UL Research Institutes

Use of Fire Dynamics Simulator to model wildland and urban interface fires.

Craig Weinschenk, PhD
March 17, 2025

Discoveries in Safety™

Fire Safety Research Institute

Agenda

01 **FDS Development**
General Update on FDS and Current State

02 **Validation Cases**
How we use CI/CD to test FDS in this space

03 **Camp Swift Example**
Recent work on presribed burn in Texas

04 **Related FSRI Efforts**
Highlighting some other efforts as a touch point for collaboration

FDS Wildland Development Timeline

2000

FDS Version 1

This is the first public release of Version 1. The initial use case was to provide insight into a LODD fire in Washington DC.

2010

WFDS (~FDS 5.4)

Ruddy Mell (NIST/USFS) forks FDS repository to add support for natural fuels/wildland scenarios.

2018 – 2020

WFDS Deprecated

Independent development of WFDS stalls and code beings being merged back into made FDS code-base.

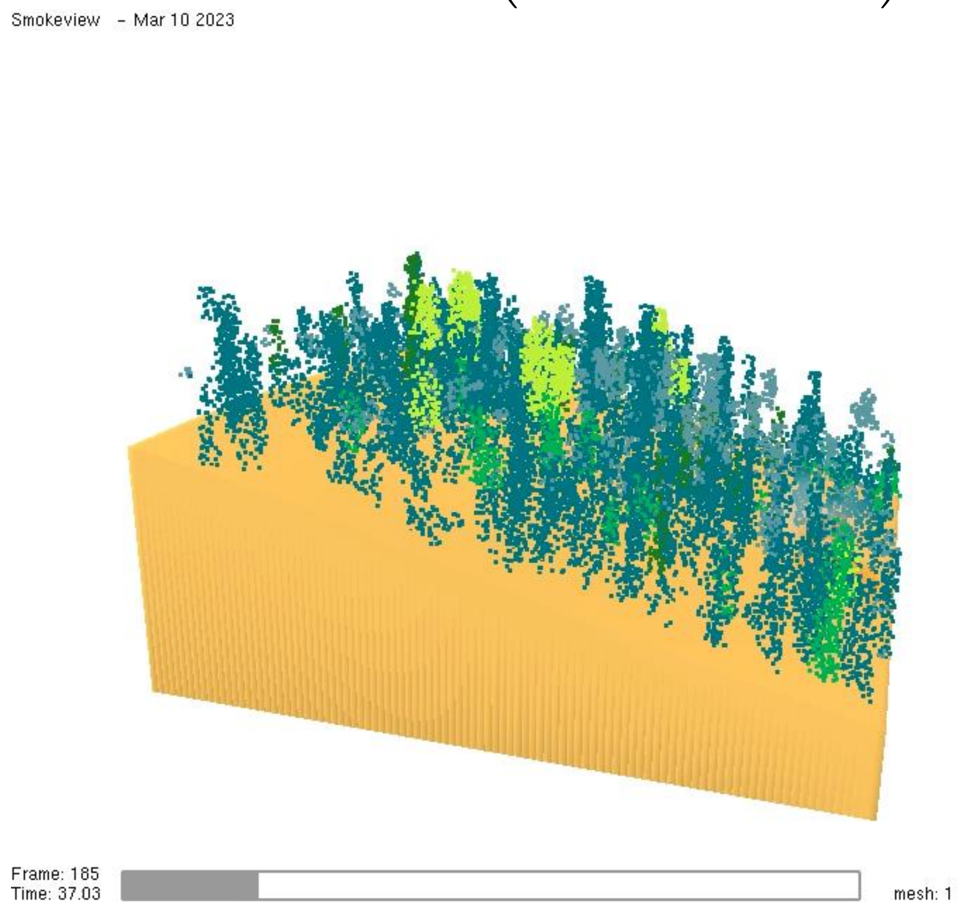
2025

FDS 6.10 (7-beta)

Current state of the code. Wildland features continue to be added including new outputs for FIRE ARRIVAL TIME and FIRE RESIDENCE TIME.

Fire Dynamics Simulator (FDS) formulation

$$\frac{\partial \bar{\rho} \tilde{Y}_\alpha}{\partial t} + \frac{\partial (\bar{\rho} \tilde{Y}_\alpha \tilde{u}_i)}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\left[\bar{\rho} D_\alpha + \frac{\mu_t}{\mathrm{Sc}_t} \right] \frac{\partial \tilde{Y}_\alpha}{\partial x_i} \right) + \overline{\dot{m}_\alpha'''}$$



Fishlake Natl. Forest, Utah (E. Mueller, A. Marcozzi, R. Parsons)

- Low-Mach LES, implicit filtering
- KE-preserving 2nd-order FD for momentum
- Block structured, Cartesian mesh
- Cutcell method for complex geometry (v7)
- Generalized lumped species
- Conservative FV 2nd-order for scalars
- TVD scalar transport (Superbee, CHARM)
- Algebraic Deardorff eddy viscosity
- Constant turbulent Schmidt and Prandtl
- Radiation solver: FVM
- Radiation absorption: gray gas
- JANAF, NASA thermodynamic properties
- 1D [3D in beta] Cartesian solid phase heat transfer
- Solid phase pyrolysis with Arrhenius kinetics
- Ad hoc solid phase mass transport
- Lagrangian particle model (thermally thick)
- Simple firebrand generation (E. Koo et al., LANL)
- Turbulent batch reactor combustion model

FDS Flame Spread Models

- **Coarsest**: level set (5 m to 100 m resolution)
- **Medium**: boundary fuel method (1 m to 10 m resolution)
- **Finest**: Lagrangian particle methods (highest level, 1 cm to 2 m resolution)

Level Set Mode

```
&MISC ..., LEVEL_SET_MODE = 1 /
&SURF ID = 'Custom Grass'
VEG_LSET_ROS_00 = 0.04
VEG_LSET_SIGMA = 11400.
VEG_LSET_BETA = 0.0012
VEG_LSET_HT = 0.51 /
```

Boundary Fuel Mode

```
&SURF ID = 'Ground Vegetation'
MATL_ID(1,1) = 'Dry Vegetation'
MATL_ID(2,1) = 'Soil'
MOISTURE_FRACTION(1) = 0.218
SURFACE_VOLUME_RATIO(1) = 3092.
MASS_PER_VOLUME(1) = 5.
THICKNESS(1:2) = 0.076,0.1 /
```

Lagrangian Particle

```
&SURF ID = 'wet vegetation'
MATL_ID(1,1:1) = 'GENERIC VEGETATION'
MOISTURE_FRACTION = 0.063
SURFACE_VOLUME_RATIO =  9770.
LENGTH = 0.20
GEOMETRY = 'CYLINDRICAL' /

&CATF OTHER_FILES='vegetation_model.txt' /
```

