

**Assessing fuels treatments in southern California National Forests in
the context of climate change**



**FINAL REPORT
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I. Abstract

One of the key uncertainties in fuels treatments is their longevity under a changing climate. Several recent studies have assessed fuel treatment effectiveness during historic fires, and in many cases found the treatment less effective than desired, particularly during extreme or record conditions. In 2007, southern California experienced one of the most severe fire seasons to-date due to record low fuel moistures early in the fire season (a key driver of the two-month long Zaca fire) and historic Santa Ana winds late in the season (resulting in several large late October fires). Climate change projections for the region suggest that these extreme conditions will be observed with increasingly greater frequency over the next half century. Southern California has one of the largest Wildland Urban Interface (WUI) extents in the country, and the extent of WUI is projected to increase significantly over the next 50 years. Fuels treatments are particularly important in mitigating wildland fire risk in WUI areas when extreme fire conditions occur. However, fuels treatments are traditionally designed to withstand historic fire weather conditions (i.e., from FireFamilyPlus), not future conditions, which makes their effectiveness less likely in the future.

In order to address uncertainties in the effectiveness of fuel treatments under a changing climate, we undertook an analysis of six fuel treatments across three southern California national forests.

Specifically, we 1) worked with USFS fire managers on the Los Padres, Angeles and San Bernardino National Forests to identify six critical landscape fuel treatments of concern, 2) developed downscaled projections of future climate and fire weather scenarios for 50 Remote Automated Weather Stations (RAWS) in southern California, 3) analyzed historical fire data from the region to identify an appropriate climatological testing window coincident with seasonality of fires that fuel treatments are meant to modify the behavior of, 4) tested the effectiveness of the six fuel treatments under future (mid-21st century) extreme fire weather as delineated from climate projections, and 5) developed guidelines and tools for incorporating future climate and fire weather scenarios into fuels treatment development. Additionally, due to the coincidence of the 2009 Station Fire burning into one of our six fuel treatment sites on the Angeles National Forest, we conducted an additional case study assessment of the Charlton-Chilao fuel treatment to assess its effectiveness during the Station Fire.

Major Findings and Outcomes:

- Fuel treatments in southern California forests should be planned for summer fuel-driven fires, not fall Santa Ana wind-driven fires, and a summer climatology window that excludes Santa Ana conditions (e.g., May 15 – Sept 15) should be used to model fire behavior and test treatment effectiveness.
- The Charlton-Chilao fuel treatment was effective in modifying the Station Fire behavior and protecting the Chilao Fire Station, but under the projected mid-21st century climate, the treatment would not have modified fire behavior as effectively, resulting in 50% greater area burned.

- All six of the fuel treatments are projected to experience significant increases in flame length, rate of spread, crown fire and other important fire behavior metrics, and will likely not meet effectiveness objectives by the mid-21st century.

II. Background and Purpose

Strategically-placed fuels treatments have gained attention as a cost-effective method to modify fire behavior in and around resources-at-risk, including ecological, cultural, and historical resources, as well as human infrastructure in the Wildland Urban Interface (WUI). Fuels treatments must be planned years in advance to go through the appropriate scoping and review processes, and as such can be implemented as much as a decade or more after they were first planned. Depending on the potential funding and resources available for retreatment, the longevity of these fuels treatments is largely unknown, and only recently have scientific studies attempted to assess fuel treatment effectiveness after a wildfire intersects a fuel treatment. Syphard *et al.* (2011) found that fire breaks on the Los Padres National Forest historically stopped approximately 46% of wildfires, while Rogers *et al.* (2008) reported that the Tunnel 2 Fuel Treatment on the San Bernardino National Forest played a critical role in aiding suppression effort during initial attack on the Grass Valley Fire in 2007, potentially saving homes and minimizing fire spread during an extreme weather event. During the 2007 Zaca Fire on the Los Padres National Forest, numerous fuels treatments from the past 20 years were observed by a senior Fire Behavior Analyst to have effect in modifying fire behavior (C. Henson, personal communication). Additionally, areas that had been untreated such as riparian zones were observed to burn at high severity.

While there are many uncertainties about the longevity of fuels treatments, a key knowledge gap is the influence of climate change on fuels treatments and their longevity over the next half century. Global climate models (GCMs) produce a strong warming signal and drying scenario in southern California (IPCC, 2007), which will not only impact live fuel moisture, but will subsequently alter the magnitude and intensity of wildfire behavior, making it increasingly difficult for firefighters to suppress wildfires with limited resources. Fuels treatments can be enormously beneficial to firefighters, particularly in the WUI areas where homes and resources will only continue to be at-risk on par with the situations observed in October 2003 and 2007. With projected rapid increases in temperature (Dettinger, 2005) and WUI expansion in non-coastal regions of southern California (Moritz and Stephens, 2006), it is reasoned that these regions will be increasingly prone to wildfire hazard in the future. Westerling and Bryant (2006) examined economic ramifications of climate change fire risks within the state of California, and found that the largest potential losses under climate change scenarios occur in WUI areas within the state.

To maximize the benefit-to-cost ratio, fuel treatments need to be designed and implemented with objectives of longevity that account for climate change. More specifically, *fuels treatments must be designed to modify future, potentially more extreme fire behavior, not historical fire behavior.*

In order to design fuel treatments that account for climate change, we undertook to answer three primary research questions:

- 1) How will climate change in southern California impact fire behavior and, particularly, extreme fire events?**
- 2) How well will *existing* fuel treatments modify future fire behavior so as to aid fire suppression?**
- 3) How can fire managers throughout southern California and nationally use this information to increase cost-effectiveness in their fuels treatment programs?**

III. Methods

To address each of these fundamental research questions, the following methods were undertaken.

- 1) How will climate change in southern California impact fire behavior and, particularly, extreme fire events?**

Southern California is a unique ecosystem that includes incredible diversity associated with both steep elevation gradients and proximity to the ocean. The diversity fosters two fire regimes that are distinct in their characteristics: one is a summer-dominant regime with fires driven primarily by topography and fuels, while the second is an autumn-dominant regime with fires driven primarily by Santa Ana wind events. To understand how climate change might impact fire behavior in this region, particularly in the context of fuel treatment effectiveness, we first had to quantitatively distinguish between these two fire regimes and determine cut-off dates for the summer-dominant, fuel and topography-driven regime. We did so utilizing a dataset of historic large wildfires in Southern California from 1948-2009, and associated each fire with wind and pressure conditions to characterize it as either a Santa Ana or non-Santa Ana fire. We then characterized each regime by timing of fire, extent of area burned, and total ignitions.

