Weather, Fire Behavior and Trends in the Central Sierra

J. Coen[1,2], W. Schroeder[3], A. Prein[2], A. Jaye[2], L. Tarnay[4]

[1] University of San Francisco
[2] National Center for Atmospheric Research
[3] NOAA NESDIS
[4] USDA Forest Service Region 5 Remote Sensing Laboratory

Sponsored by California Energy Commission, Comprehensive Open Source Development of Next Generation Wildfire Models for Grid Resiliency, EPC-18-026

pyregence.org

PYREGENCE™

Open access to the next generation of wildfire risk models and information

Primary Funding Provided by

California Energy Commission – EPIC Program (EPC-18-026)

David Saah, PhD
Principal Investigator
University of San Francisco and
Spatial Informatics Group

Shane Romsos, MSc
Project Manager
Spatial Informatics Group

pyregence.org

BACKDROP

Climate impacts California wildfire risk

- Thermodynamic: through temperature, moisture deficits, drought
  - Subsequent tree mortality: buildup of heavy ground fuels could create “mass fires”
- Changes to atmospheric circulation
  - Future projections predict wind events decrease, increase, or persist in frequency
- Seasonality, evolving vegetation

Extreme wind events are a critical factor driving many CA devastating wildfires.

- Reconstruction of historical extrema disagree
- Expansion of fire risk intelligence: weather station network, state/utility “op centers”, Wildfire Mitigation Plans, PSPSs
- Still, detection & forecasting of wind extrema and fire growth are elusive

Most destructive fires occur in the wildland urban interface and intermix where structures and wildland fuels comingle

PYREGENCE

“Extreme” fires by the numbers:

- Only 3-5% exceed 100 ha
- Largest 1% account for 80-96% of area burned
- Over the historical satellite record of burned area, days with very large daily fire growth are infrequent
- Occurrence results from a ***multi-scale*** ”Perfect storm”:

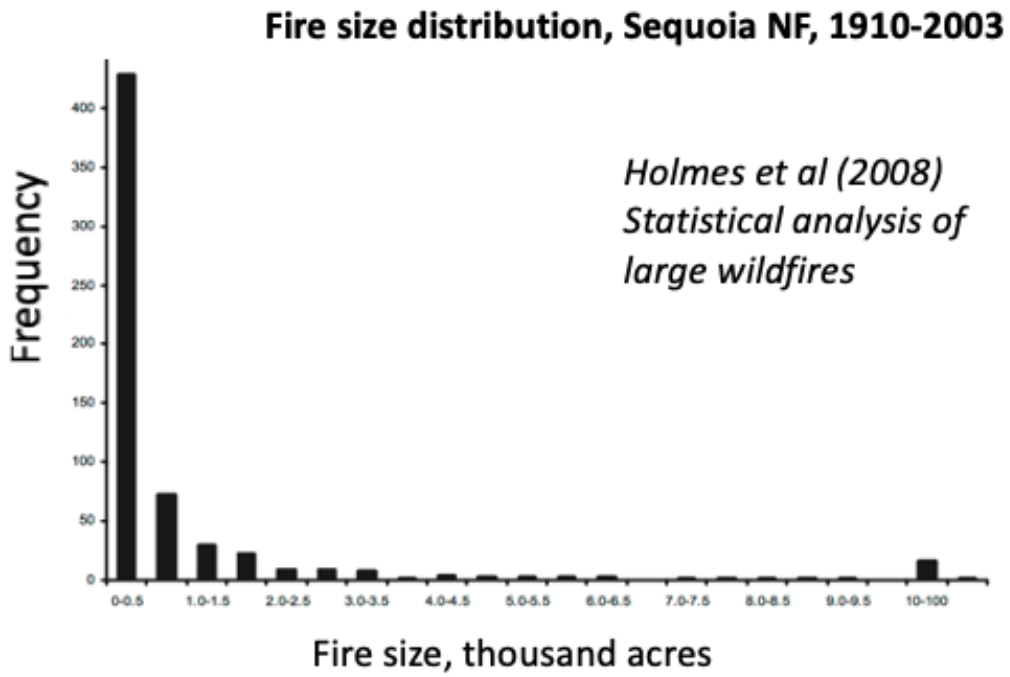
Susceptibility due to broad, slow changing factors

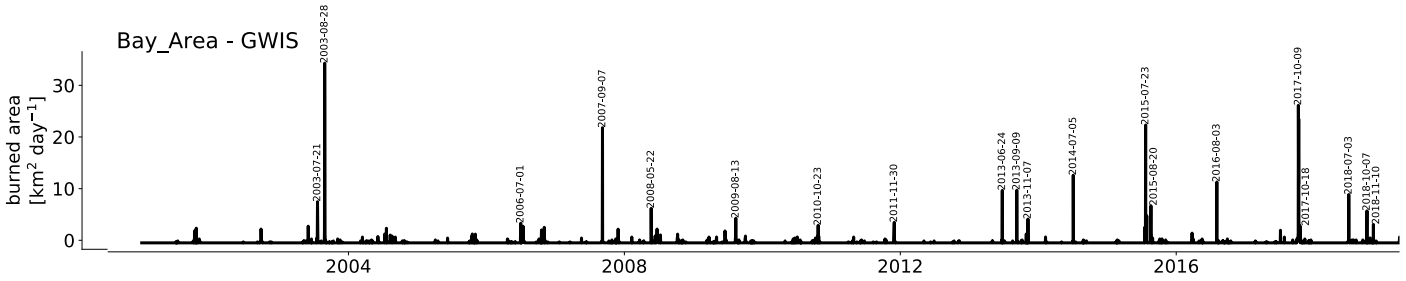
+

A 1-5 day period of locationally-specific weather

+

A fortuitous ignition at right place and time





Times series daily burned area Bay Area

We characterize conditions leading to historic CA extreme fire weather/growth with a 2-track approach:

- Extreme Weather Typing Identify archetypal *regional weather patterns* associated with past days of large fire growth over the satellite fire detection era in distinct regions across CA
  - Historical trend analysis
  - Identification in climate projections

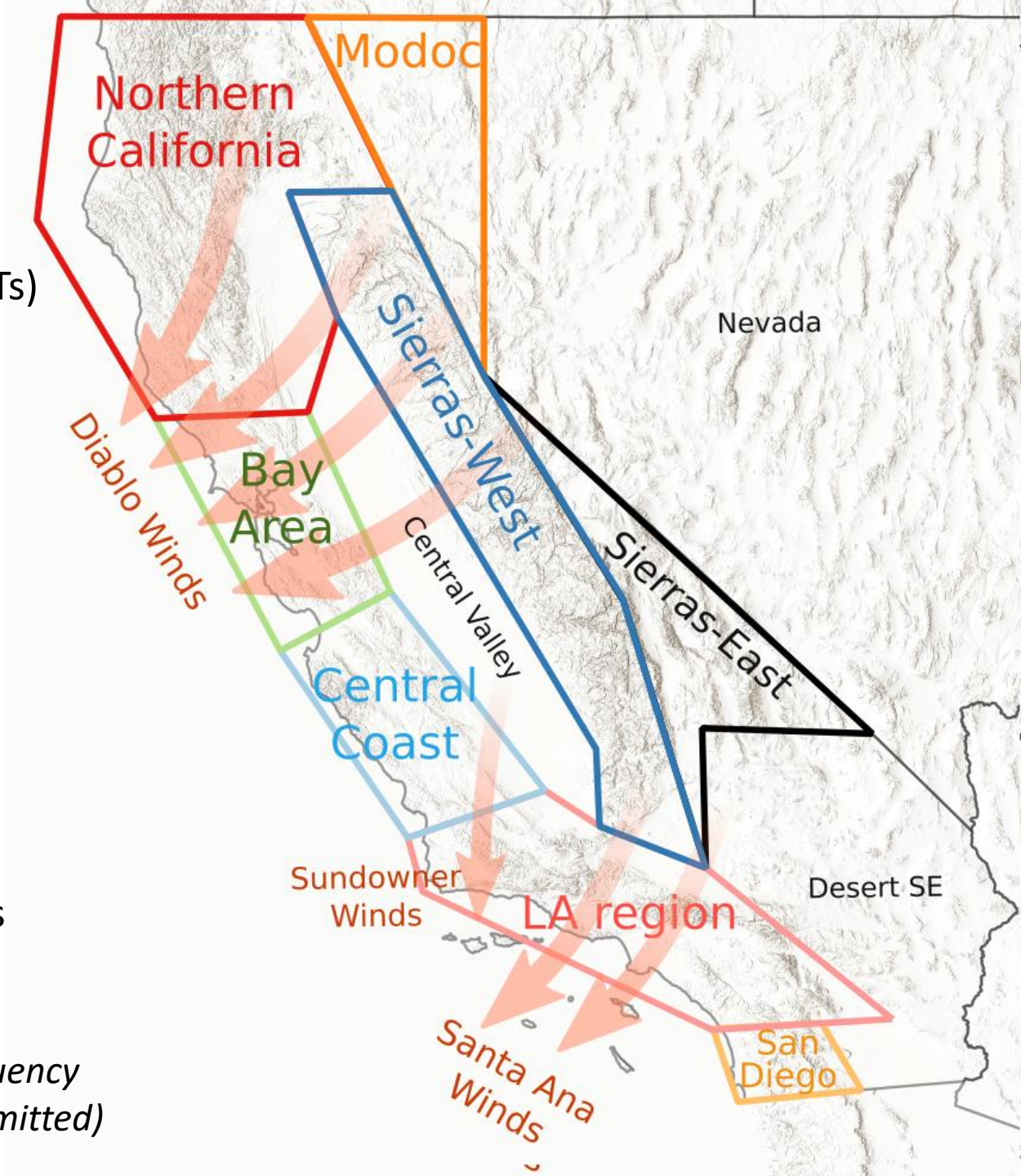
- Fine-scale deconstruction of key events Refine understanding of the airflow regime and fire behavior in these types with *convective-scale* simulations of key/typical wildfire events using a coupled weather-fire model
  - Identify conditions for extreme winds & "hotspots"

PYREGENCE™

Characterizing Historical Fires: Extreme weather typing

- **Hypothesis:** limited set of Extreme Weather Types (XWTs) that favor large daily fire growth

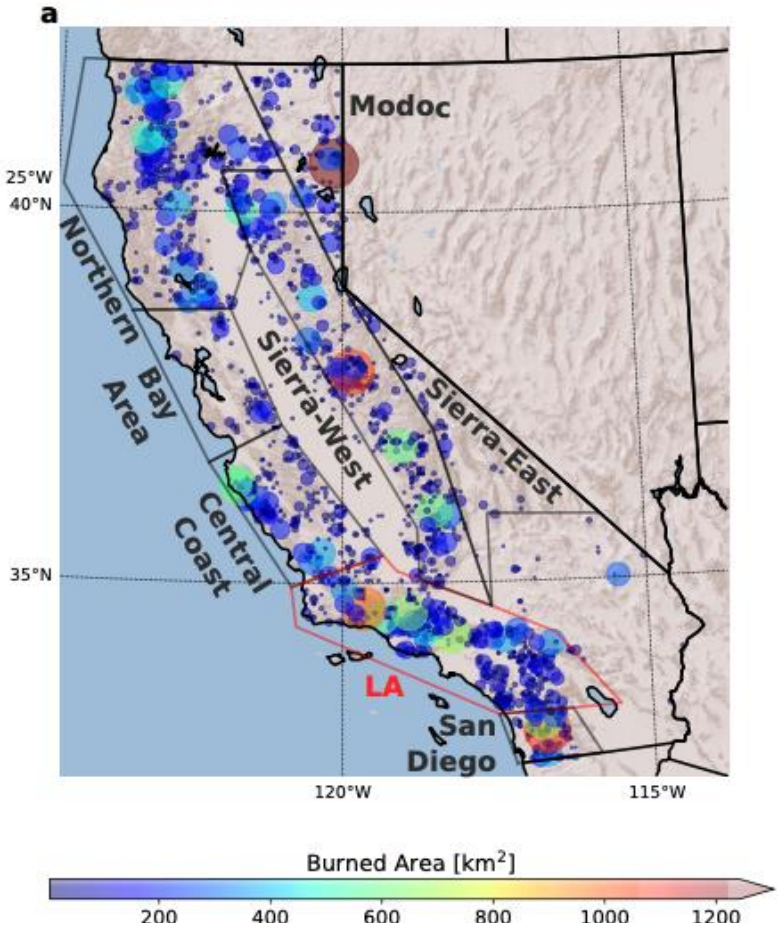
- **Method:**
  - Specify 8 homogeneous, distinct Fire Weather Regions that feature similar fire environment conditions
  - Compare ECMWF 5th generation global reanalyses (ERA5) daily average fields with Global Wildfire Information System (GWIS) dataset (Art´es et al., 2019) Jan 2001 - Nov 2019, NASA FIRMS for 2020
  - Adapt ML cluster analysis (Prein & Mearns, JGR-A, 2021) to identify 2-4 XWTs associated with the days with largest daily burned area in each region

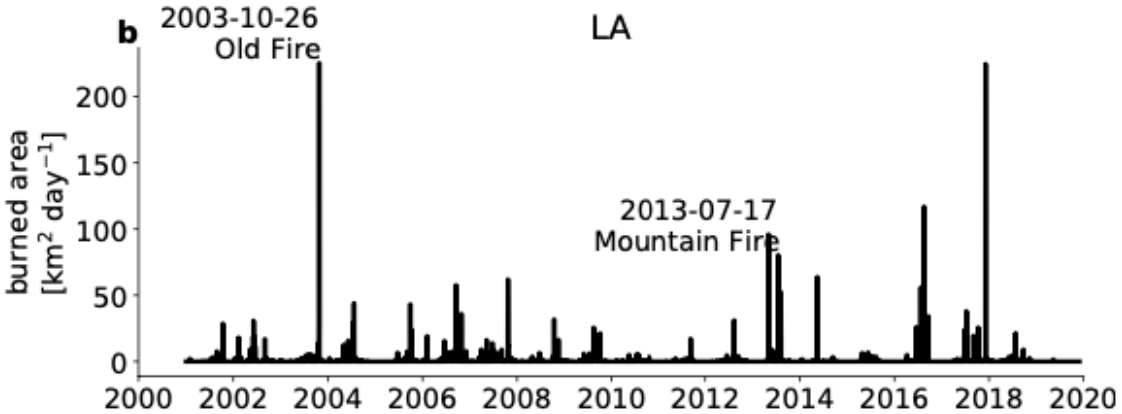


A Prein, J Coen, A Jaye (2021) The character and changing frequency of extreme California fire weather. J. Geophys Res. Atmos. (Submitted)

Extreme Weather Typing (XWT) Analysis

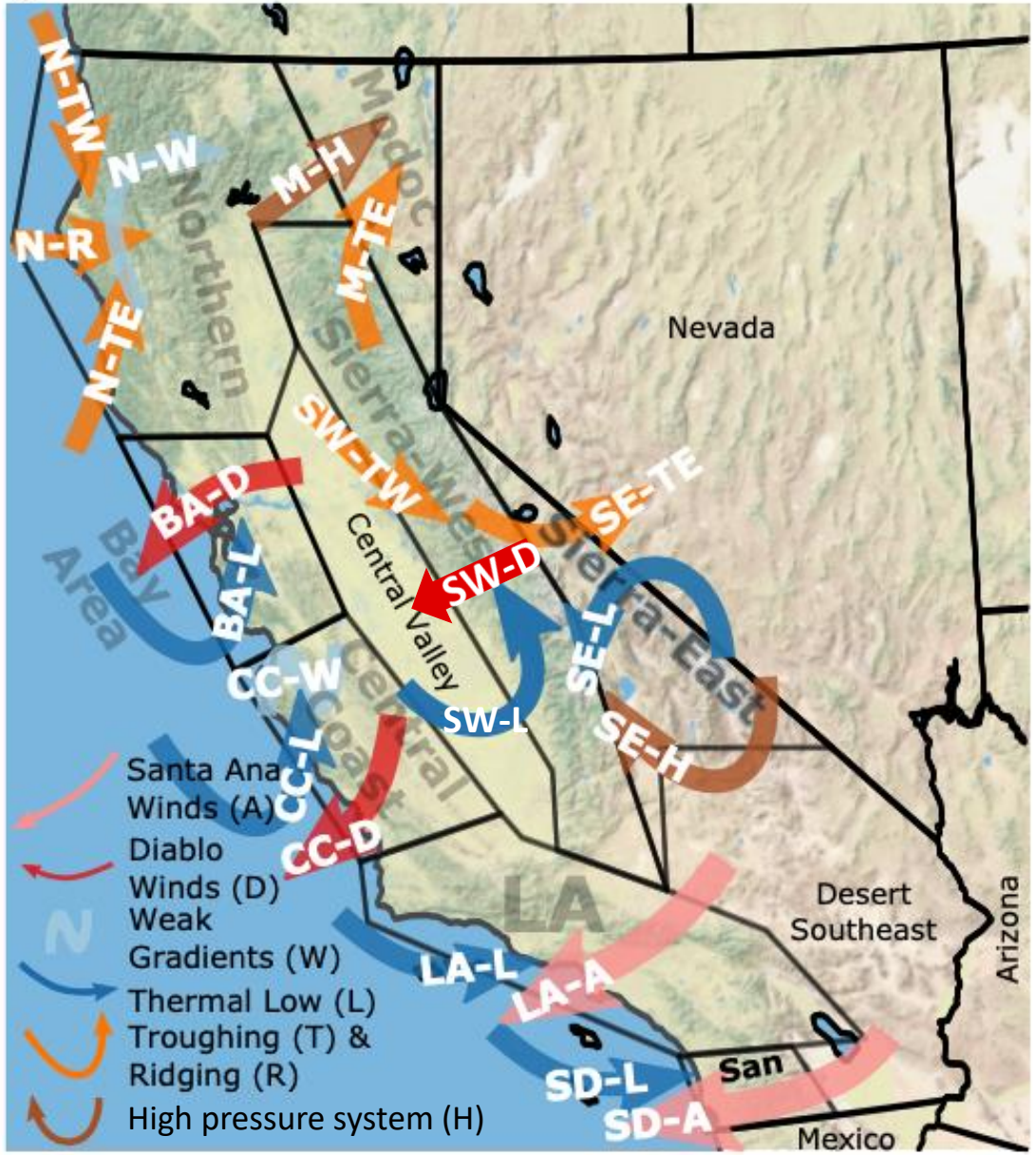
- Use the GWIS daily burned area product to accumulate daily burned area in each region (NASA FIRMS for 2020)
- Select the top N (4, 6, 10, or 16) days that are at least a week apart
- Select atmospheric variables that could characterize the large-scale flow conditions and their impact on fire behavior.
  - Tested 33 variables encompassing *dynamical forcing* (wind at various heights, pressure), *thermodynamic forcing* (T and moisture at various heights), and *convective forcing indices* for ability to predict extreme daily burned areas
  - Test all possible combinations of up to 3 of the 33 variables to ID variables whose spatial gradients have the most predictive skill





Summary of XWT results:

- The most extreme fire growth days are associated with archetypal weather patterns (XWTs)
- Some XWTs are familiar (such as Santa Ana/Diablo wind events), others less so
- Clear seasonal cycle with summer and autumn maxima
- Extreme fire days dominate burned area statistics, with top 1% of days accounting for between 35% in the Northern region – 77% in San Diego region.
- The rapid increase and decay in daily burned area indicates that extreme fire days are closely related to short-term weather conditions more so than slowly changing factors, as found elsewhere (Abatzoglou & Kolden 2011; Riley et al. 2013)



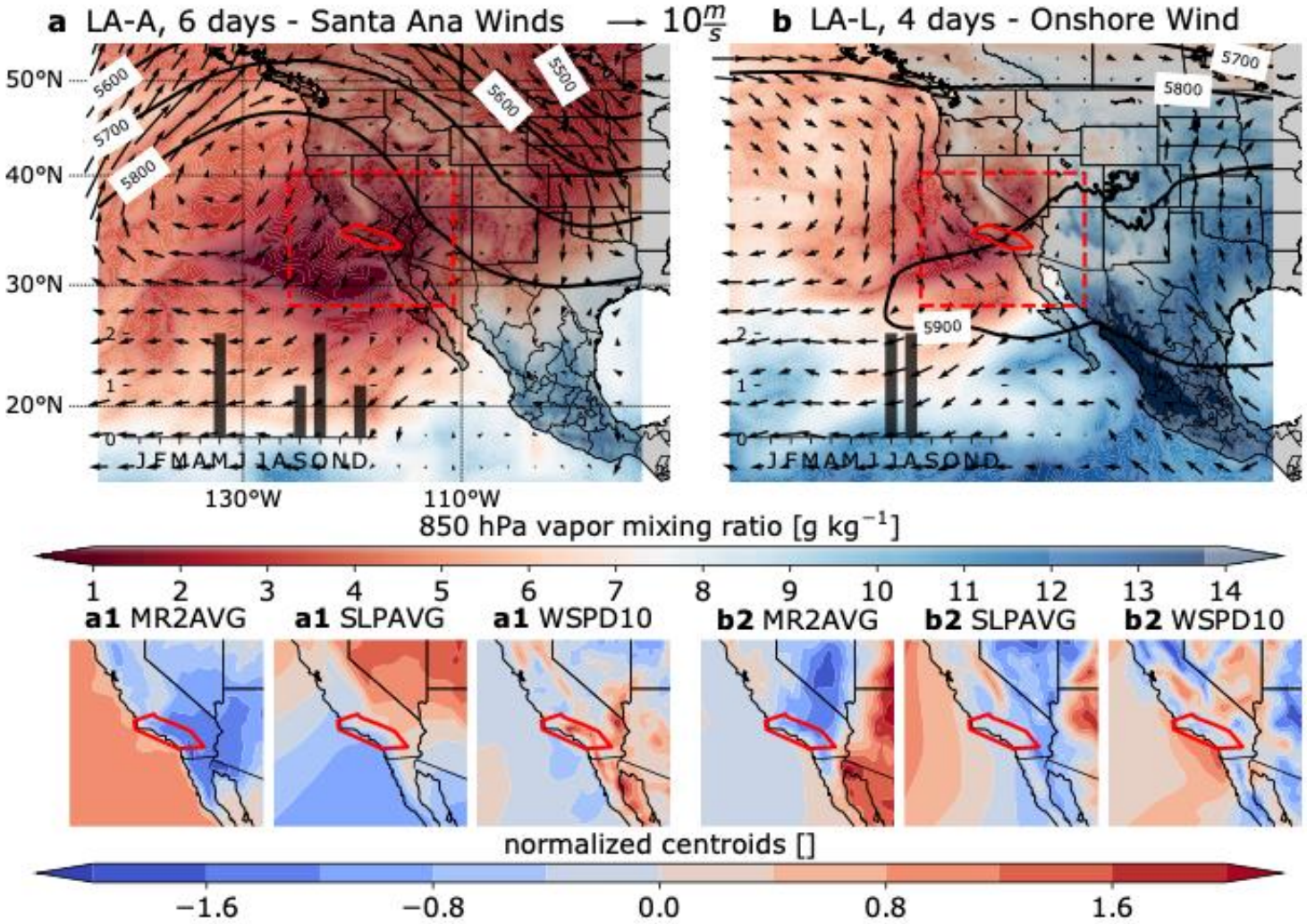
Overview of the synoptic conditions (arrow colors) and predominant low-level wind direction of identified XWTs in all eight sub-regions

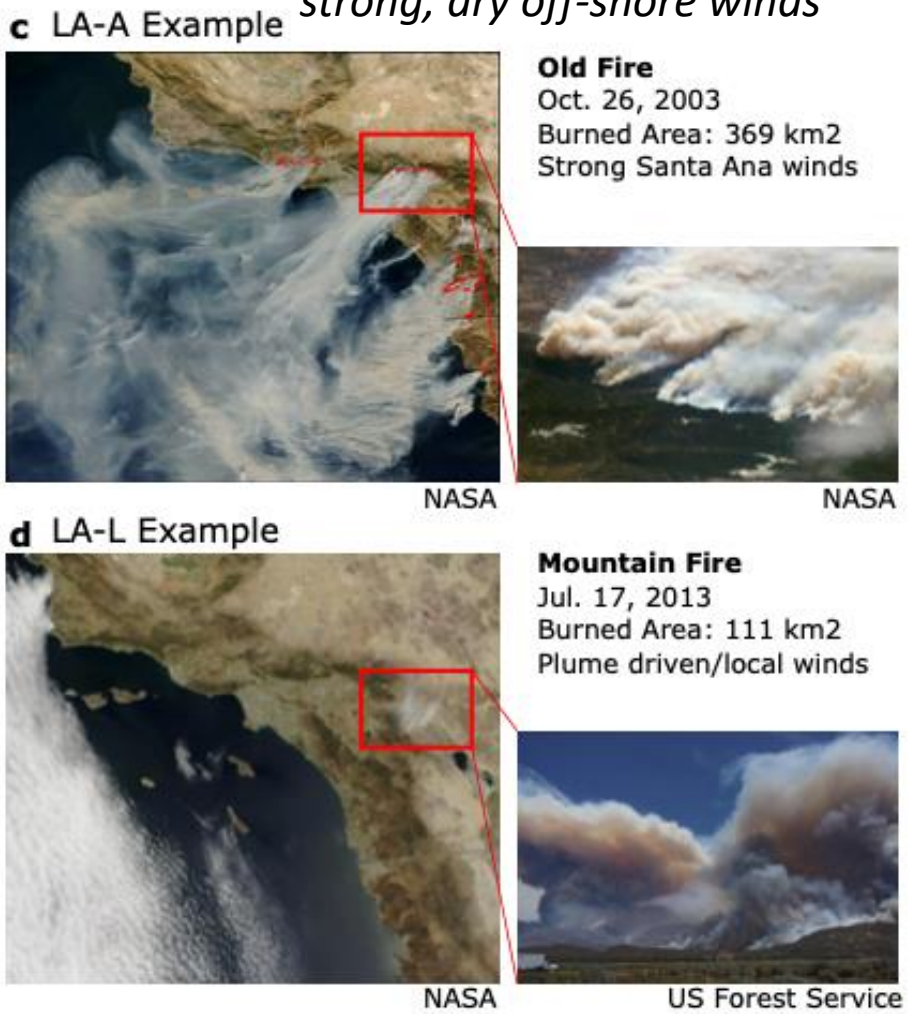
PYREGENCE™

XWTs allow us to characterize fires by types & flag days with potential for exceptional fire growth

Ex.: LA region

Wind-driven fires that occur under strong, dry off-shore winds

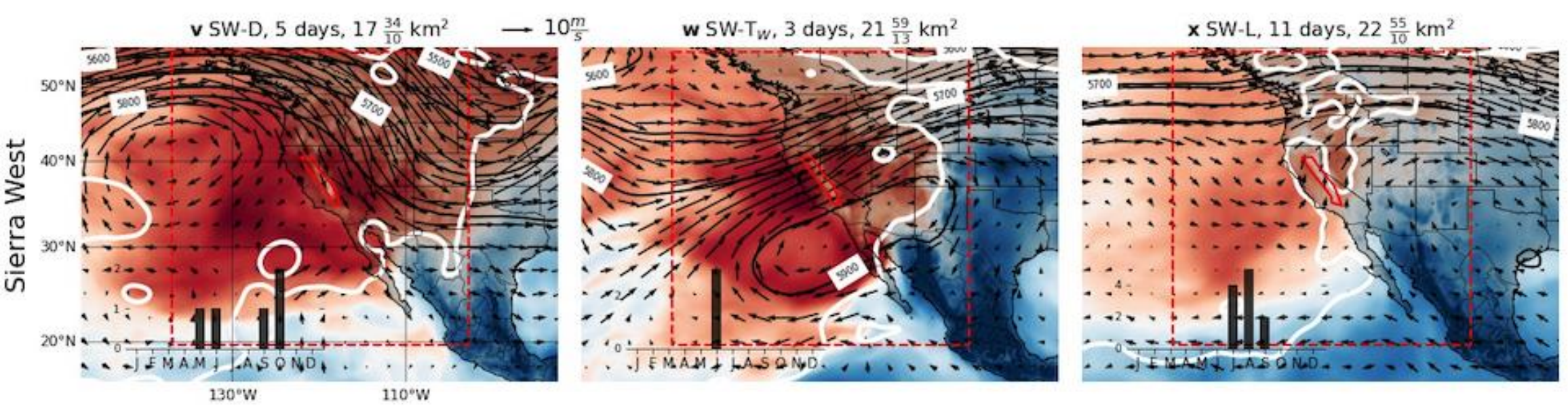




Plume-driven fires that occur low pressure anomalies (thermal low p systems)

* Pattern associated with the XWT.
* Duration
* Monthly occurrence frequency (seasonality)
* 3 variables found to best characterize XWTs

