Slide 1

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Wildland Fire Modeling to Support a Proactive Approach to Wildland Fire

Rodman Linn
LANL Scientist and Team Leader

UCSD
USGS
science for a changing world
Canada
Natural Resources Canada
Canadian Forest Service
INRAE
la science pour la vie, l'humain, la terre

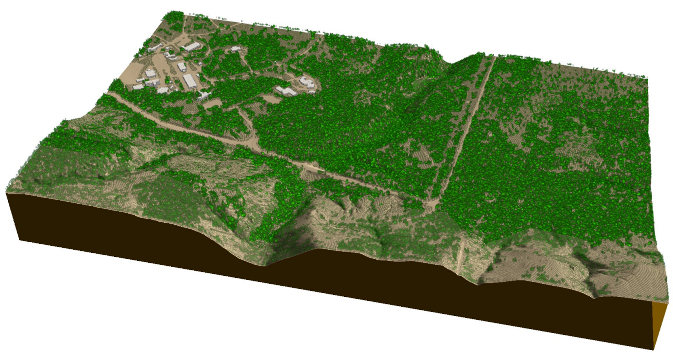
LANL Wildfire modeling

Enduring multi-fidelity capability initiated through LDRD (since 1995)

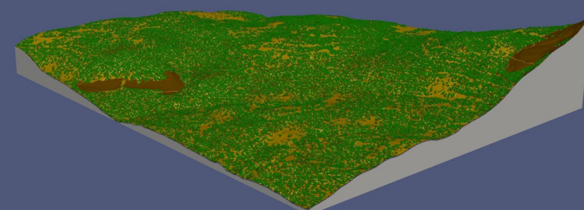
- **FIRETEC**
  - First-of-its-kind, explicitly capturing interaction between critical processes and coupling fire/atmosphere interactions
  - High performance computing basis (HPC)
- **QUIC-Fire**
  - Fast-running coupled fire/atmosphere model
  - Capable of massive ensembles or prescribed fire decision support

2003 R&D100 award

HIGRAD/FIRETEC simulation of potential fire behavior at LANL



QUIC-Fire simulation of potential fire in Valles Caldera under mild conditions



2020 R&D100 award, 2020 R&D100 Gold Medal Award
Special Recognition for Corporate Social Responsibility

Centerpiece for active collaborations:

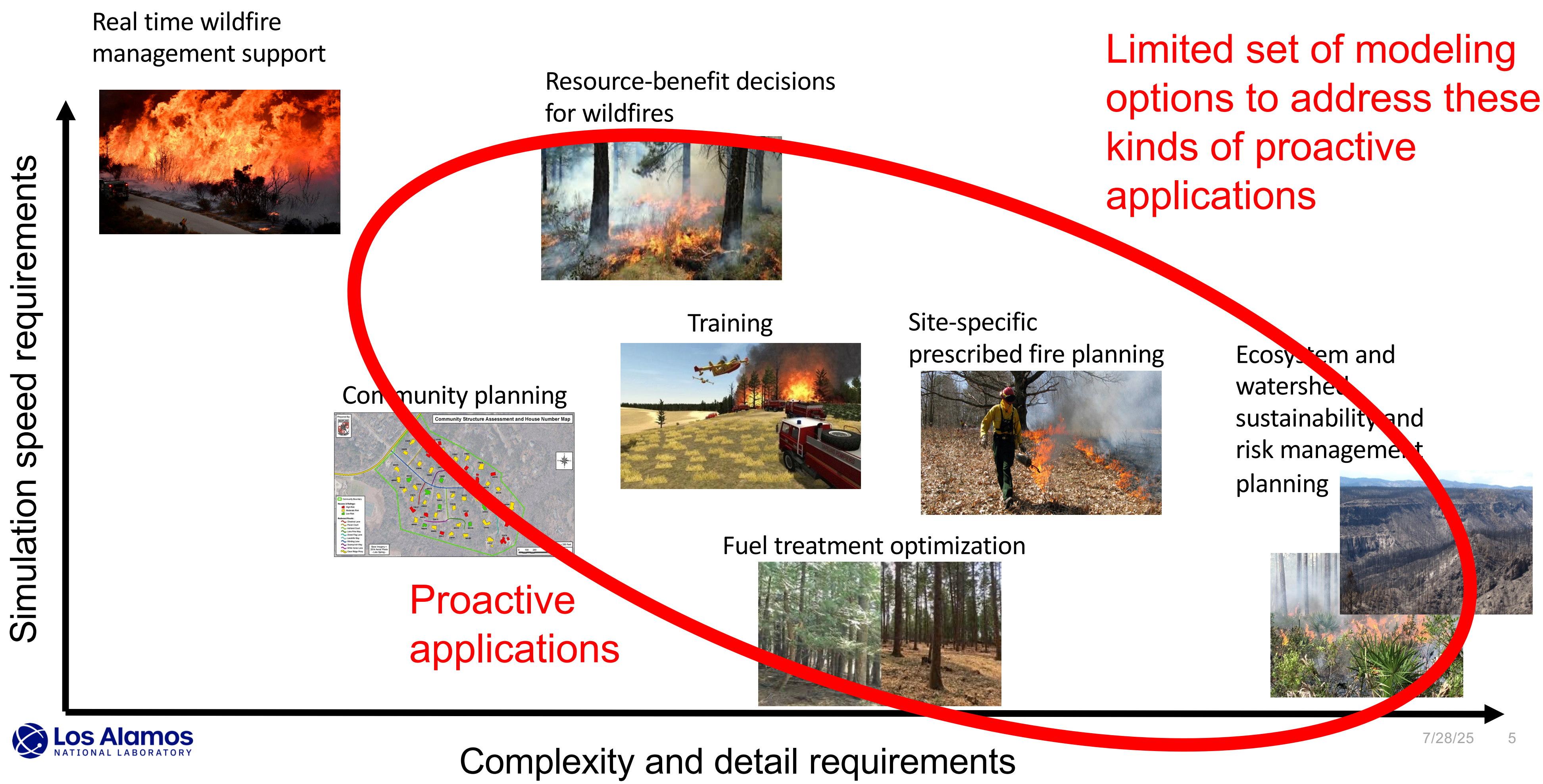
- DoD – growing number of programs
- USFS – multiple research stations (since 2002)
- USGS – LANL signed an MOU with USGS regarding wildland fire science
- US Fish and Wildlife Service
- Canadian Forest Service and Canadian Providences
- French government (INRAE)
- At least 10 universities
- **Research topic for ~41 students as LANL interns, 17 PhDs**
- **LANL is playing science leadership roles in emerging cross-agency wildland fire efforts**

Canadian Forest Service-LANL collaborative analysis (model and experiment) of the effectiveness of thinning (Alberta, Canada)

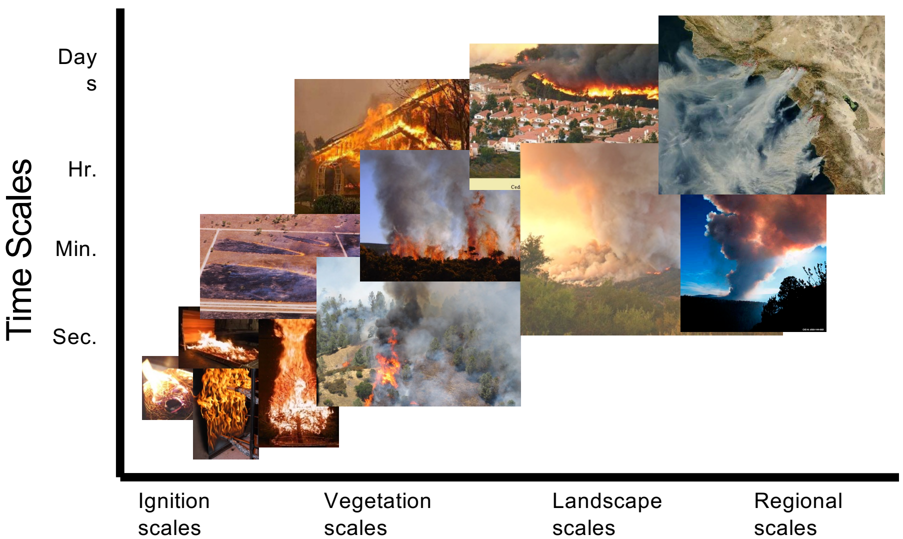
Historically, there was one focus for wildfire modeling