Second, we had to make climate change projections applicable at a scale that was relevant to fire and land managers; that of a Remote Automated Weather Station (RAWS). To accomplish this, we statistically downscaled GCM output from a set of models forced by 21st century emission scenario (IPCC, 2007) to develop regional projections of climate change for southern California for use in projecting future fire environment (i.e., weather, fuel conditions) scenarios. We compared results for 21st century runs to those from GCM models run under late 20th century conditions to examine changes in fire weather danger extremes with respect to existing fuels treatments. All RAWS located in and around these three forests in Southern California that had at least 12 years of observations over the period 1996-2010 were acquired from the Western Regional Climate Center, for a total of 50 RAWS (Figure 1).

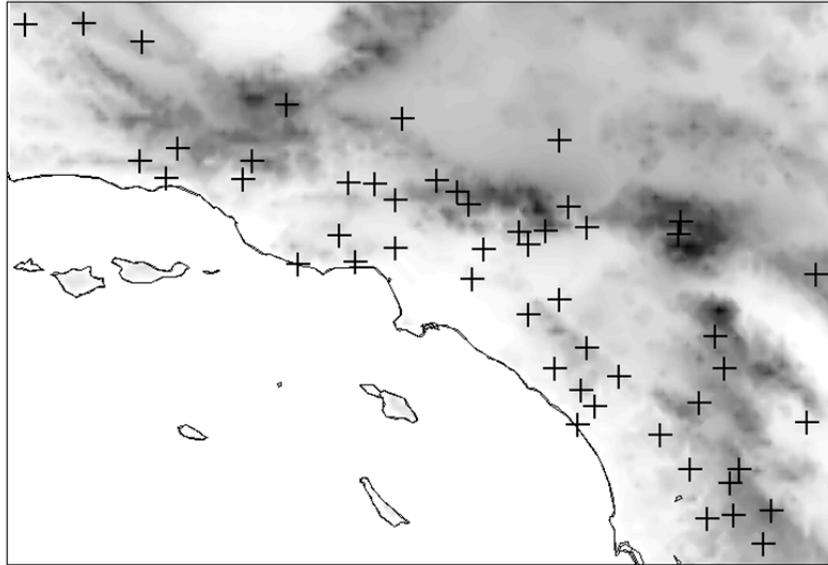


Figure 1. Location of RAWS selected for downscaling.

A critical limitation of applying RAWS data are data quality issues that often result in unrealistic values not suited to applied science. Given the focus of the present work to resolve extreme fire danger conditions, it was necessary to adequately quality control the observational dataset prior to analysis and the development of future climate scenarios. Furthermore, statistical downscaling necessitates a complete dataset void of missing data. The quality control process involves three steps. First, observations are scanned for improbable data using integrity and consistency measures (e.g., disallowing temperatures above 130F, precipitation amounts exceeding 20 inches). Next, a screening procedure to identify temporal and spatial outliers is performed on the data. This involves transforming daily observations into daily standardized anomalies by aggregating data using a 31-day moving window and covering all years of observation. Standard anomalies for precipitation and wind speed are calculated by first transforming the data by taking its square root of data to reduce data skew. Data fail the quality control when an individual station exceeds five standard deviations, or the spatial anomaly, defined as the difference between individual observations and the mean of the nearest 10 stations (e.g., Peterson *et al.*, 1998), exceeds 1.5 standard deviations. The screening process is iterated until all remaining data adhere to the quality control scheme. Observations that contained one or more variables failing quality control are considered erroneous for all elements for the given day. While this procedure was meant to identify potential erroneous data, it is feasible that it also failed to identify some poor quality data and also removed legit observations. Collectively, the quality control procedure discarded approximately 2% of the data.

Missing observations as well as observations that failed quality control are then estimated using a multiple linear regression procedure. This procedure uses a correlation matrix for each variable and month to identify the top six comparison stations. Prior analysis shows that an objective method based on correlation values often is superior to methods that chose predictor stations based on Euclidean distance in regions of complex terrain (e.g., Abatzoglou *et al.*, 2009). Linear regression across

stations is performed using available paired observations. For missing station observations, a multiple linear regression model is applied by weighting individual regressions by the squared correlation coefficient.

Downscaling Methods

The increased need for place-based climate projections has resulted in a proliferation in downscaling methods and datasets in recent years. Downscaling includes both dynamical and statistical methods, with both having their strengths and weaknesses (e.g., Fowler *et al.*, 2007). Statistical methods are used here as they can be both calibrated to historical observations for direct application and are computationally inexpensive to develop, and thus can be examined across a suite of different global climate models (GCMs). Whereas there has been much work evaluating downscaling in the context of water resources, Abatzoglou and Brown (2011) were the first to examine the influence of different downscaling methods in the context of wildfire applications. They found that the Multivariate Adaptive Constructed Analogs (MACA) method most effectively captured the characteristics of daily meteorology across temperature, humidity, precipitation and wind across the complex terrain of the western United States, and is used hereafter in this work. This method uses quantile-mapping bias correction and commonality of patterns (i.e., analogs) between coarse scale observed daily meteorological fields and coarse scale daily GCM meteorological fields.

Climate change impacts and adaptation efforts need to account for a range of future climate scenarios. A probabilistic based approach that employs a range of different scenarios can provide insight into what impacts are most likely, that can then be used in decision support systems to guide management directives and policies. The use of 13 different GCMs allows for a probabilistic range of projections and confidence intervals and is justified as initial results suggest that failing to account for a range of model results for NFDRS fire danger indices can lead to erroneous conclusions. As most scenario driven adaptations require at least 8-10 models, the use of 13 different models should account for regional variability in projected outcomes.