FDS Validation: CSIRO Grassland Fires

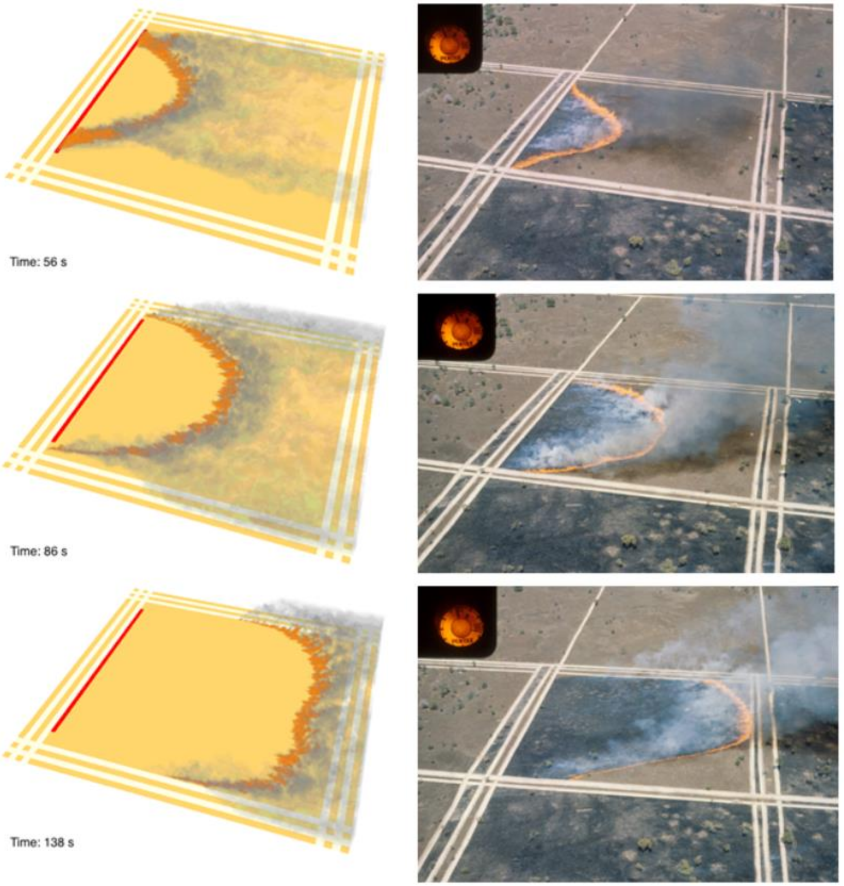
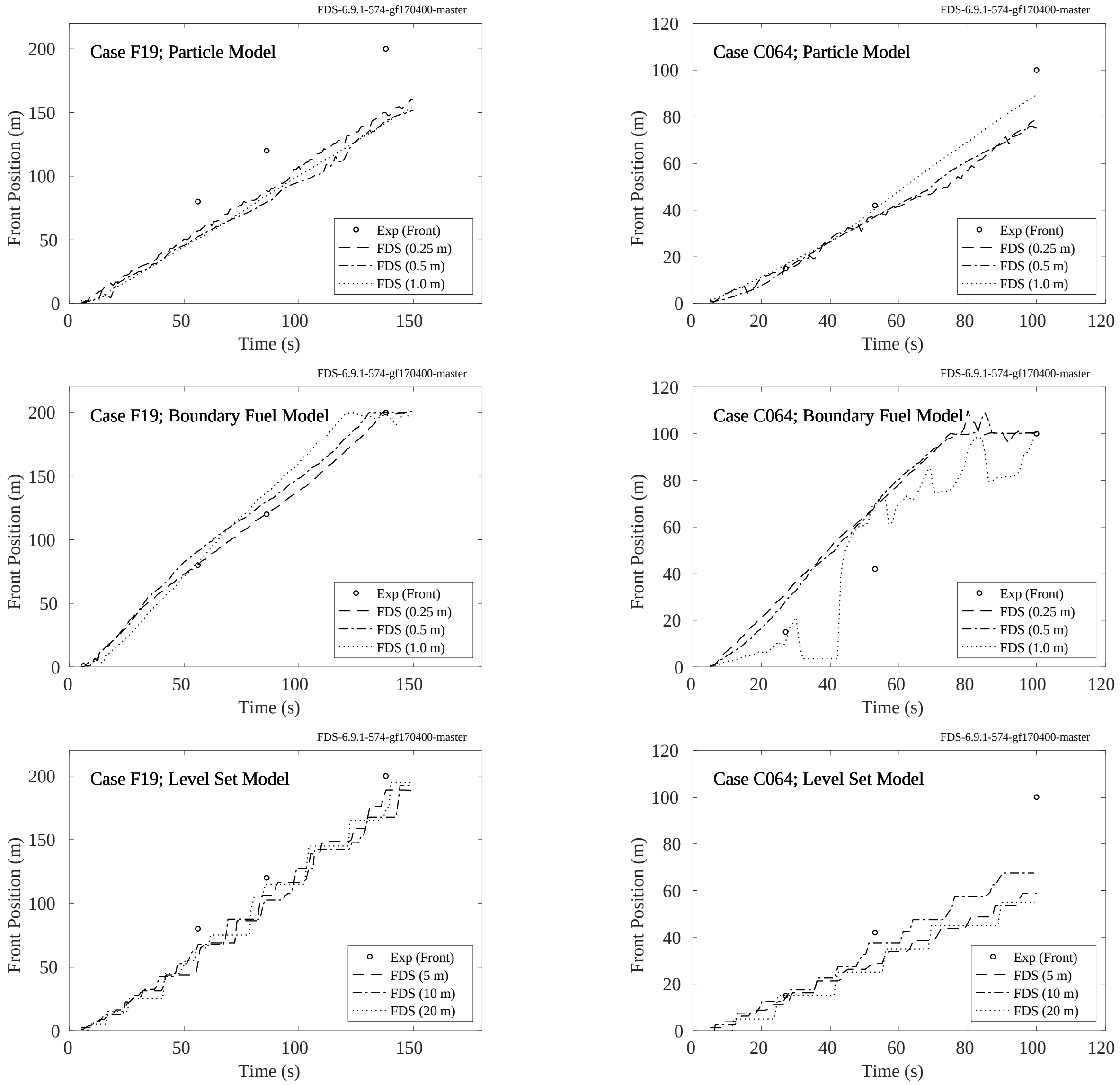
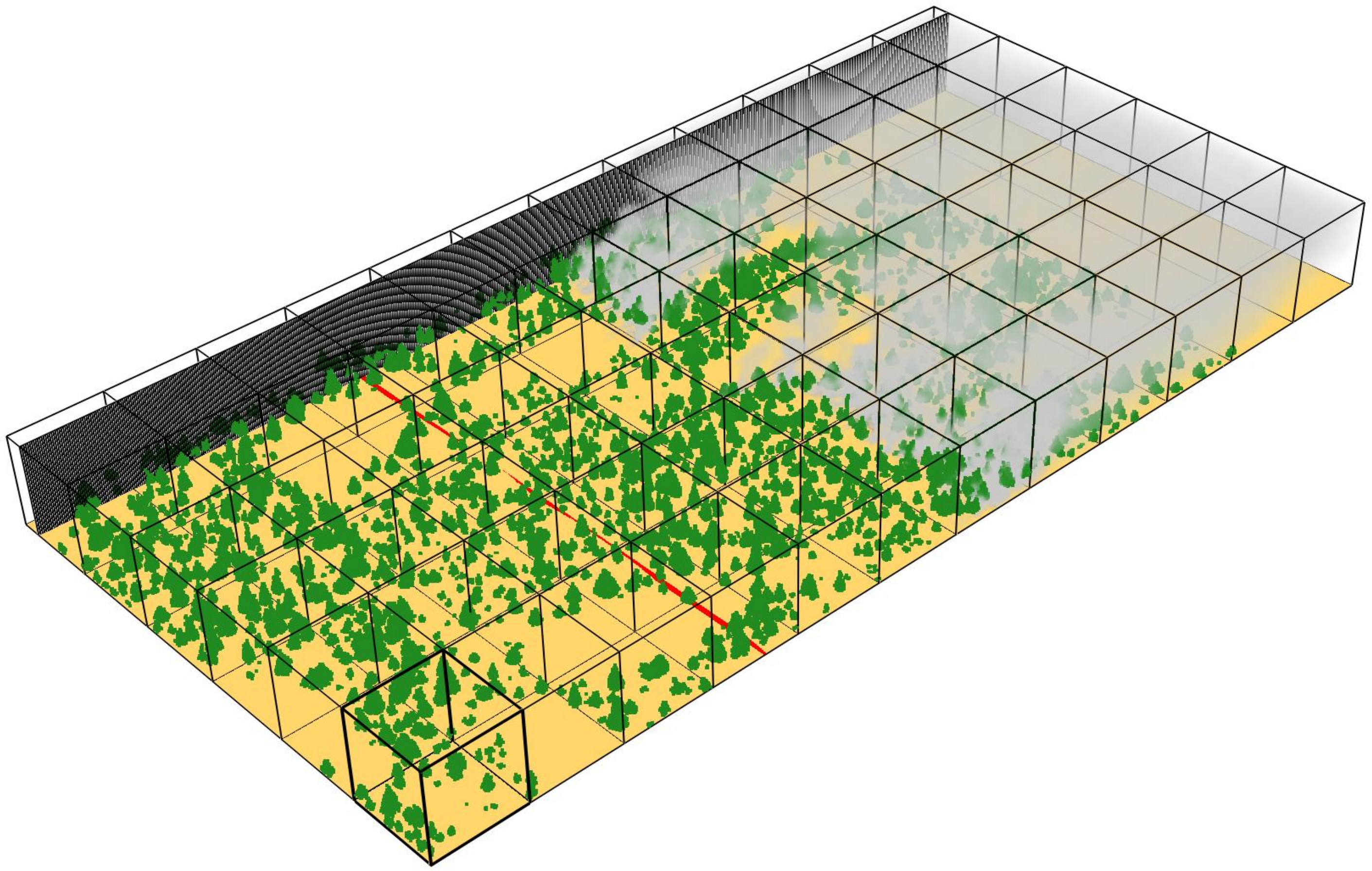


