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Open access to the next generation of wildfire science and models for grid resiliency

California Energy Commission – Electric Program Investment Charge (EPIC): #EPC-18-026

David Saah, PhD, et al.

Principal Investigator
Professor, University of San Francisco
Managing Principal, Spatial Informatics Group

Presentation Agenda

Item	Presenter(s)
Solicitation Background & Project Overview (2:00pm)	David Stoms
Summary of Major Technical Tasks	David Saah, Shane Romsos
Workgroup Presentations (2:10pm) • Key Findings and Successes • Hurdles Encountered & Lessons Learned • Summary of Results & Conclusion • Moving Forward	• **Extreme Weather** (Janice Coen & Owen Doherty) • **Tree Mortality, Fuels, & Fire Physics (**John Battles) • **Near-term Fire Modeling and Forecasting** (Chris Lautenberger) • **Long-term Wildfire Projections (**LeRoy Westerling & Ben Sleeter)
Q & A / Discussion (3:10pm)	All
Adjourn (3:30pm)	

Grant Funding Opportunity GFO-18-301

GRANT FUNDING OPPORTUNITY

WILDFIRE: ASSESSING AND PREPARING FOR RISKS UNDER CLIMATE CHANGE

GFO-18-301

http://www.energy.ca.gov/contracts/index.html

State of California

California Energy Commission

December 2018

Goals of the GFO

- Advance wildfire science to support improved grid resilience
- Incorporate that new knowledge to develop and demonstrate advanced techniques and tools that can improve the assessment of risks to the electric infrastructure from wildfires now and with a changing climate
- Develop models and analytics that can feed directly into utility management and planning
- Conduct foundational research in anticipation of California’s Fifth Climate Change Assessment

Relationship of Research Topics/Phases

Phase I

1) Develop new information and knowledge about fire behavior in extreme weather
   a) Spatial optimization modeling for configuring weather station network
   b) Physical simulation of burning after tree mortality
   c) Analysis of historical fire behavior during extreme wind events

2) Develop computationally efficient fire spread models and analytics

3) Develop long-term wildfire scenario models (Fifth Assessment)

Phase II

Run or transfer wildfire spread models and analytics

Run long-term wildfire scenario models (Fifth Assessment)

Project Focus Areas

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Extreme Weather & Wildfire

Janice Coen

Focus

- Historical fire weather analysis
- Weather station optimization model & tool
- Pilot test of upper air profiler
- CAWFE model runs

Fuel Mapping & Fire Physics

Scott Stephens

Focus

- Small- and large-scale fire physics experiments
- Tree mortality mapping and fuels recruitment projections
- Fuels characterization and mapping

Wildfire Forecasting

Chris Lautenberger

Focus

- Develop models to provide near-term fire forecast at a fine scale
- Produce decision support tools
- Cost-benefit analysis

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Climate Change & Fire Projections

LeRoy Westerling

Focus

- Develop coupled statistical/dynamical fire-climate-vegetation models
- Concepts for decision support tools
- Support California's 5th climate change assessment

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Project Partners

Institutions from industry, academia, and government

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Extreme Weather and Fire

Workgroup 1

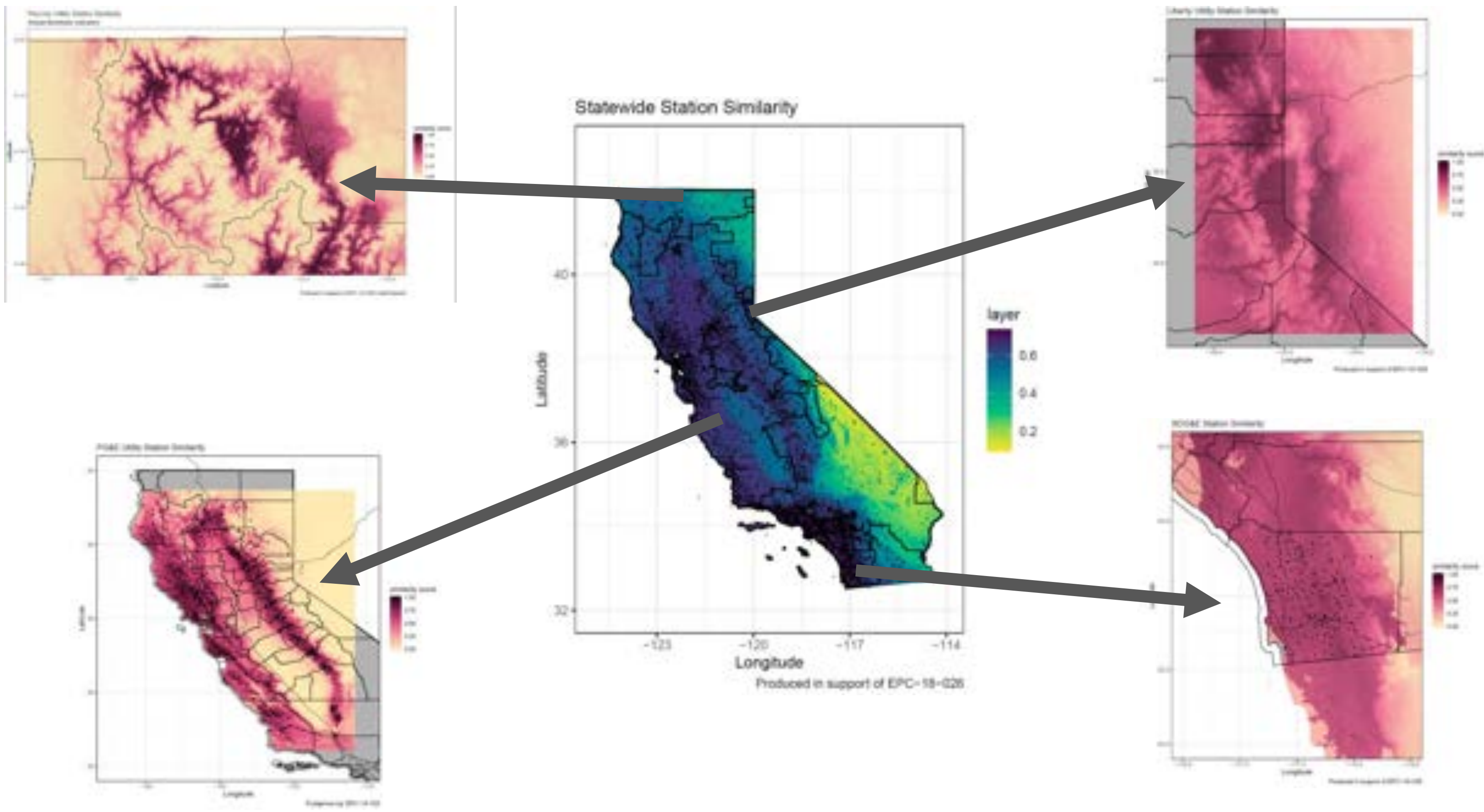
Janice Coen

Extreme Weather and Fire

Key Findings and Successes

Weather Station Optimization Framework Developed

- Applied machine learning (MaxEnt) to identify optimal locations for new weather monitoring stations.
- Produced statewide and utility-specific gap maps for improved monitoring coverage



Results/Conclusions:

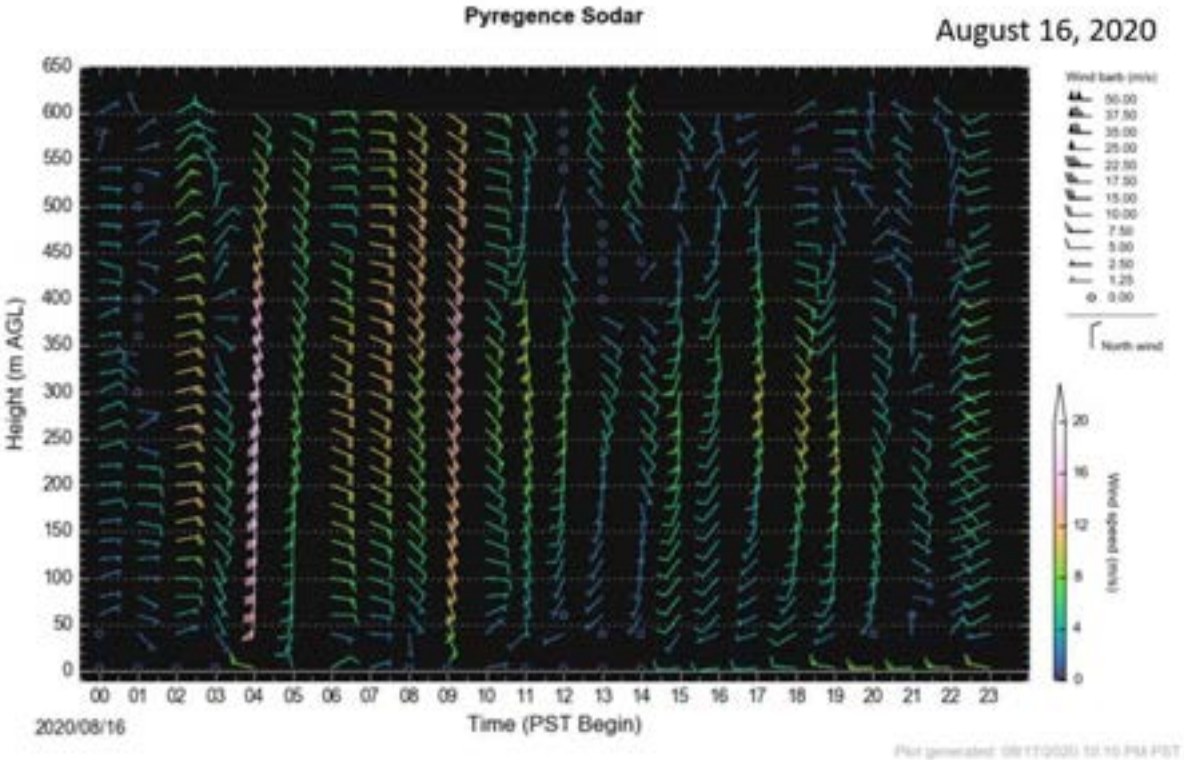
- Existing station network underrepresents critical fire weather conditions, especially in complex terrain
- MaxEnt modeling revealed high-priority locations for new stations

Extreme Weather and Fire

Key Findings and Successes

Upper-Air Profiler Pilot Successfully Demonstrated

- Deployed SODAR system captured winds from 80–650 m above ground
- Demonstrated improved short-term forecasting of extreme wind events
- Provided proof-of-concept for operational integration into fire weather systems
- Improved detection of extreme wind events critical to fire spread and PSPS decisions



Extreme Weather and Fire

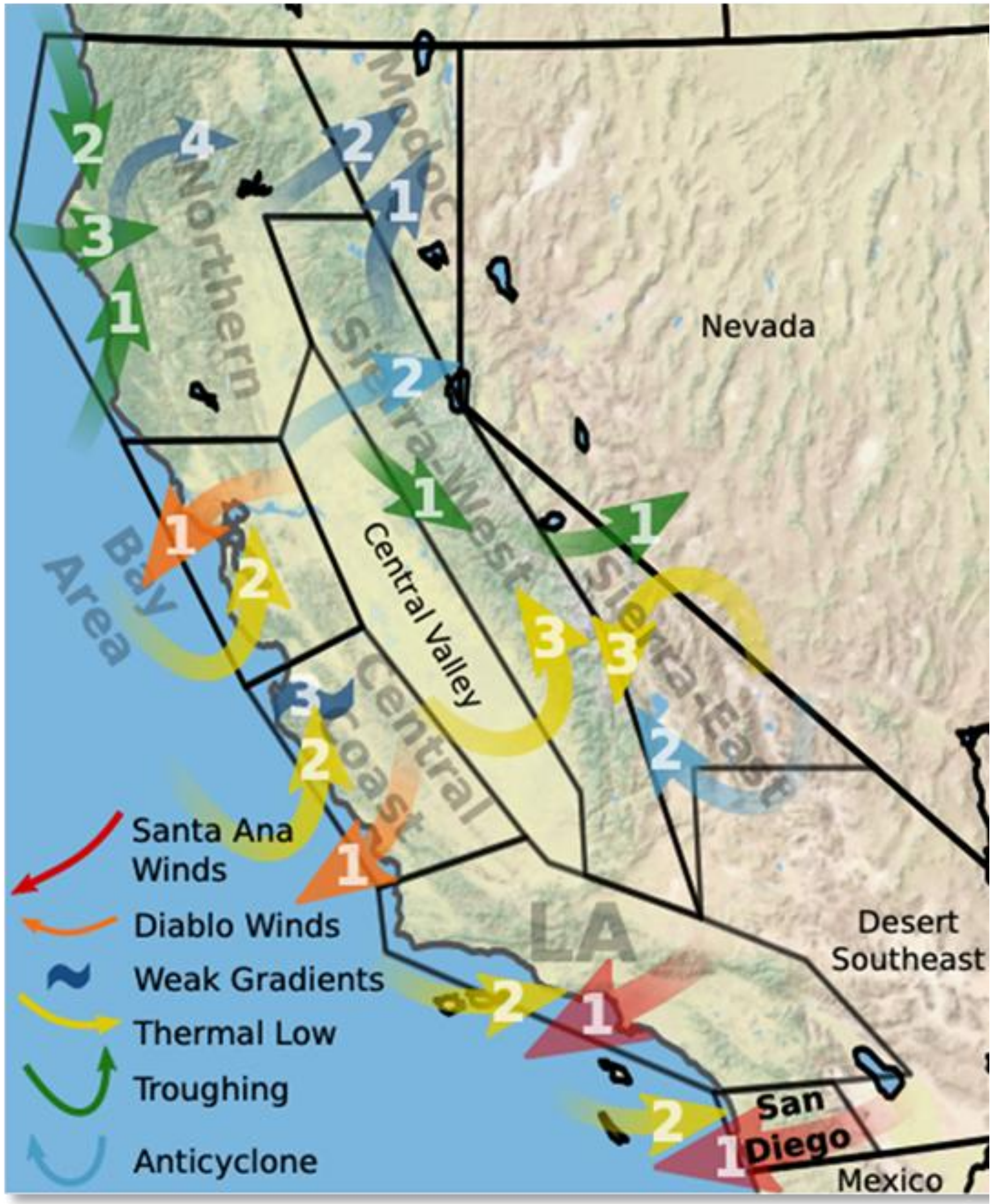
Key Findings and Successes

Established Fire Weather Typology for CA

- **Identified regional fire-weather archetypes**
  Historical reanalysis and satellite fire data were used to ID synoptic weather patterns associated with large daily fire growth

- **Quantified historical trends and future shifts**
  So. CA: Shift toward more frequent thermal lows, fewer So. CA wind events.