Real time wildfire
management support

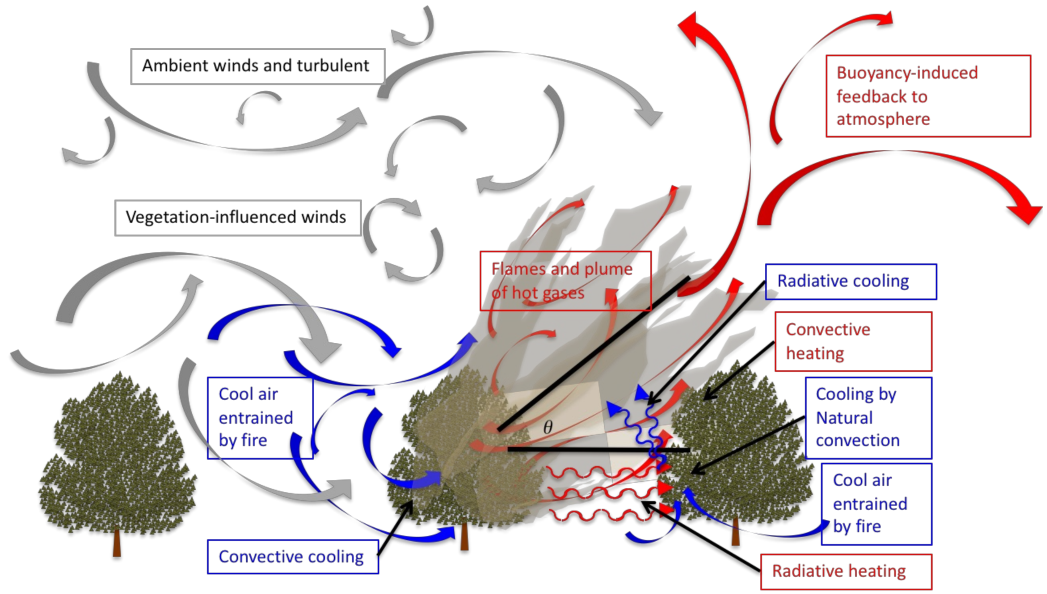
These applications highlight the need for improved science basis support



So what makes wildland fire so hard?



Large range of spatial and temporal scales for important phenomena



Fire behavior results from a complex set of interacting processes

Widely varying and dynamic fuel types and conditions

Wildland fires are not all the same

Spectrum of fires

Intense fires

- Often have strong drivers
  - Strong winds
  - Dense, continuous or extremely dry fuels
  - Topography
- Contributing factors are often landscape scales
- Resilient to fine-scale heterogeneity of fuels or short-term wind lulls/gusts

Low-intensity fires (e.g. backing, flanking or often prescribed fires)

- Lack strong drivers
- Depend on localized conditions for their sustainability
- Influenced by small-scale (meters or smaller) gaps in fuels or momentary wind fluctuations
- Correlations between transient events and fuel heterogeneities matters

LANL has been breaking new ground in fire modeling since 1990s

Leveraging unique combination of expertise:

- Mechanistic modeling of complex systems
- Multi-phase fluid dynamics and turbulence
- High performance computing

Increasing fundamental understanding of wildfire behavior and two-way feedbacks with surroundings

- Atmosphere
- Ecosystems
- Watersheds

Addressing national security concerns

- Risk management
- Weapon effects

Providing science basis to improve site-wide resilience

LANL has an inherent interest in wildfires due to it's frequent exposure to wildfires

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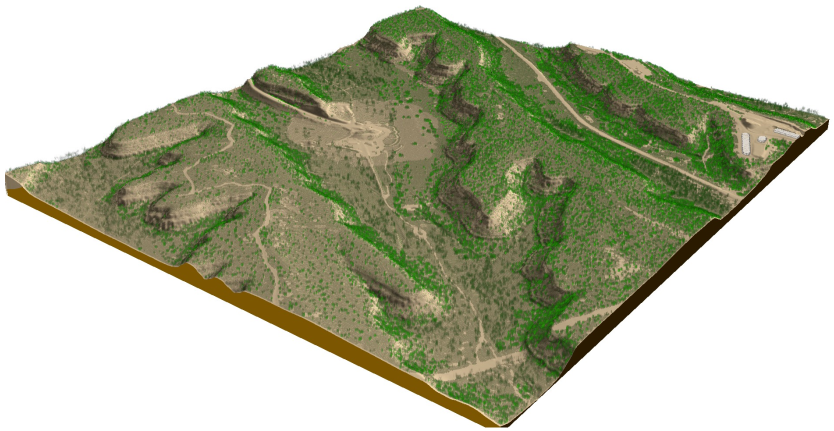
Understanding site operations risk



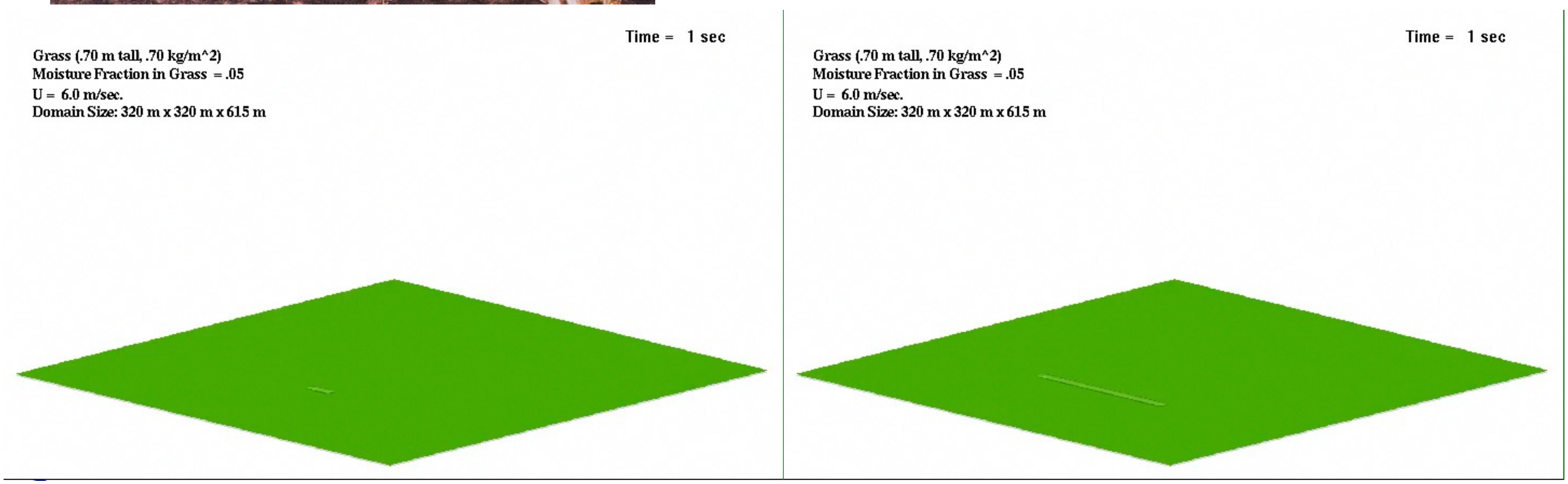
Consider fire behavior in a "simple" fire scenario

Don’t we just need to know local fuels, winds, moisture, slope?

Linn, R. R., Cunningham, P., 2005: “Numerical simulations of grassfires using coupled atmosphere-fire model: Basic fire behavior and dependence of wind speed.” *J. Geophys. Res*., **110**, D131007, doi:10,1029/2004JD005/597.

Don’t we just need to know local fuels, winds, moisture, slope?

Wildfire behavior depends on many factors which are influenced by the fire itself through the fluid motions of the surrounding atmosphere.