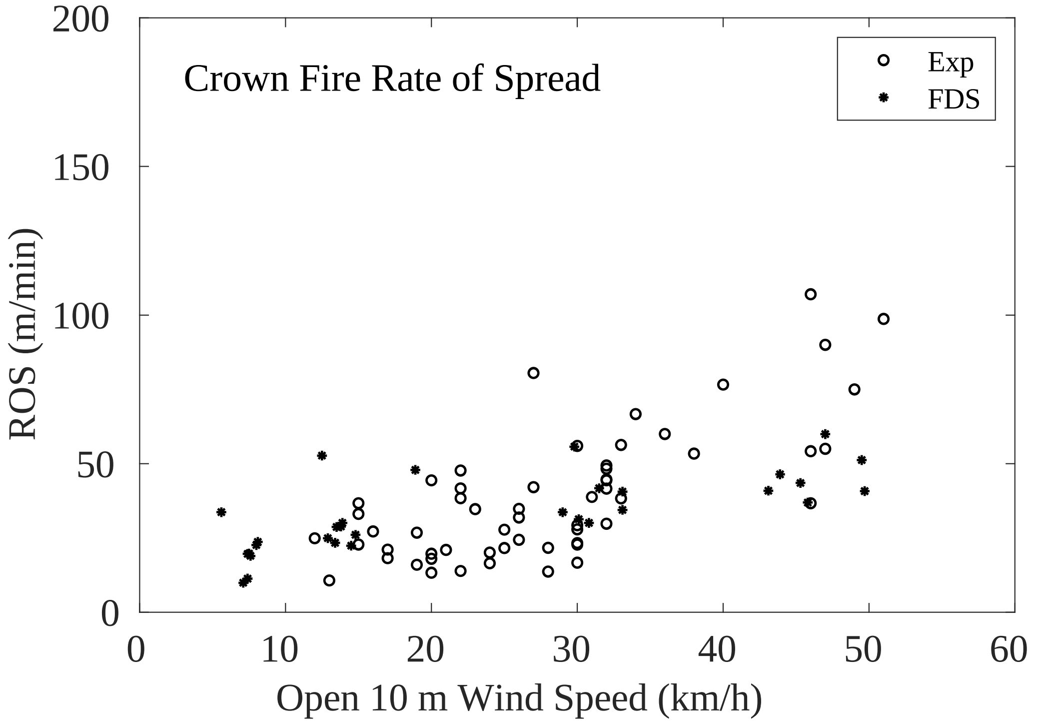
Figure 4. Photographs of the experiment and snapshots of the simulation (medium resolution Particle Model) of CSIRO Grassland Fire F19, 56 s, 86 s, and 138 s following ignition.



Cheney, N.; Gould, J.; Catchpole, W. The Influence of Fuel, Weather and Fire Shape Variables on Fire-Spread in Grasslands. International Journal of Wildland Fire 1993, 3, 31–44.

