Fire. Not the disturbance you think it is.

And we are not going to use your grandfather's model to understand it

Earth and Environmental Sciences
Los Alamos National Laboratory
Adam Atchley
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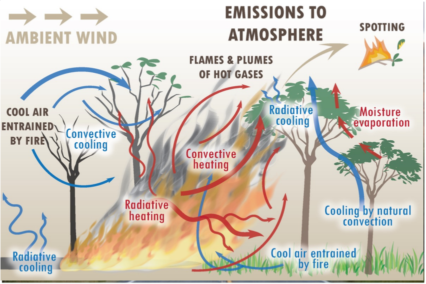
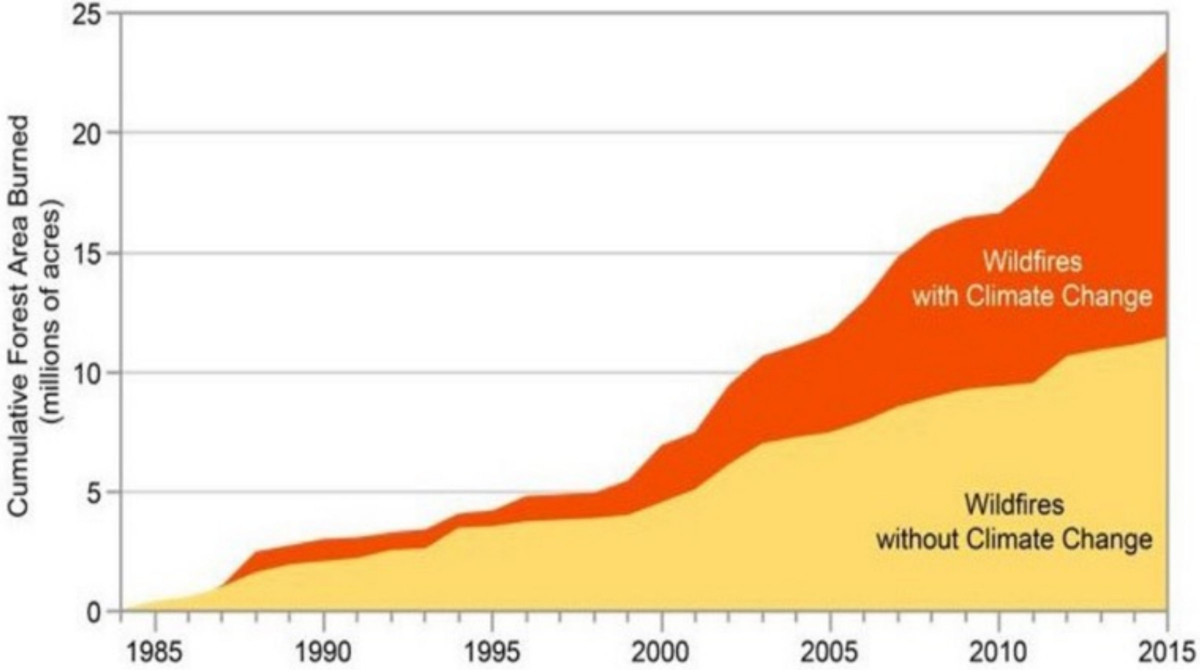


Climate Change and Wildfire

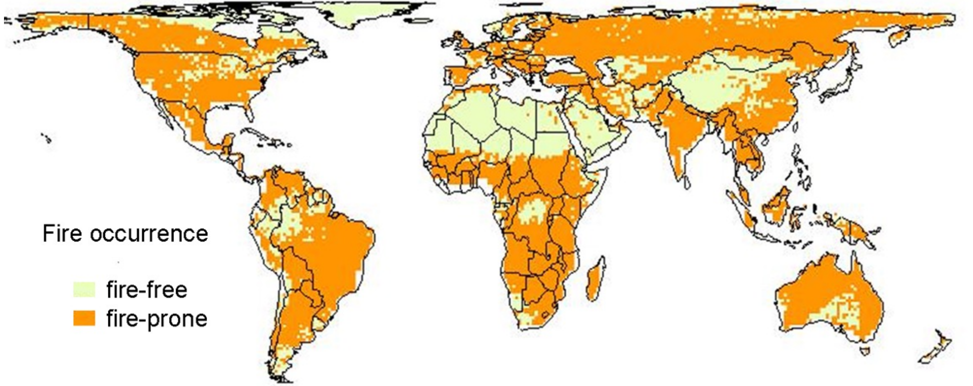
Studies reveal that wildfire activity will continue to increase due to climate change

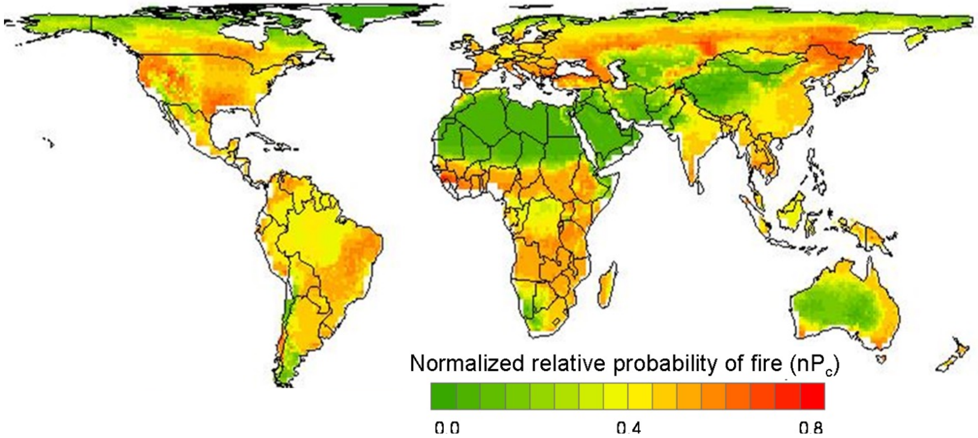
Cumulative area burned 1984–2015

Adapted from Abatzoglu and Williams (2016)



Ecosystems Need and Are Adapted to Fire





Courtesy: Krawchuck et al., 2009. PlosOne

High-Frequency, Low-Severity and Low-Frequency, High-Severity Forests

Ponderosa pine
High-frequency, low-severity fires

Lodgepole pine
Low-frequency, high-severity fires

Structural forest differences and evolutionary traits determine fire behavior and ecosystem response to fire disturbance

Fire Suppression = High Fuel Density →High Fire Severity

Born: 1950

Capitan, New Mexico

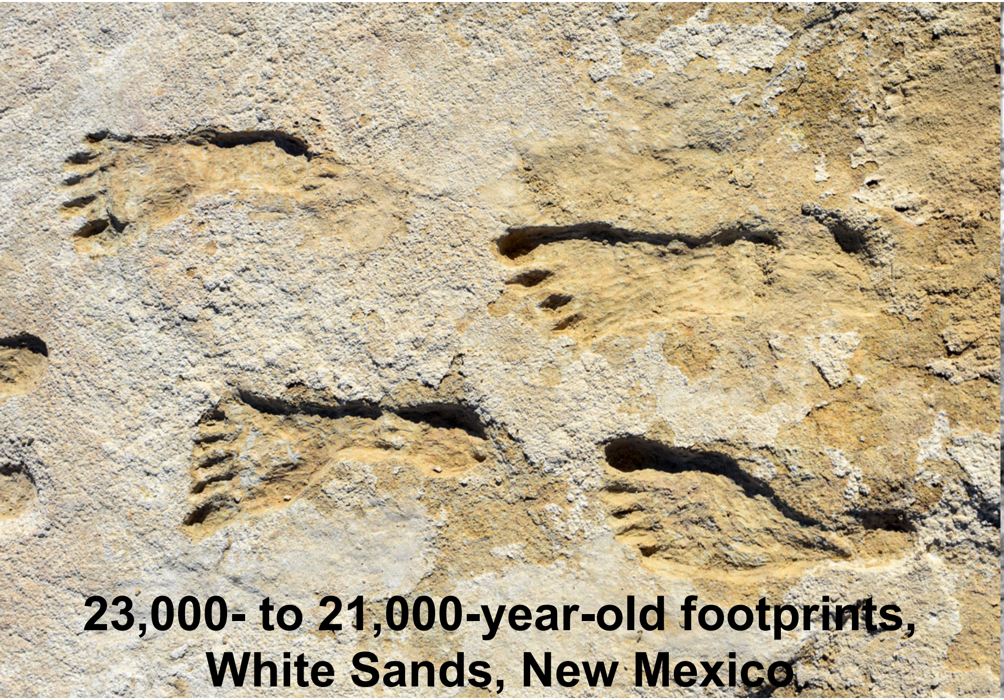
(live mascot)

~ 1944 USFS

Prescribed Fire in Action

Photo Credit: Sustainable Northwest, Steve Rondeau (Klamath Tribes Natural Resources Director). Klamath Tribes restoration prescription and Forest Service prescribed fire (April 2021) after the 2021 Bootleg Fire on the Fremont-Winema National Forest.

