Oct 14-15 Fall 2019
Technical Meeting
Albuquerque, NM, USA

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WSSCI
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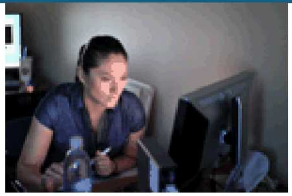
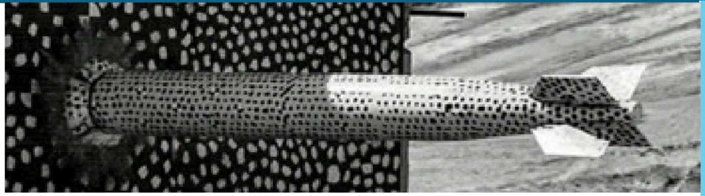
SAND2019-12308C

Los Alamos NATIONAL LABORATORY EST.1943

A High Flux Forest Fire Scenario for Assessing Relative Model Accuracy for CFD Tools





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Fire Science and Technology Department

Fire Science & Technology

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Outline

1. Introduction
    1. Differentiating factors in high flux ignitions
    2. Motivating Test at SNL Solar Tower
2. Methods
    1. SIERRA/Fluid Mechanics/Fuego at SNL
    2. HIGRAD/FIRETEC at LANL
    3. Scenario and parameter study
3. Results
    1. Mass Loss
    2. 60 second predicted imagery and videos
4. Discussion of Findings
5. Summary/Conclusions

High Heat Flux Ignition

Why we care?

- Fires from above ground nuclear detonations
- Directed energy weapons
- Lightning strikes
- Ablation
- Processing of solids to liquids

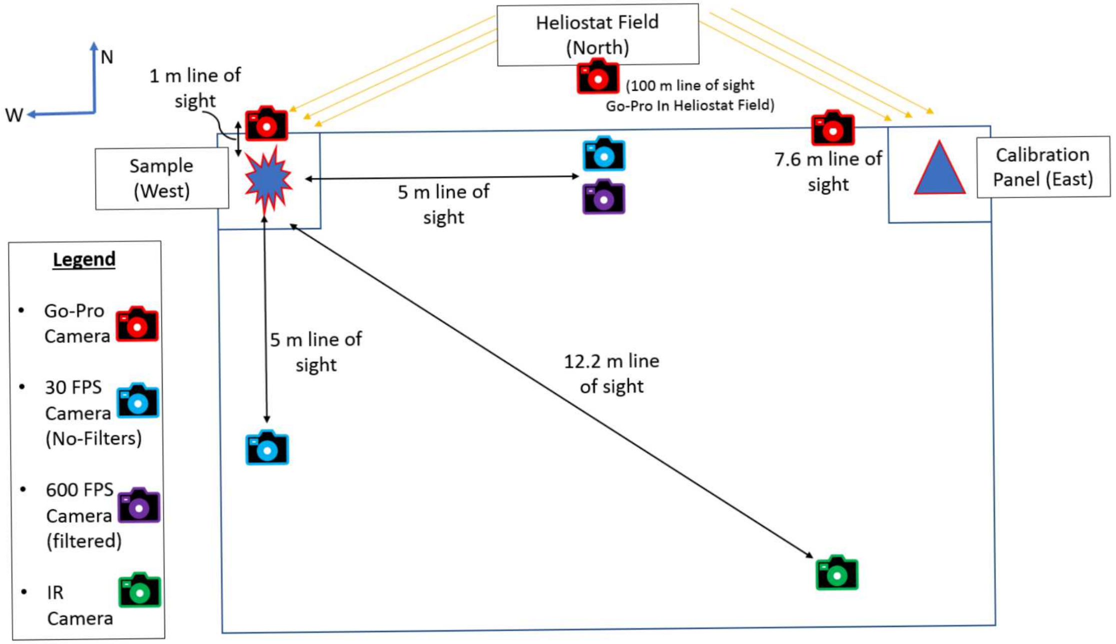
Differentiating features

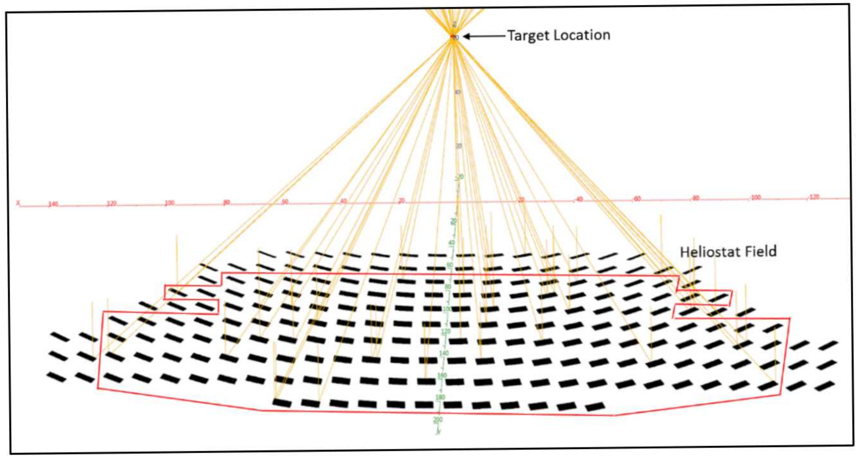
- Short pulses, comparatively fast ignition
- Ignition and mass loss might not collapse to the more traditional environment variables (by temperature, flux, energy, etc.)
- Ignition behavior might be different (sustained flaming, char formation, opacity, etc.)
- Reaction kinetics may not be linear through the regime change
- Transition to more conventional burning

Program Fire Test Facilities

Solar Tower (SNL)

- Relevant fluxes at meter-scale spot
- Field of heliostat mirrors
- Variety of video cameras fielded for the test
- Two shots performed prior to test phase

