Role of Surface Topography and Vegetation (STV) Structure in Wildland Fire Dynamics

Tirtha Banerjee, Ph.D.

Associate Professor

Department of Civil and Environmental Engineering,

UC Irvine

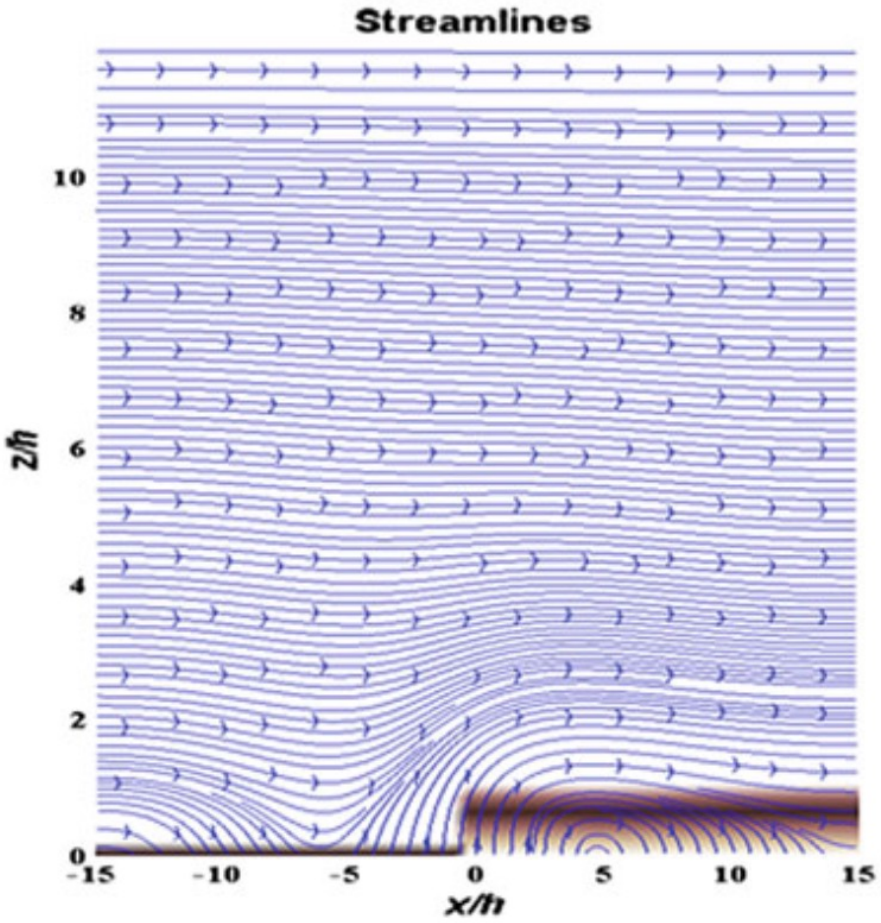
Questions:

- **Background**
- **STV applications**
  - **Edge effects**
  - **Fire behavior on complex terrain**
  - **Embers and WUI fires**
- **Wishlist**

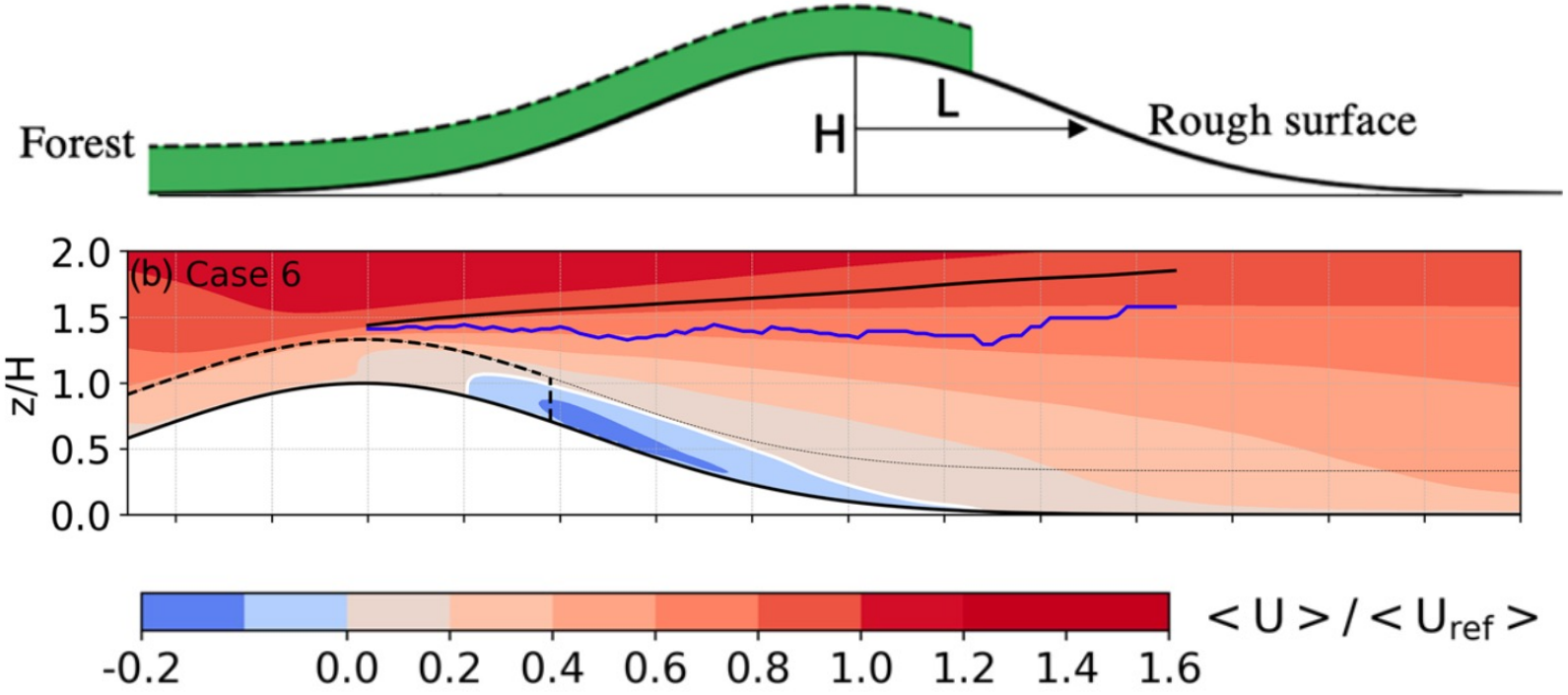
Margarita Rivera, a Ph.D. student at U.C. Irvine, using a drip torch during the prescribed burn.