FDS Validation: Crown Fires

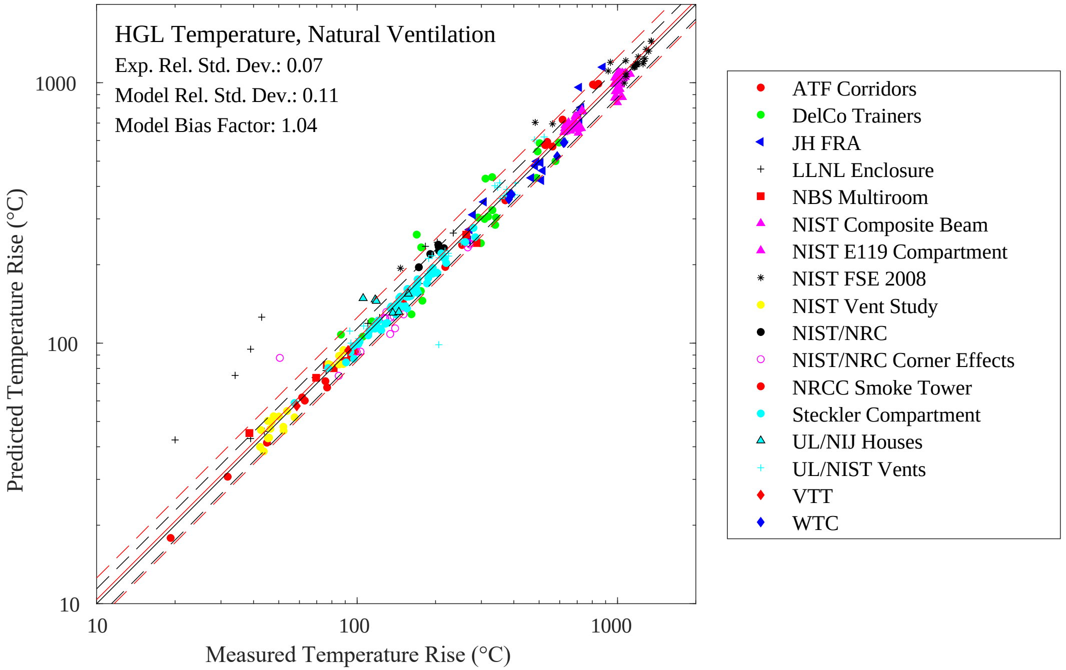


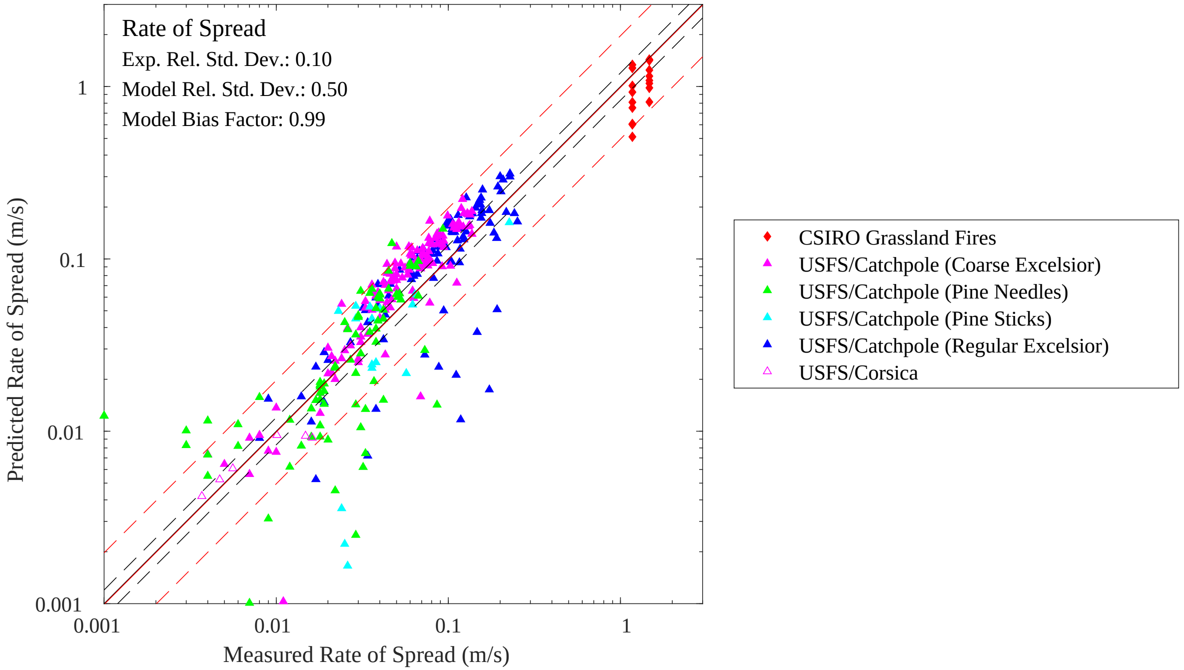


M.E. Alexander and M.G. Cruz. Evaluating a model for predicting active crown fire rate of spread using wildfire observations. Canadian Journal of Forest Research, 36:3015–3028, 2006.

Fire Science State of the Art

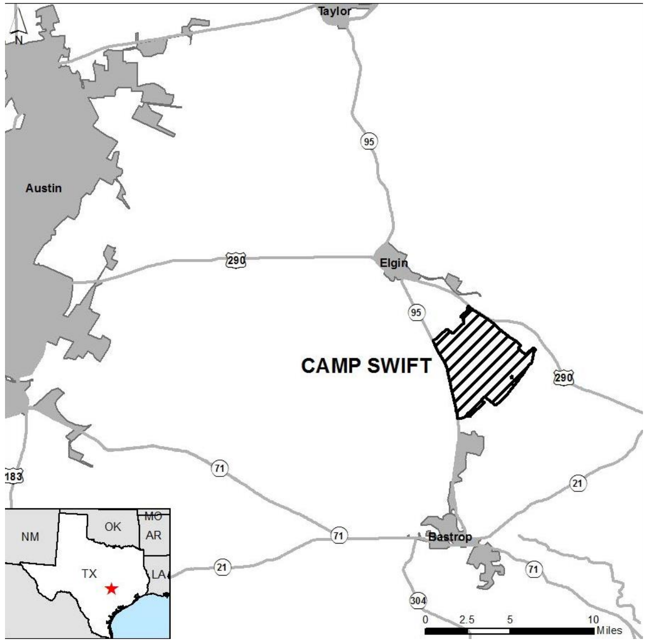
Prescribing the fuel mass loss rate (that is, fuel boundary conditions) and **predicting** the fuel mass loss rate are two completely different worlds.