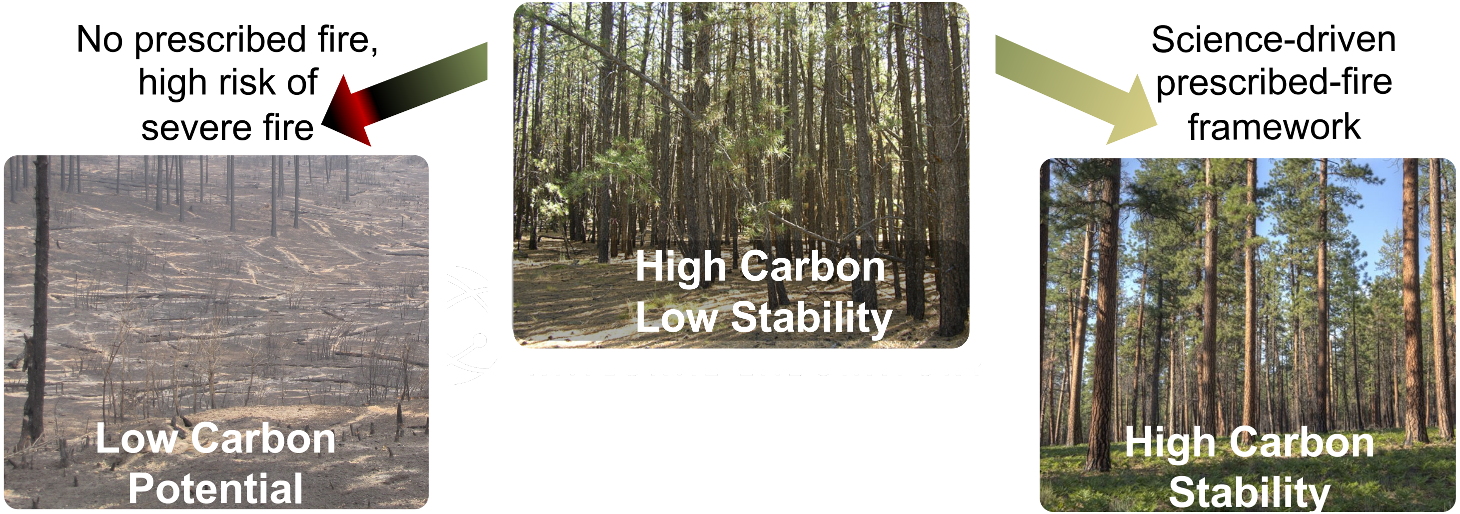
Our ‘natural’ ecosystem reference point was always managed or in transition from that managed state



23,000- to 21,000-year-old footprints, White Sands, New Mexico

Late 19th Century Fire-Dependent Forests

Prescribed Fire Prevents Ecosystem Transition, But Is Understudied



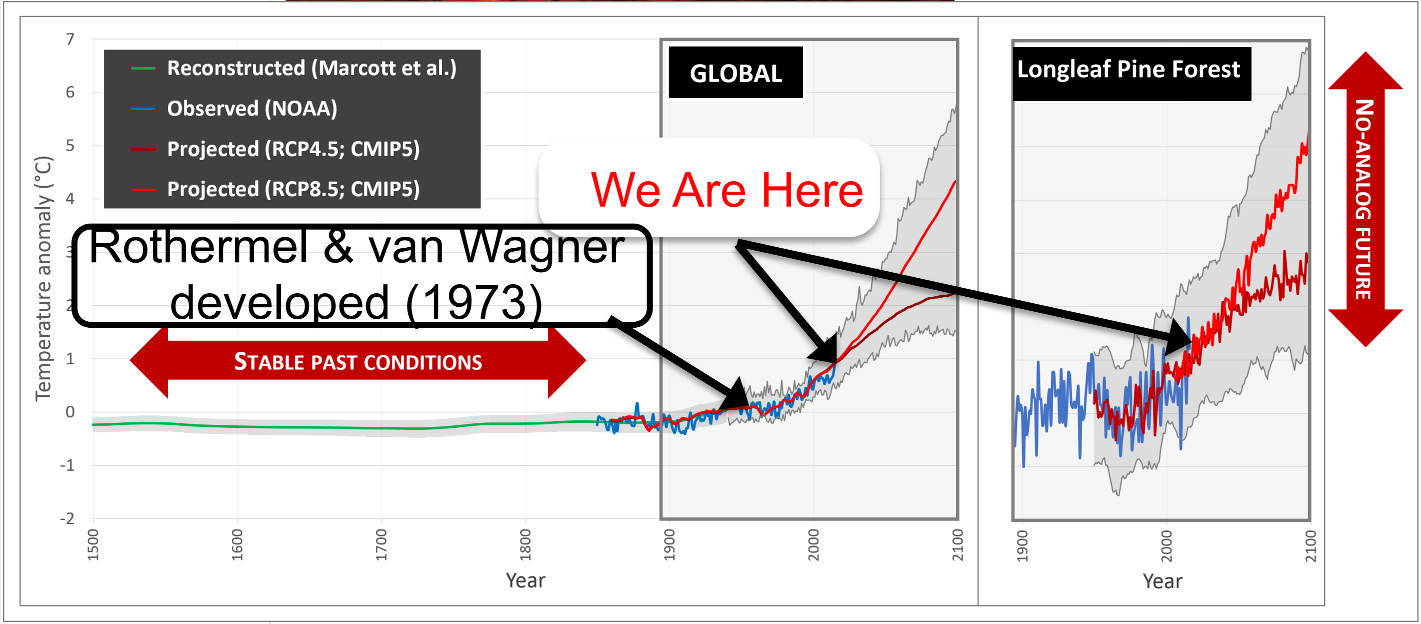
High-severity fire ~ ecosystem transition

Frequent fire forest structure

- Wildland fire science has been focused on high-severity wildfires but does not address prescribed fire conditions.
- Prescribed fire takes place in marginal burning conditions where forest structure, fuel moisture, etc. have outsized controls on successful application.
- Success of prescribed fire depends on a new science basis and more sensitive model applications. - Heirs et al., 2020. *Fire Ecol* **16,** 11 (2020). https://doi.org/10.1186/s42408-020-0070-8

Climate Change is Breaking Empirical Fire Models

- **Changing Fire Conditions**
  - **CLIMATE:** Temperature, precipitation (hot droughts).
- **Empirical models of the past, such as Rothermels and van Wagners are outside of their validation range.**
  - Fire Models: BEHAVE, SpitFire-FATES, etc. are all combinations of Rothermels and van Wagner



We Are Here

Rothermel & van Wagner developed (1973)

STABLE PAST CONDITIONS

NO-ANALOG FUTURE

BY JEFF TOLLEFSON

In California, where the state's largest wildfire on record continues to burn, fires are getting bigger and less predictable — so much so that scientists are struggling to model them. Now, two research

abnormal fire seasons around the world. The giant California fire has torched about 166,000 hectares since late July, and continues to burn in the northern part of the state. British Columbia in Canada is now experiencing its worst fire season on record (see 'Scorched earth'). And in late July, after

MARK RALSTON/AFP/GETTY

Swapping out the empirical models with mechanistic approaches

Rothermel Fire Spread Model(s) (1972)

$$R = \frac{I_R \zeta(\phi_w + \phi_s)}{\rho_b \epsilon Q_{ig}} \qquad I_R = R_v w_n l_h$$

Van Wagner Crown Scorch Model (1973)

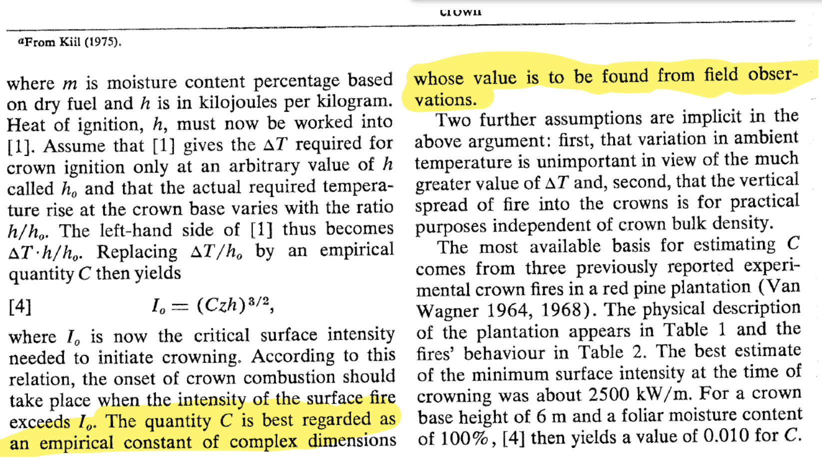
$$h_s = \frac{3.94 I^{7/6}}{(0.107I + U^3)^{1/2}(60 - T)}$$

Van Wagner Crown Combustion Model (1975)

$$I_0 = (Czh)^{3/2}$$

What exactly is C?

Is 3.941 constant everywhere?