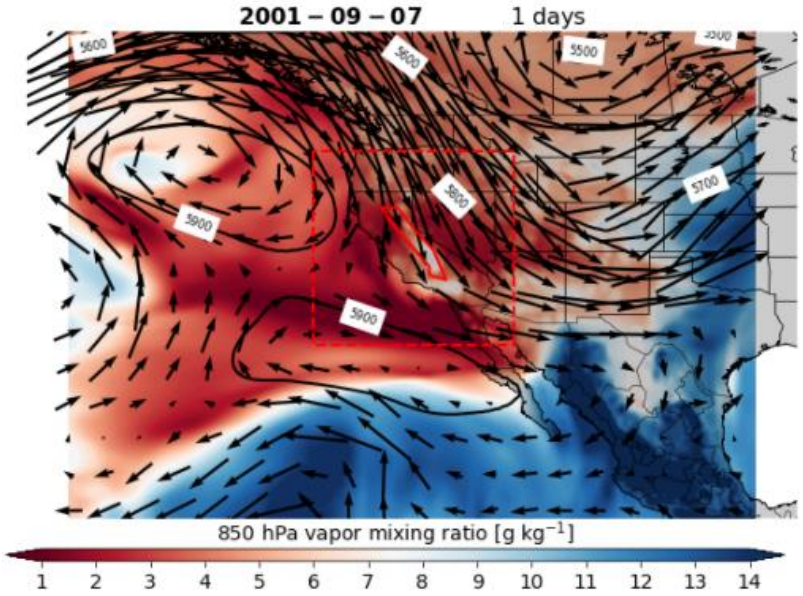
Sierra-West Region

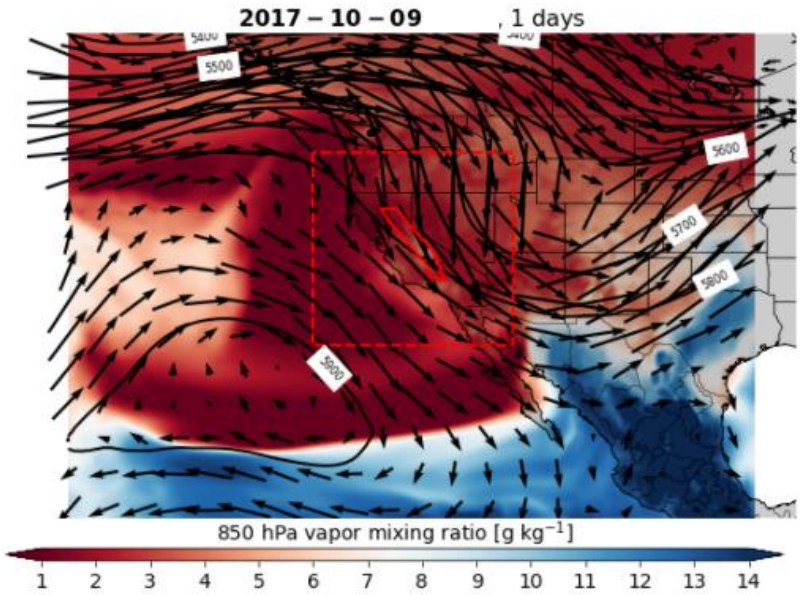


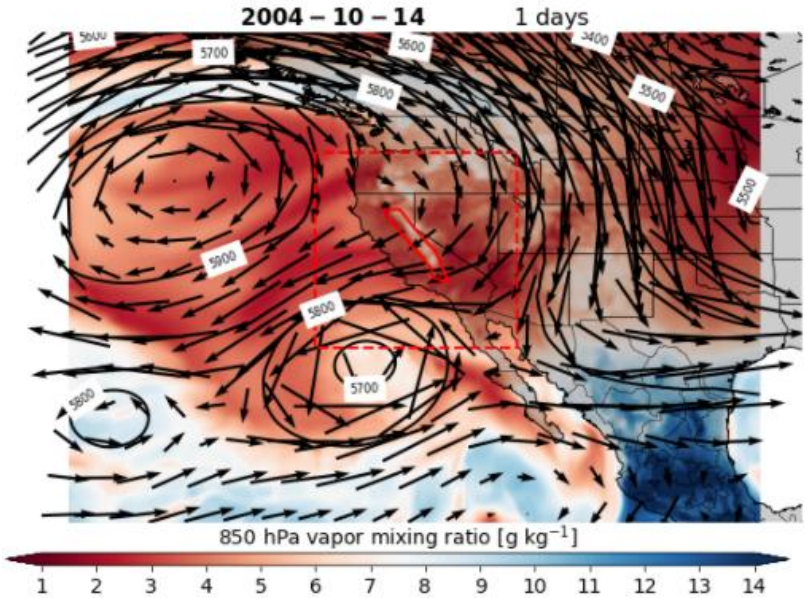
SW-D: strong NW winds on west side of a trough with surface downslope

SW-TW: SW winds within a high pressure system

SW-L: NE winds within a thermal low-pressure system







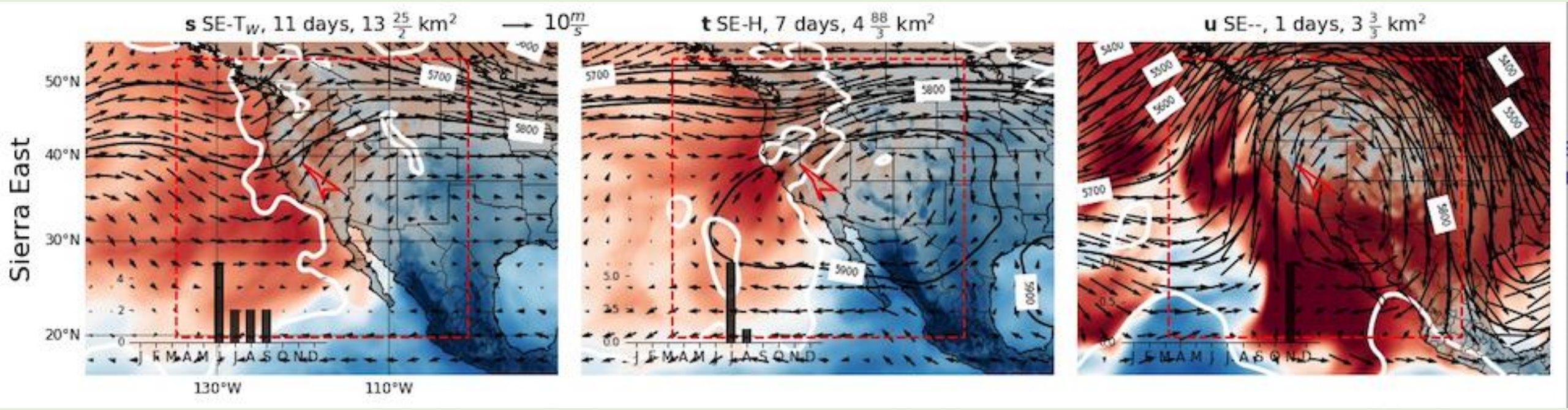
Sierra West wind Events

Top 6 Burned area days

Wind events

If we consider the Top20 Days:
'2016-06-25', '2015-09-13', '2002-07-22', '2001-09-07', '2012-08-12', '2017-10-09',
'2017-07-19', '2008-07-10', '2011-09-11', '2015-06-21', '2001-08-21', '2013-05-02', '2017-07-09', '2007-06-24', '2014-08-19', '2004-10-14', '2013-08-24', '2008-06-13', '2016-08-20', '2008-06-23'

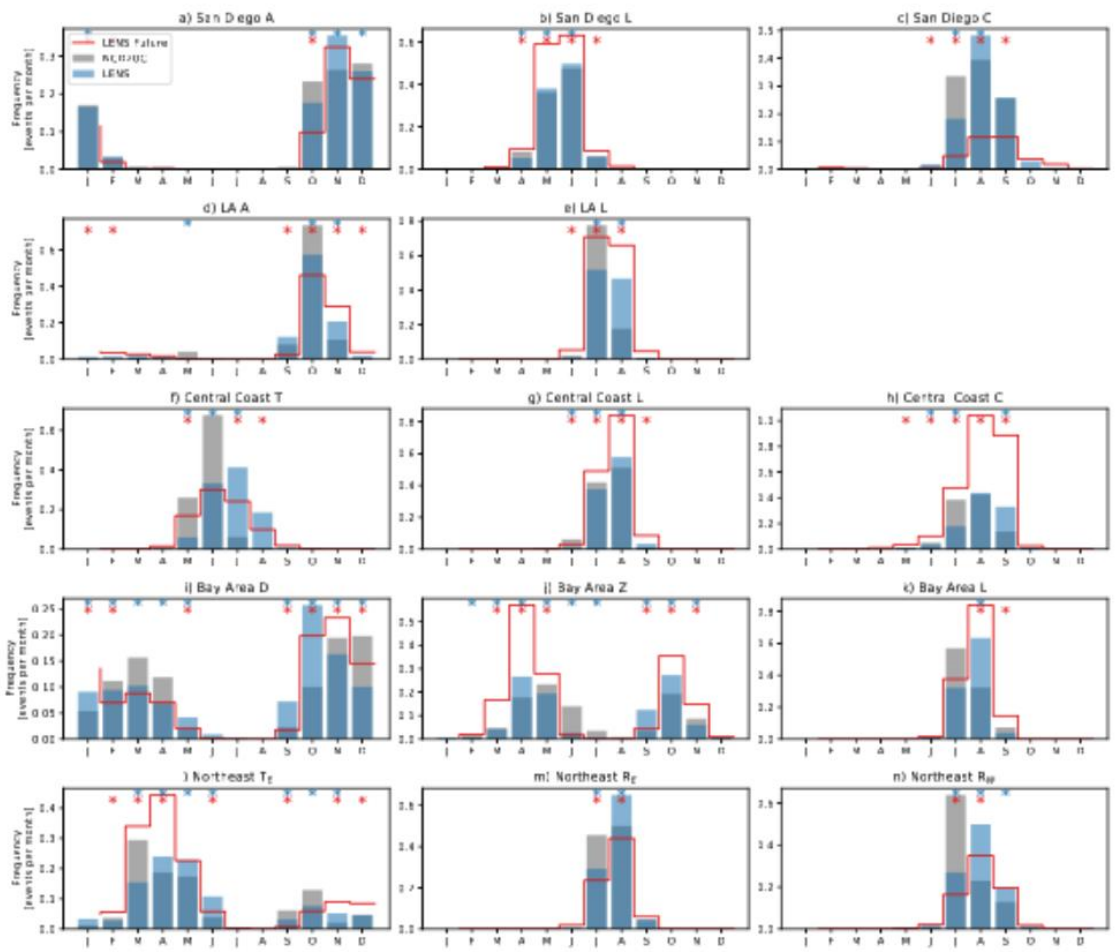
Sierra-East Region



SE-TW – SW winds in a trough

SE-H –W/SW winds caused by anti-cyclone over Four Corners area

SE- dry, SW winds caused by a ridge



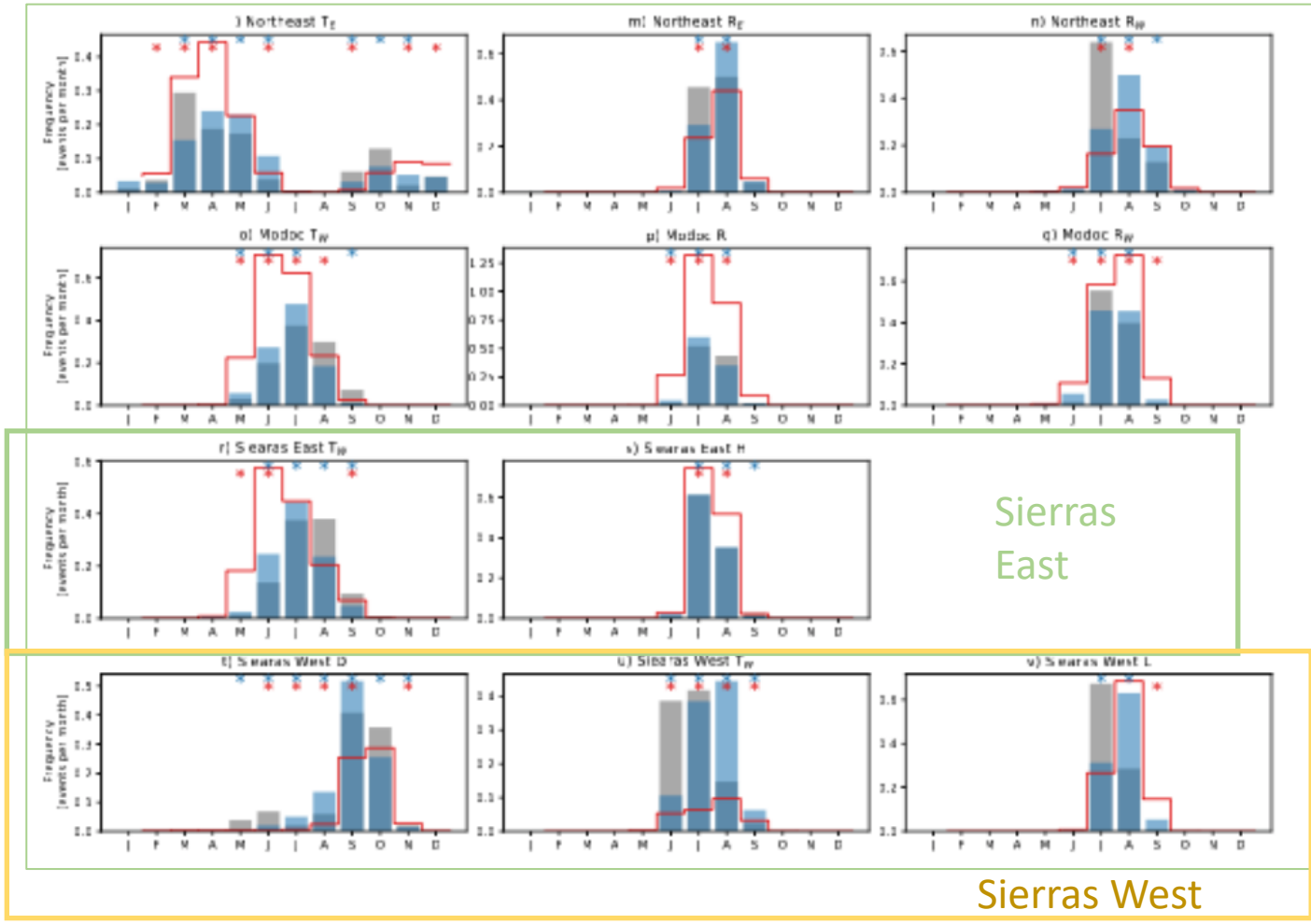


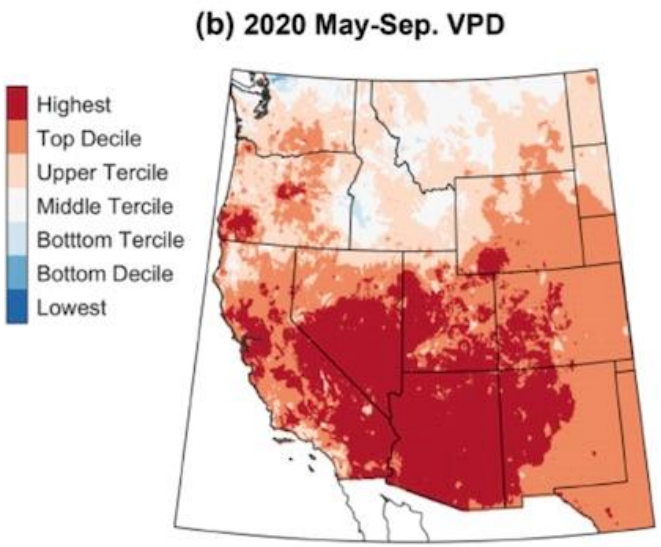
Figure 4. Annual cycle of current climate (1975–2015) XWTs in the NCD20C (gray bars), LENS (blue bars), and future climate (2060–2100) LENS simulations (red line). Results for different fire regions are chosn in rows and XWTs are shown in columns. Month that have significantly different XWT frequencies in the current climate LENS simulations compared to NCD20C are highlighted with a blue asterix. Months with significant changes in future climate XWT frequencies are highlighted with a red astrix. Significance is assessed by a two-sided Mann-Whitney U test (P=0.05).

<u>Future:</u>

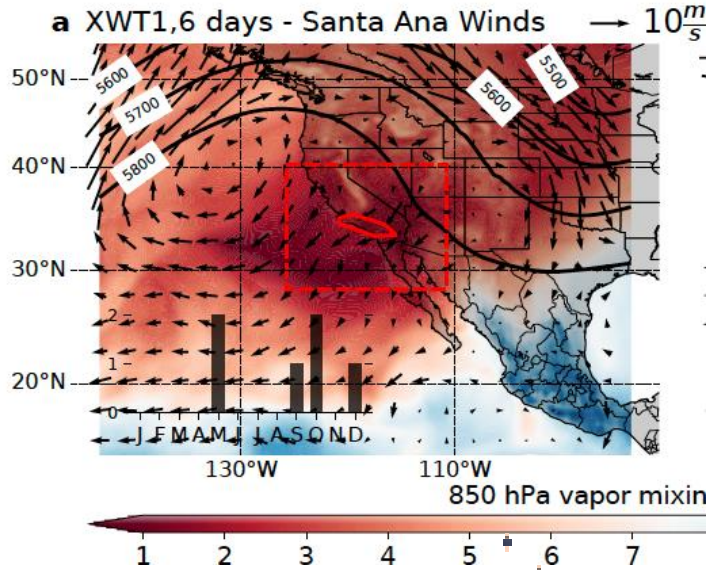
Eastern Sierras: increase in frequency in spring-summer wind events

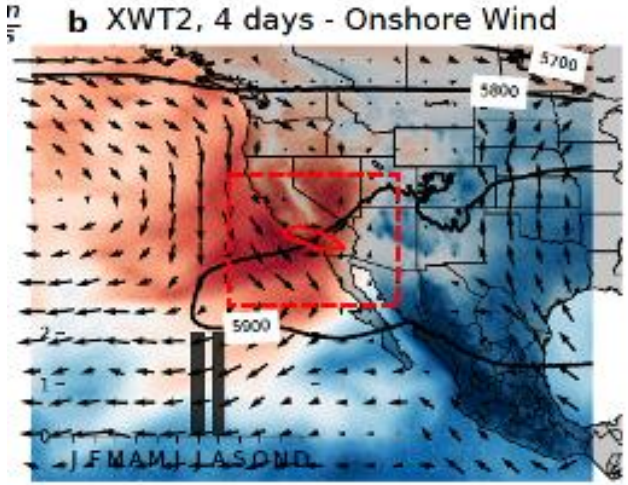
Western Sierras: Contraction in the Diablo season and decrease in frequency. Shift in month of the upslope events deeper into fall

Multiscale analysis of historical fires: Joining the scales



Courtesy of L. Tarnay





Topography shape and features, atmospheric stability, airflow dynamics

Ex.: Woolsey Fire

Inclined canyons, heavy mortality, a gentle nudge of wind upslope…

Ex.: Creek Fire

Underlying conditions + regional weather pattern + local factors = !!!!!!

Approach: Catalog susceptibility to types of events across CA & place in knowledge framework for practical use

PYREGENCE

Mechanisms for extreme fire growth:

Rapid fire growth occurs at either end of a spectrum

Wildland **fire events** are often classified as either **wind-driven** or **plume-driven**, depending on which appears to be driving fire growth. Both types are ultimately driven by strong winds, but….

Ambient winds are usually weak. Strong winds are internally generated by fire's heat release ("fire-induced winds")

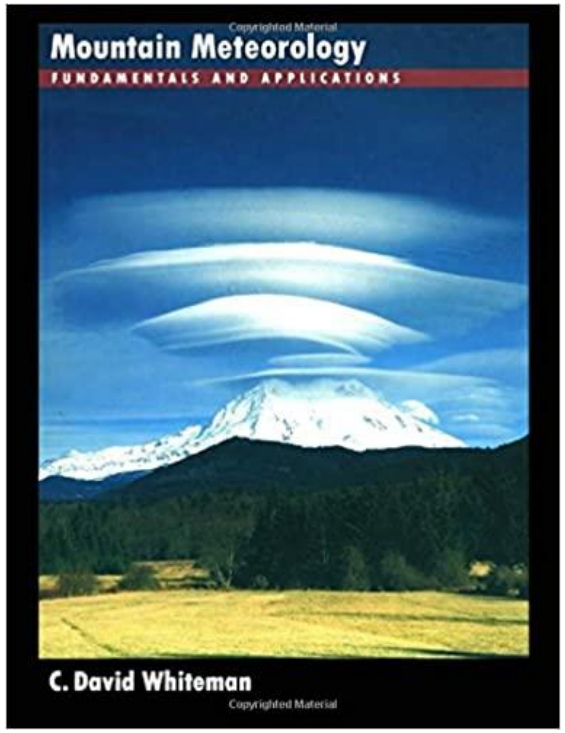
Ambient winds are strong. Events often associated with exceptional ambient winds.

Currently: Events appear mysterious because extrema at both ends are the weakest links of current tools
Whether plume-driven fire-induced winds or complex airflows in mountainous terrain, no simple tool succeeds.

Wind-driven wildfire events - Background (1)

Idealized examples

- Airflow over complex terrain: flow regimes
  - Some of important parameters: atmospheric static stability (lapse rate), wind speed, terrain aspect ratio (slope). Flow can do many different things.
  - Whiteman - Mountain Meteorology describes many flow regimes



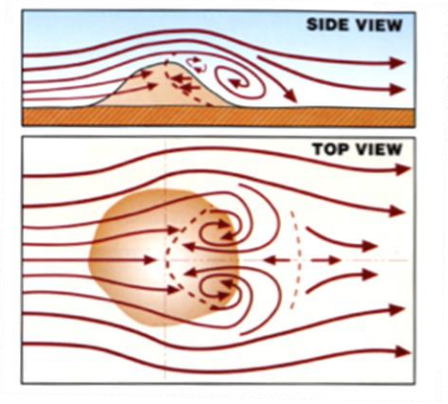


Fig. 1a. Neutrally stratified air is easily carried over a mountain barrier and may produce eddies on the lee side. (From Whiteman, 2000)

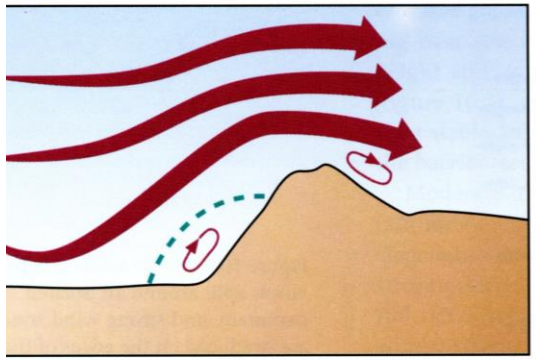
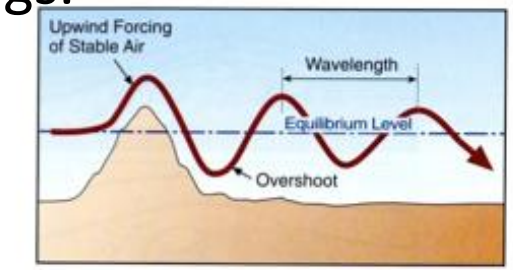


Fig. 1b. Depending on air speed and stability, steepness may cause airflow to separate from the ground on the lee side of terrain. (From Whiteman, 2000)

Isentropes – lines of constant "potential temperature"



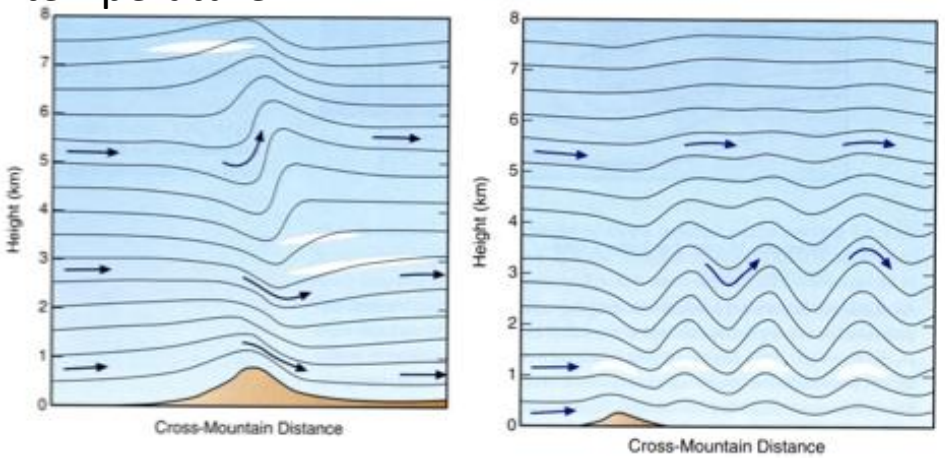


Fig 2. a) Schematic of generation of gravity waves, b) Vertically propagating mountain wave, and c) trapped lee wave. All figures from Whiteman(2000).

Wind-driven wildfire events: Background (2)

Looking for real analogues in other locations

- In investigations of 2000s Diablo/Santa Ana fire events, analogies made with studies of windstorms. Ex.: CO Front Range of Rocky Mountains

- Hypotheses: atmospheric gravity wave steepening and/or breaking, wave reflections from critical levels….

- Do these apply to CA events?

1972 Boulder downslope windstorm (Peltier and Clark, 1979)

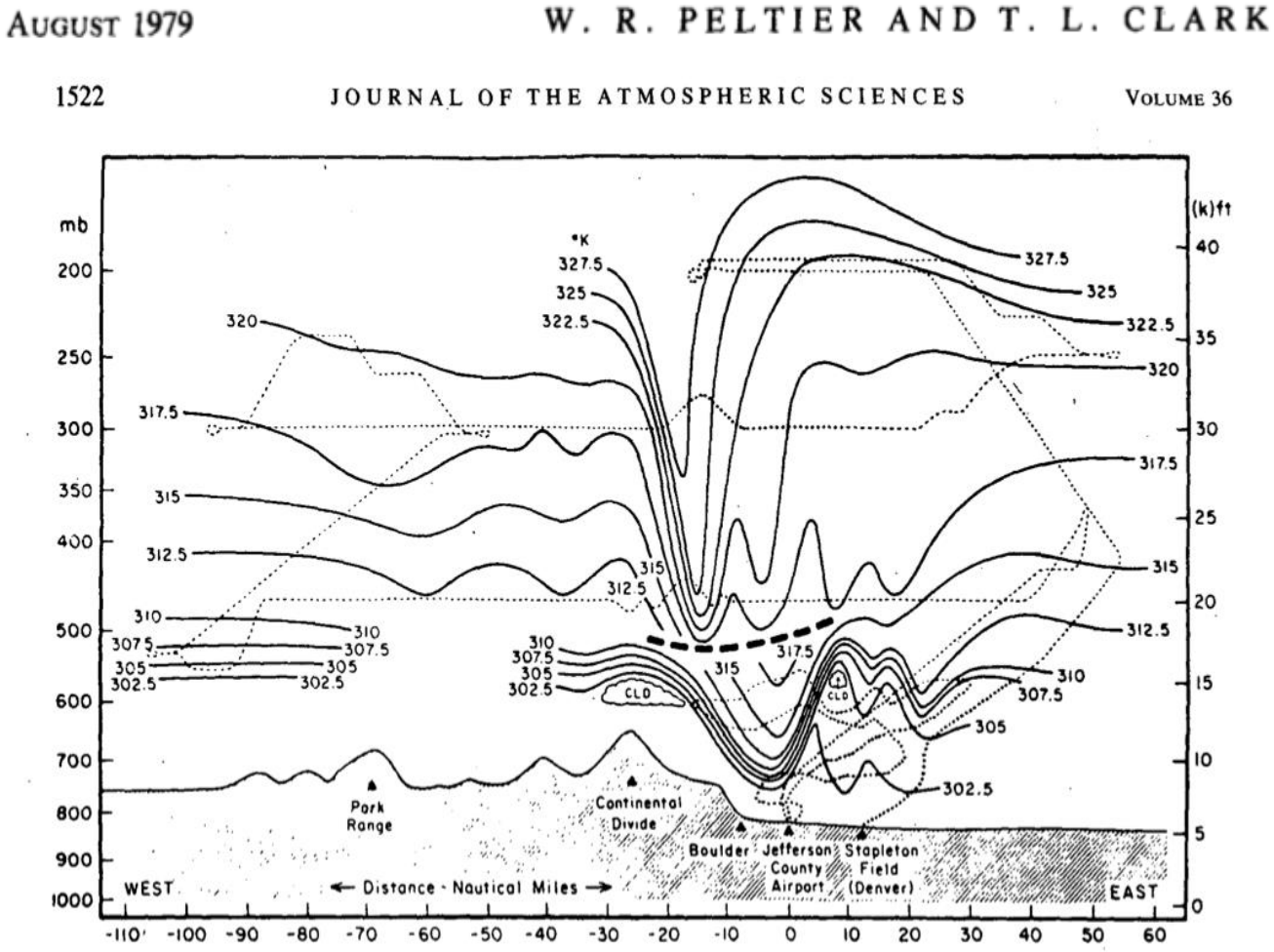
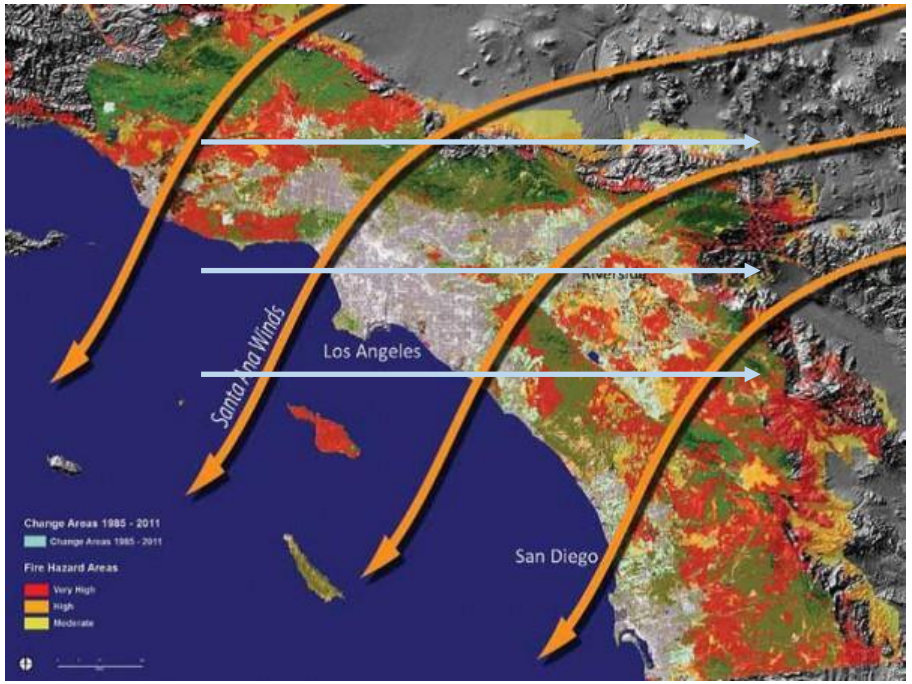


FIG. 26. Isentrope field for the 11 January 1972 severe wind storm in Boulder (after Lilly, 1978).

