2014 California King Fire Rapid Response: Deconstructing megafire behavior

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Project Summary: collect and research synergistic use of airborne technologies for pre-, active, and post-fire applications

Earth Observations: AVIRIS, MODIS/ASTER (MASTER), LiDAR

Data archived: ORNL; wildfire.jpl.nasa.gov

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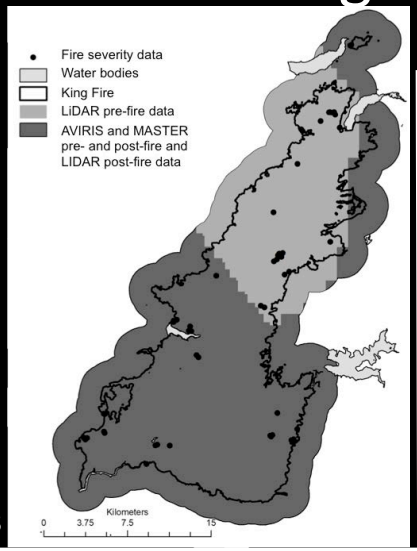
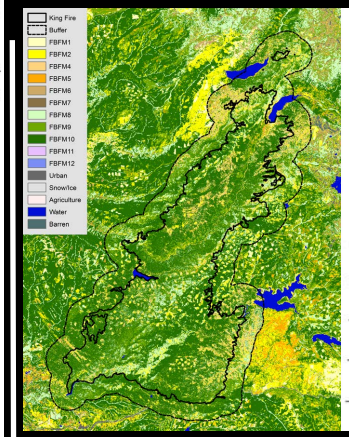
NASA Applied Science: Rapid Response to the 2014 California King Megafire

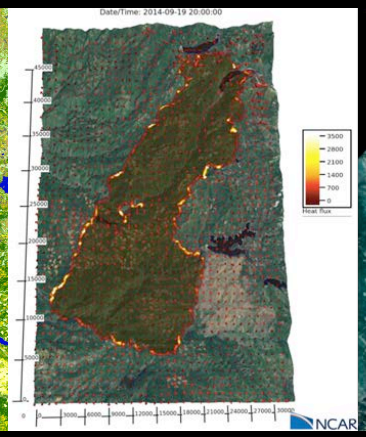
Background

- Megafires are fires that have high financial cost and likely long-term ecological and hydrological effects
- Megafire occurrence is increasing
- The September 2014 King (mega-)Fire burned in the Sierra Nevada Mtns., CA over an area previously surveyed by imaging spectroscopy (AVIRIS), LiDAR & high-spatial resolution multi-band thermal IR (MASTER)
- This is an unprecedented opportunity to study megafire behavior and effects

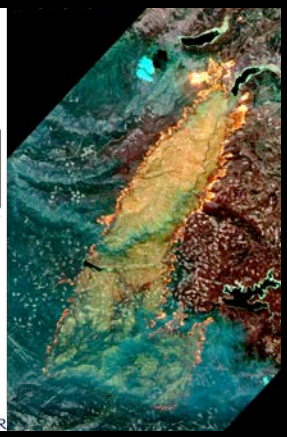




Fuel model map



CAWFE Fire Simulation



MASTER Thermal IR Data

Methods

- Data Collection
  - Commissioned post-fire LiDAR using ASO
  - Pre-HyspIRI airborne campaign of AVIRIS and MASTER
- Data processing
  - AVIRIS Level 2 orthorectified surface reflectance
  - MASTER Level 2 LST and emissivity
  - AVIRIS & MASTER Level 3 spectral indices (e.g., NDVI)
  - LiDAR Level 2 vegetation structural metrics
- Archived data at ORNL DAAC & http://wildfire.jpl.nasa.gov/
- Analysis
  - Data products of dominant species and vegetation structure were used to develop fuel model map
  - Sensitivity analyses of 375 m pixel x 1 minute fire behavior simulations using CAWFE model

Findings

- High data dimensionality of AVIRIS and 3D structure from LiDAR are necessary inputs to characterize the fuel environment
- Fuels matter differently based on different aspects of fire behavior:

Fire Behavior	Important Fuel Parameter
Spread rate	Horizontal connectivity and fuel condition
Fire extent	Fuel type and vertical structure

- Contrary to previous thought about extreme fires, neither fuels nor mesoscale weather are completely responsible for fire behavior and effects
- King Fire is proof that the intrinsic feedback between fire and local weather is a key player

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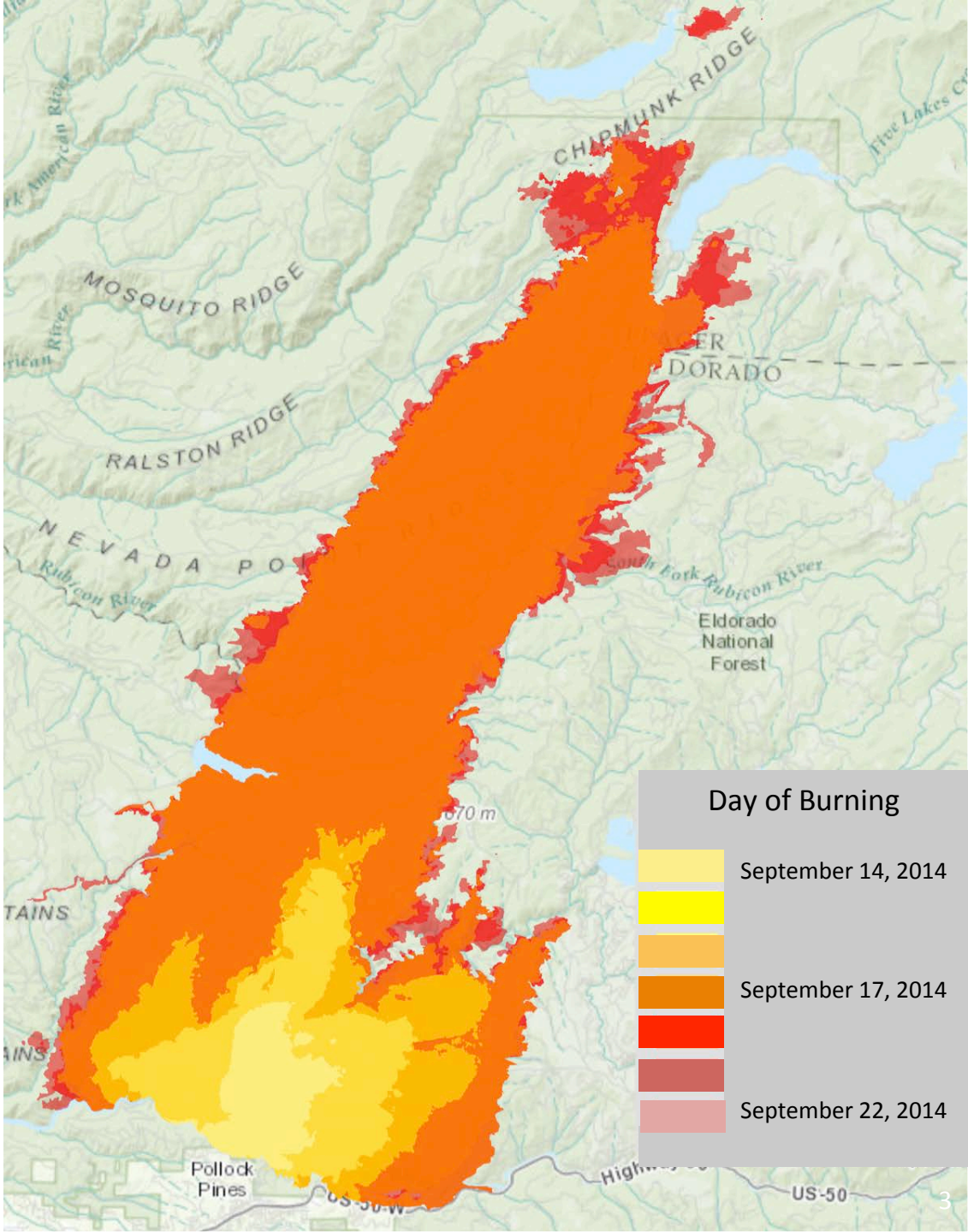
We focused an investigation of megafire behavior and effects on the King Fire because it had overlap of these three technologies and had substantial ecological and societal impact

