California Energy Commission
Draft Report

Long-term Risk Projections Modeling Framework Summary

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Enhancements to long-term fire and vegetation models planned for this project to support California's Fifth Climate Change Assessment attempt to address baseline needs identified by the project team and input provided through user engagement interviews. Specifically, updates will encompass multiple improvements in datasets and model outputs that will improve the ability of fire projections to better represent changes in extreme events and their impacts. Computationally efficient models will support the development of large numbers of scenarios at an affordable cost in time and money, to allow exploration of the complex climate adaptation and mitigation policy space with respect to wildfire and the resources and values impacted by wildfire. This will facilitate stakeholder needs for integrating adaptation and mitigation strategies into projections for fire, vegetation and climate (Figure 1 provides a conceptual illustration of the modeling framework). At the same time, high fidelity models that can capture dynamic, nonlinear interactions between coupled human and natural systems at policy- and management-relevant spatial and temporal resolutions will facilitate the kinds of planning required to manage risks to specific types of infrastructure, such as transmission lines.

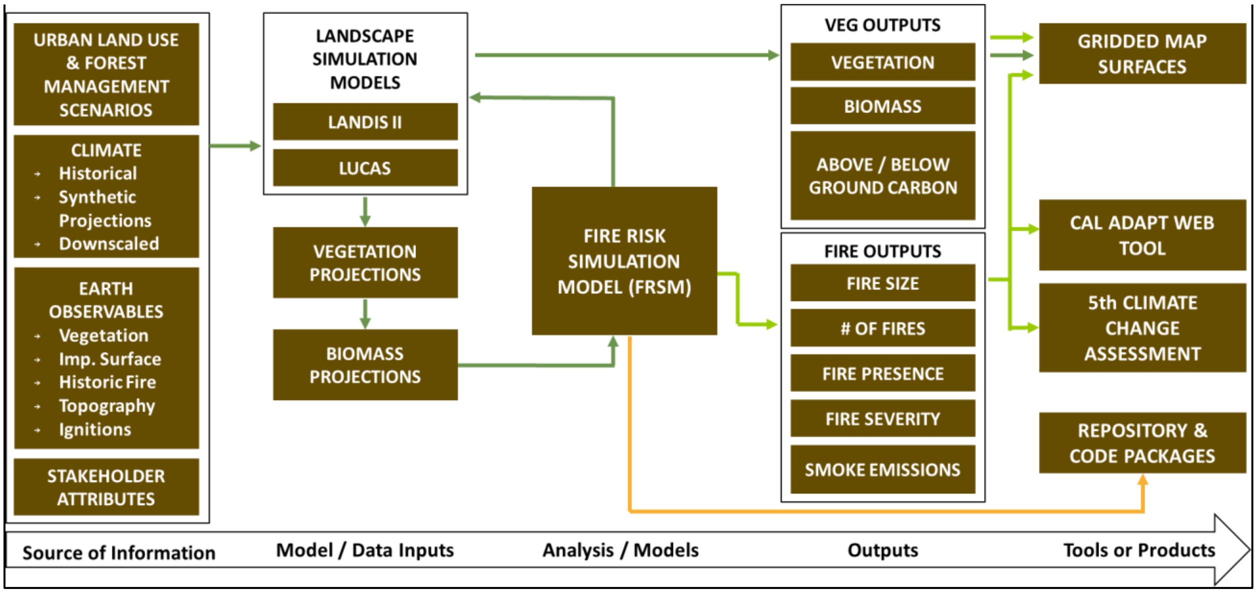

Figure 1. *Visualization of the modeling framework for long-term wildfire projections.*

2. Introduction

Large wildfires have been increasing in frequency, size and severity across diverse ecosystems within the State of California (Williams et al 2019). This trend has been apparent for several decades—since the mid-1980s—in the western United States and elsewhere around the world. The timing of the first noticeable trends in wildfire activity in California and the West closely coincides with when the impacts of anthropogenic warming first produced a statistically significant signal in the hydrology of the western United States in the mid-1980s (Barnett et al 2008, Westerling et al 2006, Westerling 2016, Williams et al 2019). However, the most dramatic impacts in California have become apparent more recently in the last decade, especially at the lower elevations where most Californians live, as increasing variability in the onset of Autumn precipitation may be extending the fire season coincident with seasonal wind events that can promote extreme fire events later in the year than was previously typical for the largest fires (Goss et al 2020).