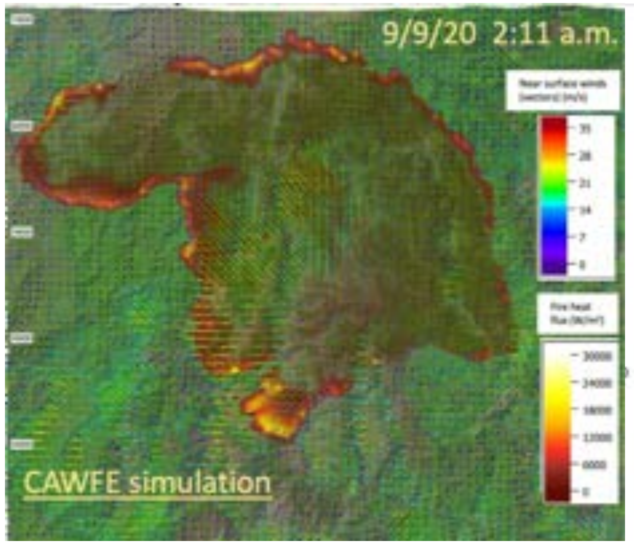
- **Linked weather patterns to fire-growth modes**
  Connected distinct atmospheric regimes with different fire behavior types, including wind-driven, plume-driven, and anomalous events.

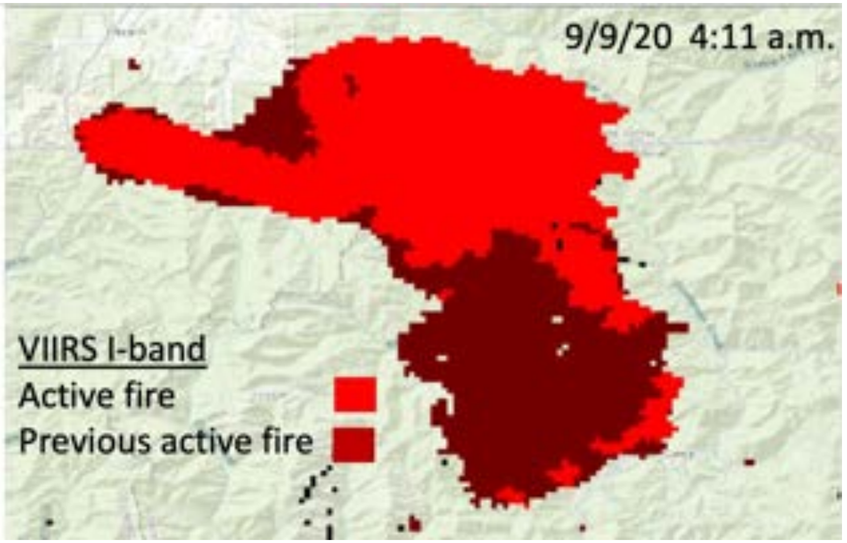


Weather types that drive extreme wildfire in different regions of California

Extreme Weather and Fire
Key Findings and Successes

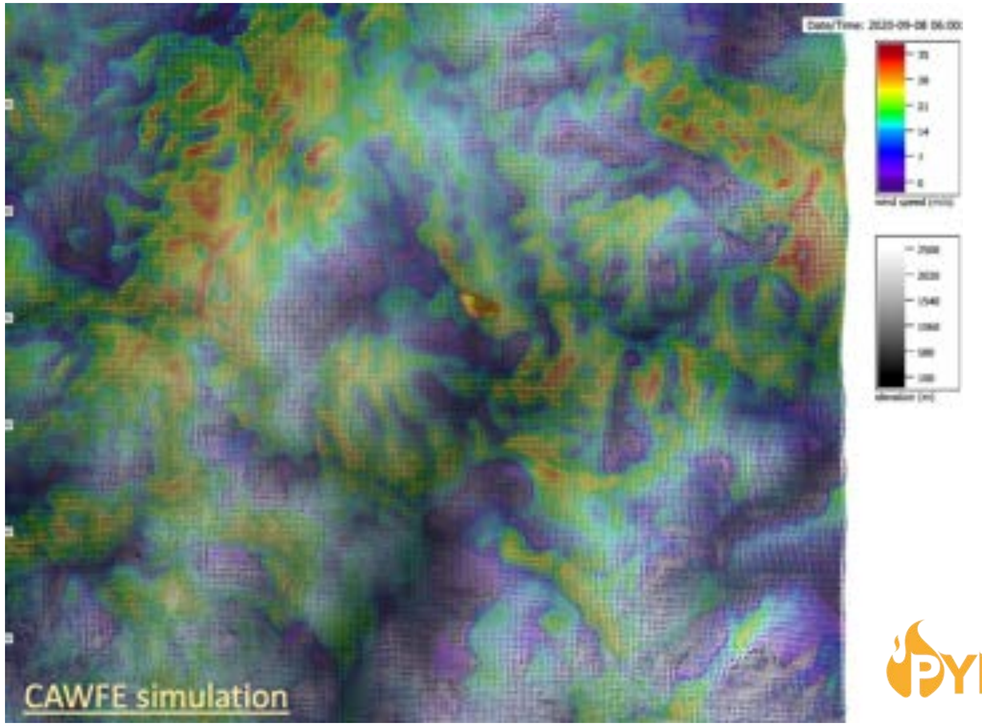
Slater Fire





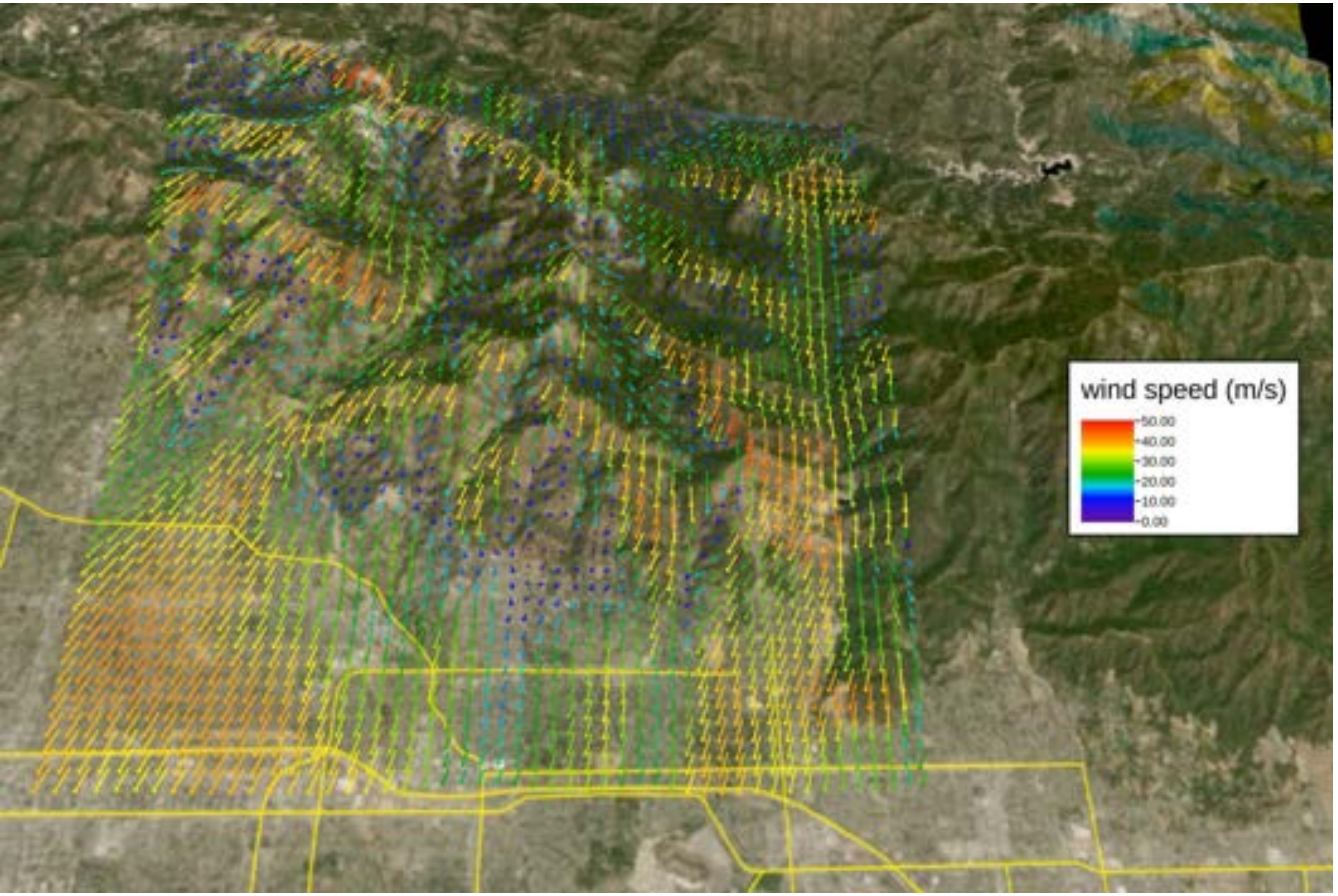
Coupled Weather-Fire Modeling
Applied CAWFE to 22+ historical fires, reproducing wind-, plume-driven, and anomalous events

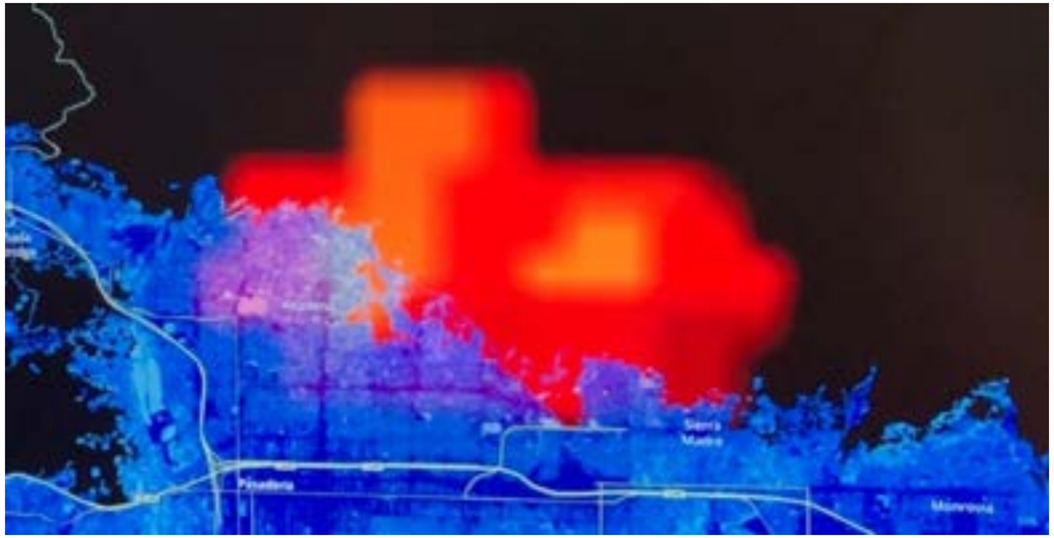
Established a two-scale framework for CA fire risk
The work *connects* large-scale weather-pattern analysis with fine-scale event modeling, avoiding the usual split between regional climate statistics and event-scale fire behavior.



Coupled Atmospheric Modeling (CAWFE)

Eaton Fire

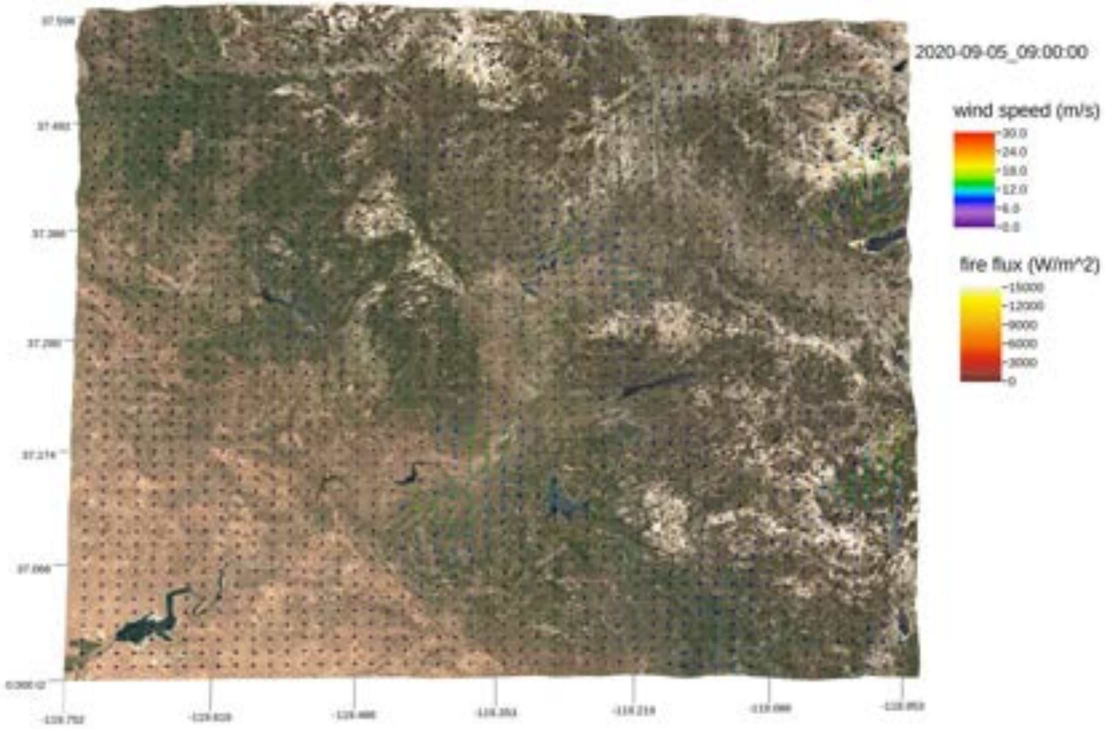




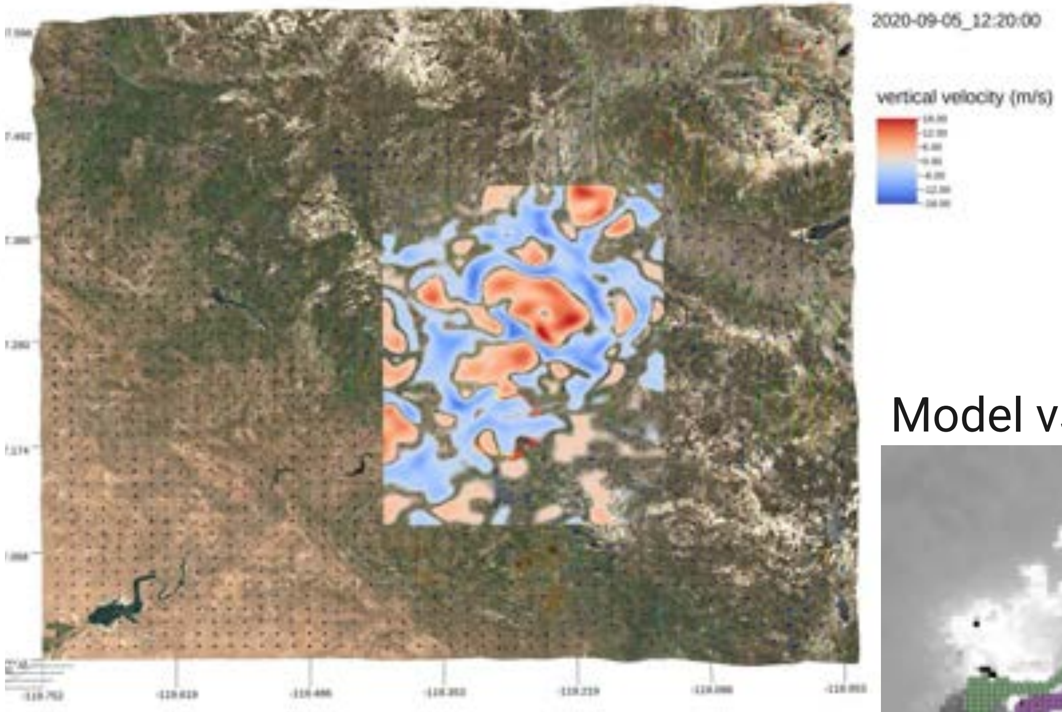
Hot: high peak wind speed
Cool: low peak wind speed

