Microscale Fire Weather and Event Prediction

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[4]Spatial Informatics Group

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Roadmap

- Projects/research fire weather & event modelling
    - ➢ What are we trying to predict?
    - ➢ What have we learned?
    - ➢ What’s holding us back?
- Where are we heading next?
- How does this apply to operations?

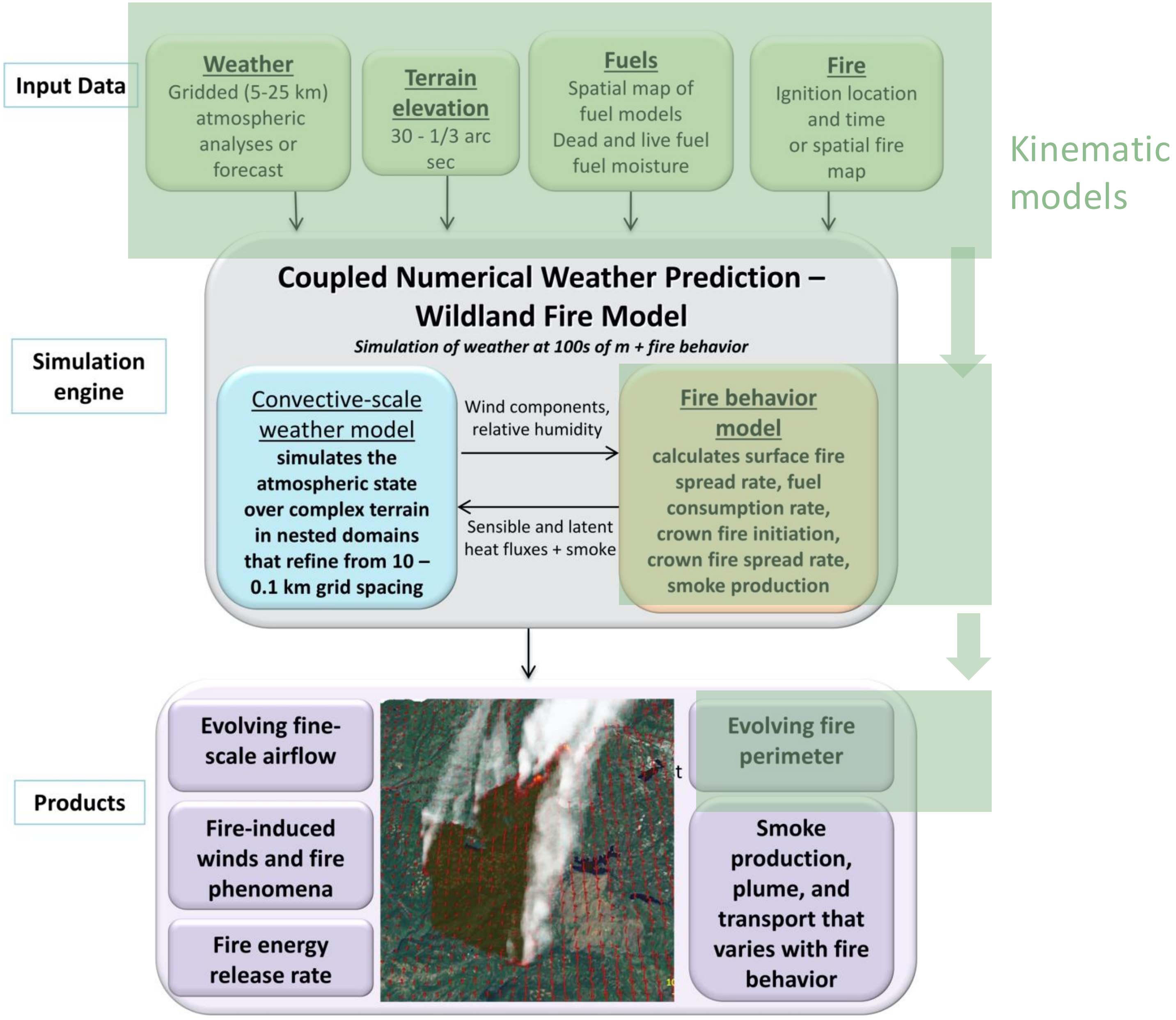
CAWFE®

Coupled Atmosphere-Wildland Fire Environment

- Built on the Clark-Hall numerical weather prediction model (***not*** WRF)
  - Developed to model airflows in steep (up to 40° slope), complex topography
  - Maintains sharp scalar gradients

- Compared to kinematic models, it captures additional factors that influence fire behavior
  - fire-induced winds
  - fine-scale accelerations underlying exceptional wind maxima
  - transient weather factors like pyrocu and gust fronts
  - fire phenomena

CAWFE® Modeling System



Coen, J. L., E. N. Stavros, and J. A. Fites-Kaufman 2018: Deconstructing the King megafire. Ecol. Applics., 28(6), 1565-1580

What are we trying to predict?

(How do we evaluate how good our prediction was?)

- Fire progression "Rate of Spread"
  - Easily gamed with selection of cases & periods shown; continued encouragement to "calibrate" (Stratton, 1986) spread response to wind or adjustment of inputs
- Distinctive features, transient behaviors – merging, splitting, acceleration, blowups, changes in direction
- Fire phenomena. Ex.: the timing, magnitude, location, path of fire whirls, pyrocumuli, or horizontal roll vortices

Additional possibilities with new generation of coupled models

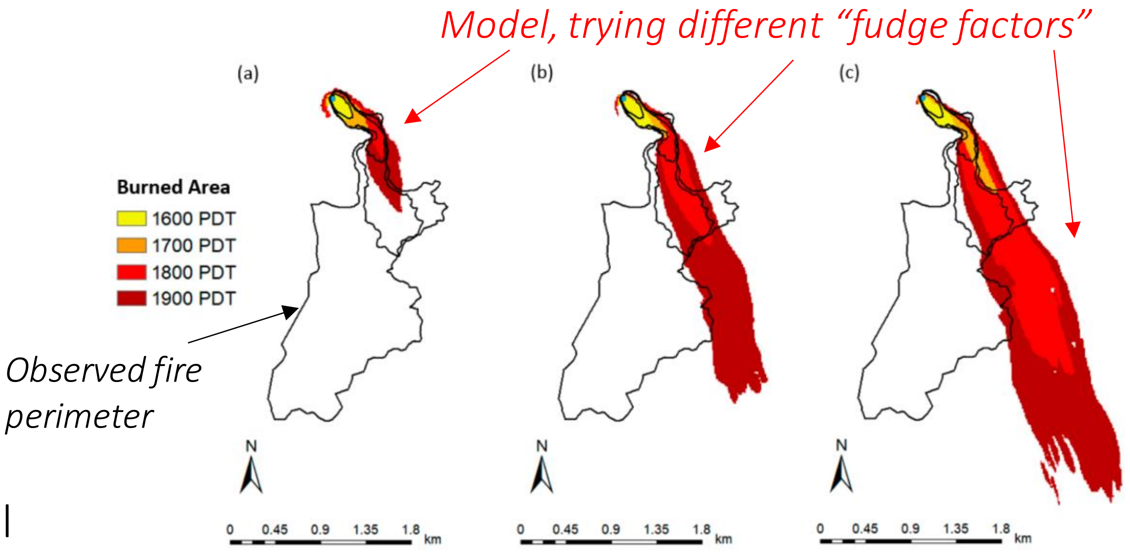


Figure 5. Sherpa fire ignition (blue dot), observed perimeters at 1600, 1700, 1800, and 1900 PDT (black polygons), and the simulated FARSITE burn areas (colored polygons) for simulations with **(a)** 1.0 GF, **(b)** 1.4 GF, and **(c)** 1.7 GF.

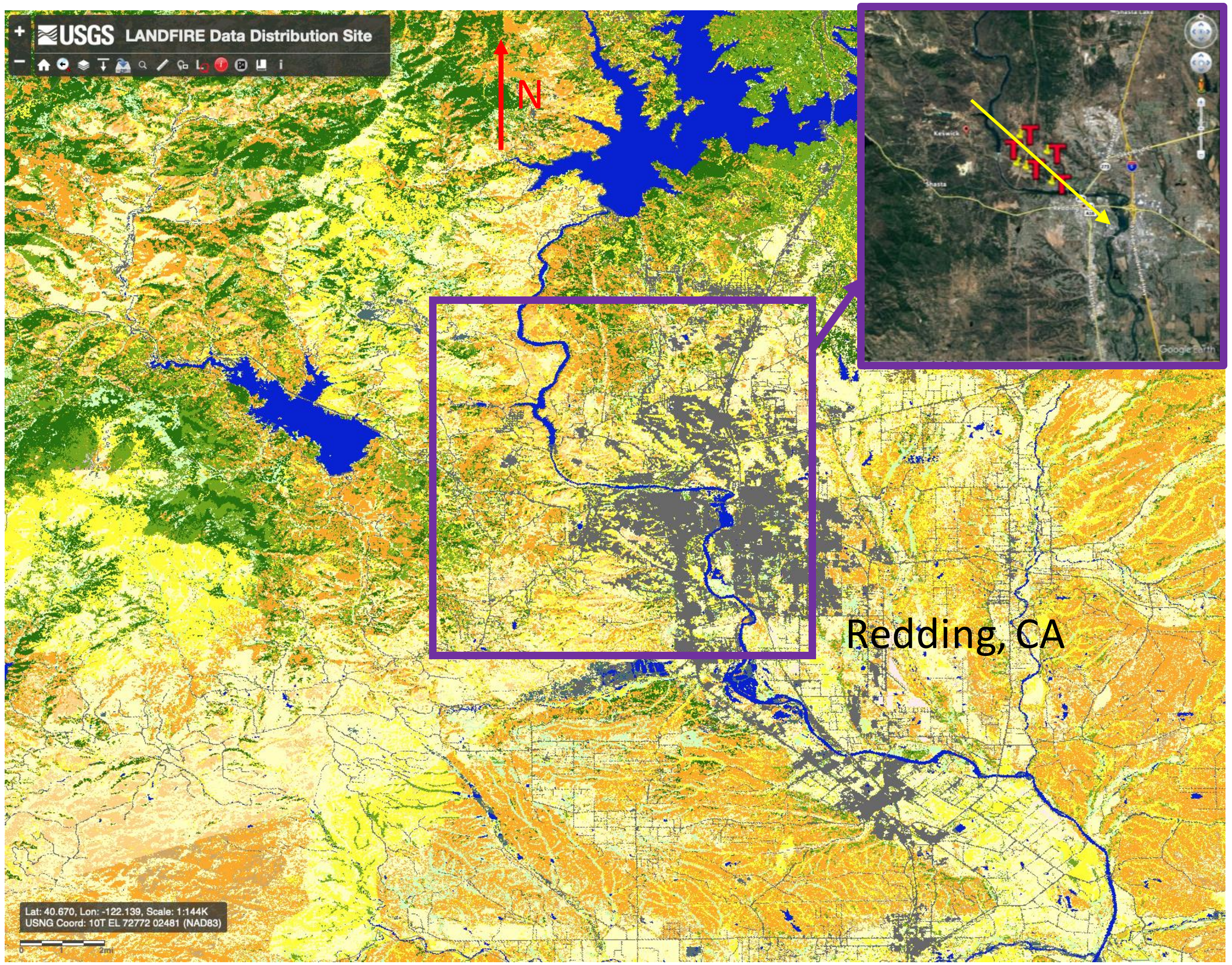
FARSITE simulations of Sherpa Fire, with various "gust factors" (Zigner et al. (2020) FIRE)

Coen, J., M. Cruz, D. Rosales-Giron, and K. Speer (2022) Coupled Fire-Atmosphere Model Evaluation and Challenges. In: K. Speer & S. Goodrick (Eds.) Wildland Fire Dynamics: Fire Effects and Behavior from a Fluid Dynamics Perspective. Cambridge: Cambridge University Press.