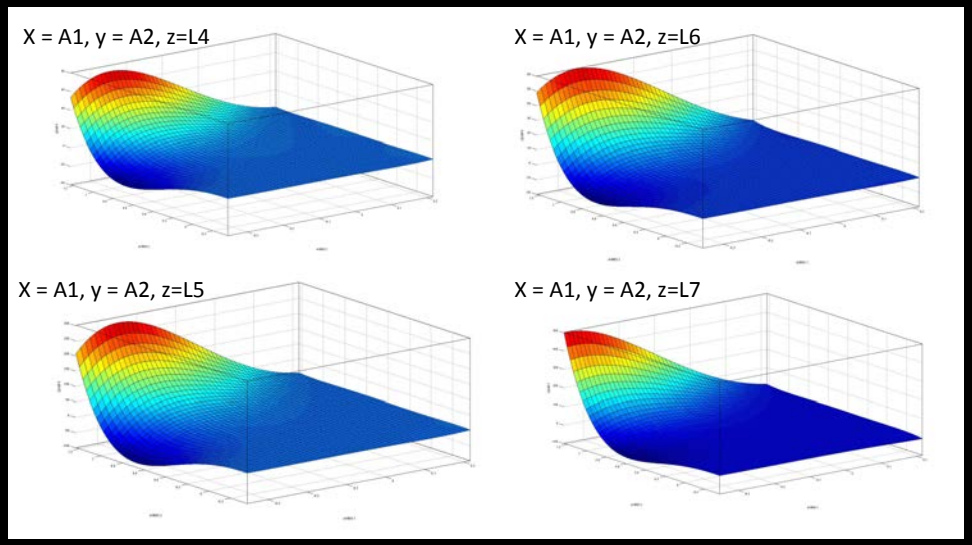


The observations from these technologies were used to:

1. Investigate relationships between spectral response and structure
2. Develop a procedure for classifying fuel models only using observations from remote sensig: Mapping Fuels Using Estimates from LiDAR and Spectroscopy (Map FUELS)
3. Deconstruct megafire behavior

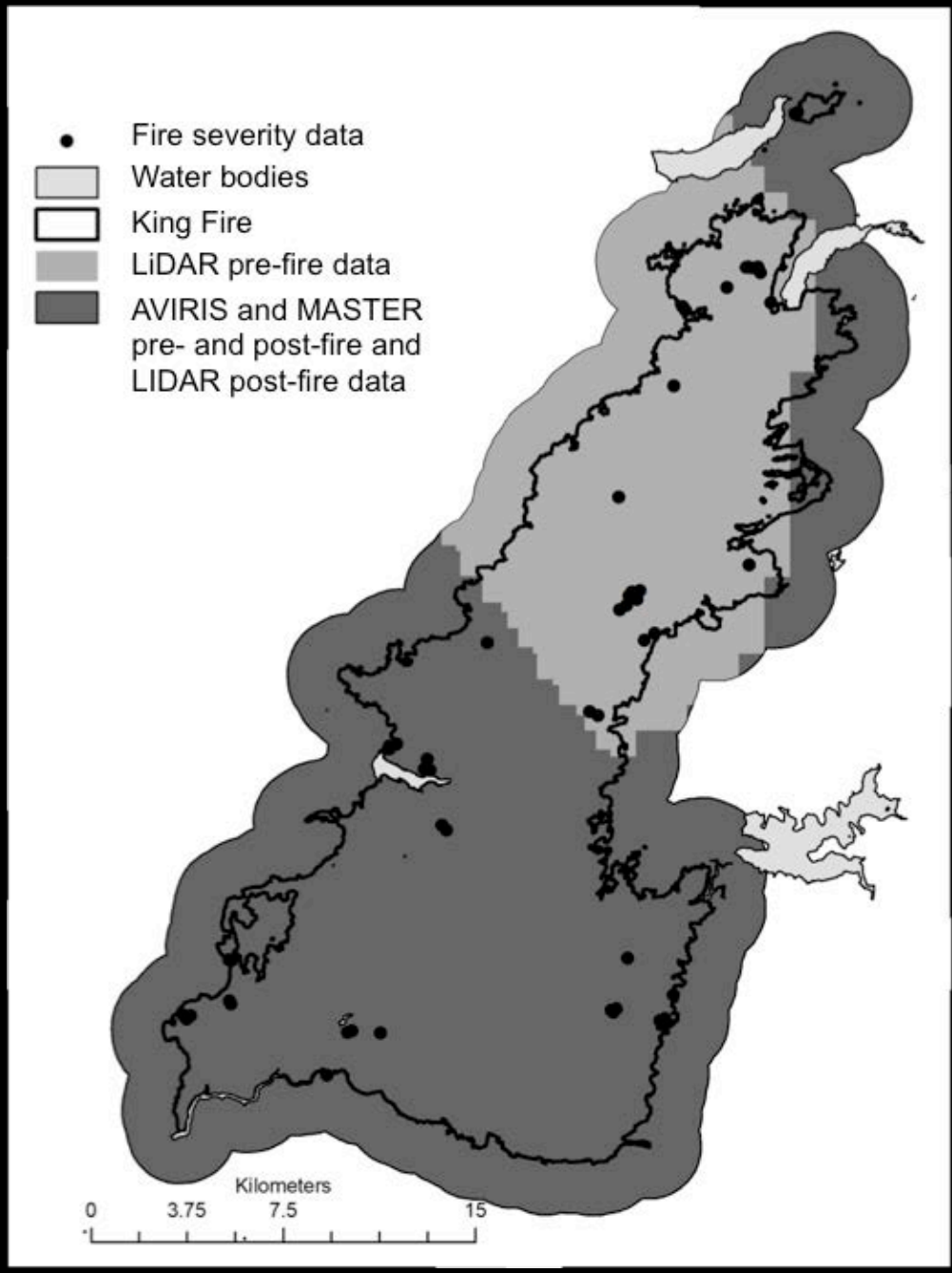
1. Investigating spectral signature and structure…

- H1: There is a unique spectral signature for specific vegetation structures
  - Method: Random Forests (20 trees) with LiDAR = f(AVIRIS spectral signature)
- H2: structure defines the spectral signature
  - Method: PCA & multivariate regression with AVIRIS PCs = f(LiDAR)
- Both hypotheses rejected as developed models had low predictability ($R^2 < 0.1$)