The goal of the fire modeling that has supported the previous four California State Climate Assessments has always been to illustrate for policymakers and risk managers, as well as for the broader public, what the likely impact of climate scenarios coupled with land management and development patterns might be on wildfire in the State. On the one hand, there has been an increasingly urgent need for detailed future wildfire scenarios. On the other hand there have always been constraints that the modeling teams have to contend with, including limited funding and time, the data available to support modeling and the construction of scenarios, and the incremental learning on the part of both the scientific modeling community and the policy and management community. Over time, our view of the informational needs of end users and their capacity to assimilate the types of information modeling can provide, and the ability of the scientific and modeling community to serve those needs, evolves.

The design of the Pyregence modeling framework for long term fire risk models (Figure 1) highlights a tension between two priorities identified from stakeholders. On the one hand, a need for computationally efficient models that can support the development of large numbers of scenarios at an affordable cost in time and money, to allow exploration of the complex climate adaptation and mitigation policy space with respect to wildfire and the resources and values impacted by wildfire. This will facilitate stakeholder needs for integrating adaptation and mitigation strategies as identified in the Long Term Baseline Needs Assessment. And on the other hand, there is a need for high fidelity models that can capture dynamic, nonlinear interactions between coupled human and natural systems at policy- and management-relevant spatial and temporal resolutions, which will facilitate the kinds of planning required to manage risks to infrastructure (e.g. transmission lines).

The Pyregence modeling framework addresses these competing needs with a strategy that pursues parallel development of—and integration across—computationally efficient statistical fire models and dynamic land surface models that incorporate complex feedbacks between wildfire, climate, ecosystems, and development footprints.

Statistical fire models can simulate extreme fire events for scenarios combining, for example, modeled climate trajectories with projected population and development footprints and prescribed levels of fuels management efforts. And because even under extreme conditions, the occurrence of a very large, high-severity fire is still a relatively low probability event at any given point in space and time, the ability of statistical models to cheaply simulate large numbers of future outcomes is valuable for exploring potential fire risks under any specific future scenario. Statistical models, however, are mathematical extrapolations from a limited set of observations of fires and the conditions they arose under in the recent historical period, and cannot by themselves easily incorporate feedbacks to fire risks from future changes in fuels due to changes in fire and climate, particularly as climate and fire move outside the historically observed range.

Dynamic vegetation models are more data and computationally intensive but can incorporate our best understanding of fundamental drivers of interactions between climate, ecosystems and fire, and resulting impacts on things like carbon storage and fuels characteristics.

Coupling statistical fire models with dynamic vegetation models can improve the outputs from both: simulated fires from statistical models in one time step can update fire risks in vegetation models, while resulting changes in vegetation (i.e, in biomass and fuels structure) from dynamic models can be fed back into statistical fire models to update subsequent fire risks. (See for example, Hurteau et al 2019).

Improvements in input data—including newly available methods for downscaling windspeed and direction, and relative humidity, combined with improvements in climate data spatial resolution from 6 km to 3 km and temporal resolution from daily to hourly—will facilitate efforts to more faithfully model the most extreme fires, as will additional observations of very extreme fires in the last few years.

The result is a suite of statistical models that simulate large wildfire occurrence, extent, severity and emissions at 3 km resolution for long term climate, fuels management and development scenarios. Simulated fires from a subset of scenarios are then downscaled further to 30 m, and fire simulations are also summarized at 1 km for input to dynamic vegetation models. Dynamic vegetation models are then run with either unidirectional coupling (fire risks from statistical fire models are used to update vegetation models) or bidirectional coupling (changes in fuels in vegetation models also feed back into statistical fire models to change subsequent fire risks).

For a range of future climate, development, and fuels management scenarios, then, these models—individually and in coupled modes—will produce a library of simulated large fires events (location, size, and severity) at multiple spatial resolutions, with corresponding simulations of vegetation, biomass, fuels characteristics, carbon, and air pollution emissions through 2099. These data will be further aggregated to produce risk maps corresponding to different time periods in each scenario, as well as summarizing the variability of risks within and across scenarios. But the raw simulations will also be especially valuable for understanding what individual future extreme events could look like.