- NOAA non-specific forecast of high winds in mountains
- CAWFE: 40 m/s wind “hot spot” near ignition

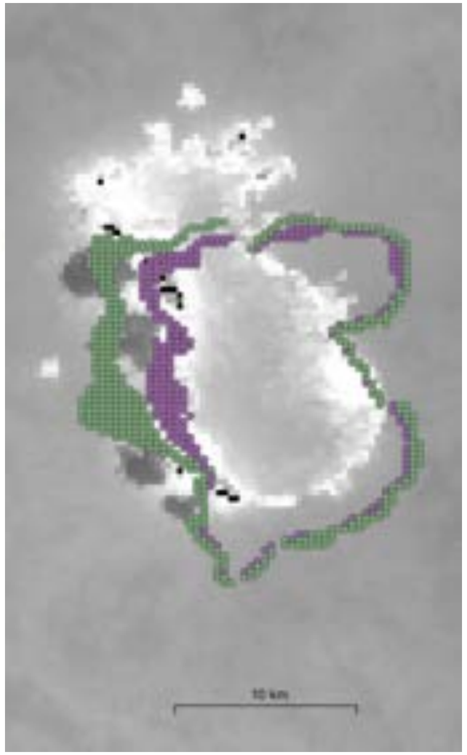
2020 Creek Fire



Vertical velocity at 3.2 km AGL



Model vs. VIIRS SWIR



- How did fuels, terrain, weak ambient winds, and fire–atmosphere feedbacks interact to produce the Creek Fire's rapid plume-dominated growth?
- Did mortality-related coarse woody debris increase horizontal spread and area, or instead intensify vertical plume organization and smoke transport?

Coen, J. L. and W. Schroeder. The 2020 Creek Fire: An Investigation into Understanding and Attribution of Fire Behavior. (in prep.)

Extreme Weather and Fire

Hurdles and Lessons Learned

Upper Air Profiler

- Noise interference impacted some observations during pilot deployment; a consideration for placement
- Surface observations alone miss key boundary-layer wind behavior that drives extreme fire spread

Advanced Coupled Modeling

- Wind extrema often lie between stations and are not resolved by mesoscale model grids
- Though more complex than ELMFIRE/GridFire, CAWFE has been operationalized and it appears possible to run in a situational awareness platform like PyreCast
- Provides more realistic fire behavior under both wind-driven and plume-driven conditions in CA's complex scenarios

Weather Monitoring Station Coverage

- Existing station networks underrepresent critical fire-weather conditions, especially in complex terrain and high-risk zones
- Gaps in capturing extreme winds, low humidity, and terrain-driven variability
- Strategic placement of stations using modeling (e.g., MaxEnt) or vertical profiles (vertical profiler) can improve hazard detection

Extreme Weather Types

- A small number of atmospheric patterns drive most extreme fire events (not all are extreme)
- Traditional fire weather indices bundle fire-favoring variables but do not flag the weather patterns in which extreme fire growth is realized

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Extreme Weather and Fire

Putting the weather-typing and case studies together….

A framework that links event-scale CAWFE case studies with California fire weather-type analysis to explain how extreme wildfire risk emerges across scales.

- Central point: ‘*Climate’ increases background wildfire susceptibility but extreme fire growth is realized only when susceptibility coincides with a short-lived, location-specific fire weather regime and an ignition.*

- This framework helps explain why warm, dry years do not always produce extreme burned area, while a small number of fires and rapid-growth days dominate wildfire impacts.

- For prediction and risk assessment, the key question becomes not only whether conditions are hotter or drier, but whether the relevant fire-weather regimes occur, persist, and align with vulnerable landscapes and ignitions.

- Points to new approach to improving short- and long-term fire risk assessment.

Coen, J. L., 2026, Climate Influences Wildfire Activity Through Opportunity: An Event-Scale Perspective. Fire, 9, 164. https://doi.org/10.3390/fire9040164.

Extreme Weather and Fire

Moving Forward

Weather Stations Optimization

- Develop cost-benefit frameworks for monitoring investments
- Consider expanding weather station network in identified gap areas where feasible

Extreme Weather Types

- Evaluate future shifts in fire weather regimes under CMIP6 scenarios
- Advance real-time detection of weather types for operational forecasting
- Improve linkages between synoptic patterns and local fire behavior

Upper Air Profiler

- Evaluate integration of surface + upper-air data streams into forecasting systems
- Consider deployment of upper-air profilers in high-risk regions
- Improve representation of boundary-layer winds in wildfire models

Advanced Coupled Modeling

- Expand use of coupled weather-fire models for extreme event prediction

Fuels, Tree Mortality, and Fire Physics

Workgroup 2
John Battles

State-wide Fuel and Tree Mortality Mapping
(Salo and Pyrologix)

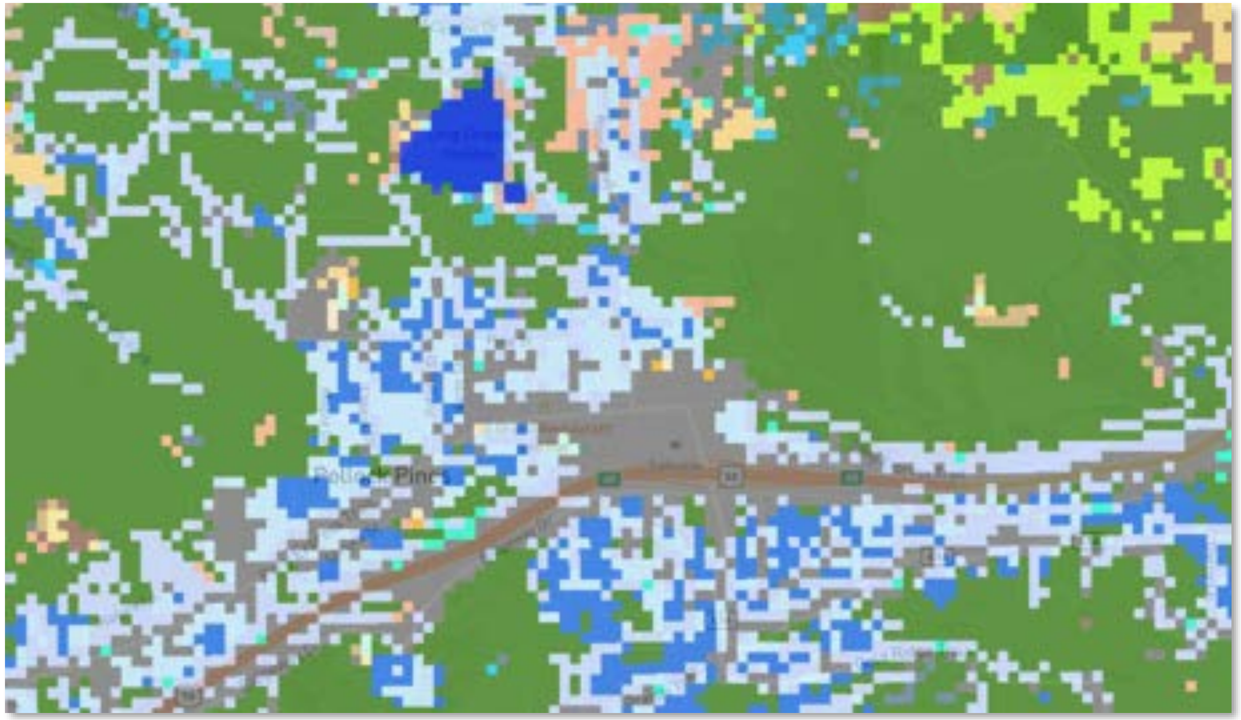
Mapped fine-scale fuel loads

- 10m and 30m resolution
- Annual: 2020-2022 (Salo and Pyrologix)
- High resolution fuels tested with near-term fire models (ELMFIRE)

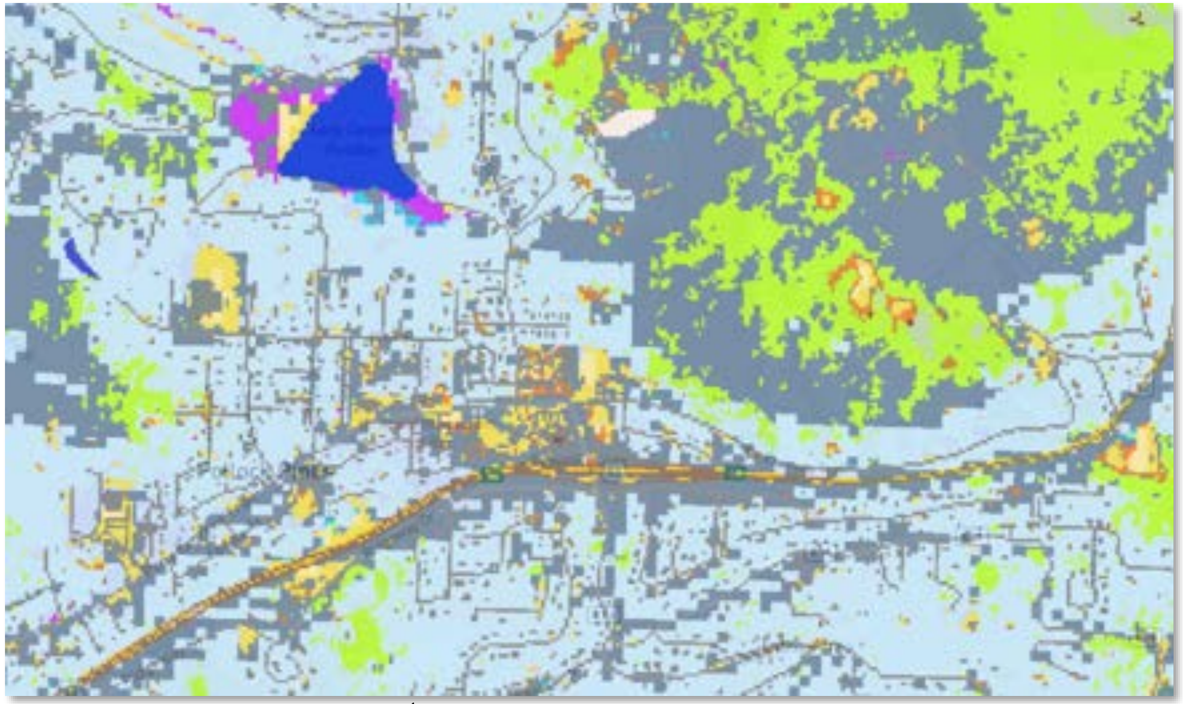
Mapped tree mortality using deep learning models and satellite data

- 30 m resolution
- Annual: 2016-2018
- Demonstrated workflow for map production

Fuel Mapping

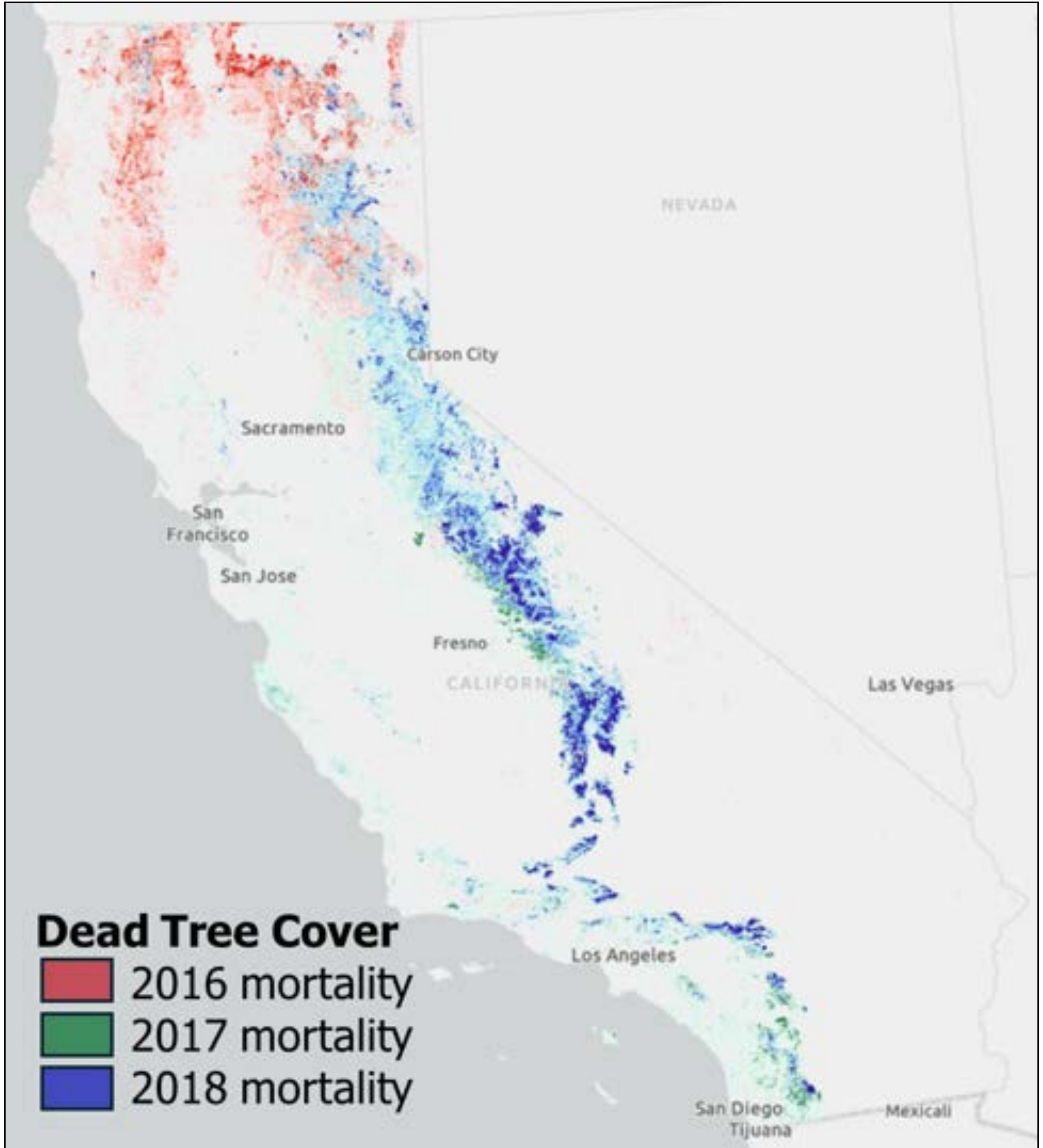


30 m Fuels Mapping (Pyrologix- Fuelscape 2022)