Motivation: Wildfires, fuel management and prescribed fires

Edges and gaps in forest canopies



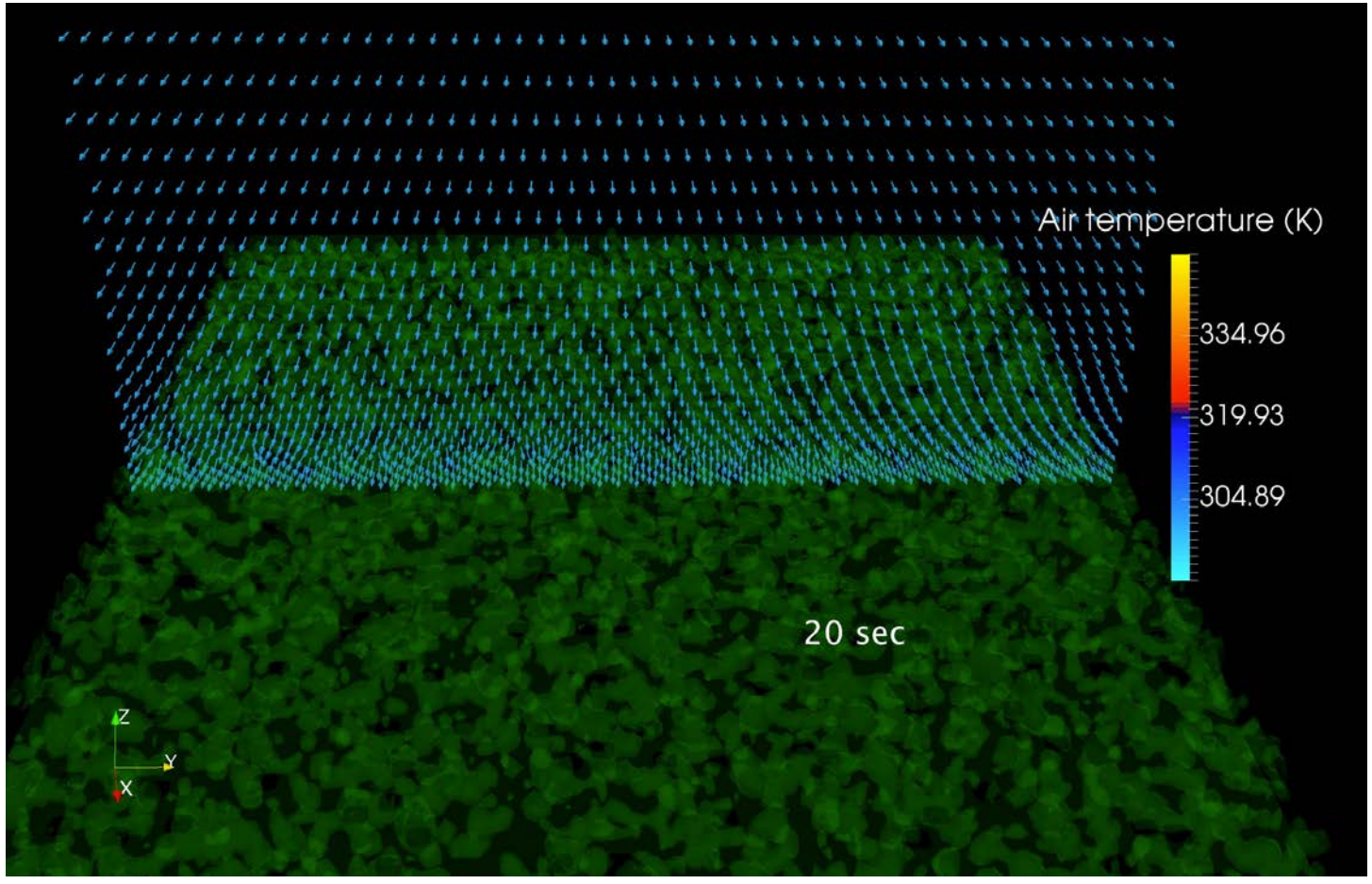
Banerjee et al., BLM, 2013

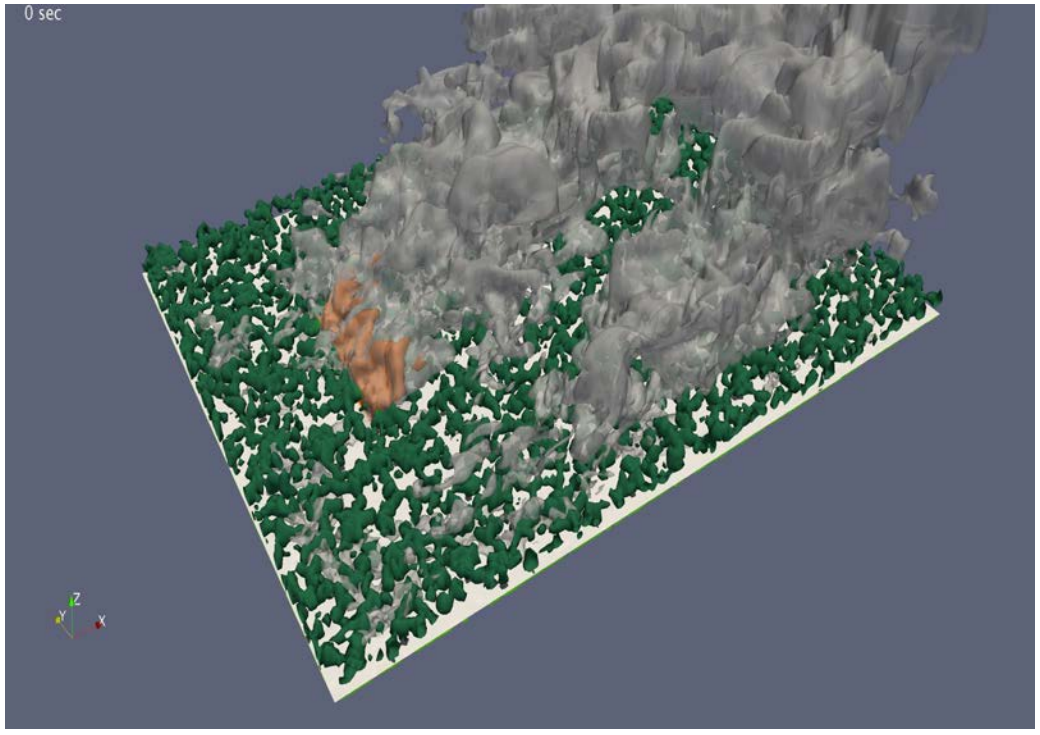


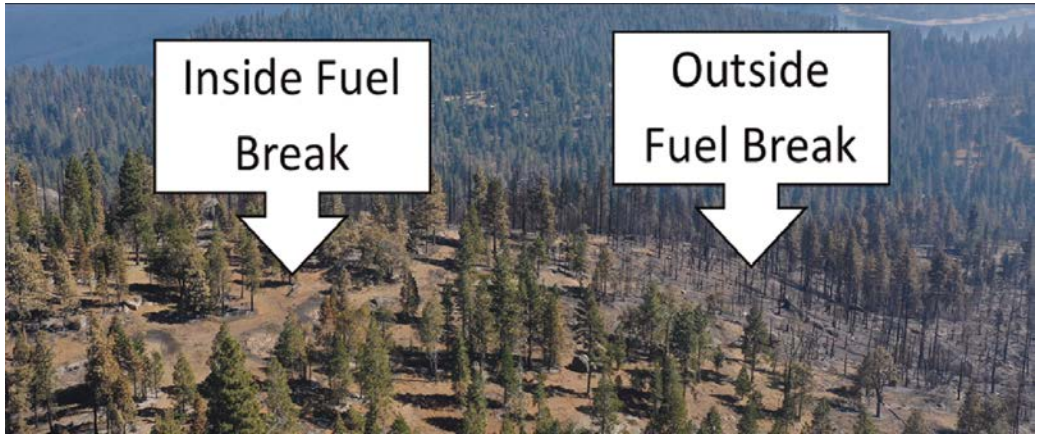
Ma, Liu, Banerjee et al., JGR-Atm, 2020

- Edges, gaps, and slopes can induce recirculations