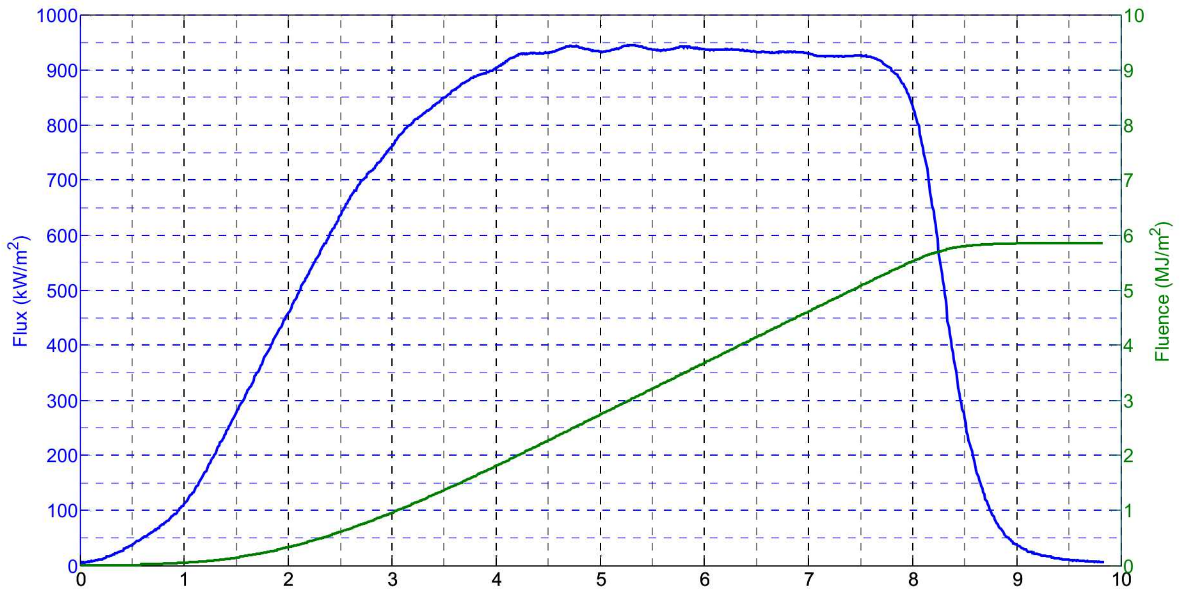




Program Fire Test Facilities

Tree Shot

- Tree was mounted on tower stand
- Slow flux ramp (4 seconds) due to heliostat motors
- Fast drop at 8 seconds
- Tree ignited by 4 seconds



Test Outcome

Tree burned for > 0.5 min

- Exposure was < 10 seconds

Localized burning beyond exposure for 20-40 seconds

8 sec.

32 sec.

4.4 sec

Methods – SIERRA/Fuego (Sandia)

Sandia's fire tool enables low-Mach number reacting flow simulations

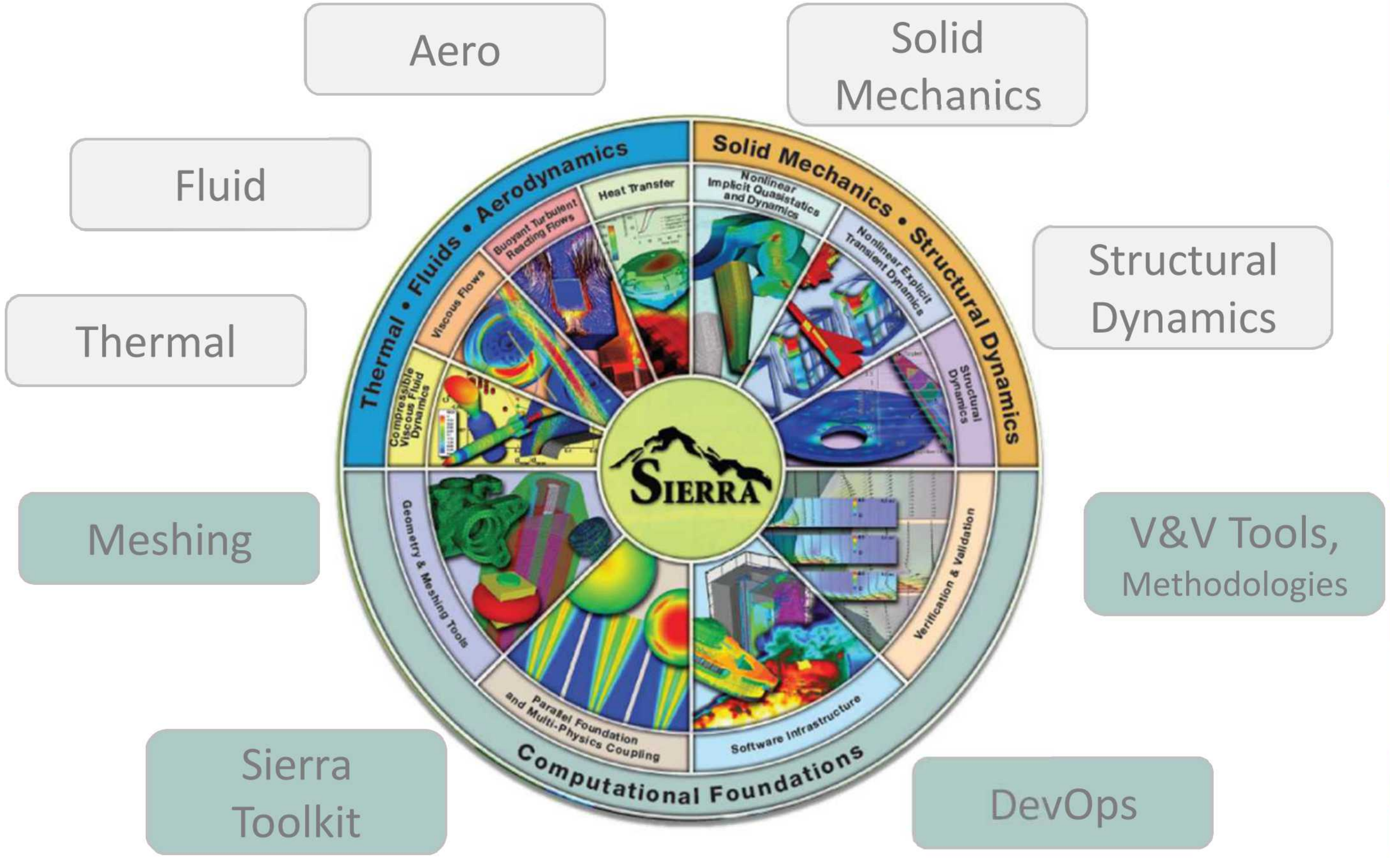
- A variety of turbulence models
- Lagrangian particle methods
- Participating media radiation (PMR)
- CVFEM
- A variety of pre- and post-processing tools