Planners trying to manage wildfire risks to energy infrastructure can use the history of observed fire events and observed impacts on energy infrastructure to estimate probabilities of losses conditional on the presence of a fire with specific characteristics, as well as characteristics of the infrastructure exposed to the risk, and then use these probabilities with simulated fires from this framework to project future losses under diverse future scenarios.

3. Source of Information and Model Inputs

The following table summarizes model inputs, application or purpose, source and reference to model inputs (as illustrated in Figure 1)

Input	Application	Source	Reference
Temperature - historic	Parameterizing statistical fire models and spinning up dynamic vegetation models	TBN. Contract to be awarded by CEC. Currently substituting GridMET	http://www.climatologylab.org/gridmet.html
Precipitation - historic	Parameterizing statistical fire models and spinning up dynamic vegetation models	TBN. Contract to be awarded by CEC. Currently substituting GridMET	http://www.climatologylab.org/gridmet.html
Vector wind - historic	Parameterizing statistical fire models	TBN. Contract to be awarded by CEC. Currently substituting GridMET	http://www.climatologylab.org/gridmet.html
Relative humidity - historic	Parameterizing statistical fire models	TBN. Contract to be awarded by CEC. Currently substituting GridMET	http://www.climatologylab.org/gridmet.html
Soil moisture	Comparison with relative humidity for parameterizing statistical fire models	Land Surface Hydrology Research Group – Drought Monitors	http://www.hydro.ucla.edu/SurfaceWaterGroup/data.php
Fire history	Parameterizing statistical fire models, and implementing a common fire history during historic period in vegetation model spinup	MTBS - Monitoring Trends in Burn Severity	https://www.mtbs.gov/
Vegetation	Parameterizing statistical fire models and spinning up dynamic vegetation models	LANDFIRE	https://www.landfire.gov/version_comparison.php
Topography	Parameterizing statistical fire models and spinning up dynamic vegetation models	LANDFIRE	https://www.landfire.gov/version_comparison.php
Forest Harvest	LULC Change initialization in LUCAS	LANDFIRE	https://www.landfire.gov/version_comparison.php
Landcover	categorical land cover	National Land Cover Database	http://www.mrlc.gov/

Input	Application	Source	Reference
Initial Forest Stand Age	Land cover initialization	U.S. Forest Service GNN (CA/OR/WA)	https://lemma.forestry.oregonstate.edu/data/plot-database
Housing Density	Parameterizing statistical fire models, spinning up dynamic vegetation models, constructing development scenarios	Wildland-urban interface change (WUI) 1990-2010	http://silvis.forest.wisc.edu/data/wui-change/
Building footprints	Parameterizing statistical fire downscaling models, spinning up dynamic vegetation models, constructing development scenarios	GIS data layer of building/structure footprints for California	https://github.com/Microsoft/USBuildingFootprints
Urbanization and Ag expansion/contraction	LULC Change initialization in LUCAS	California Farmland Mapping and Monitoring Program	https://www.conservation.ca.gov/dlrp/fmmp
Insect/Drought mortality	LULC Change initialization in LUCAS	US Forest Service Aerial Detection Surveys	https://www.fs.usda.gov/detail/r5/forest-grasslandhealth/?cid=fsbdev3_046696
Transmission lines	Incorporating values at risk into models and scenarios	The California Energy Commission (CEC) Electric Transmission Line geospatial data layer	https://cecgis-caenergy.opendata.arcgis.com/datasets/260b4513acdb4a3a8e4d64e69fc84fee_0/data
Substations	Incorporating values at risk into models and scenarios	The California Energy Commission (CEC) Electric Substation geospatial point data laye	https://cecgis-caenergy.opendata.arcgis.com/datasets/california-electric-substation/data
Temperature - projected	Projecting changes in fire, vegetation, fuels, carbon	TBN. Contract to be awarded by CEC.	