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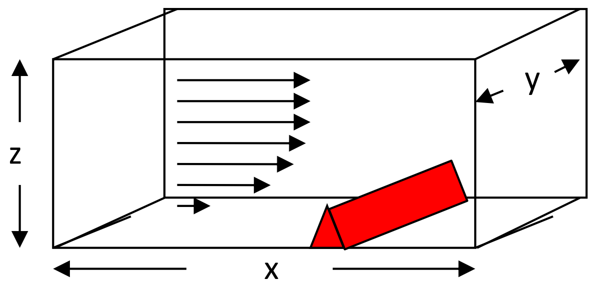
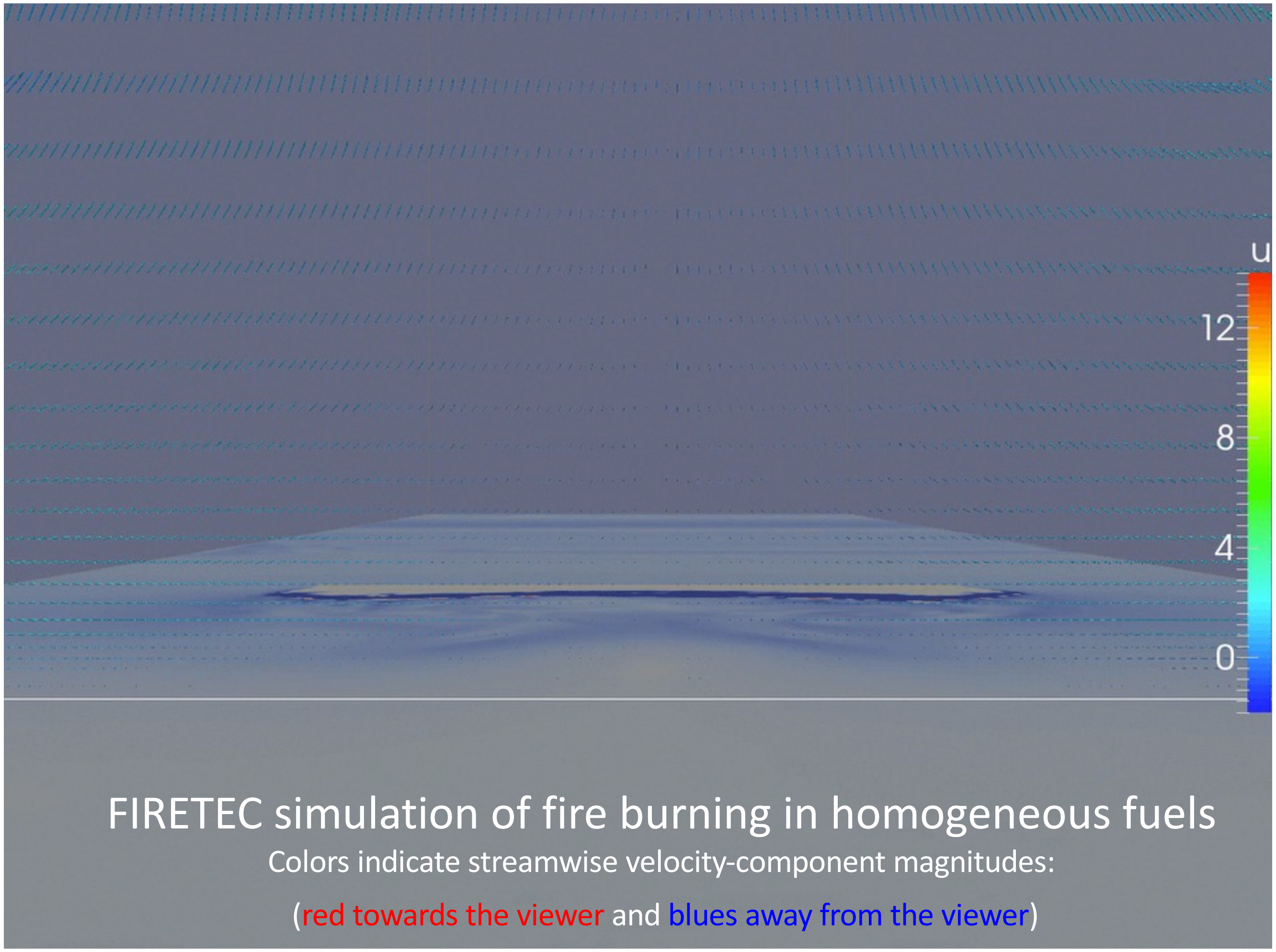
Addressing challenges with next-generation models :

Increasing our fundamental understanding of wildland fire phenomenology



Historically, model developers have used a "Wall of flame" concept to model development by turning it into a 1-D or 2D problem.

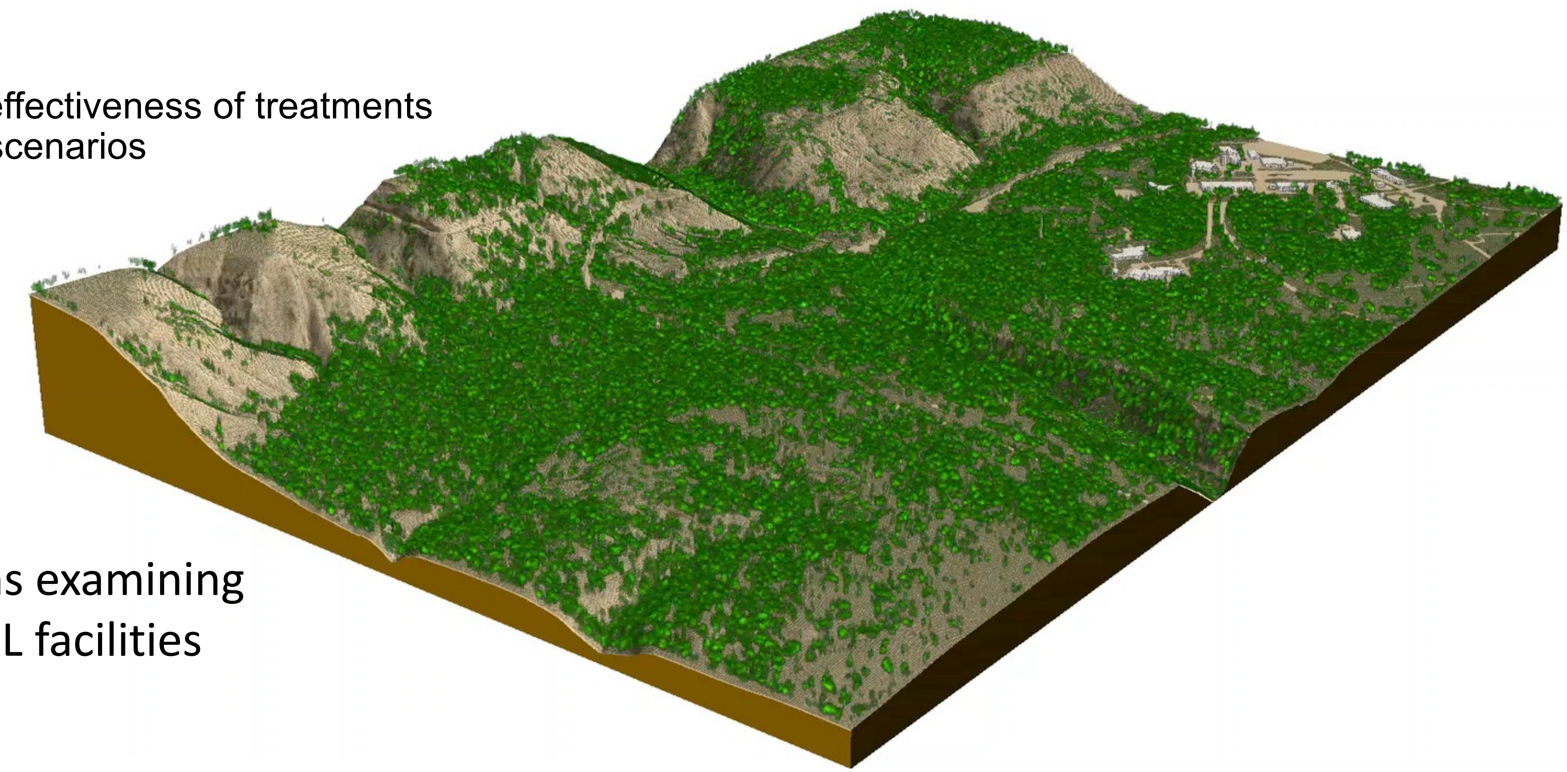
Unfortunately, wildfires often do not behave like a wall of flame.