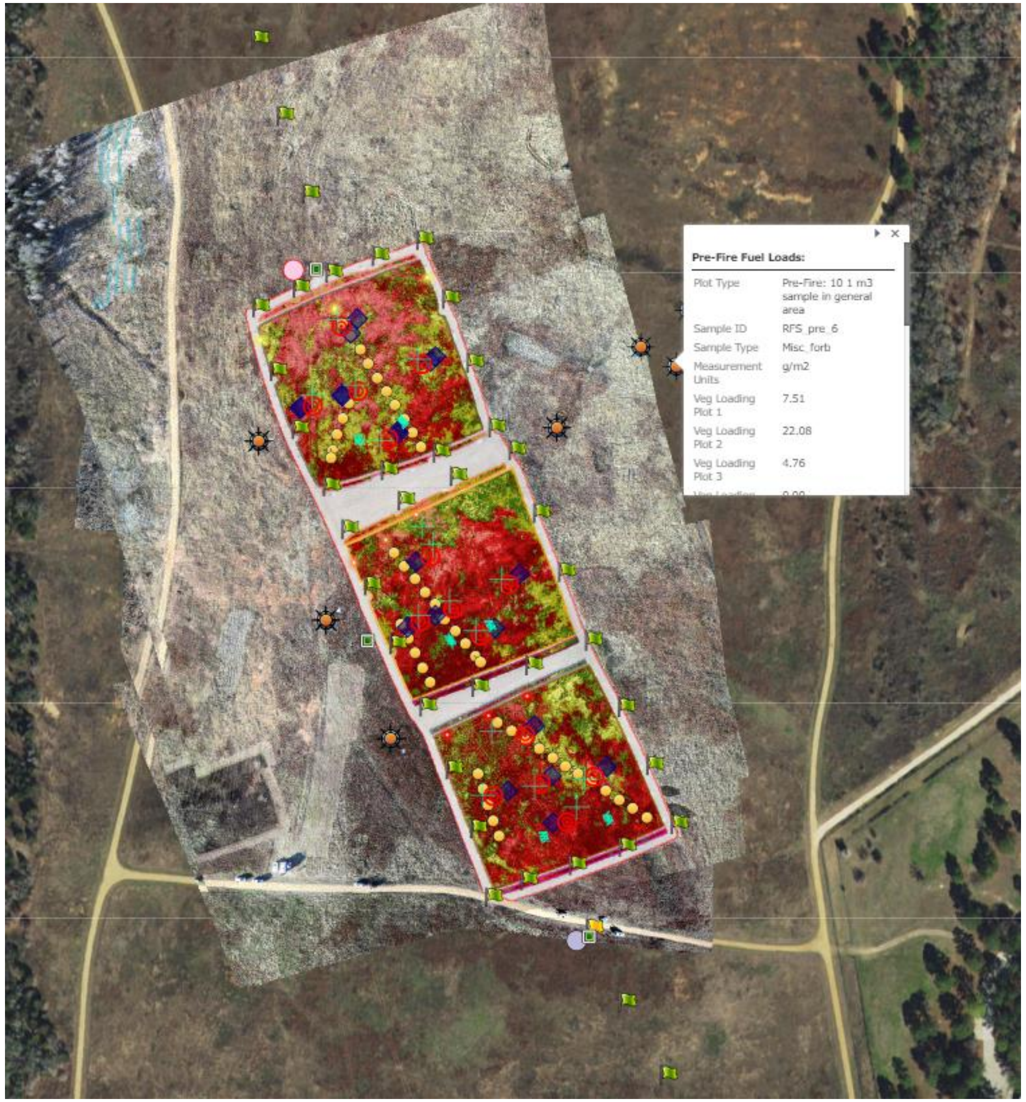




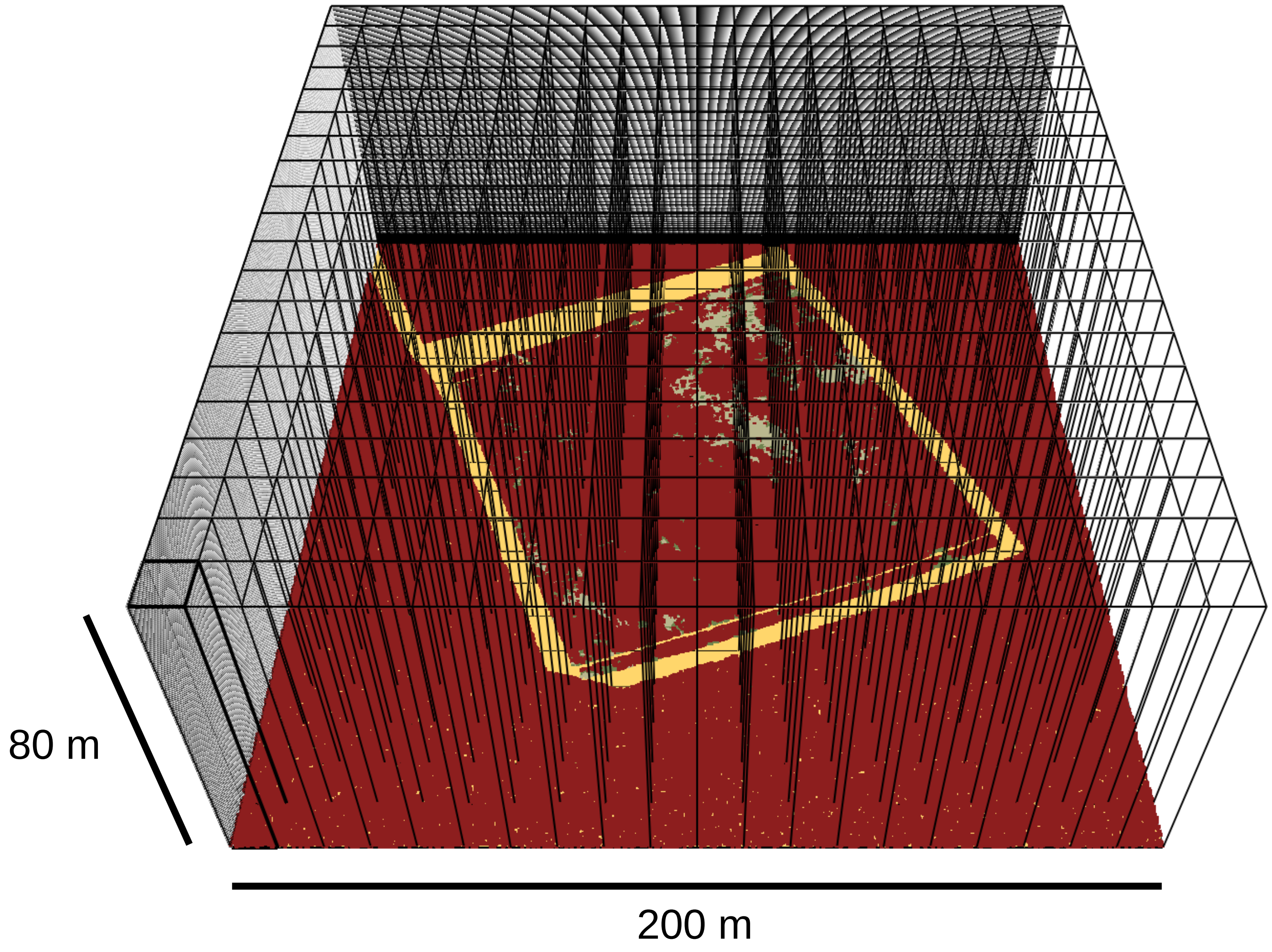
Camp Swift Experiments (2014)

Purpose: An initial step towards building case studies and experiments from both real-world and controlled fire environments to validate and evaluate physics-based fire models.





