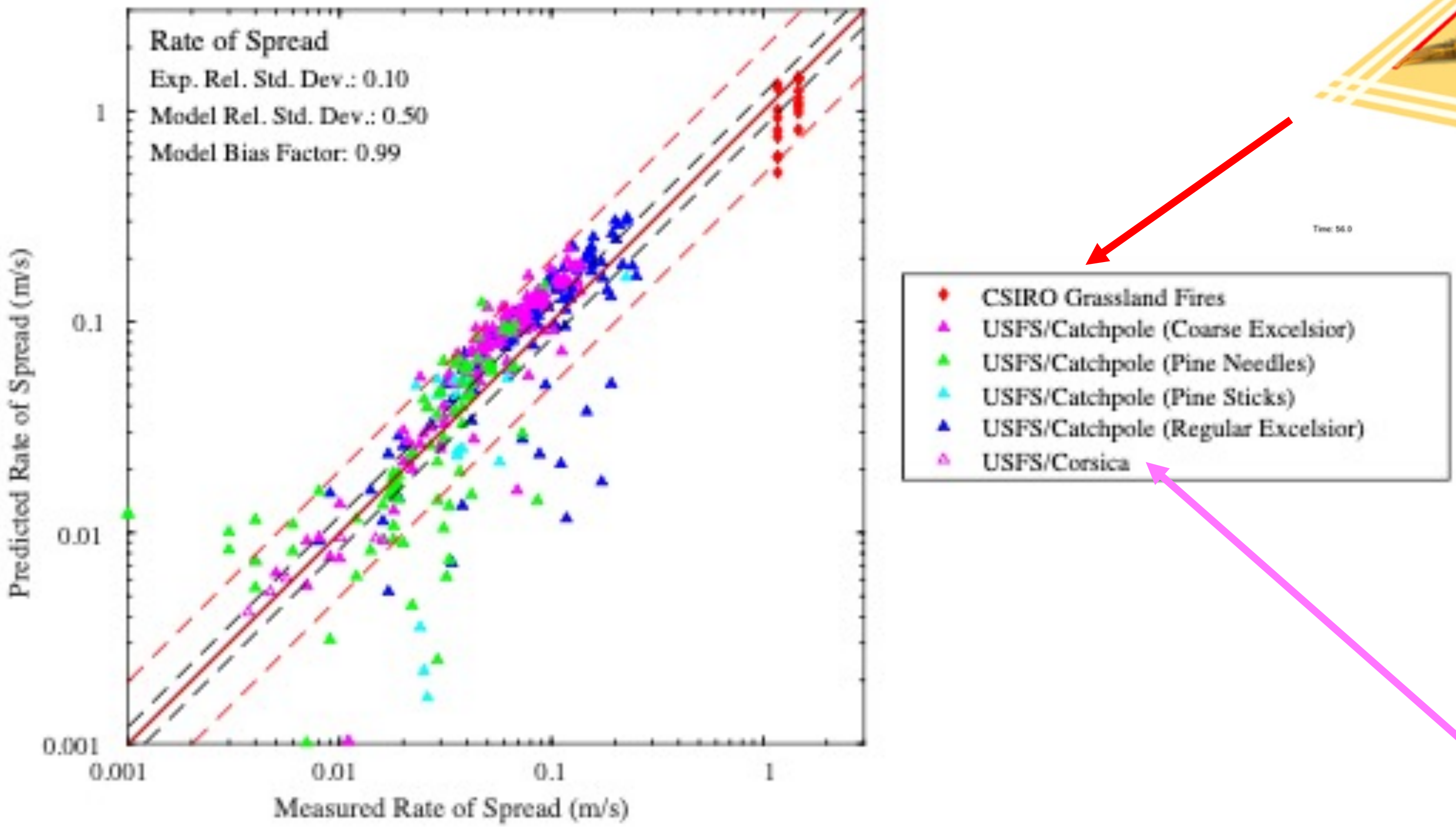


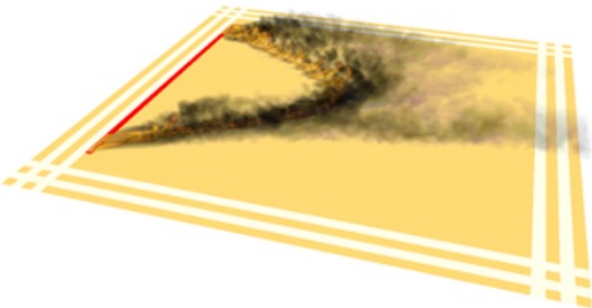