Addressing challenges with next-generation models :

Evaluating wildland fire risk to specific communities, facilities, or infrastructure

- Risk under current range of conditions
- Identification of dangerous scenarios
- Potential influence of landscape treatments
  - Mechanical treatments
  - Prescribed fire
  - Combinations
- Evolution of risks and effectiveness of treatments under climate change scenarios



FIRETEC simulations examining wildfire risk to LANL facilities

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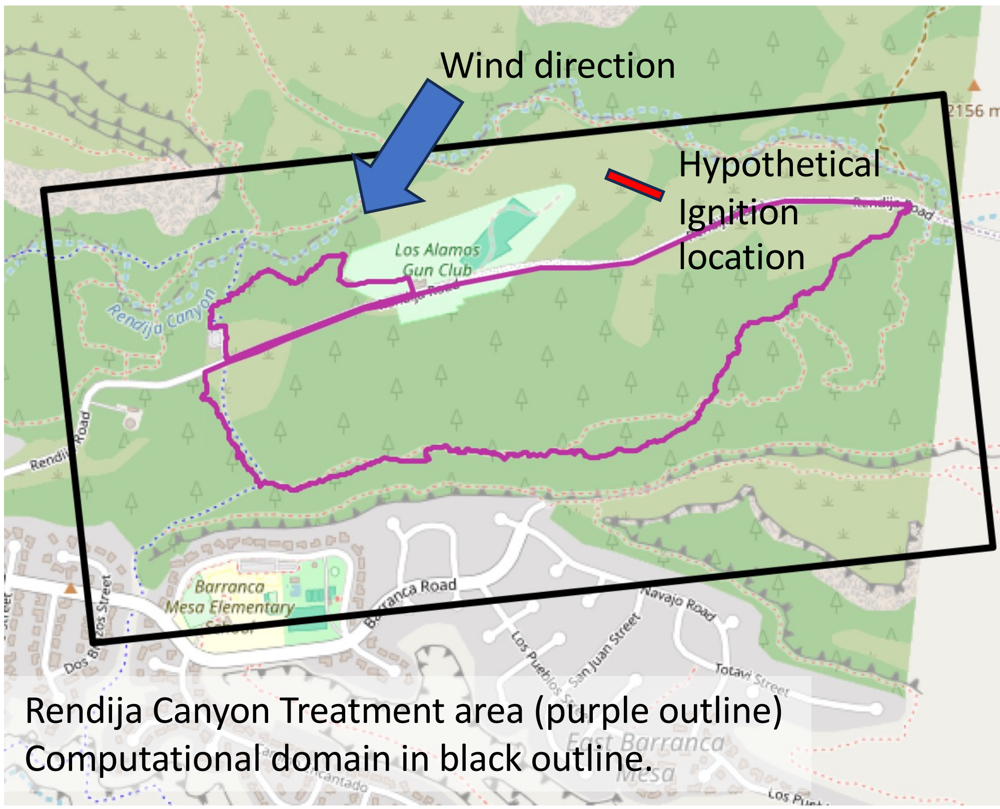
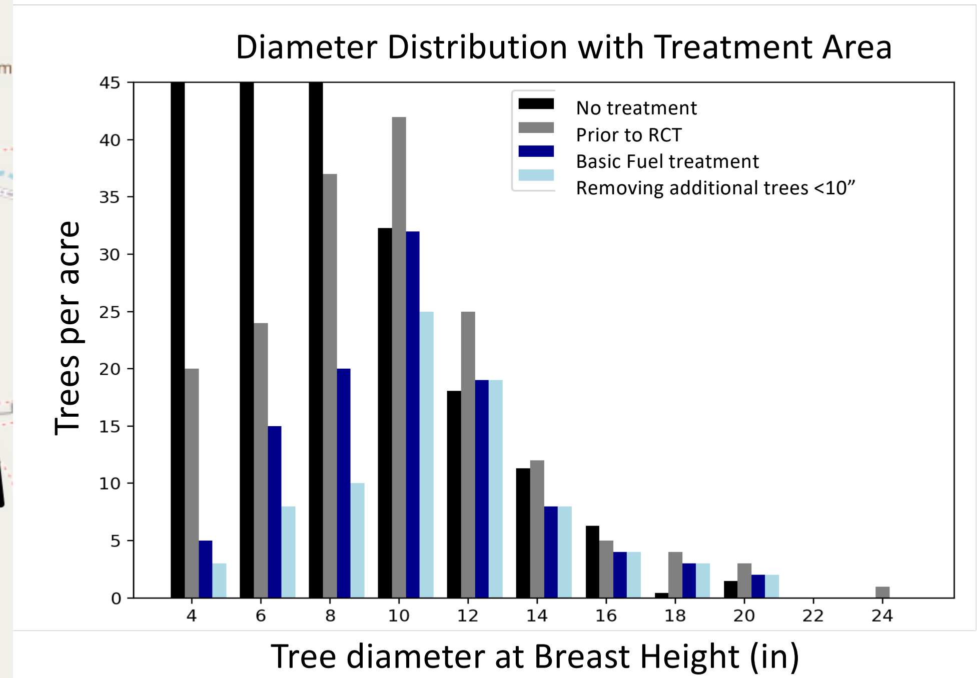
Example: understanding effects of fuel treatments at LANL



Rendija Canyon Treatment area (purple outline)
Computational domain in black outline.

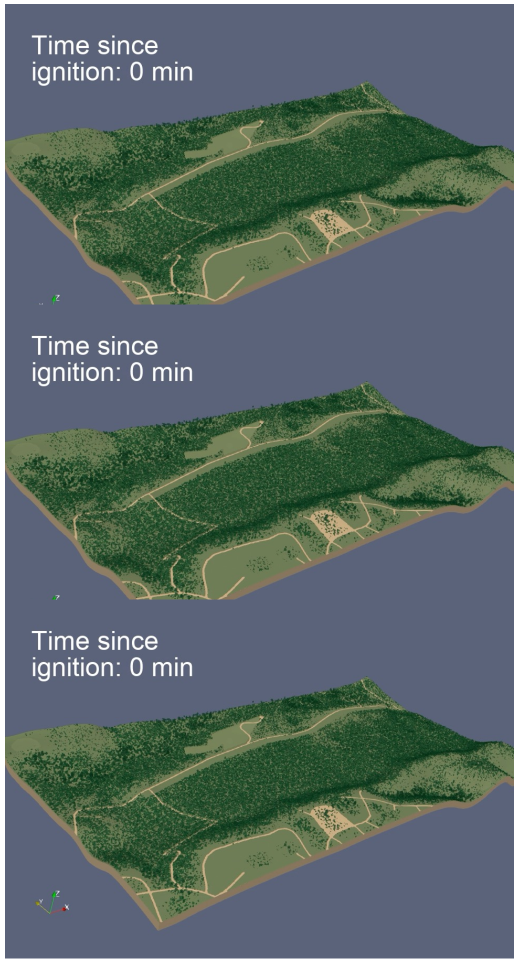


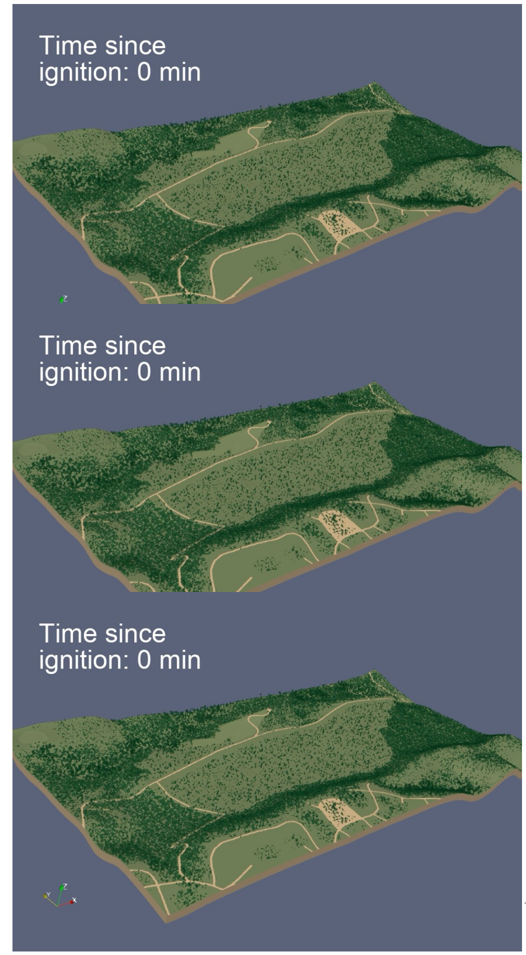
Effects of fuel moisture at under strong winds (27 mph)