- The flow structures can change with the forest structure, density and configuration

Wind/turbulence during wildland fires



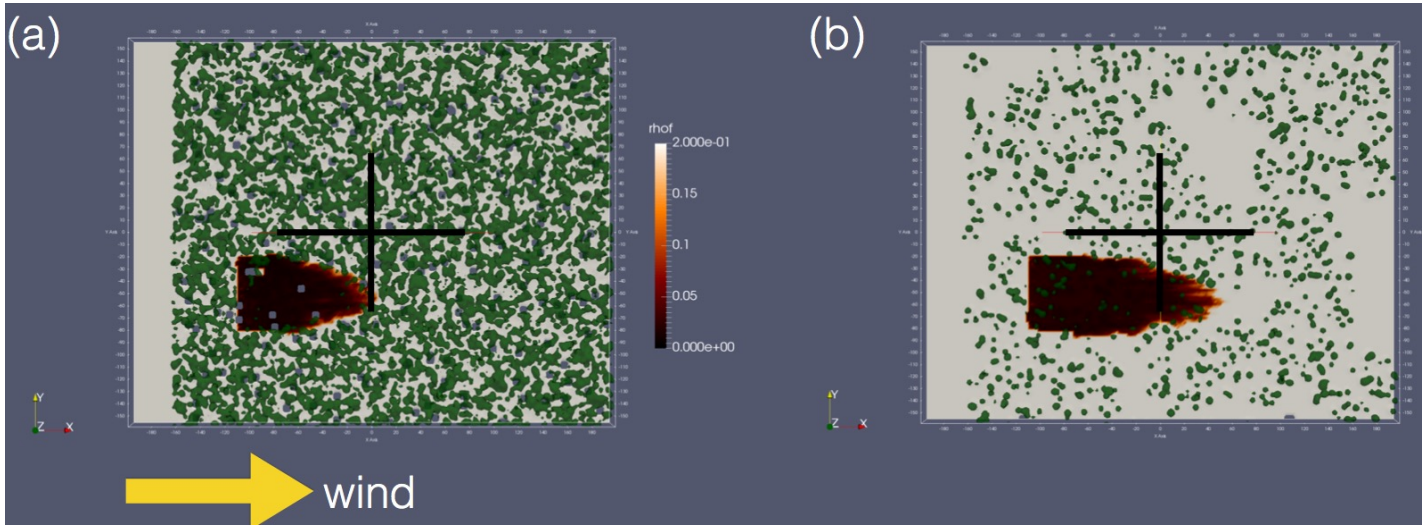


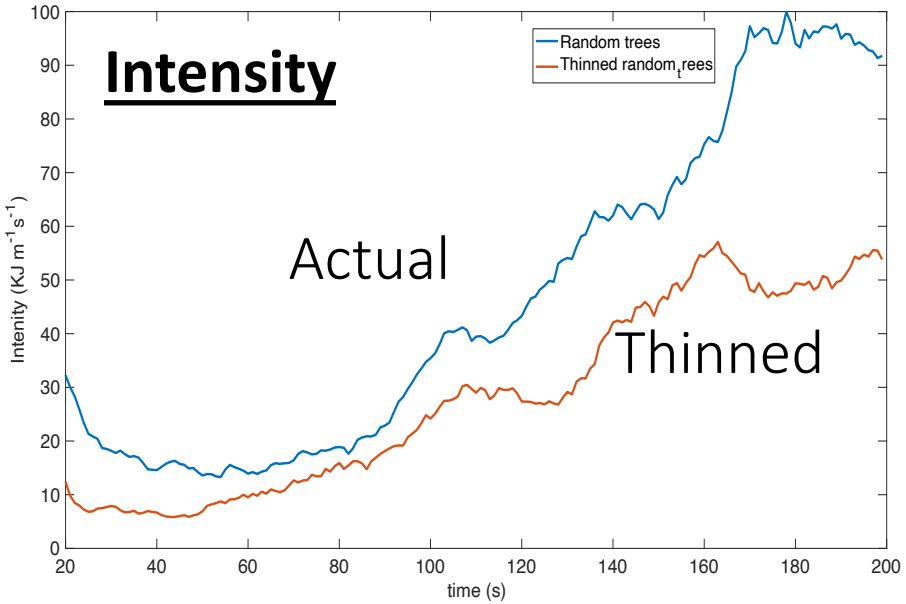


- Fire behavior across edges and fuel breaks can be impacted by local flow and circulations
- Fuel break effectiveness can be impacted