Aside: ‘Validation’?? cases





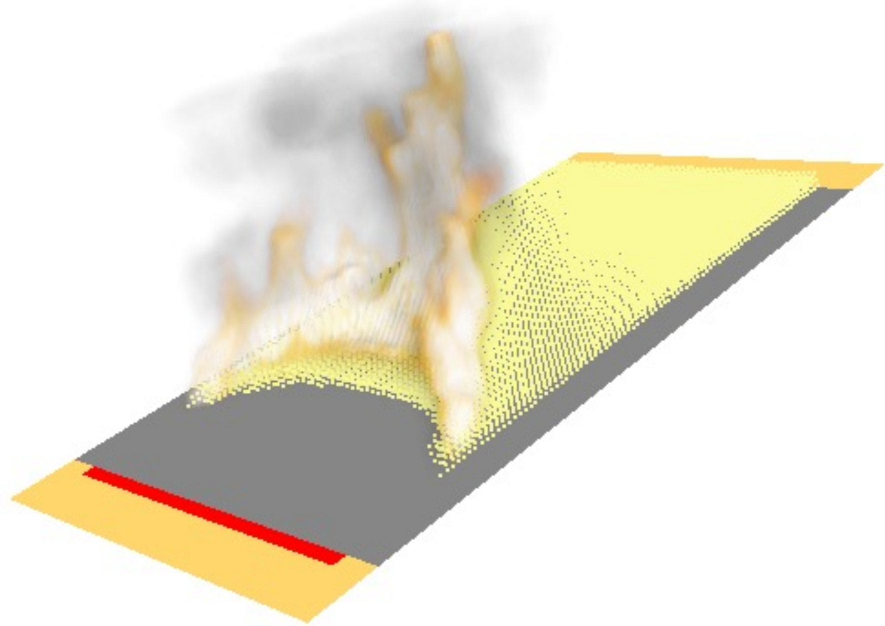
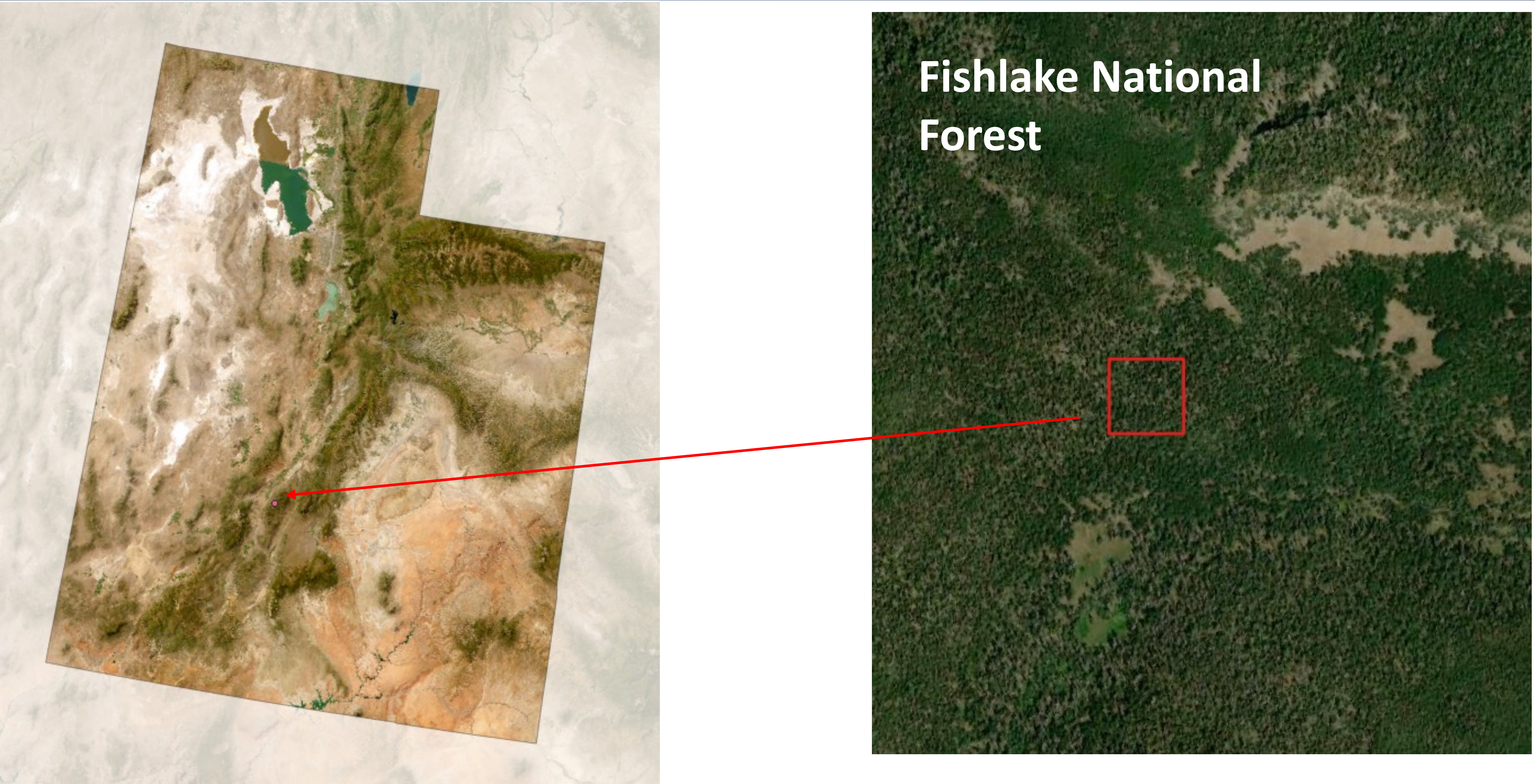