Fine Dead Fuel Moisture (FDFM)
(e.g. grasses, pine litter)

No Treatment since 1950

Basic treatment + additional <10’’ removal





Extremely dry 5%

Typical LA fire season 8%

Less-severe conditions 10%

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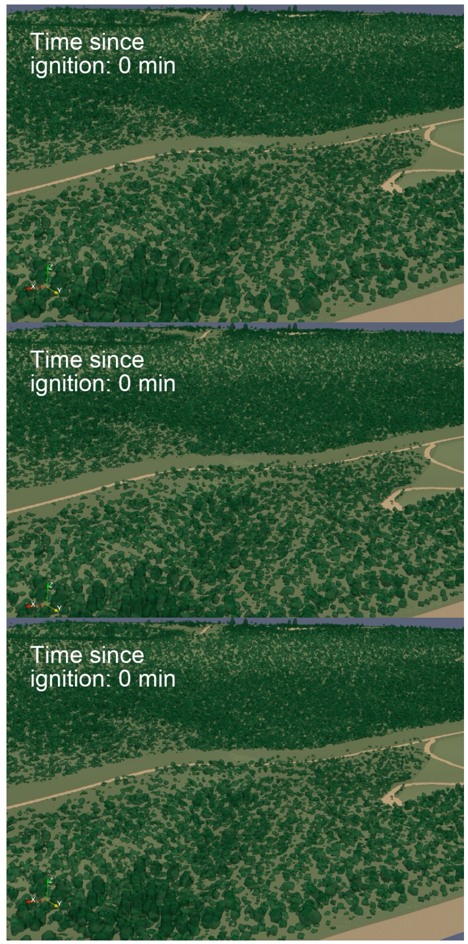
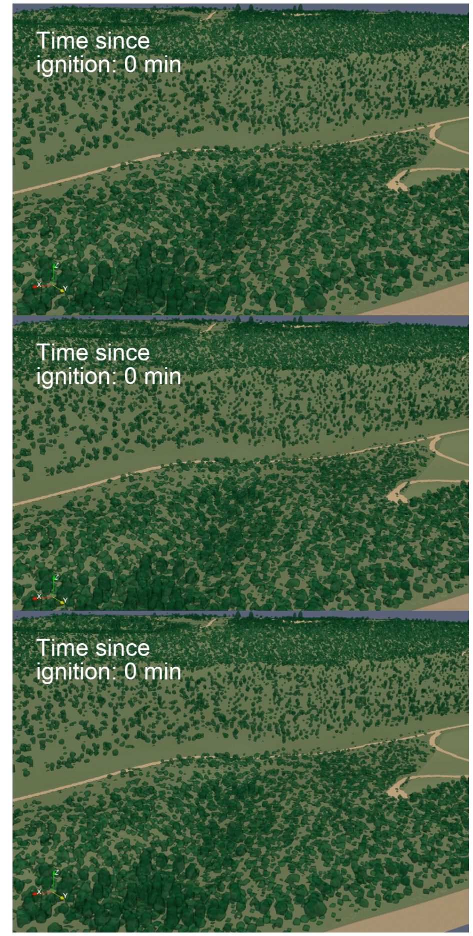
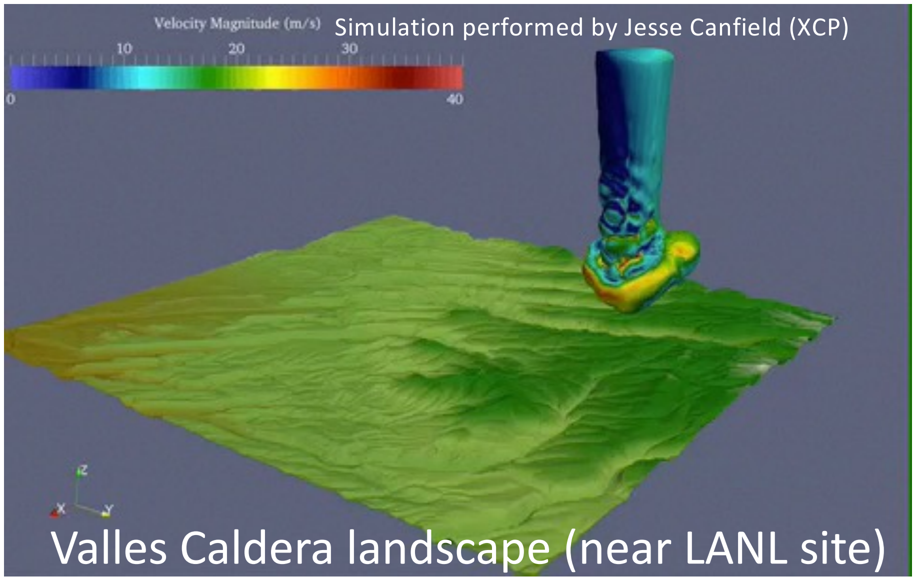


Basic treatment + additional <10’’ removal

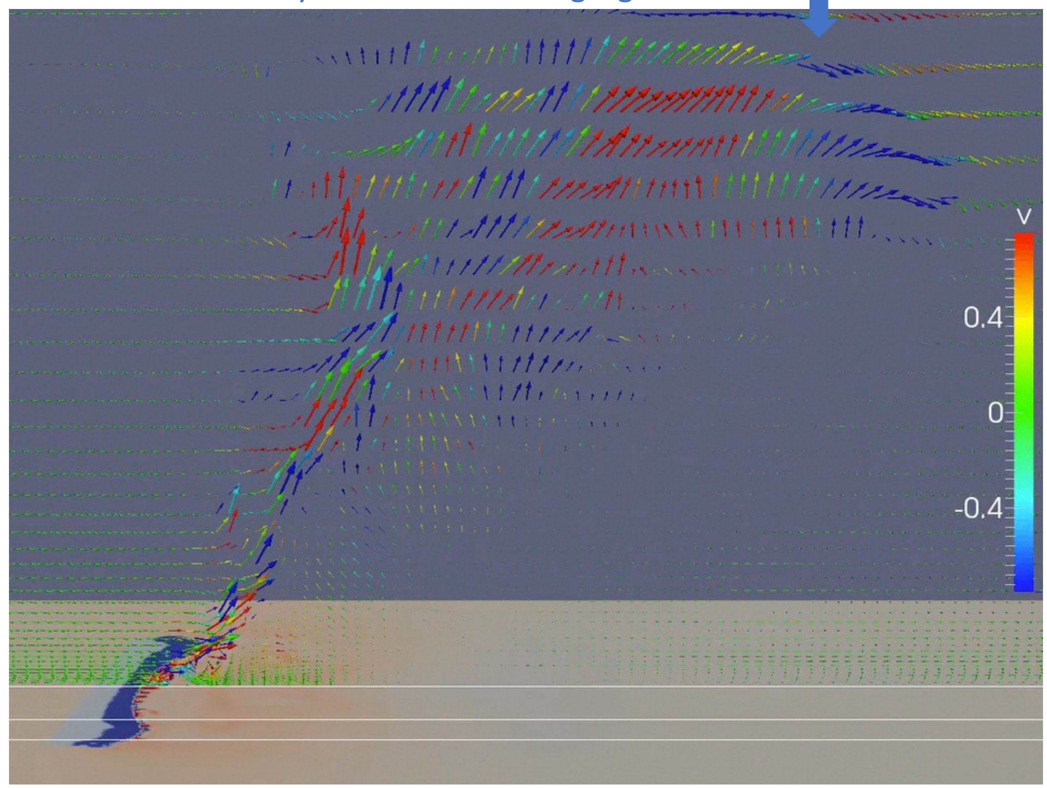


Addressing challenges with next-generation models :

Study low-frequency but high-consequence events



Density current intersecting a grass fire



Downwash events cause density current flow patterns

- Moving faster than ambient winds
- Containing "back-spin" vorticity
- Amplifies multiple aspects of fire