Given that the inter-model spread exceeds the changes seen for different emission pathways at the regional level, we decided to focus on a single emission scenario (SRES-A1B) and thirteen different GCMs (Table 1). Using the MACA method daily GCM weather observations for three different time periods, (i) late 20th century (1971-2000), (ii) mid-21st century (2046-2065) and (iii) late 21st century (2081-2100) were downscaled to the 50 RAWS observations in southern California. Given the uncertainty associated with late-21st century projections and the limited temporal period for which fuel treatments are meant to be effective without significant maintenance, we conducted all analyses with mid-21st century projections.

Table 1: List of Coupled Model Intercomparison Project (CMIP3) GCMs used.

Center	Model	Country
BCCR	BCM2.0	Norway
CCCma	CGCM3.1T47	Canada
CCCma	CGCM3.1T63	Canada
CNRM	CM3	France
CSIRO	Mk3.5	Australia
GFDL	CM2.0	USA
GFDL	CM2.1	USA
IPSL	CM4	France
LASG	FGOALS-g1.0	China
MPI-M	ECHAM5	Germany
MRI	CGCM2.3.2	Japan
NIES	MIROC3.2hires	Japan
NIES	MIROC3.2medres	Japan

2) How well will *existing and planned* fuel treatments modify future fire behavior so as to aid fire suppression?

We met with fire managers from the Los Padres, Angeles, and San Bernardino National Forests in 2008 and 2009 to identify six fuel treatments that are high priority treatments for mitigating large fire risk in the Wildland-Urban Interface (WUI). For each treatment, we developed both 90th and 97th-percentile weather and fuel condition scenarios for both historic and future (mid-21st century) climatology, using both a middle-of-the-road global climate model (GCM) and a worst-case scenario GCM. We used these scenarios to model the future fire danger and fire behavior and assess fuel treatment effectiveness in modifying fire behavior. The treatments chosen by the fire managers were both established and in-progress at the time of selection, and all were fully implemented by the close of the project. They included:

- a) Ojai Community Defense Zone, Los Padres National Forest
- b) Lenora Divide Fuel Break, Angeles National Forest
- c) Charlton-Chilao Vegetation Treatment, Angeles National Forest
- d) Tanbark Fuel Break, Angeles National Forest
- e) Arrowhead Vegetation Treatment, San Bernardino National Forest
- f) Angelus Oaks Community Defense Zone, San Bernardino National Forest

For each fuel treatment, we constructed both historic and future 90th and 97th percentile wind and weather scenarios in FireFamilyPlus software from the RAWS that most closely reflected the climatology of each treatment site. For sites where no single RAWS was the best choice, we constructed a SIG (special interest group) from several RAWS. We used two models from the thirteen described above: the GFDL CM 2.0 (USA), which represented a moderate or ‘middle-of-the-road’ projection for future climate conditions, and the CGCM2.3.2 (Japan), which represented an extreme, or ‘worst-case scenario’

projection for future conditions. These eight scenarios (Historic v. Future, 90th v. 97th, and Moderate v. Extreme) for each fuel treatment were each utilized as inputs to a fire behavior modeling run in ArcFuels (including FARSITE and FlamMap). Runs utilized two different landscapes (Treated vs. Untreated) developed from the 2008 LANDFIRE 'Refresh' (Version 1.1.0) update (www.landfire.gov). Fuels layers were aggregated to Landscape files, including Fuel Model (40 Scott & Burgan Models), Canopy Cover, Canopy Bulk Density, Canopy Height, and Canopy Base Height. For Treated landscapes, fuel layers were modified to reflect the treatment levels described in the Environmental Impact Statement, Environmental Analysis, Burn Plan, or other Fuel Treatment Planning Document. For example, the Charlton-Chilao Vegetation Treatment involved three treatment intensities in different polygons: 25, 50, and 75 percent reduction in fuels. Fuel models were altered to represent this reduction based on fuel model descriptions, and canopy characteristics were similarly altered. In addition to the published plans, ocular estimates of fuel reduction from pictures and field data acquired in November 2008 and March 2009 were supplemented to help select fuel models and alter canopy layers.

For each of the 96 total conditions (8 scenarios x 6 treatment locations x 2 treatment alternatives), five fire behavior outputs were modeled in FlamMap: Flame length (FL), Fire Line Intensity (FLI), Rate of Spread (ROS), Crown Fire (CF) and Burning Probability (BP). Additionally, for the 2009 Station Fire, we modeled the final fire perimeters in FARSITE for both each of the eight scenarios for both treated and untreated landscapes.

Add-on objective: Assess the role of the Charlton-Chilao Vegetation Treatment in modifying behavior on the 2009 Station Fire

In September of 2009, the Station Fire outside of Los Angeles burned directly into the Charlton-Chilao Vegetation Treatment, with the result being that the fire minimally impacted the Chilao Flats campground and fire station. This unexpected event provided an opportunity to assess the effectiveness of the Charlton-Chilao treatment in modifying fire behavior as witnessed by fire personnel on the scene and through modeling. To this end, we interviewed the captain and engine foreman at the Chilao Flats fire station, who were present immediately prior to the fire front reaching the Chilao Flats area. These interviewees not only assisted in implementing the fuel treatment as part of the crew's project work, but then directed the operations to use the vegetation treatment as an anchor point for suppression efforts during the fire, and observed fire behavior on the site. Numerous photographs of fire behavior in the treatment area were provided by these individuals to assist in reconstructing the fire behavior during the Station Fire. This allowed us to assess the percentile conditions present during the fire, and determine whether the Charlton-Chilao Vegetation Treatment would have the same effectiveness under future, mid-21st century conditions using the methods described above.

3) **How can fire managers throughout southern California use this information to maximize fuel treatment longevity efficiently and at the lowest cost? How can fire managers nationally use this information to increase cost-effectiveness in their fuels treatment programs?**

We developed guidelines and best practices for assessing fuels treatments in southern California chaparral shrublands and forests to maximize the longevity of new and existing fuel treatments under projected climate change. These guidelines utilized the southern California fuel treatments as a case study, but were generalized to apply nationally and include resources for fire managers across the US. We developed a Best Practices guide, and created an online workshop and tutorial such that fire managers in other regions can adopt methods to incorporate climate change projections into fuel treatment design and implementation. We demonstrated these Best Practices and on-line tutorial initially in a workshop in October 2011, and will demonstrate them again and solicit feedback for final edits during the December 2012 AFE Fire Congress in Portland, Oregon.