10 m Fuels Mapping (Salo Sciences – California Forest Observatory, 2020)

Tree Mortality Mapping



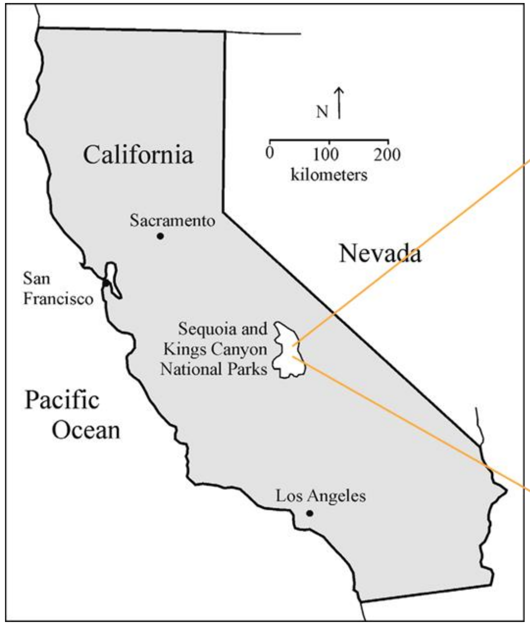
Fuel Characterization and Recruitment
(UC Berkeley)

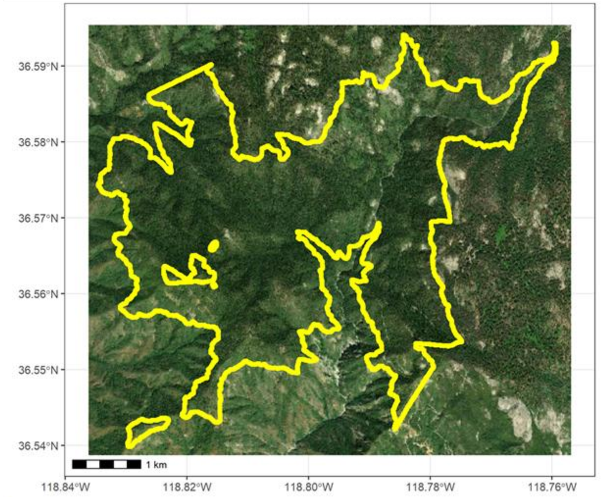
Fuels characterization

- Developed high-resolution, spatially explicit fuel measurement protocols
- Modelled real-world fuel heterogeneity
- Generate realistic fuel beds for modeling

Fuel recruitment

- Measured downed wood recruitment (snag fall rates)
- Modelled fuel demography
- Project fuel load recruitment rates





USGS

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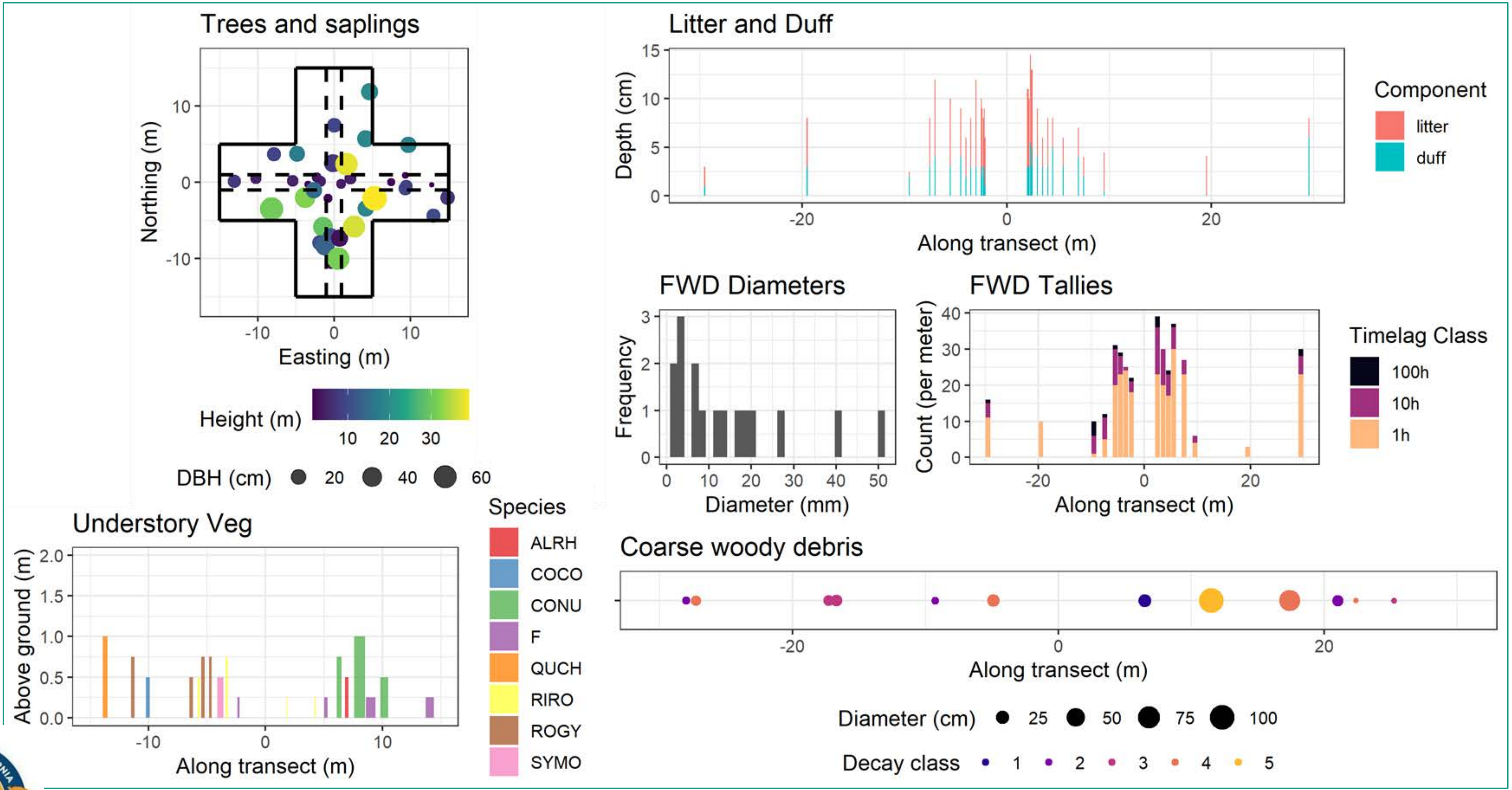
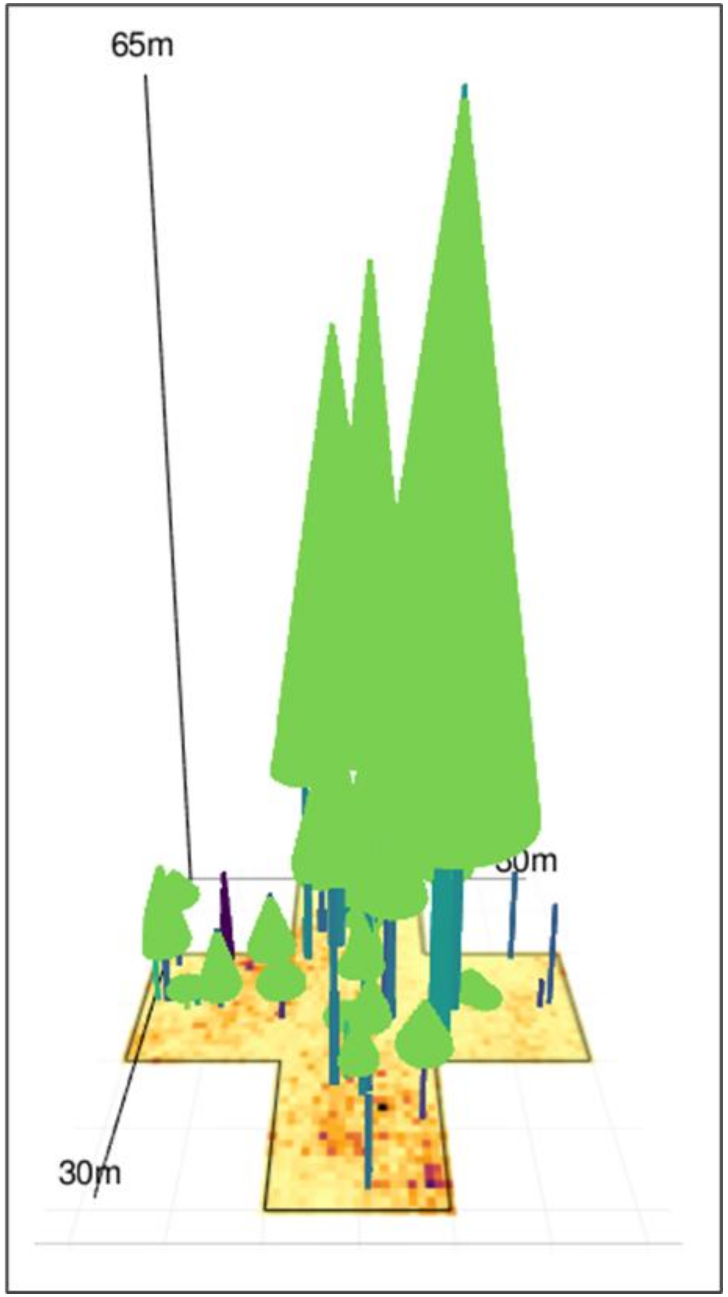
Fuel Measurement Protocol



Modeled Real-world Fuel Map

Fuel Component	Statistical Analysis
Litter, duff, and fuelbed depth	Gaussian process modelling
Fine woody debris loading	Gaussian process modelling
Fine woody debris particle sizes	GLM
Trees and seedlings	Point pattern statistics + voxelization
Understory vegetation	TBD (Binomial GP model)
Coarse woody debris	TBD (GP coarse, point pattern fine)



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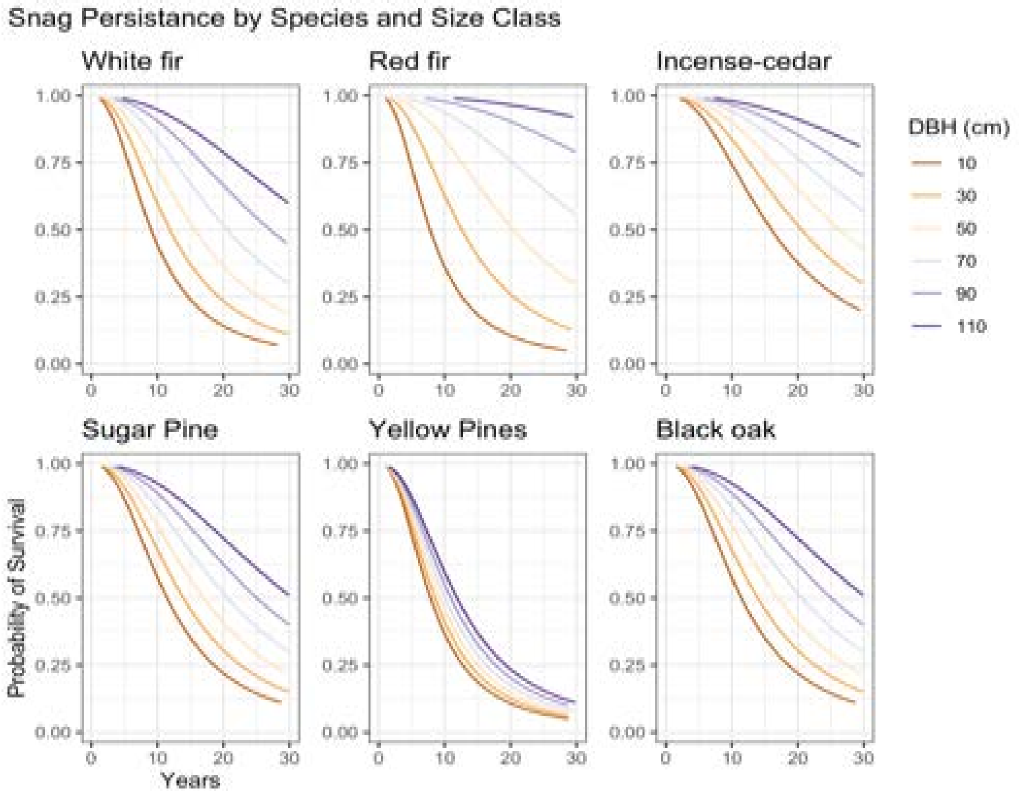
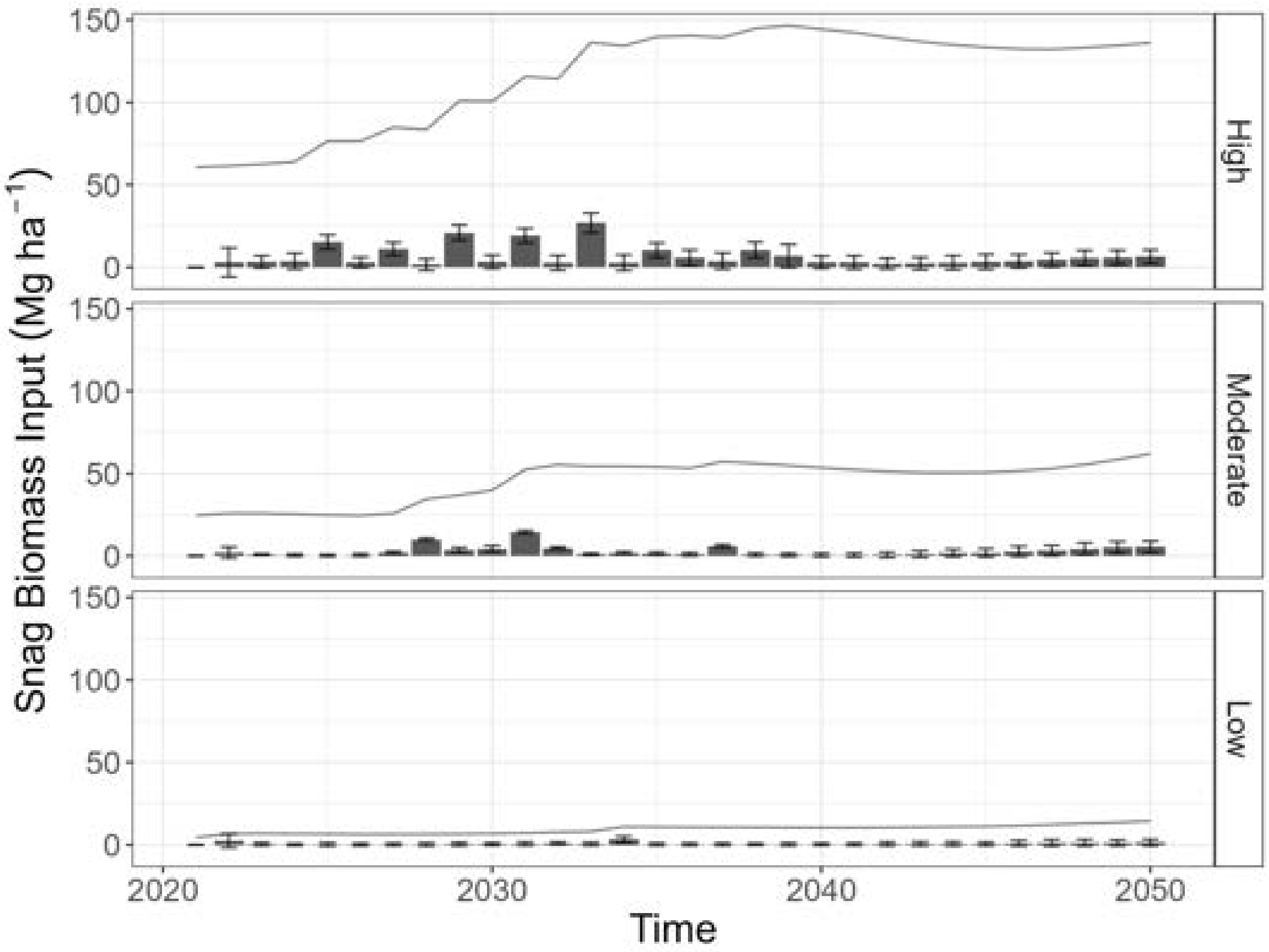
Fuel Recruitment