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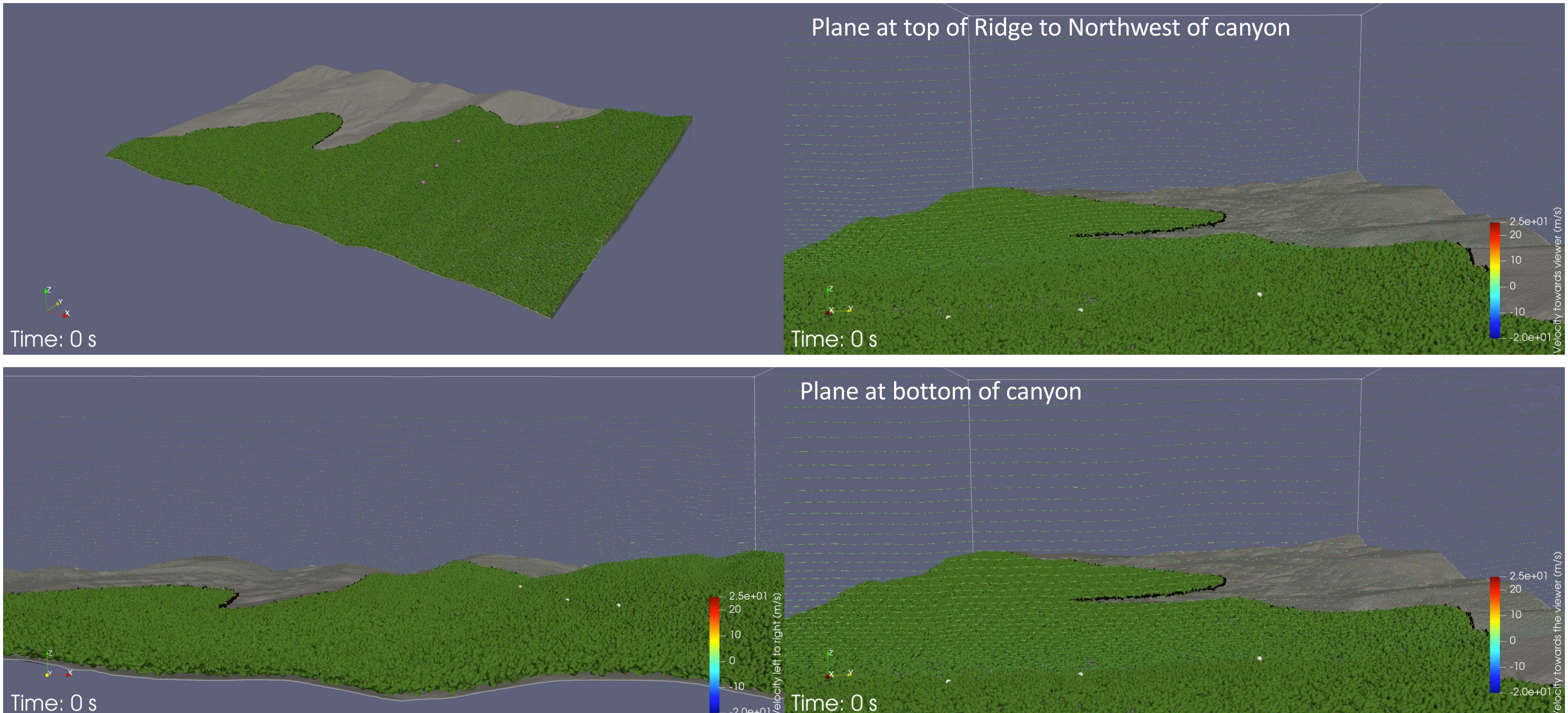
Opportunities for next generation fire models :

Training and lessons learned



Addressing challenges with next-generation models (deeper dive):

Planning and optimizing prescribed fires

Wildland fires are not all the same

Spectrum of fires

Intense fires

- Often have strong drivers
  - Strong winds
  - Dense, continuous or extremely dry fuels
  - Topography
- Contributing factors are often landscape scales
- Resilient to fine-scale heterogeneity of fuels or short-term wind lulls/gusts

Many prescribed fires fall in this category (not all)

Low intensity fires (e.g. backing, flanking or often prescribed fires)

- Lack strong drivers
- Depend on localized conditions for their sustainability
- Influenced by small-scale (meters or smaller) gaps in fuels or momentary wind fluctuations
- Correlations between transient events and fuel heterogeneities matters

What makes the context for prescribed fires and wildfires so different?

Ability to plan

- How to burn
- What to burn
- Where to burn
- When to burn

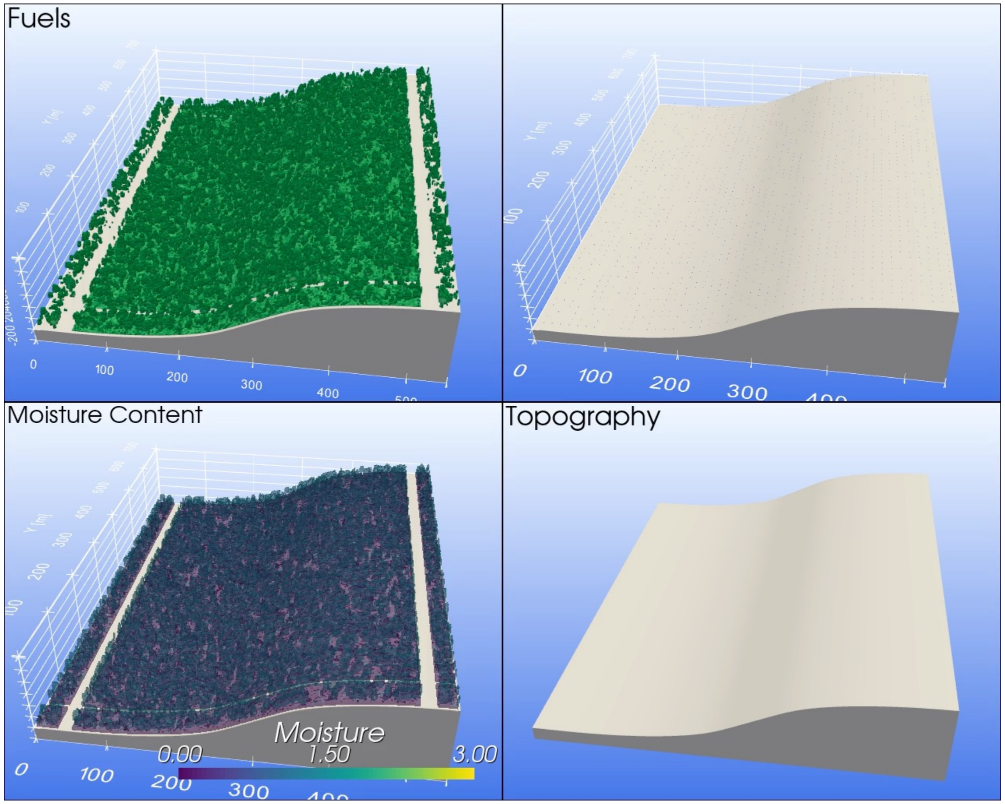
Responsibility

- Achieve objectives
  - Risk reduction
  - Ecological benefits
- Avoid undesirable consequences
  - Escape fires
  - Safety risks
  - Ecological damage
  - Watershed effects
  - Smoke exposure to communities
  - ….