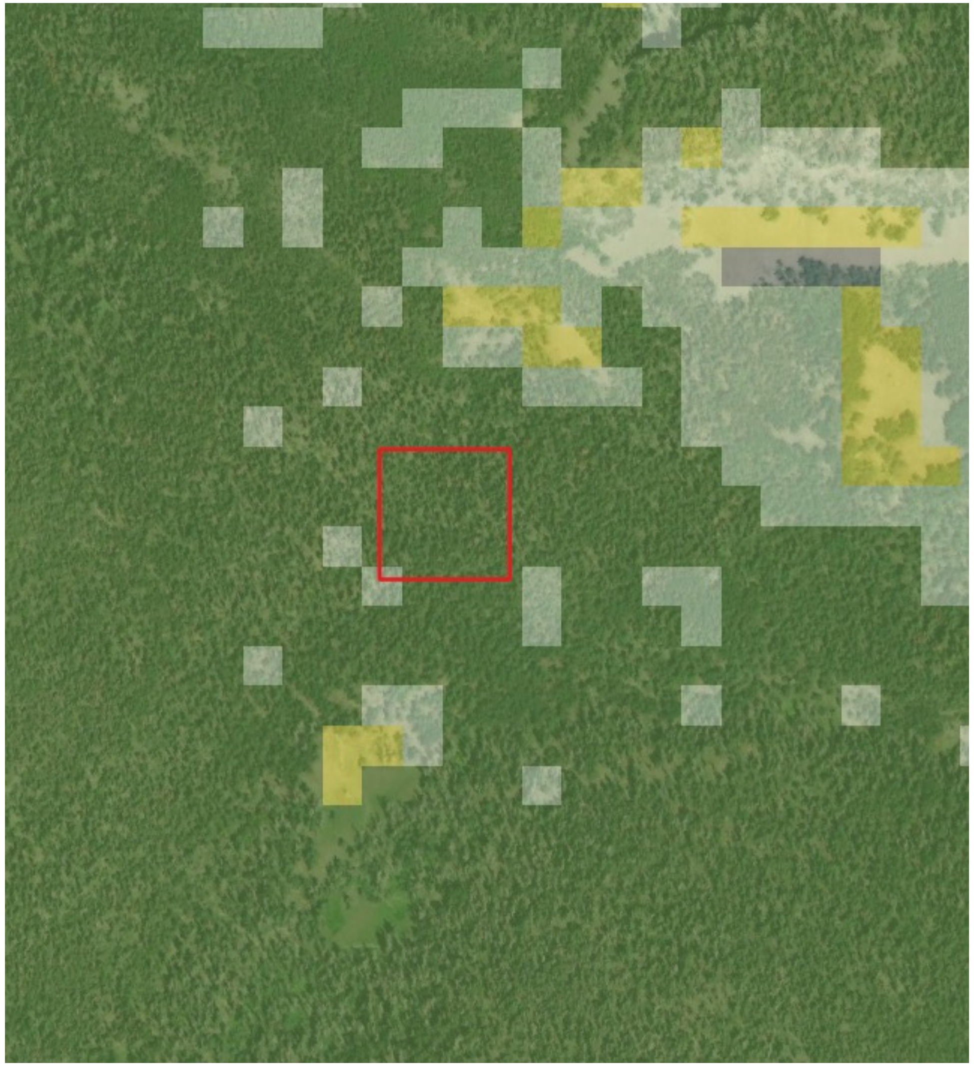
Figure 14.93: Summary, Wildfire Rate of Spread.