[a]From Kill (1975).

where m is moisture content percentage based on dry fuel and h is in kilojoules per kilogram. Heat of ignition, h, must now be worked into [1]. Assume that [1] gives the ΔT required for crown ignition only at an arbitrary value of h called h_o and that the actual required temperature rise at the crown base varies with the ratio h/h_o. The left-hand side of [1] thus becomes $\Delta T \cdot h/h_o$. Replacing $\Delta T/h_o$ by an empirical quantity C then yields

[4] $I_o = (Czh)^{3/2}$,

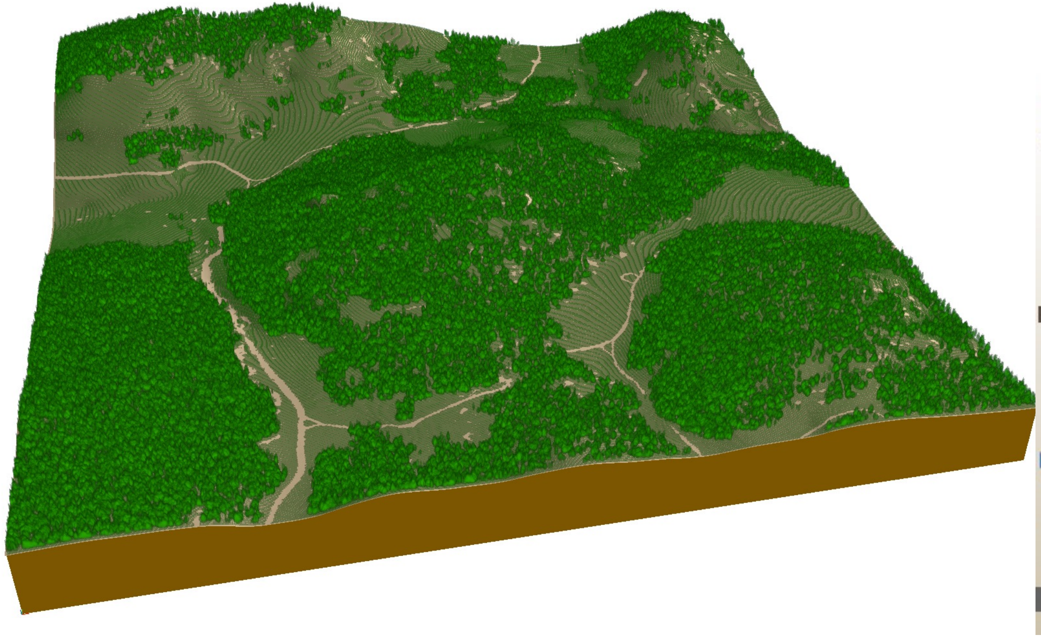
where I_o is now the critical surface intensity needed to initiate crowning. According to this relation, the onset of crown combustion should take place when the intensity of the surface fire exceeds I_o. The quantity C is best regarded as an empirical constant of complex dimensions whose value is to be found from field observations.

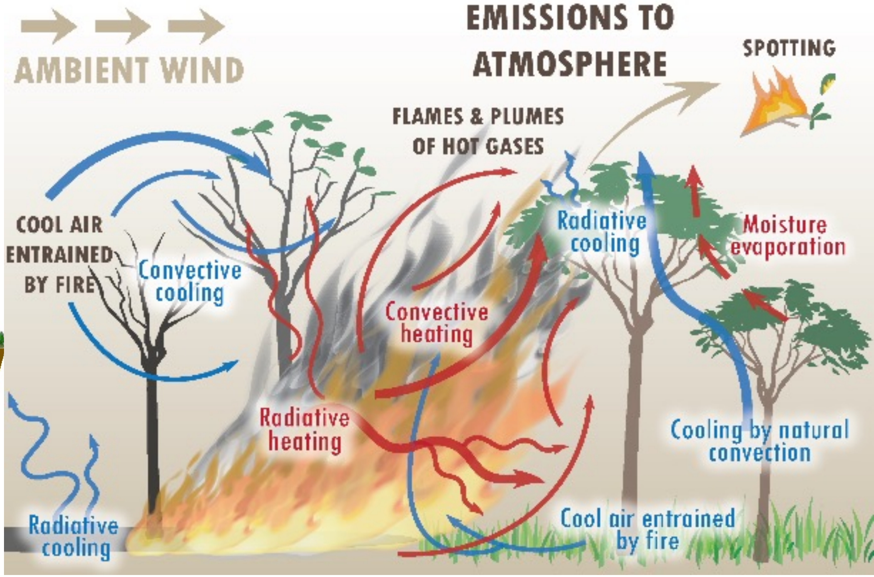
Two further assumptions are implicit in the above argument: first, that variation in ambient temperature is unimportant in view of the much greater value of ΔT and, second, that the vertical spread of fire into the crowns is for practical purposes independent of crown bulk density.

The most available basis for estimating C comes from three previously reported experimental crown fires in a red pine plantation (Van Wagner 1964, 1968). The physical description of the plantation appears in Table 1 and the fires' behaviour in Table 2. The best estimate of the minimum surface intensity at the time of crowning was about 2500 kW/m. For a crown base height of 6 m and a foliar moisture content of 100%, [4] then yields a value of 0.010 for C.