SIERRA enables coupling methods with other modules within the same framework

Sandia's fire team has worked towards validating the computational capability

- Datasets for high quality validation
- Quantitative methods for uncertainties

SIERRA is a computational framework



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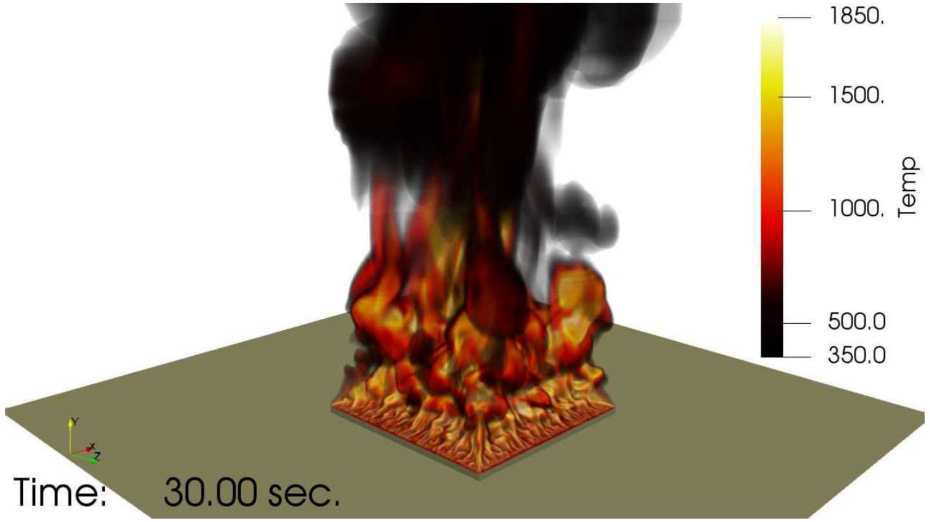
Methods – SIERRA/Fuego (Sandia)

30’ square pool fire engulfing an object



Results used the following

- TFNS for turbulence (hybrid LES/RANS)
- A 5 step reaction method for biomass
  - Water evaporation, char, tar, light gases, char oxidation
- Gray PMR including soot and product gases using SYRINX
- A ‘wall temperature’ approximation for the upwind boundaries.
- 1D conduction on the ground to simulate the
- Eddy Dissipation Concept (EDC) for reactions, Tessner soot model

All results here used 430,000 domain nodes, uniform spacing in tree region, slight relaxation towards boundaries (20 cm node spacing)

Point free-stream drag of particles (likely over-estimates drag)

‘Firebrand’ capability, particles released when decomposition exceeds critical threshold

Methods – HIGRAD/FIRETEC (LANL)

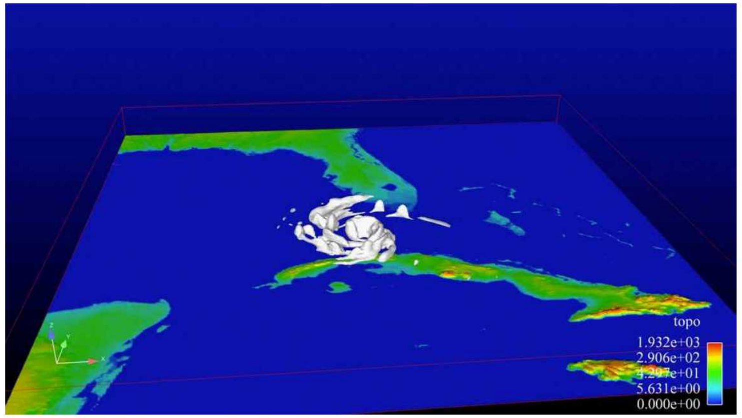
Fire-atmosphere interaction model

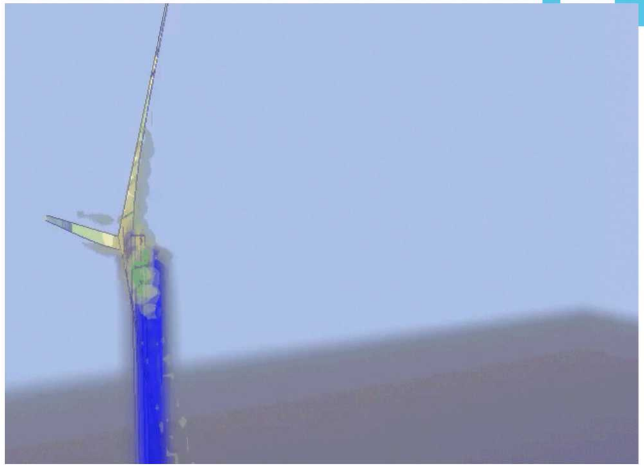
- HIGRAD : Atmospheric CFD model
  - Fully compressible flow solver
  - LES approach for sub-grid turbulence
- FIRETEC : Fire-physics model
- Massively parallelized code

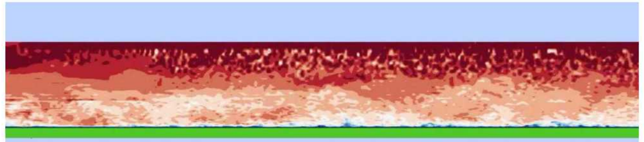
HIGRAD has been used for various atmospheric applications including

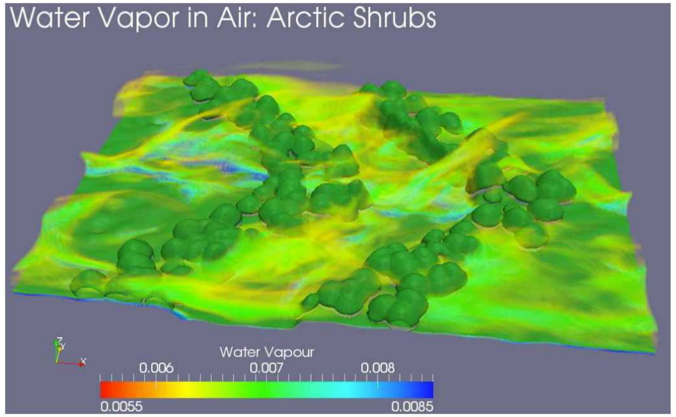
- Hurricanes
- Wind turbine performance and wakes
- Vegetation-atmosphere interaction
- Dispersion
- Explosion

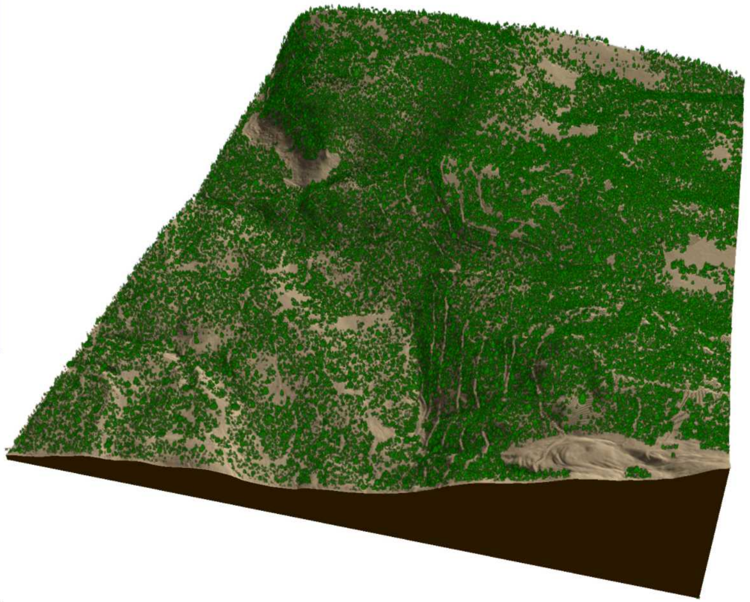
Fire-atmosphere interaction is critical for fire behavior and spread for large-scale (outdoor) fires, including firebrand transport.