IV. Key Findings

The findings presented here summarize modeled projected changes in fire behavior associated with future climate conditions. Full data products, including gridded fire behavior outputs and climate data, are available on the project website (<http://nimbus.cos.uidaho.edu/jfsp>).

Research Question 1: How will climate change in southern California impact fire behavior and, particularly, extreme fire events?

- Fire regimes are bimodal in southern California, with approximately 55% of wildfire area burned historically attributed to summer season fires, and 45% attributed to autumn, Santa Ana wind-driven fires (Figures 2 and 3).
- The multi-model ensemble mean (an average of 13 GCMs) projects May-August temperatures of 5 degrees warmer than the historical (1970-2000) period, and February-June precipitation at 8% less. While model projections vary widely, there is strong agreement in warmer summers and drier spring and early summer periods (Figure 4).
- Drier spring months are projected to contribute to a significant increase in fire danger, as represented by Energy Release Component (ERC) in Figure 5, during the early part of the fire season (April/May). In southern California, an increase in fire danger associated with drying in the early part of fire season promotes an increase in fire activity during a period when activity has historically been low. This was actualized during the 2009 Jesusita Fire in Santa Barbara, which ignited the first week of May and consumed over 8,000 acres and 80 homes. Early drying also facilitates reduced live fuel moisture and increases the potential for large, mid-summer wildfires like the 2007 Zaca Fire.

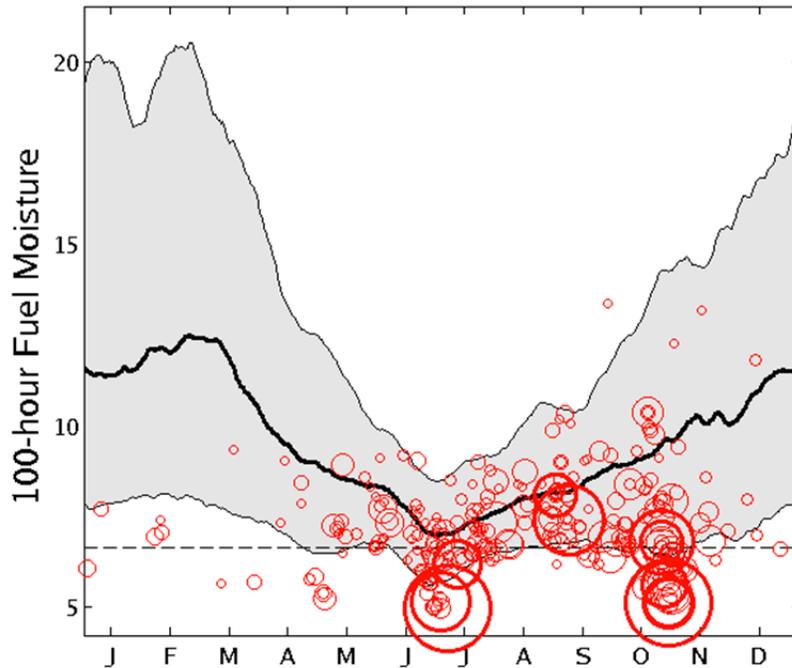


Figure 2. Distribution of wildfires from the study region by ignition date and 100-hour fuel moisture at time of ignition demonstrates the bi-modal fire regime. Circle size corresponds to final fire size, with large (>100,000 acres) fire in bold. Black line corresponds to daily median 100-hr fuel moistures, with shaded area as 95th percentile distribution.

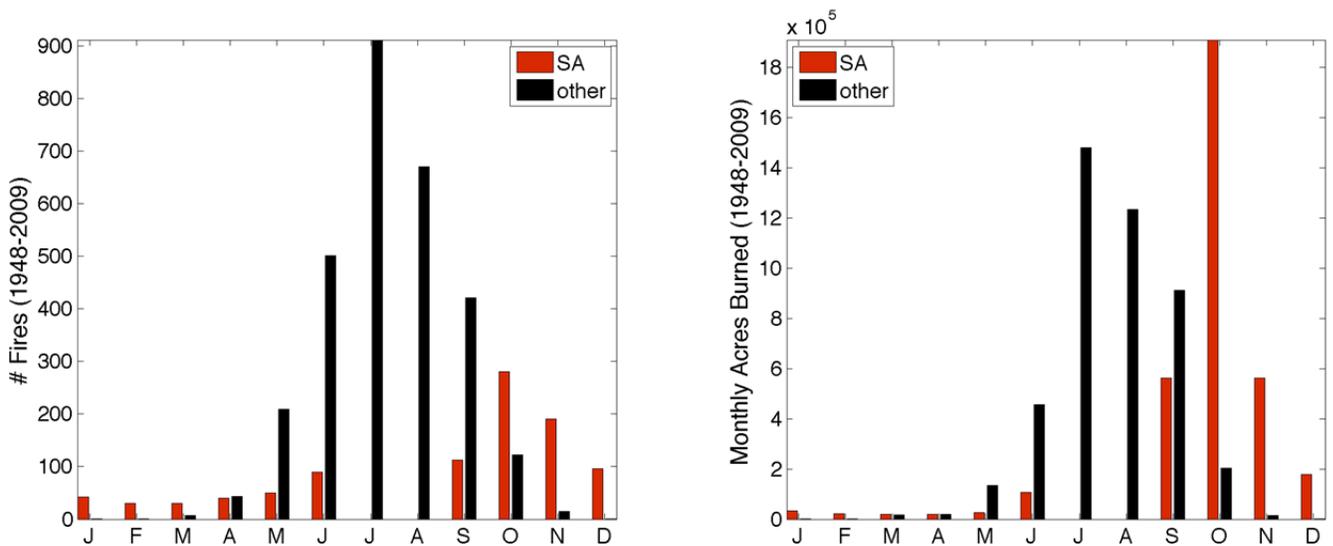


Figure 3. The proportion of fires (left) and total area burned (right) by month for wildfires from 1948-2009. This shows the bimodality between wind-driven fires that occur under Santa Ana conditions (red) and non-Santa Ana fires (black).