Swapping out the empirical models with mechanistic approaches

FIRETEC – 3D Navier-Stokes Fluid Dynamics

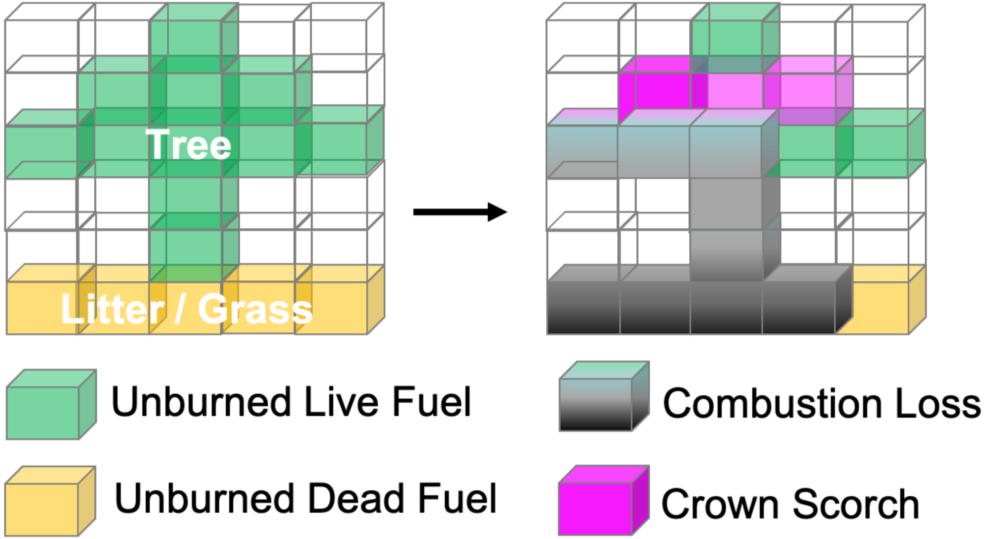


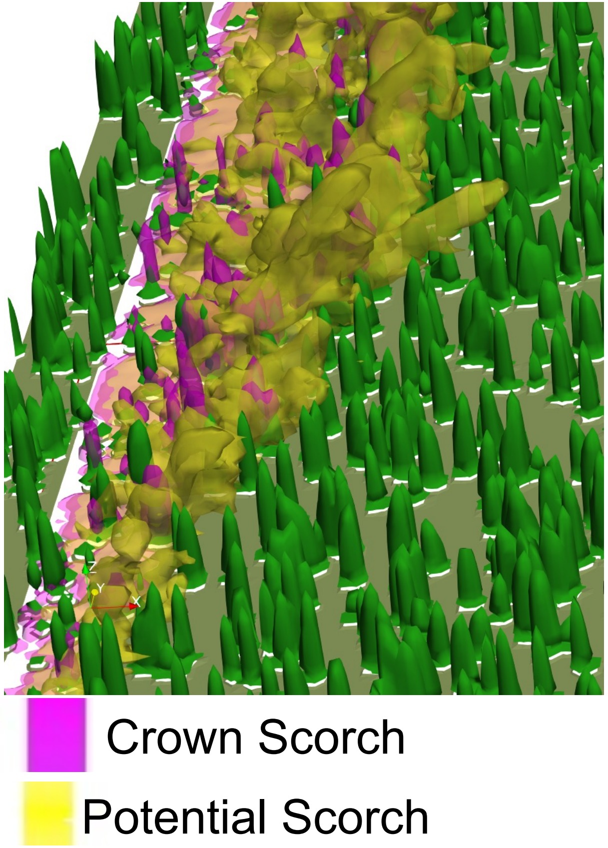


Mechanistic Approach: Crown Scorch

Solid temperatures above 60 degrees C

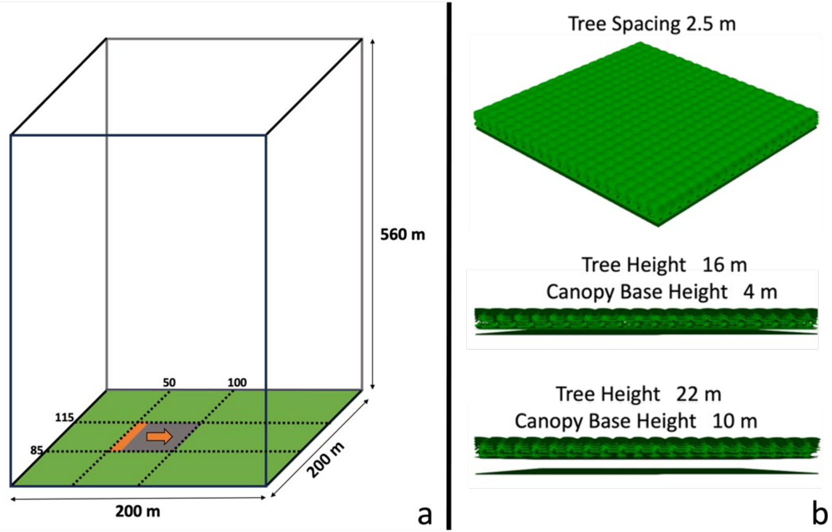
assume crown scorch



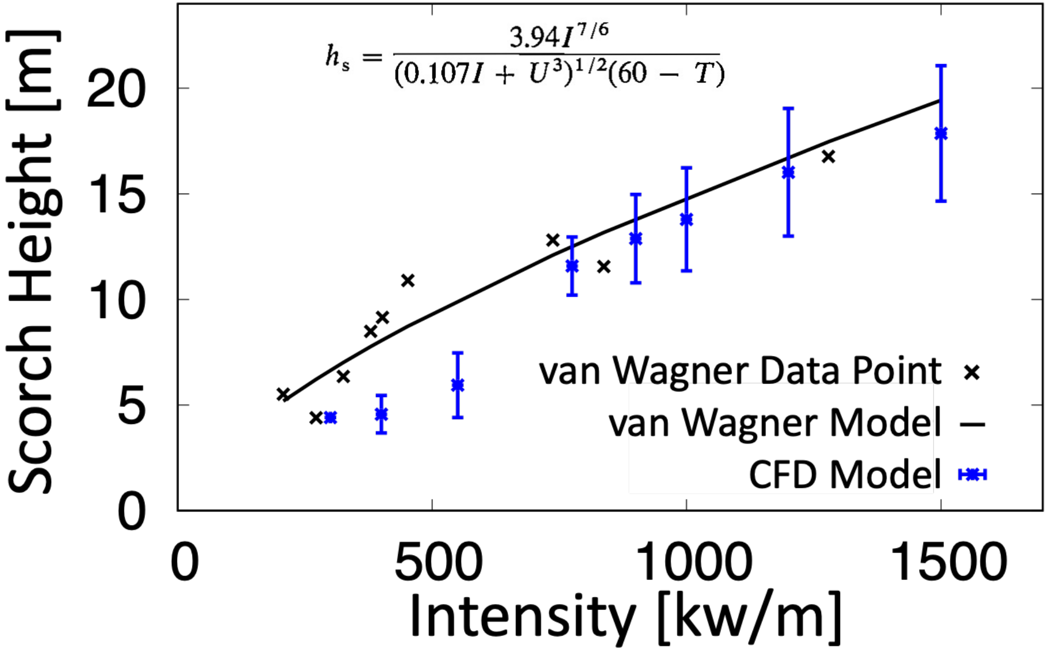


Compare to Van Wagner’s Data & Model

Simulating a hotplate along the surface to control for energy intensity

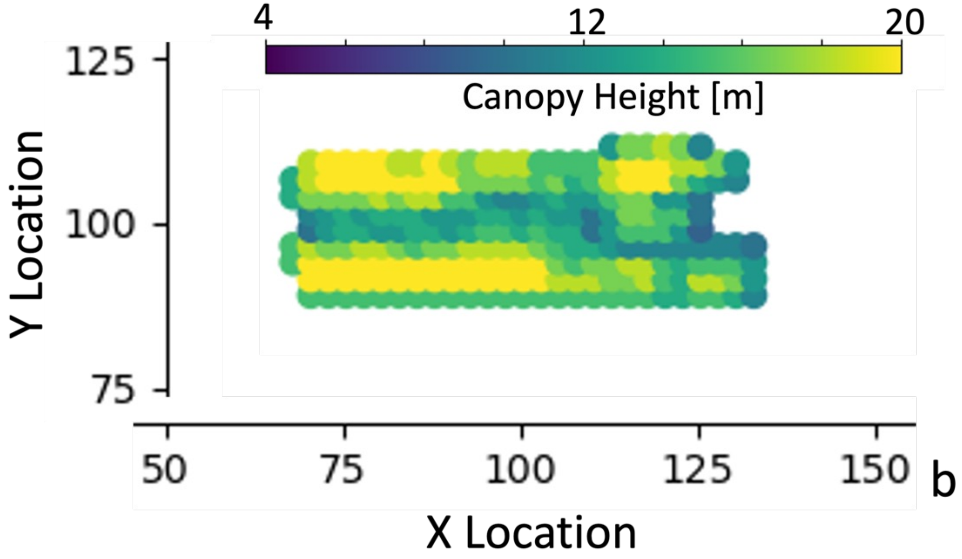


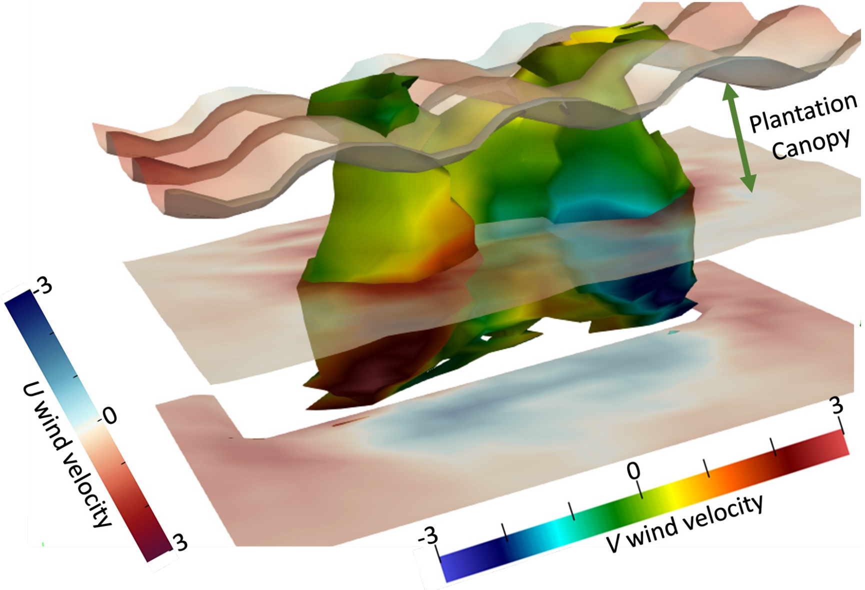
Validation of Crown Scorch Modeling
Van Wagner 1973



Buoyant Plume Dynamics

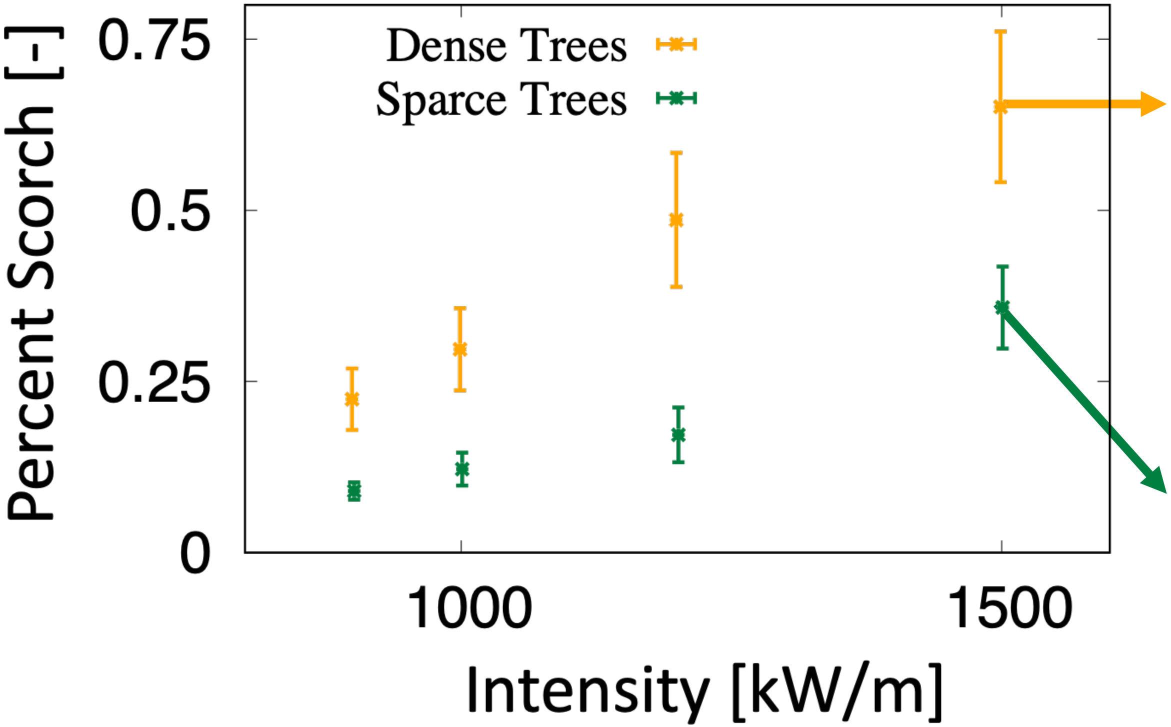
Buoyant Plume Dynamics Create Crown Scorch Variability