Predicting fire phenomena:

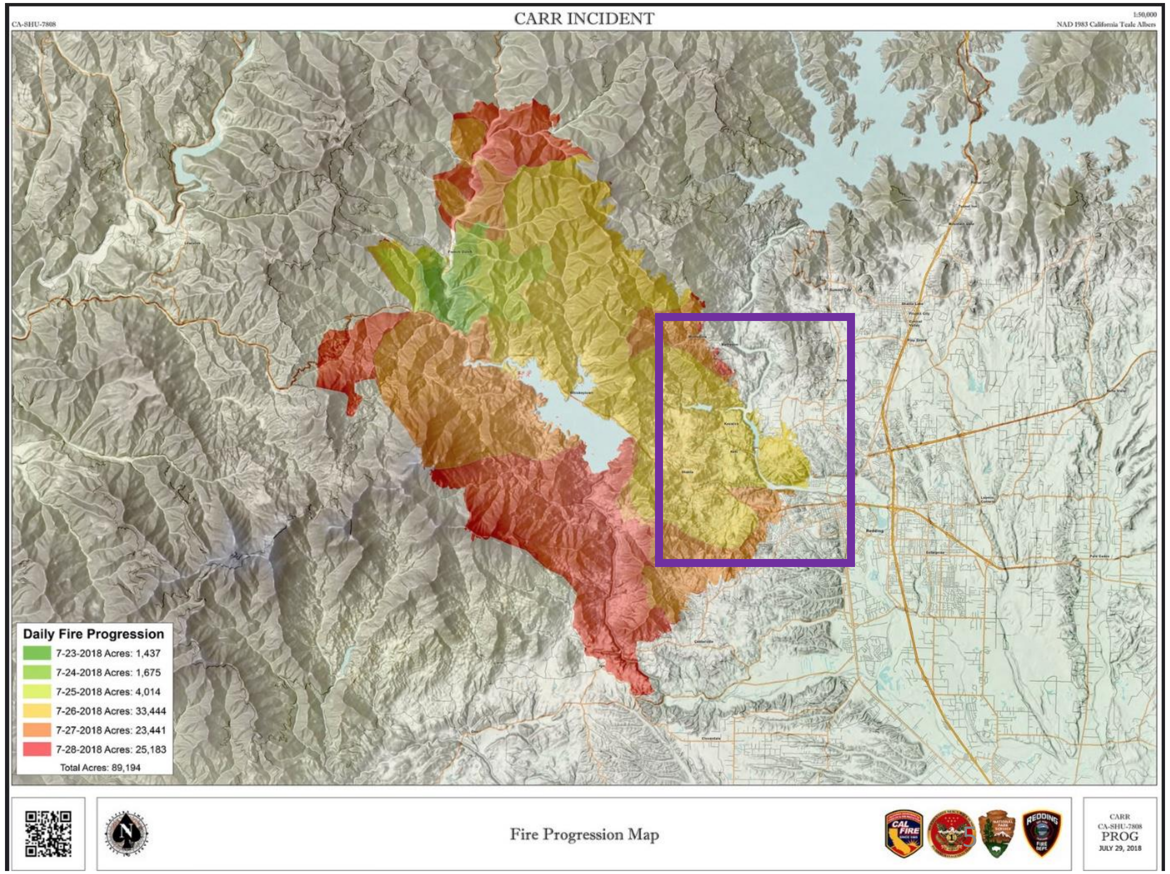
2018 Carr Fire Redding, CA

Significant aspects: Community destruction. Large fire whirls

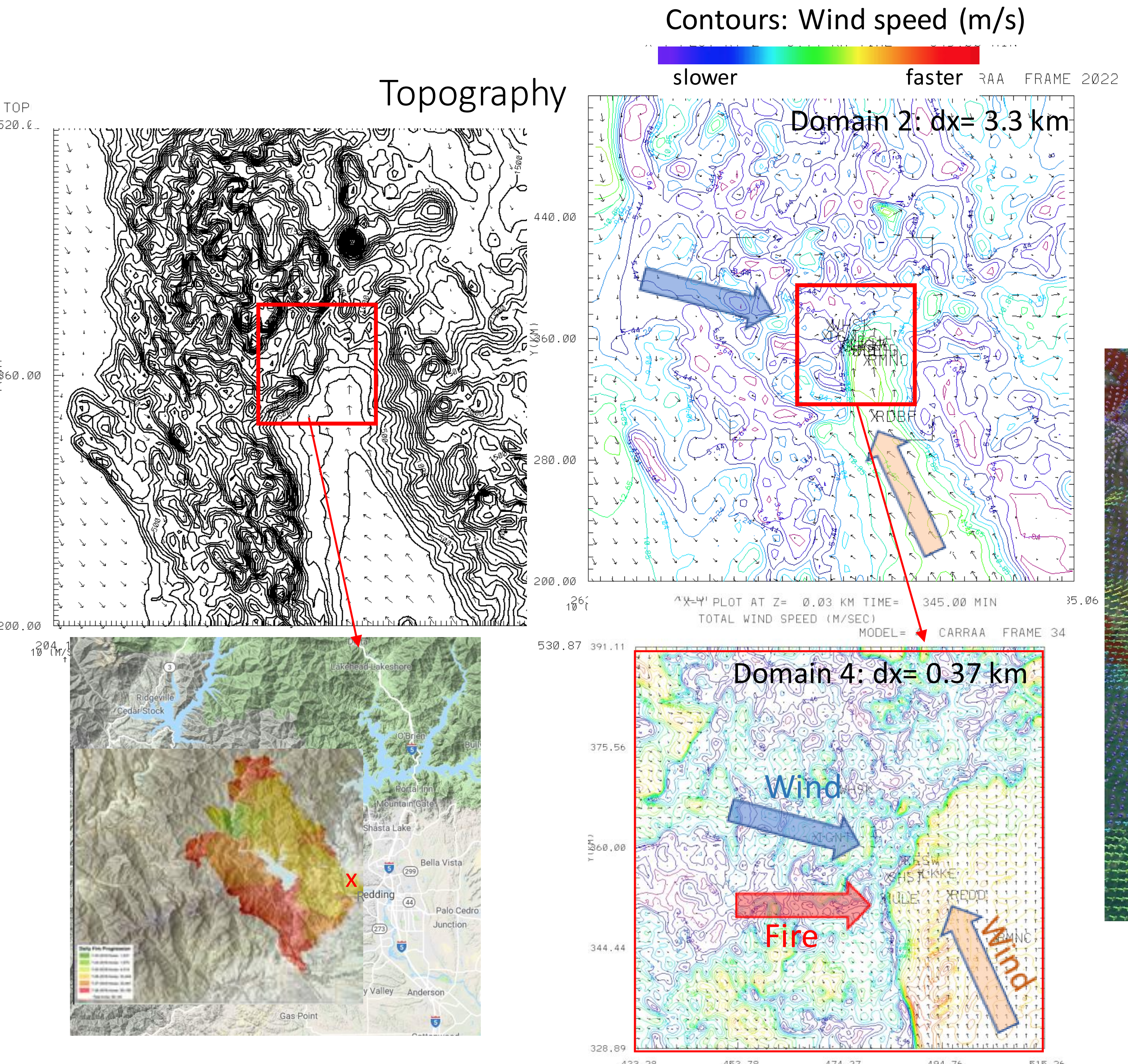


Picture 5- Helicopter Coordinator looking southeast at fire tornado over Lake Keswick Estates. Click here to view video

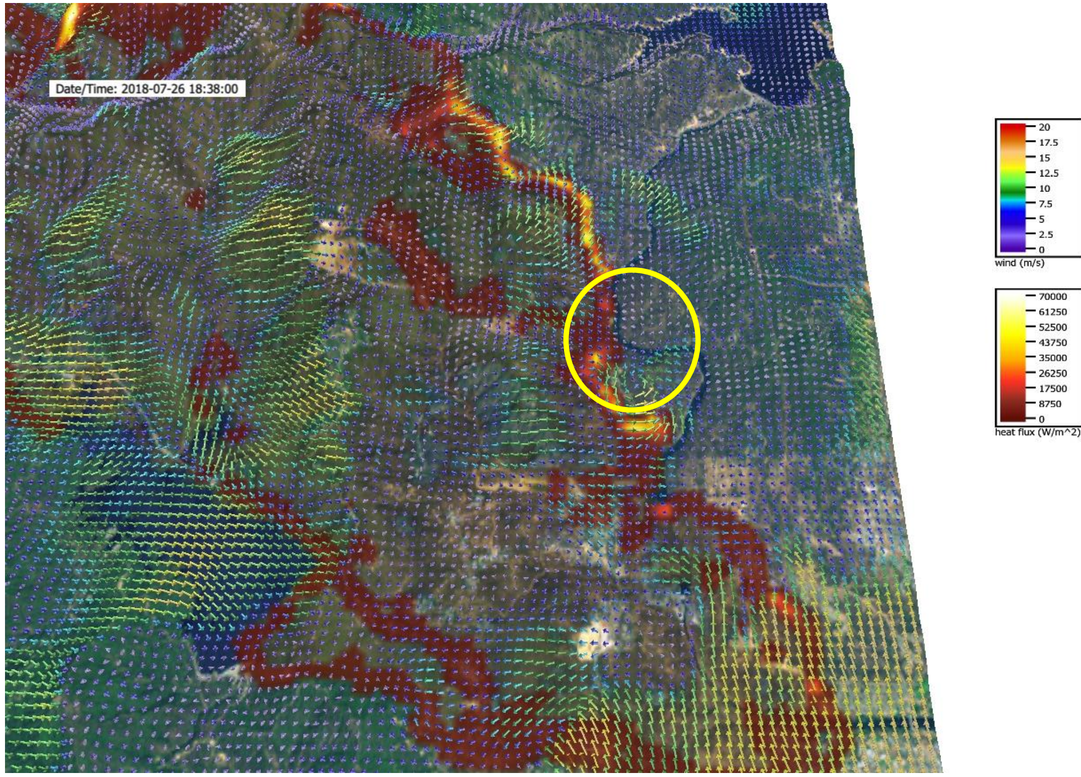
It was around this time when a large rotating plume of smoke was observed developing north of Land Park near Buenaventura Boulevard. The swirling winds at the base of the plume dramatically increased fire intensity. The rotating plume continued to intensify until it developed into a fire tornado. Winds dramatically increased near the fire tornado, and embers were lofted in many directions. The fire front exhibited erratic and rapid growth during this period.



Fire whirls form when weather (or the fire) sets up a wind shear zone and the fire line crosses it.