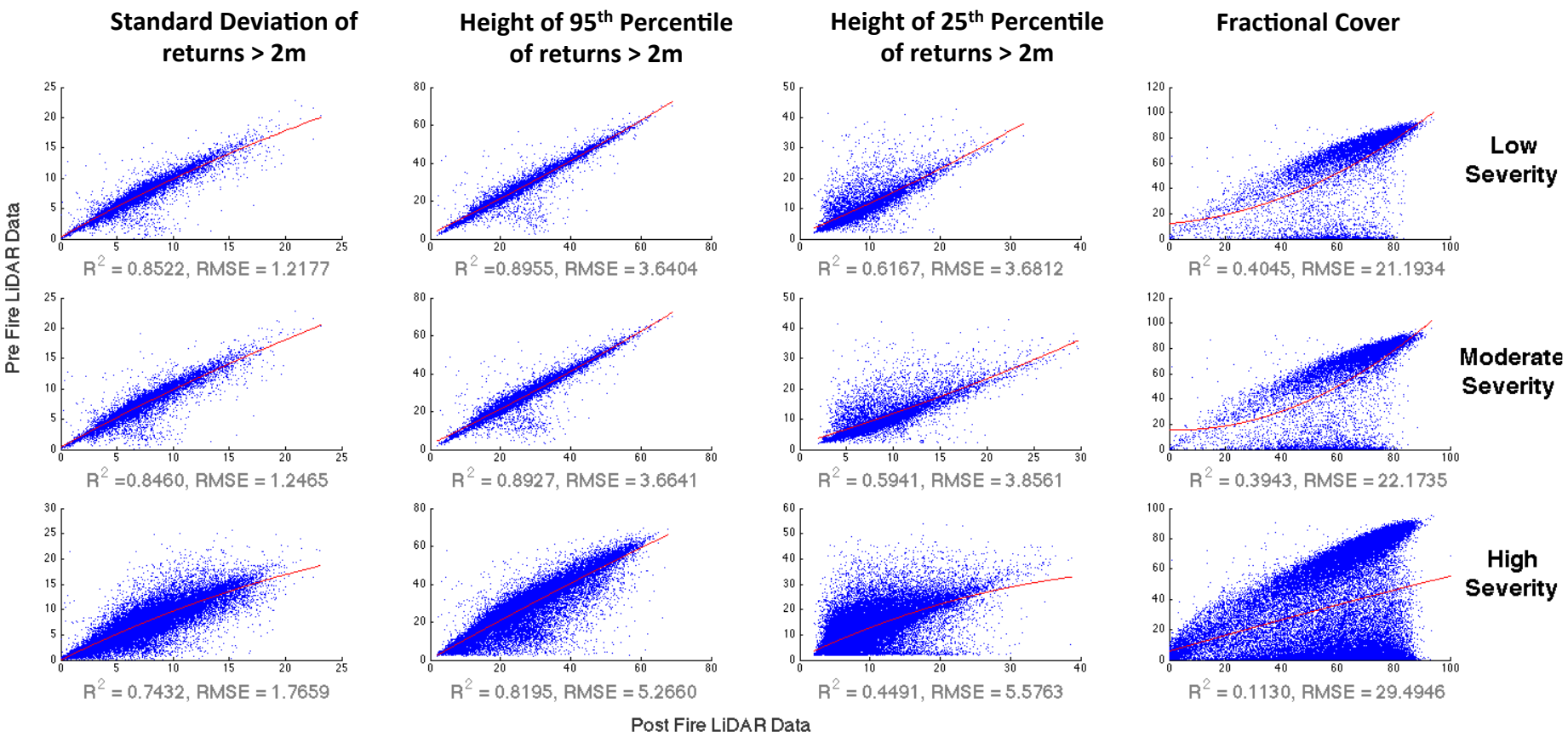


Key Finding: Although previous studies have found that physical effects of structure (e.g., interspecies competition for water) have a spectral response, structure alone, does not

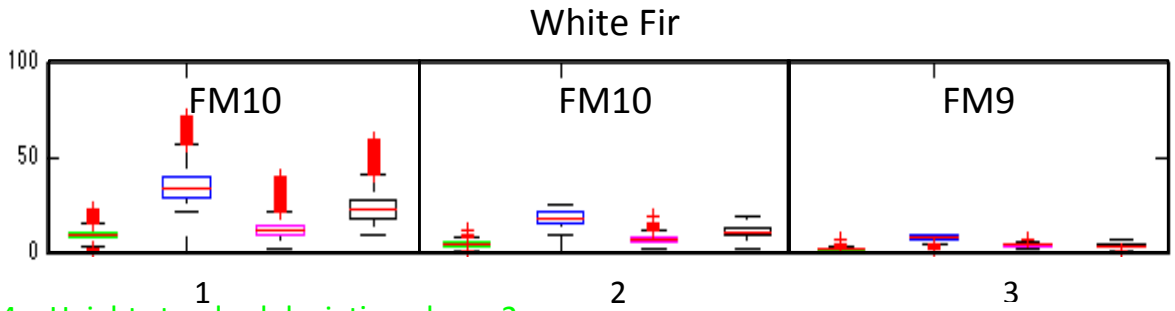
2. MapFUELS – fuel model classification using only remote sensing observations from LiDAR and AVIRIS



Regression models of post-fire structure were used to extrapolate pre-fire structure, to integrate observations of structure in fuel model classifications