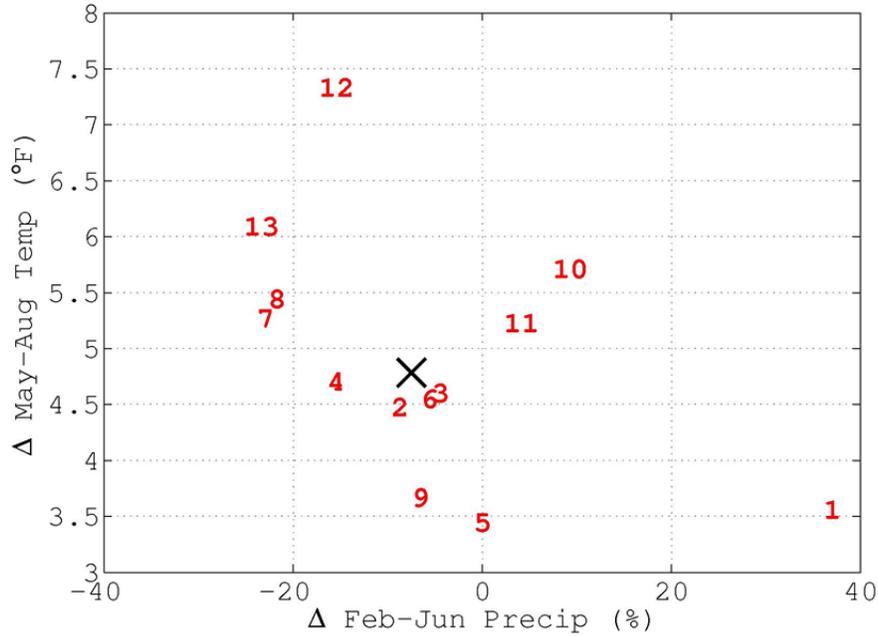


Figure 4. Distribution of model projections for mid-21st century departures in May-August temperature and February-June precipitation from historical normals for 13 GCMs (red numbers) and the multi-model ensemble mean (black 'X').

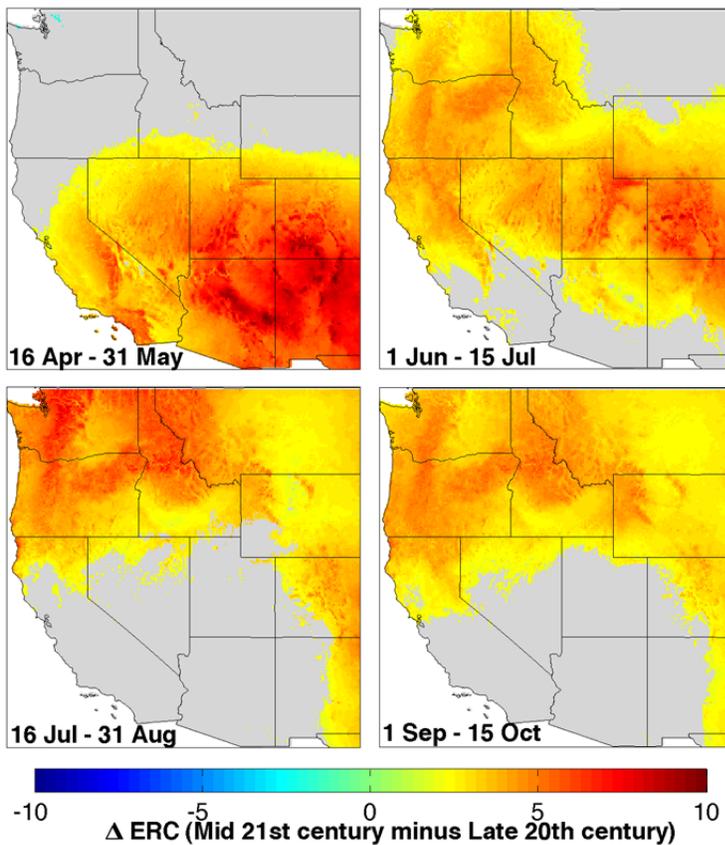


Figure 5. Mid-21st century ERC averaged across 13 models as a departure from late 20th century historical normals for four temporal periods. Color indicates that greater than 2/3 of models agree on the direction of change (positive or negative), while gray areas are not characterized by such model agreement.

Research Question 2: How well will existing fuel treatments modify future fire behavior so as to aid fire suppression?

- Future fire behavior projected by the middle-of-the-road GCM was less than a 25% increase from modeled fire behavior for the late 20th century, with a mean increase of 5-15%. For example, for the Arrowhead treatment on the San Bernardino National Forest, the mean increase in flame length (represented in Figure 6 as a distribution across the landscape) was 10%, and 97% of the treatment area saw less than a 16% increase. However, small pockets of fuels were modeled at a 60-70% increase in flame length.
- The worst-case scenario GCM produced similar increases in fire behavior to the middle-of-the-road scenario for 90th percentile conditions. In some cases, there was no difference between changes in fire behavior associated with the two scenarios.
- The worst-case scenario GCM produced the greatest increases in fire behavior associated with the 97th percentile conditions, but these increases were primarily seen in flame lengths and burn probability. Fire line intensity and rate of spread did not increase significantly under mid-21st century 97th percentile conditions as compared to 90th percentile conditions.
- Results suggest that while some treatments (e.g., Charlton-Chilao) will be effective in modifying fire behavior even under the worst-case scenario future conditions, others (e.g., Ojai CDZ) will not, and will require alternative treatment strategies to be effective.