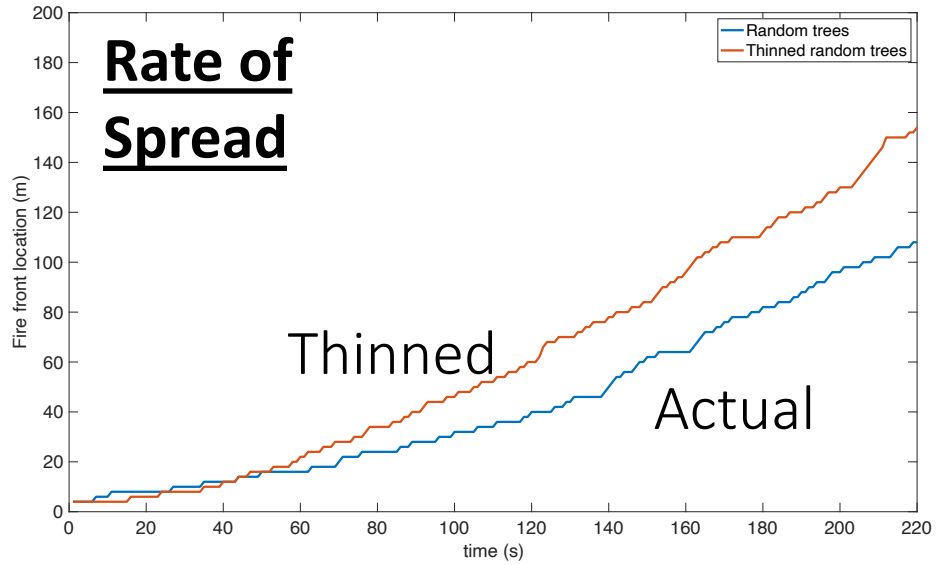
Baijnath Rodino, … Banerjee et al., For Ecol. and Management, 2023

Effects of thinning/ fuel treatment



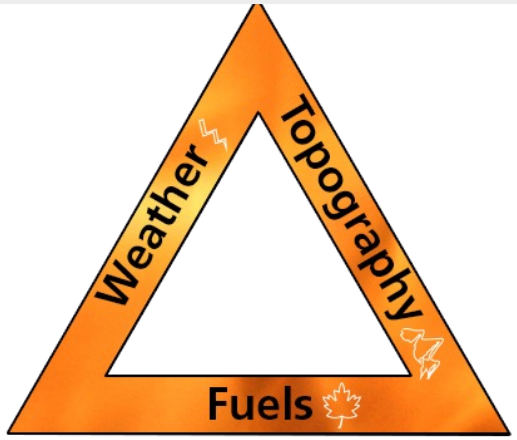


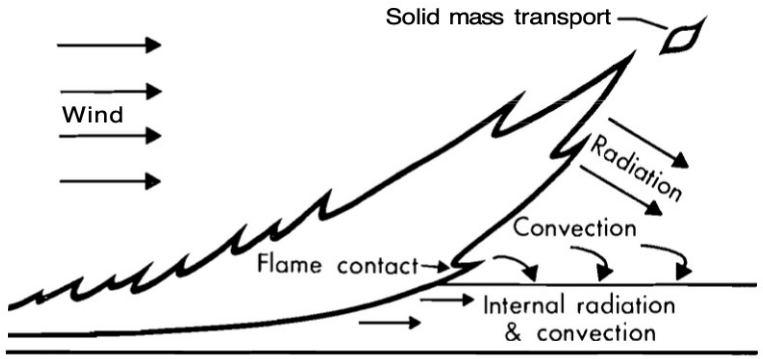
- Edges and gaps can introduce uncertainties in fire behavior by adding novel flow structures and changing turbulence
- Sparser canopy can also be drier, impacting fuel moisture and thus fire behavior
- Implications for management. Optimize speed/intensity?



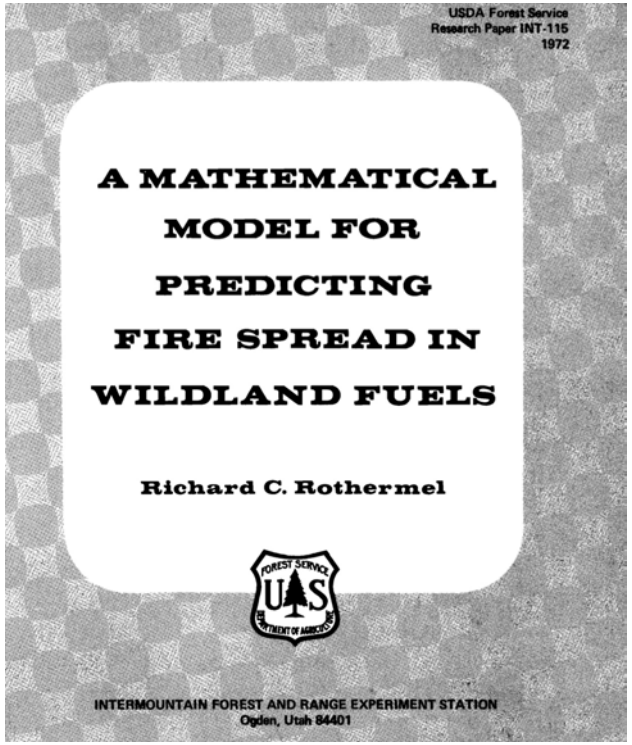
Banerjee et al., Sci Rep, 2020; Banerjee, Forests, 2020