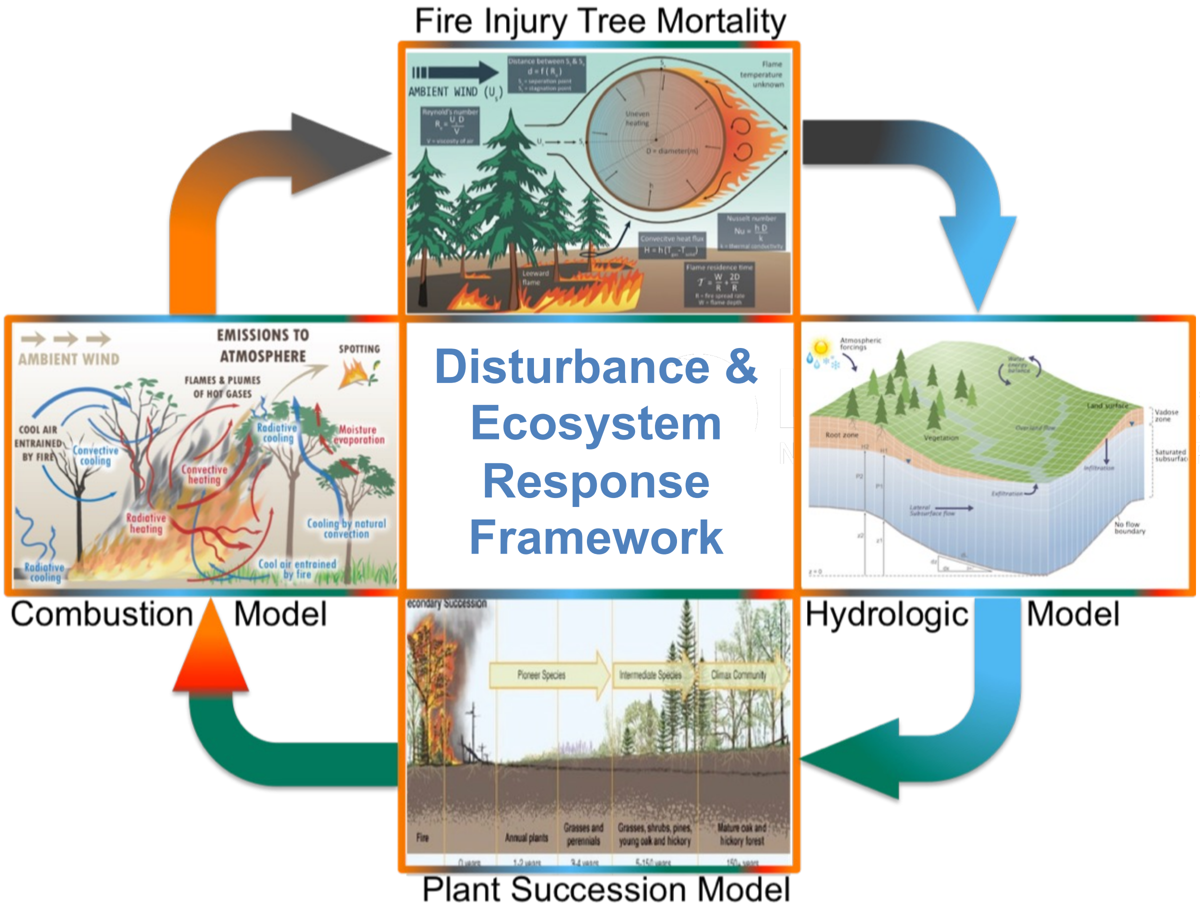
W – Velocity wind structures show hot air moving up.

Forest Structure & Crown Scorch Resiliency



3D simulation capabilities identify resilient forest structures that can build ecosystem resiliency.

Disturbance and Response-Modeling Framework


Fire Injury Tree Mortality

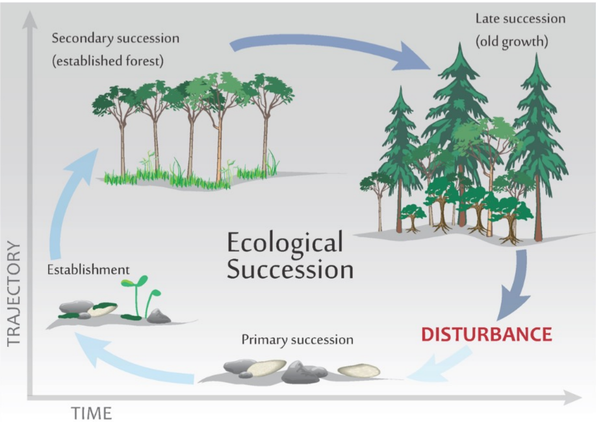
Combustion Model

Disturbance & Ecosystem Response Framework

Hydrologic Model

Plant Succession Model

- ➢ Simulates ecohydrology response to fire disturbances.
- ➢ Loops fire disturbance and ecohydrological response to simulate future fire disturbances and ecosystem trajectory.

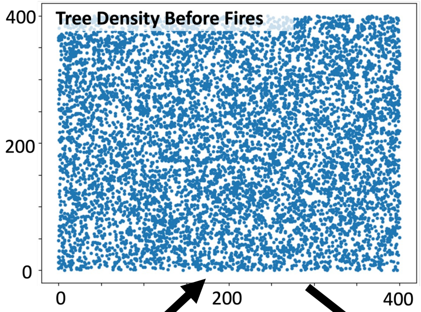


Traditional Succession model

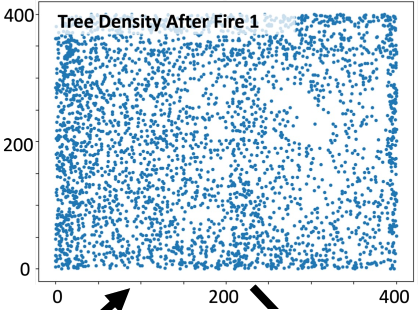
Forest Structure Matters!

Los Alamos
NATIONAL LABORATORY

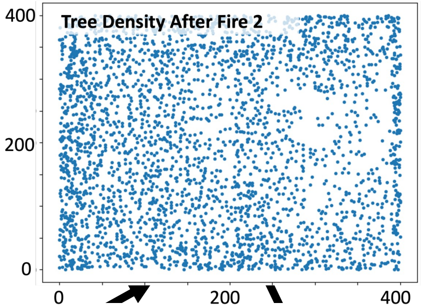
Fire Excluded



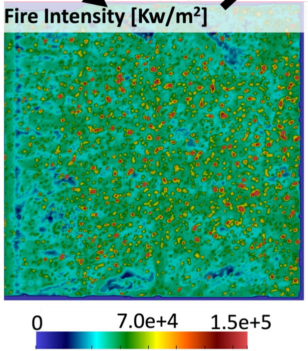
Fire Impacted



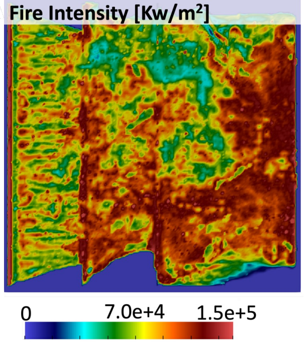
Fire Resilient



Forest structure bakes in fire resiliency.