Dead wood input = snag fall rate



Fuel accumulation as a function of tree mortality



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Fire Physics

Conducted small- and large-scale burn experiments

- Measured heat release rates, mass loss, O_2 consumption, CO, CO_2 and $PM_{2.5}$ emissions
- Smoldering vs. flaming transitions captured

Built a large-scale combustion facility to simulate real-world wildfire fuel conditions

Developed initial physically based combustion models capturing

- Wood to char transitions
- Wind-driving heat flux effects

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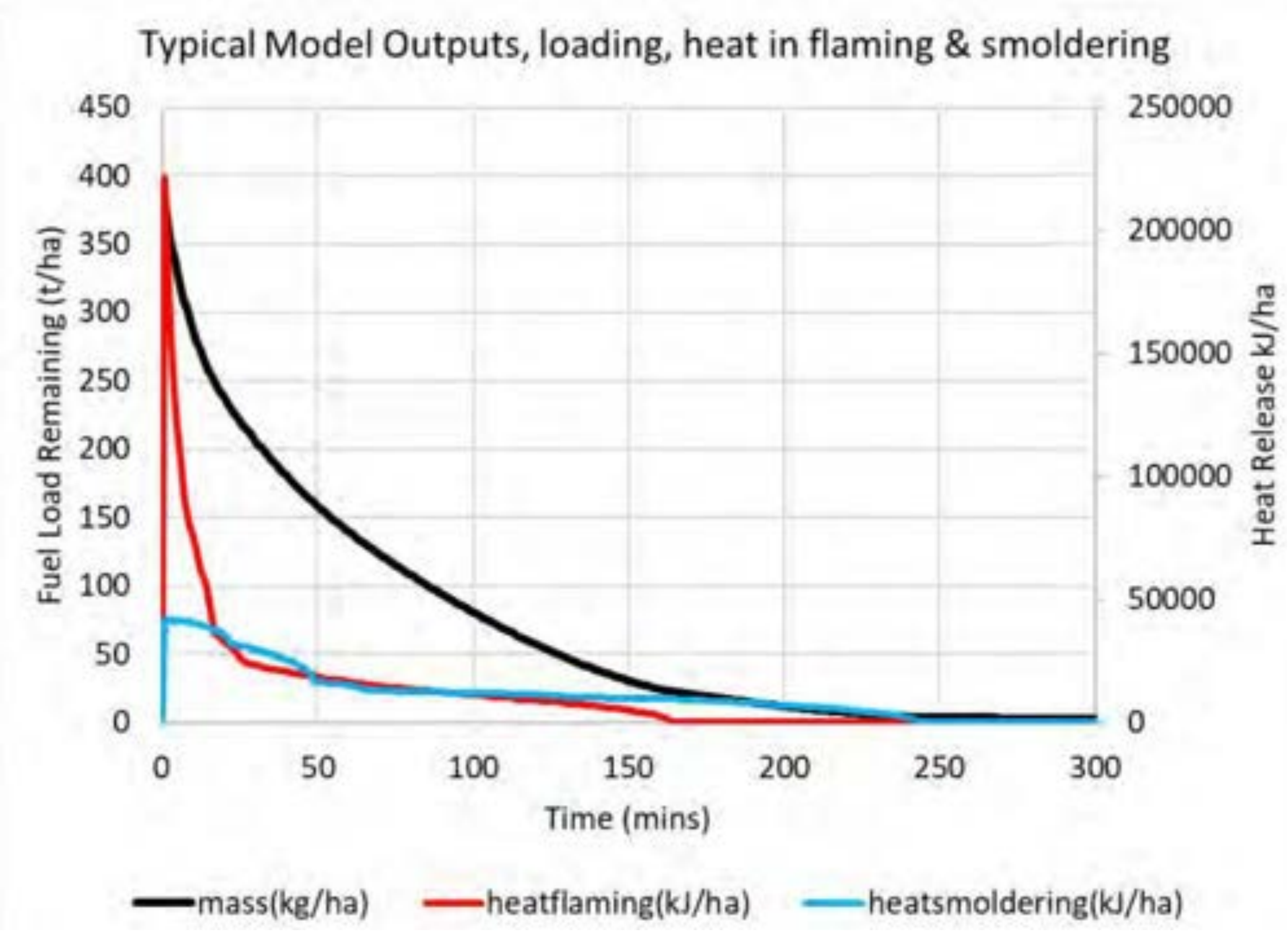
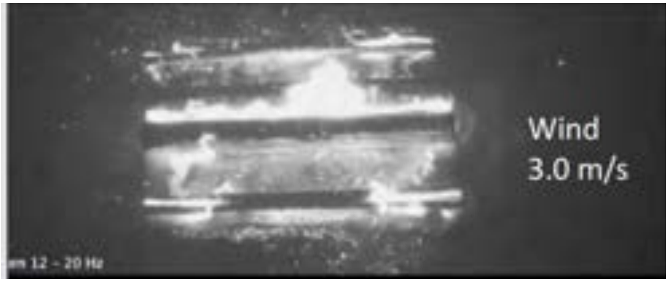
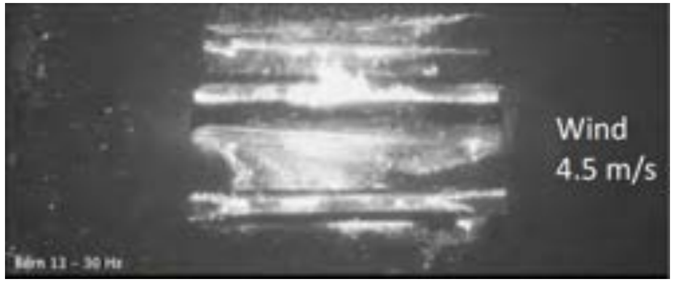
Large-scale Burn Experiments







Emissions Increase

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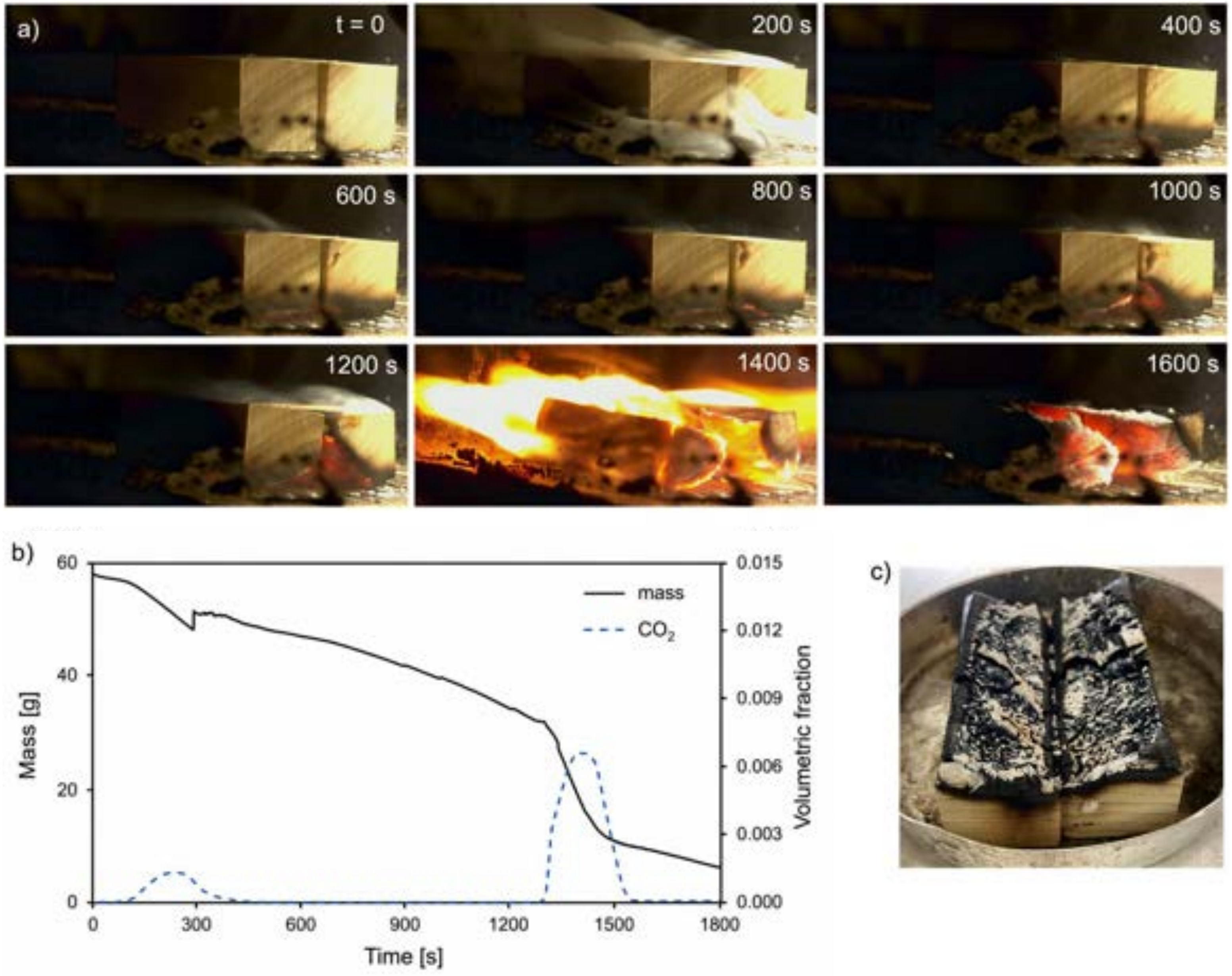
Small Scale Burn Experiments



Challenges and Lessons Learned

Challenges

- Legacy models miss large fuels & long-duration combustion
- Smoldering behavior poorly understood/represented in models
- Fuel heterogeneity not captured by current systems
- Measurement/data limitations (PM, heat flux, large fuels)
- Uncertain fuel accumulation from tree mortality
- Gap between research outputs and operational models

Lessons Learned

- Large fuels + duff should be explicitly modeled
- Smoldering is critical to fire persistence & emissions
- Fuel spatial pattern ≠ average fuel load
- Tree mortality drives long-term fire hazard
- Need physics-based, time-evolving fire models
- Modernized modeling required for extreme fire prediction

Summary

Results

- Remote sensing + deep learning methods improve tree mortality detection (Salo).
- Fuels are highly heterogeneous at fine spatial scales, testing assumptions of uniform fuel loads (Foster).
- Tree mortality is driving long-term increases in hazardous surface fuels (Northrup).
- Current fire behavior models underrepresent large-fuel combustion and long-duration heat release (Stephens et al.)
- Fire physics is non-linear and ventilation-driven, requiring new physically based modeling approaches (Finney, Fire Lab)

Conclusion

- Wildfire models must explicitly represent fuels and fire physics to accurately predict fire behavior and support grid resilience planning

Moving Forward

Operationalize Tree Mortality & Fuels Datasets

- Integrate datasets into near- and long-term fire models
- Build models to help better integrate fine-scale spatial heterogeneity of fuels

Expand Fuel Load Forecasting & Succession Modeling

- Extend projections to capture statewide-scale increases in surface fuels

Expand Laboratory & Field Experiments

- Capture wider fuel types, size and species; broader moisture and wind conditions

Integrate Fire Physics into Operational Models

- Incorporate large-fuel combustion, smoldering, and long-duration heat release into fire behavior models.
- Move beyond thin flame-front assumptions to represent mass fire dynamics

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Near-Term Wildfire Forecasting

Workgroup 3
Chris Lautenberger

Near-term Wildfire Forecasting:

Capabilities

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- A web-based near-term wildfire forecasting platform based on open-source models, science, and datasets
- Supports operational decision-making for utilities and risk managers

Tools

- **Active Fire Forecasts** - Forecasts spread of current wildfires (up to 14-day forecast horizon, refreshed every ~12 hours)
- **Fire Weather Forecasts** - Up to 16-day outlook for key wildfire-driving weather indices (9 forecast models, updated every 6 hours)
- **Risk/Consequence/Hazard Forecasts** - Models millions of simulated fire ignitions (to/from grid) to identify hazards and vulnerabilities (5-day forecast horizon, refreshed daily)
- **Fuels Viewer** - Allows viewing of current and historical fuels data and other landscape data