FDS Simulation Setup



Total Time = 180 s

25 cm case

- 20 x 20 = 400 mesh blocks
- 25 cm horizontal resolution
- 25 cm (20m) to 5 m vertical res
- 33,280,000 cells
- clock time: 06:03:09

10 cm case

- 32 x 32 = 1024 mesh blocks
- 10 cm horizontal resolution
- 10 cm (20 m) to 6 m vertical res
- 268,435,456 cells
- clock time: 2-19:44:59

FDS Setup Vegetation Model

$$\text{R1} : \text{moisture} \rightarrow \text{water vapor}$$

$$\text{R2} : \text{vege} \rightarrow \nu_{\text{char}}\,\text{char} + \nu_{\text{fv}}\,\text{fuel vapor}$$

$$\text{R3} : \text{char} + \nu_{\text{air}}\,\text{air} \rightarrow \nu_{\text{ash}}\,\text{ash} + \nu_{\text{prod}}\,\text{prod}$$

Reaction	A	E	n_s	n_{O_2}	component ν					H_r
	1/s	J/mol			ν_{air}	ν_{char}	ν_{fv}	ν_{ash}	ν_{prod}	kJ/kg
R1	4290	43800	1	0						2296
R2	1040	61041	1	0		0.25	0.75			4182
R3	465	68000	1	1	−7.17			0.04	8.13	−25000

$$r_{\alpha\beta} = \underbrace{\rho_{s,\alpha}^{n_{s,\alpha\beta}}}_{\text{Reactant dependency}} \underbrace{A_{\alpha\beta}\,\exp\left(-\frac{E_{\alpha\beta}}{RT_s}\right)}_{\text{Arrhenius function}} \underbrace{\left[X_{O_2}(x)\right]^{n_{O_2,\alpha\beta}}}_{\text{Oxidation function}} \underbrace{T_s^{n_{t,\alpha\beta}}}_{\text{Power function}}$$

$$\dot{q}_{s,c}'''(x) = -\sum_{\beta=1}^{N_r} r_{\alpha\beta}(x) H_{r,\alpha\beta}$$

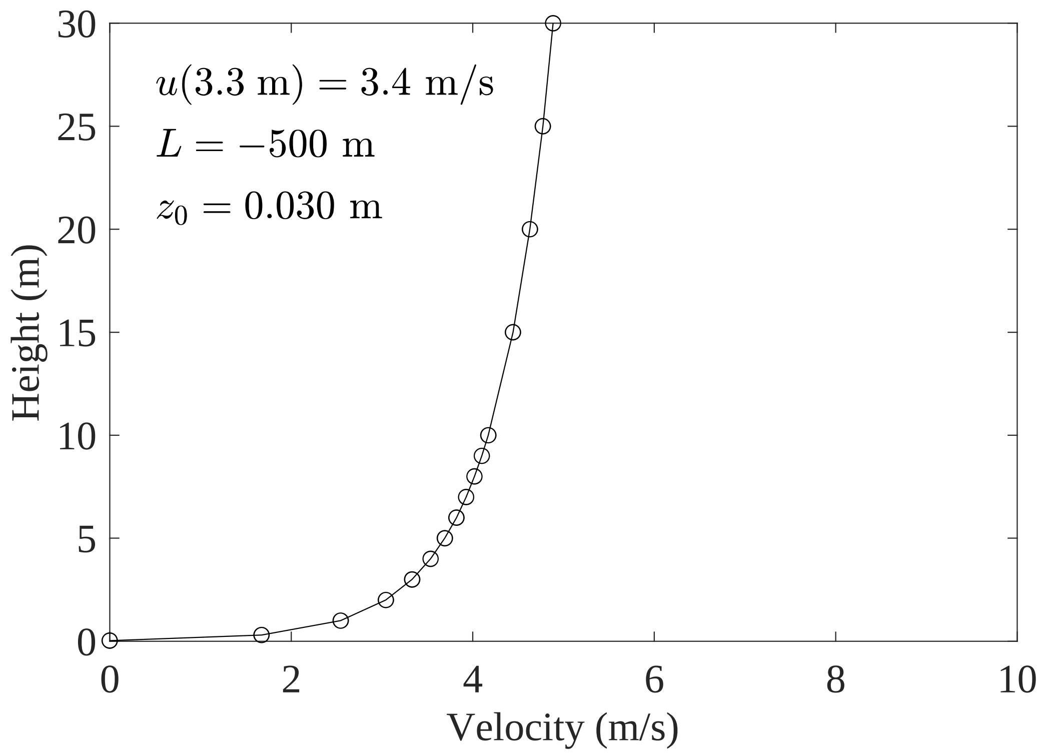
from Camp Swift Story Map

Component	ρ [kg/m^3]	k [W/(m K)]	c_v [kJ/(kg K)]
moisture	1000	0.062	4.18
vegetation	500	0.20	c_v ramp
char	300	0.052	c_v ramp
ash	67	0.10	c_v ramp

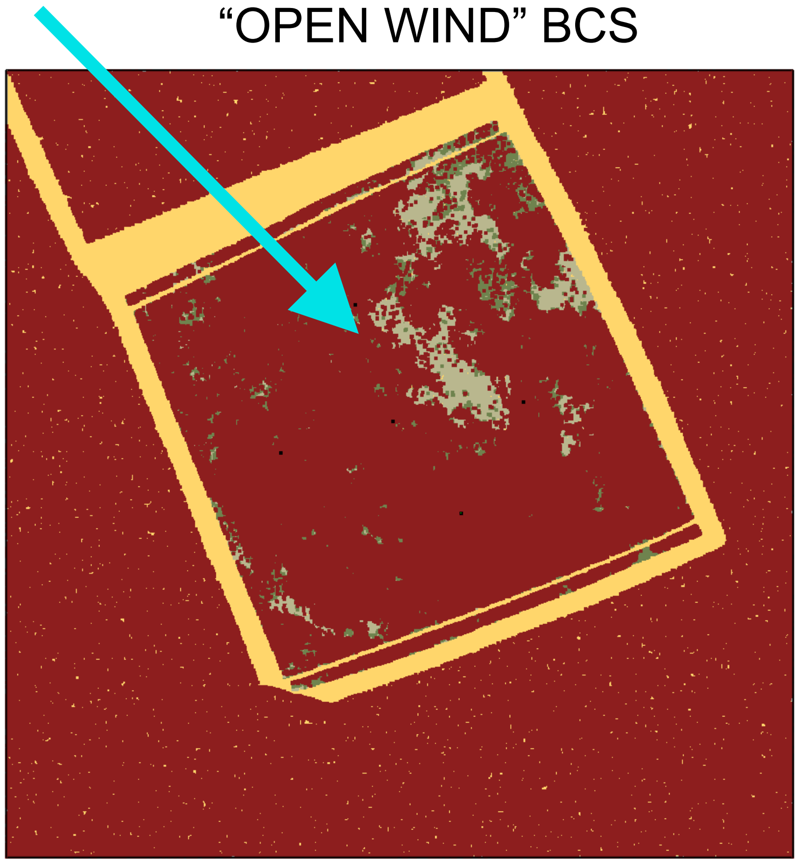
```
&RAMP ID='c_v', T=  0., F=1.1 /
&RAMP ID='c_v', T=200., F=2.0 /
&RAMP ID='c_v', T=800., F=2.0 /
```