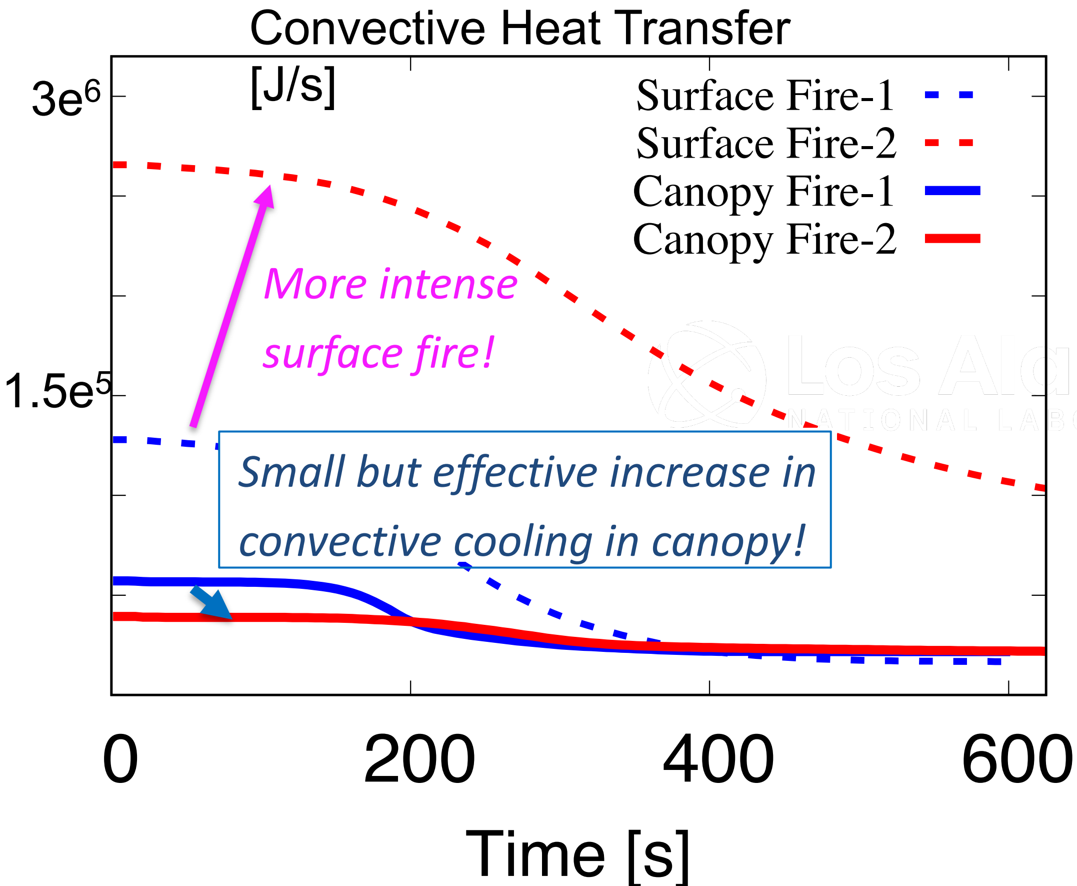


Fire #1:
Moderate Intensity
Kills a lot of Trees



Fire #2:
High Intensity
Most Trees Survive

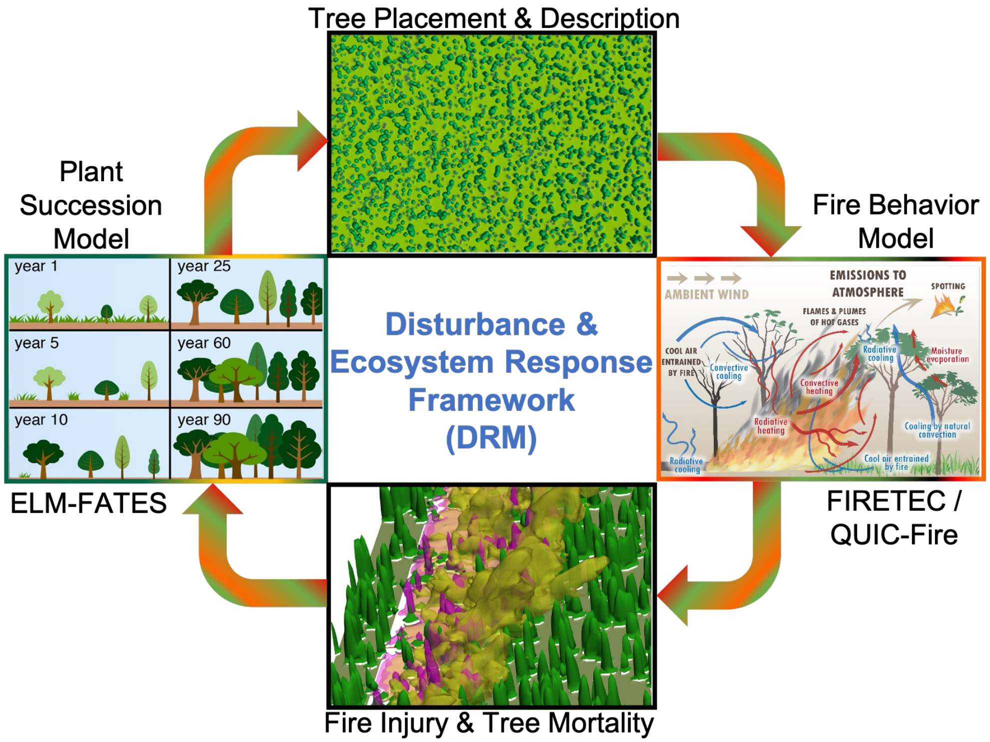
Forest Structure Matters!



More intense surface fire!

Small but effective increase in convective cooling in canopy!

Testing Prescribed fire Return Intervals



Tree Placement & Description

Plant Succession Model

ELM-FATES

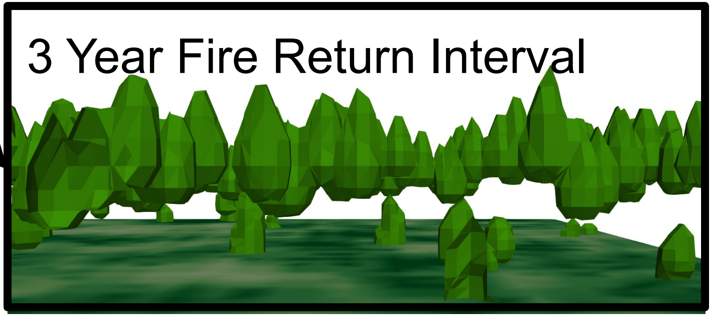
Disturbance & Ecosystem Response Framework (DRM)

Fire Behavior Model

FIRETEC / QUIC-Fire

Fire Injury & Tree Mortality

6 Year Fire Return Interval

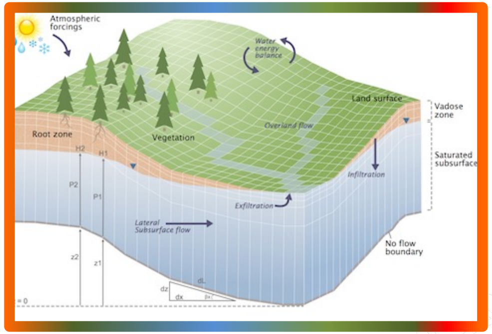


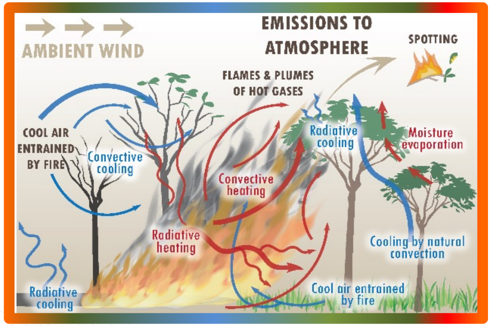
3 Year Fire Return Interval

- ➢ We see characteristic forest structures develop that reflect fire return intervals and become more resilient with increasing fire intensity.

Fuel Moisture Loading and Fire Behavior: Coupling Hydrology to Fire

Hydrologic Models informing Fire Behavior models.





1) Live fuel moisture.

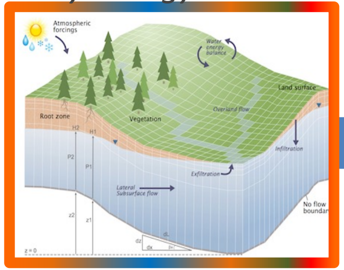
- Species response to soil water.
- Ecosystem characteristic.

2) Dead fuel moisture & canopy water storage.

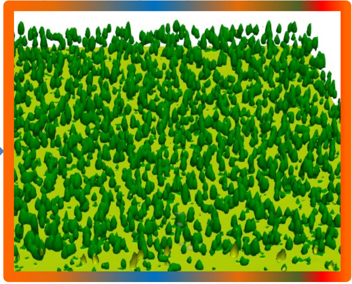
- Amount of water held in the canopy.
- Determined by weather & vegetation structure.