Input	**Application**	**Source**	**Reference**
Precipitation - projected	Projecting changes in fire, vegetation, fuels, carbon	TBN. Contract to be awarded by CEC.	These data do not exist yet. The downscaling methodology funded by the CEC is based on LOCA method (see Pierce et al 2014)
Vector wind - projected	Projecting changes in fire, vegetation, fuels, carbon	TBN. Contract to be awarded by CEC.	See above
Relative humidity - projected	Projecting changes in fire, vegetation, fuels, carbon	TBN. Contract to be awarded by CEC.	See above
Ecoregions	level III and level IV ecoregions across the continental US f. summarizing outputs by ecoregion	EPA	https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states
Protected Areas Database	protected areas and public lands GIS layer. Initialization of LULC	USGS	https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap/science/protected-areas
Counties	U.S. Census Bureau Tiger Line Files. Summarizing outputs by county. LULC initialization.	US Census Bureau	https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html

4. Models

Fire Risk Simulation Models are comprised of a suite of statistical models (see for example Westerling 2018, Westerling et al 2011), including:

- Large fire presence/absence model: logistic regression of large (> 1,000 ha) fire occurrence on climate and land surface characteristics
- Large fire extent model: Generalized Pareto distribution model conditional on climate, land surface characteristics and presence of fire > 1,000 ha
- Fractional fire severity model: multinomial logit model of the joint distribution of low, moderate and high severity fire fractions conditional on fire size, climate and land surface characteristics

- Statistical downscaling model: generalized additive multinomial logit model for 30 m burn probabilities conditional on fire size, climate and land surface characteristics

LUCAS: Land Use and Carbon Scenario Simulator combines (see for example Sleeter et al 2019):

- State-and-Transition Simulation Model to simulate changes in land-use across a range of geographic scales.
- Stock and Flow Model to track the movement of carbon between different “pools” including interactions between land and atmosphere.
- Linkage to the Integrated Biosphere Simulator (IBIS) dynamic global vegetation model.

LANDIS-II:

Forest succession and disturbance model, with the Century Succession extension to simulate carbon pools and fluxes and the Dynamic Leaf Biomass Fuel extension and Dynamic Fire extension to simulate wildfire and fuels. Extensions incorporate competition from shrub species and fuels effects from insect- and drought-caused mortality (see for example Kroffcheck et al 2017 & 2018).

5. Outputs

Probability of large fire presence/absence: 3 km gridded monthly or bimonthly probability of large fire presence, for historic climate, for resampled historic climate test run, for projected climate and other scenarios, (time step is still being decided), statistical models and coupled models.

Simulated fire presence/absence: 3 km gridded monthly or bimonthly simulated large fire ignitions, for historic climate, for resampled historic climate test run, for projected climate and other scenarios statistical models and coupled models.

Simulated fire area burned: 3 km gridded monthly or bimonthly simulated large fire area burned by ignition point, for historic climate, for resampled historic climate test run, for projected climate and other scenarios, statistical models and coupled models.

Simulated fire severity: 3 km gridded monthly or bimonthly simulated large fire areas burned by severity class, mapped by ignition point, for historic climate, for resampled historic climate test run, for projected climate and other scenarios, statistical models and coupled models.

Annualized, allocated fire area burned: 3 km gridded annual simulated large fire area burned allocated to ignition grid cell and surrounding grid cells according to average available burnable vegetated area, for historic climate, for resampled historic climate test run, for projected climate and other scenarios, statistical models and coupled models.

Downscaled simulated fire area burned: 30 m gridded monthly or bimonthly simulated large fire area burned, by severity class - format to be determined, for historic climate, statistical models and coupled models.

Fire risk maps: 3 km gridded decadal expected area burned and average fire rotation maps for historic climate, for resampled historic climate test run, for projected climate and other scenarios, statistical models and coupled models. These are also summarized at 1 km as well for LUCAS.

Vegetation maps: 1 km gridded decadal biomass, vegetation and fuels characteristics and carbon storage maps for historic climate, for resampled historic climate test run, for projected climate and other scenarios, for coupled models only. Including annual maps and probabilities of Land Use and Land Cover (LULC) and LULC Change, Forest Age, Carbon Stocks (11 pools), Carbon Fluxes (all flows between pools), and Net Carbon Fluxes (NPP, NEP, NECB). Outputs will be available as tabular summaries (summarized by ecoregion, county, and ownership) as well as spatial maps (1-km resolution on an annual timestep).