FDS Wind Field Setup

```
-- Constant inflow
&WIND SPEED=3.4, DIRECTION=312.5, L=-500., Z_0=0.03, Z_REF=3.3/
```



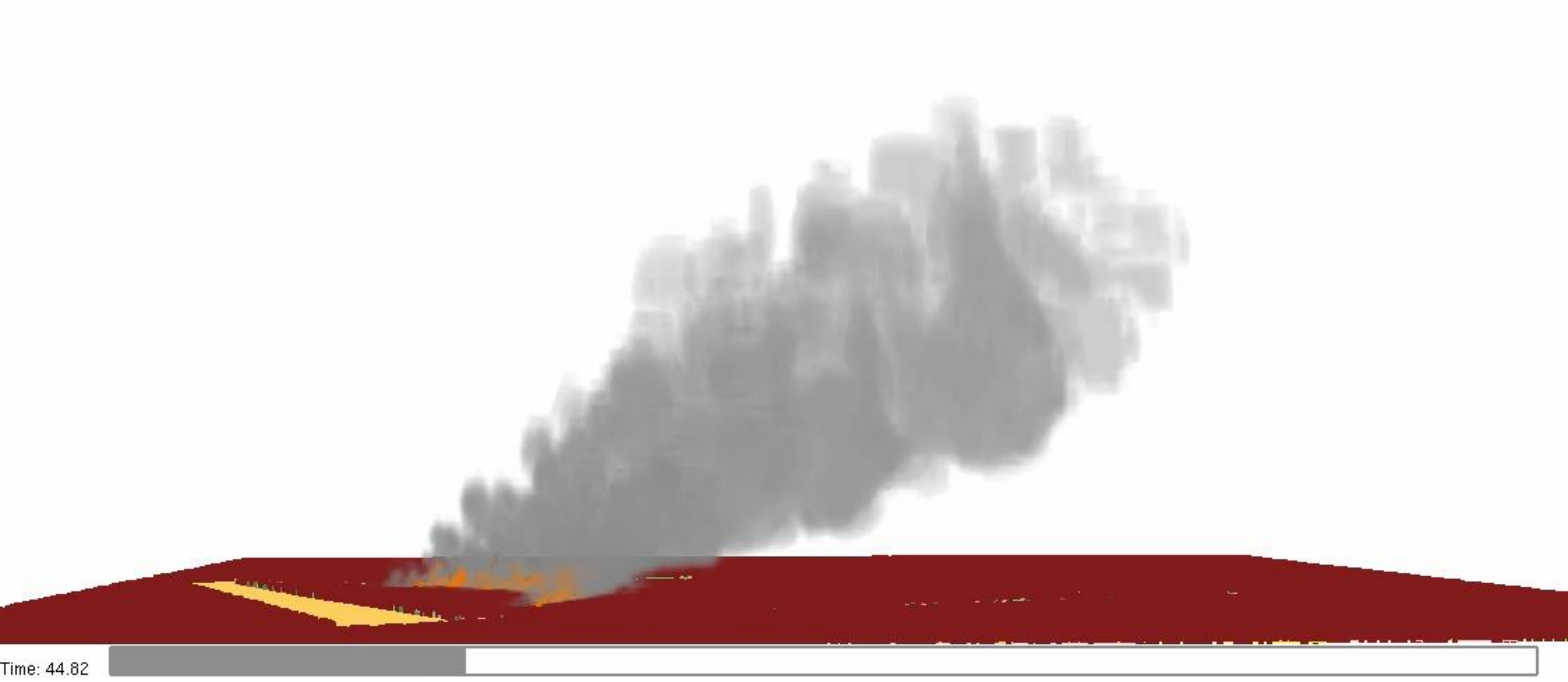
“OPEN WIND” BCS



$$\texttt{BXS(J,K)} \equiv H_{\frac{1}{2},jk} = H^n_{1,jk} + \frac{\delta x}{2}\left[\frac{u_\infty(z,t) - u^n_{0,jk}}{\delta t}\right]$$

Burn Block 1 Experiment Video

FDS Results HRRPUV and Smoke (25 cm)



Camp Swift – Preliminary Conclusions

- With the current model setup and formulation, we are missing the persistence of the flank fire, which is critical for prediction of prescribed burn behavior.
- The model results are reasonably consistent from 25 cm resolution down to 5 cm resolution, indicating that one of our original hypotheses – that high enough resolution would allow accurate flank fire behavior – may be incorrect, and that an improvement to the model or a closer look at fuel properties may be needed.
- There are efforts underway to improve the assimilation of the measured wind field, as well as comparing with other available data products.