Opportunities for next-generation models:
Prescribed fire planning and optimization

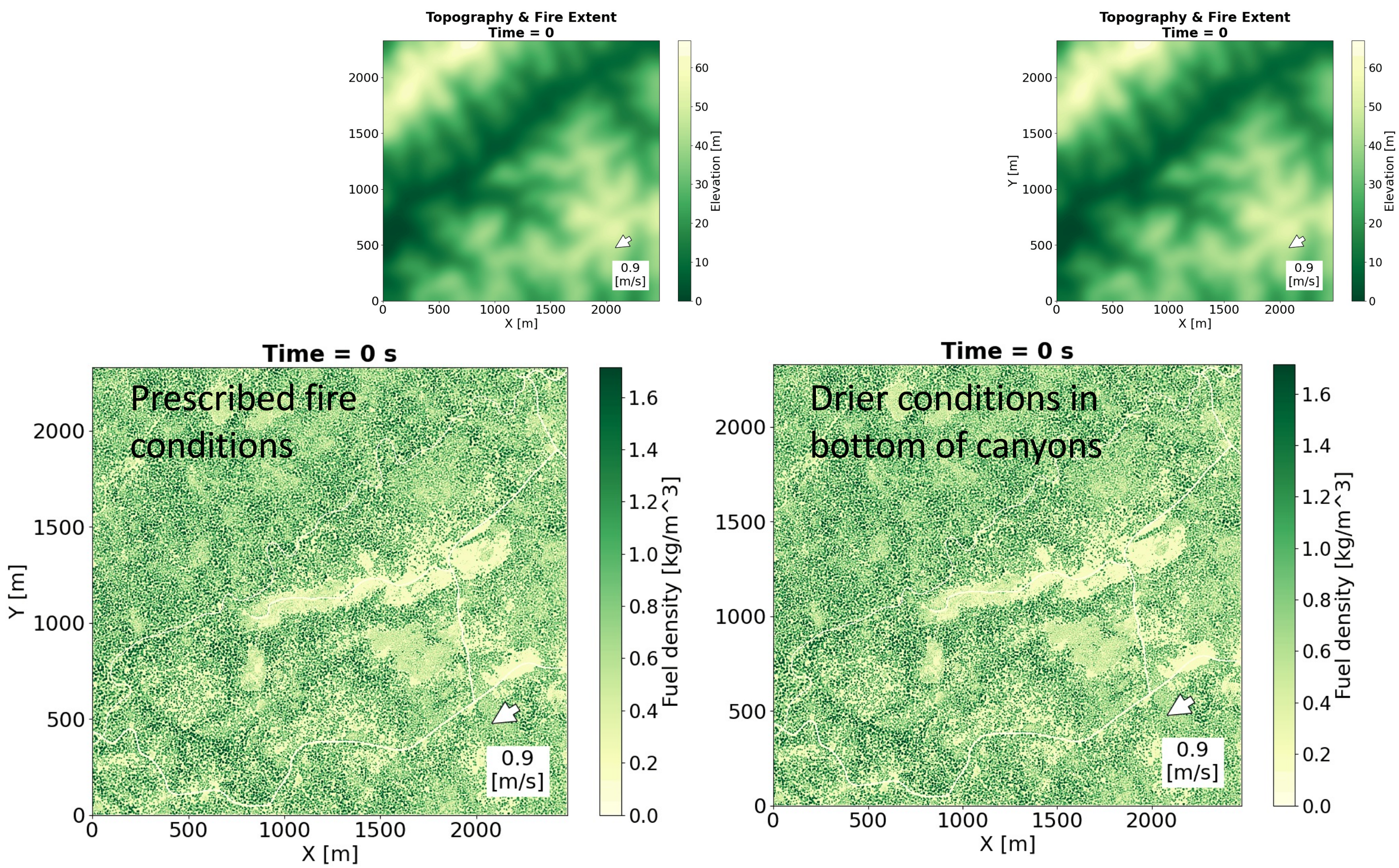
Modeling opportunities

- **Refining prescription windows**
  - Weather
  - Fuels
- **Ignition strategy**
- **Smoke trajectories (including influences of ignition patterns)**
- **Contingency options**
- **Landscape planning**
  - Leveraging preexisting burn scars
  - Optimizing use of resources



Opportunities for next-generation models:
Prescribed fire planning and optimization

- Prescribed fire ignitions are engineered based on site and conditions
  - Technique
  - Pattern
  - Density
  - Rate
- Increased science basis can help meet objectives while avoiding unintended consequences



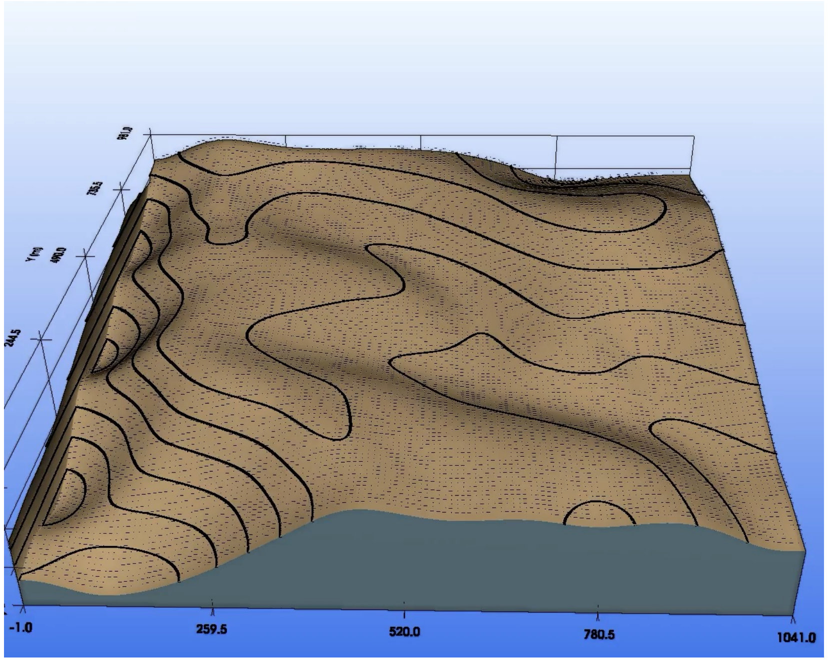
Hitchiti prescribed fire scenarios (Piedmont NWR): effort led by John Wallace (USFWS), JK Hiers (USGS/TTRS), J O'Brien (USFS)

Opportunities:
Modeling in support of proactive approaches to wildland fire

Models complement existing knowledge-based expertise by:

- **Evaluating trade-off’s** for various management strategies
  - Prescribed fire vs. mechanical treatments vs. combination vs. no management
    - Fire risk
    - Short and long term ecosystem and watershed effects
    - Smoke
  - Enabling cost benefit analysis
- Accelerating **training**
- Allowing **exploration** of fire changes in response to changes in conditions (including no-analog fire environments)
- Identifying **potentially dangerous scenarios**
  - During prescribed fire site and condition-specific scenarios
  - as ecosystems evolve after management actions
- **Optimizing treatments**
- Supporting **communication**

Examination of prescribed fire scenario at Bandelier Natl. Monument Winds=5 mph, grass FM=15%, Shrub FM=150%

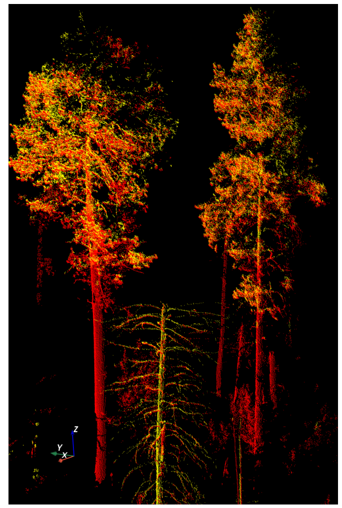


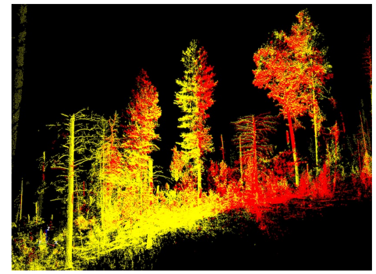
Simulation by Niko Tutland (New Mexico Consortium) with Ellis Margolis (USGS)

New ways of assessing vegetation conditions and structure

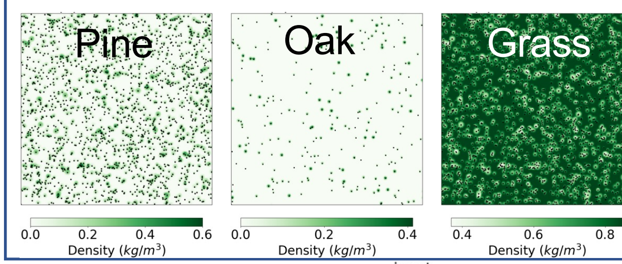
Combining measurements and modeling

- Overstory
  - Airborne Lidar
  - Terrestrial Lidar
  - High resolution photogrammetry
- Midstory
  - Terrestrial Lidar
  - Generative modeling
- Surface fuels
  - Mechanistic modeling
  - AI/ML extrapolation based on canopy structure and arrangement