6. Products

Products from this framework include statewide mapped surfaces of simulated wildfire events (location, extent, severity, emissions) for a range of climate, fuels and land use scenarios, driven by both stand-alone statistical fire models, and dynamic land surface models coupled with statistical fire models. In addition to simulated fire events, this framework will produce maps of expected (i.e. average) and extreme quantile fire risks, vegetation and fuels characteristics, biomass, carbon, and pollution emissions. LUCAS and statistical Fire Risk Simulation Model outputs, and coupled outputs from these models, will be statewide, assuming downscaled climate data are provided statewide. LANDIS-II and coupled statistical-LANDIS-II outputs will cover Sierra Nevada forests at minimum. LUCAS outputs Include annual maps and probabilities of Land Use and Land Cover (LULC) and LULC Change, Forest Age, Carbon Stocks (11 pools), Carbon Fluxes (all flows between pools), and Net Carbon Fluxes (NPP, NEP, NECB). Outputs will be available as tabular summaries (summarized by ecoregion, county, and ownership) as well as statewide spatial maps (1-km resolution on an annual timestep). LANDIS-II outputs include maps biomass, above and below ground carbon, species level information on number and age of cohorts, fire number, area burned, and severity for Sierra Nevada forests.

Additional products include open source code archives, documentation, and datasets required to run these models, and a white paper informed by both stakeholder engagement and our science team outlining requirements that should be included in a suite of outreach tools that would make these data products more accessible, should funding be identified to develop additional outreach tools. We will also provide data outputs to CalAdapt, but the platform is not currently configured to take advantage of all the available data.

7. Schedule

Parallel modeling efforts are underway throughout the first year and a half of the project, with coordination of model integration and scenario implementation across platforms commencing in Fall 2020 (See attached Gantt chart). Because a comprehensive historical reference dataset is not yet ready for use by the project (pending CEC awarding a competitive contract later this year), efforts to provide proxy historical data have been ongoing. Currently, daily GridMET 1/24th degree gridded climate data have been interpolated to a 1/32nd degree grid and are being used for model development and testing. These data are not of the same quality as what we ultimately expect to use for the reference historical dataset, and do not contain hourly data. They do facilitate testing for model development and allow us to work from a standardized data infrastructure for code development. We will use historic data resampled to provide some extreme climate scenarios for a “kick-test” to see how models behave under climatic conditions more extreme than in the historical record used for model parameterization. It would be optimal to be able do this with the hourly reference data set, but we currently anticipate that those data will not be available in time given the current schedule for awarding a contract for data development. Consequently, our schedule for and initial model inter-comparison and assessment may not be able to leverage hourly data on climate extremes. Development of fire scenarios for historical observed climate will commence in Spring 2022, taking advantage of lessons learned from the model inter-comparison and assessment “kick-test”, and assuming that a historical climate reference dataset is provided by Fall 2021. Any further delay in obtaining this dataset would adversely affect the rest of the project schedule. Similarly, the schedule for implementation of long-term projections in the second phase of the project is conditioned on delivery of at least some downscaled and validated climate scenarios by Spring 2022, as well as on the timely availability of historical climate reference dataset.

8. Discussion

The model enhancements discussed in the Framework presented here, and in the Long-term Risk Projections Baseline Needs Assessment, attempt to address several of the baseline needs identified by the project team and input provided through user engagement interviews. Updates will encompass multiple improvements in datasets and model outputs that will improve the ability of fire projections to better represent changes in extreme events and their impacts.

A critical need is for consensus from IOUs and state agencies on the range of fuels management scenarios and the range of development footprint scenarios to be incorporated into modeling for the 5th Assessment. The modeling team proposes to incorporate scenarios that represent bounding extremes on what is likely to occur, as well as “business as usual” scenarios that lie in between these extremes. Policy makers, managers, and investors may hold other preferences that would need to be accounted for early in the development of scenario datasets, but which have not yet been volunteered through our stakeholder engagements.

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