CAWFE Sim: using "WUI" loads where urban

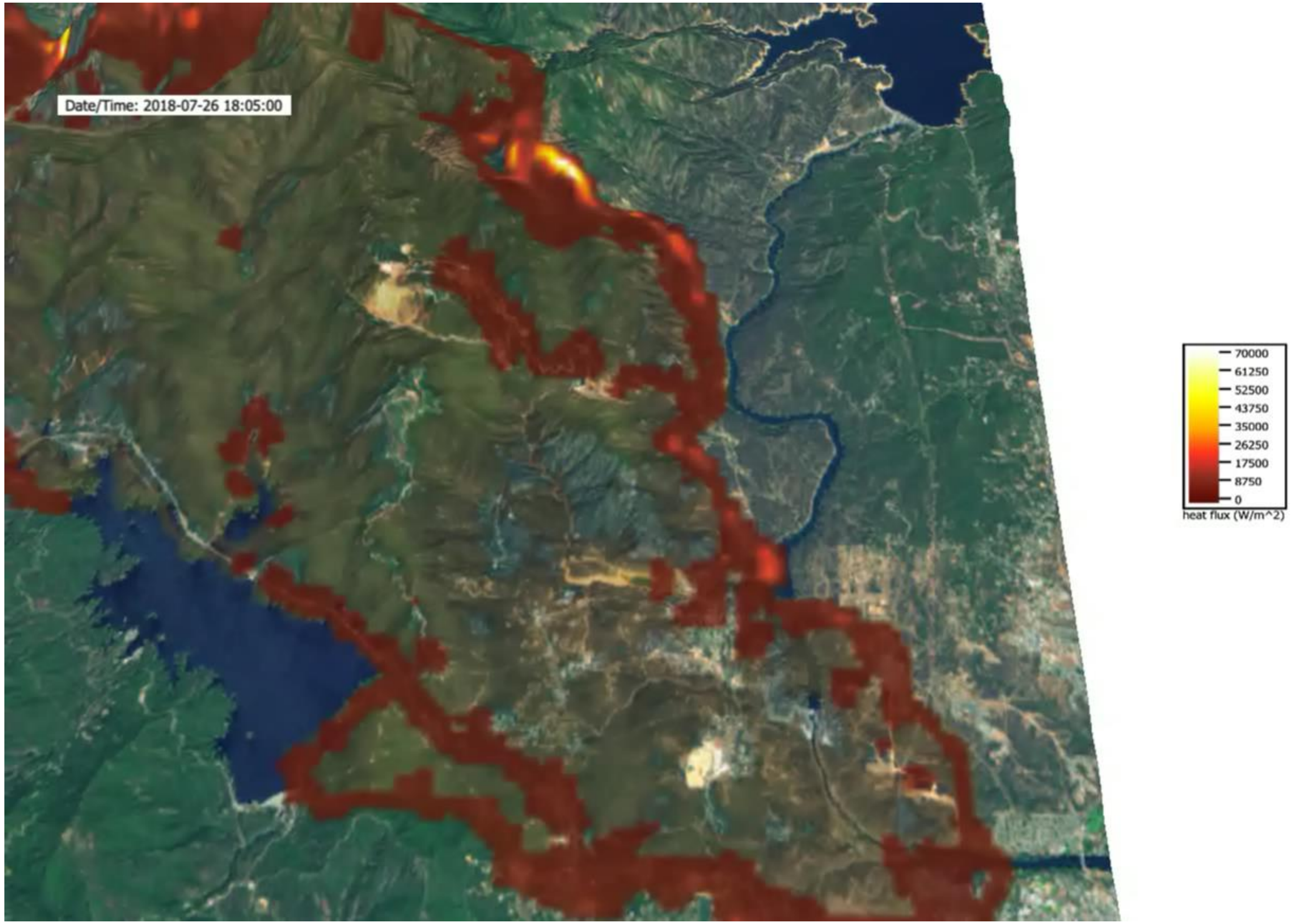


Carr Fire whirl

Formation of multiple fire whirls (as noted) along intersection of airflows as fire runs across the shear zone.

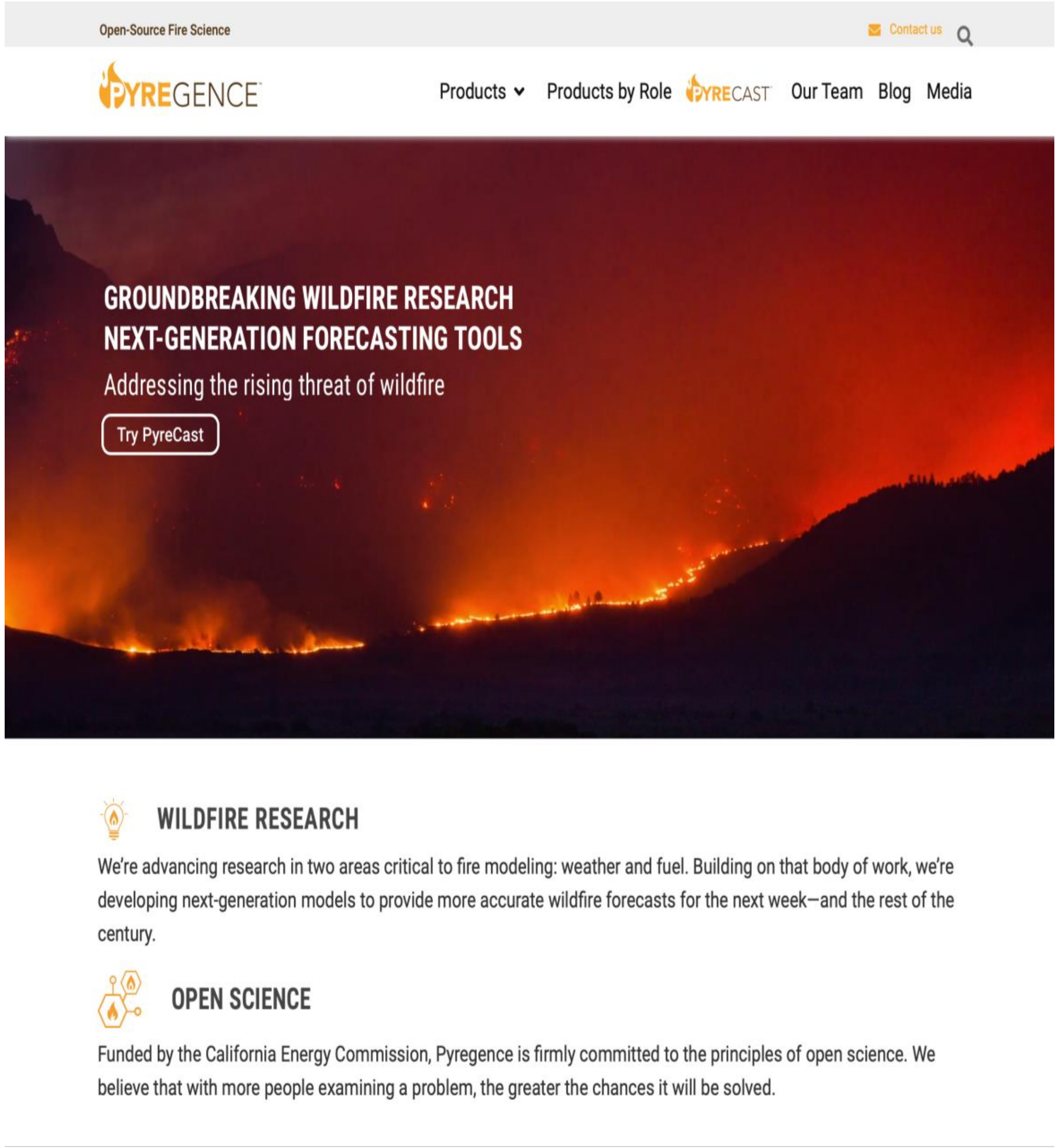
Would this be a good "forecast"?

- ✓ Multiple fire whirls
- PARTIAL CREDIT Location
- ✓ Approximate time
- ✗ Direction of travel?



Oct. 8 9 PM – Oct. 9 6:45 AM 1 frame = 1 minute dx=dy=180 m

What have we learned?



Pyregence Consortium (pyregence.org)

Advance knowledge & applications to help manage past, present, and future wildfire risks from and to the utility grid

Composed of leading researchers from 18 institutions across industry, academia, and government, as well as software developers and designers:

SCOPE OF WORK OVERVIEW

PYREGENCE

California Energy Commission
Commission Agreement Manager
David Stoms

Spatial Informatics Group

Principal Investigator
David Saah, PhD
Project Management
Shane Romsos

Technical Advisory Committee

Users/Stakeholders

Extreme Weather & Wildfire

Lead - Janice Coen, PhD

Tasks

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

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UNIVERSITY OF SAN FRANCISCO

Fuel Mapping & Fire Physics

Lead – Scott Stephens, PhD

Tasks

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

Berkeley UNIVERSITY OF CALIFORNIA

Wildfire Forecasting

Lead – Chris Lautenberger, PhD

Tasks

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

REAX ENGINEERING

Climate Change & Fire Projections

Lead – Leroy Westerling, PhD

Tasks

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

UNIVERSITY OF CALIFORNIA MERCED

EXTREME WEATHER & WILDFIRE WORKGROUP (WG1)

Fine-scale deconstruction of key events

- Understand the airflow regime & fire behavior with *convective-scale* simulations using CAWFE
- Identify conditions for extreme winds & “hotspots”

Activities

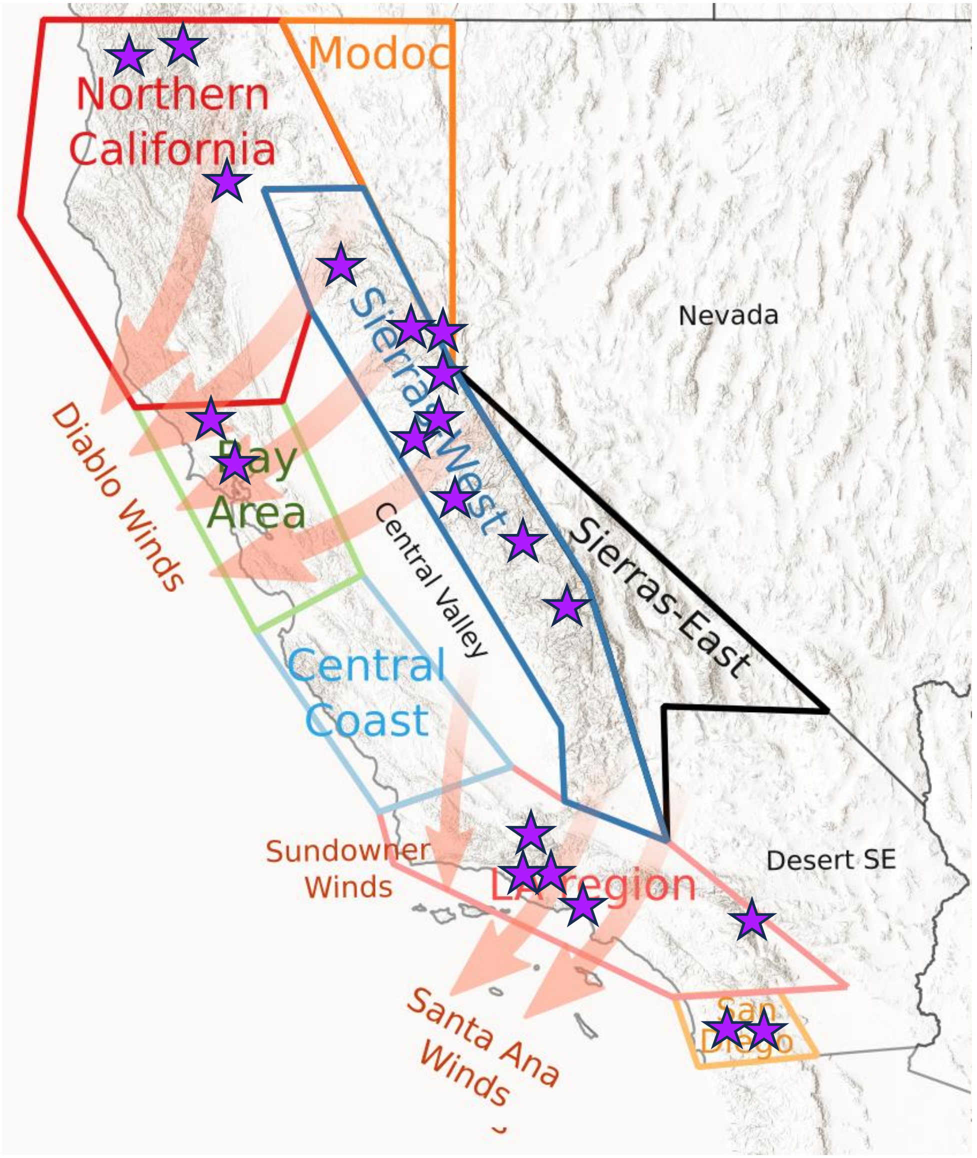
~ Several dozen CAWFE modeling studies of landscape-scale wildfire event growth periods

Investigated *unrecognized* high speed microscale airflow regimes assoc. with downslope wind events