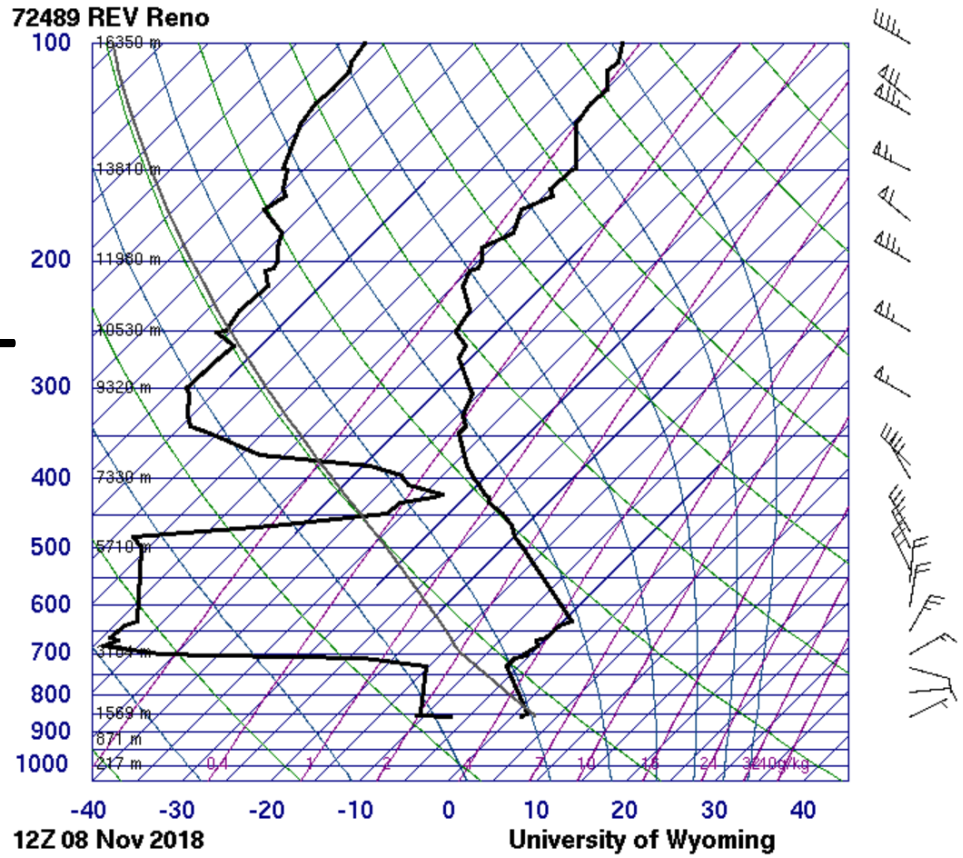
Flow regime factors influencing microscale winds in offshore wind-driven events

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



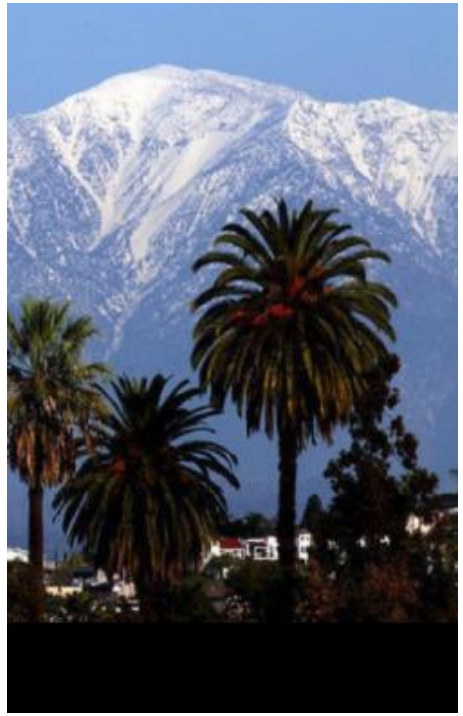
+

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



+

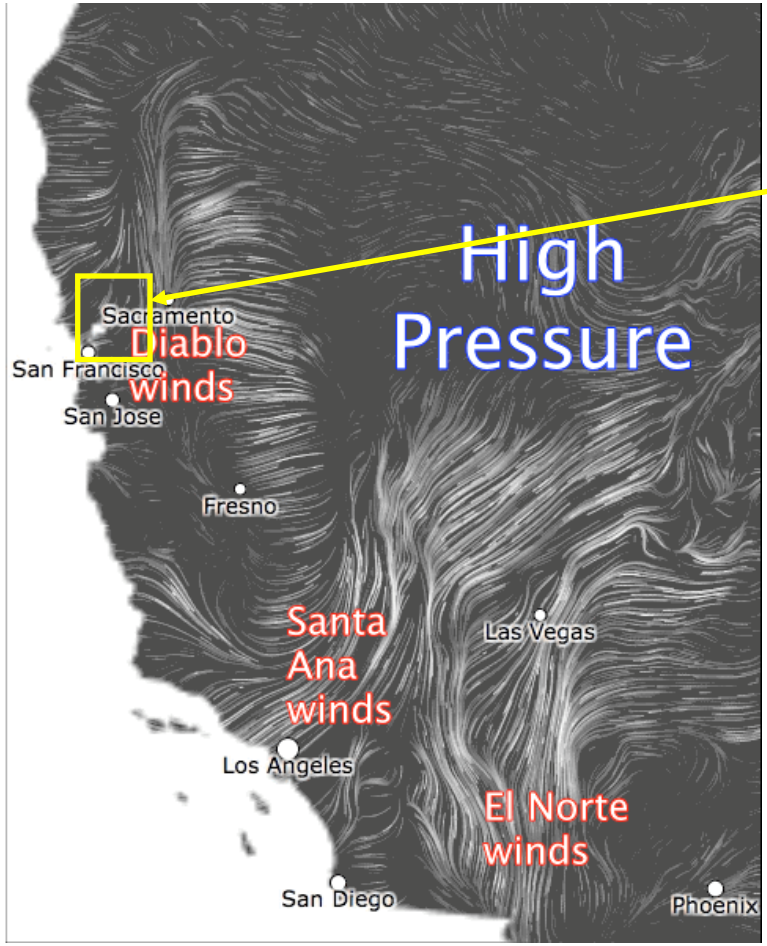
Topography features



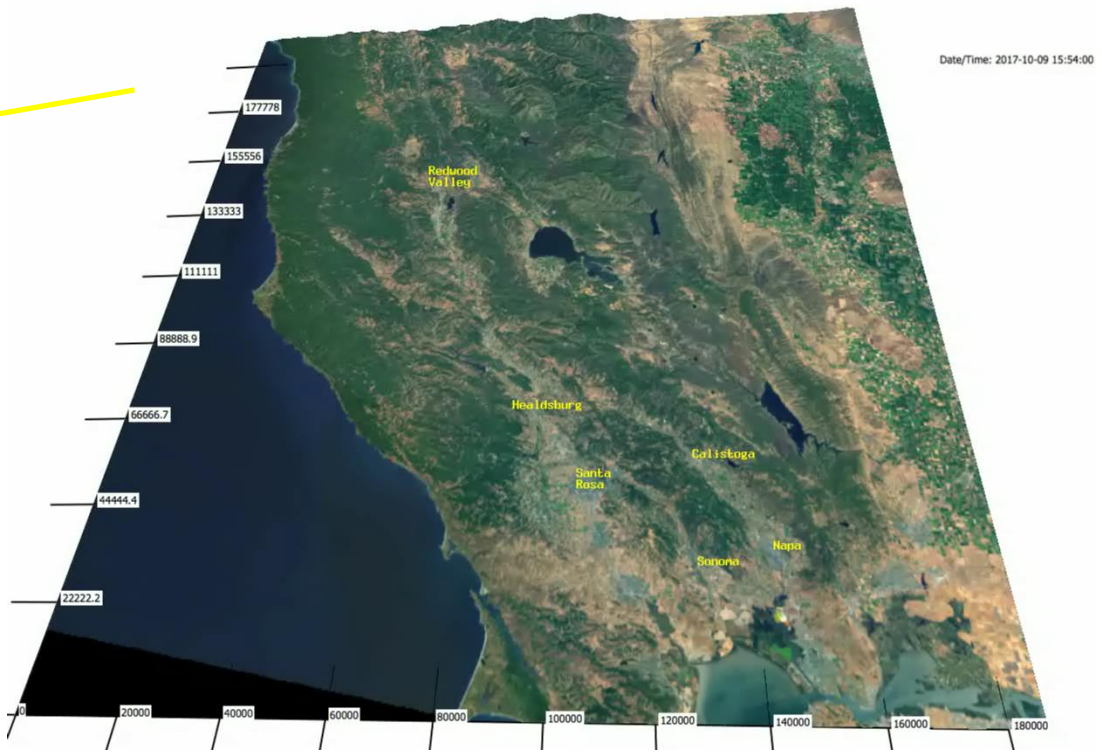
This combination – very stable surface layer traveling at high speed over a range of terrain features creates unique flow effects (but doesn't support waves).

Wind-driven wildfire events

- Events vary in strength (based on pressure gradient)
- Location of strongest winds passes from north to south
- Great deal of variability across CA
- Little examination of details in Santa Ana or Diablo airflow
- CA events are unique, few resemble existing scientific literature
- Important science gaps.



2017 Napa Firestorm
4D weather simulated using CAWFE model
Shown: near-surface wind
Oct. 8 11 am – Oct. 9 2017 ~4 PM PDT



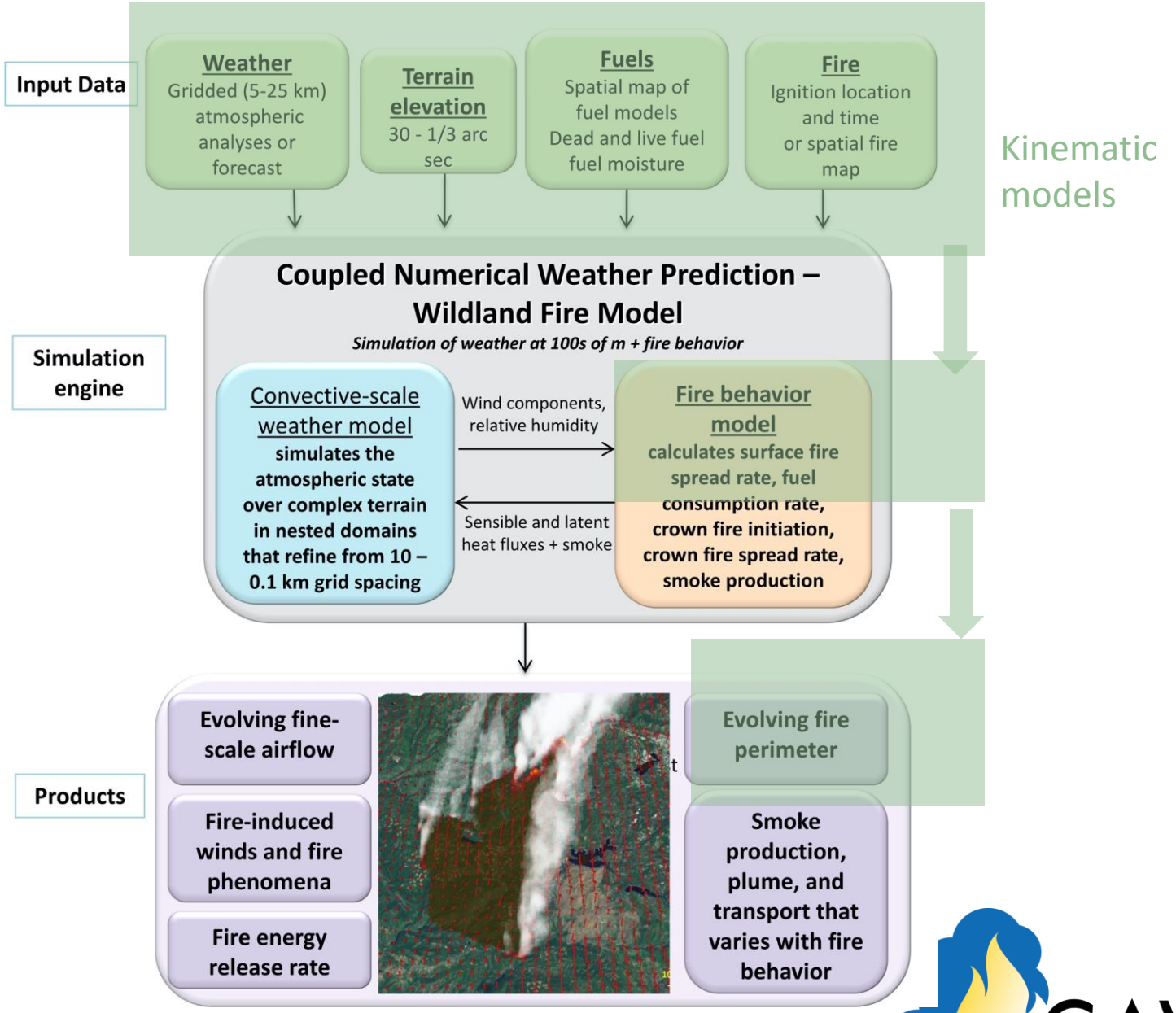
The Diablo wind event created local regions with greater accelerations, stagnation regions, and pulses/surges

Method

- Apply CAWFE coupled weather – fire model optimized for fine-scale simulations in complex terrain to historical fire events

- Value: 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



CAWFE™
Coupled Atmosphere-Wildland Fire Environment

The CAWFE® model couples Numerical Weather Prediction with a wildland fire behavior module

a. The Clark-Hall Numerical Weather Prediction Model

Solves prognostic fluid dynamics equations of motion for air momentum, pressure, a thermodynamic variable, water vapor, and hydrometeors on a finite difference grid.

Dynamic core

- 3-dim., time dependent
- Nonhydrostatic, anelastic *Solution method*
- Terrain-following coordinates, vertically stretched grid
- Vertical + horizontal grid refinement
- 2-way interacting nested domains
- OpenMP[a] and MPI[b] parallelization

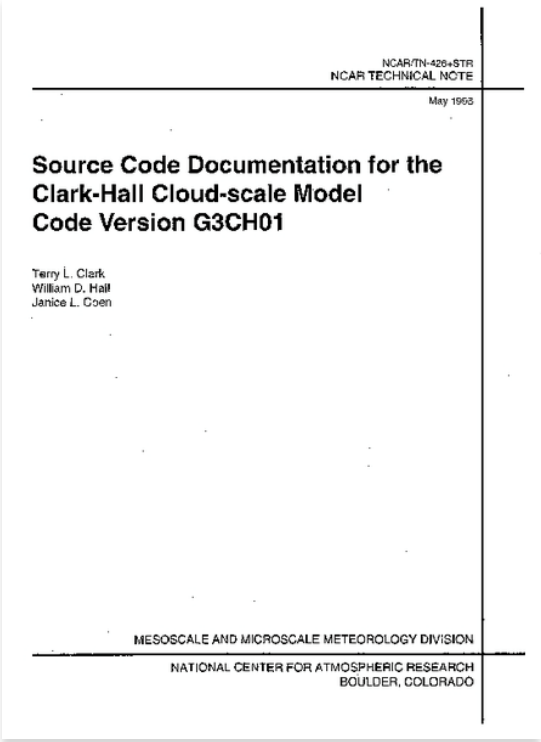
Introduction of wx environment

- Large-scale initialization of atmospheric environment using gridded analyses or forecast

Physics packages

- Models formation of clouds, rain, ice, and hail in "pyrocumulus" clouds over fires
- Tracks smoke transport
- Aspect-dependent solar heating

Designed for high-resolution (~ 100s m) simulations in steep, complex terrain.


NCAR/TN-426+STR
NCAR TECHNICAL NOTE
May 1996

Source Code Documentation for the Clark-Hall Cloud-scale Model Code Version G3CH01

Terry L. Clark
William D. Hall
Janice L. Coen

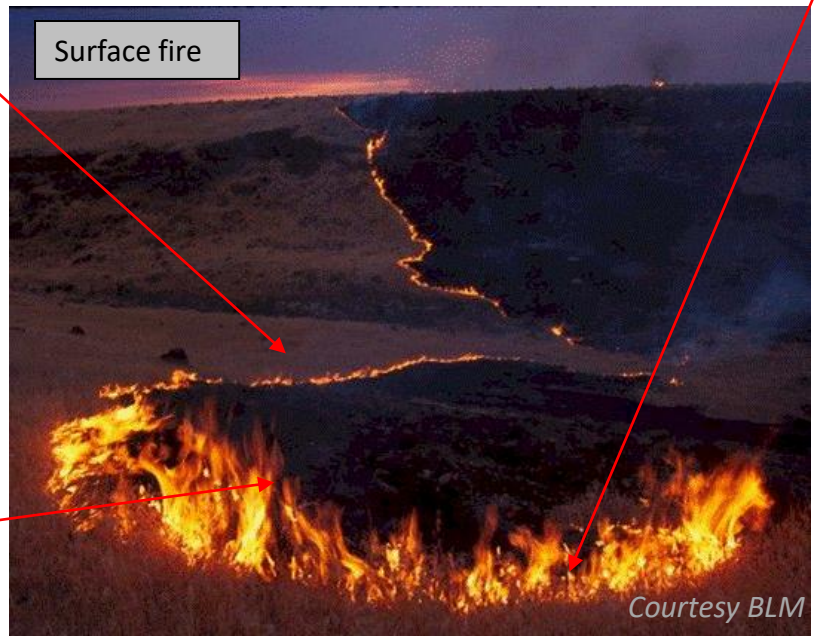
MESOSCALE AND MICROSCALE METEOROLOGY DIVISION
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
BOULDER, COLORADO

[a] *Clark, Hall, Coen 1996: Source Code Doc. for the Clark-Hall Cloud-scale Model. NCAR Tech Note.*
[b] *Clark et al. 2003: Numerical simulations of grassland fires. J. Geophys. Res.*

b. A Fire Behavior Module

Overview of Components

1. Represent & track the (subgrid-scale) **interface** between burning and nonburning regions (the 'flaming front')



2. Rate of spread (ROS) of flaming front calculated as function of **fire-affected** wind, fuel, and slope using semi-empirical equations (i.e. Rothermel (1972))

3. Post-frontal heat & water vapor release. Once ignited, the fuel remaining decays exponentially, acc. to lab experiments (BURNUP).

4. Heat, water vapor, and smoke fluxes released by surface fire into lowest layers of atmospheric model

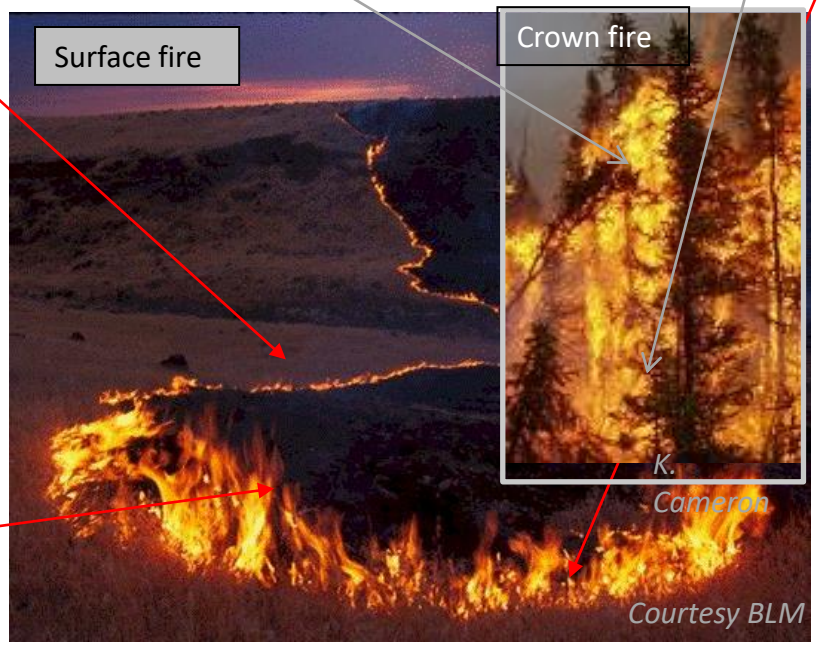
b. A Fire Behavior Module

Overview of Components

6. Calculate the rate of spread of the crown fire using empirical relationships to surface fire ROS

5. Surface fire heats and dries canopy. Does the surface fire heat flux exceed the (empirical) threshold to transition into the tree canopy (if present)?

1. Represent & track the (subgrid-scale) **interface** between burning and nonburning regions (the 'flaming front')

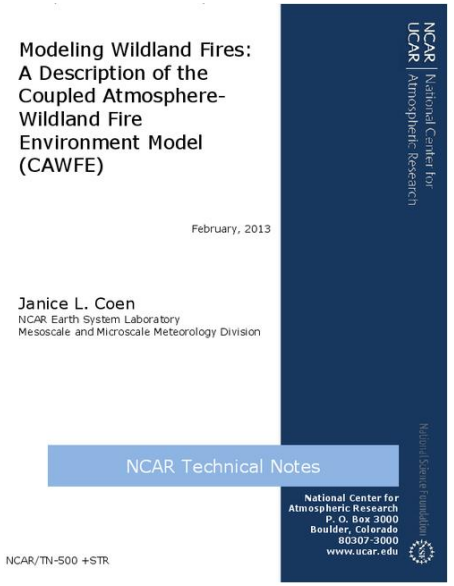


2. Rate of spread (ROS) of flaming front calculated as function of **fire-affected** wind, fuel, and slope using semi-empirical equations (i.e. Rothermel (1972))

3. Post-frontal heat & water vapor release. Once ignited, the fuel remaining decays exponentially, acc. to lab experiments.

4. Heat, water vapor, and smoke fluxes released by surface fire into lowest layers of atmospheric model

7. Heat, water vapor, and smoke fluxes released by crown fire into atmospheric model


Modeling Wildland Fires: A Description of the Coupled Atmosphere-Wildland Fire Environment Model (CAWFE)

February, 2013

Janice L. Coen
NCAR Earth System Laboratory
Mesoscale and Microscale Meteorology Division

NCAR Technical Notes

NCAR/TN-500 +STR

National Center for Atmospheric Research
P. O. Box 3000
Boulder, Colorado
80307-3000
www.ucar.edu

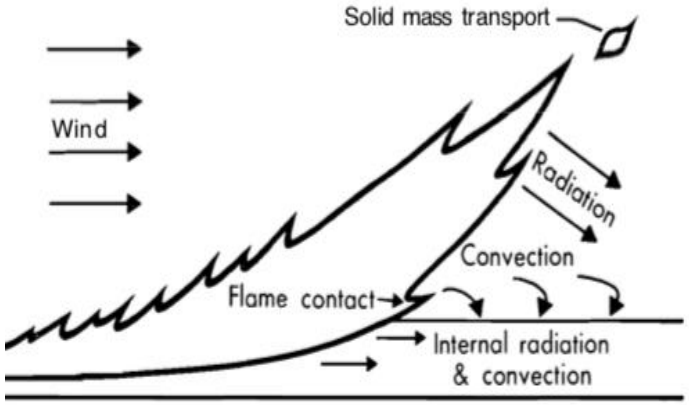
NCAR | UCAR National Center for Atmospheric Research

Atmosphere-fire "Coupling" allows the effects of environmental factors to *amplify* and *reinforce* each other through the atmospheric medium

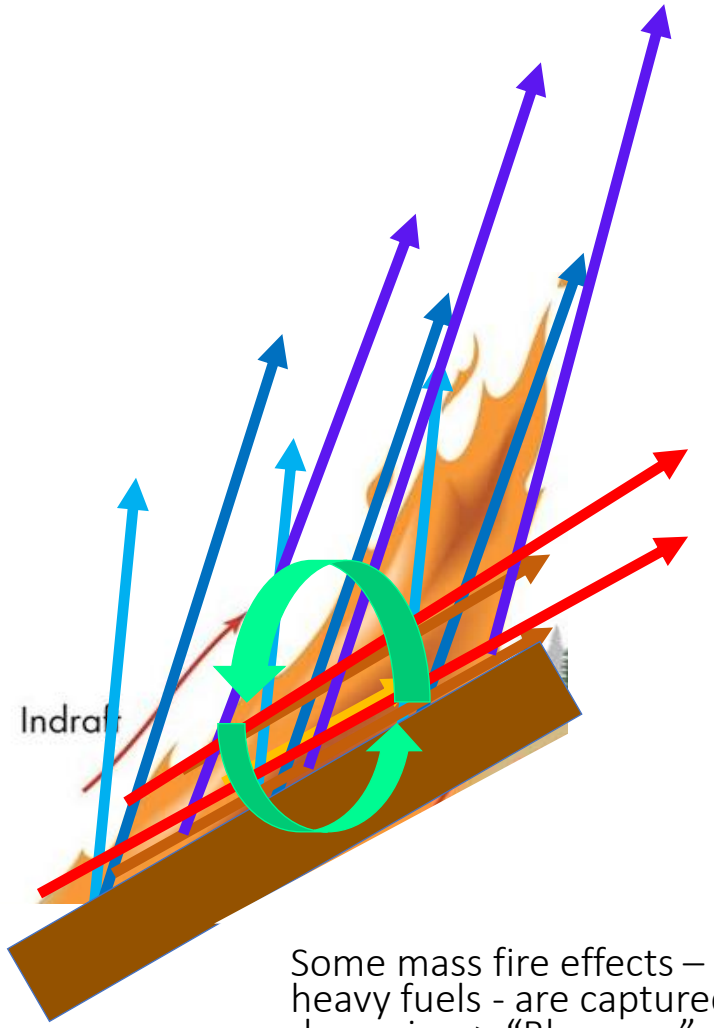
Semi-empirical Spread Rate of a Flaming Front
Rothermel (1972)

$$R = Ro\,(1 + \phi_w + \phi_s)$$

No-wind spread rate on flat ground (Fuel properties only) — wind factor — slope factor



Wind: has the strongest effect on fire but is "invisible" and the most variable in time and (perhaps) space



Some mass fire effects – and the effects of heavy fuels - are captured through internal dynamics -> "Blow-ups" "Fire storms"

CAWFE model configuration for real event

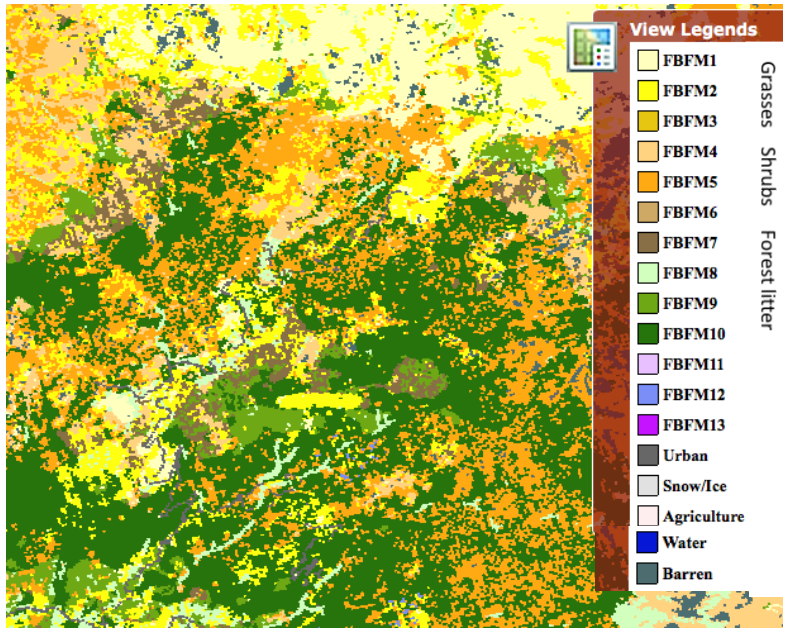
INPUT DATA: (1) Gridded synoptic/global weather analyses (past) or forecast (future)

INPUT DATA: (2) Terrain elevation data

INPUT DATA: (3) Fuel map (surface + canopy fuels) → spatial variability and fuel moisture

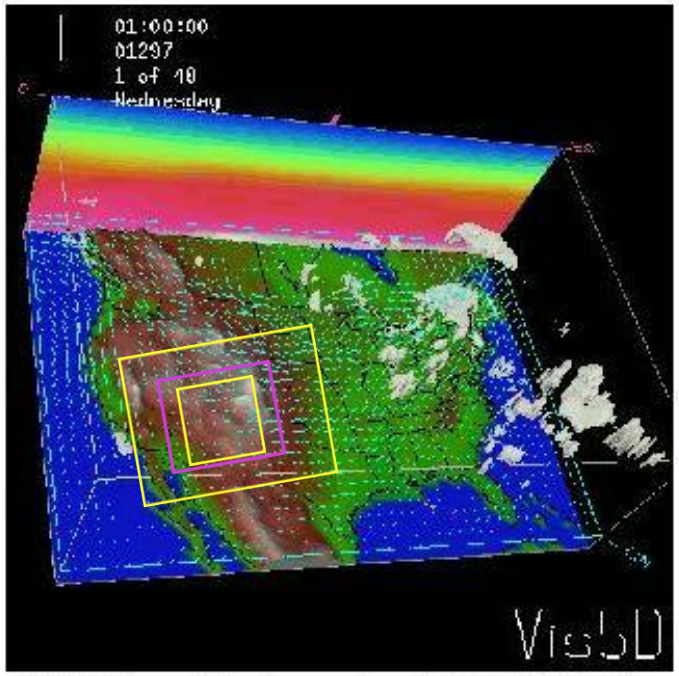
INPUT DATA: (4) Fire ignition: Time and location