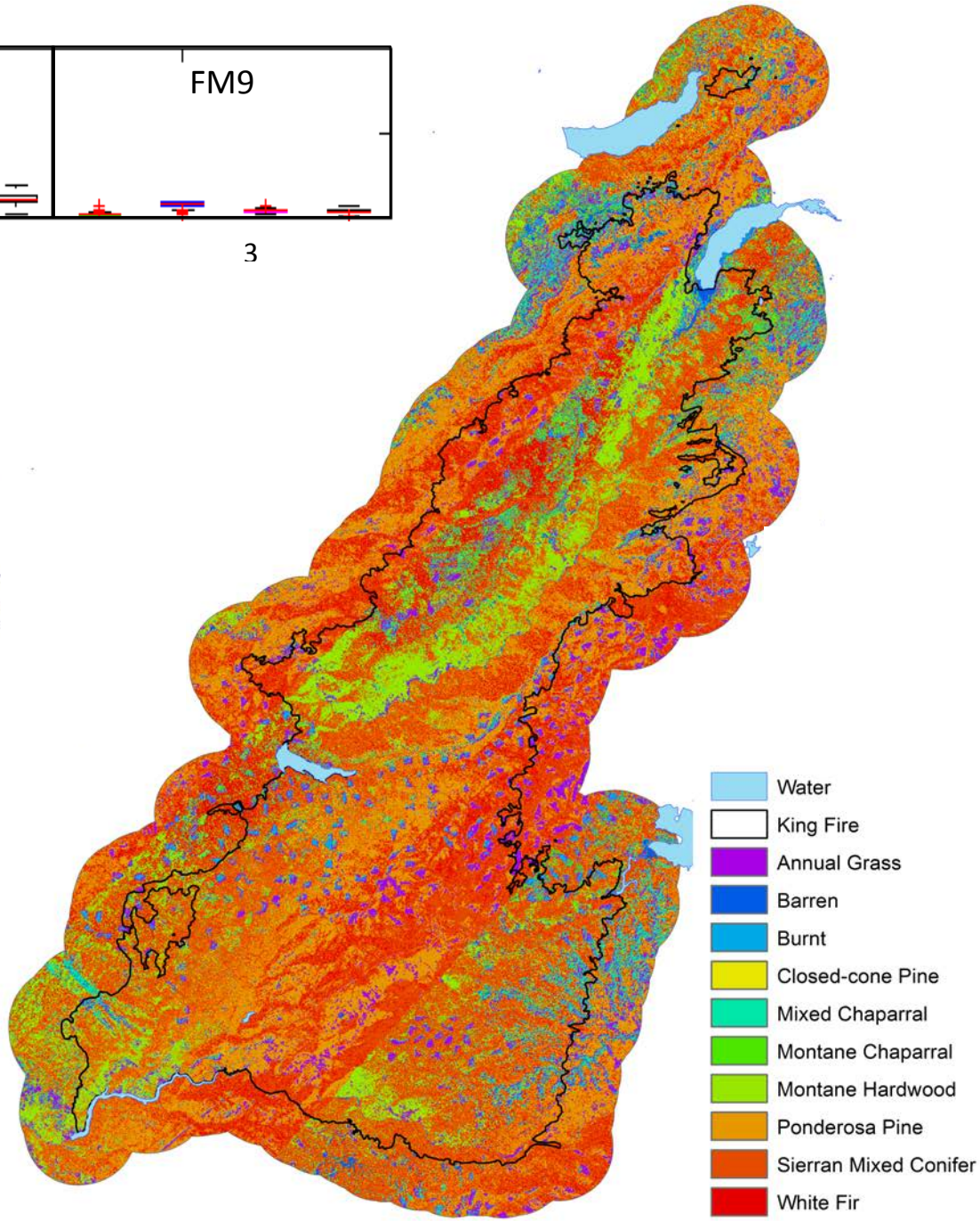
R^2 =	0.79	0.86	0.53	0.22



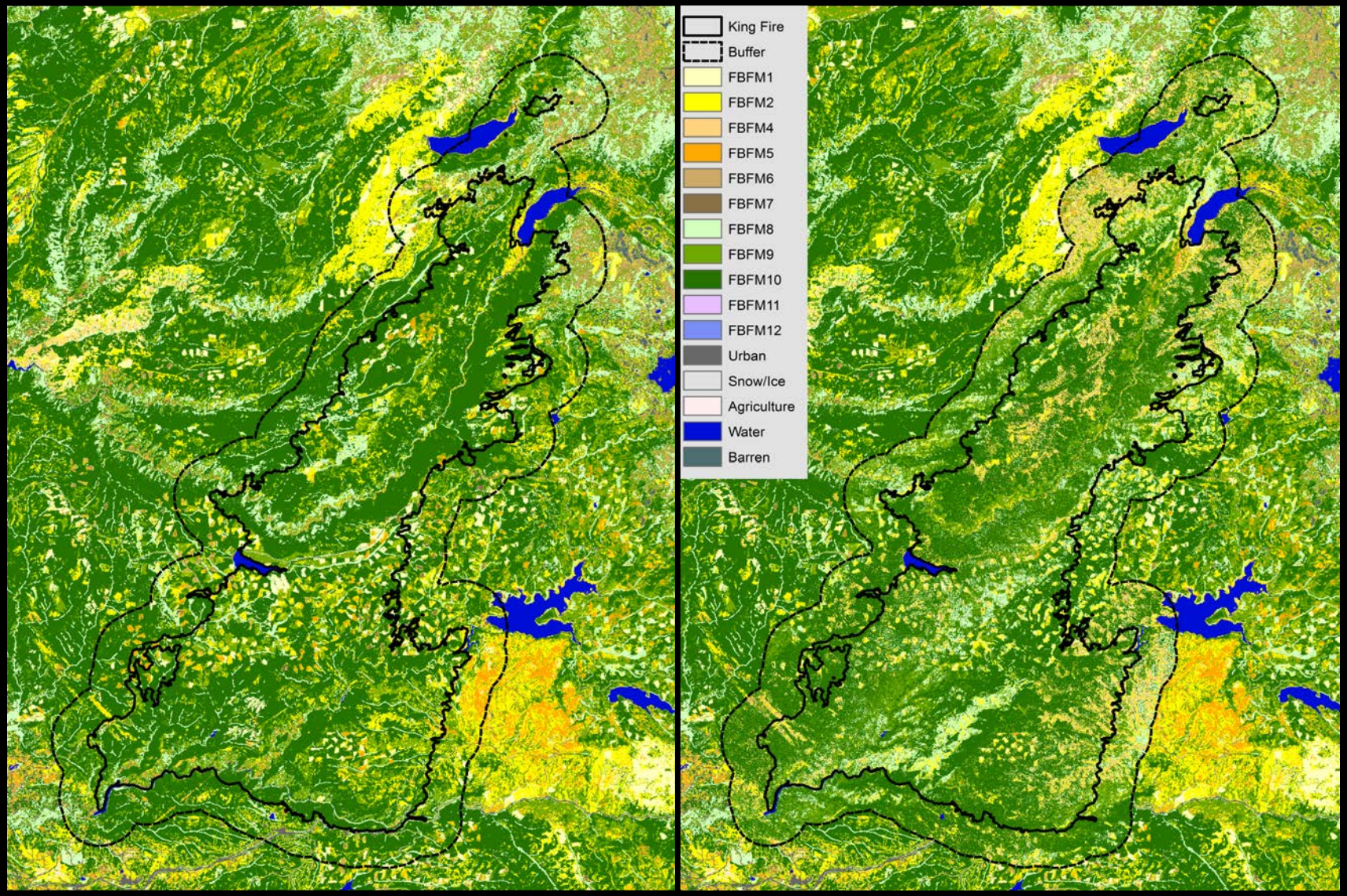
L4 = Height standard deviation above 2 m
L5 = Height p95 for all returns above 2 m
L 6 = Height p25 for all returns above 2 m
L5 – L6 = Canopy depth from p25 to p95

We used AVIRIS to create a dominant vegetation map

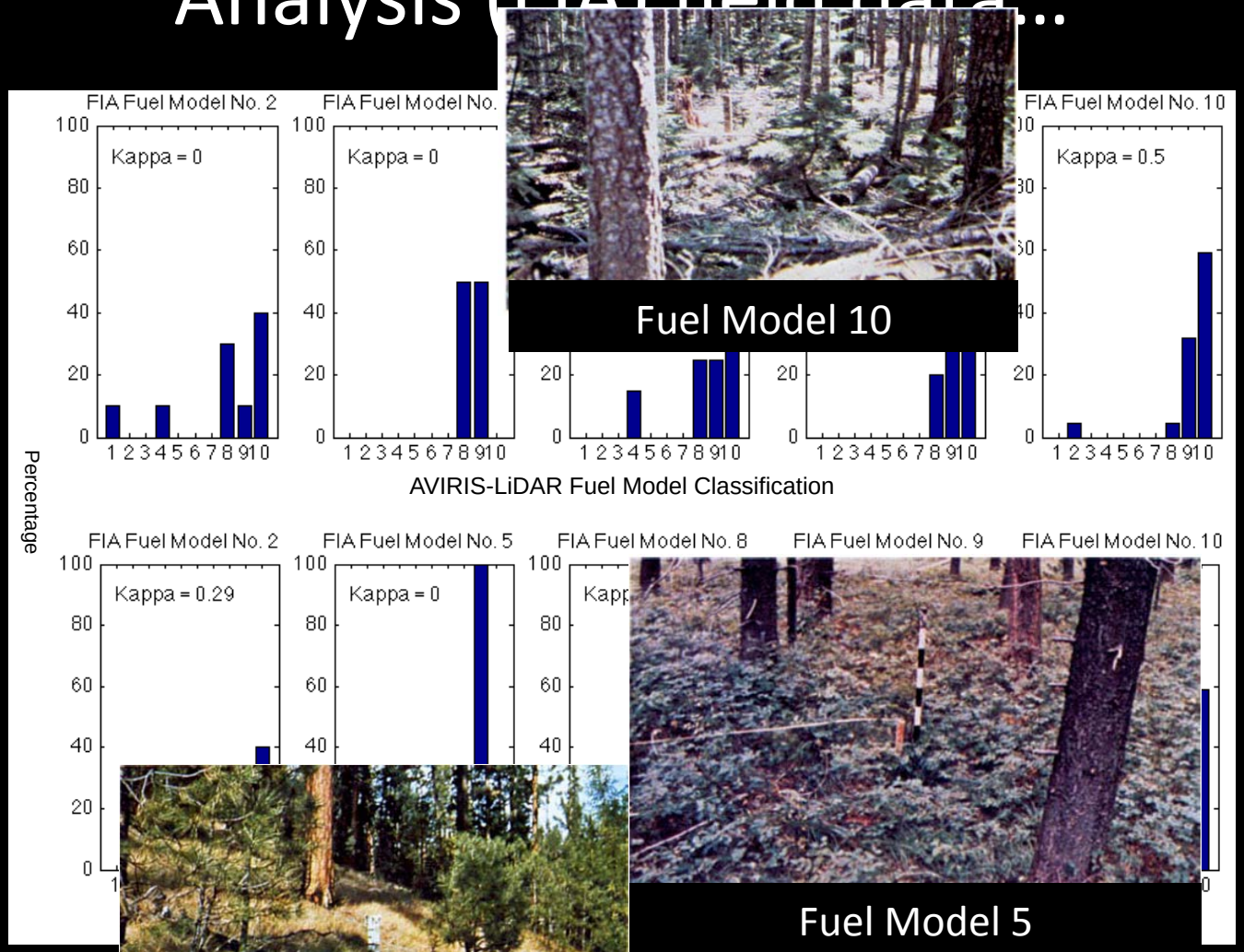
…and clusters of LiDAR structural metrics classified by dominant vegetation type to cross-walk to Anderson 13 fuel models