National Emergency Response Information System

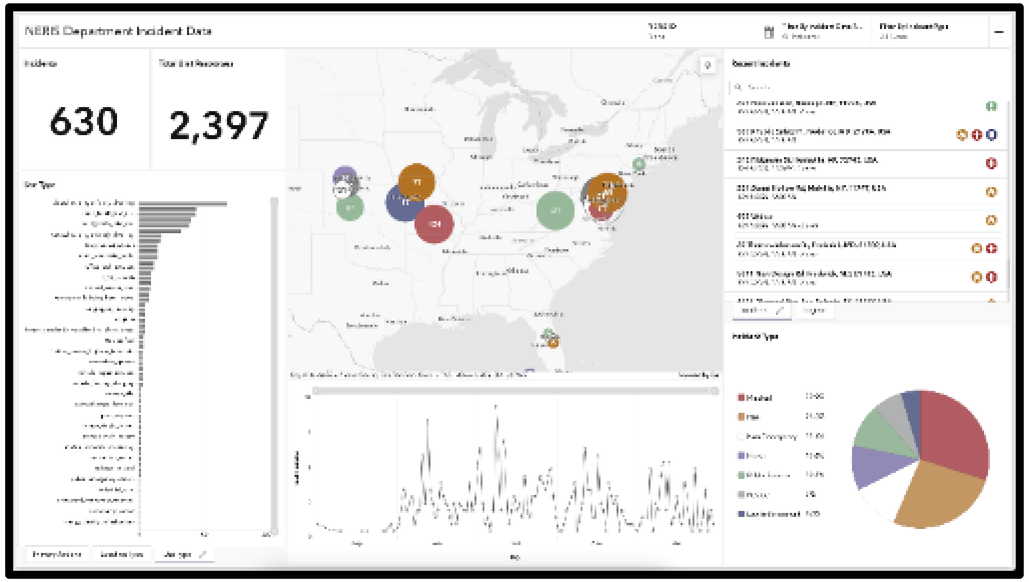
NERIS

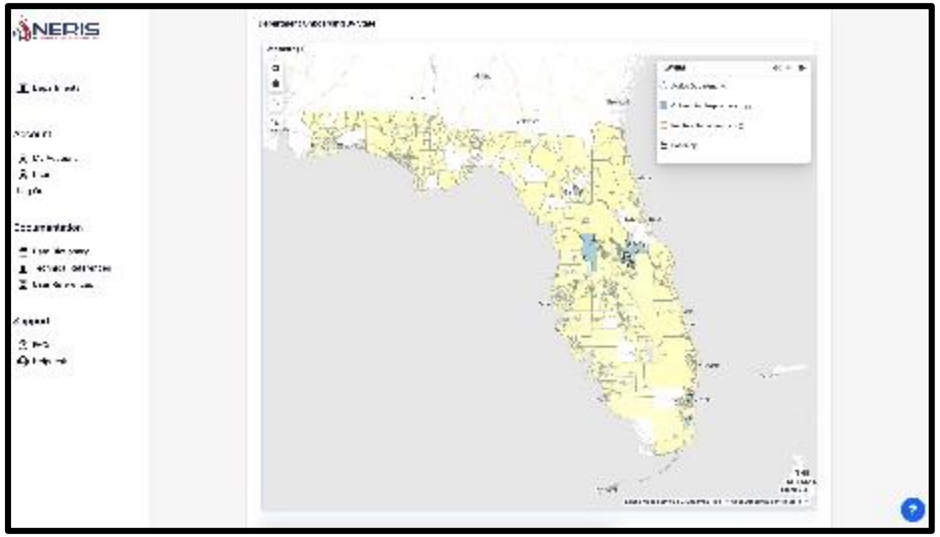
NATIONAL EMERGENCY RESPONSE INFORMATION SYSTEM

The goal of NERIS is to empower the local fire and emergency services community by equipping them with near real-time information and analytic tools that support data informed decision-making for enhanced preparedness and response to incidents involving all hazards.

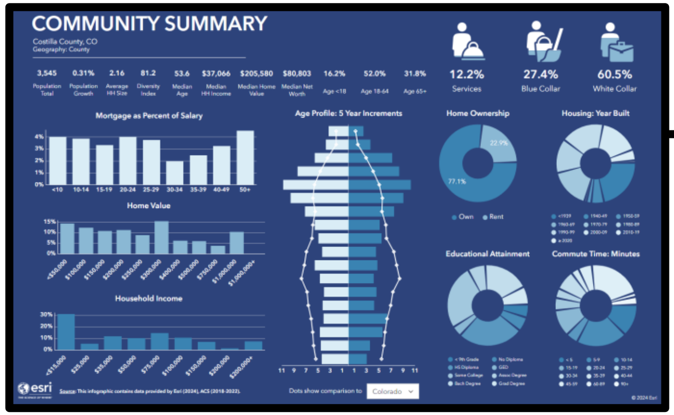
NERIS Fast Facts

- **Firefighter-first** design
- **Improved data** quality, reliability, and accuracy
- Near **real time, fully geospatial** data
- **Highly flexible**, relying on data integration from best available sources for better intelligence
- **All-hazards:** All incidents local fire & EMS responds to
- **Streamlined and efficient** data collection, data sharing, and analytics
- **Insights on** emerging threats and hazards
- **Agile, development keeping pace** with evolving needs, science, and technology advancements

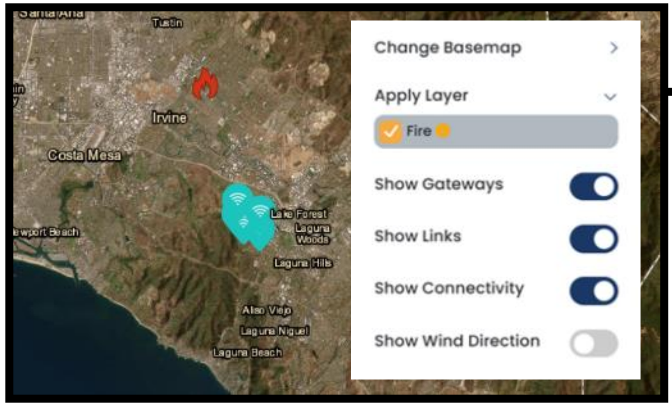




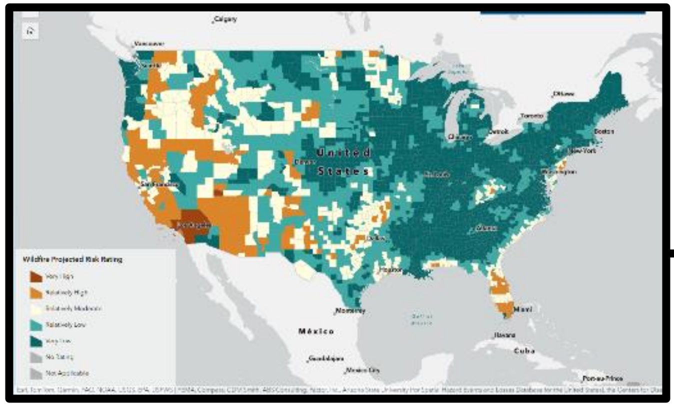
Future Fire Department Fingerprint with NERIS



Community Demographics



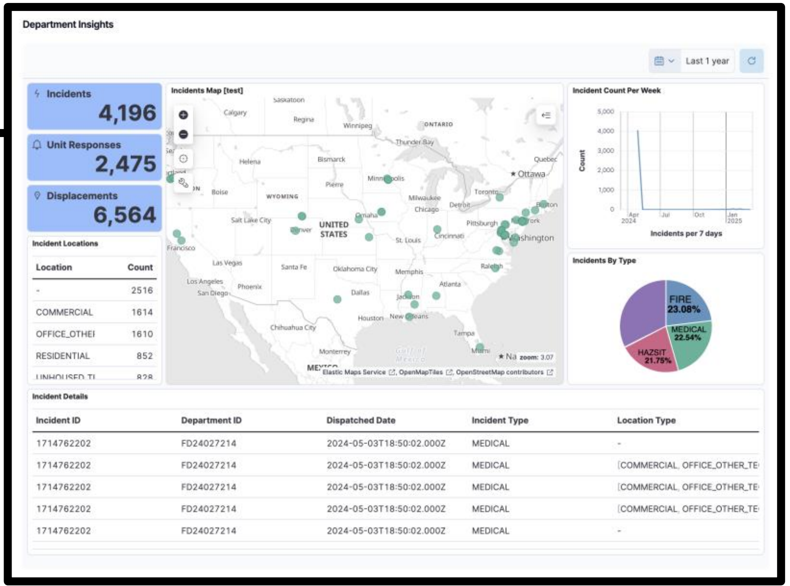
Early Detection Sensor Data



Current & Future Fire Risk

NERIS Fire Department Profile

NERIS Intelligence: Community Risk, Performance, Actions & Tactics



Research Institutes

Fire Safety
Research Institute

Thank you