Landfire.gov



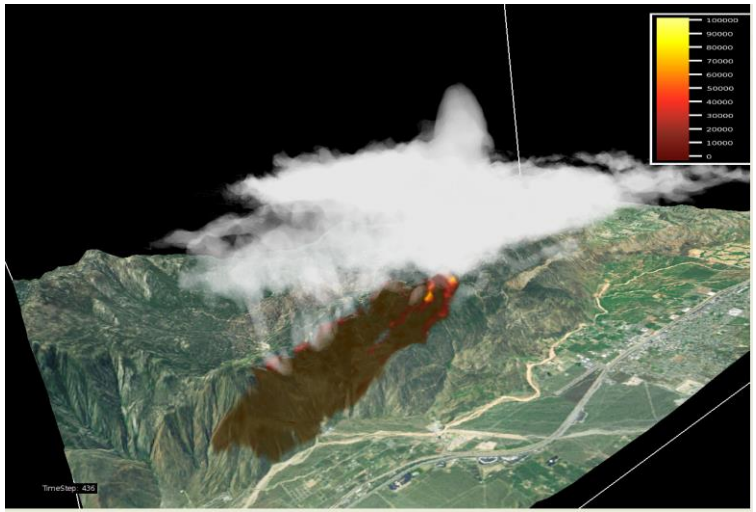
(Categorical) Surface Fuel Model

5 simultaneous nested weather modeling domains with horizontal grid spacing 10 km, 3.33 km, 1.11 km, 370 m, and 123 m telescope from a national forecast…

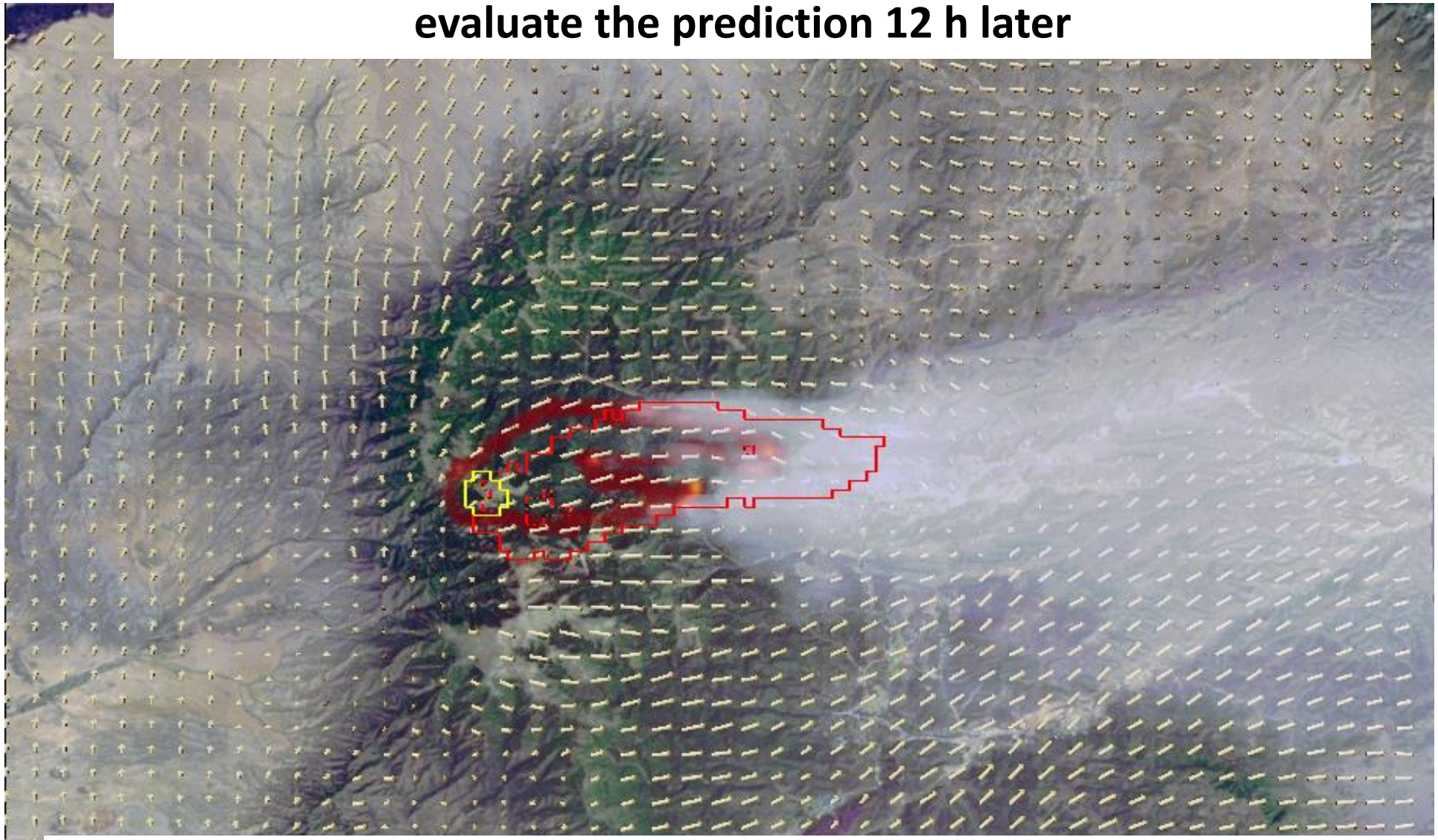


Grid refinement

…to, for example, a 25 km x 25 km area near a fire.



VIIRS data can be used to start the fire 'in progress' and evaluate the prediction 12 h later



Yellow perimeter: VIIRS fire perimeter used for model initialization

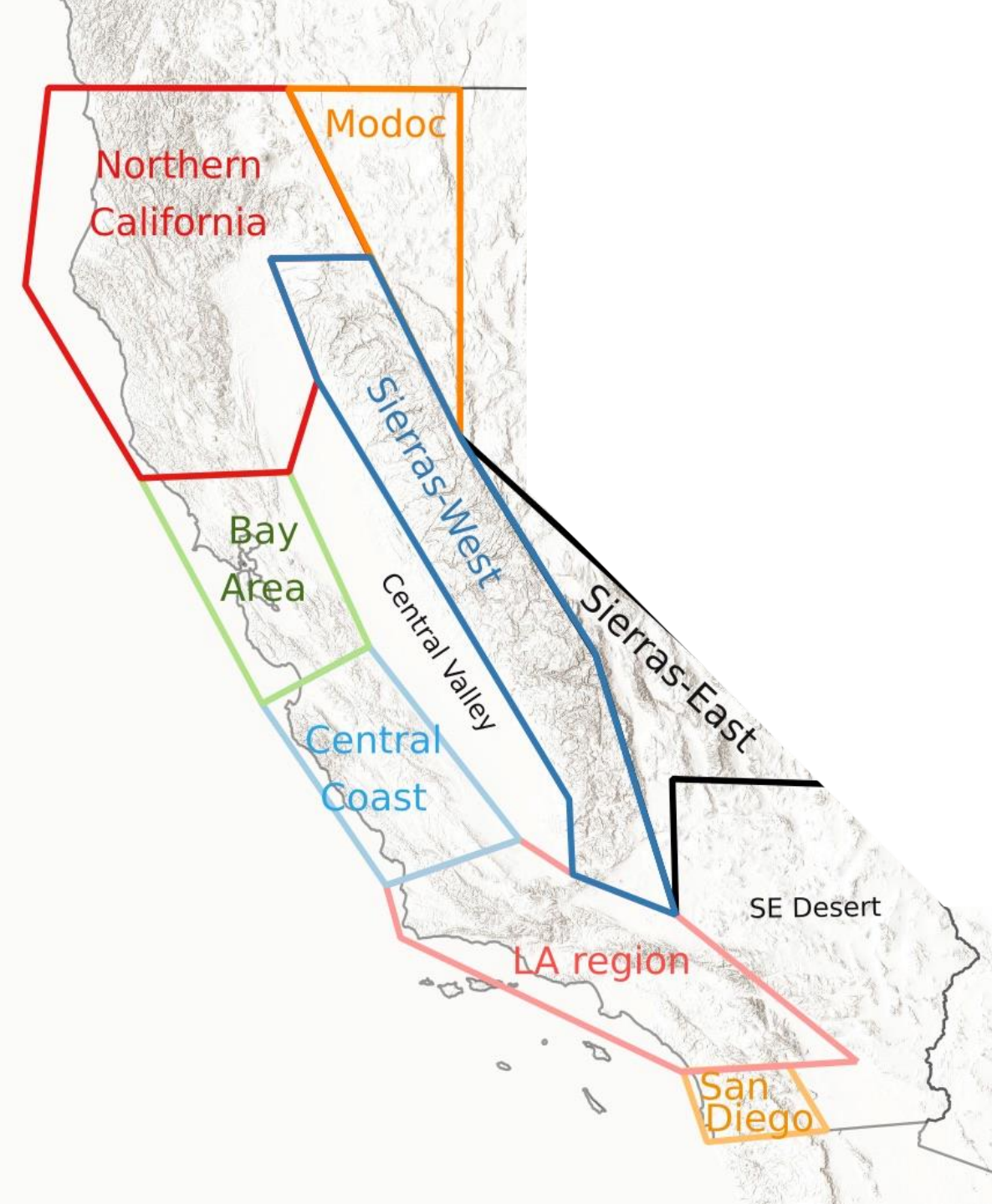
Red perimeter: VIIRS fire perimeter 12 h later

Wind-driven wildfire events

Classify problematic areas by:

- Terrain aspect ratio
  - Sierras vs gentler Transverse ranges and west coastal ranges
- Over vs. through:
  - Flow over the top of continuous ranges
  - Flow over but there are notches/saddles
    - Broad dips
    - Narrow breaks aligned along airflow (e.g. narrow river valleys, narrower than NWP forecast)
  - Flow between: Not over, but through broad valleys & passes

- Intersecting airflows
- Local anomalies
- Transience – magnitude & period of pulses
- Contribution of built structures on event dynamics



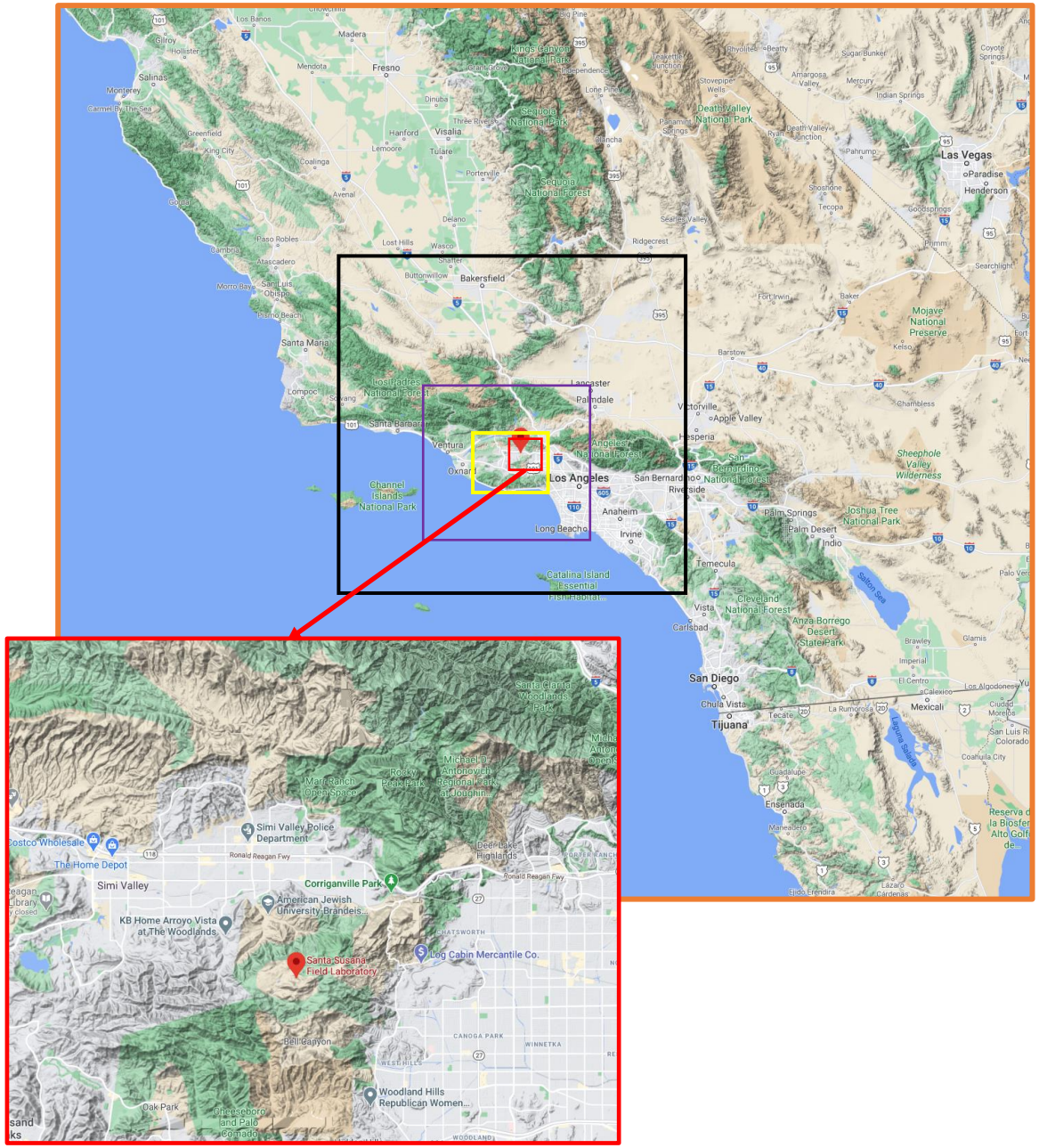
Woolsey Fire

November 8, 2018

5 nested modeling domains telescope from regional to microscale resolution

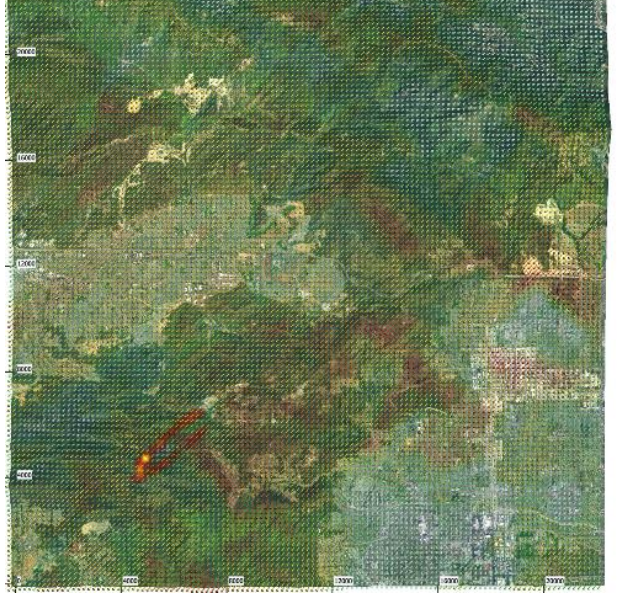
Grid size:
D1: 10.0 km
D2: 3.3 km
D3: 1.1 km
D4: 370 m
D5: 185 m

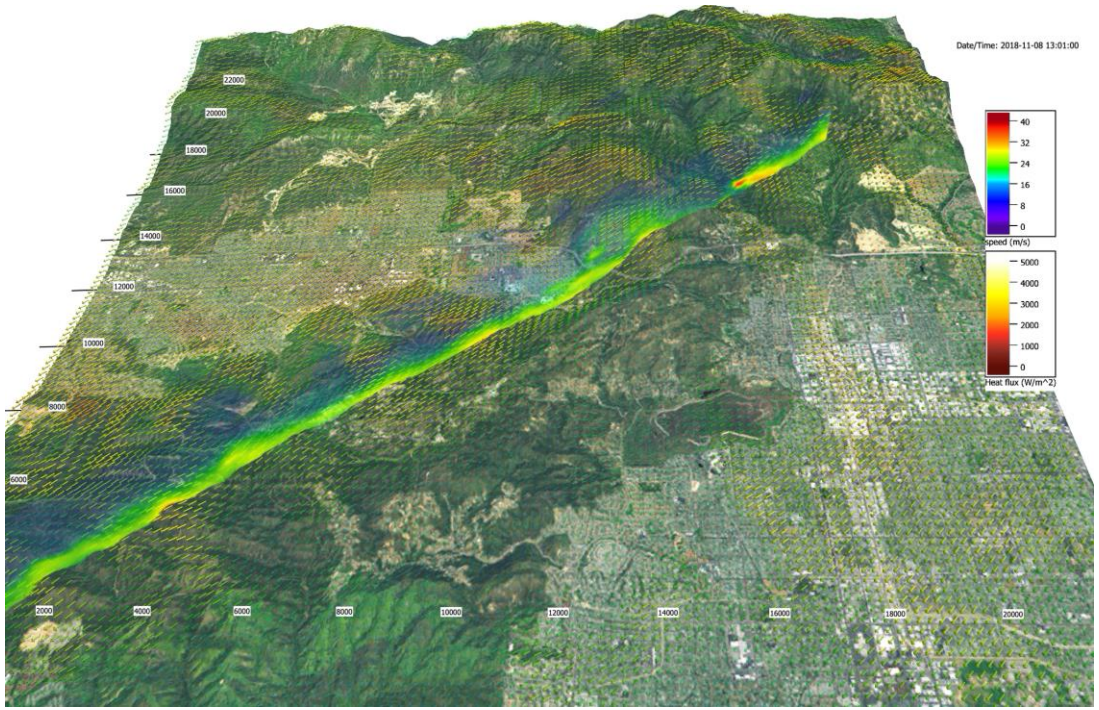
D1 starts at 11/08/18 10 a.m. local time

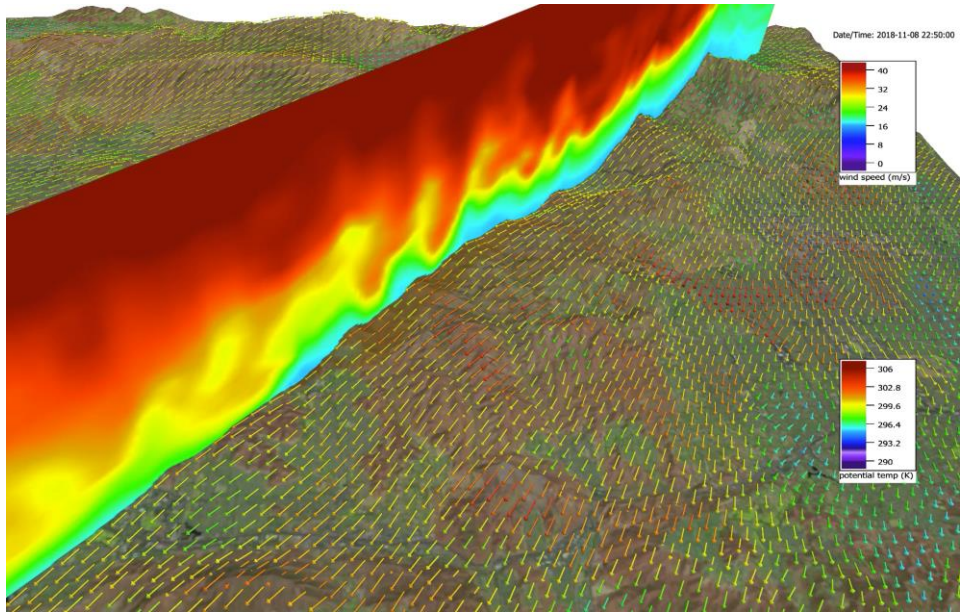


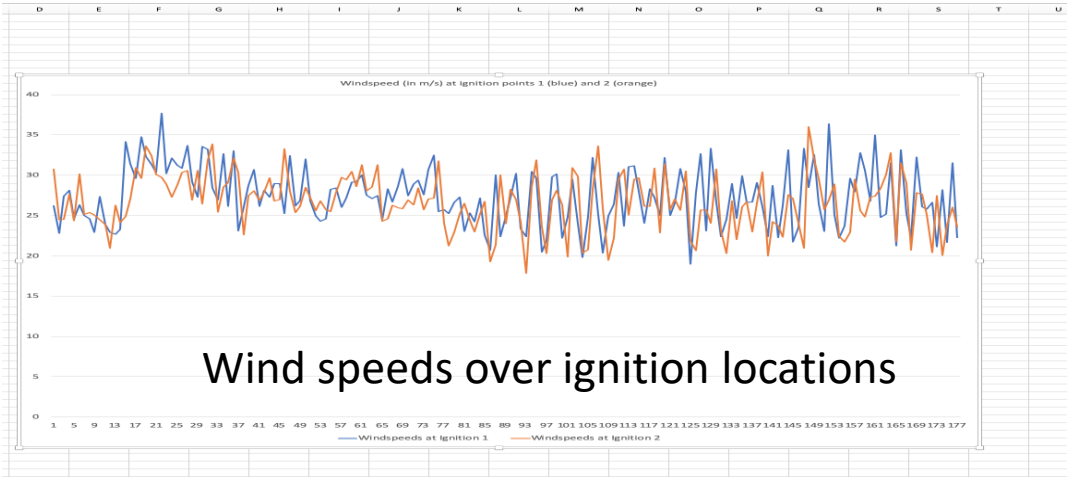
Woolsey Fire

- Santa Ana
- Narrow river of strong winds
- Relatively simple Bernoulli-like (airfoil) acceleration in flow over shallow features but…
- +/- 4 m/s pulses in winds from upwind mountain range, 2 min interval