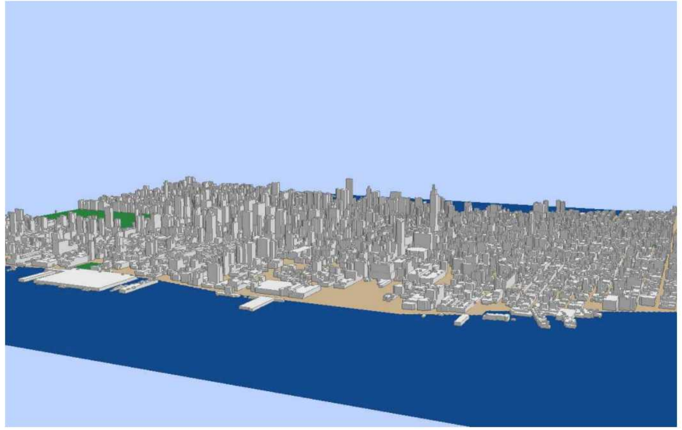
Methods – HIGRAD/FIRETEC (LANL)

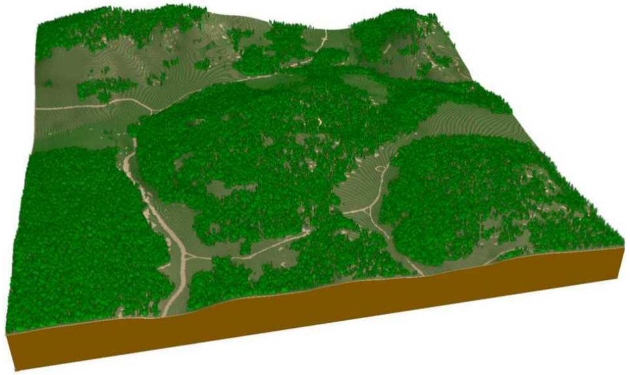
HIGRAD/FIRETEC – Large-scale fire simulation tool

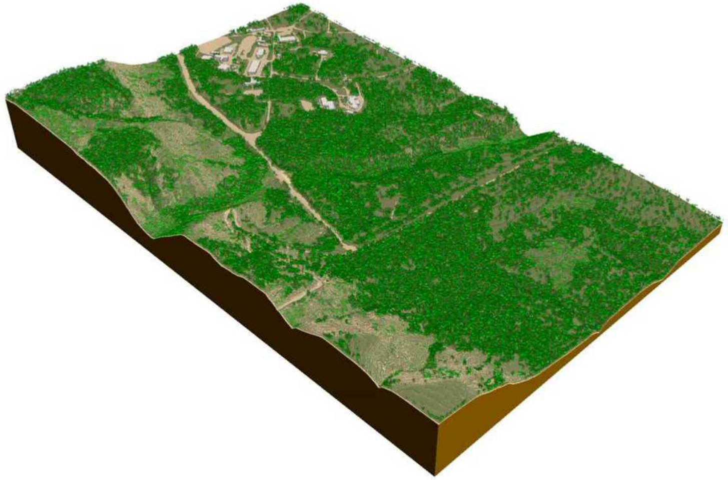
- Physics-based fire spread model
- Typical resolution: 1-10 m
- Fuel as porous media
- PDF approach to fuel characteristics (e.g. T_s)
- Monte-Carlo method for thermal radiation

Accurate sub-grid model and parameterization is important.

- SIERRA/Fuego can help HIGRAD/FIRETEC, (and vice versa?)
- For this study, HIGRAD/FIRETEC simulations tried to match SIERRA/Fuego simulations, as much as possible.







Methods – Scenario of Interest

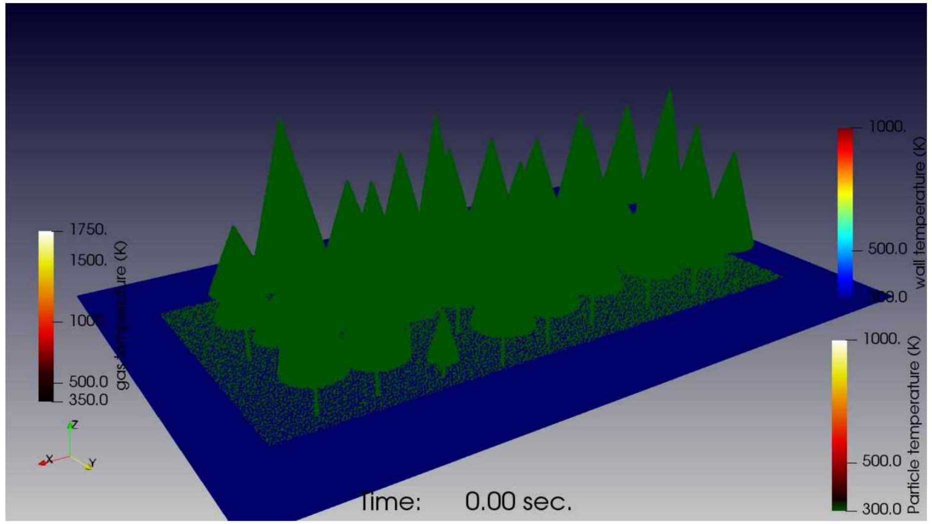
Notional forest model created from a constrained randomization model designed to space trees evenly

We use the same flux profile as the test at the solar tower to provide credibility to the predictive results of the models