Fires within forested mountains No. CA, thunderstorm outflows

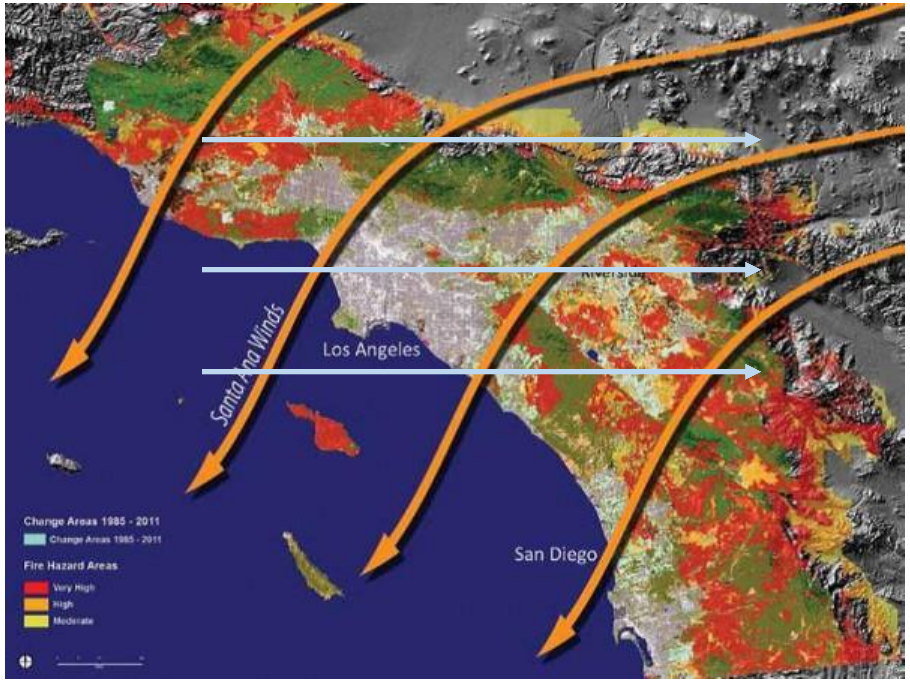
Plume-driven events, anomalous circulations

Prototype forecasting of wind hotspots & subsequent fires



Flow regime factors influencing microscale winds in offshore wind-driven events

High speed winds that back (rotate counterclockwise) with height from Surface to mid- atmosphere



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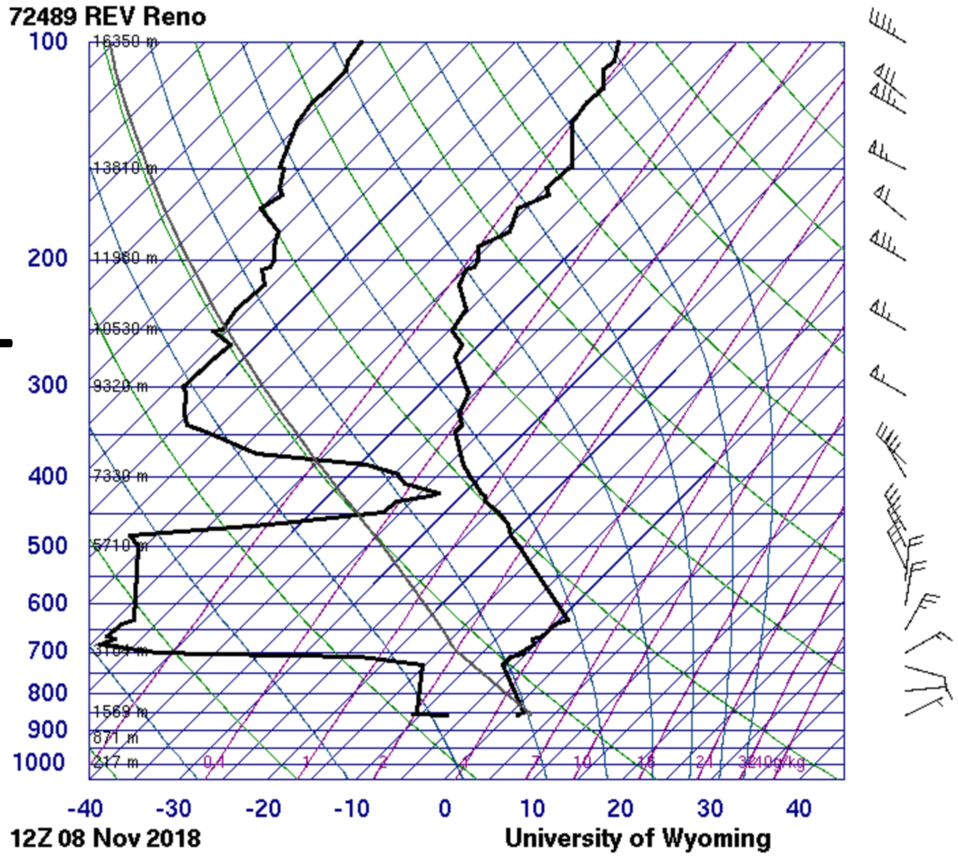
Very stable layer (~1-1.5 km deep) of air near the surface



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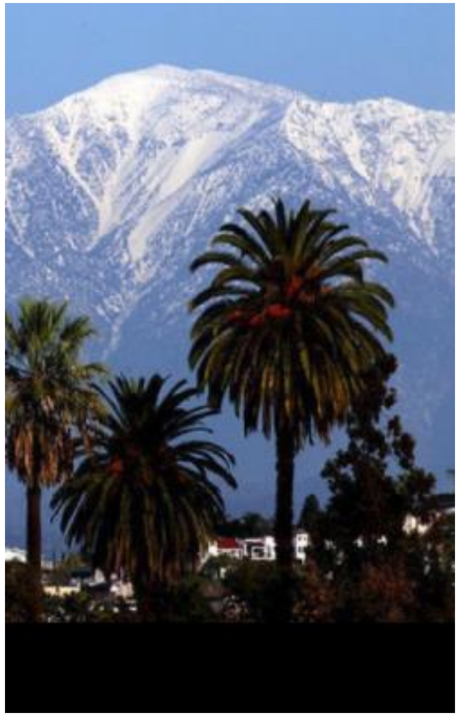
Topography features

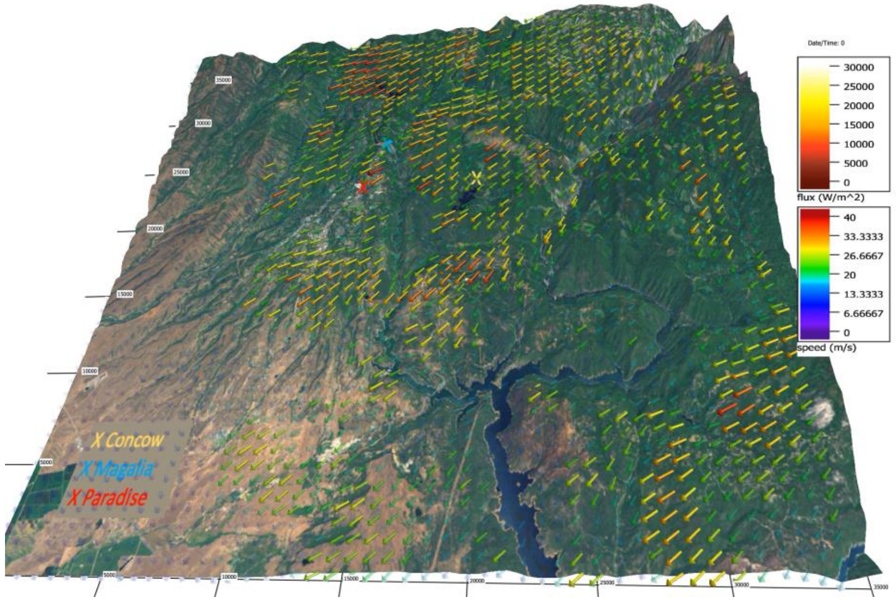


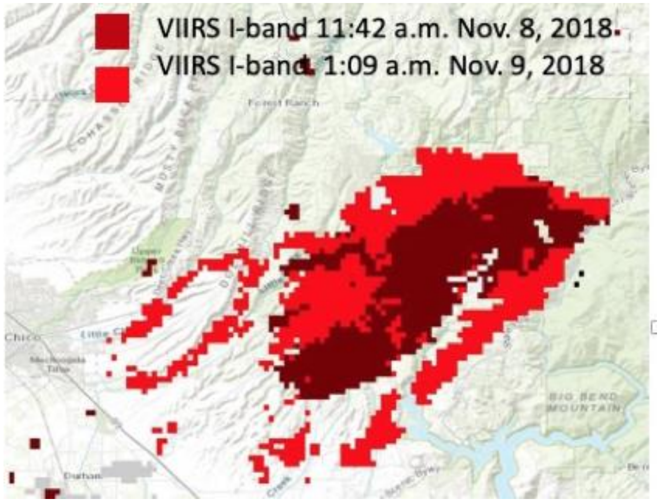
This combination – very stable surface layer traveling at high speed over a range of terrain features creates unique flow effects (but doesn't support waves).

Camp Fire - Paradise, CA

CAWFE simulation

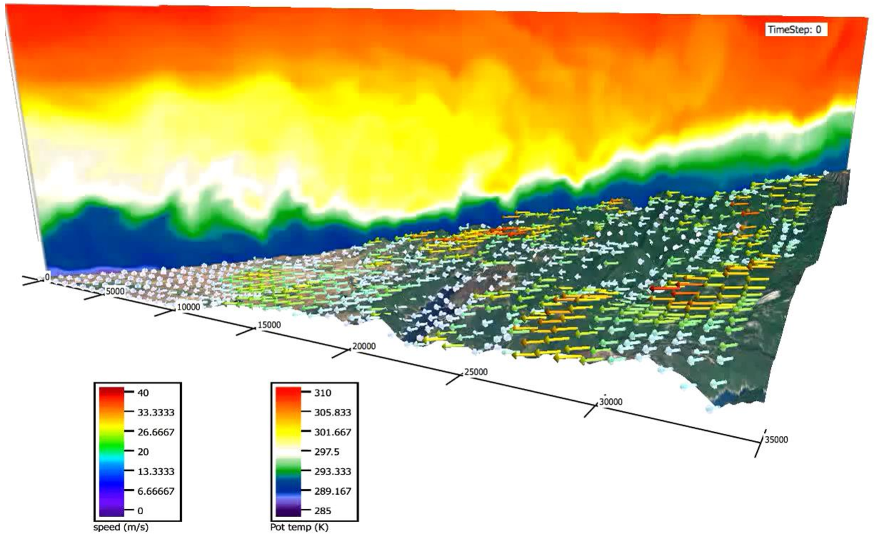
6:15 a.m. – 2:00 PM Nov. 8 2018 dx=dy=370 m

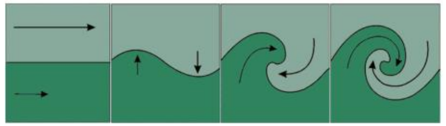




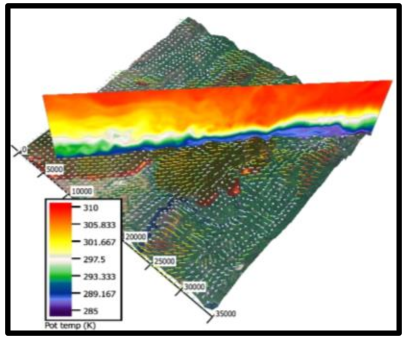
Shear instability created pulses of strong winds near the surface over the Camp Fire