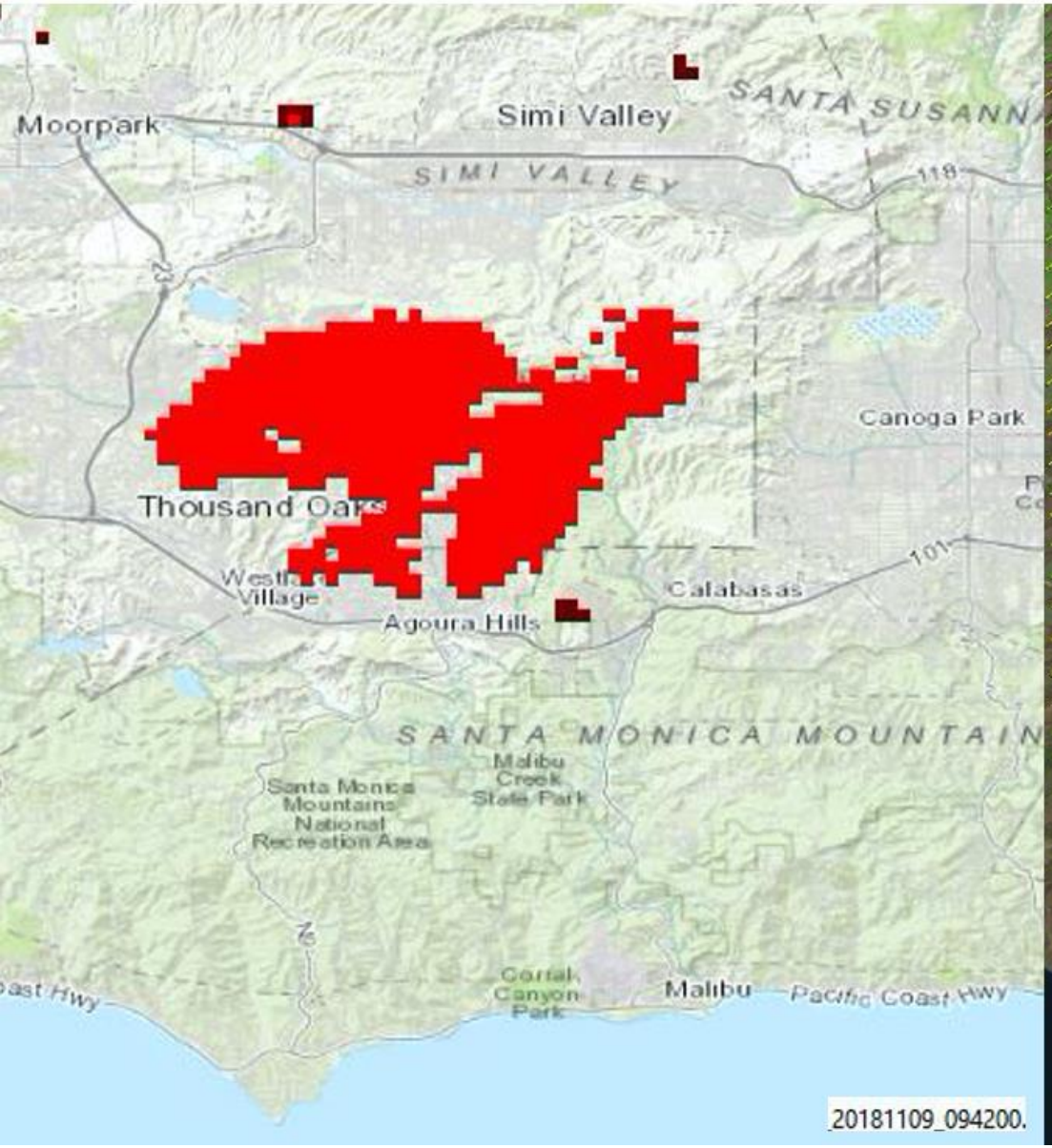


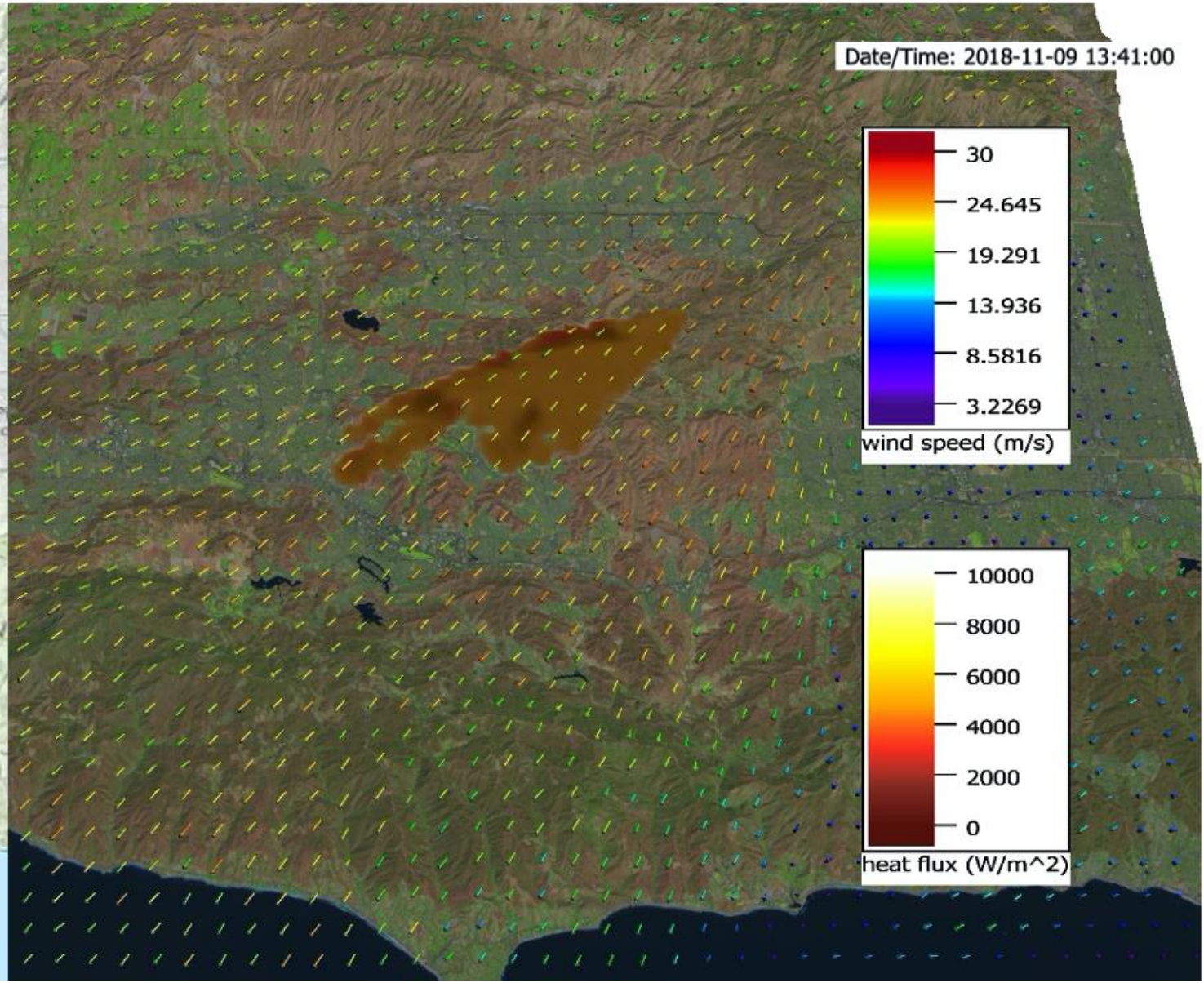




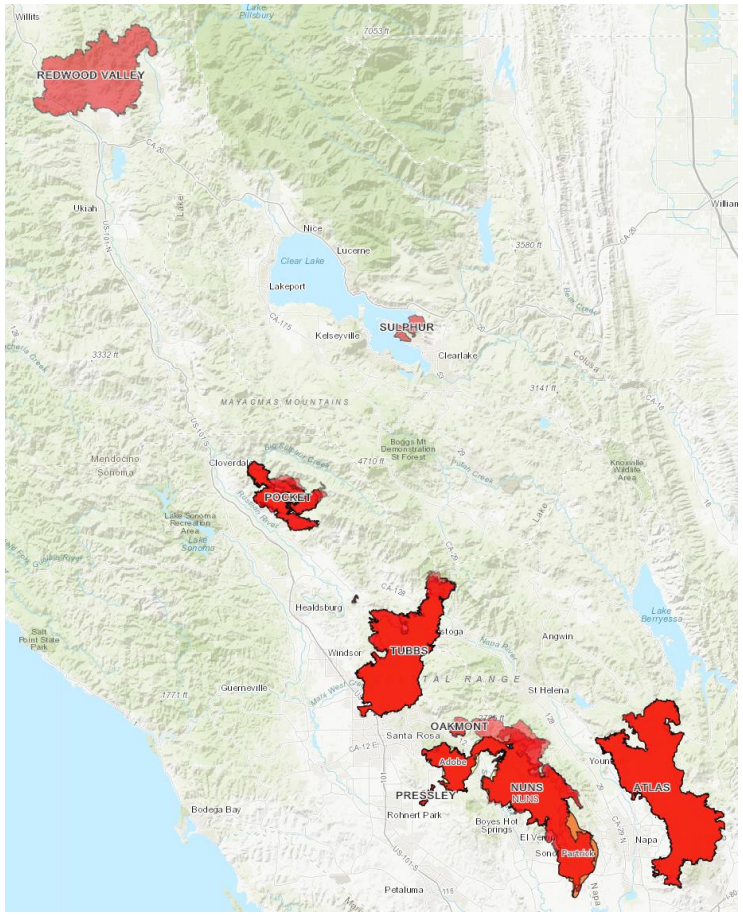
Wind speeds over ignition locations

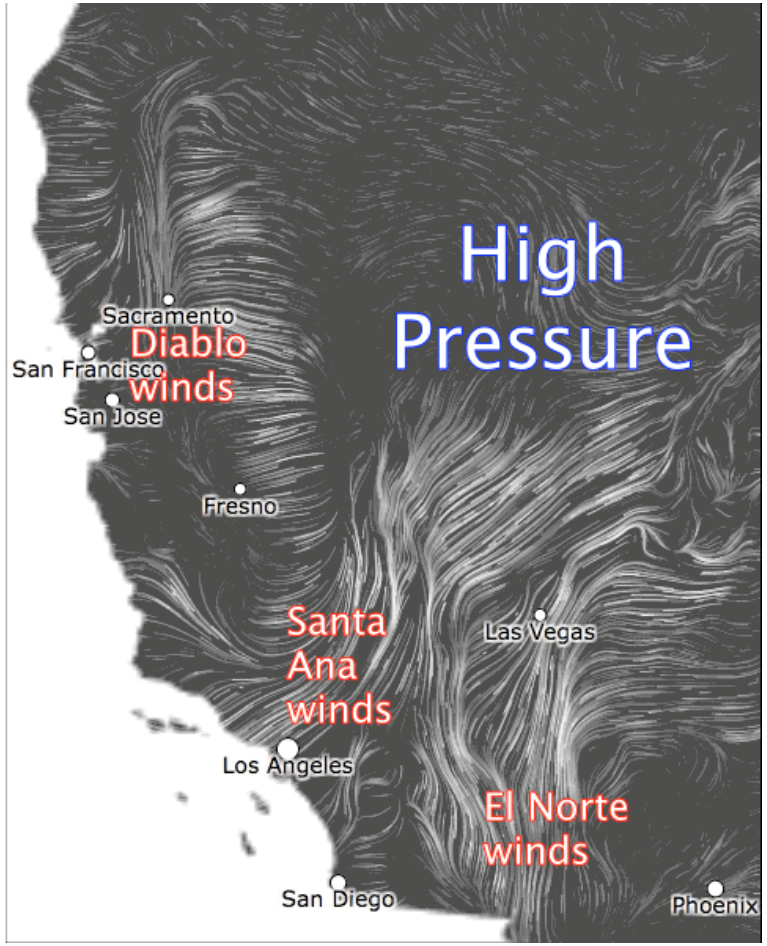
Woolsey - evaluation





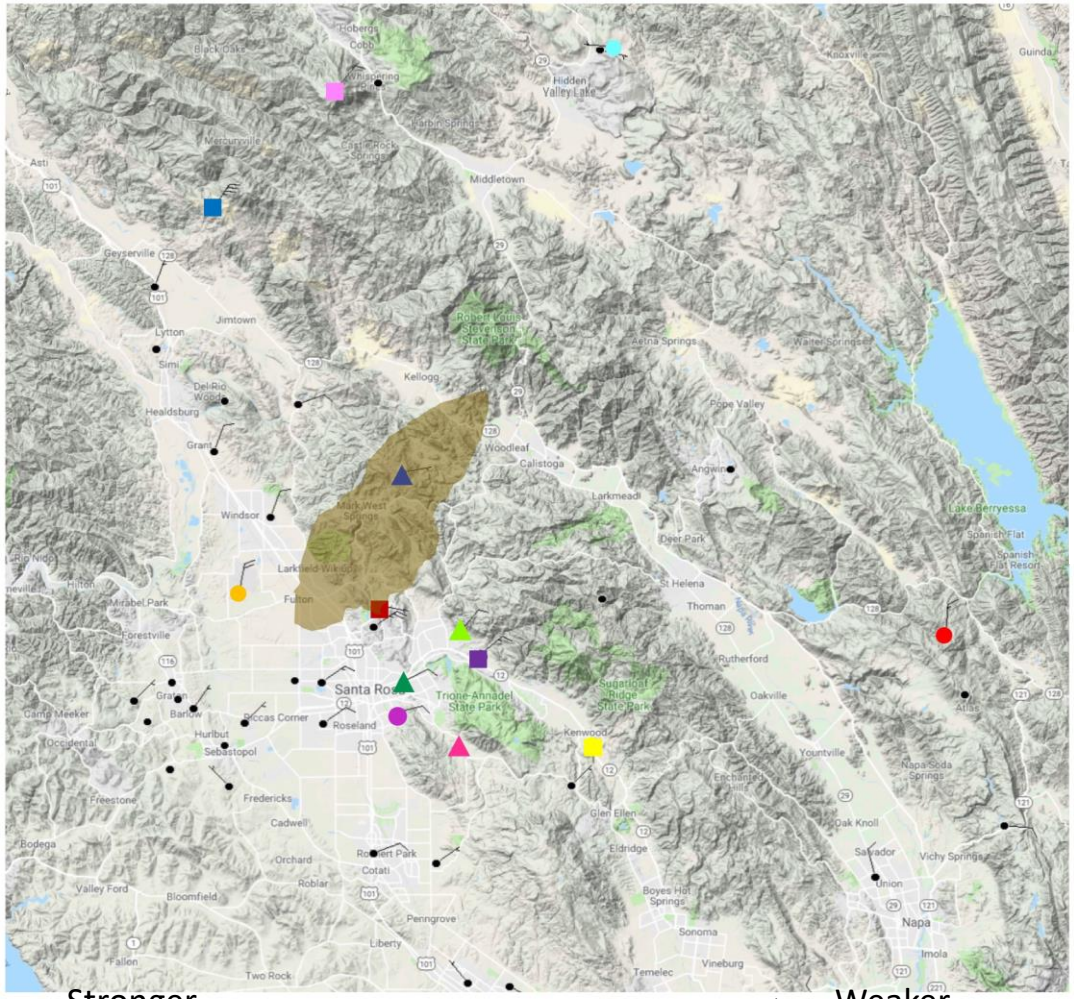
October 8-9, 2017 North Bay Wildfires





On Oct. 8-9, > 170 wildfires ignited in the Wine Country, northern coastal ranges, and Butte and Nevada Counties to the west, north, and east of CA's northern Sacramento Valley and spread rapidly during local peaks of an unusually strong Diablo wind event

Local mesonet provided an unclear message about what was happening

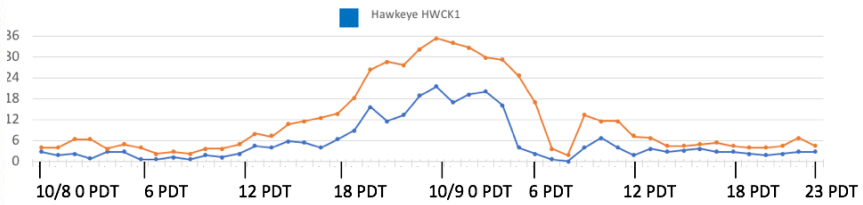


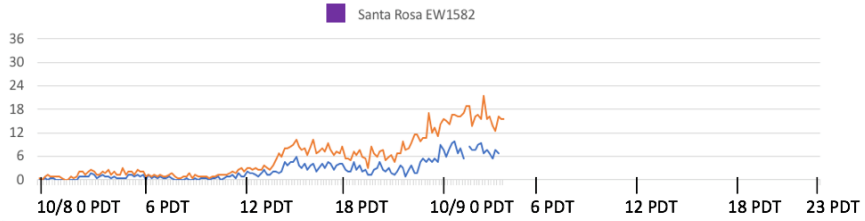
Stronger → Weaker

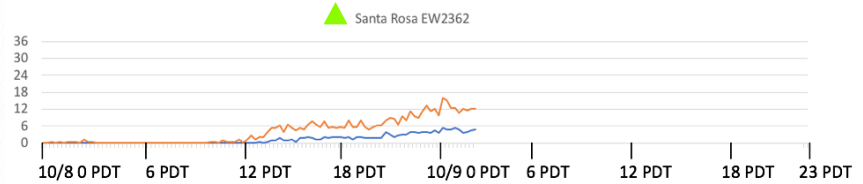
	Station
■	Hawkeye HWCK1
■	Santa Rosa RSAC1
■	Lake County RAWS1 LKRC1
■	Kenwood KENWW
■	Santa Rosa EW1582

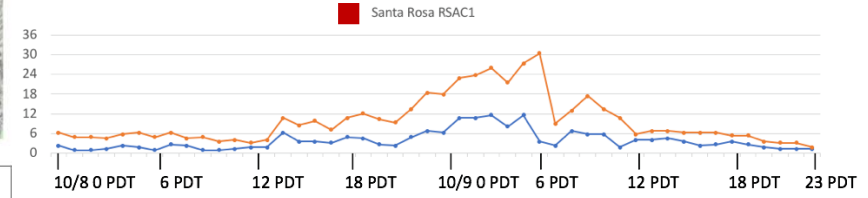
	Station
●	Santa Rosa Sonoma County Airport KSTS
●	Atlas Peak ATLC1
●	Lower Lake EW5568
●	Santa Rosa DW9840

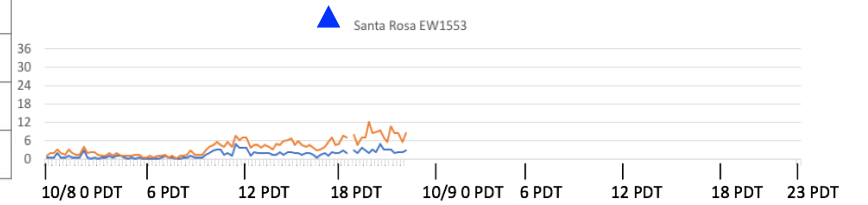
	Station
▲	Santa Rosa EW2362
▲	Lower Bennett Valley BVYWW
▲	Santa Rosa CW3628
▲	Santa Rosa EW1553









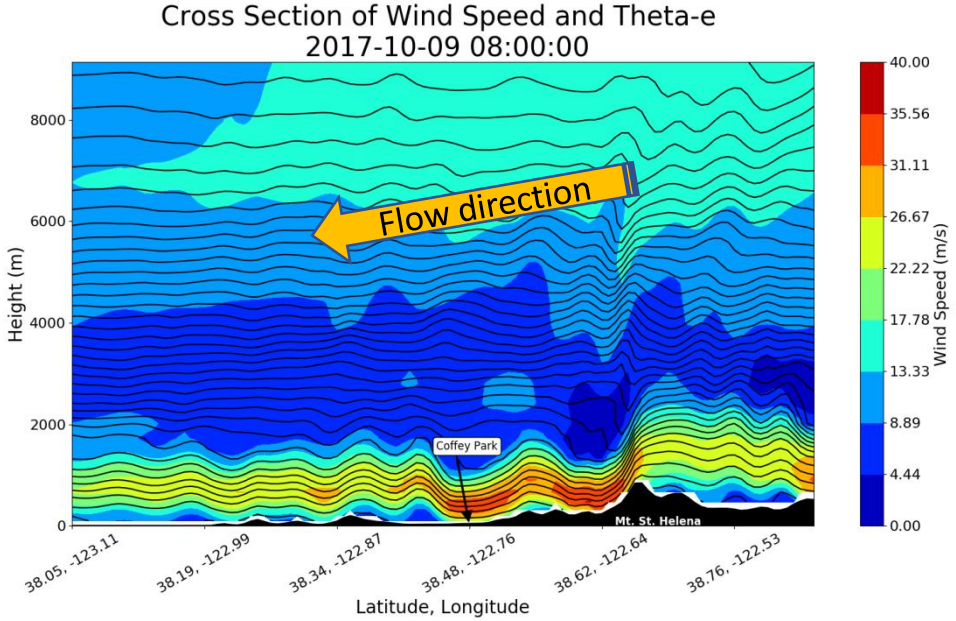


Regional simulations with a mesoscale model tell *some* of what happened

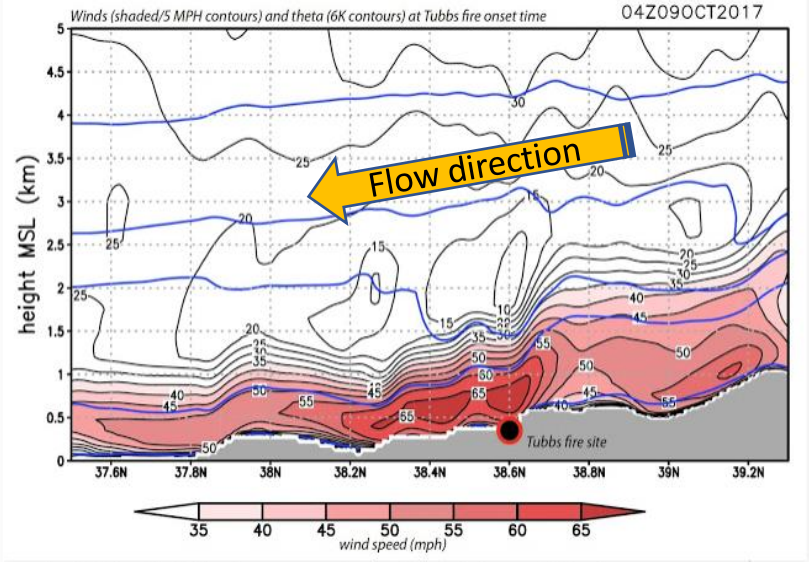
WRF simulations of Oct. 8, 2017

- Operational models produce strong winds over ridges
  - HRRR: 25-28 m/s near Santa Rosa
- Mesoscale model (WRF) research simulations
  - C. Bowers, R. Fovell WRF sims: peak ~ 31 m/s

C. Bowers (WRF sim.)



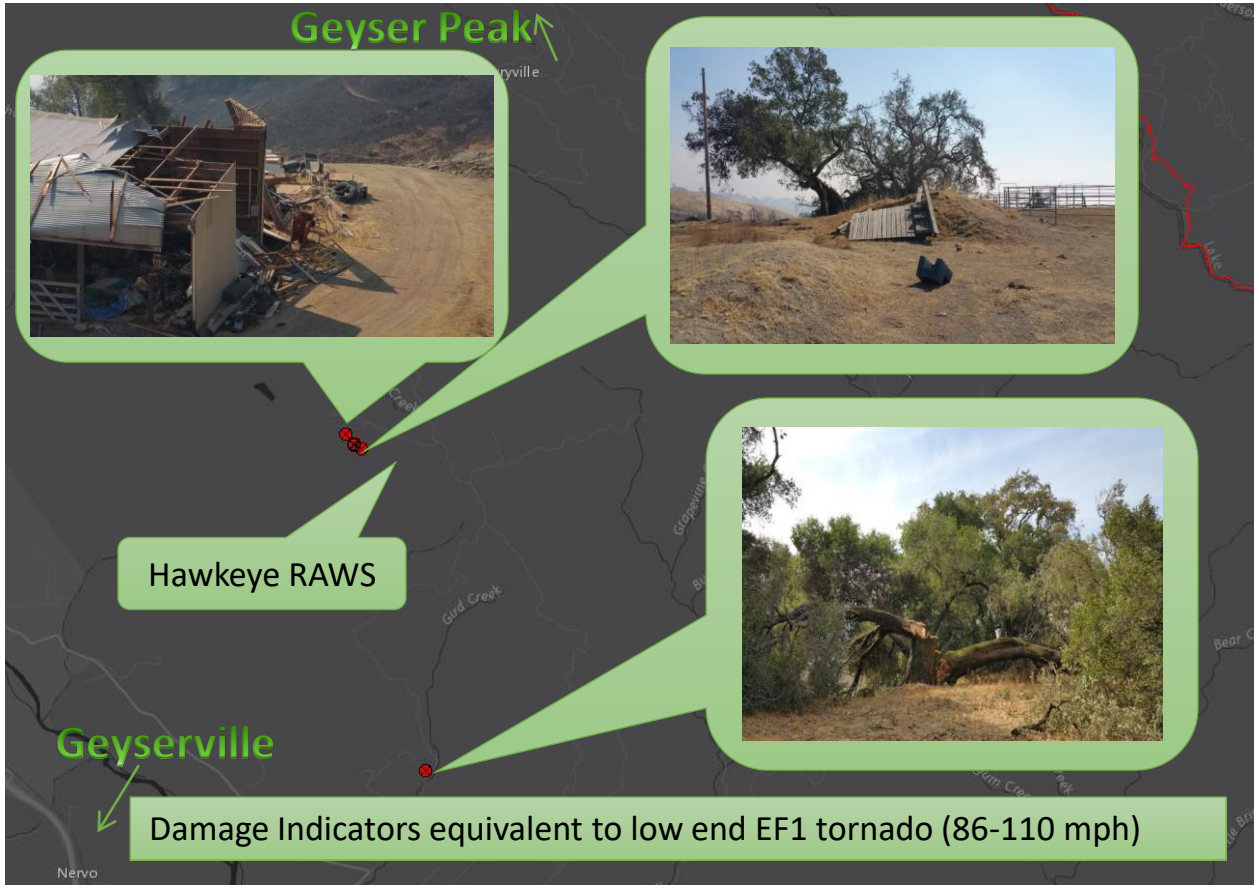
R. Fovell via C. Mass



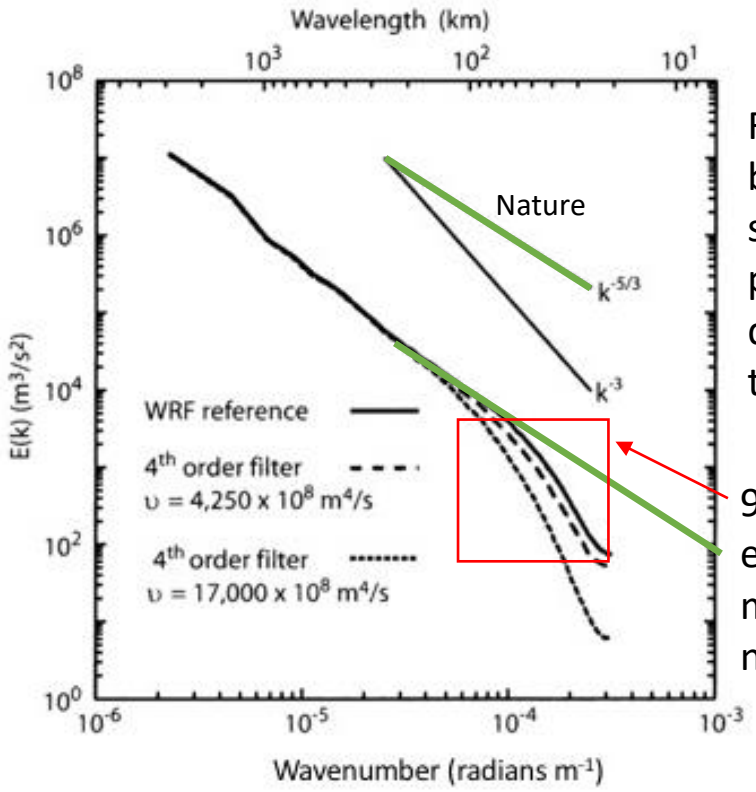
The predicted winds at the Tubbs site was scary strong, with max winds around 70 mph.

Wind Damage suggests extreme winds in area

(photos courtesy of M. Mehle, NWS)



WRF simulated energy spectrum



Fire motions should build up from fine scales (right side of plot) through damped region of the spectra

90-99% of the energy in fine-scale motions that exist in nature are missing.

Skamarock, W.C. Evaluating mesoscale NWP models using kinetic energy spectra. *Mon. Weather Rev.* **2004**, *132*, 3019–3032.

Fire wx forecasters using mesoscale forecasts report **success** at capturing regional wind events' timing and strength.

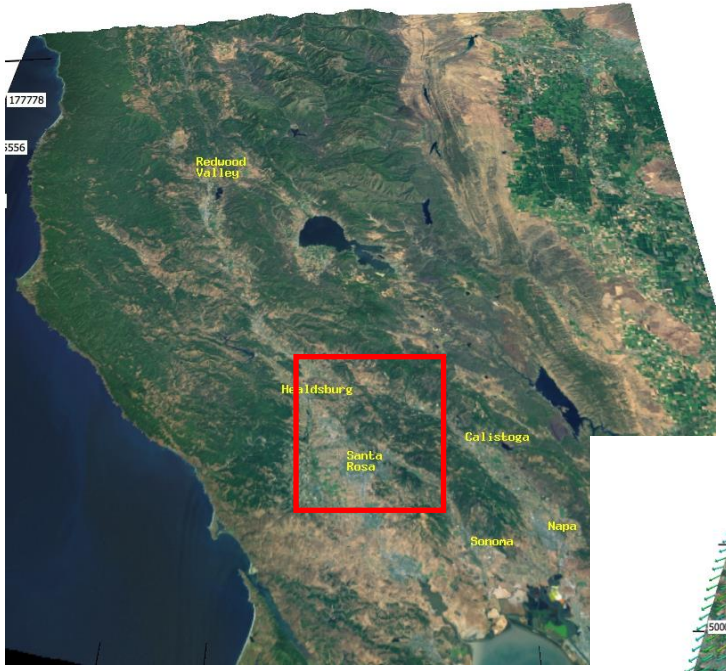
All finite-difference models stray from natural energy spectra at small scales*, however….

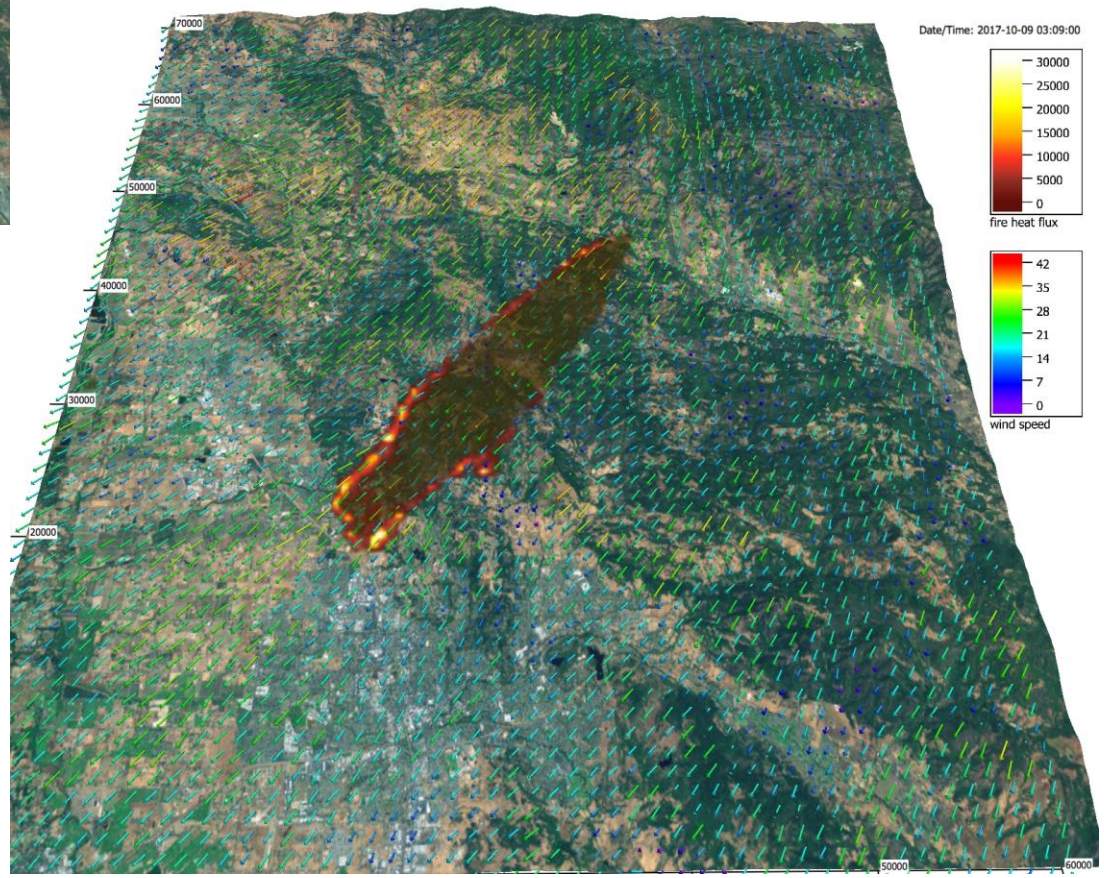
Dynamic core factors like divergence dampener (a result of WRF compressible formulation) and other design choices damp small motions and smooth sharp gradients

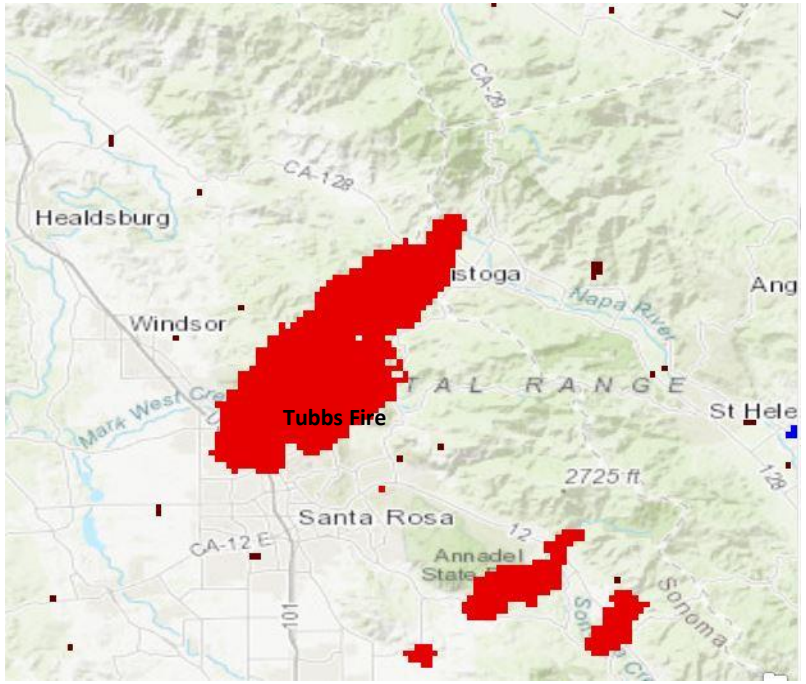
- Under-represent small, strong wind phenomena/extrema
- WRF-based coupled weather-fire simulations lack features in fire shape and underrepresent fire phenomena

*LES mode – TKE, periodic boundary conditions etc. trickery

CAWFE simulation of the Tubbs Fire
Oct. 8 9 PM – Oct. 9 6:45 AM





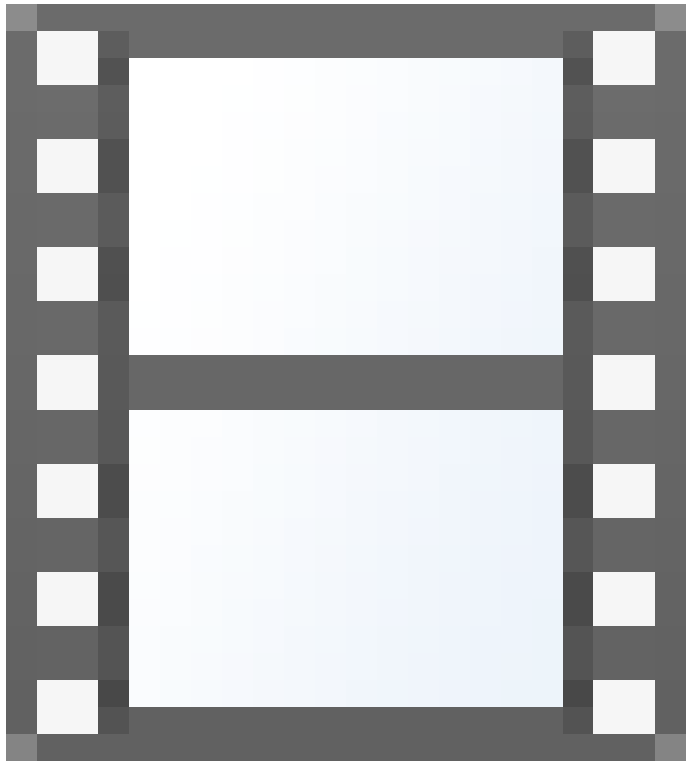


Visible and Infrared Imaging Radiometer Suite (VIIRS) active fire detections at 3:09 A.M. Oct 9. 2017

Coen, Schroeder, and Quayle (2018) Atmosphere.