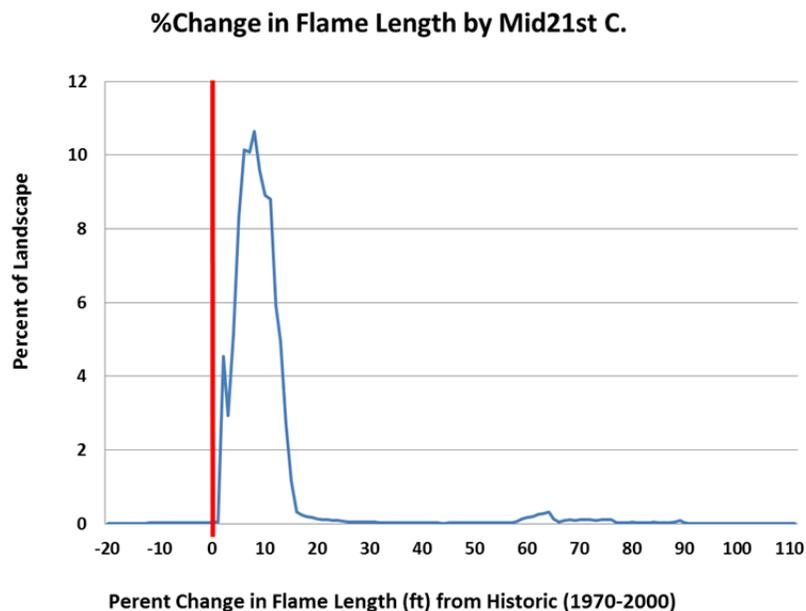


Figure 6. Projected increase in modeled flame length for the area within a fuel treatment for the Arrowhead Vegetation Treatment using middle-of-the-road GCM-derived outputs for the mid-21st century (2046-2065) as compared to the historic period (1970-2000).

Add-on research question: Assess the role of the Charlton-Chilao Vegetation Treatment in modifying behavior on the 2009 Station Fire

- We found that the Charlton-Chilao Vegetation Treatment burned under approximately the 90th percentile historic conditions. If the fuel treatment had not been implemented, modeled fire behavior for the untreated landscape indicated that the Station Fire would have been nearly 15% greater in extent, burning an additional 10,000 ha (Figure 7) under the observed weather conditions (acquired from the Chilao RAWS).
- There was no significant difference in modeled fire behavior between historic and future middle-of-the-road or worst-case scenario, GCM-derived 97th percentile conditions within the fuel treatment (Figure 8). However, there was a 49% increase in area burned under future, worst-case scenario conditions, associated with significant increases in fire behavior outside of fuel treatments.

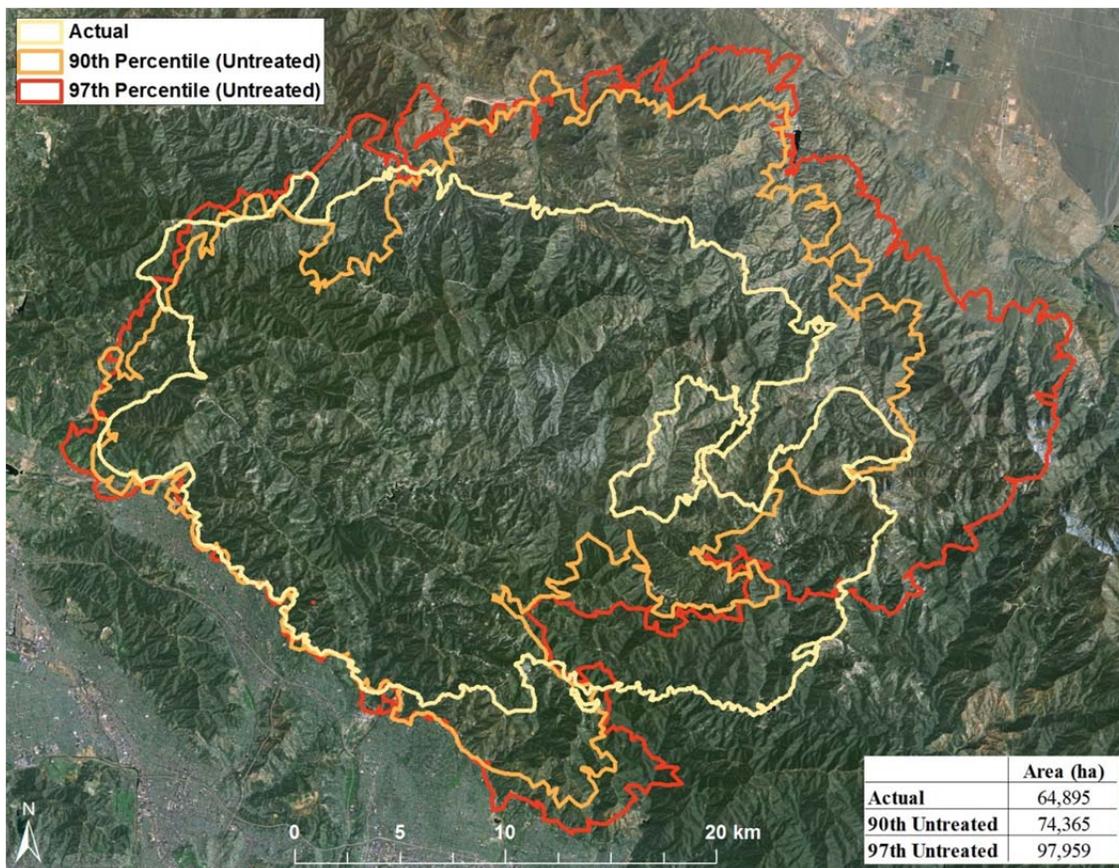


Figure 7. Fire perimeter extents for the actual Station Fire and the untreated landscape at both 90th and 97th percentile historic conditions as modeled in FARSITE show the role the treatments had in limiting progression on the eastern flank of the fire.