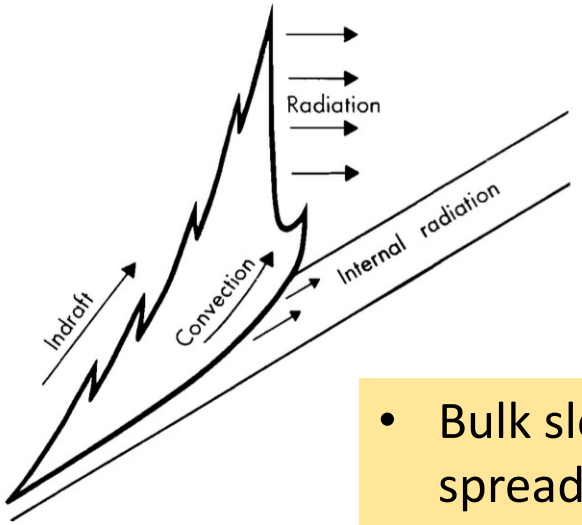
Fire behavior on complex terrain





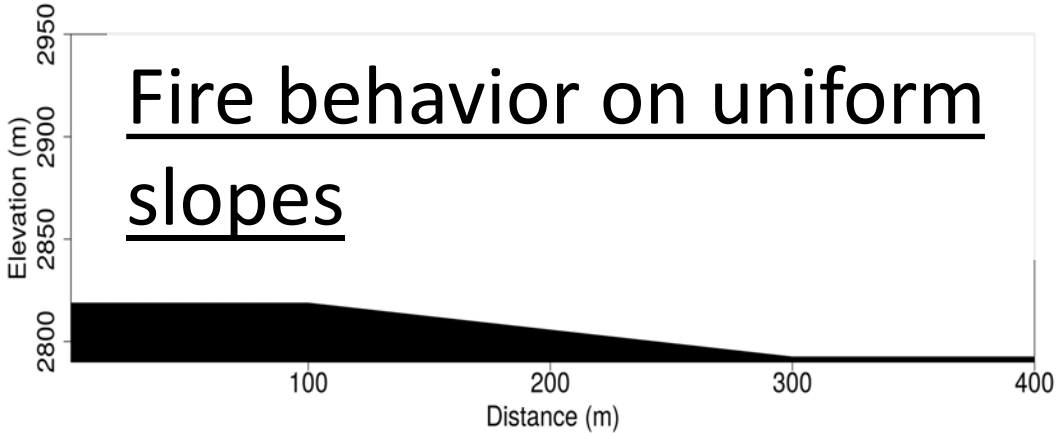
$$R = \frac{I_R \xi (1+\phi_w+\phi_s)}{\rho_b \epsilon Q_{ig}}$$

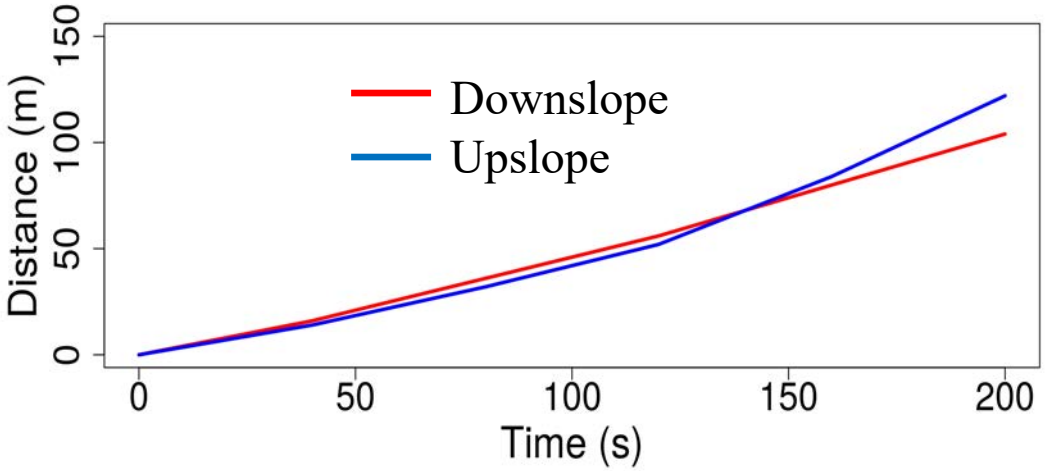


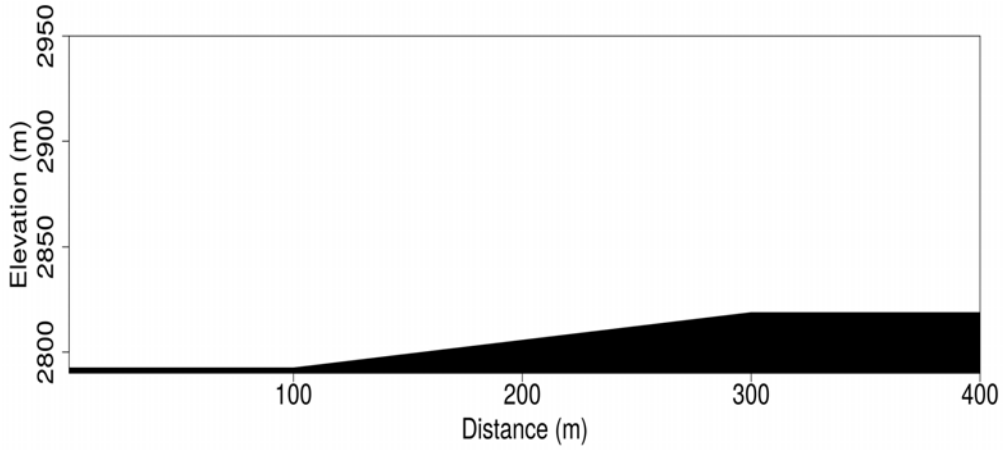


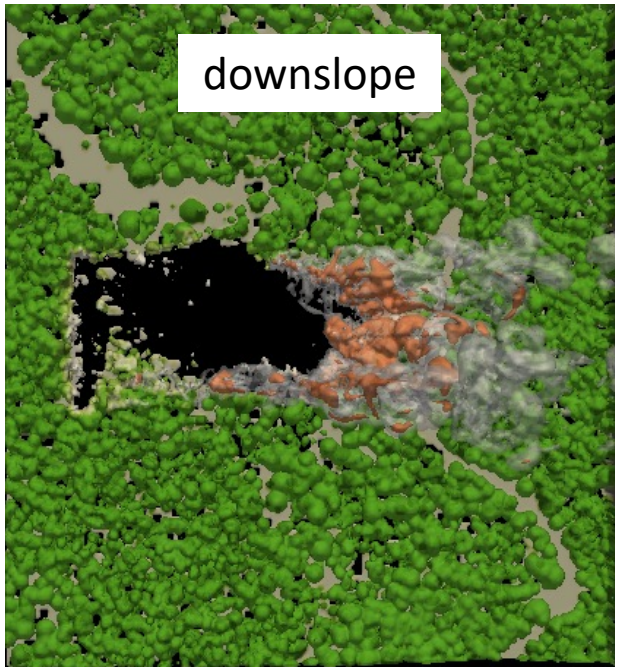
- Bulk slope factors used to adjust the rate of spread
- CFD-based models are used to drive wind flow