Simulated wind peaks exceed 40 m s^{-1} (~90 mph) on secondary ridges

Vertical cross section along flow over Tubbs fire
Contours: speed in plane

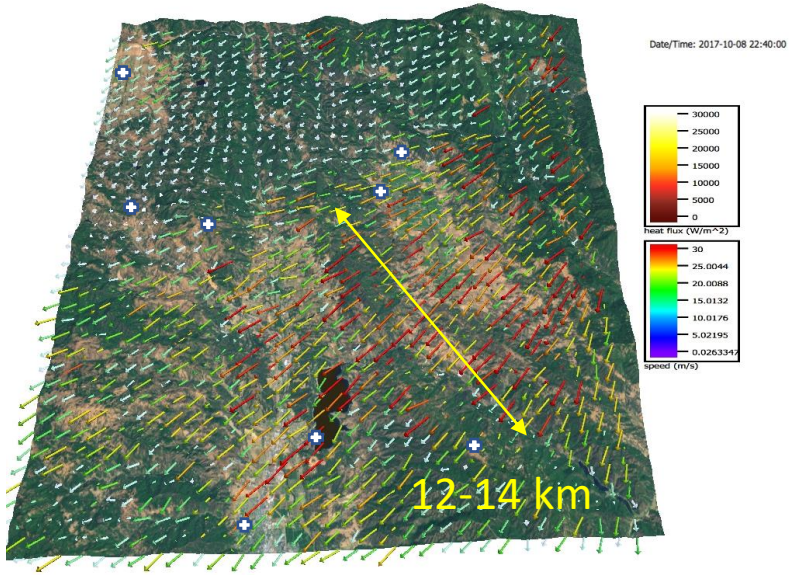


- Shallow (< 1500 m) high speed flow of stable air
  - Surges from upstream move through
- But, Fr >> 1
  - kinetic forces ⟷ >> buoyancy ↕ forces i.e. too fast for stability effects (like waves).
- Meteorological lore: Behaves like neutrally-stratified flow, with acceleration over ridges
  - **Our results**: *Mostly*, but eddies of extremely fast air shed & flow downstream
- Eddies get additional acceleration over secondary ridges, boosting peak winds over 40 m s^{-1} .
  - Ex: Tubbs ignition area

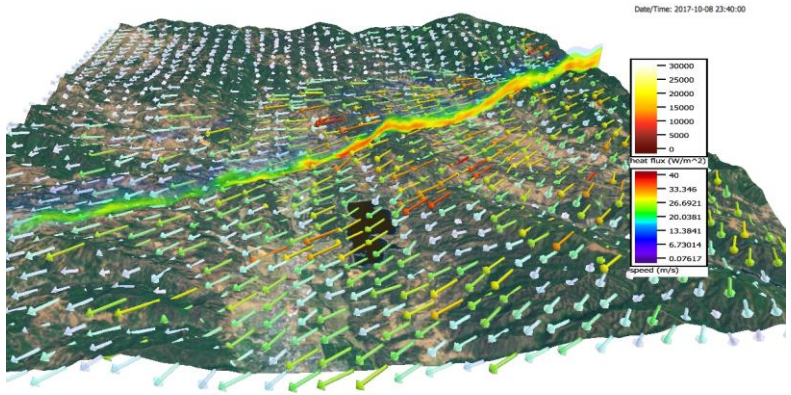
Coen, Schroeder, and Quayle (2018) Atmosphere.

Redwood Valley Fire

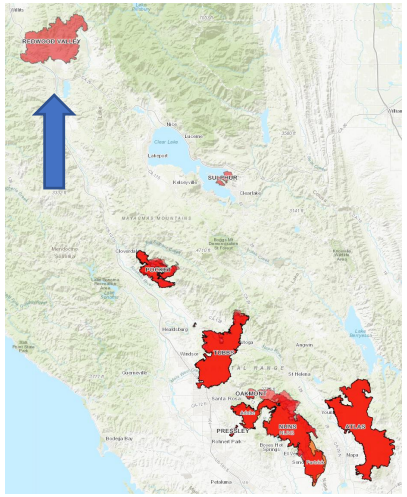
10:40 PM 10/8

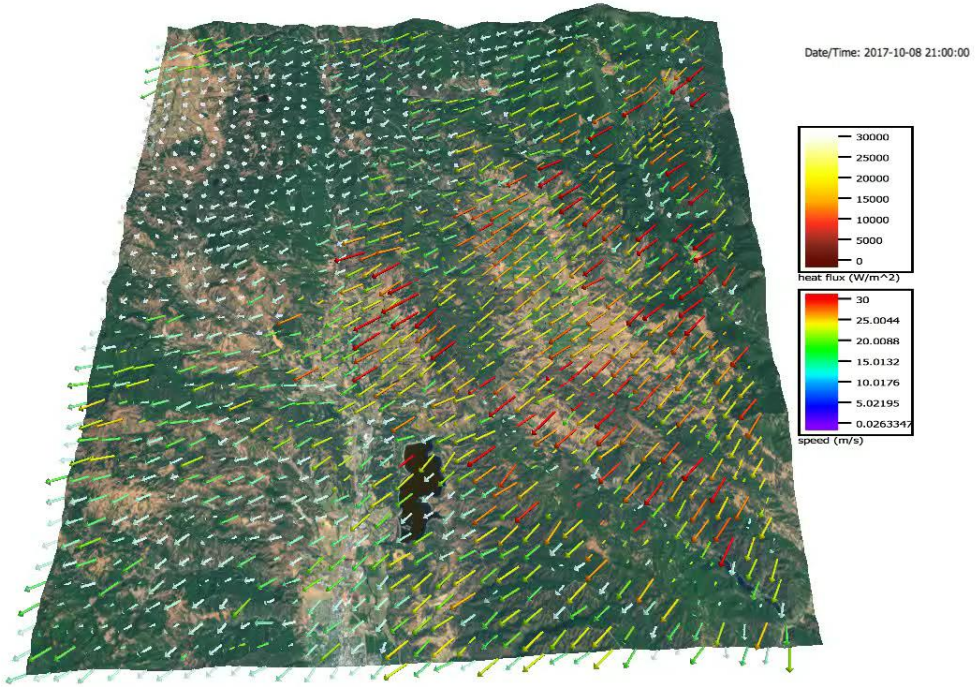


Mesonet stations reporting on 10/8/17



Further north, the pressure gradient drover air over a lower barrier in the Sierras, creating a shallow, narrow river of high speed air that reportedly ignited the Redwood Valley Fire.



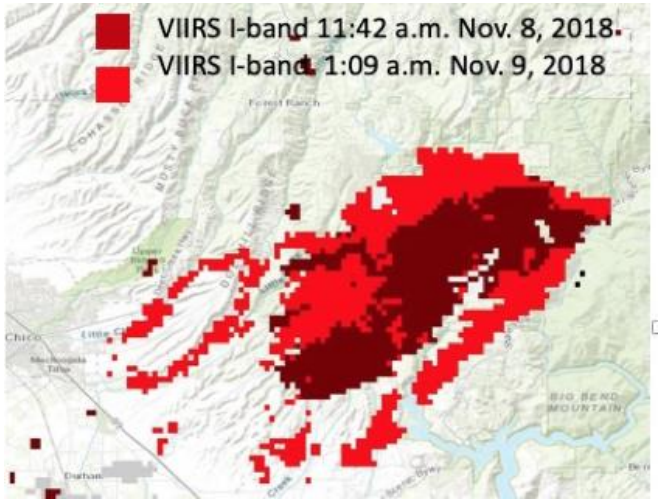


Camp Fire - Paradise, CA

Satellite Active Fire Detections

Landsat OLI 10:45 a.m. Nov. 8, 2018

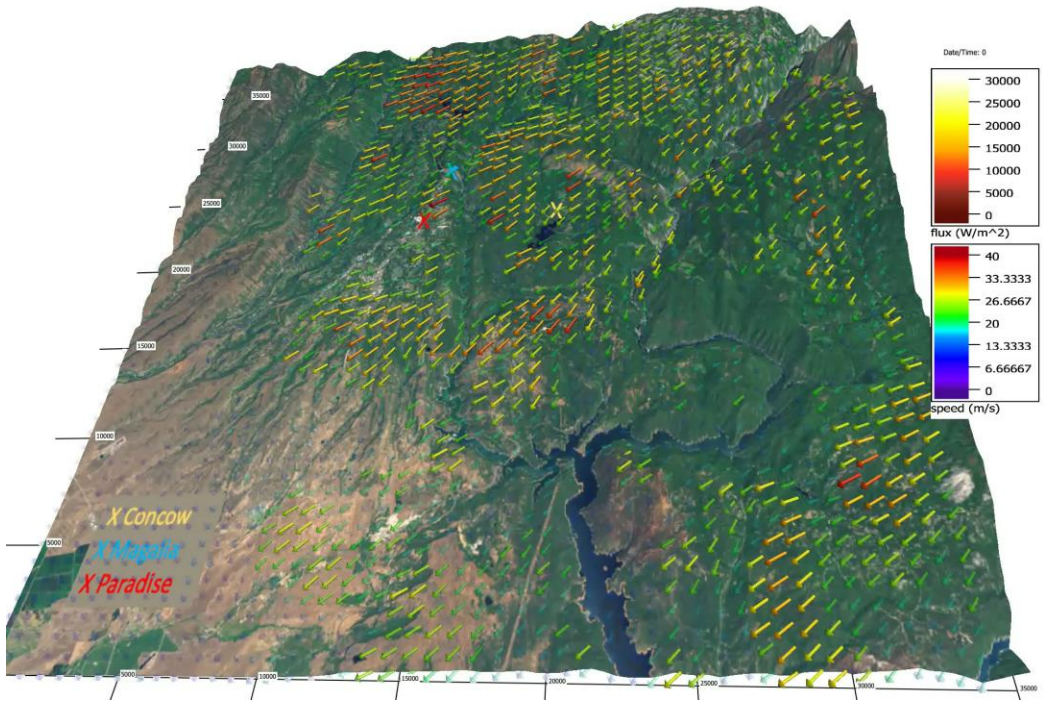
Landsat OLI SW image, 11/8/18 10:45 a.m.



CAWFE simulation

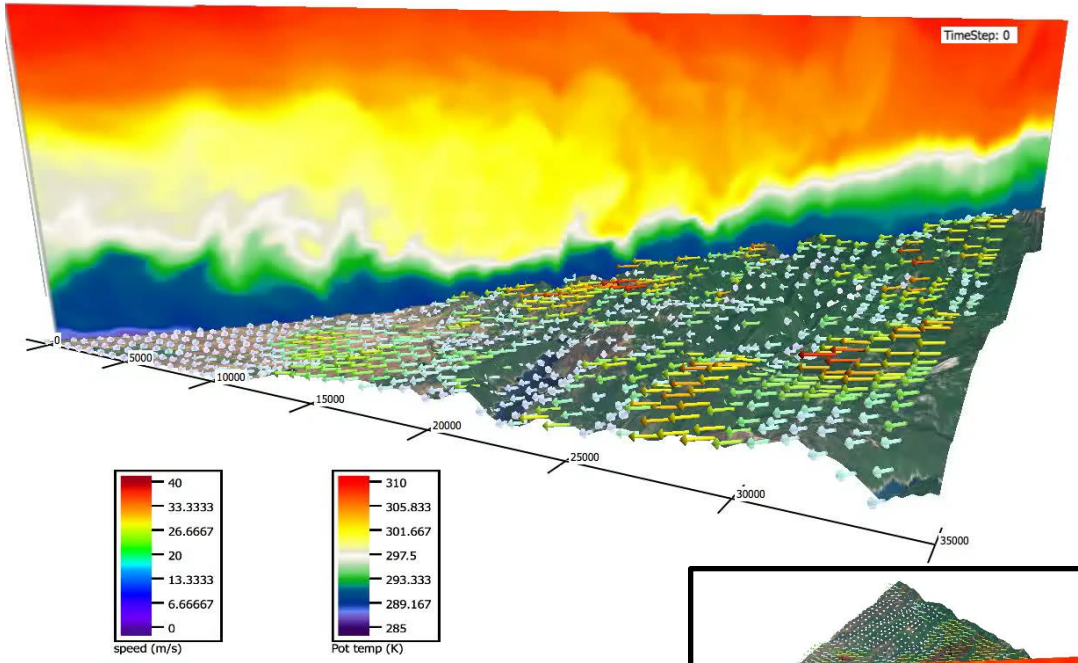
6:15 a.m. – 2:00 PM Nov. 8 2018 1 frame = 1 minute

dx=dy=370 m

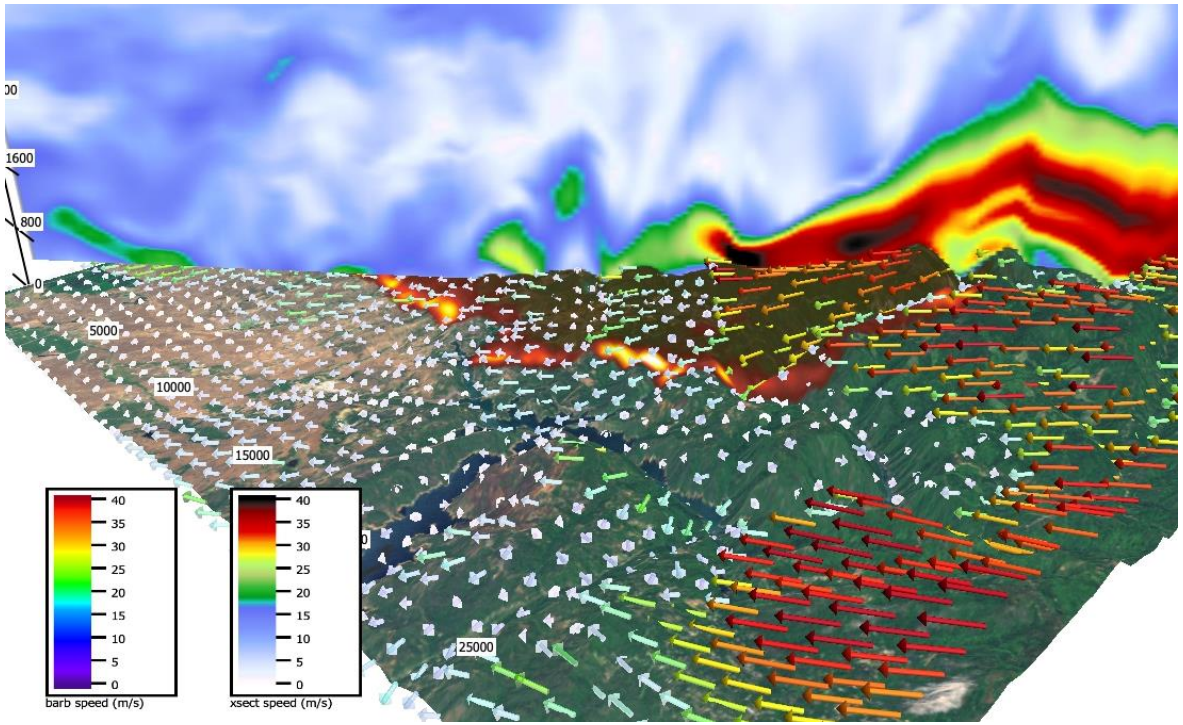


Shear instability created pulses of strong winds near the surface over the Camp Fire

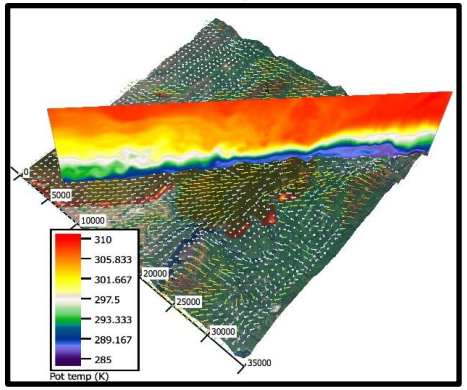
Vertical cross section of potential temperature along flow



Vertical cross section of speed in plane

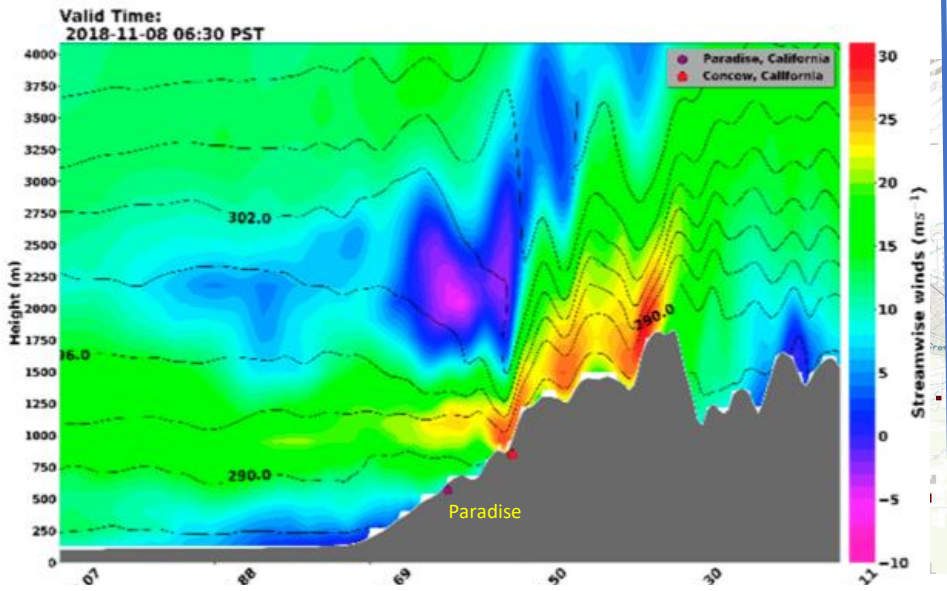


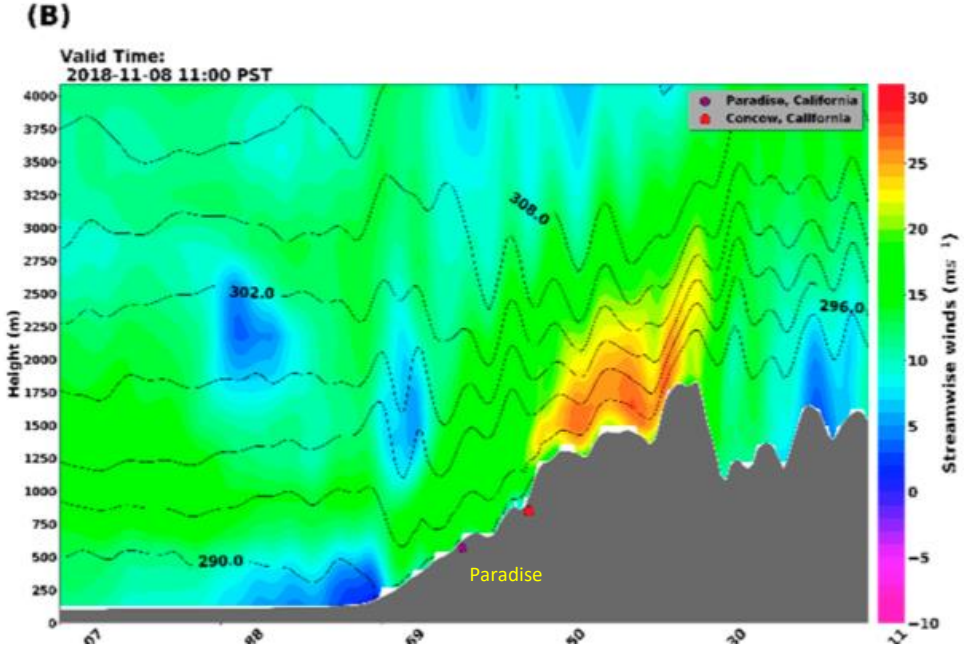
Vertical cross section location



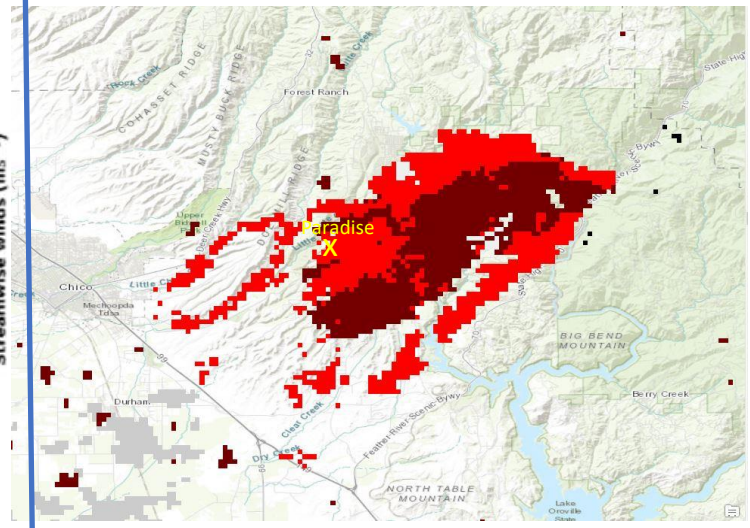
WRF-based simulations of Camp Fire weather and fire growth

Weather (Brewer and Clements 2019)





VIIRS fire detection data

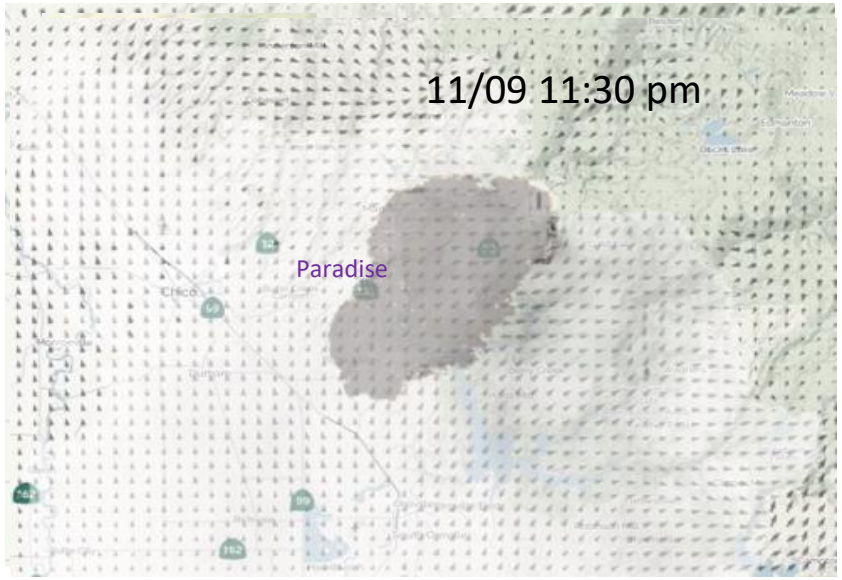


VIIRS I-band 11:42 a.m. Nov. 8, 2018
VIIRS I-band 1:09 a.m. Nov. 9, 2018

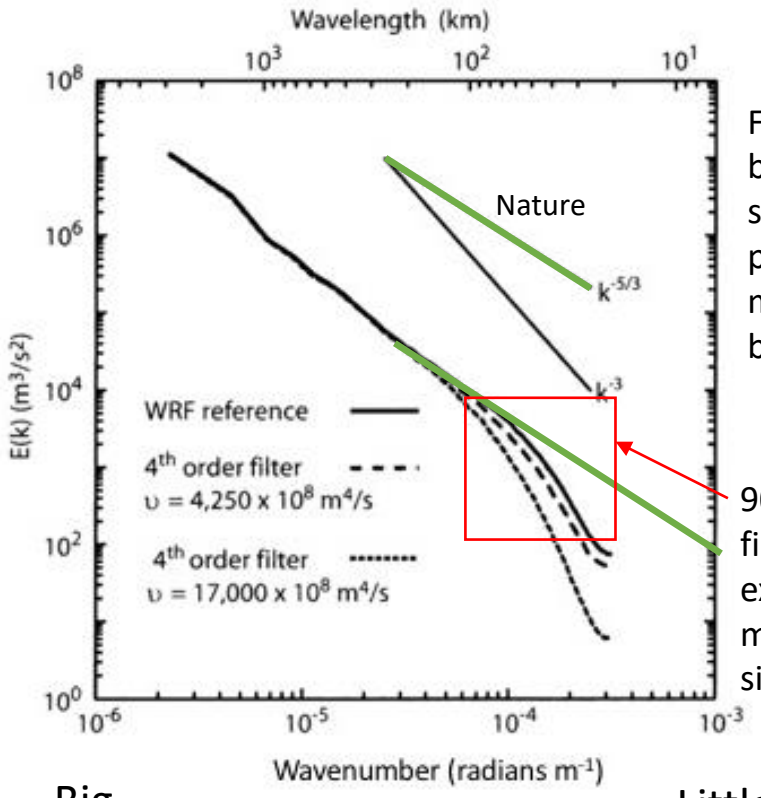
The Camp Fire reached Paradise in about 4 h (~10:45 am). WRF-based coupled models would have predicted that the Camp fire would not have reached Paradise even by the end of the first day (17.5 h).

Or the second - a catastrophic prediction.

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



The numerical algorithms in WRF community atmospheric model vigorously suppress small scale motions and smooth gradients



Fire energy should build up from fine scales (right side of plot) through region mostly heavily damped by WRF dynamic core

90-99% of the energy in fine-scale motions that exist in nature are missing in WRF simulations.

Big eddies

Little eddies

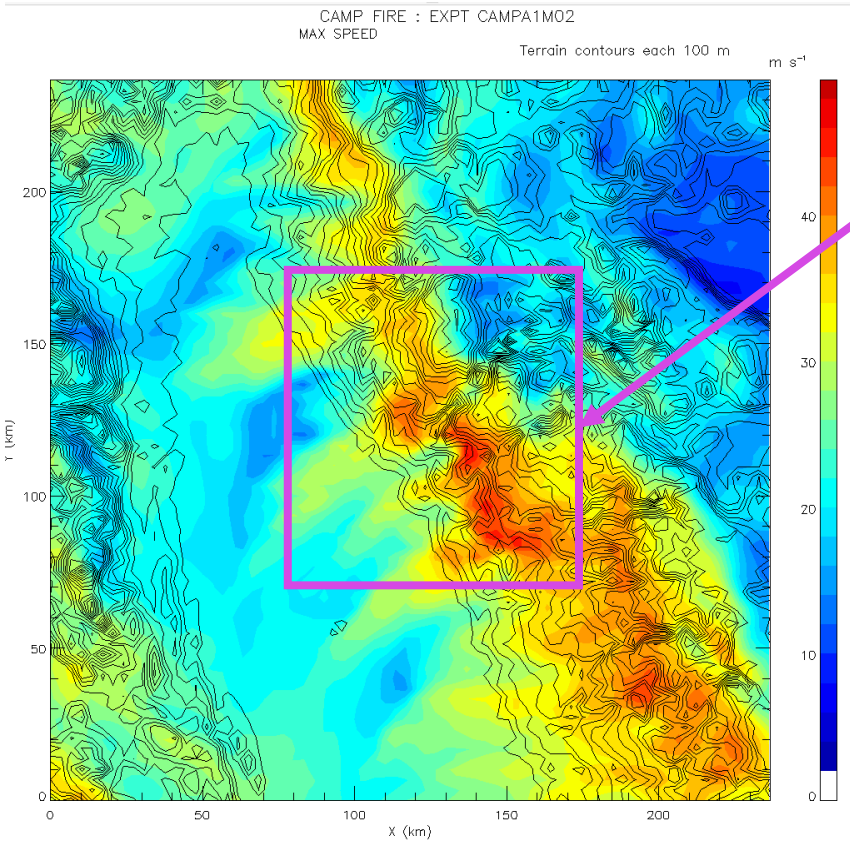
Skamarock, W.C. Evaluating mesoscale NWP models using kinetic energy spectra. *Mon. Weather Rev.* **2004**, *132*, 3019–3032.