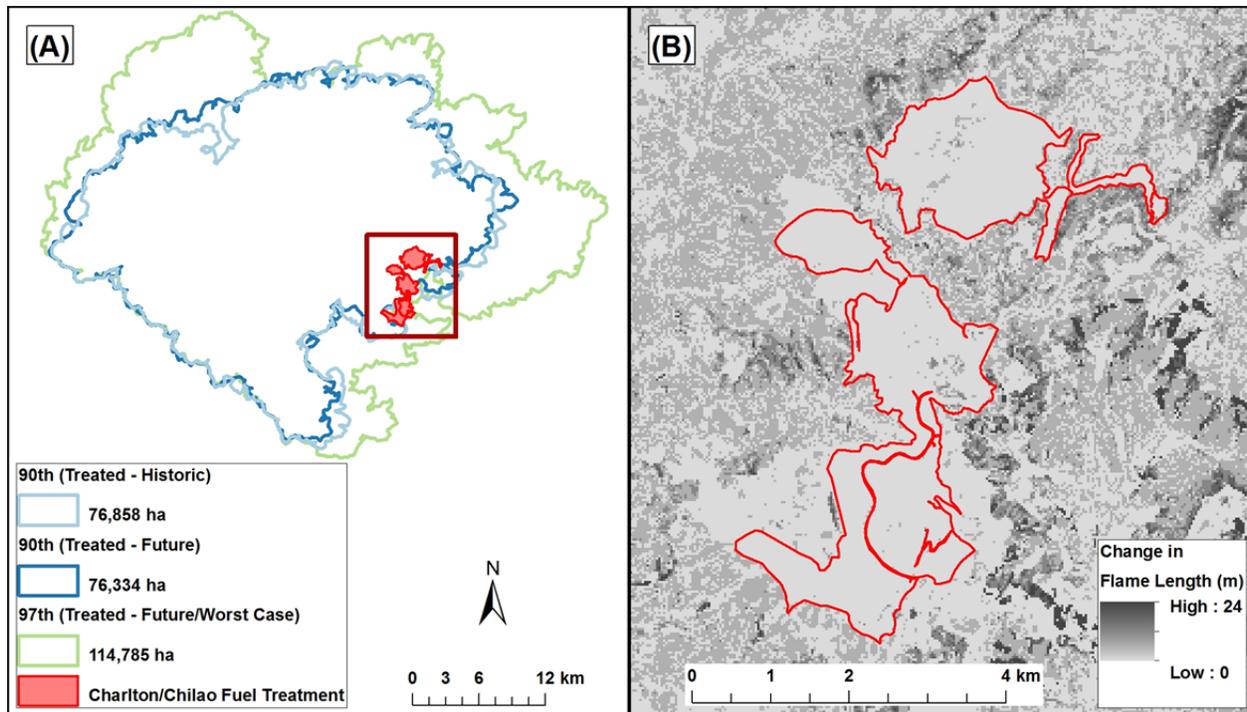


Figure 8. (A) Modeled differences in fire extent associated with future 90th percentile projected conditions, and future 97th percentile/worst-case scenario projected conditions as compared to modeled historic conditions. (B) Increases in flame length under future 97th percentile/worst-case scenario projected conditions as compared to historic 90th percentile show that while surrounding vegetation would see increases in flame length of up to 24m over the historic period fire behavior, the fire behavior within the fuel treatment would not significantly change.

Research Question 3: How can fire managers throughout southern California and nationally use this information to increase cost-effectiveness in their fuels treatment programs?

- Managers can utilize newly available global climate model data that has been made available by multiple research entities in a spatial resolution and data format that is more user-friendly and directed at management uses.
- We outline 12 best practices for utilizing and making decision based on climate model projections and the resulting fire behavior model outputs in the Best Practices guide.
- Alternatives that utilize climate model projections can be developed as part of the NEPA planning process, but should be produced with expert guidance from a fire behavior analyst.

V. Management Implications

While the fire community has begun to recognize the implication of climate change and its effects on wildfires in recent years, there have been few efforts to link global-scale climate change to specific fire management efforts on the ground. This project is the first to specifically address the projected increase in frequency and magnitude of extreme fire events related to fuel treatment effectiveness, and how fuels management might respond to these projections through fuels treatment planning, implementation, and management. It provides a methodology to integrate climate change information into fuels management, and exemplifies these methods through case studies on southern California forests. Furthermore, it provides data and training to southern California fire and fuels managers to enable future fuels treatment planning beyond the case studies. Finally, it provides a framework for other regions to address incorporating climate change information into fire and fuels planning.

There are two specific management implications we wish to elaborate upon. First, there has been considerable effort to retrospectively assess fuel treatment effectiveness recently, resulting in several publications that highlight varying degrees of success in modifying fire behavior. In southern California, Syphard et al. (2011) found that fuel breaks were effective in mitigating wildfire advancement 46% of the time, but acknowledged that it was difficult to attribute successful versus unsuccessful intersections between fire and a fuel break. Their analysis, however, did not address whether the primary driver of the fire was wind or fuels. This has been a common theme among retrospective assessments of fuel breaks.

We propose that, as the name suggests, a fuel break is intended to remove fuel from a wildfire. Thus, a fuel break is likely to be most successful in modifying fuel-driven fire behavior, and less successful in modifying wind-driven fire behavior, where ember carry and pre-ignition ahead of the flaming front are factors. In southern California, this means that fuel treatments are more likely to succeed during mid-summer, fuel-driven fires, and less likely to succeed during autumn, Santa Ana wind-driven wildfires. *This is particularly important for fire management to recognize when trying to convey the benefits and utility of fuel treatments to both the public and other land management units who might otherwise hold false or unrealistic expectations of fuel treatment effectiveness in wind-driven fires.*

Second, we here used two GCMs to highlight the projected differences between a middle-of-the-road scenario and a worst-case scenario. However, both models utilized the middle-of-the-road A1B emissions scenario, which itself is a moderate projection of climate change. Fire managers need to understand that in the five years between the 2007 IPCC report identifying the emissions scenarios and the 2012 publication of this report, there is already ample evidence to suggest that global emissions significantly exceed the projections of the A1B scenario, and are already more aligned with the “worst-case” A2 emissions scenario. If that trend continues, it signifies that the worst-case scenario depicted here will likely be exceeded by the mid-21st century.

VI. Relationship to other recent findings and ongoing work

This work fuses previous and ongoing efforts in two distinct sub-disciplines of fire science: understanding fuel treatment effectiveness and projecting future fire activity under a changed climate. Syphard et al. (2011) found fuel treatment effectiveness in the Los Padres National Forest to be highly variable, but strongly dependent upon concurrent suppression activity and resource support. Rogers et al. (2008) found that fuel treatments were instrumental in mitigating fire impacts on the 2007 Grass Valley fire on the San Bernardino National Forest.