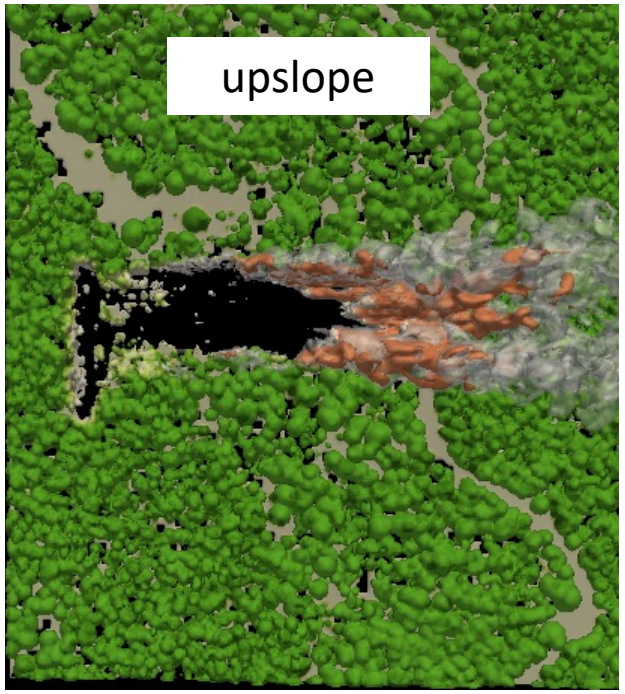
Fire behavior on uniform slopes



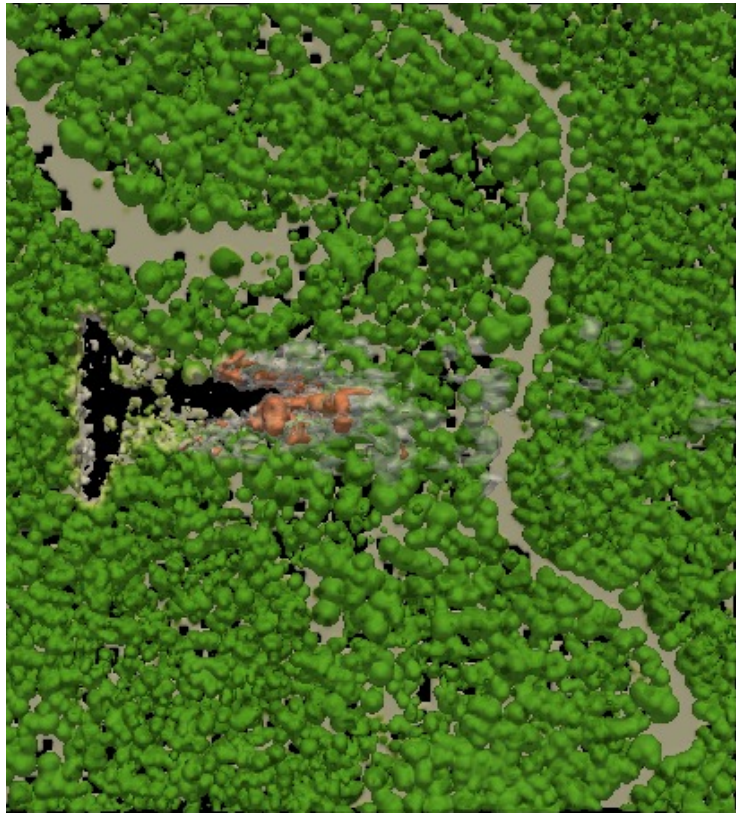






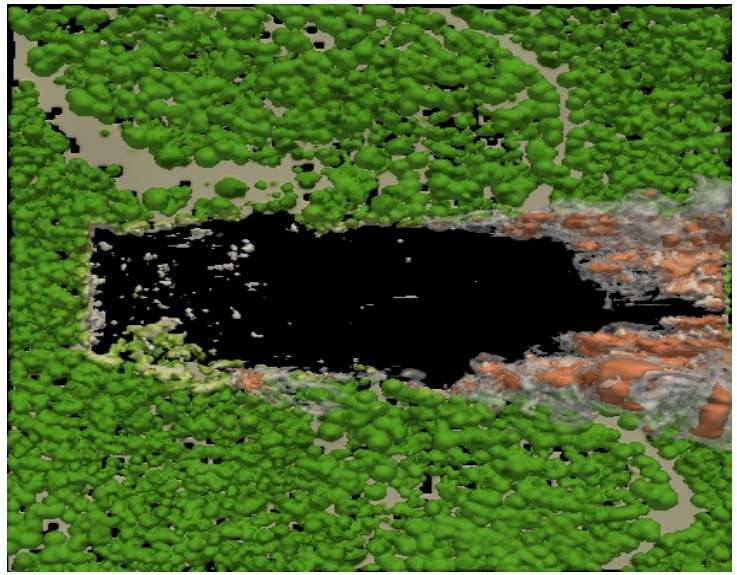


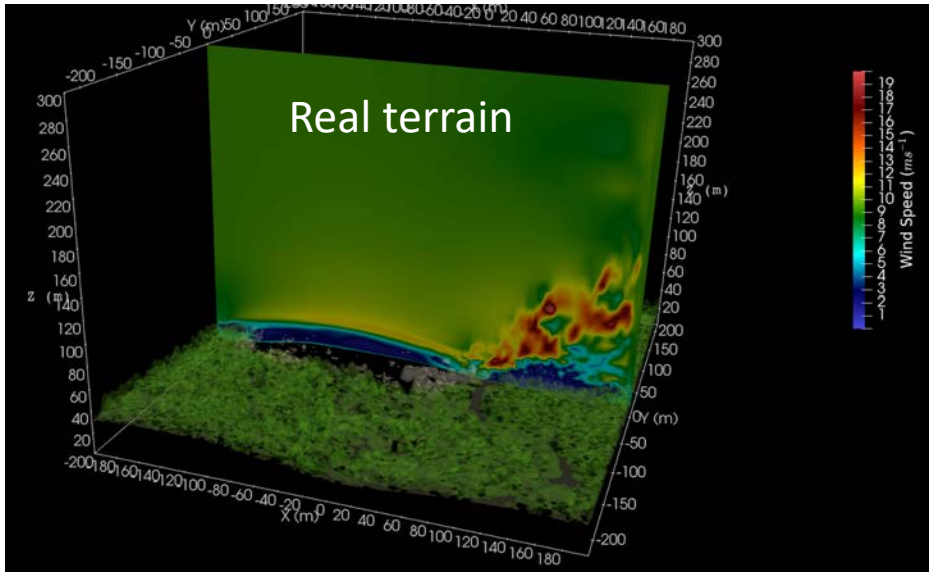
Reference: flat case

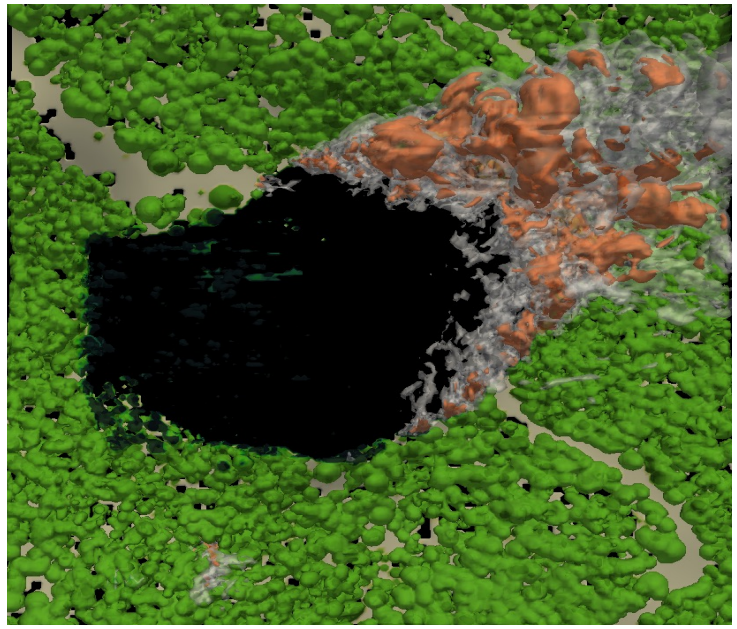