Vertical cross section of potential temperature along flow

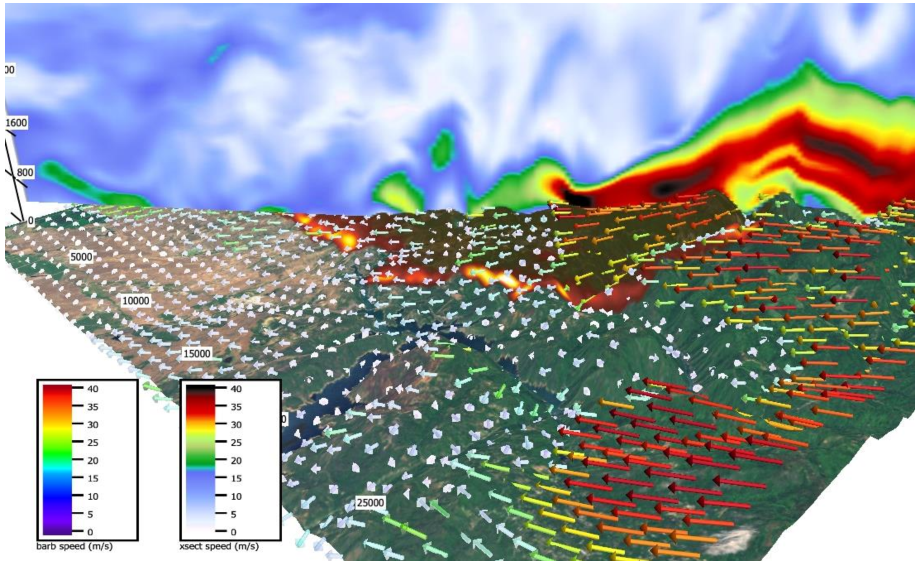




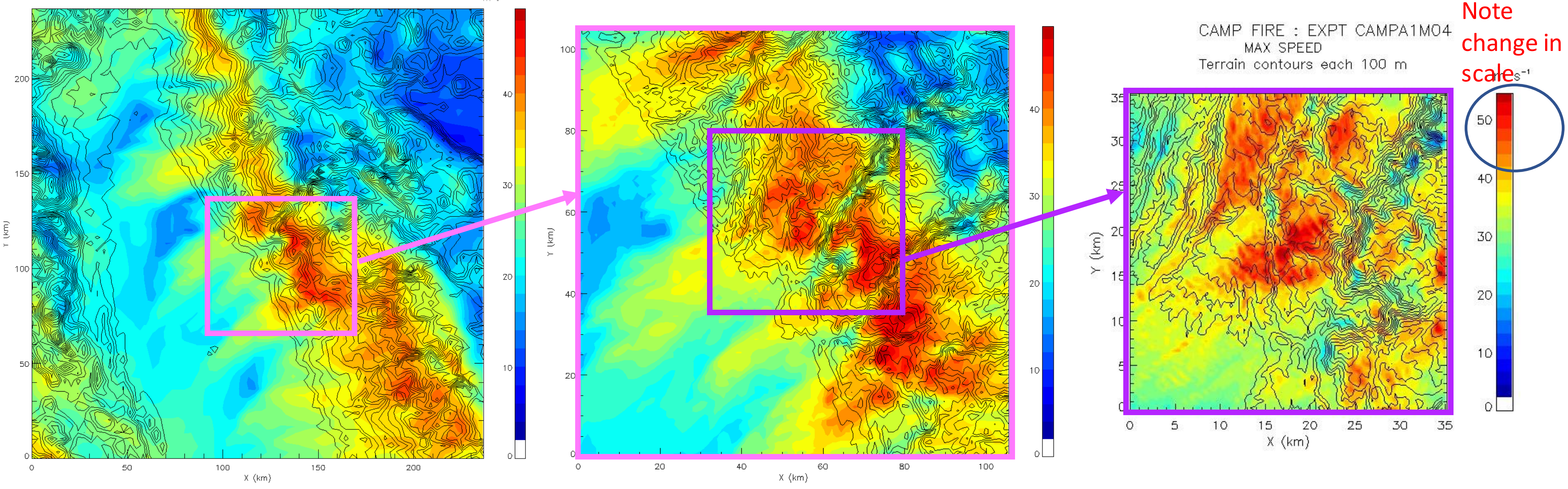
K. Mattila



Vertical cross section of speed in plane



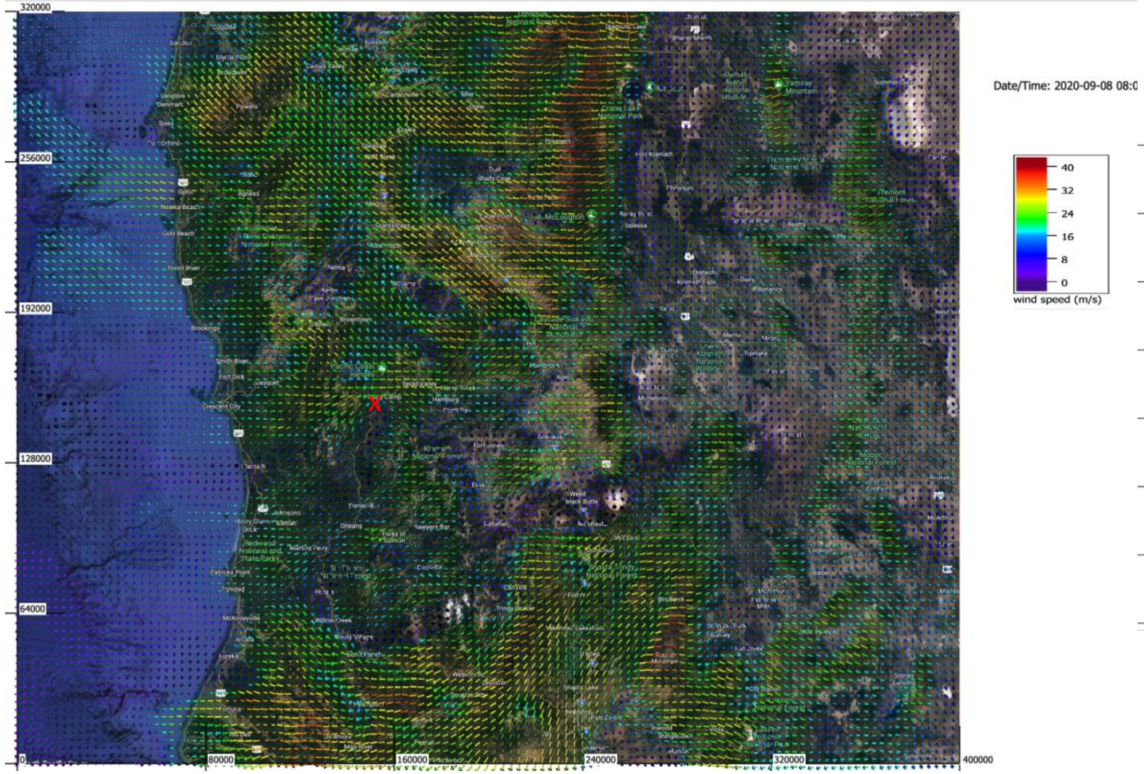
Max windspeed d2 (dx=3.3 km) Max windspeed d3 (dx=1.1 km) Max windspeed d4 (dx=0.37 km)



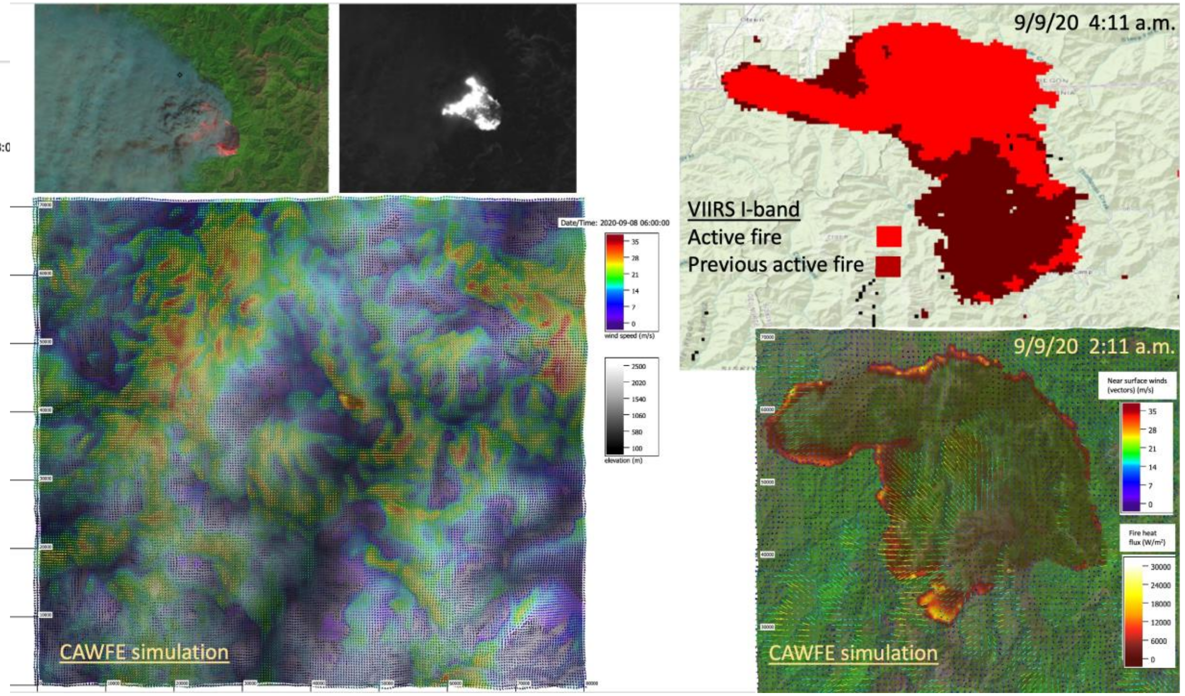
The Camp Fire area *was* the wind "hot spot" along the Sierras

- In a "strong" wind event, maxima appear on slope faces
- Transient behavior producing peak winds appear in CAWFE simulations only when dx < 1 km

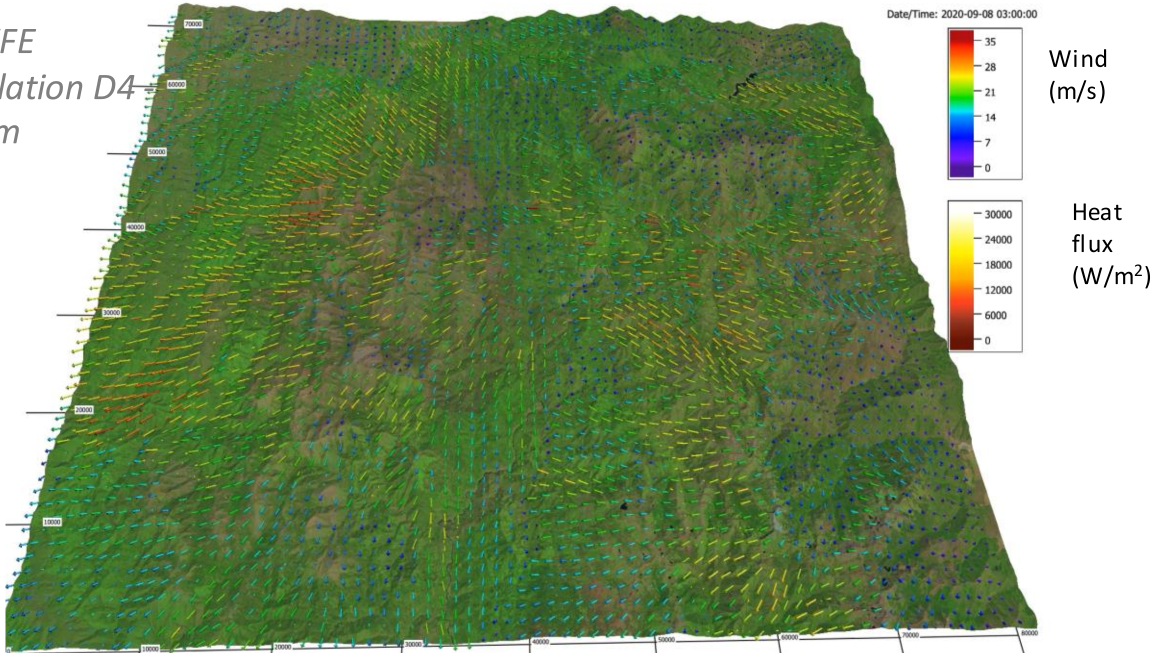
Slater Fire



CAWFE simulation D2 – 3.3 km



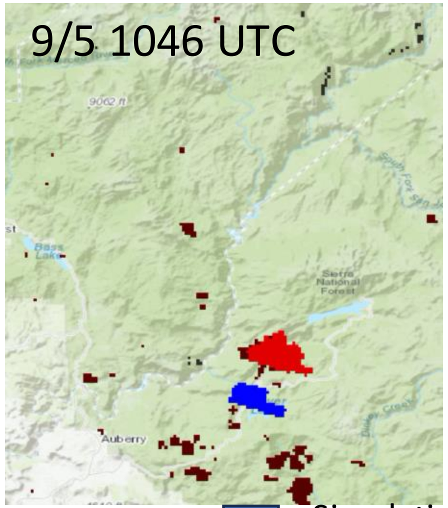
CAWFE simulation D4 370 m



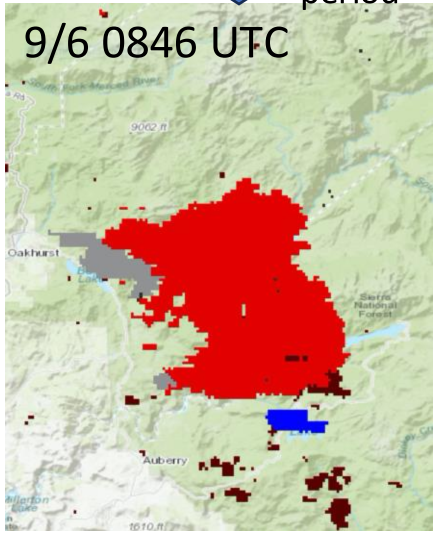
East wind event

Gusts in lee of N-S ridges 5-10 m/s
Growth from SE to NW in sheltered valley flow
Transient “gusts” only appear in < 1.1 km simulations