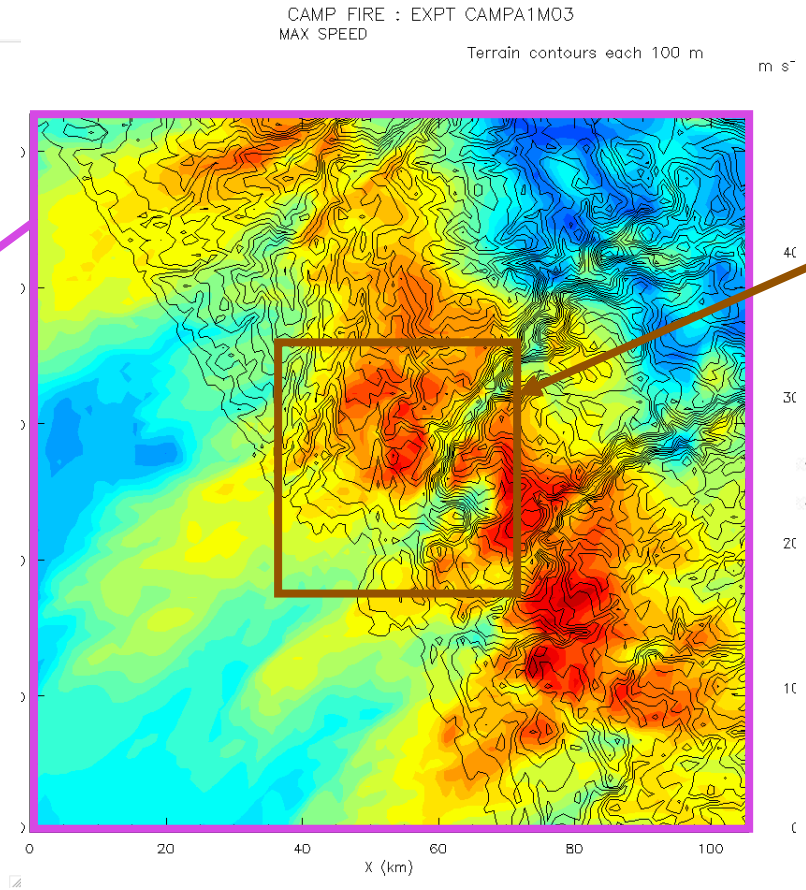
Results:

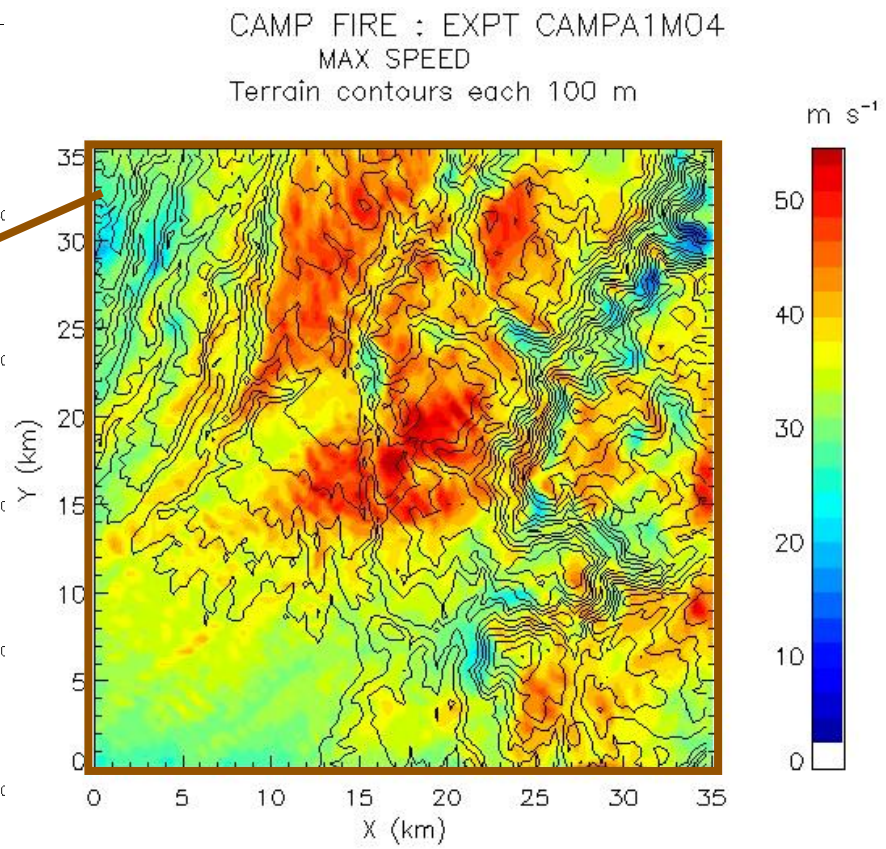
- **WRF unable to represent small, strong wind phenomena** - Small, sharp gradients (i.e. extrema) are smoothed out
  - *PSPS intelligence still underestimates wind maxima*

- **WRF-based coupled weather-fire models are unable to reproduce fire behavior.** Local winds driving the wildfires, fire phenomena, and wildfire shape are unnaturally smoothed out
  - *This is nevertheless being promoted as an operational forecast tool.*

As high pressure inland pushed air over the Sierras toward the coast, a relatively low barrier upwind of Paradise/Oroville allowed a cross-barrier flow stronger than elsewhere in the range







D2: 3.3 km grid spacing

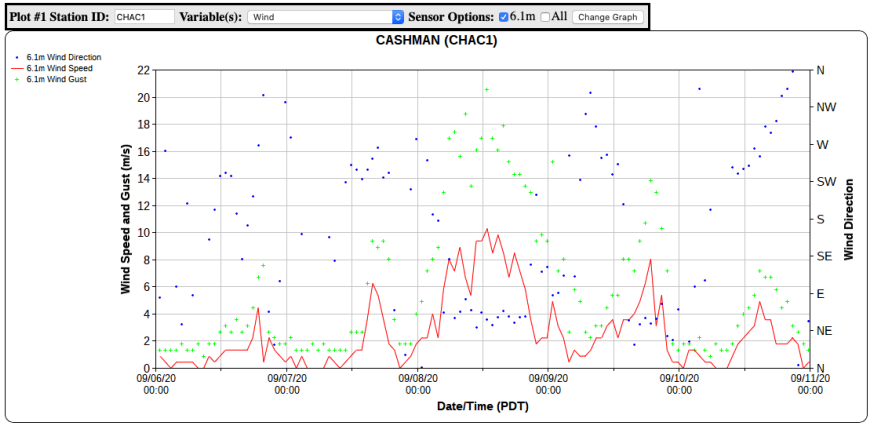
D3: 1.1 km grid spacing

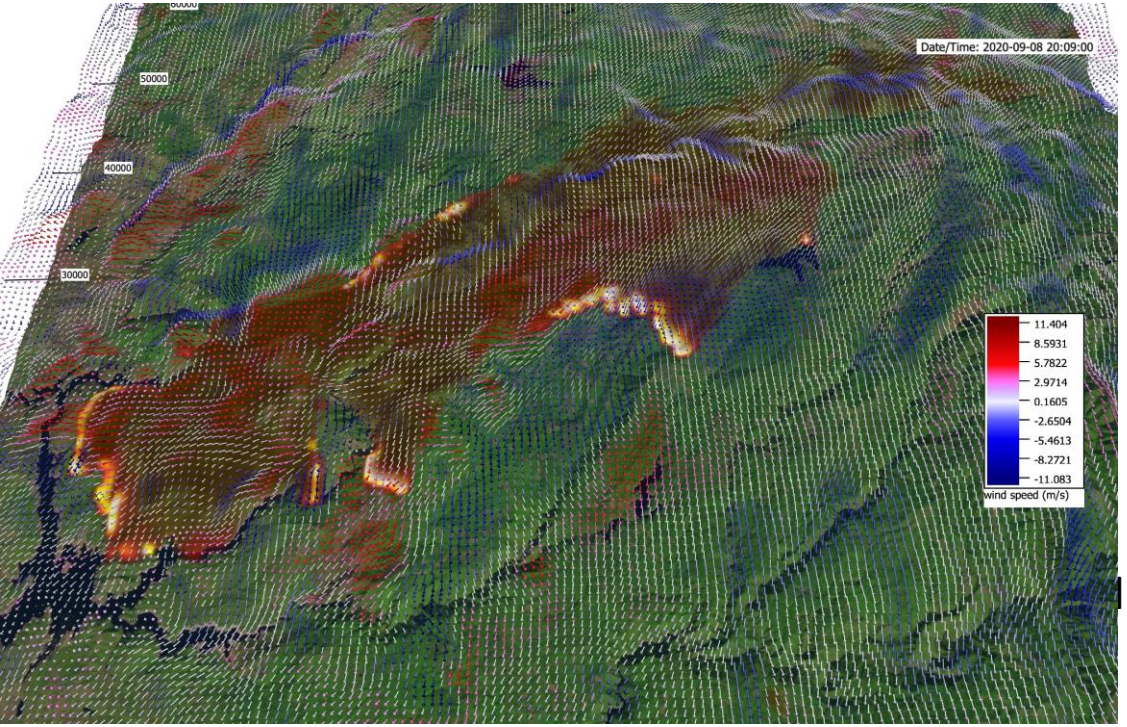
D4: 0.37 km grid spacing

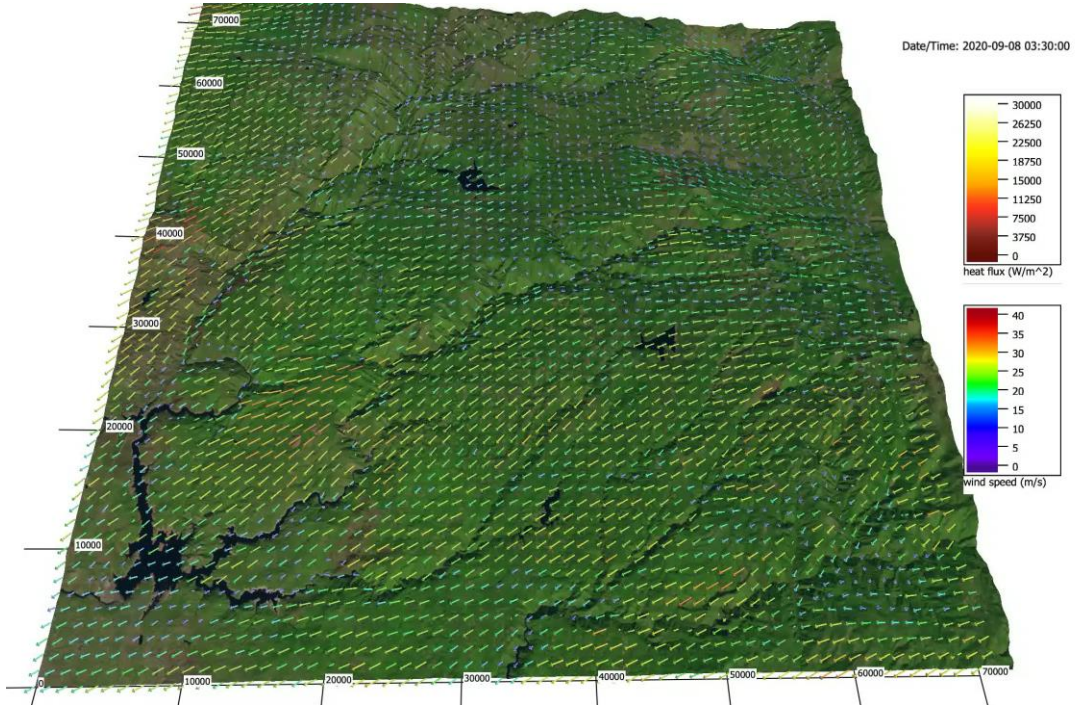
A "wind extrema map" - A worthy goal?

North Complex (Bear Fire)

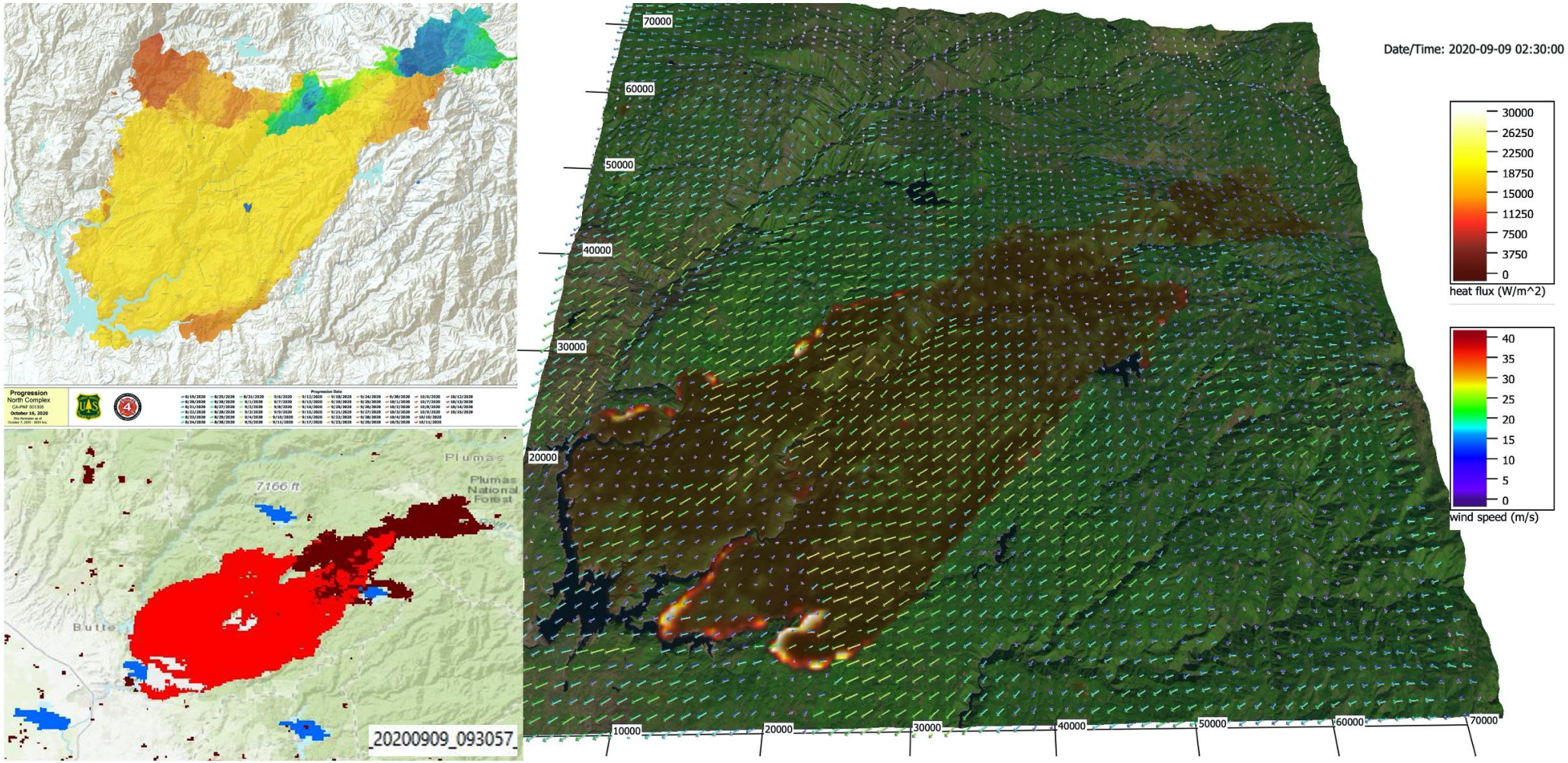
- Moderate (frontal) wind event
- Winds on downslope faces but strongest within the drainage
- “Drano” effect







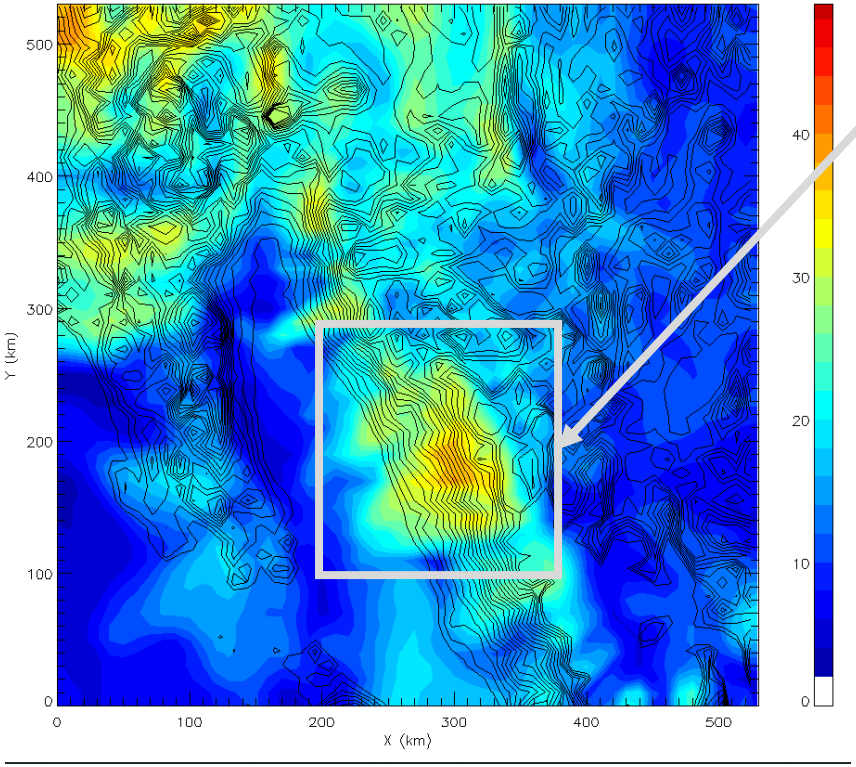
North Complex - evaluation



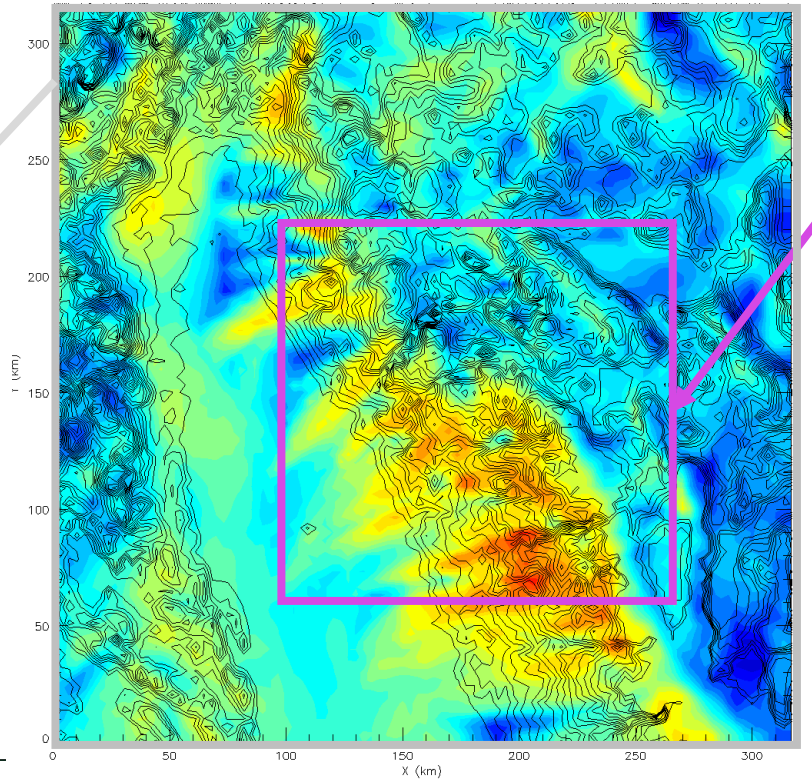
Labor Day wind event

Refining from regional-scale modeling to the microscale brings out locations experiencing strong winds.

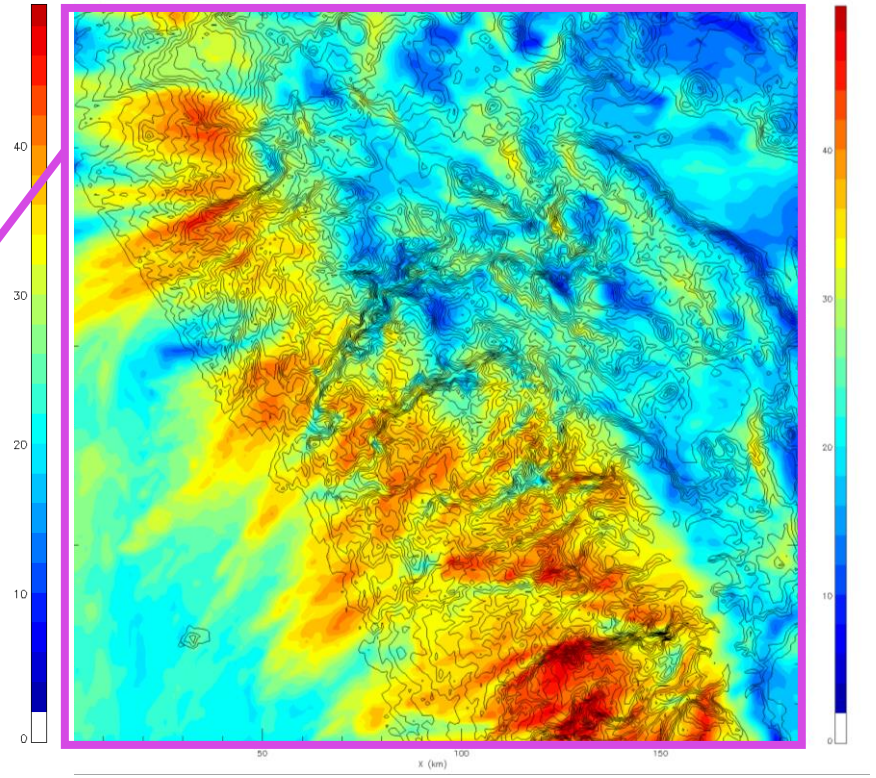
Moderate strength events produce strongest winds more within the canyons.



D1: 10.0 km grid spacing



D2: 3.3 km grid spacing



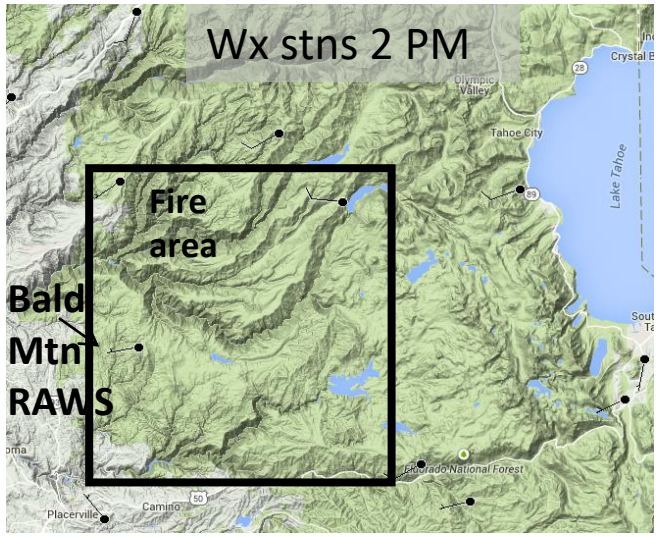
D3: 1.1 km grid spacing

Plume-driven fires

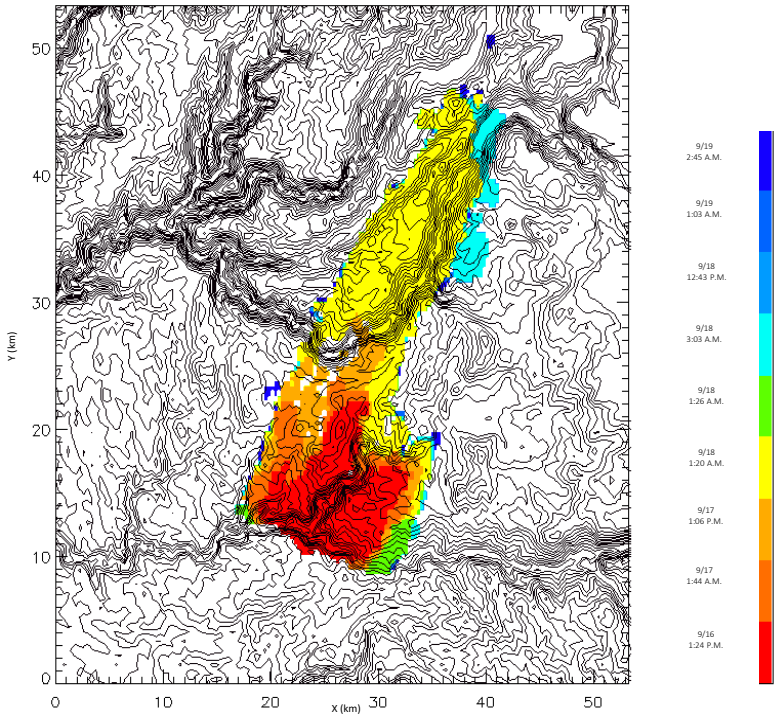
King Fire. Image courtesy of Jeff Zimmerman

The 2014 King Megafire (Sierra Nevada Mtns)

Though widely attributed to drought and fuel accumulation, the King Fire owed its unanticipated rapid growth to (1) microscale circulations within the Rubicon Canyon and (2) fire-induced winds.

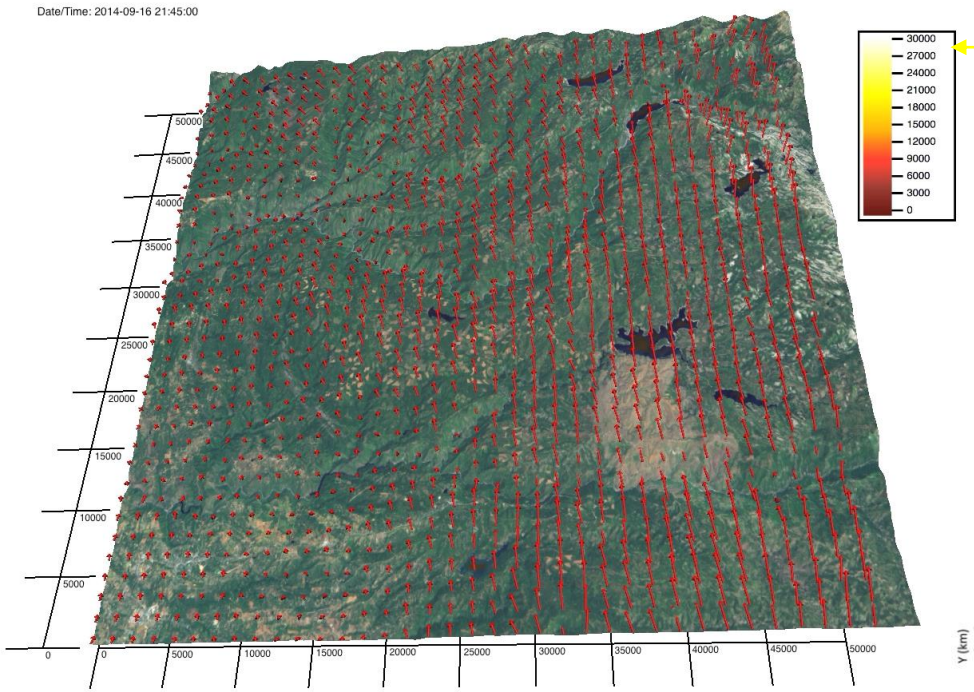


2014 King Fire VIIRS IR fire maps



CAWFE simulation

9/16/14 9:45 pm – 9/18/14 10:45 am (37 hr)



Other phenomena:

Multiple plumes

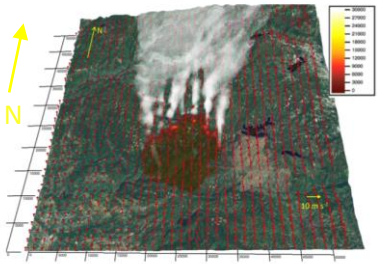
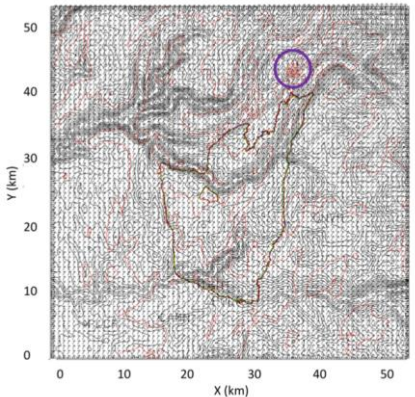


Figure S2. Simulated fire heat flux (in W m^{-2}, according to color bar at right) from the Control experiment at 2:31 A.M. 17 September showing the King fire's multiple plumes.

PyroCu at top of canyon



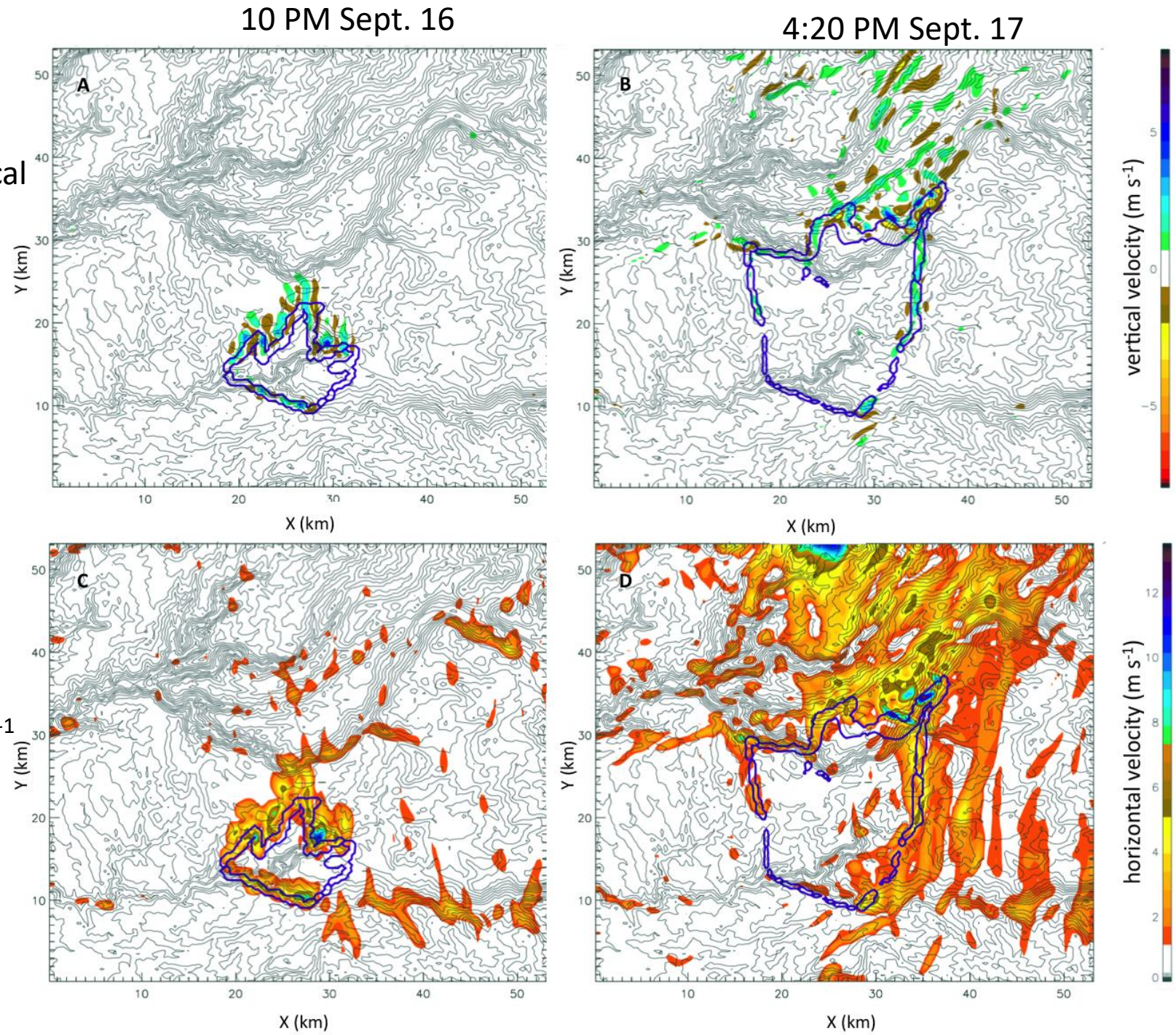
Coen,. Stavros, and Fites-Kaufman, 2018: Deconstructing the King megafire. Ecol. Applic.