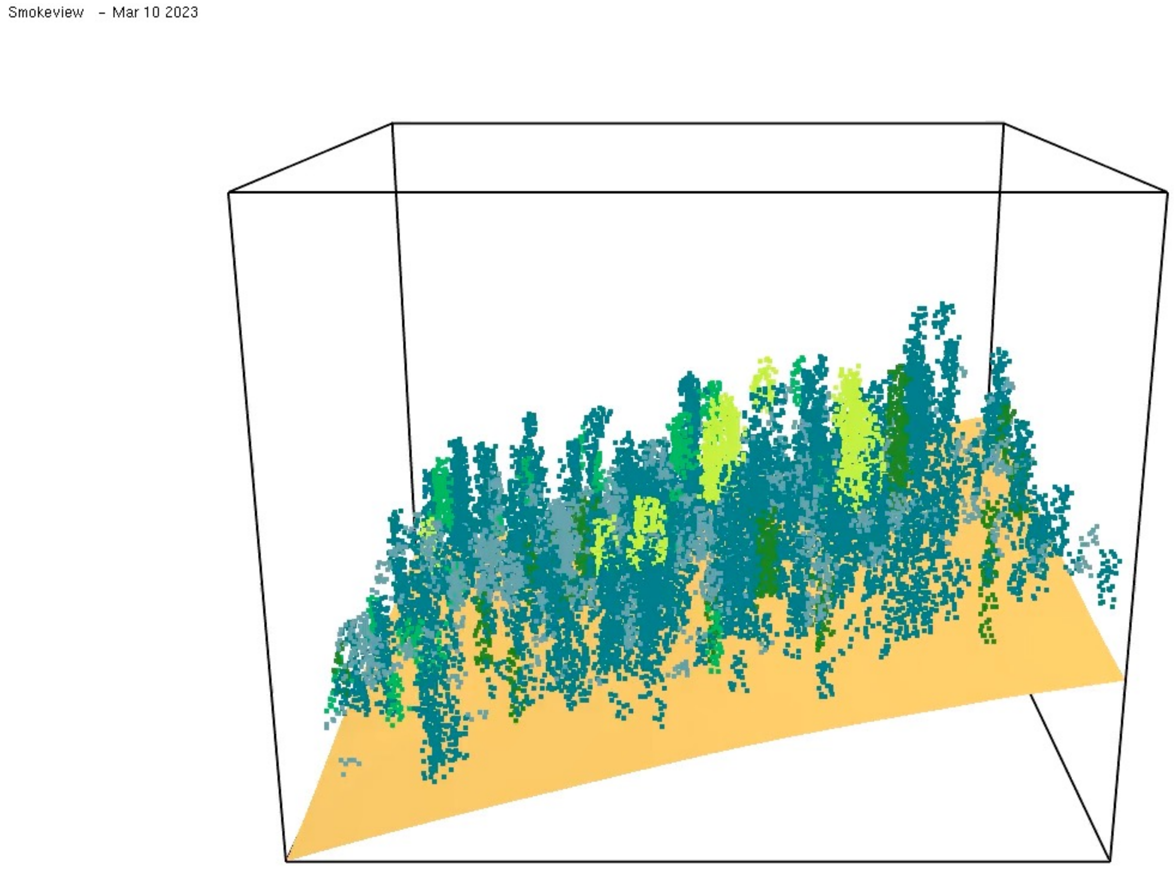
Tapping into other resources



FastFuels API

Tapping into other resources





- Extend to other fuel models?
- Extend beyond fuel (e.g. weather models)

mesh: 1

Summary

NIST ENGINEERING LABORATORY

- CFD models offer opportunity for significant insight into fire dynamics
  - They are tools – we must recognize both the capabilities and the limitations!
- Challenges to model application include:
  - Parameterizing existing submodels and ensuring applicability
  - (re)Formulating submodels when the need arises
- In WUI fire research, CFD models are gaining increased use, with a focus on:
  - Structure/vegetation or structure/structure interaction
  - Firebrands
  - Prescribed fire/fireline interaction