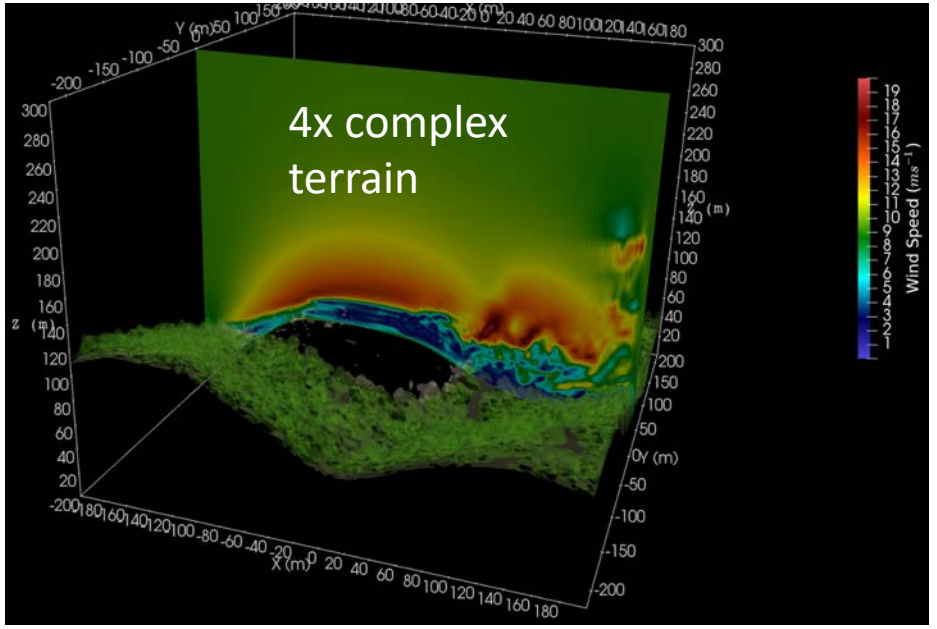
- Usually fires move faster on uniform upslopes, consistent with Rothermal's approach

Fire behavior on complex surfaces









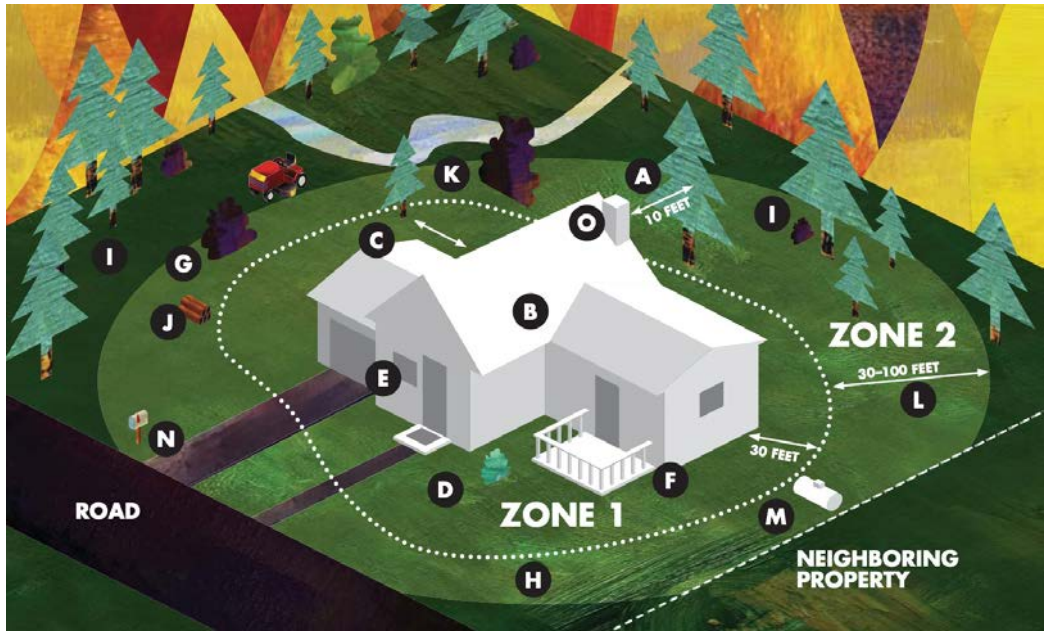
California Wildfires Are Breaking the Rules by Burning Downhill Fast