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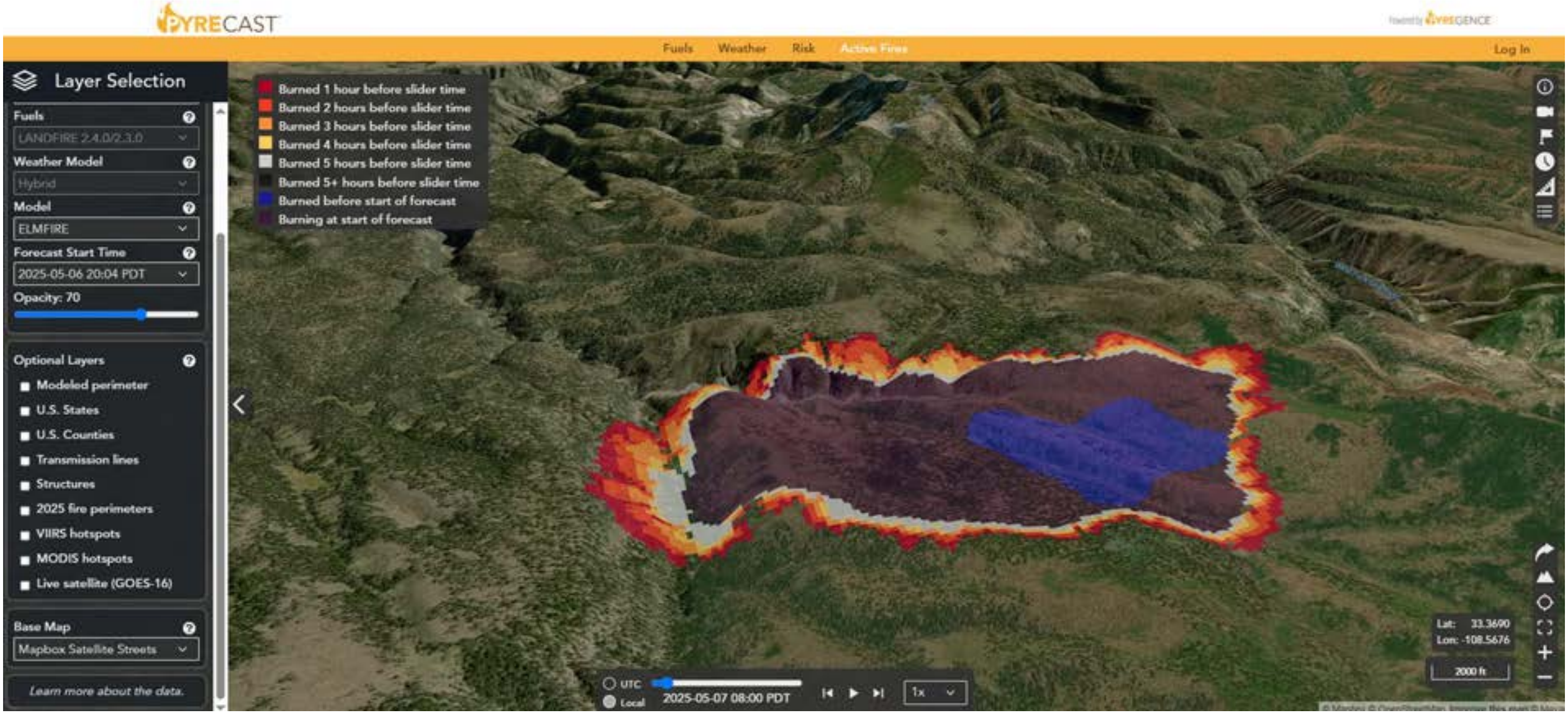
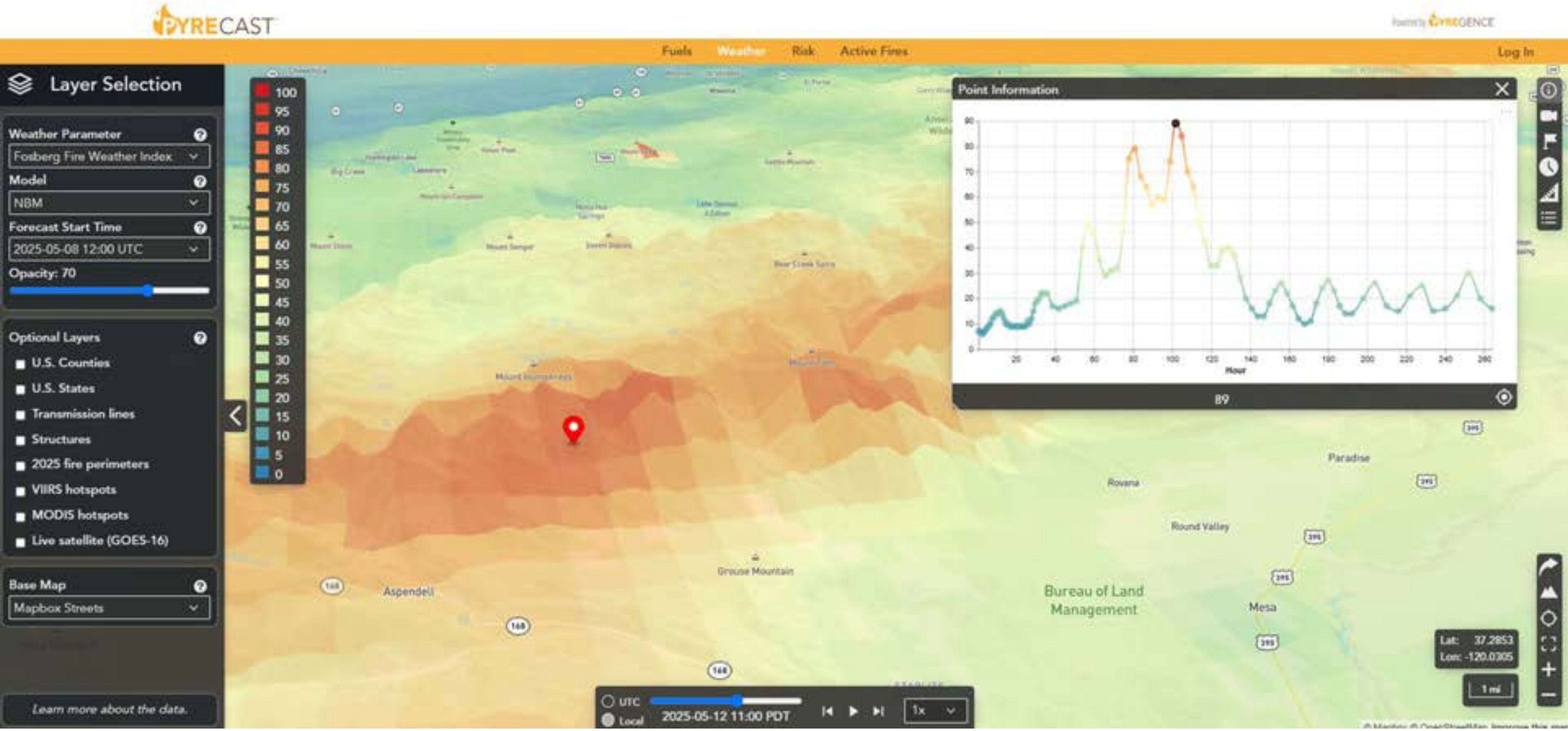
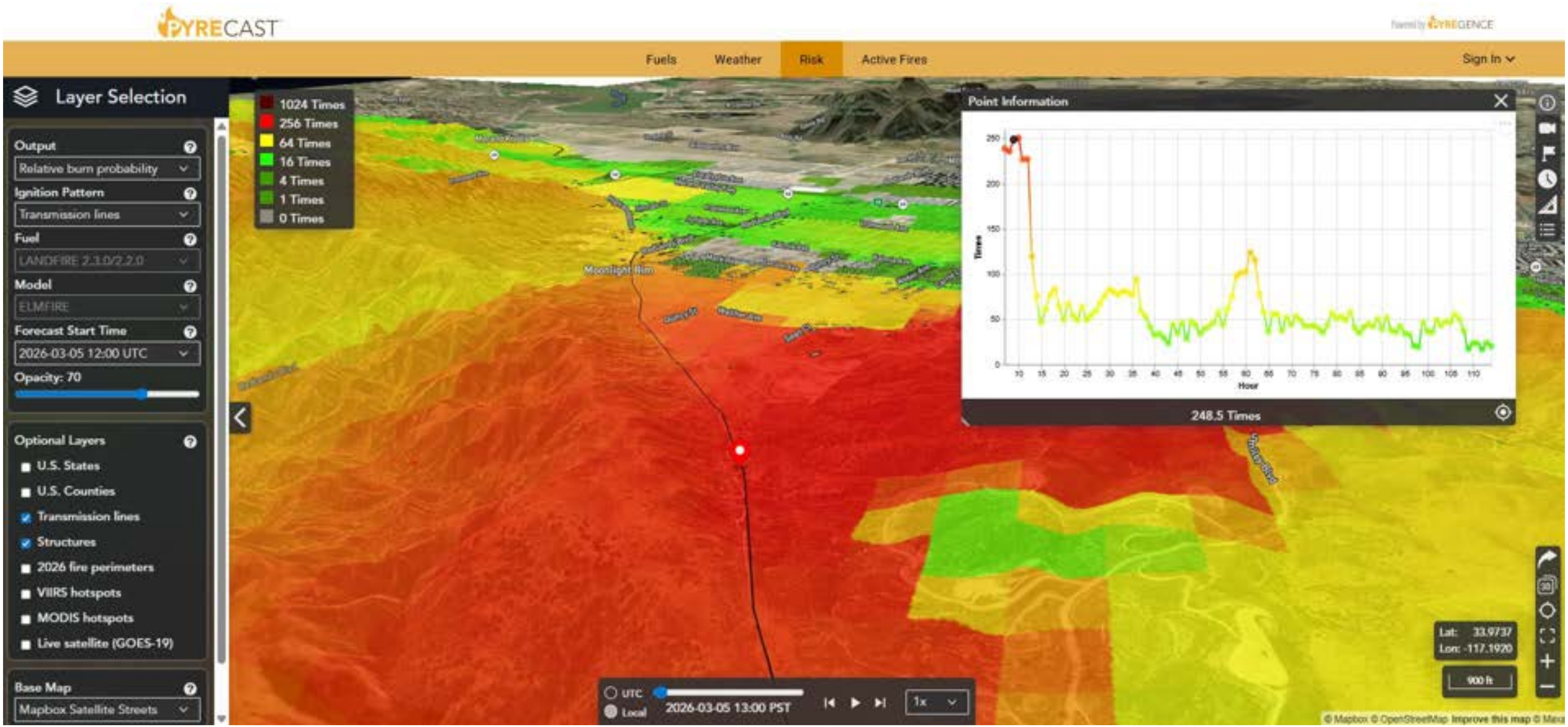
ACTIVE FIRE FORECAST TOOL (fire progression)



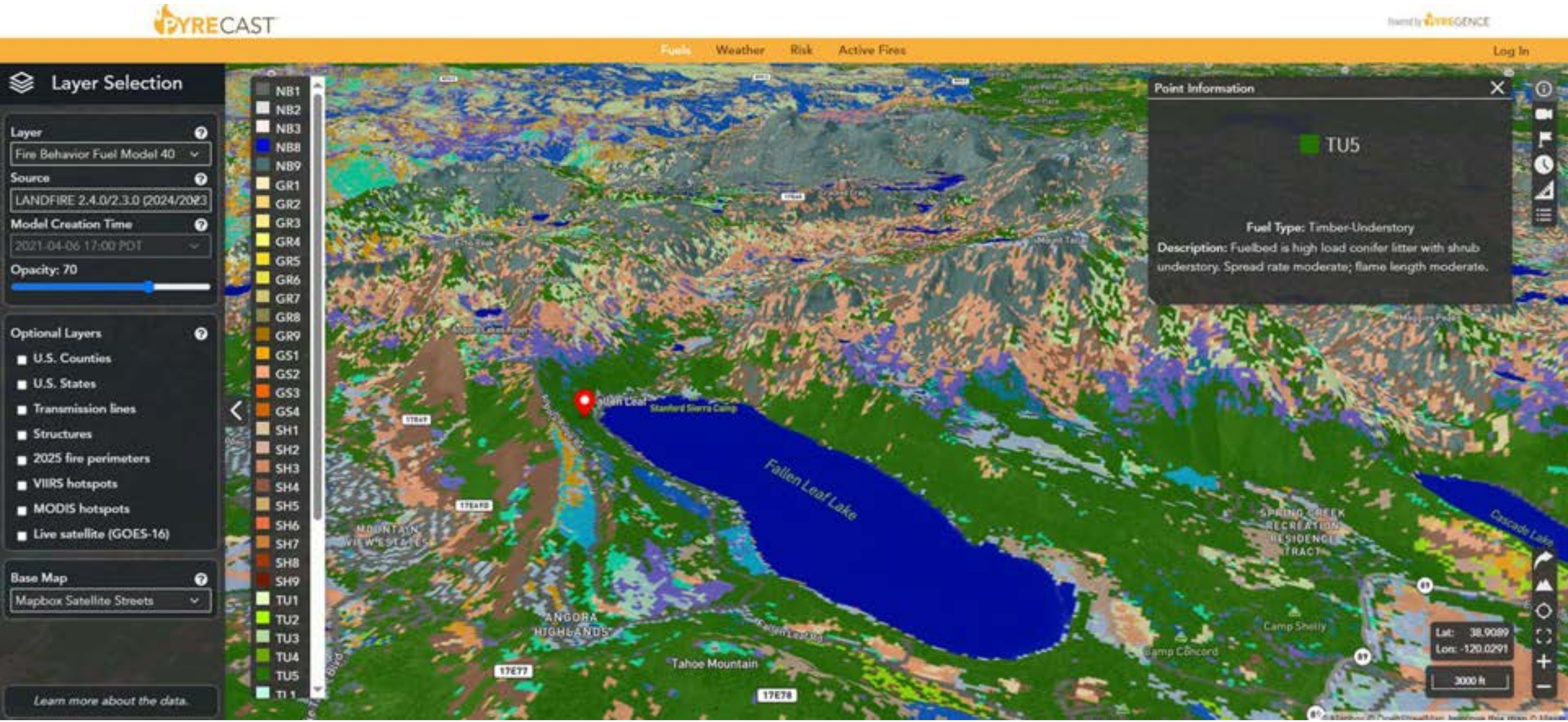
WEATHER FORECAST TOOL (Fosberg fire weather index)



RISK FORECAST TOOL (burn probability, overhead line ignitions)



FUELS VIEWER



Near-term Wildfire Forecasting Models

Key Findings and Successes

- Publicly available fire spread forecasting platform
- Can perform high-resolution (10m to 30m) near-term forecasts
- Strong model performance for wind-driven fires
- Demonstrated utility cost-saving potential
- Open access model code and data outputs

Near-term Wildfire Forecasting Models

Hurdles and Lessons Learned

Hurdles

- Fire initialization errors from satellite data
- Suppression not represented in models
- Challenges modeling post-rain fire rekindling
- High computational demand during peak season or with high-resolution inputs

Lessons Learned

- Forecast accuracy depends on input data quality
- Wind-driven fires more predictable than plume-driven
- Ensemble modeling improves reliability (worst vs best case)

Near-term Wildfire Forecasting Models

Summary of Results and Conclusions

Results

- Majority of active fire forecasts rated ‘acceptable’ or better
- Capable of continuous forecasting across multiple fires
- Platform improved through iterative updates throughout the project
- Used by utilities and agencies

Conclusions

- Near-term forecasting is operationally viable
- Improves situational awareness and decision-making
- Supports grid resilience and public safety
- Limitations remain in extreme fire modeling (e.g., mass fire and plume events)

Near-term Wildfire Forecasting Models

Moving Forward

Fire Behavior Models

- WUI Fire Spread (Cloudfire, UC Berkeley – Gollner Lab)
- Pyretechnics model integration, suppression algorithm (EPIC - SIG)
- Operationalize CAWFE model and use cases (SBIR, EPIC – Coen, SIG)
- Methods for near real-time performance benchmarking (EPIC – UC Irvine)
- ‘RAPID-FIRE’ ML-based model development (EPIC - LLNL)
- ELMFIRE reconfiguration for Canadian fuels system (Cloudfire)

Inputs

- High-resolution fuels data (EPIC - Planet Labs)
- Remotely sensing methods for forecasting surface/canopy fuel moisture (EPIC - Planet Labs)
- Real-time initial ignition locations (Watch Duty partnership)
- AI downscaled weather forecast (SIG)

Outputs

- Animated probabilistic fire spread forecasts (SBIR)
- Suppressed fire perimeter forecasts (SIG/Cloudfire)
- Season fire weather forecasts (EPIC-AIRI)
- National Fire Danger Rating System indices (Cloudfire)
- Smoke forecasts (Cloudfire)