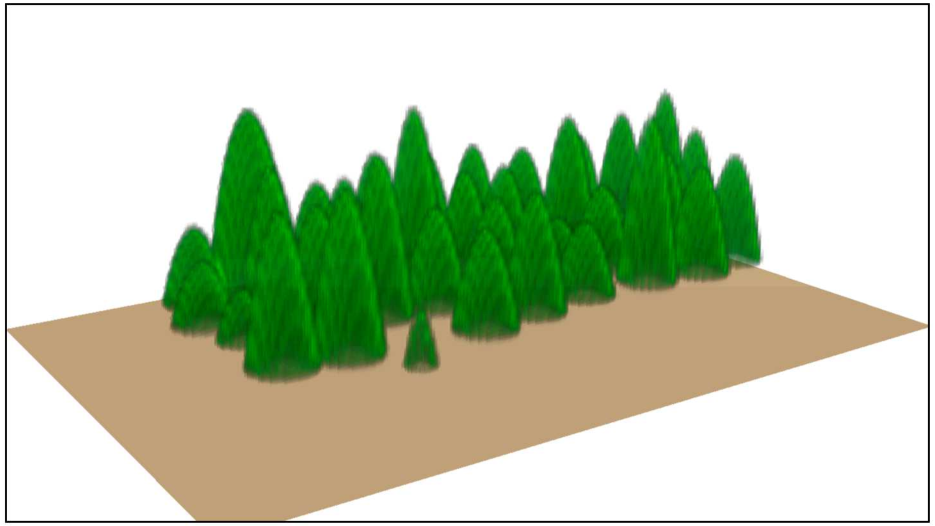
Canopy mass of 4400 kg, or about 120 kg per tree.

Tree	x (m)	y (m)	Tree Height (m)	Crown Base Height (m)	Crown Radius (m)
1	0.319	0.112	6.3	1.74	1.1
2	2.73	0.5	5.4	1.72	1.13
3	5.21	0.2	3	0.8	0.5
4	7.9	0	7.4	1.7	1.17
5	-2.3	-0.3	4.7	1.8	1.11
6	0	-2.8	5.4	1.7	1.13
7	2.8	-2.6	5.5	1.7	1.12
8	-2.9	-2.7	4.2	1.9	1.06
9	2.4	-4.7	8.8	1.7	1.14
10	-0.3	-5.3	5.9	1.8	1.07
11	-5.5	-0.4	8.3	1.7	1.1
12	-2.1	-5.2	5.9	1.7	1.15
13	5.1	-2.6	7.7	1.7	1.07
14	-5.1	-2.7	5.2	1.7	1.15
15	5	-5.4	6.3	1.8	1.12
16	-5.4	-5.3	7.5	1.8	1.15
17	-0.1	-7.8	6.2	1.8	1.09
18	-7.9	-0.1	6.1	1.75	1.16
19	7.5	-2.8	6.2	1.9	1.13
20	2.4	-7.7	6.5	1.7	1.09
21	-7.8	-2.1	6.4	1.8	1.1
22	-2.5	-8	6.2	1.7	1.11
23	5	-7.6	5.7	1.8	1.17
24	-4.9	-7.8	5.8	1.8	1.18
25	-7.7	-5.5	4	1.8	1.02
26	8.1	-5.1	7.2	1.8	1.06
27	-10.1	-0.5	6.2	1.8	1.14
28	-9.9	-2.6	6.9	1.8	1.08
29	10.3	0	7	1.8	1.15
30	-7.7	-7.5	6.1	1.9	1.13
31	10.3	-3	3.7	1.8	0.84
32	7.7	-7.7	8.8	1.9	1.6
33	-10.3	-4.9	8.1	1.9	1.06
34	10.8	-5.1	4.2	1.9	1.06
35	10	-7.7	4.7	1.8	1.13
36	-10.4	-7.8	6.7	1.8	1.08

Scenario was modeled in both SIERRA/Fuego and HIGRAD/FIRETEC



SIERRA/Fuego



HIGRAD/FIRETEC

Mass Loss Comparison Results

Baseline velocity compares well at 60 second (1.25 m/s)

Reverse direction results similar

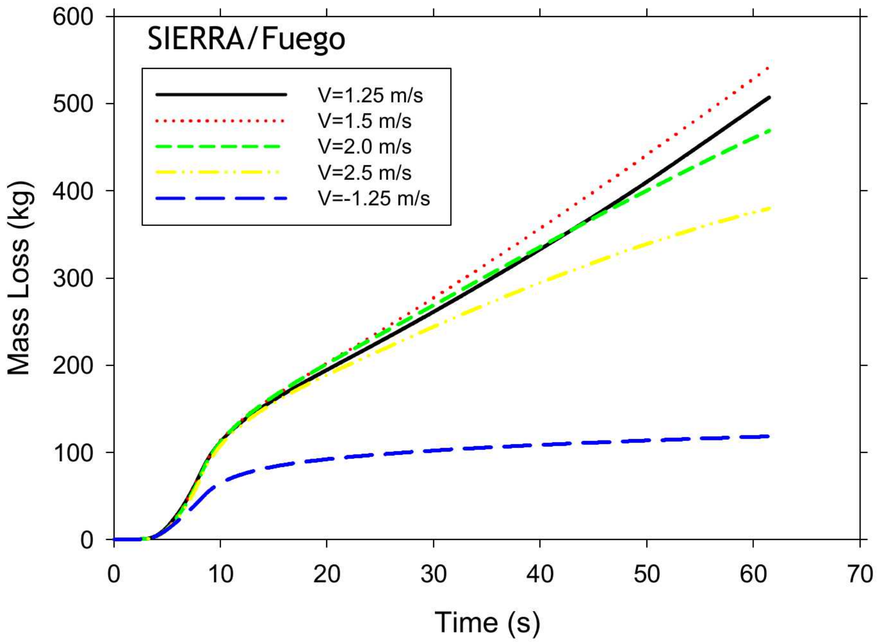
HIGRAD/FIRETEC predicts increasing mass loss with wind, Fuego results decrease