Forest Structure Management & Fuel Moisture Modeling

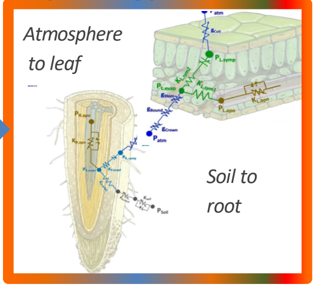
Hydrology Model

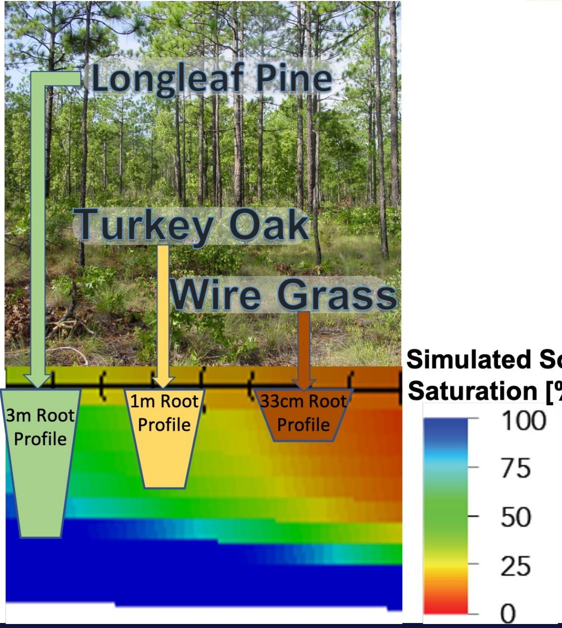


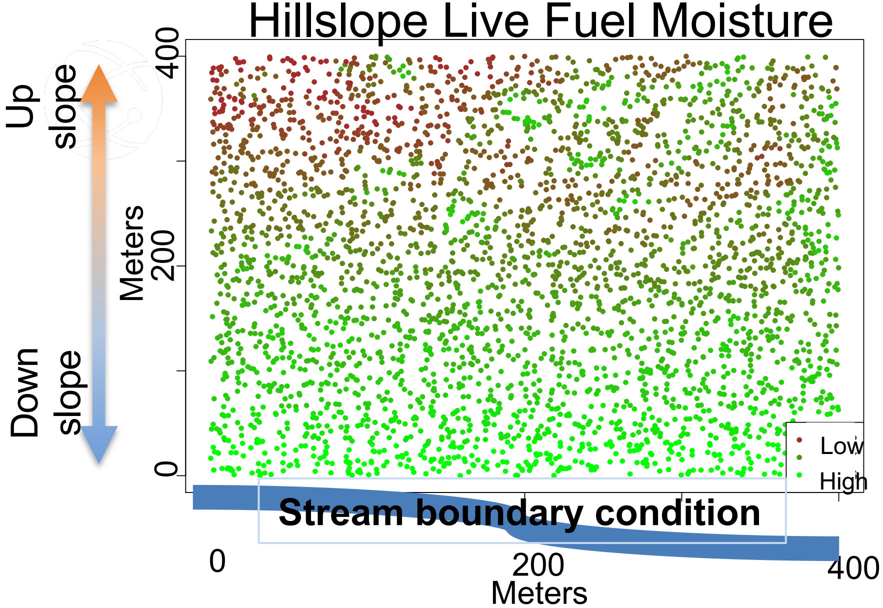
3D Forest Structure



Plant Physiology - Transpiration





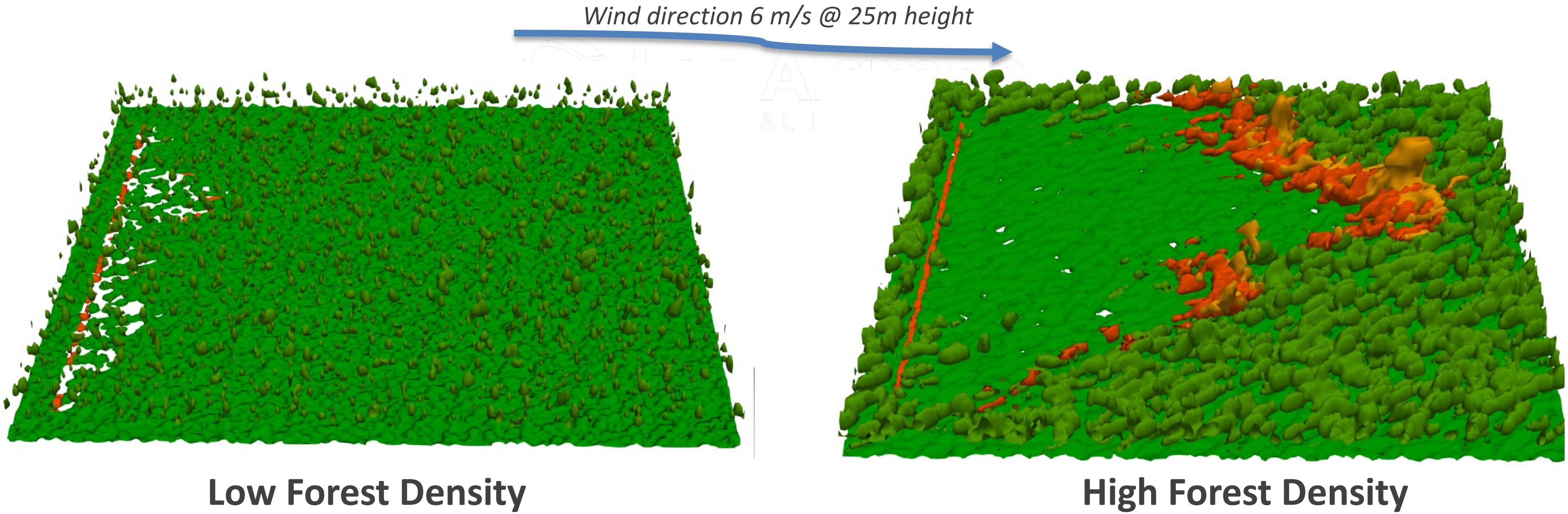


Caleb Adams
graduate Student (UT Austin)
DOE graduate Student Fellowship

Results: Compare Low Density Forest Fire to High Density Forest Fire

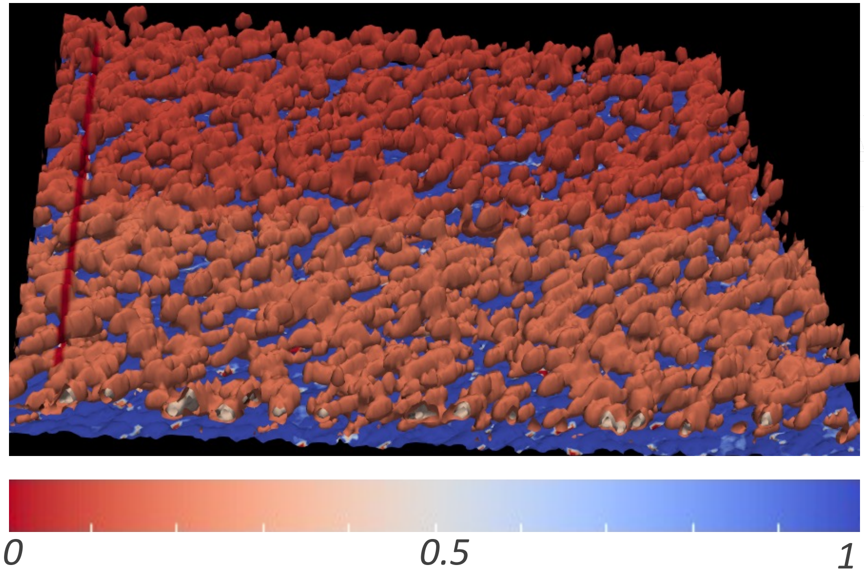
High density forest results in a canopy fire, where as low density forest results in low intensity surface fire.

Canopy fire is a result of 1) lower fuel moisture loading and 2) increased ‘ladder’ fuels.

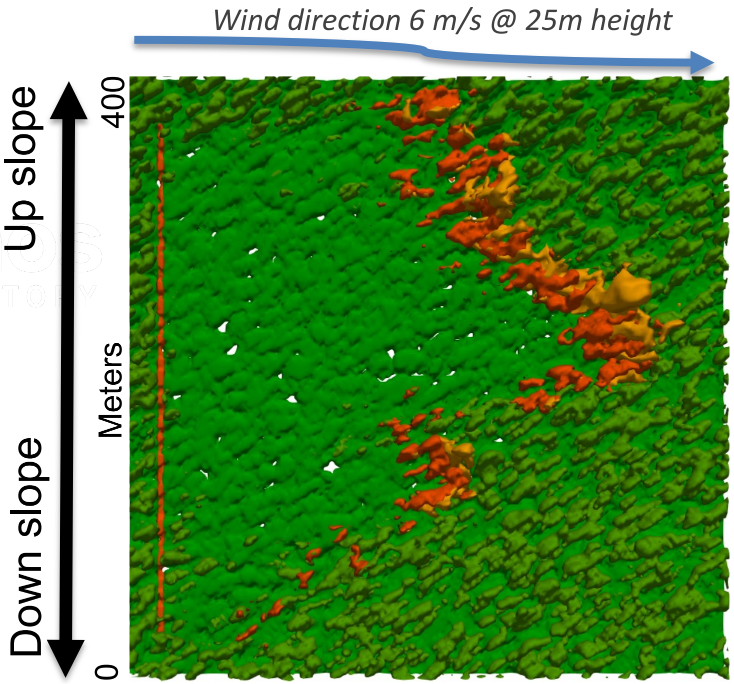


Results: Live Fuel Moisture Gradient Drives Fire Spread & Intensity

Fire moves up hill due to decreased fuel moisture loading (fire simulation neglected topography, but hydrological simulation accounted for topography).



High Forest Density Fuel Moisture Loading [-]



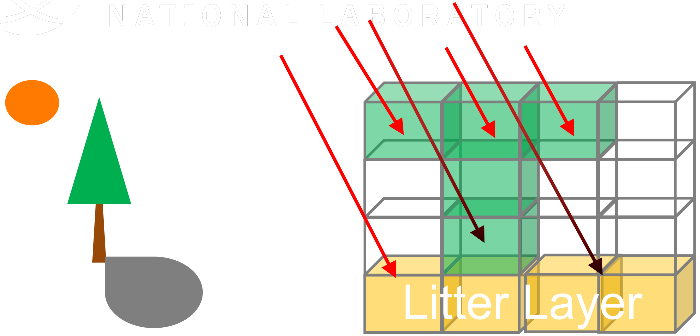
High Forest Density

Dead Fuel Moisture: Canopy Energy Balance Model

Solar heating exerts strong controls on fuel moisture loading in humid forests. ~ Kreye et al., 2018

Determined by weather and vegetation structure.