Long-Term Projections

Workgroup 4
LeRoy Westerling

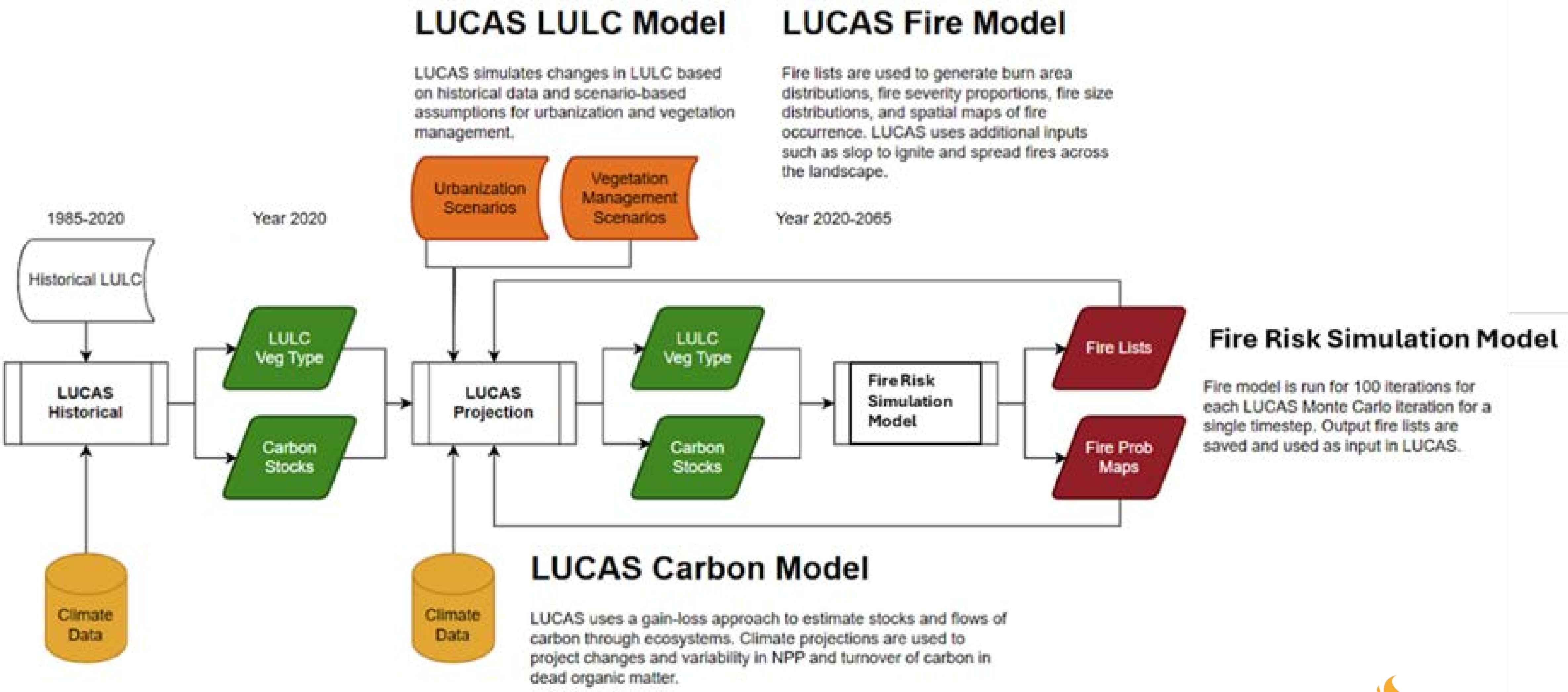
Long-term Projections

Key Findings and Successes

- Integrated multi-model wildfire-climate-vegetation framework
- Supports long-term grid resilience and climate adaptation
- Coupled LUCAS–FRSM and LANDIS-II models
- Scenario-based projections in forested landscapes (LANDIS-II) and across California (LUCAS/FRSM)
- Multi-scenario projections (climate, urban growth, vegetation management)
- Consistent trends across independent coupled models
- Machine learning improves ignition and burn probability modeling (Hawbaker)

Long-term Projections

LUCAS/FRSM Framework



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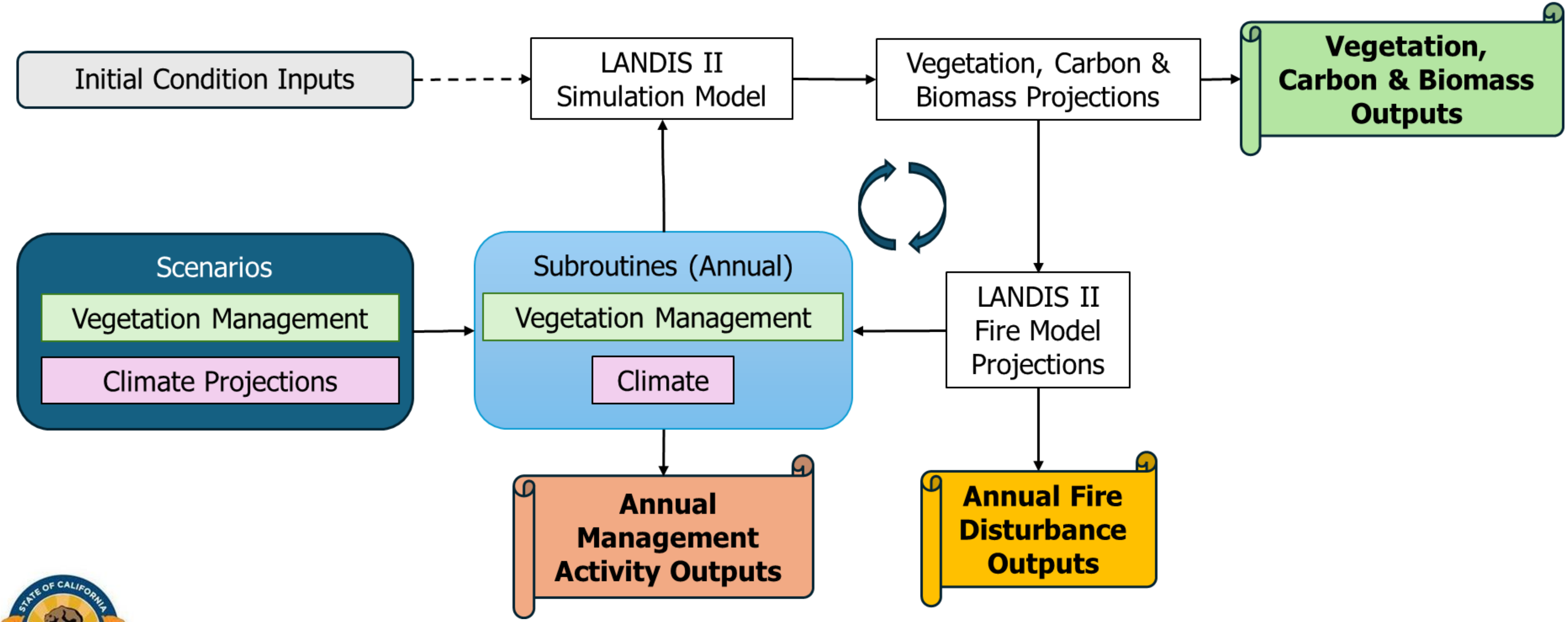
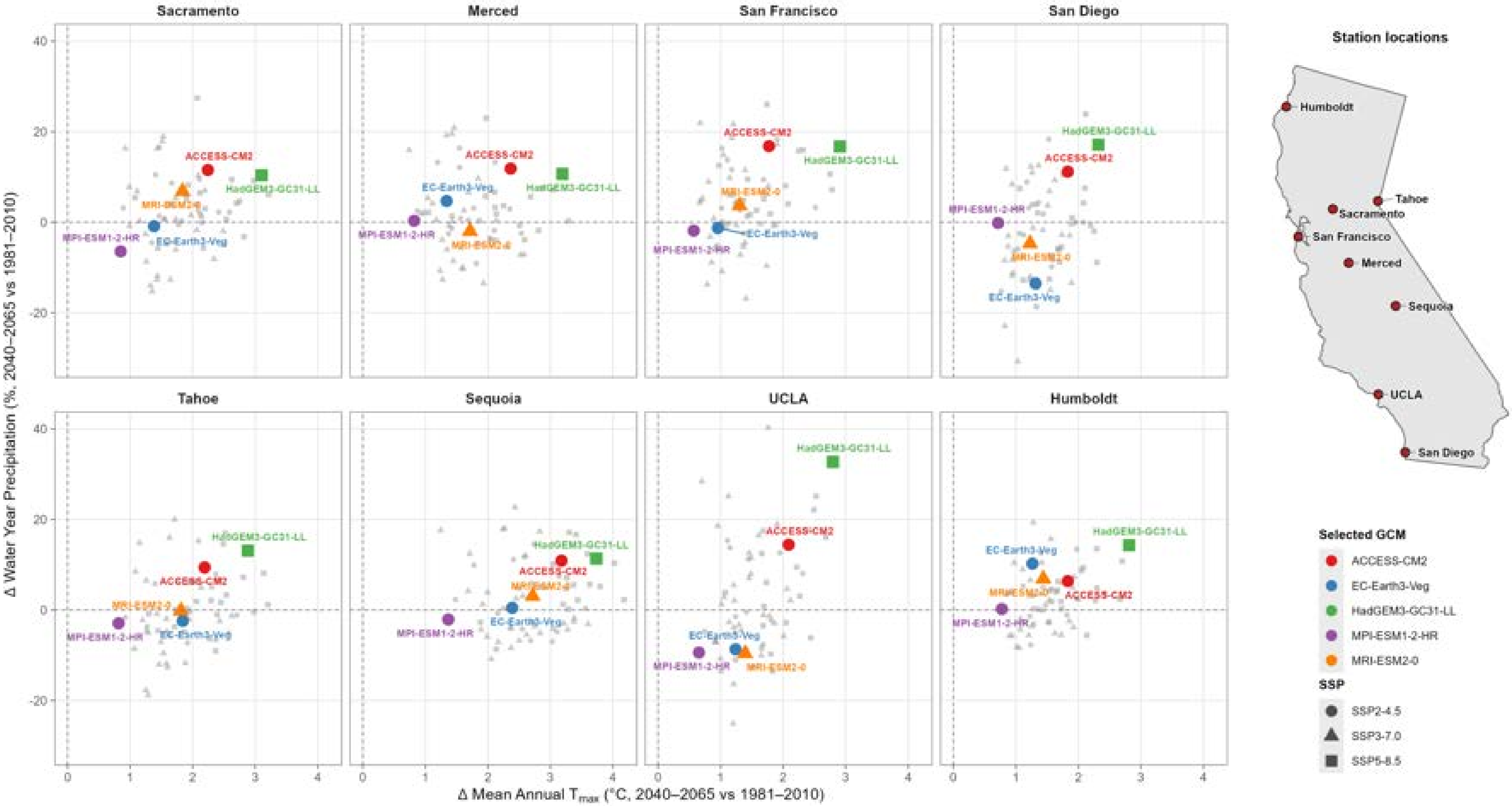
Long-term Projections

Simplified LANDIS-II Framework

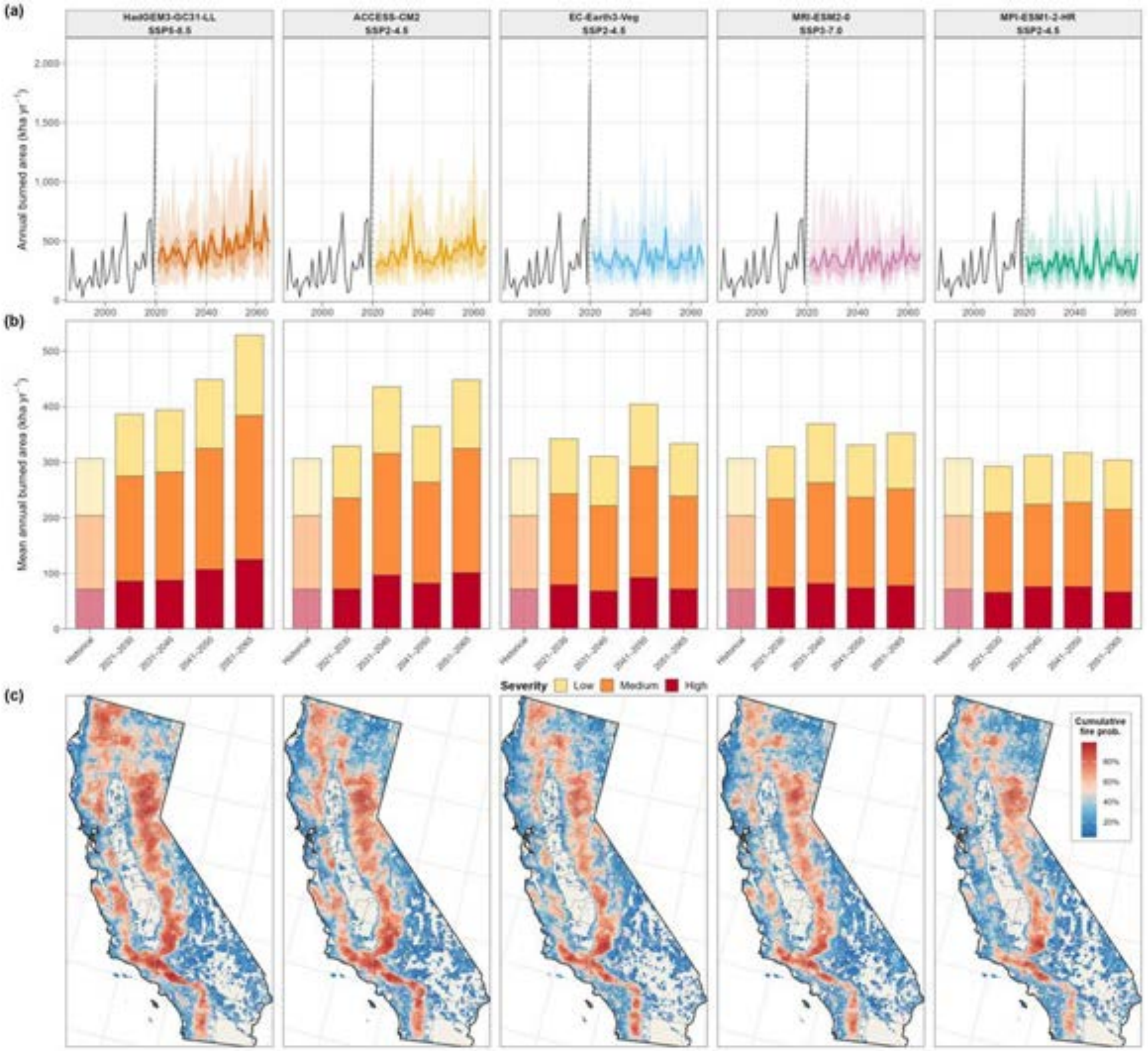


Long-term Projections: Climate Scenarios



Long-term Projections: Example LUCAS/FRSM Results (Sleeter et al., forthcoming)