Plume-driven events: 2020 Creek Fire



Simulation period

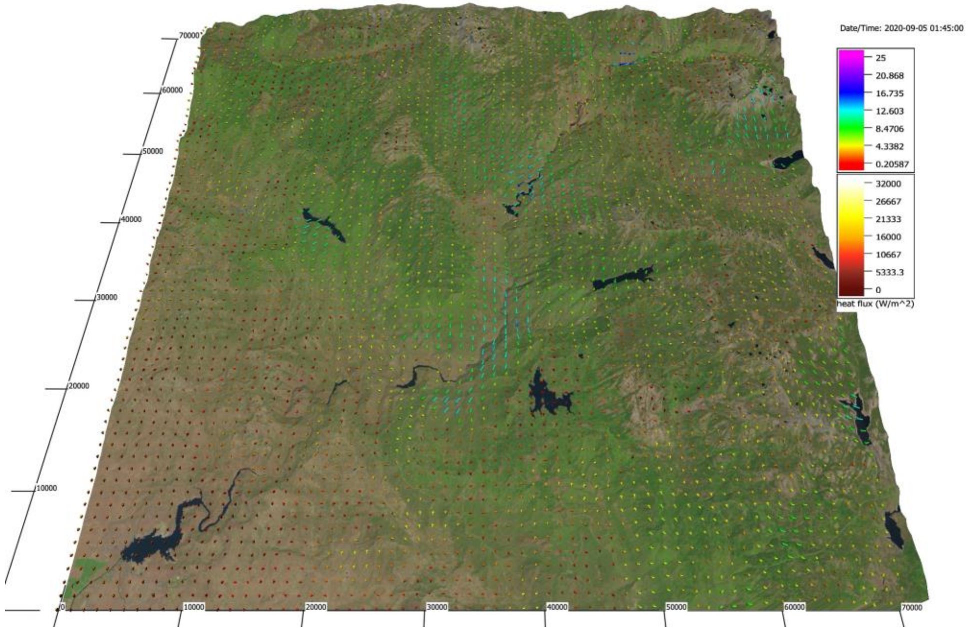


Red: active fire

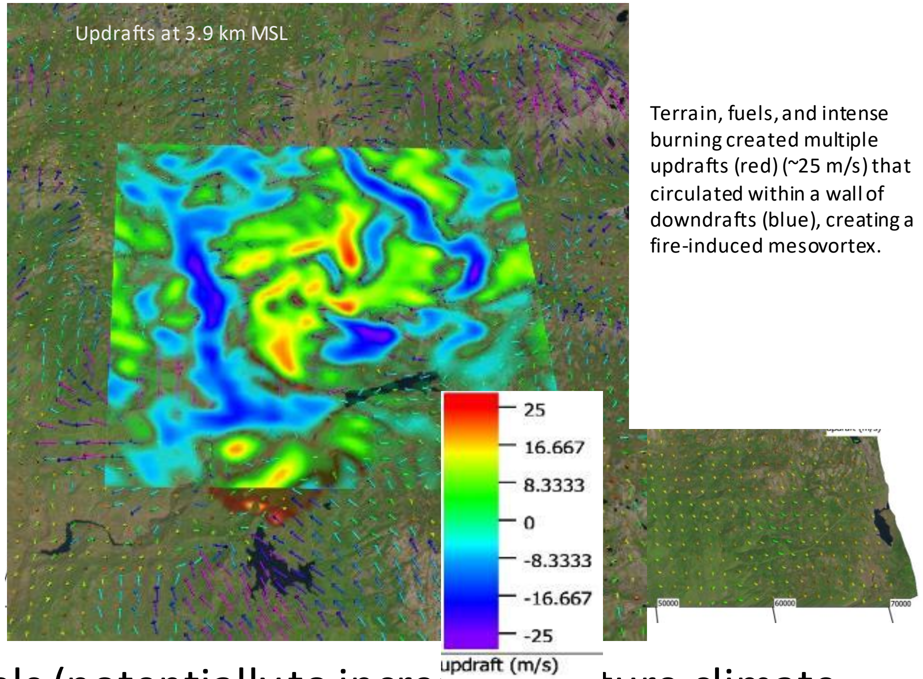
Brick: previously detected active fire

Local time: UTC - 7

Near-surface winds and fire spread



vertical velocity at 3.9 km AGL



Terrain, fuels, and intense burning created multiple updrafts (red) (~25 m/s) that circulated within a wall of downdrafts (blue), creating a fire-induced mesovortex.

Widely speculated that high mortality fuels (potentially to increase in future climate scenarios) caused the deep pyrocumulus. But only in later days did the fire reached high mortality areas.

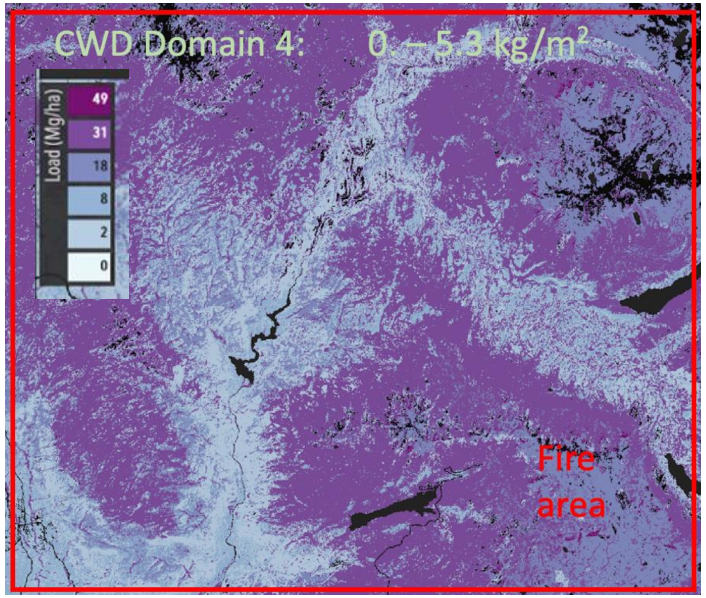
Here, using standard LANDFIRE surface & canopy fuel data, we see anomalous spread in early period resulted from local topo - fire-induced wind interactions.

CWD effects summary:

- Widely speculated that high mortality fuels contributed to Creek Fire's rapid growth.
  - Not supported by results.
  - Brief, small differences in perimeter
  - Note: some CWD (comparable to surface fuel loads) but not the highest CWD values located in this area.

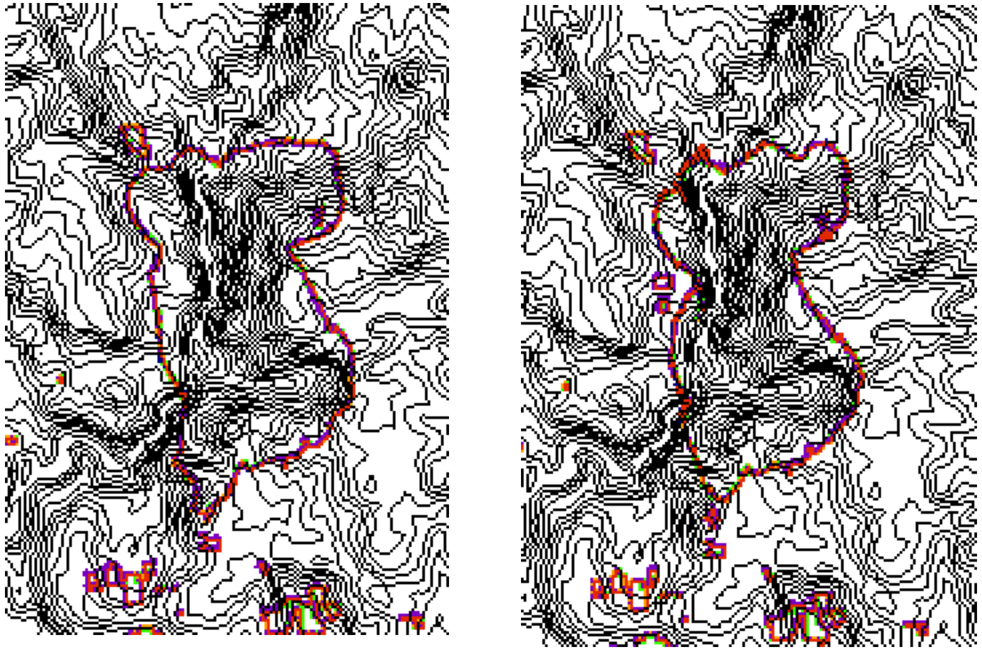
- But, there are significant effects on vertical growth.
  - Stronger maximum updraft
  - Vertical vorticity is increased in middle atmosphere
  - More smoke is transported into mid & upper atmosphere

Coen, AFE, Monterey, CA. Dec. 2023



W. Siegmund, Olympic NP. Creative Commons license

Control simulation Including CWD



CAWFE simulated results, 9 PM local time 9/5

What’s holding us back?

Sources & attribution of simulation error

“Wildfire Analyst” – private sector model supporting CalFIRE

Selected cases: Poor performance on all non-trivial shapes.

“Success!”

Advances in Forest Fire Research 2022 - D. X. Viegas & L.M. Ribeiro (Ed.)
Chapter 1 - Decision Support Systems and Tools

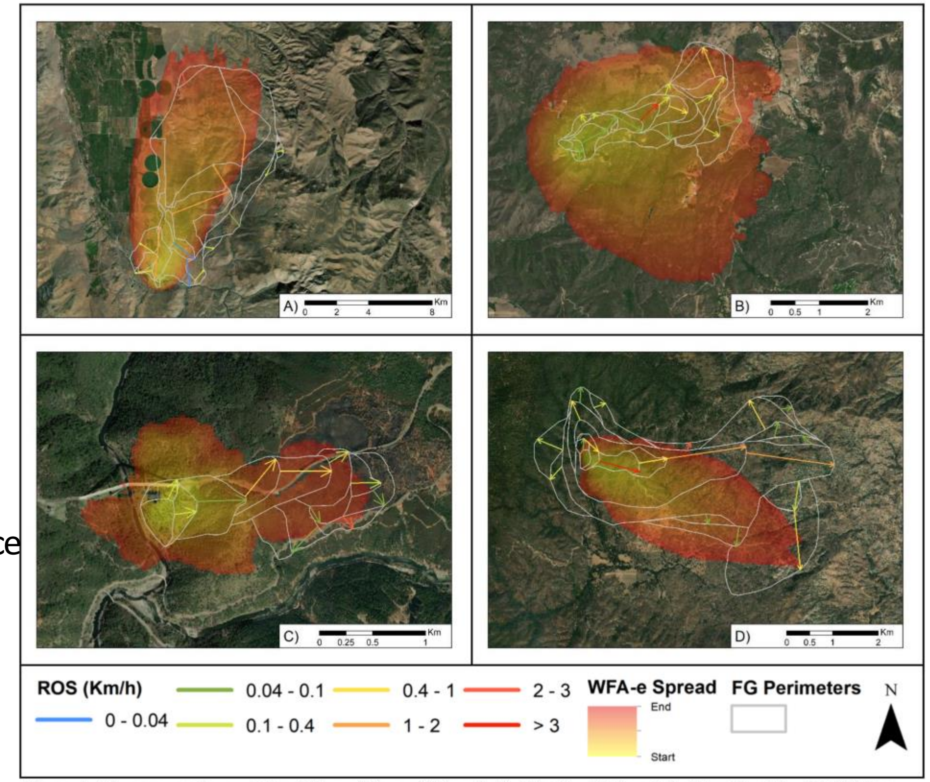


Figure 1. Fire progression and simulation of four wildfires in California. A) Mountain View fire (lat = 38.515; lon = -119.465; 2020/11/17); B) Chaparral fire (lat = 33.485; lon = -117.399; 2021/08/28); C) Bridge fire (lat = 38.921; lon = -121.037; 2021/09/05); D) French fire (lat = 35.687; lon = -118.55; 2021/08/18); Note that the FG polygons and