LANDFIRE (left) vs. MapFUELS (right) fuel models within the King Fire perimeter + 2 km buffer showing “slight” agreement



Comparing to Forest Inventory Analysis (FIA) field data…



Fuel Model 10

Fuel Model 2

Fuel Model 5

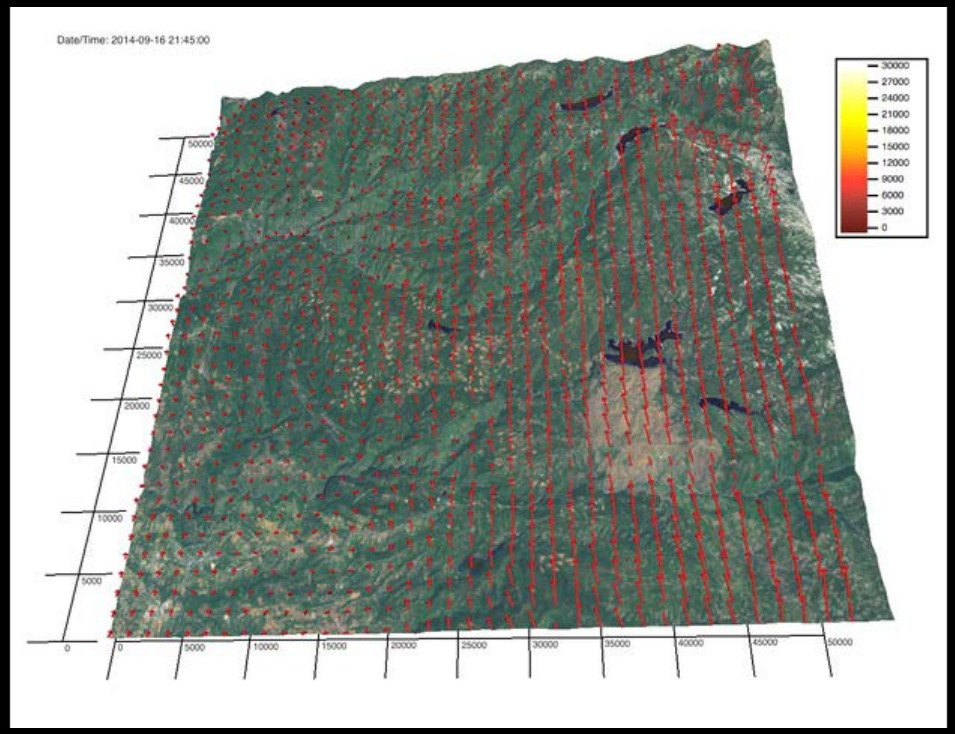
- Similar performance in FM 10 with dense overstory, thus two approaches see the same
- MapFUELS outperforms LANDFIRE except in FM2, which depends on horizontal connectivity, which is not considered in MapFUELS
- Neither approach classifies well FM5 with surface fires in the understory

3. Deconstructing megafire behavior

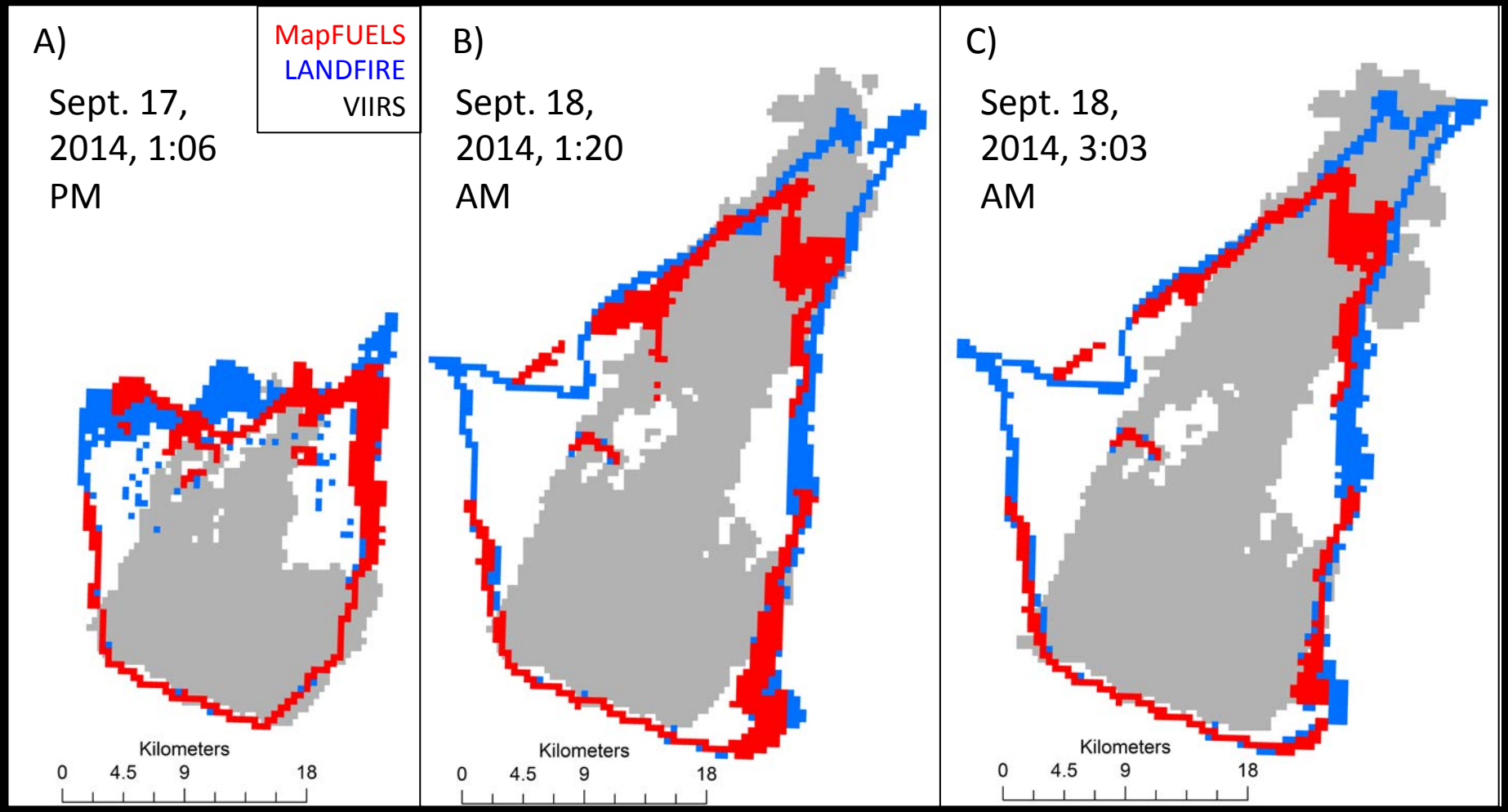
Used the Coupled Atmosphere Wildland Fire Experiment (CAWFE) Model to test fire behavior sensitivity to:

- Fuels characteristics – using knowledge of how LANDFIRE and MapFUELS observe fuel characteristics (i.e., structure & composition) differently

- Parameterizations of:
  - Fuel Moisture
  - Fuel density (a function of load and depth)

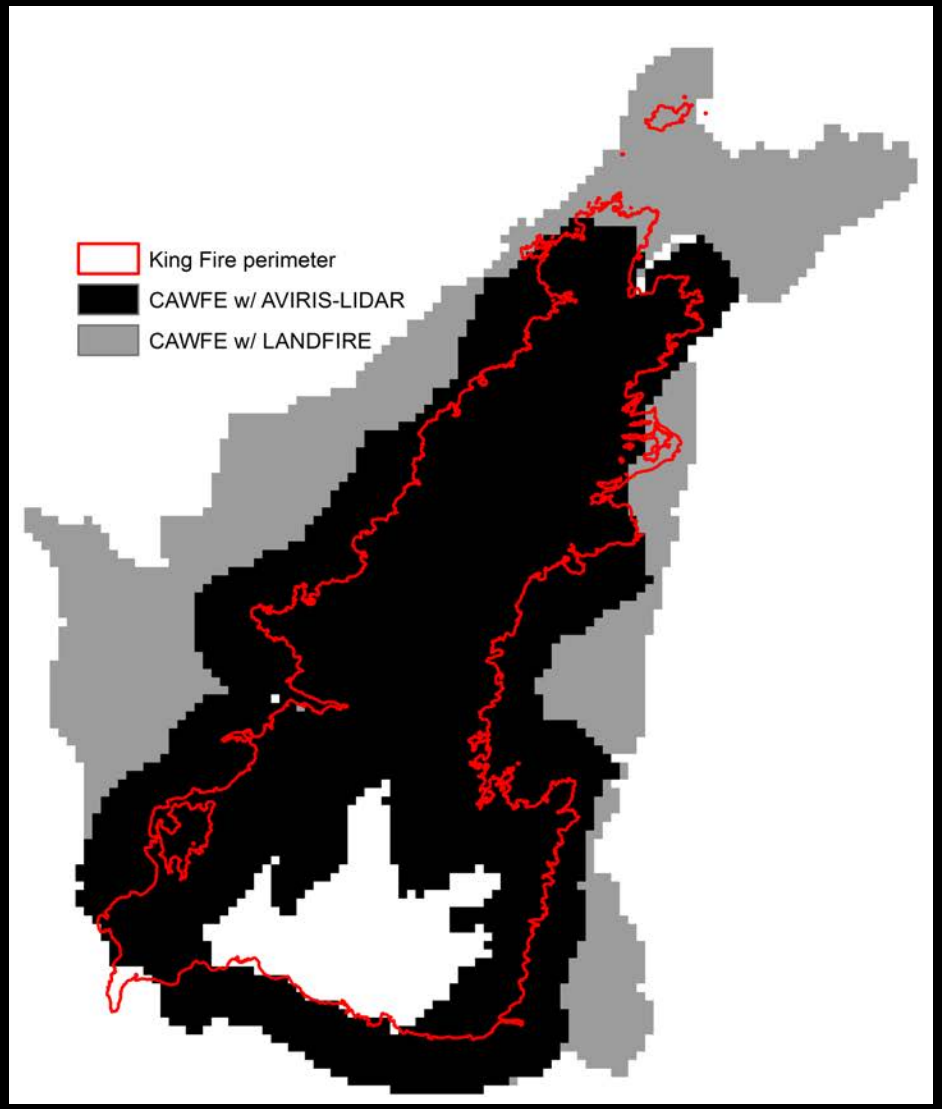


Spread rate sensitive to horizontal fuel connectivity

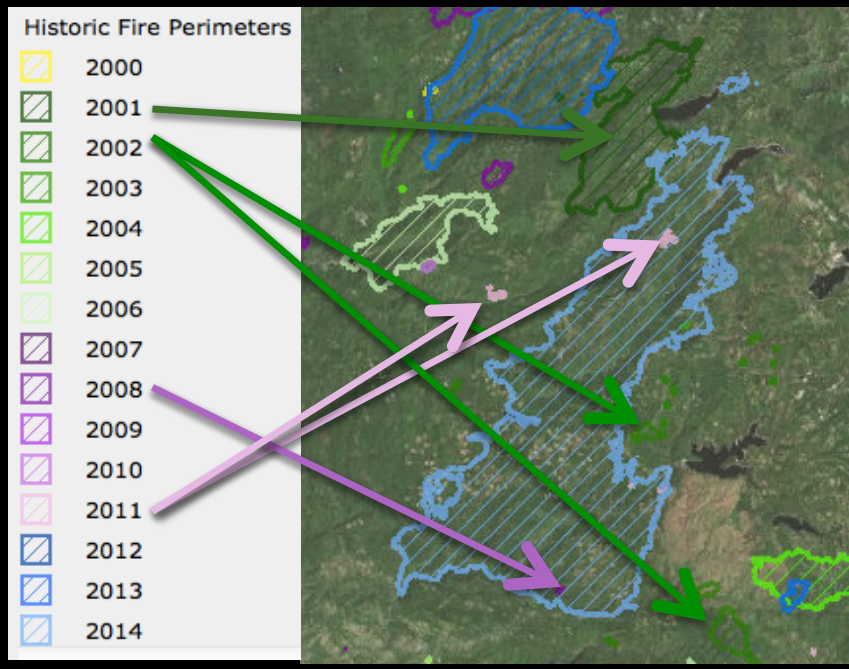


- LANDFIRE better captures spread rate
- Possibly because LANDFIRE considers fractional vegetation cover and MapFUELS captures fuel type and vertical structure