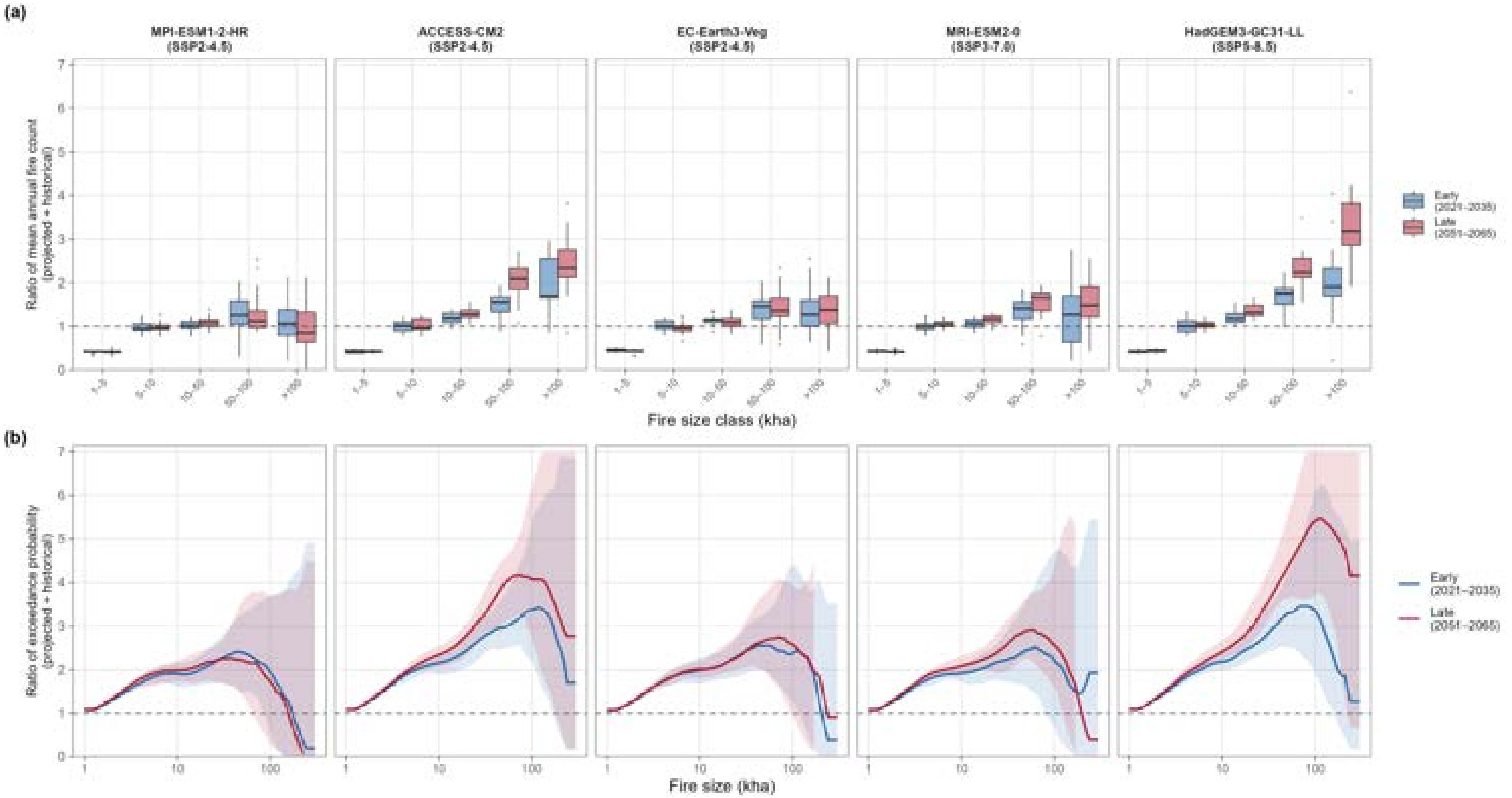
(a) Annual burned area time series by GCM
(b) Mean annual burned area by fire severity class and decade for each GCM
(c) Cumulative fire probability (2021–2065) per GCM



Long-term Projections – Example LUCAS/FRSM Results (Sleeter et al., forthcoming)

2021–2035 & 2036 – 2065 vs historical through 2020:

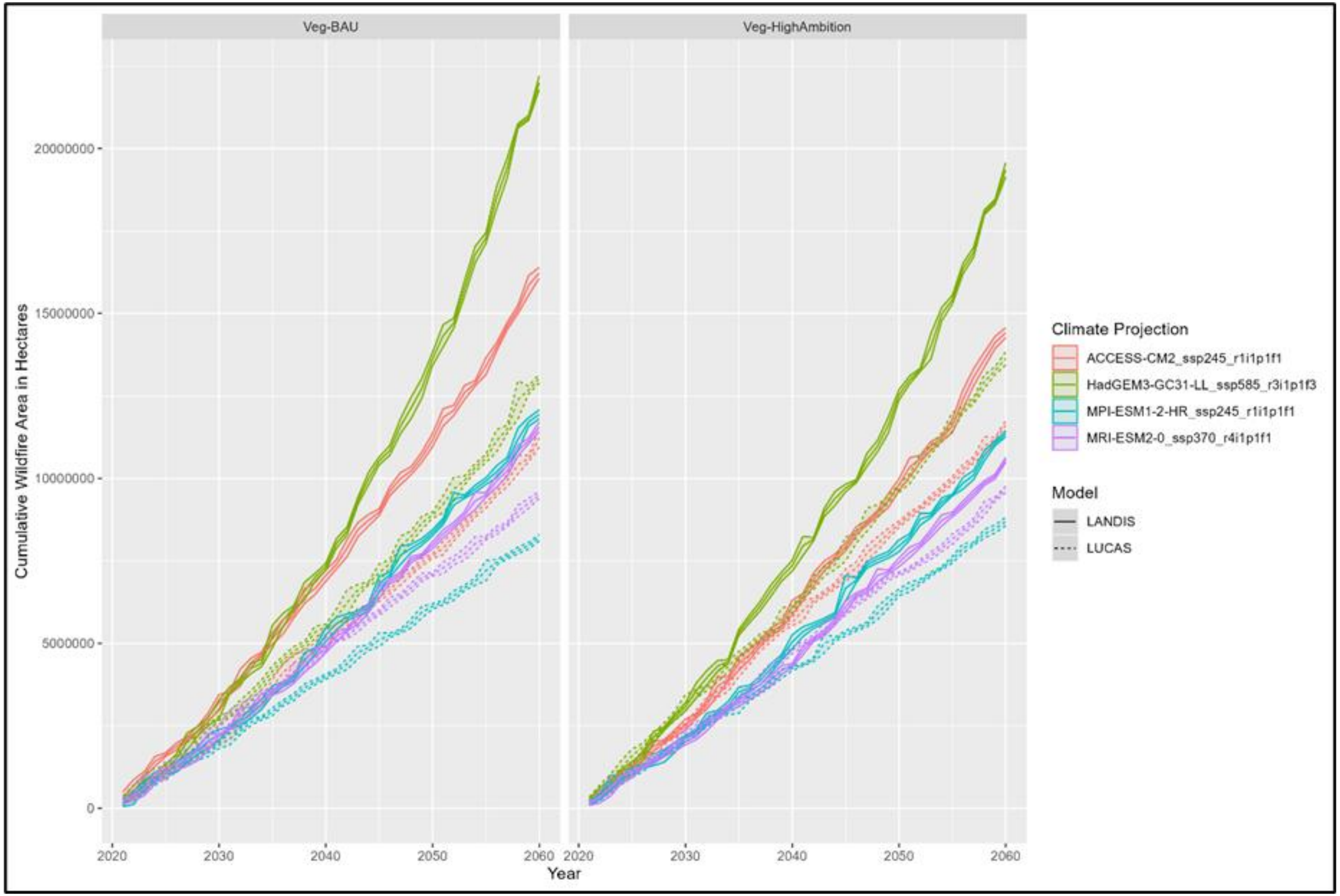
(a) Fire counts by GCM
(b) Fire size class by GCM



Long-term Projections: Example LANDIS-II Results

Left Panel – Business as Usual Vegetation Management Scenario

Right Panel – Left Panel "High Ambition" Vegetation Management Scenario



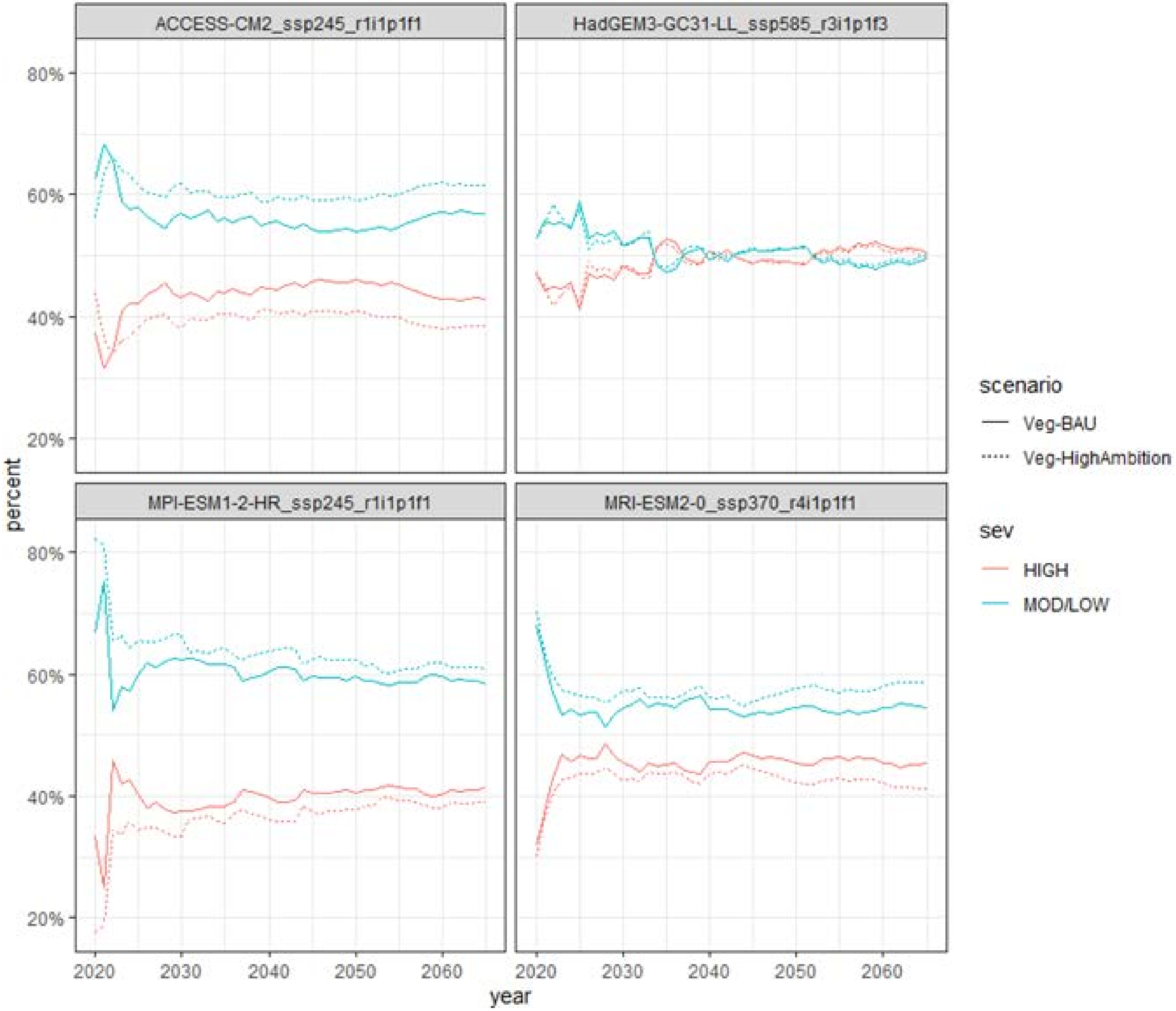
Projected Cumulative Wildfire Area Burned (hectares) in California's Forested Landscapes under Business as Usual and High Ambition Vegetation Management Scenarios

Long-term Projections: Example LANDIS-II Results

Vegetation management makes a difference in severity…

But it can be overwhelmed by more extreme warming scenarios

Y-axis = % of annual wildfire area



Long-term Projections

Hurdles and Lessons Learned

Hurdles

- Delayed delivery of climate data
- Climate data biases (e.g., relative humidity)
- Model structural uncertainty across frameworks
- Limited skill for extreme fire events
- High computational and integration complexity

Lessons Learned

- Climate appears to be the dominant driver of wildfire behavior
- Dynamic coupling is essential for realism
- Uncertainty must be explicitly represented
- Multi-scale integration is critical

Tree Mortality, Fuel Measurement, and Fire Physics

Summary of Results and Conclusions

Results

- Wildfire activity projected to increase, even with high ambition vegetation management
- Forests may transition from carbon sink to source
- Temperature-driven decomposition is a key driver
- Strong regional variability across California

Conclusions

- Wildfire activity is climate-driven and systemically coupled
- Long-term carbon loss likely across forests
- Critical for utility planning and resilience investments
- Consistent model agreement strengthens confidence

Long-term Projections

Moving Forward

- Expand vegetation management and land use policy scenarios
- Integrate socioeconomic exposure/vulnerability
- Develop cost-benefit frameworks
- Link long-term projections to operational tools (e.g., UCLA project; EPC-25-032)
- Publications

Project Wrap-up

- Advanced wildfire science through research on:
    - Extreme fire weather and monitoring
    - Fuels, tree mortality, and fire physics
    - Near-term wildfire models
    - Long-term wildfire and climate projections
- PyreCast demonstrated the value operational wildfire forecasting tools for improving situational awareness and supporting utility decision-making.
- Long-term modeling frameworks provide insights for grid resilience planning, climate adaptation, and wildfire mitigation investments.
- Open-access datasets, models, and tools create a foundation for continued collaboration among utilities, agencies, and researchers.

Open Resources

Data Repositories
- Project Data – https://data.pyregence.org/
- Near-term forecast data - https://data.pyrecast.org/
- Long-term projection data:
  - LUCAS-FRSM model outputs - https://www.sciencebase.gov/catalog/item/691cee75d4be021d1d89b3f9
  - https://data.pyregence.org/wg4/CEC-Submitted/
  - http://ungoliant.ucmerced.edu/data/
  - Historical and projected climate data - https://analytics.cal-adapt.org/data/catalog/

Code Repositories
- GridFire and FRSM (Westerling Model) – https://github.com/pyregence
- ELMFIRE - https://elmfire.io/
- LANDIS II - https://github.com/LANDIS-II-Foundation
- LUCAS/FRSM - https://data.pyregence.org/wg4/Coupled_LUCAS_FRSM/LUCAS%20California%20Coupled%20Fire%20Model/

Thank You!

- California Energy Commission and EPIC Program (David Stoms, Alex Horangic, and Susan Wilhelm)
- Technical Advisory Committee
- Project Partners and Research Collaborators
- Stakeholders (Utilities, Risk Managers, State Agencies)

Questions and Comments

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