Validation of operational fire spread models in California

Adrián Cardil*[1,2,3]; Santiago Monedero[1]; Miguel Ángel Navarrete[1]; Sergio de-Miguel[2,3]; Carlos A. Silva[4]; Raúl Quilez[1]; Scott Purdy[1]; Joaquin Ramirez*[1]

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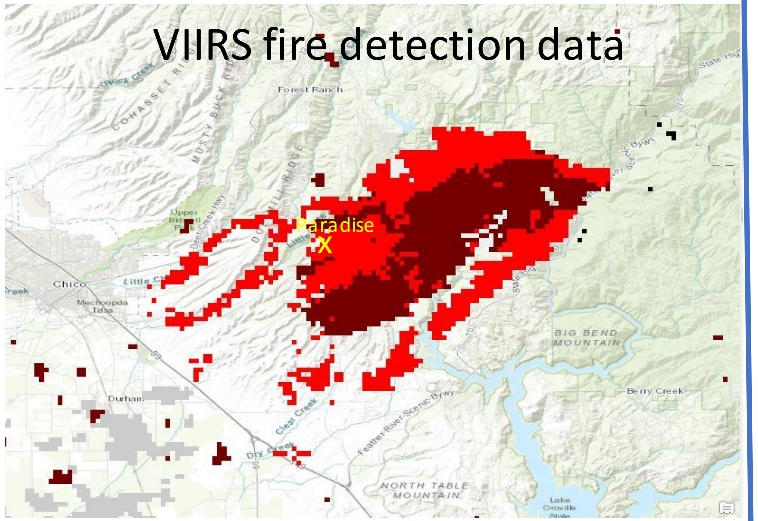
What, if taken away from good simulations, breaks it?

Accurate simulation of fire events

(using standard fuel info, weather, semi-empirical formula, etc.)

2018 Camp Fire - 5 yrs on: A Make-or-Break test for operational use?

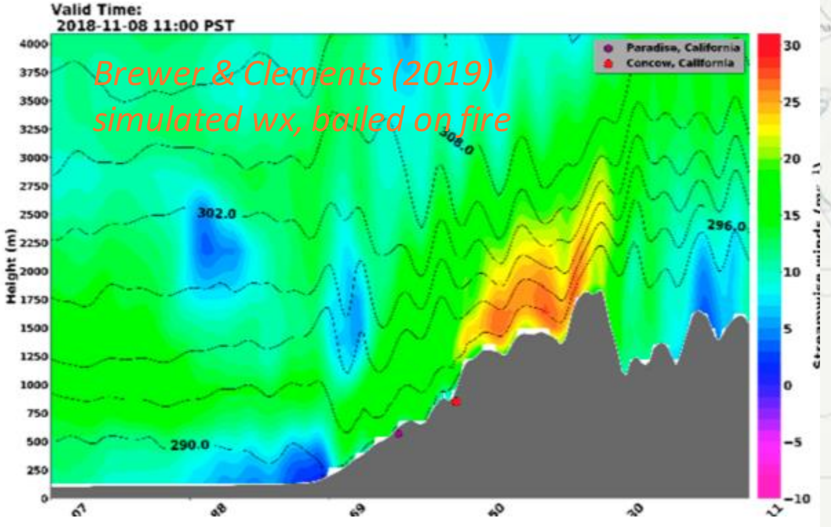


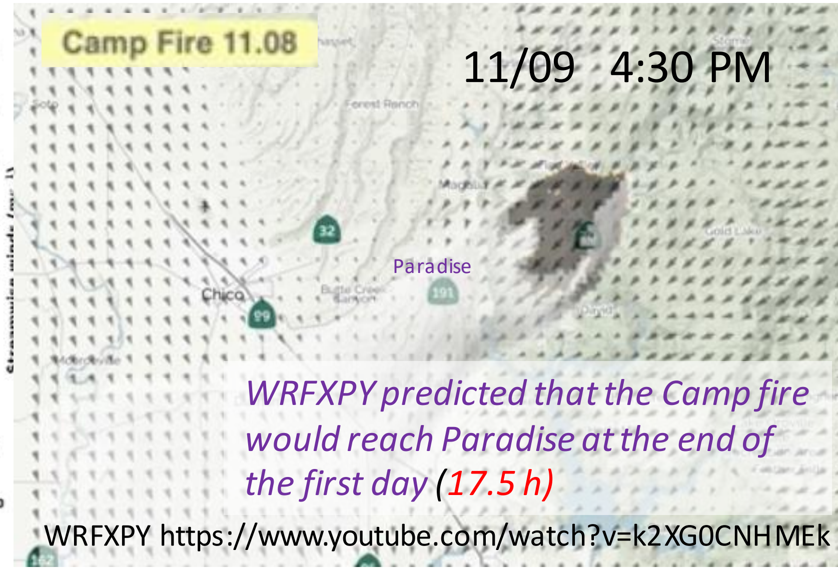
VIIRS I-band 11:42 a.m. Nov. 8, 2018
VIIRS I-band 1:09 a.m. Nov. 9, 2018

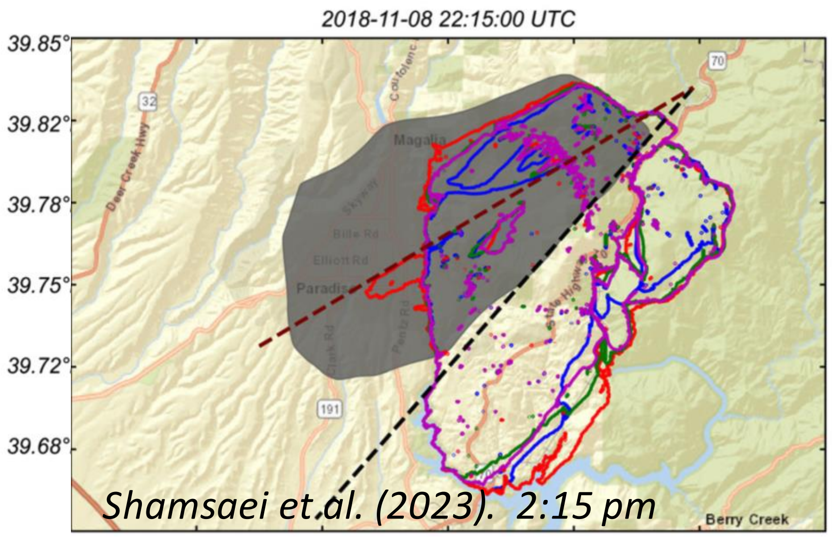
The Camp Fire reached Paradise in about 4 h (~10:45 am) after ignition. Killed 85+ people.

- Decision info: ***Will the fire be driven downslope into community?***
- Current paradigm: Simulate downslope winds, declare victory!
- When coupled to fire behavior, ***consistently fails*** to bring fire into razed communities
- Consistent problem in downslope events (e.g.: Chimney Tops 2, Painted Cave. Lahaina?)
- ***Catastrophic if used as an evac warning***

Fire growth predictions with WRF-based coupled weather-fire models

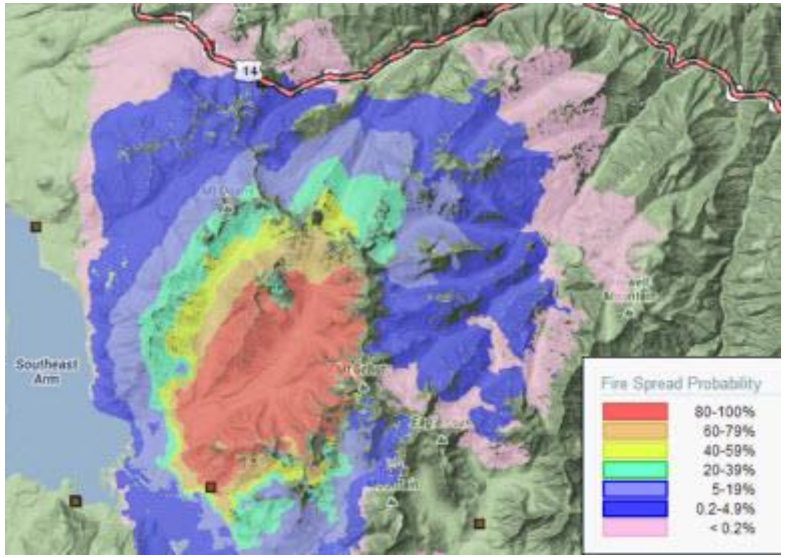






"Uncertainty" concept borrowed to explain/account for poor simulations

"Uncertainty"
Model error



Sample output from official operational tool FSPro. *(NWCG Training material.)*

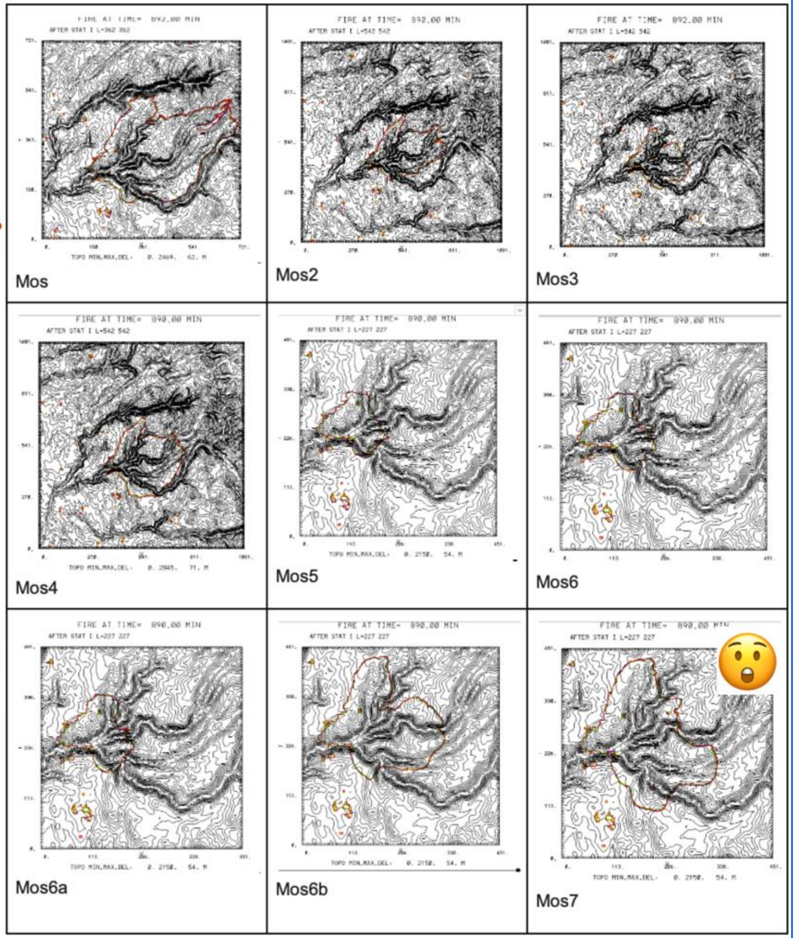
<u>Intended as "probabilistic forecast"</u>

- Climatology-driven: But past does not = current immediate future
- Validation & interpretation of probabilistic forecasts is challenging