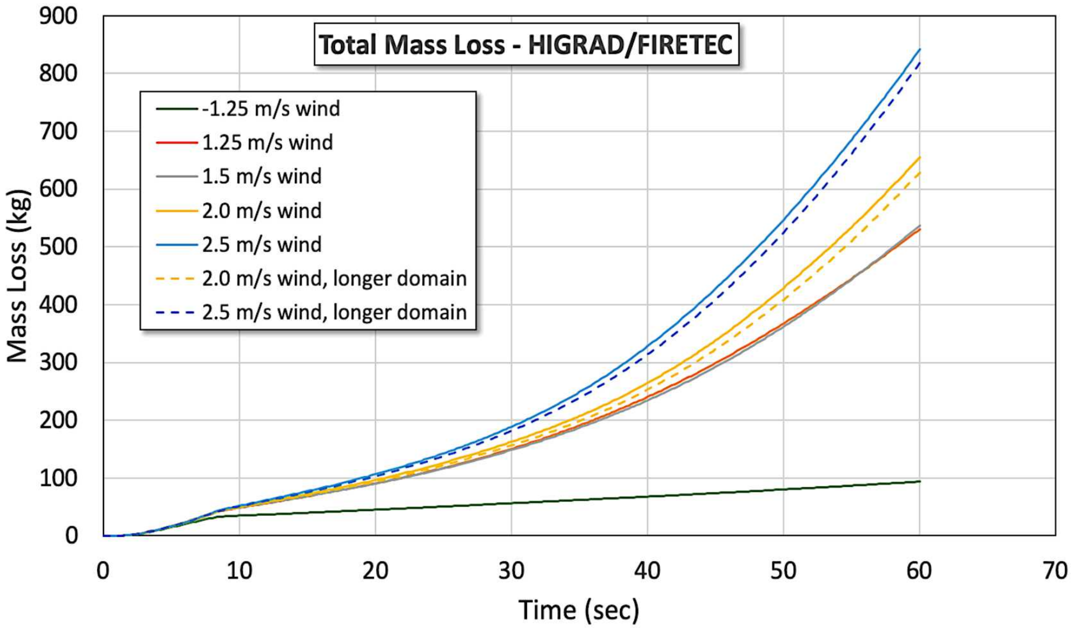
Larger domains were used in HIGRAD/FIRETEC simulations, due to the differences in top and outflow boundary conditions.

4.5M grid points for 30m x 20m x **60m** (taller domain)

45M grid points for 30m x **200m** x 60m (longer domain)

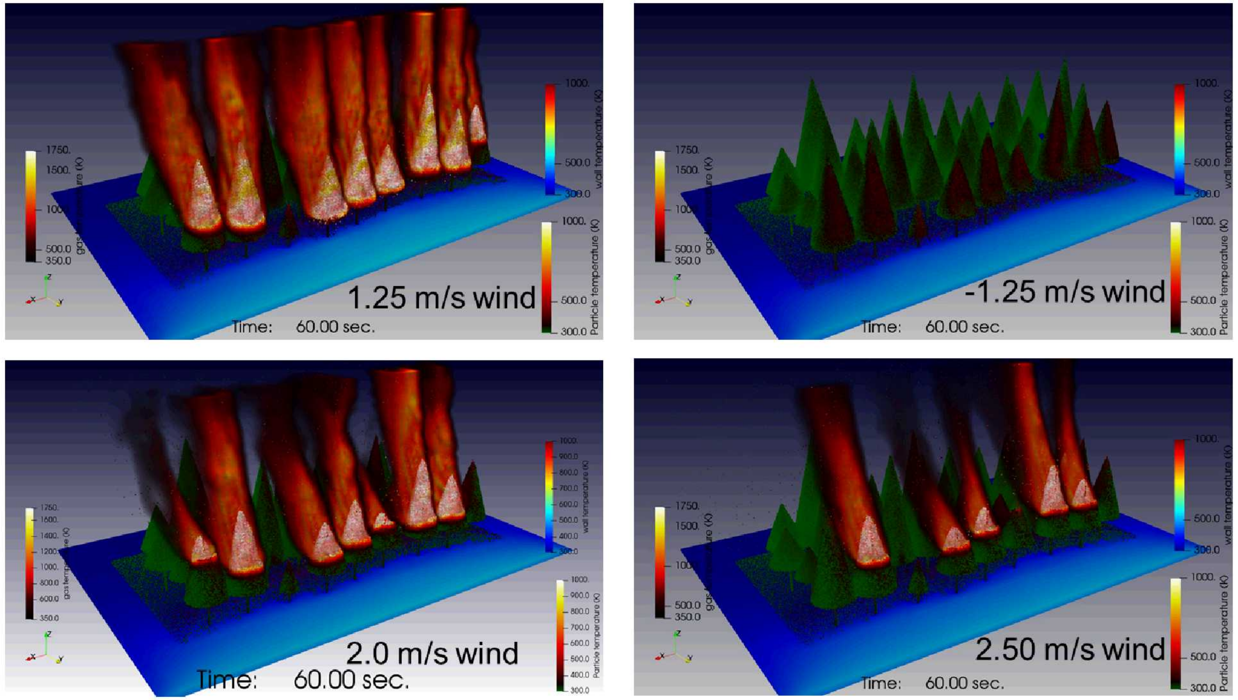
Impact of relaxed outflow boundary condition on total mass burn was negligible.