Photos courtesy of Jeff Zimmerman

Fire-Induced winds

Impacts on vertical wind velocity:
-3.4 - +8.7 m s^{-1}

Impacts on horizontal wind speed: 0-11.1 m s^{-1}

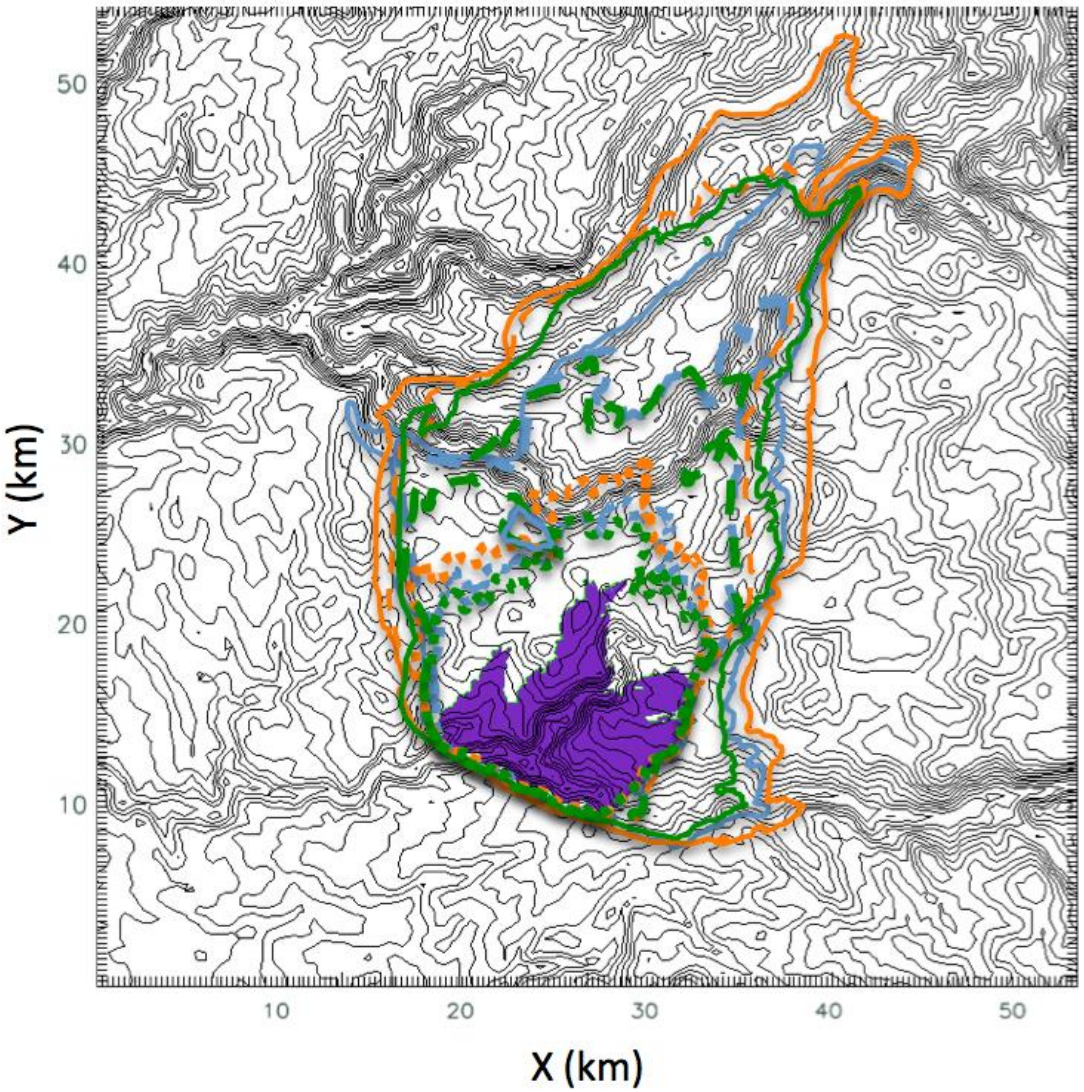


Impacts on vertical wind velocity:
-5 - +14.5 m s^{-1}

Impacts on horizontal wind speed:
0-13.7 m s^{-1}

To what extent did dry conditions (through surface fuel dead fuel moisture content) affect fire growth or extent?

At t= 12 h 24 h 36 h



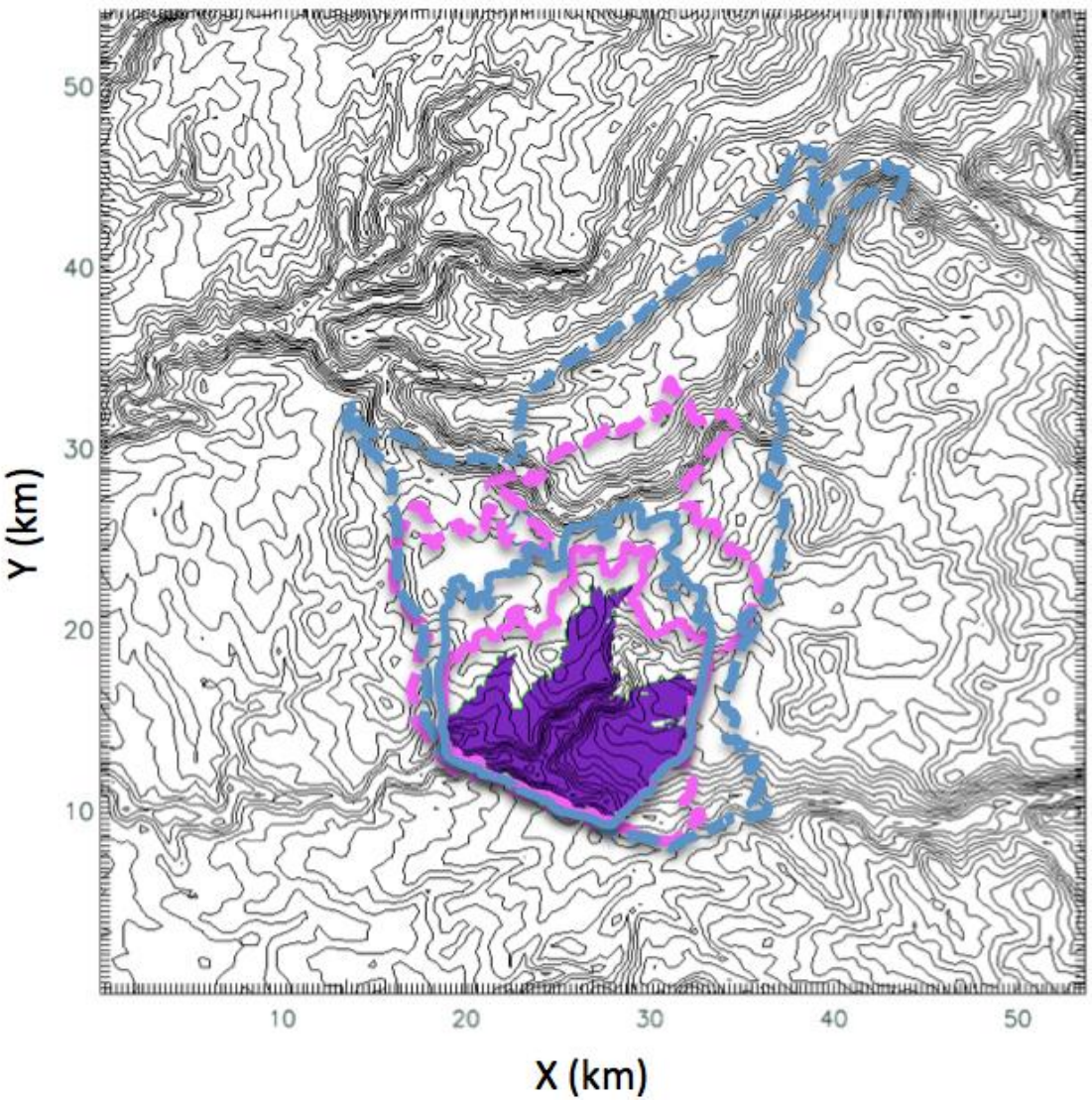
Dead fuel moisture content

- 8% (historical high)
- **5% (observed, <u>historical average</u>)**
- 3% (historical low)

Fuel moisture effect in very dry conditions as fire climbs inclined terrain

To what extent did surface fuel accumulation contribute to rapid growth or extent?

at t=12 h 36 h



Fuel load

Standard properties assoc. with each fuel model

½ the fuel load in half the depth

Fuel amount has weak effect on how fast fire spreads on flat ground.

Rim Fire

L. Tarnay et al. (2020) Smoke symposium. "Modeled effects of fuel reductic

What if we had been able to treat Rim area with fire beforehand?

- Previous treatments aided the suppression of the Rim fire
  - And help limit September smoke impacts
- Can we model those fuels and see a difference in fire spread
- Would it have made a difference to have brought fire down farther out of Yosemite?

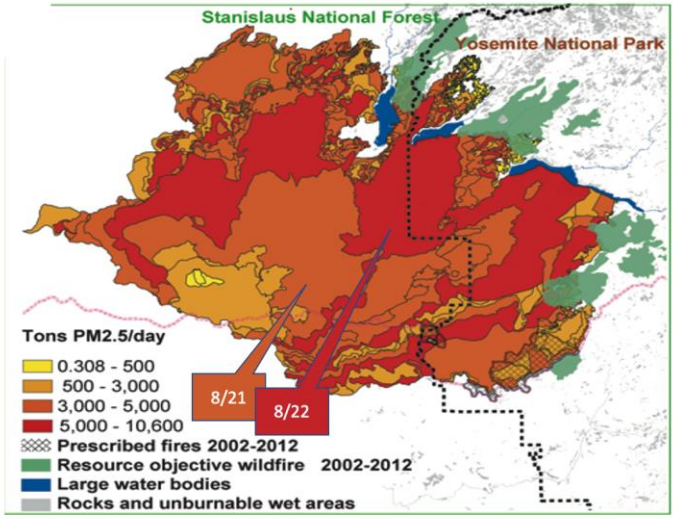
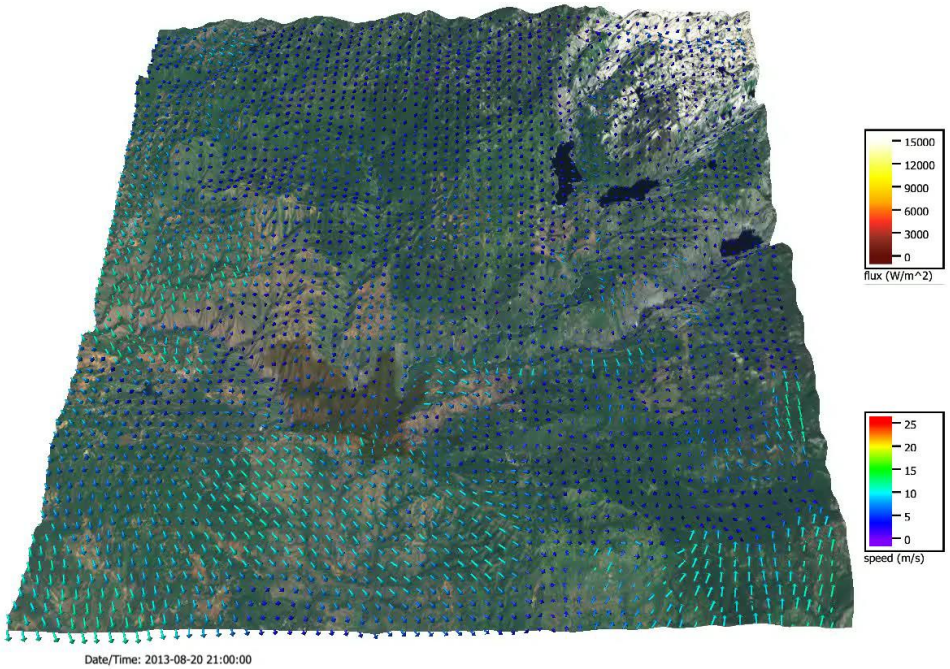
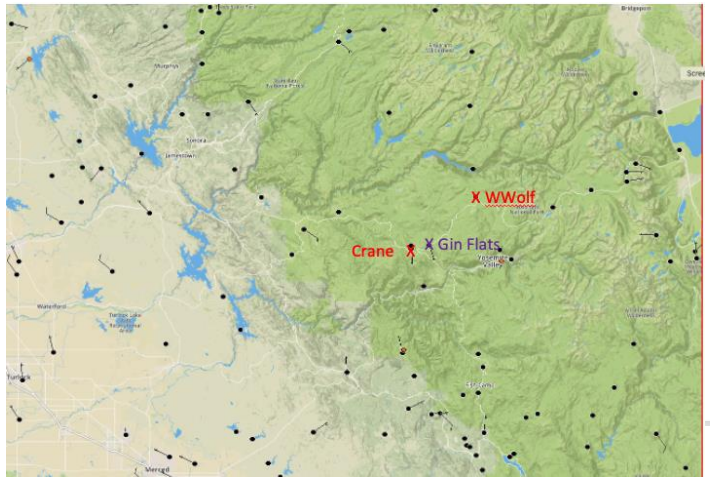
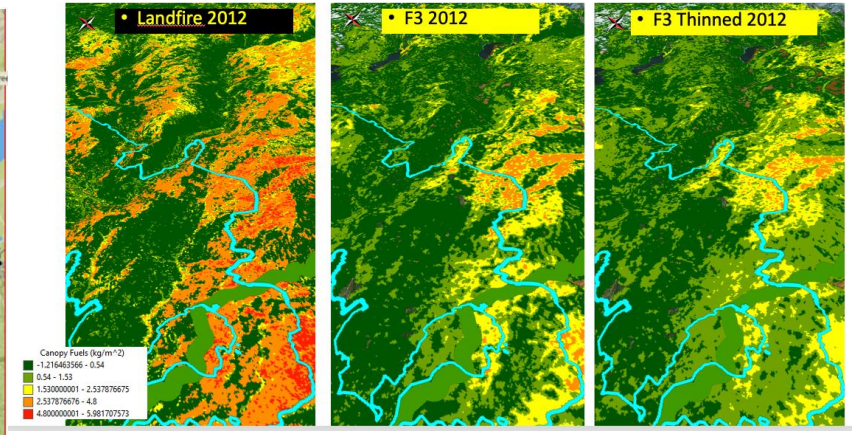


Figure adapted from Long et al., 2017

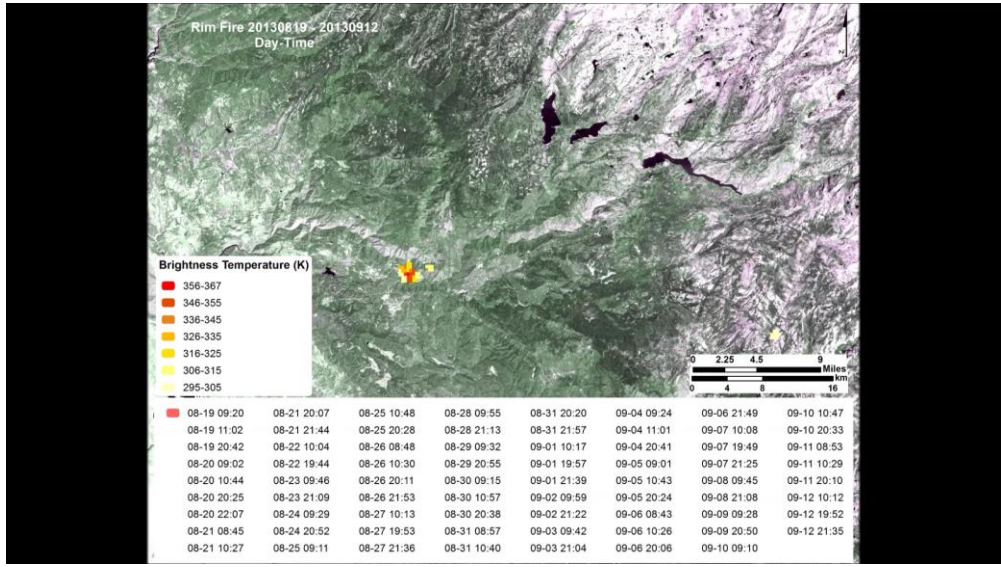




Poorly characterized winds



Uncertainty in fuels exceeds treatment effects

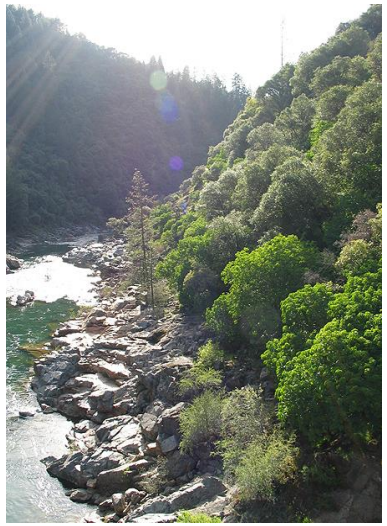


VIIRS fire progression, Courtesy W. Schroeder

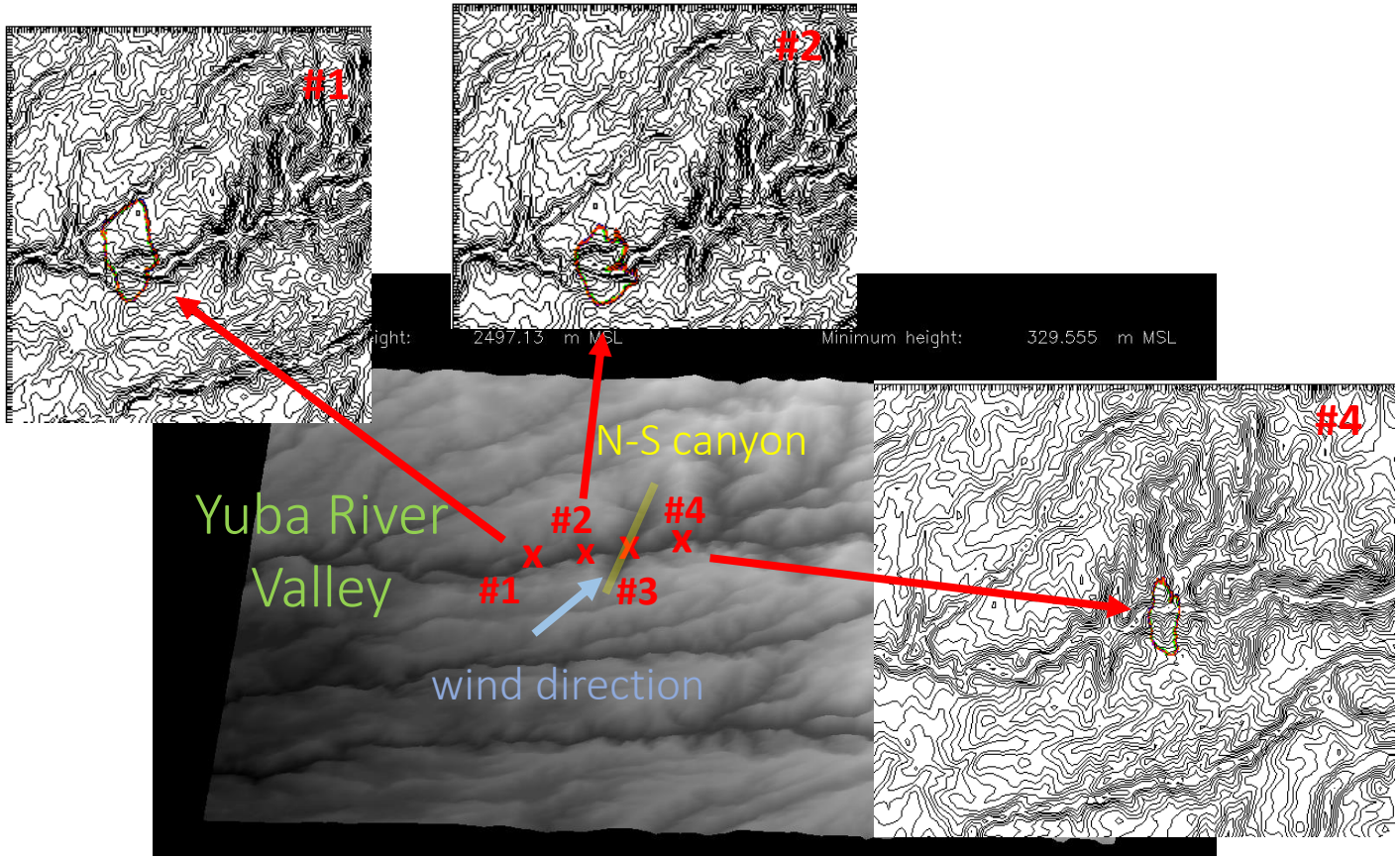
Identifying areas at risk for rapid large fire growth

Simulated 12-h of growth from ***hypothetical*** ignitions along the Yuba River Valley

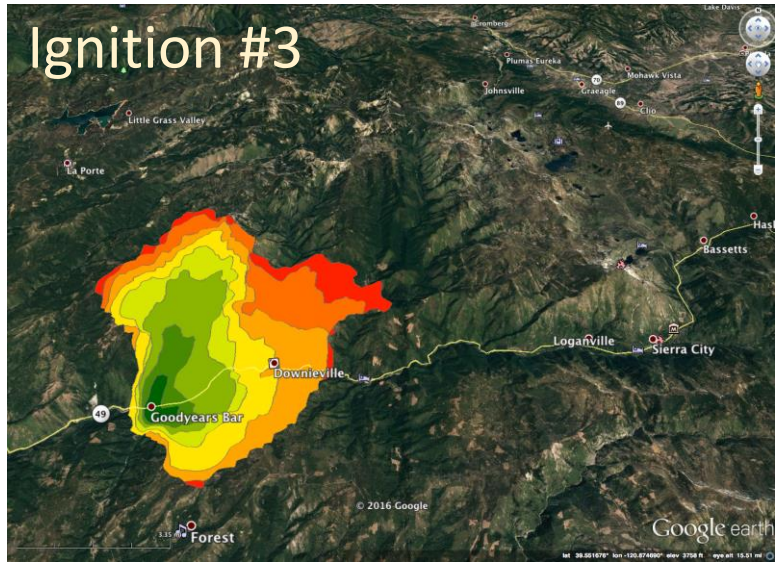
Yuba River Valley



On 9/17/14 (the day of the King fire run), weather was typical for fall – weak southwesterlies.



3 of 4 hypothetical ignitions along the Yuba River generated small fires.



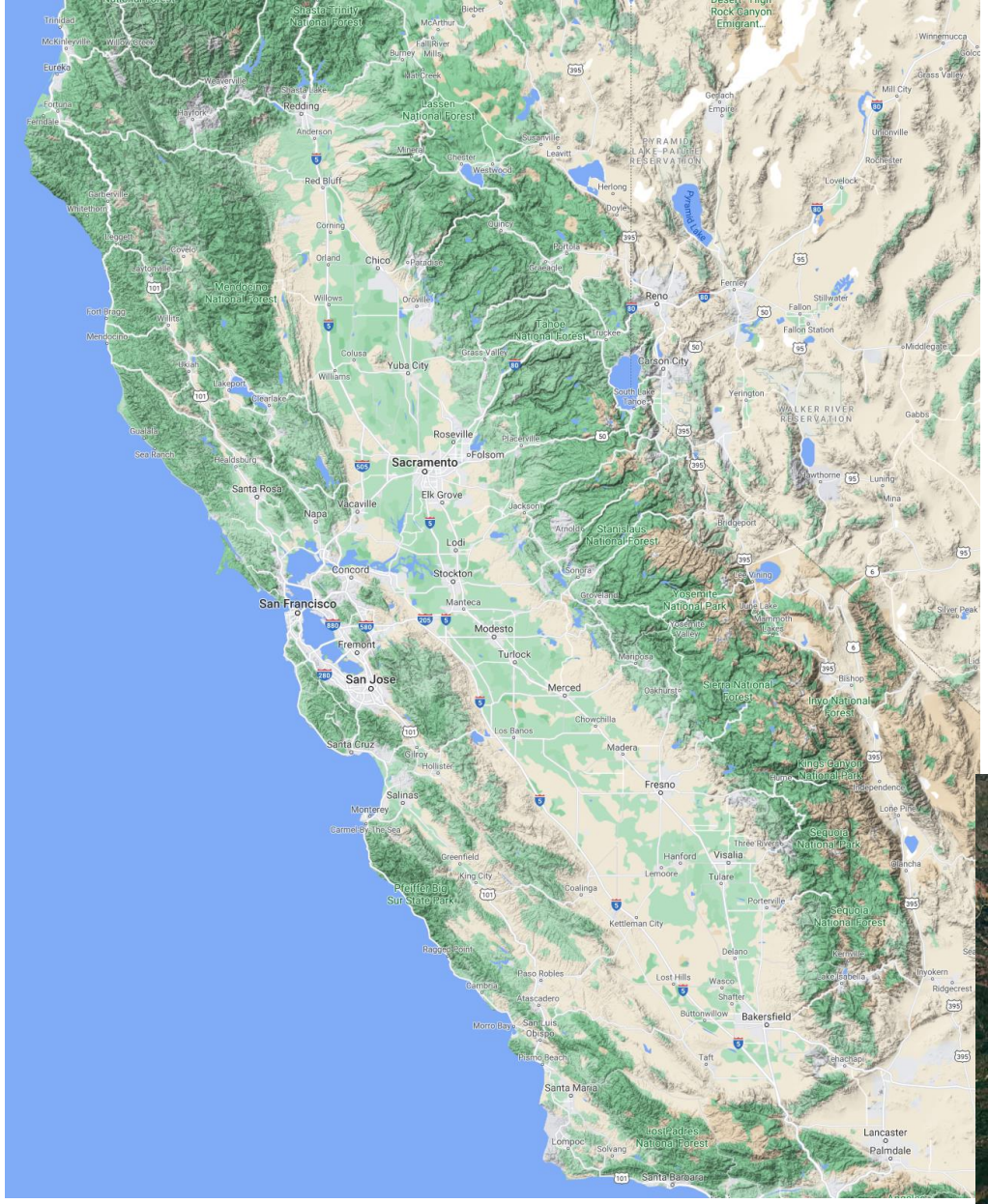
#3 had the same weather and fuel conditions, but the ignition near Goodyears Bar grew rapidly - 12,140 ha (30k acres) in a 12 h burning period - due to fine-scale atmospheric circulations and fire-atmosphere feedbacks.

“Plume-driven” fire takeaways:

- “Extreme” fires can occur during conditions (weather) that are not extreme.
- Primary factors shaping a fire and driving the rapid growth (microscale circulations and fire-induced winds) may not be apparent.
- Fuel moisture and load may only have noticeable impact where fires are growing upslope, where they can reinforce each other.
- Small factors and luck (ignition location) can make or break large fire growth among several ignitions in similar conditions

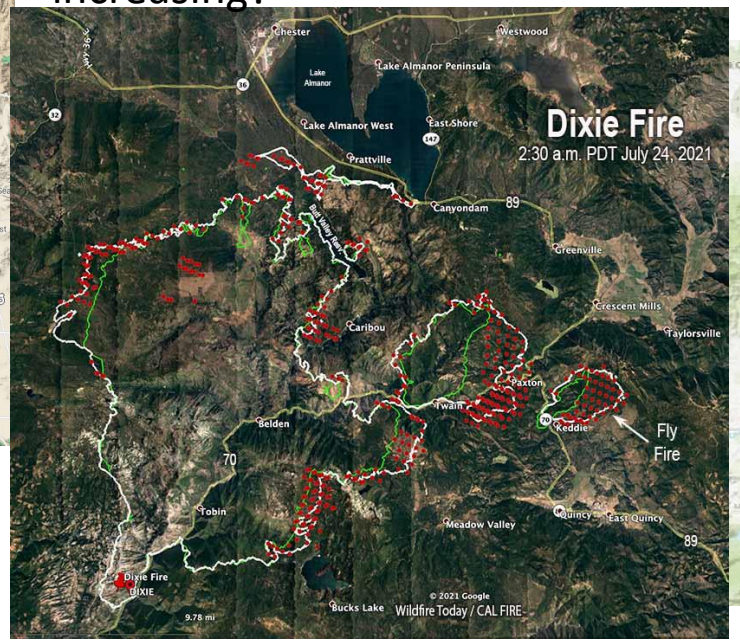
What controls the growth of plume-driven fires?

- Varying fuel & moisture content had small effect on ROS, effect was limited to inclined terrain, where their effect was combined.
- Weather window closed (recall XWTs)
- Some are topographically limited. But…

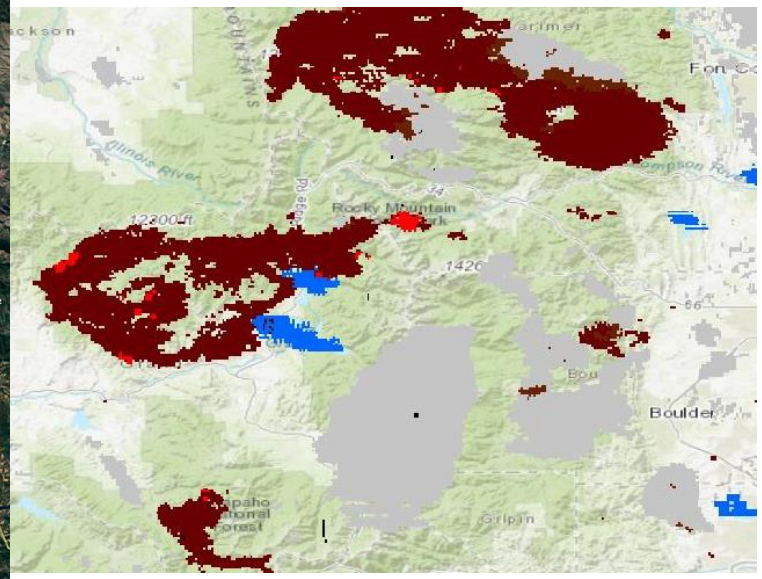


Susceptibility in river valleys in Sierra West & coastal regions

Prein et al.: Back to back XWTs increasing?



CO East Troublesome fire: spotted over Continental Divide



Summary

- Risk: regional weather patterns, local wind flows, seasonality of weather patterns overlapping susceptibility
  - “Camp Fire” scenarios can’t happen everywhere
  - Weather station network and mesoscale forecast models (and associated products) are much coarser than topography here, and still do not indicate the strength of wind maxima
- Filling a scientific gap.
  - Because of unique flow factors, certain topographic configurations in wind events can produce local rivers of strong, gusty winds
  - Problem areas vary with strength of event
- Cataloging mechanisms/locations with potential for factors to combine creating an extreme growth day
- Multiscale aspects to risk
  - Not every fire has potential to become megafire
- Fire weather index, hot dry windy, etc. attempt to get at danger. XWT typing, trends in their frequency, and mechanisms for generating rapid fire growth are another approach to identifying a high risk day/location

Thank you.

This material is based upon work supported by *California Energy Commission, Comprehensive Open Source Development of Next Generation Wildfire Models for Grid Resiliency, EPC-18-026,* NIST under award 70NANB19H054, and NASA under Award 80NSSC20K0206

NCAR is sponsored by the National Science Foundation.

For more information:
janicec@ucar.edu