Coupled weather-wildland fire behavior model

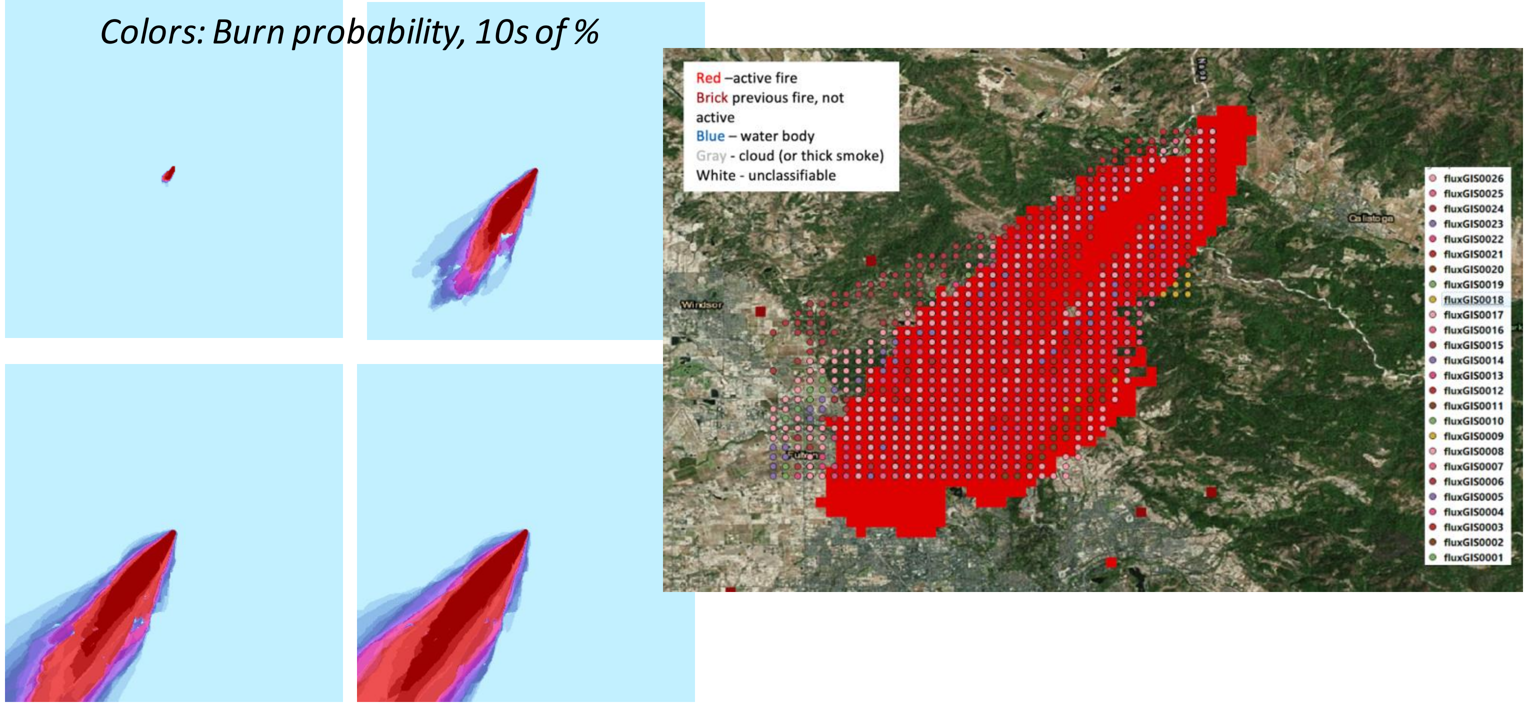
The existing uncertainty in fire environment inputs and from physics parameter choices may *amplify* in nonlinear, convective-scale fire dynamics.

Simulations of the 2022 Mosquito Fire



CAWFE Ensembles

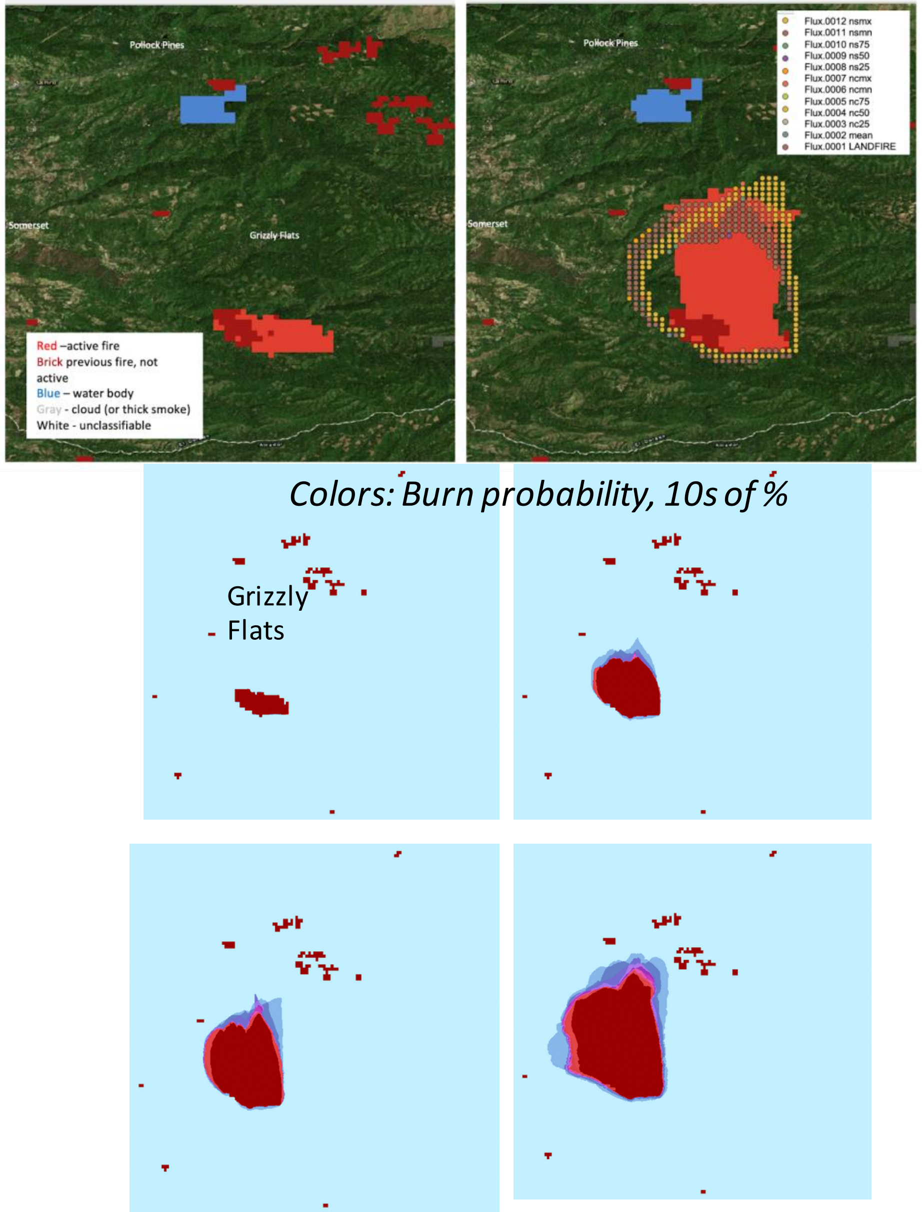
- Single processor, simple to “operationalize”, NRT on workstation



Weather input- varying CAWFE ensemble of Tubbs Fire:

- Ensemble has some spread, would not be enough to save a poor forecast
- “Uncertain” areas in ROS (not shown) indicate wind max “hotspots”

Science outcome



Caldor Fire: 12-member fuel-varying ensemble.

1) “Better” fuel info won’t save a poor simulation
2) Widespread fuel reduction would have weak impact

Science outcome

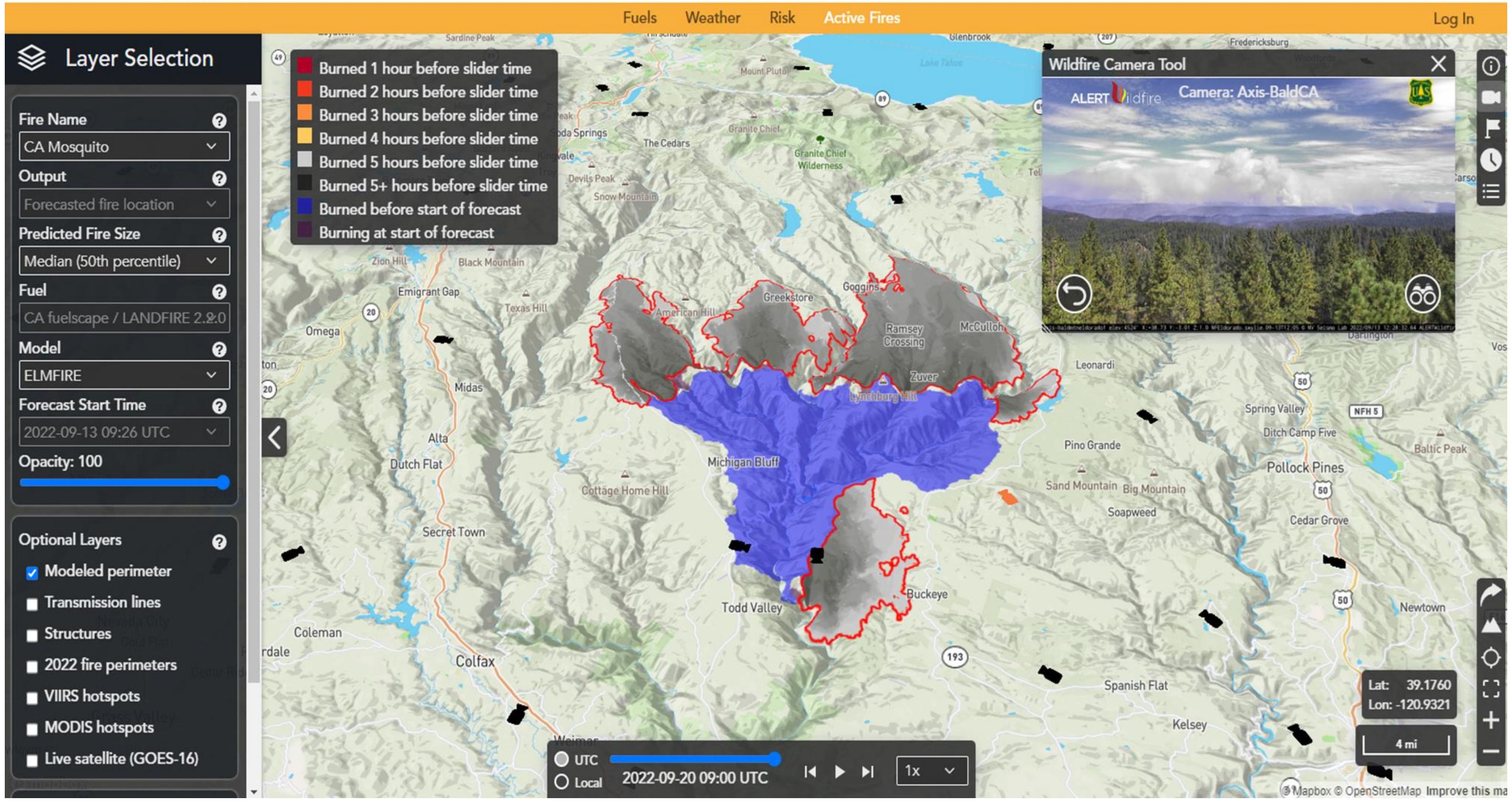
How does this apply to operations?

PYREGENCE™

PyreCast®

Operated by Pyregence.org

- Public-facing forecast of fire growth for California, now fires across the U.S.
- Open science model "sandbox"
- Multiple models (ELMFire GridFire)
- "Uncertainty" is included as a range of 1000s of input parameters.



CAWFE has been operationalized, integrated with the preprocessing & postprocessing workflow

- Configured for single processor, 34 h forecast.
- Timing depends on size of domain, time step, etc. 6-7x RT for 25 km x 25 km domain; 20x for new ig
- AWS Cloud: Additional ~25% speedup
- "Train the trainer" approach to expanding us

Summary & Conclusions

- Lives depend on this.
- Distinguishing characteristics of each landscape-scale fire ***are*** predictable.
  - Weather community sees (obs & models) with mesoscale glasses. (e.g. Microscale is weak & unimportant.)
  - Realism, wind extrema, & transient nature *only appear at dx << 1 km* & not in all coupled models.
- Models are a test of our understanding.
  - Decades of "calibration"/fudging continue to hinder progress & obscure understanding of why fires behaved as they did & much more.
- Attribution of model error is speculative.
  - *No agreement* how big the error is or where it came from.
- Instead of spinning poor simulations as successes, let's use as teaching moments
- While historically agency-driven, new opportunities with new partners

Thank you.

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