Projections of future fire activity in the western US are widely variable, with some of the lowest levels of agreement in coastal California. Westerling and Bryant (2008) suggest that fire regimes where fine fuels are limited may actually see a decrease in fire activity in the 21st century, although this is highly dependent on choice of GCM and the uncertain impacts of climate change on Santa Ana events. Abatzoglou and Kolden (2011), however, suggest that while limitations on fine fuels will likely be a factor in desert systems, there is strong model agreement that the coastal mountains of southern California will see significantly greater fire activity and higher fire danger by the end of the 21st century. The current project expands on that effort by identifying the seasonality of changes in southern California to project an increase in early summer, fuel-driven fire activity.

VII. Future work needed

This project demonstrated the capacity to downscale coarse global climate model output to a spatial scale that can be used to model the mitigative effects of fuel treatments, but this is only a first step in truly understanding how to manage changing fire regimes. Future work will be required to address several key components:

- New emissions scenarios released in 2011 by the IPCC are now being integrated into both existing and new global climate models and will produce a new suite of output projections for the remainder of the 21st century. These new, updated outputs should be the foundation of future fire activity modeling efforts.
- Results from southern California forests and shrublands are applicable only within those ecosystems. Findings of fuel treatment effectiveness found for this region should not, under any circumstances, be globally applied to other regions. Future efforts will need to model fuel treatment effectiveness for local ecosystems and fire regimes individually. Best practices are universal, quantitative findings are not.
- One of the primary uncertainties in modeling future fire behavior is the vegetation landscape. A key next step is to model future vegetation utilizing an established vegetation state-and-transition model such as the Vegetation Dynamics Development Tool (VDDT) used by the LANDFIRE program, and then translating modeled vegetation into fuel models and crown characteristics.

VIII. Deliverables

Deliverable Type (See Format Overview, Section VIII)	Description	Delivery Dates
Manual	'Developing Fuel Treatments for a Future Climate: Best Practices and Use of Climate Projections.' White paper published online.	March 2012 (ongoing edits from workshop)
Non-refereed publication	Project Report	October 2012
Refereed publications	<p>Publications resulting wholly or in part from JFSP funding:</p> <p>Abatzoglou, J.T. 2012, Development of gridded surface meteorological data for ecological applications and modeling, <i>International Journal of Climatology</i>, doi: 10.1002/joc.3413</p> <p>Abatzoglou, J.T., and T.J. Brown. 2011, A Comparison of Statistical Downscaling Methods Suited for Wildfire Applications, <i>International Journal of Climatology</i>, doi:10.1002/joc.2312</p> <p>Behrens, K., C.A. Kolden, and J.T. Abatzoglou. Assessing Fuel Treatment Effectiveness for Future Climate Conditions in Southern California: A Case Study of the 2009 Station Fire. <i>In internal review, to be submitted to Forest Ecology and Management.</i></p> <p>Kolden, C.A., J.T. Abatzoglou, and T.J. Brown. Fuel treatment effectiveness under future climates. <i>To be submitted to International Journal of Wildland Fire.</i></p> <p>Abatzoglou, J.T., and C.A. Kolden. Characterizing dichotomous drivers of seasonal fire regimes in southern California. <i>To be submitted to Agricultural and Forest Meteorology.</i></p>	<p>2012</p> <p>2011</p> <p>In review</p> <p>In progress</p> <p>In progress</p>
Dataset	.fw9 files for Historic (1971-2000), mid-21 st century (2046-2065), and late-21 st century (2081-2100) daily weather streams in RAWS format (including station data, temp., precip., RH, and winds) from 13 Global Climate Models using the A1B emissions scenario for 50 RAWS locations across Southern California	July 2011
Dataset	12 FARSITE and FLAMMAP-compatible landscape files (.lcp format) reflecting Treated and Untreated conditions for six fuel treatments across three southern California national forests (Los Padres, Angeles, and San Bernardino)	March 2012

Training sessions/meeting	Meetings with forest fire and fuels management personnel to: 1) Identify fuel treatments for study 2) Collect field data post-treatment 3) Conduct interviews and collect data from Station Fire	November 2008 March 2009 November 2009
Workshop/training session	Workshop at AMS Fire and Forest Meteorology Conference, Palm Springs, CA, October 27, 2011 Workshop at AFE 5 th Fire Congress, Portland, Oregon, December 3, 2012	October 2011 December 2012
Site Visit/Field Tour	Reconfigured to be an online workshop due to travel restriction on forest personnel (see below in Website)	August 2012, Ongoing
Conference presentation/poster	Brown, T.J., and C.A. Kolden. "Assessing fuels treatments in southern California National Forests and WUI in the context of climate change." International Conference on Fire Behaviour and Risk; Alghero, Italy, October 2011 Abatzoglou, J.T. "Can climate scenarios inform fire management? From GMC to RAWS." American Meteorological Society Fire and Forest Meteorology 9 th symposium. Palm Spring, CA, October 2011. Brown, T.J. "Assessing fuels treatments in southern California National Forests and WUI in the context of climate change." Monash University, Melbourne, Australia, February 2012. Behrens, K. "Fuel treatment effectiveness in modifying fire behavior on the 2009 Station Fire." University of Idaho Geography Department seminar, Moscow, Idaho, April 2012. Abatzoglou, J.T. "Catastrophic wildfires: a new normal?" Aquarium of the Pacific Speaker Series, Long Beach, CA, May 2012. Kolden, C.A. "Fuel treatment effectiveness in a changing climate: a case study from Southern California." AFE 5 th Fire Congress, Portland, Oregon, December 2012.	October 2011 October 2011 February 2012 April 2012 May 2012 December 2012
Website	Website (http://nimbus.cos.uidaho.edu/ifsp) has been reconfigured to accomplish two objectives: 1) Serve the .fw9 and .lcp files created for this project as described in the above sections on data sets. 2) Present an online tutorial/workshop for using these data to assess the effectiveness of fuel treatments under future climate conditions. This online tutorial is being updated based on feedback received at the December 2012 Fire Congress live workshop; final tutorial expected online no later than January 2013.	August 2012, Ongoing

VIII. References

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