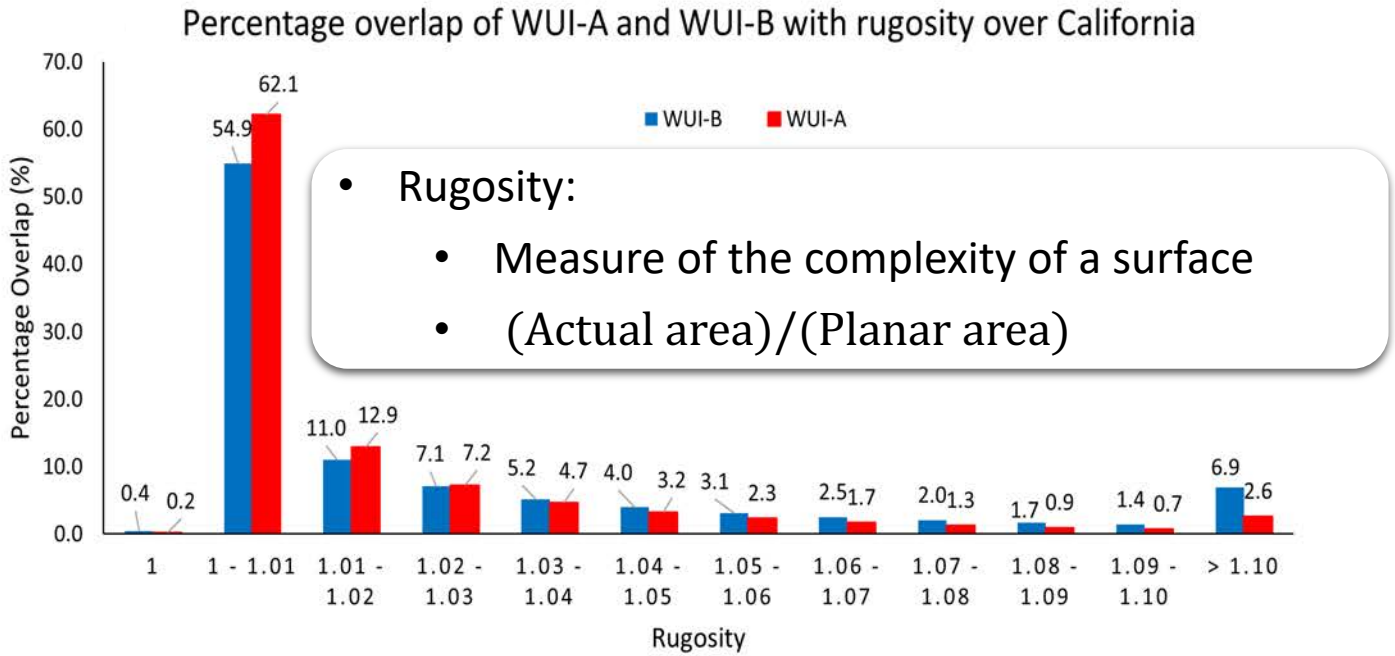
Wildfires typically tend to race uphill and creep slowly downhill. But this fire season is hardly typical. **(David McNew/Getty Images)**

Then there's the wind. During the day, when fires are typically most active, wind tends to blow uphill, carrying heat and embers up the slope. Facing a fire coming up a hill has long been a serious threat to firefighters, and fires moving rapidly uphill have been implicated in many of the deadliest fires for firefighters, such as the South Canyon Fire of 1994 and the Mann Gulch Fire of 1949, which killed 14 and 13 firefighters, respectively.

- Unexpected fire behavior can happen
- Terrain complexity is important
- Lack of validation data

Role of ember transport in the wildland urban interface (WUI)



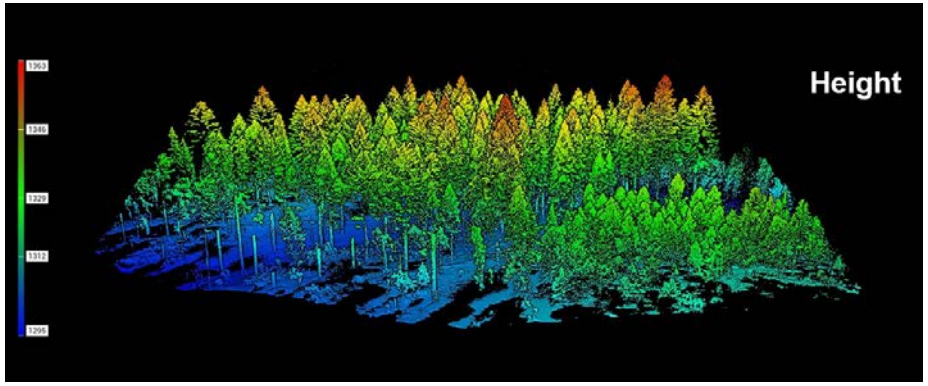


- Rugosity:
  - Measure of the complexity of a surface
  - (Actual area)/(Planar area)

Kumar, … Banerjee, Ecosphere, 2022

- Complex topography might mean more complex rescue, firefighting, and evacuation operations
- Topography can induce wind and turbulence, which cause uncertainty in ember transport
- WUI definitions need to be revised based on ember travel distance

Ongoing work to address challenges



NSF NASA FOREST SERVICE US DEPARTMENT OF AGRICULTURE

UNIVERSITY of CALIFORNIA
Office of the President

Wishlist

What kind of spatial/temporal requirements do stakeholders want?

- Higher frequency observation of fire growth and behavior
- More widespread measurement of meteorological and turbulence parameters

- What would be game-changing for your specific application, enabling entirely new possibilities?

- Estimating wind flow and turbulence in the atmospheric boundary layer during wildfires
- High-resolution fuel maps

- What kind of data latency do you require?

Near real-time

- What is your wish list beyond current capabilities?

- Estimation of surface fuel distribution (below canopy) in very high resolution, such as fuel loading, horizontal and vertical structure, live and dead fuel moisture
- Tracking embers from wildfires

- What kind of product (level) would be most useful to you?

Long-term observations of wind, turbulence, and ABL dynamics for managed and unmanaged forests on complex terrain

Summary of key takeaways

- Heterogeneities of land cover and terrain can induce flow structures like recirculations adding uncertainties to fire behavior
- Changes in micrometeorology can impact fire behavior by altering fuel moisture
- Terrain effects are hard to capture with simple bulk factors
- Terrain complexity (beyond slope and aspect) can impact wind and thus fire behavior can unexpected ways
- Ember travel distance can be impacted due to terrain effects and cause structure damage in the WUI