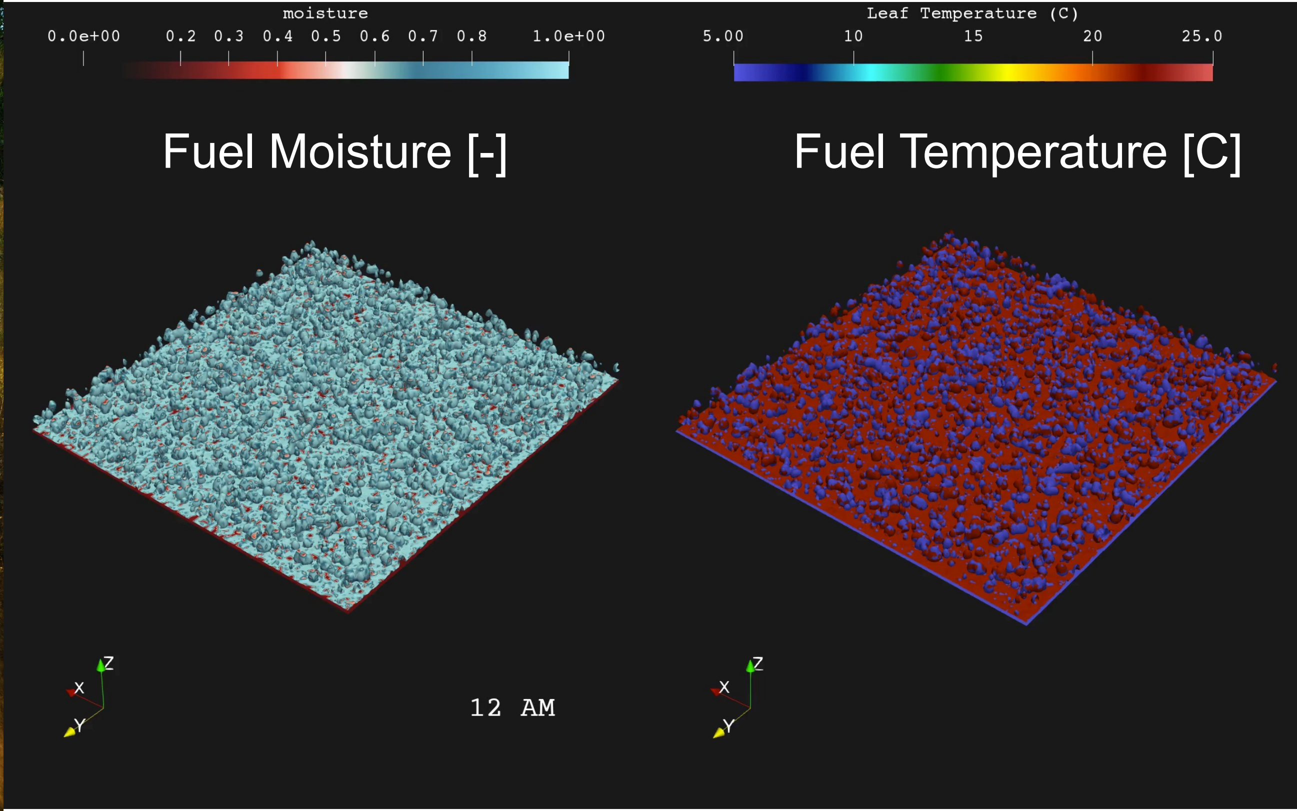
- Step 1) Find all locations in domain where fuel casts shade.
- Step 2) Sum all shade being cast on fuel for given time step.
- Step 3) Simulate surface energy balance for each cell with fuel using meteorological data.



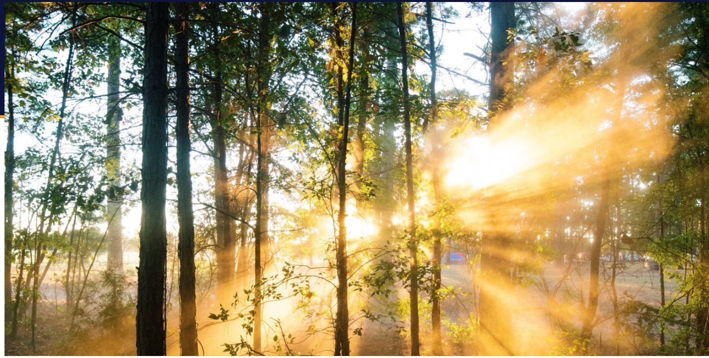
$$0 = (1-\alpha)Q^{ShortWave} + Q_{(Ts)}^{LongWaveNet} + Q_{(Ts)}^{LatentHeat} + Q_{(Ts)}^{SensibleHeat}$$

Evolving Fuel Moisture & Forest Structure

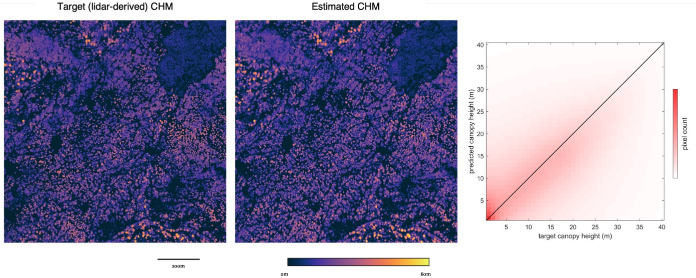
Dead Fuel Moisture

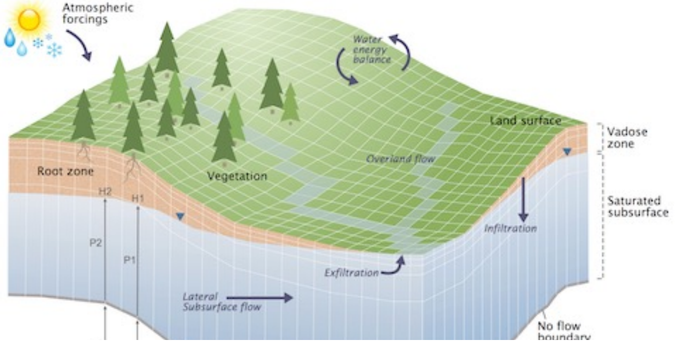


Optimizing 3D landscape forest structure to maximize hydrologic gains: A proactive approach to mitigate climate change on western landscapes



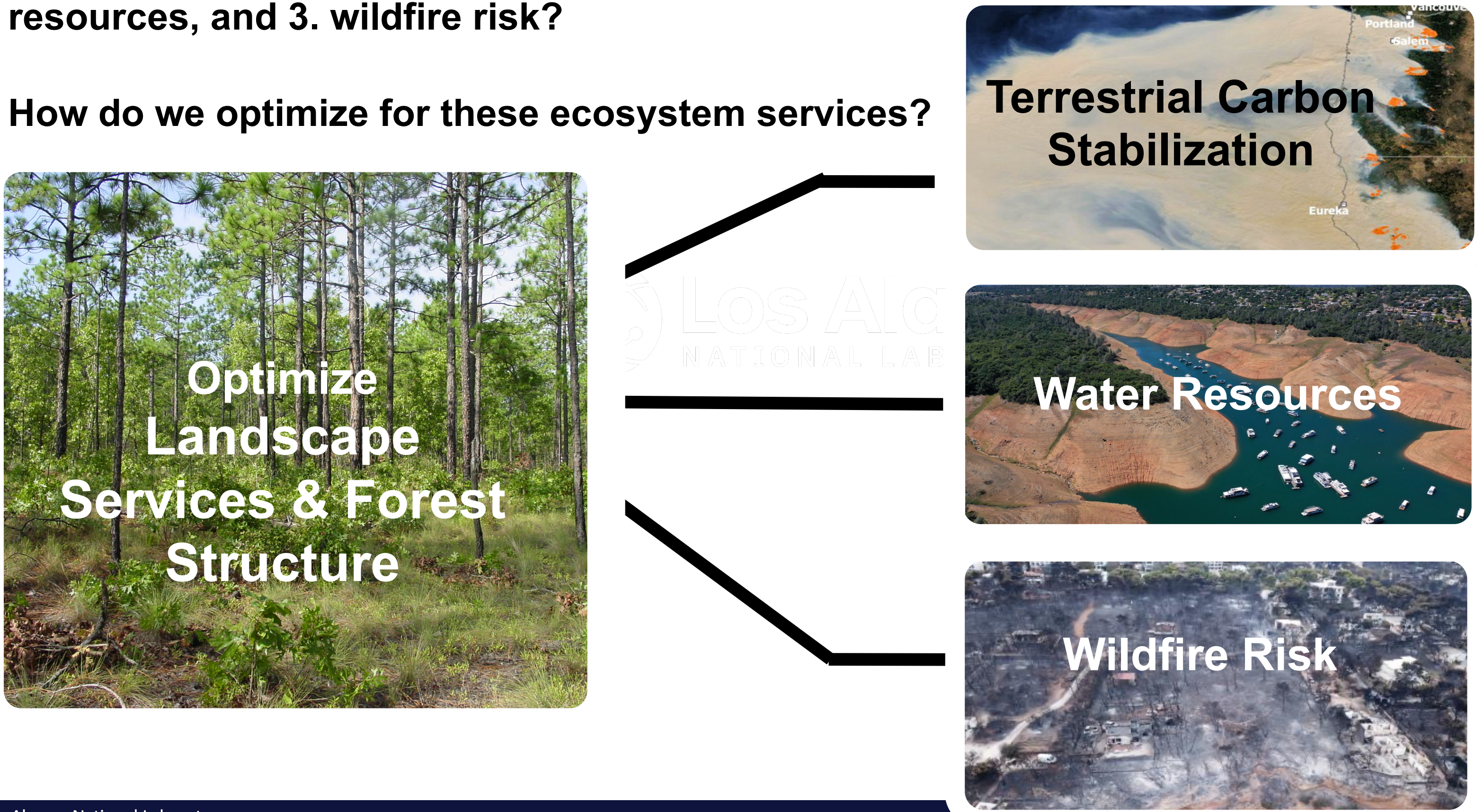
WoldView High-resolution Satellite imagery & Terrestrial lidar→ Forest characterization (Chuck Abolt)





Optimizing the Use of Prescribed Fire for Carbon, Water, & Fire Risk

- How does forest structure influence 1. ecosystem stability (carbon storage), 2. water resources, and 3. wildfire risk?
- How do we optimize for these ecosystem services?



Optimize Landscape Services & Forest Structure

Terrestrial Carbon Stabilization

Water Resources

Wildfire Risk