Fire extent sensitive to vertical fuel connectivity and successional state



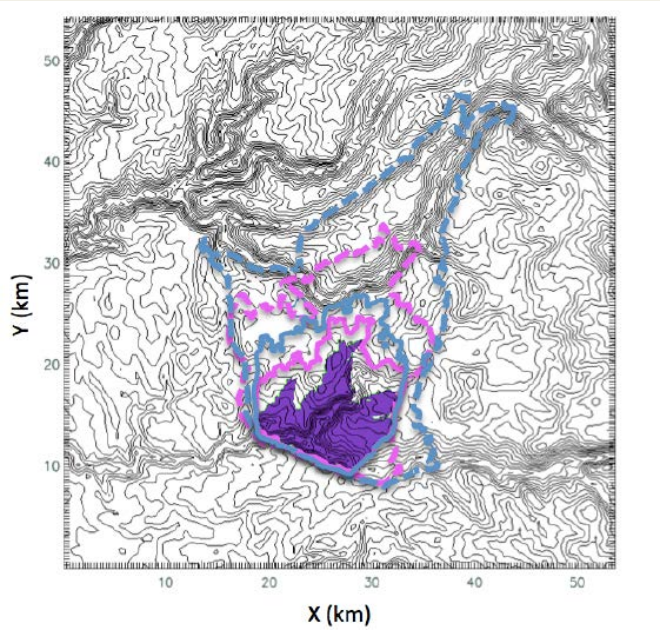
After considering past fires, it seems that AVIRIS-LiDAR better captures the fuel type and structure (i.e., successional stage) post disturbance (i.e., not mature stands)



Geomac, USGS

Fuel density doesn't necessarily mean bigger fires (topographic and weather constraints), but it ***does*** affect spread rate, especially going upslope

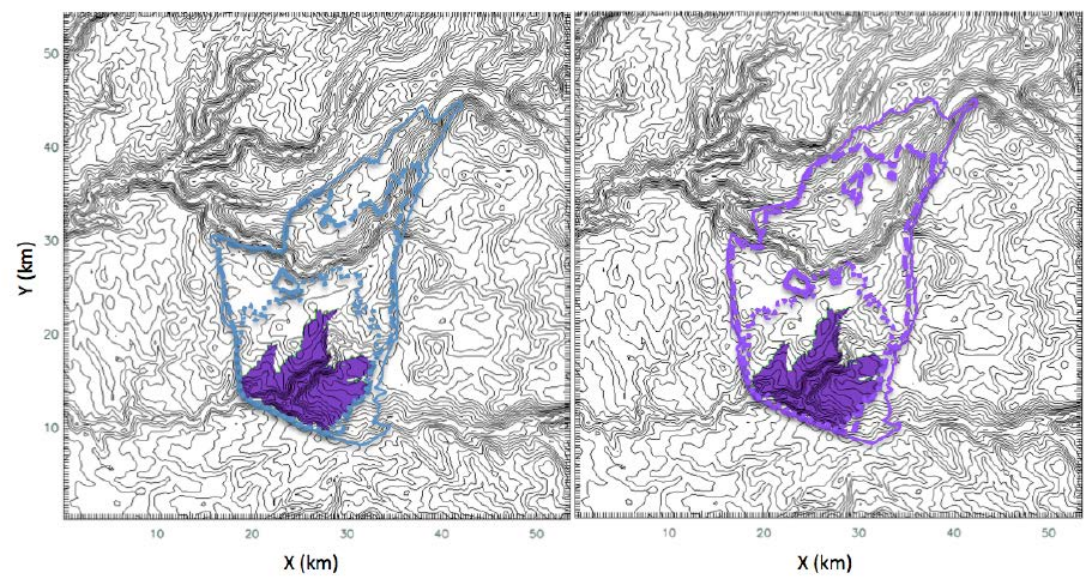
Surface



Half fuel load and depth

Current fuel load and depth

Canopy



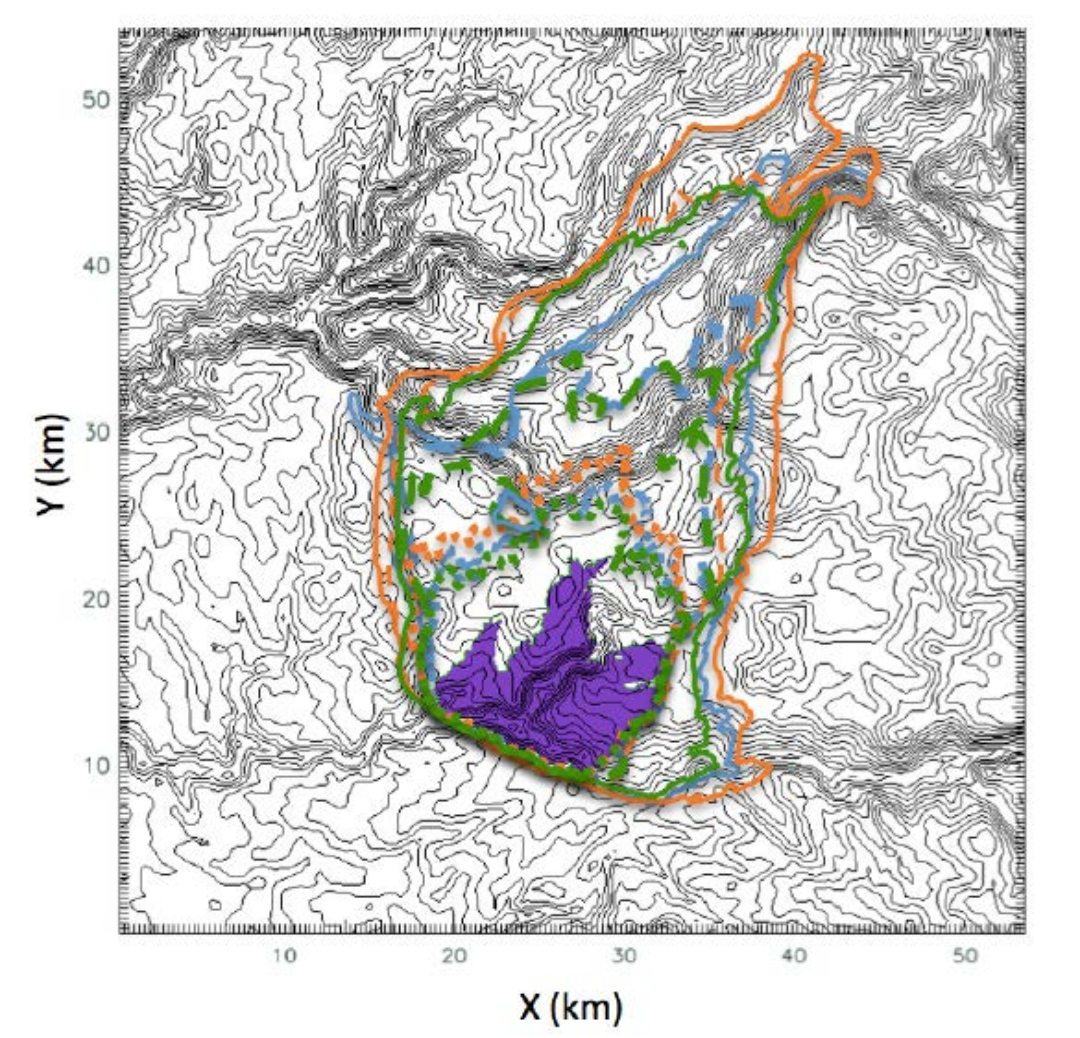
Triple canopy fuel load and depth

Current canopy fuel load and depth

12 h, 24 h and 36 h into the simulation starting from the NIROPs (purple) perimeter at 9:49 P.M. 16 September 2014

Fuel moisture influences spread rate, but perhaps only in the most extreme cases and does not affect final fire extent

Historical High (8%)
Historical Low (3%)
Current (5%)