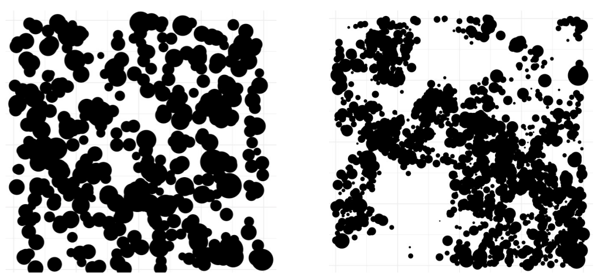

ALS-TLS Co-registration

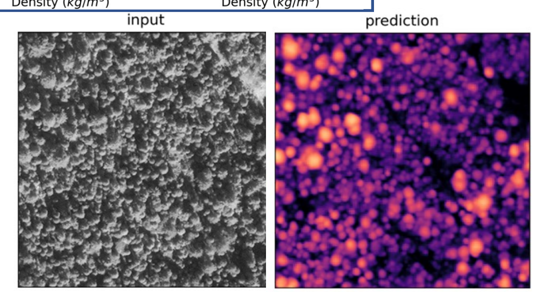

TLS-TLS Co-registration


Structure from motion



Mechanistic modeling for surface fuels


Generative modeling for shrub distributions



Satellite-based tree height prediction

Examining the site-specific roles that fire can play in ecosystem/watershed sustainability

- Different types of fire affect ecosystems and hydrology differently
- Successive fires can have cumulative impacts on ecology and hydrology

- For example: Choosing to use when, where and how to use prescribed fire effects:
  - Wildfire risk
  - Ecosystem health and resilience
  - Watersheds
  - Air quality

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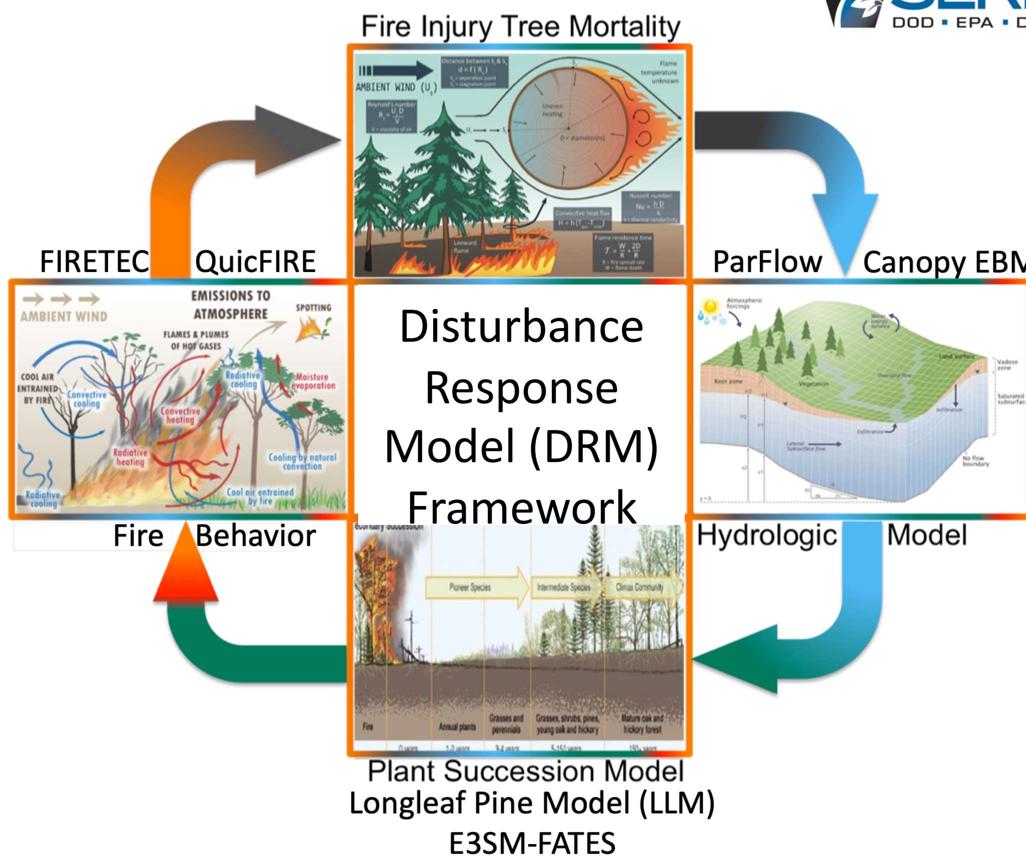
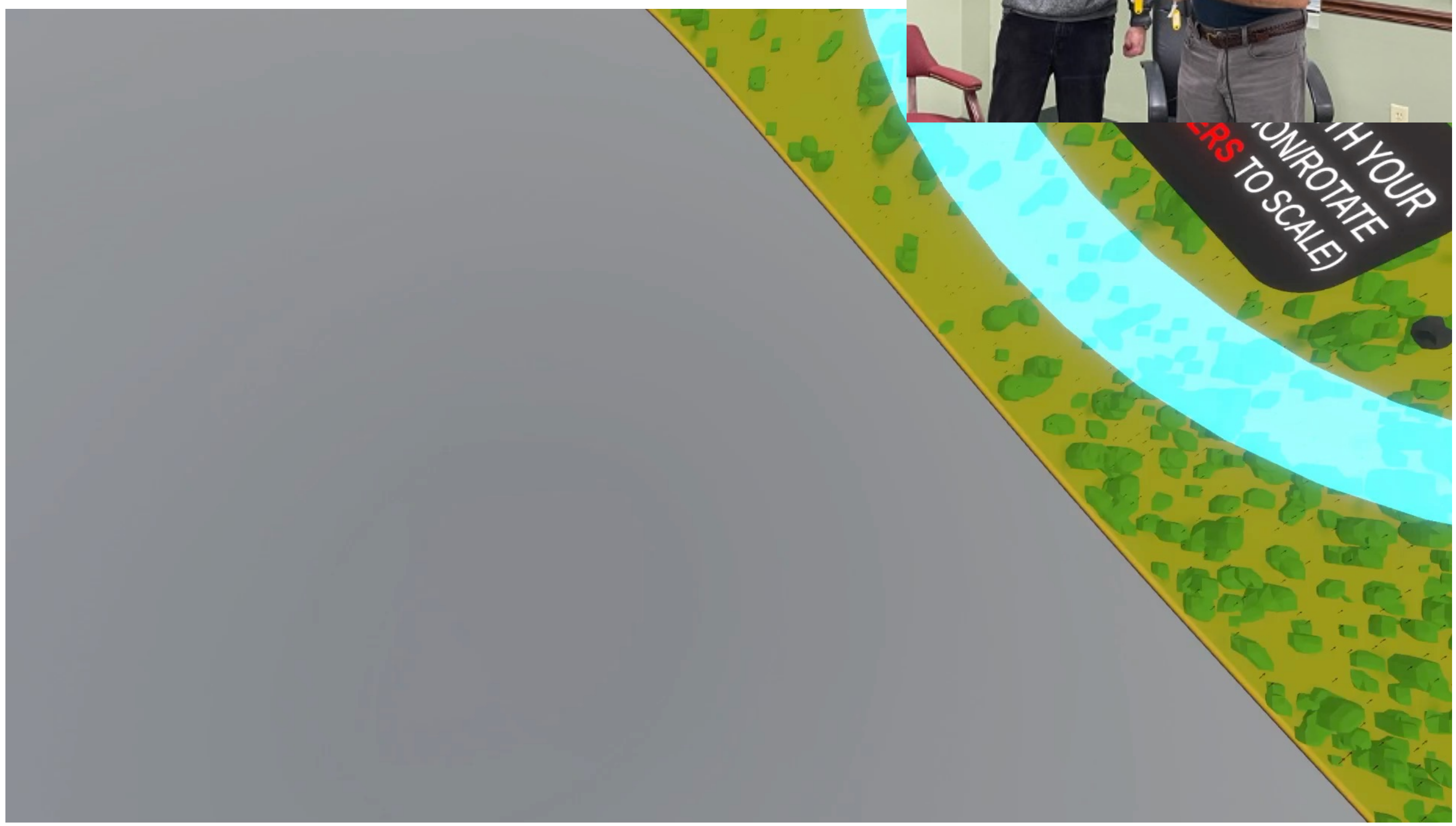


Addressing challenges with next-generation models :

Practitioner training

Using VR to make next generation fire model information more accessible



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Questions?