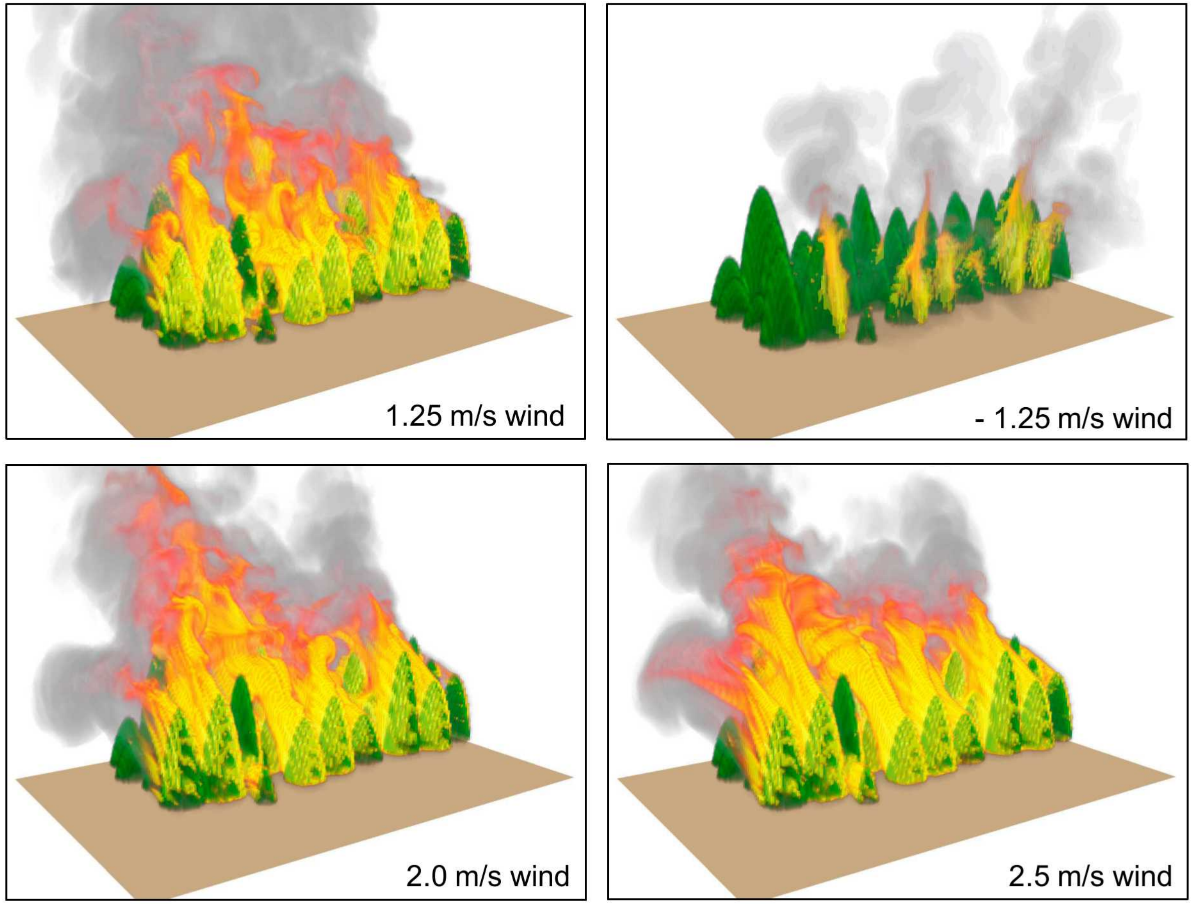




60 Second Comparison Results

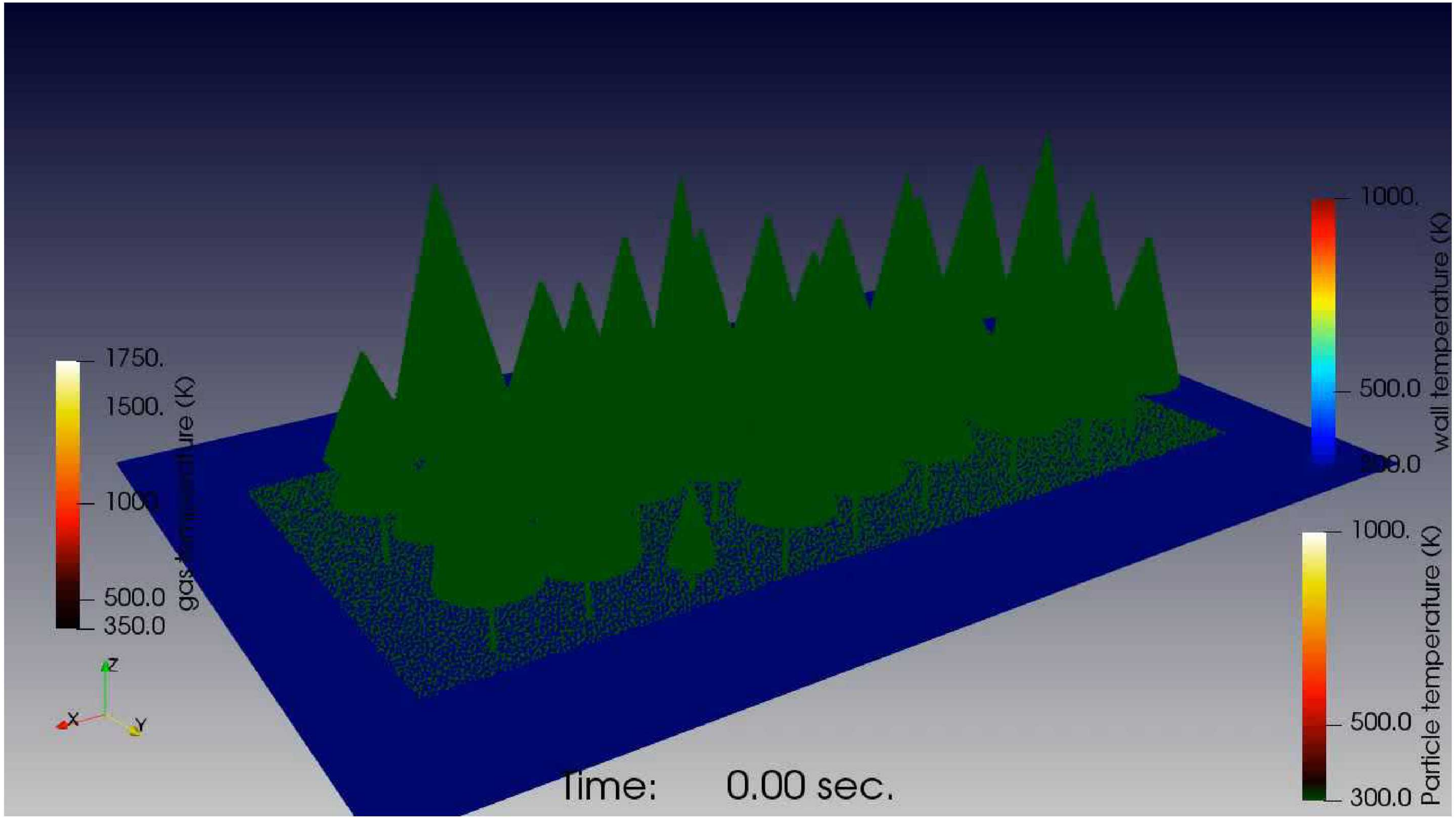
Renderings of predicted fires shows differences