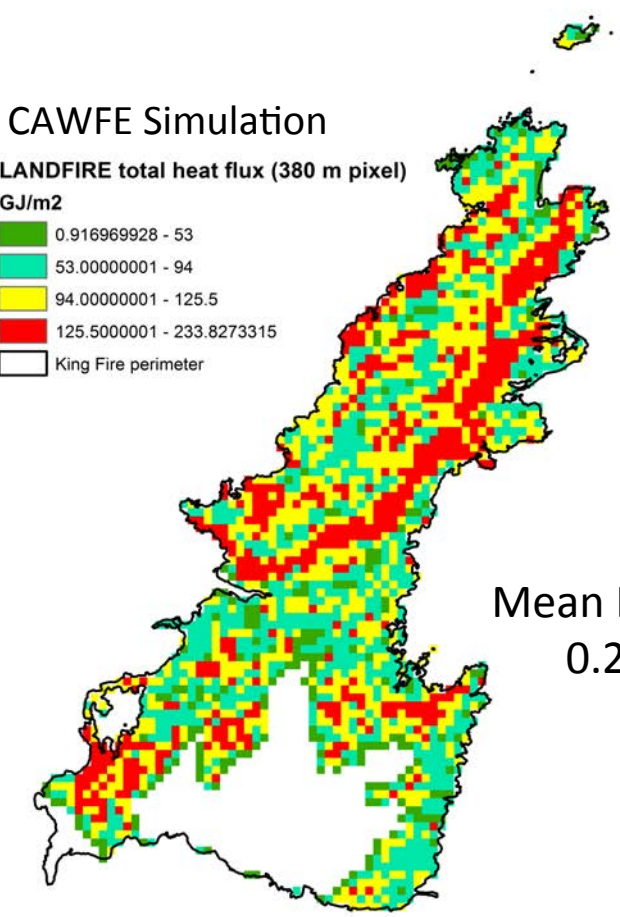


12 h (dotted line), 24 h (dashed line) and 36 h (solid line) into the simulation initialized by the NIROPs (purple) fire perimeter at 9:49 P.M. 16 September 2014

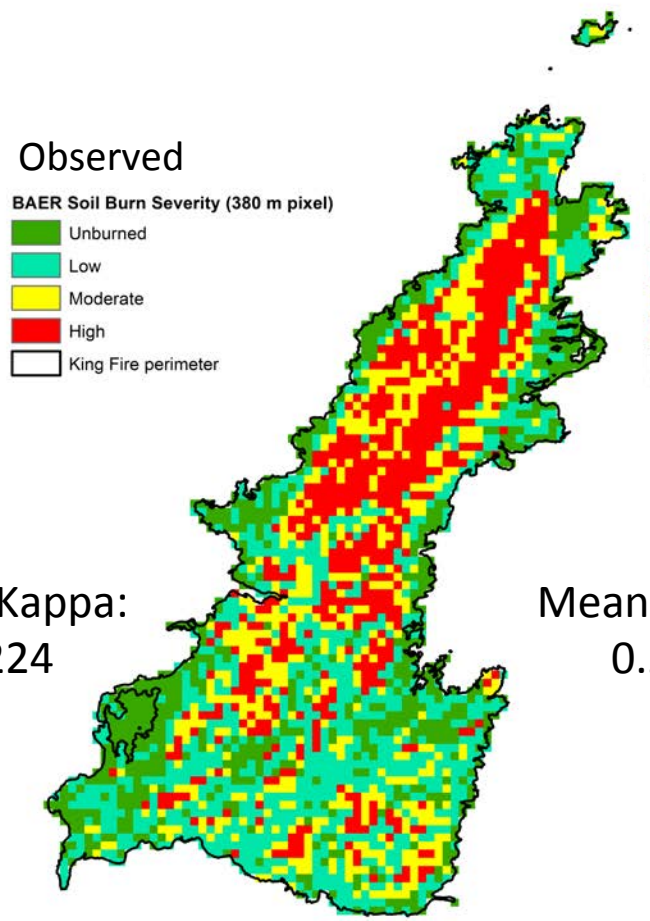
Total heat release plays a role in determining fire effects, specifically soil burn severity, ***BUT…***

It is not the whole story, other factors (like duration of sustained heat) also play a role

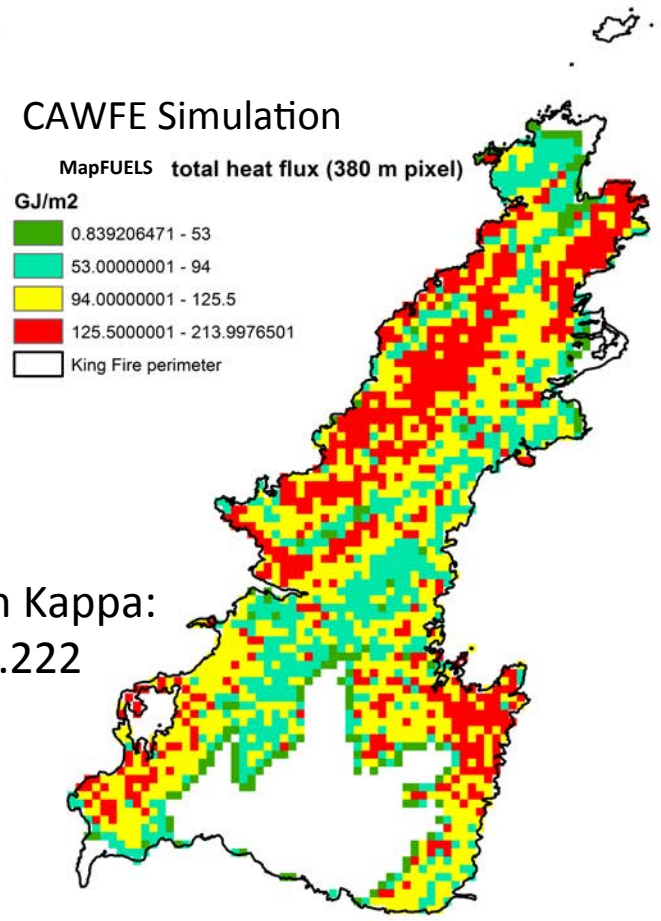
Total Heat Flux/ Fire Effects	LANDFIRE (kappa)	MapFUELS (kappa)
Low	0.29	0.28
Moderate	0.22	0.25
High	0.24	0.26



Mean Kappa: 0.224



Mean Kappa: 0.222



Summary of Findings

- Fuels matter but they matter differently based on what aspect of fire behavior you look at:
  - Spread Rate – horizontal connectivity and fuel condition
  - Fire Extent – fuel type and vertical structure
  - Total Heat Flux relates to fire effects
    - Spread rate has a slightly bigger role in low severity
    - Fuel type and vertical structure has a slightly bigger role in moderate-high severity
- Contrary to previous thought about extreme fires, neither fuels nor weather are completely responsible for fire behavior and effects
  - high resolution fuel maps and fire simulation show strong coupling in fuels *and* localized fire weather
- ARL6 – not used in Environmental Impact Assessment, but actively being used in post-fire regeneration monitoring

Megafires and Beyond

- Challenge:
  - Limited extent of these technologies
  - Computational costs
  - MapFUELS generalized approach for broader application (GEDI, EnMAP, etc.) beyond this case study
- Intrinsic feedback between fire and weather requires high spatial and temporal resolution model
- Fire behavior models may want to adapt and bypass subjective assignment of fuel model classifications and directly ingest highly variable fuel characteristics that can be observed from remote sensing

Thank you!

The work presented is from three publications currently in review:

1. Stavros EN, Tane Z, Kane VR, Veraverbeke S, McGaughey B, Lutz JA, Ramirez C, McGaughey RJ, *Nature Scientific Data.*
2. Stavros EN, Coen J, Signh H, Schimel D, *Remote Sensing of Environment*.
3. Coen J, Stavros EN, Fites-Kaufman JA, Schimel D, *Proceedings of National Academy of Sciences*.

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