SIERRA/Fuego Video

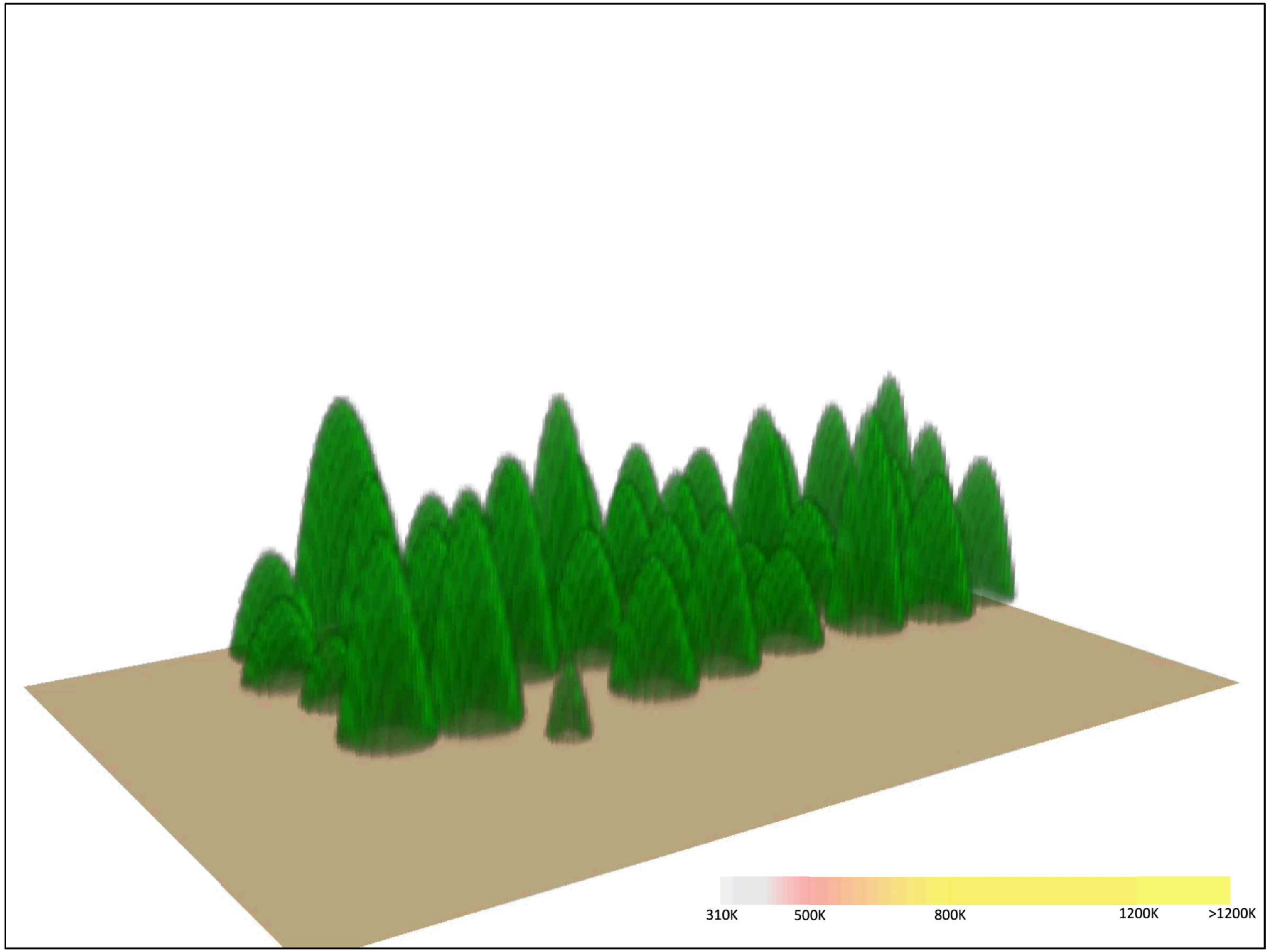
Fuego video simulation shows dynamic response of the combustible particles



HIGRAD/FIRETEC Video

HIGRAD/FIRETEC Video shows predicted dynamics. (1.25 m/s case)

Gas temperature and fuel density are visualized.



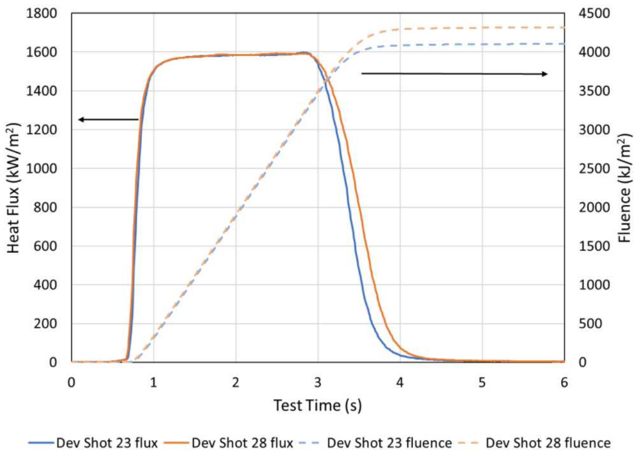
Summary

- A notional scenario was developed to test simulations of ignition and burning of a stand of trees
  - The scenario is reported such that it can become a common test case
  - The scenario has similarity to a test, that provides confidence in accuracy of model predictions
- HIGRAD/FIRETEC and SIERRA/Fuego were used to simulate the scenario
  - A comparative parameter study involving wind speed was performed
  - Both codes predicted a significant reduction in burn with negative wind direction
  - Mass loss predictions were similar, with increasing differences for high wind cases
- Mass loss and imagery from videos was used to compare the predicted outcome
  - Agreement exceeded expectations, as both codes are still in need of development for confident application to this type of simulation scenario

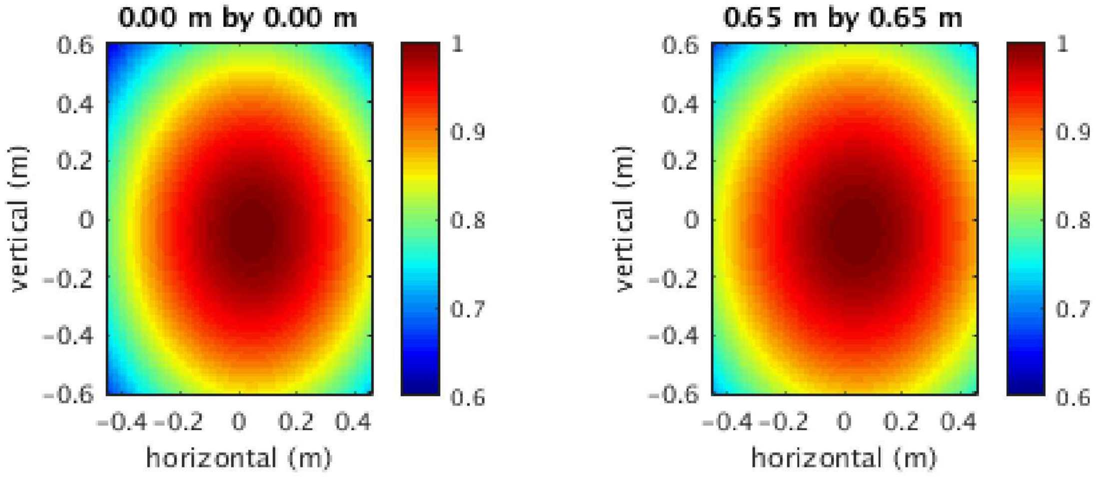
Extras

Solar Tower Flux

Example temporal profiles (from instrumentation)



Example spatial profiles (from ray trace models)



Fine Fire Simulation Video