Studying the Effects of a Changing Climate on Wildfires and the Impacts to the United States' Air Quality

Maria Val Martin, Jeffrey R. Pierce, and Colette L. Heald

In the United States, wildfires burn millions of acres every year, releasing large amounts of gases and particles to the atmosphere. For example, in the summer of 2014, six wildfires burned more than 135,000 acres (54,600 ha), polluting fairly populated areas of California, such as Napa County (Inciweb 2014). The amount of acres burned does not account for smaller and more remote fires that continued to burn throughout the State. Smoke from fires negatively impacts humans and ecosystems. While direct smoke inhalation is potentially lethal, sublethal concentrations adversely affect human health for particularly sensitive populations (e.g., children and elderly) in both the short and the long term, and for individuals who are occupationally exposed and may inhale smoke under conditions of highly aerobic physical activity. Smoke particles with aerodynamic diameter below 2.5 micrometers (i.e., $PM_{2.5}$) are particularly toxic since they can penetrate into the lungs, with protracted effects from even a single exposure (Pope et al. 2002).

Maria Val Martin is a professor at the Colorado State University, Department of Atmospheric Science, and the University of Sheffield United Kingdom, Department of Chemical and Biological Engineering. Jeffrey R. Pierce is a professor at the Massachusetts Institute of Technology, Department of Civil and Environmental Engineering. Colette Heald is a professor at the Massachusetts Institute of Technology, Department of Atmospheric and Planetary Sciences.

Smoke concentration levels near the fire are of primary concern for human health. In addition, smoke can be transported hundreds of miles downwind by prevailing winds or convective winds generated by fires themselves with concentrations sufficient to make it the most significant source of air pollution over large areas (Val Martin et al. 2013). Smoke from long-distance fires can also adversely affect visibility in national parks and wilderness areas designated federally as "Class I" because of their pristine air quality. In these Class I protected areas, within both the Western and the Southeastern United States, conditions of lower visibility are most often associated with wildfires upwind (figure 1) (U.S. EPA 1999).

Fire activity is strongly related to weather and climate. Observations over the Western United States have shown an upward trend of area burned resulting from increasing fire activity, most likely due to climate change (Westerling et al. 2006). In California, which is experiencing intense drought conditions, 4,172 wildfires were recorded from January to August 2014, a 30-percent increase from the average of 3,198 fire events from the previous 5 seasons. Current modeling efforts consistently suggest that fire activity will continue to rise dramatically over the next century

Figure 1. *An example of Yosemite National Park during a clear day (left) versus a hazy day, showing air quality degradation from wildfire smoke (right). Photo: Interagency Monitoring of Protected Visual Environments <http://vista.cira.colostate.edu/improve/>.*

(Xue et al. 2013). Climate-driven changes in fire emissions can be an important factor controlling $PM_{2.5}$ concentrations. For example, previous studies have projected that increased fire activity over the Western United States will nearly double carbonaceous aerosol by 2050 and produce a significant increase in annual mean $PM_{2.5}$ and haze (Spracklen et al. 2009, Xue et al. 2013).

Current meteorological conditions, such as high temperature, low precipitation, and low relative humidity, affect the extent of area burned by fires, regardless of whether the fires are started by lightning or by human activity (Westerling et al. 2006). In addition, meteorological conditions experienced during the months or years preceding the fire may influence the amount of fuel and fuel moisture, which in turn can significantly affect the area burned (Westerling et al. 2006). On the other hand, land-use management and fire suppression may help reduce wildfire severity (Prichard et al. 2010, Kloster et al. 2010). Addressing these concerns requires coupling of climate, vegetation, and fire models.

Fire models have been used in recent years to simulate present day and future fire activity and emissions. These fire parameterizations were developed by regressing meteorological variables and fire indexes onto observed area burned (Spracklen et al. 2009) by empirical functions based on state variables such as soil moisture, temperature, relative humidity, and road and population density (Thonicke et al. 2001, Crevoisier et al. 2007) or by complex process-based fire parameterization schemes (Li et al. 2012). Current estimates of increased area burned, however, show little consistency across models, with ranges from 50 to 150 percent in 2050 to 20 to 100 percent in 2100. In addition, and quite surprisingly, only two studies to date (Spracklen et al. 2009, Yue et al. 2013) have projected the effects of future fires on surface air quality. These papers only focused on the effects of wildfires on black carbon and organic aerosol over the Western United States and at a rather coarse (~250 x 311 miles [~400 x 500 km]) spatial resolution.

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To project fire smoke impacts on air quality due to climate change over the United States at the regional scale, climate inputs at resolutions fine enough to capture the spatial variability of both climate and land cover are required (McKenzie et al. 2014). Global atmospheric and climate models typically run at horizontal grid spacing of 62 x 311 miles (100 to 500 km). However, grid resolutions of 2.5 to 22 miles (4 to 36 km) better capture spatial variability, although local phenomena important for fire are not resolved even at these smaller scales (McKenzie et al., 2014). Regional climate models provide this increased horizontal resolution, but cannot simulate closed systems, such as atmospheric, oceanic, and land-surface processes and their interactions. For this reason, these models need to be fed by boundary conditions obtained from global model outputs, with potential biases introduced when "downscaling" climate projections from the global to the regional model.

Under the scope of a 2014 Joint Fire Science Program Grant, we are currently investigating future wildfire activity and consequences on air quality over the United States. In this study, we focus on major air pollutants, such as $PM_{2.5}$ and ozone, and employ the global Community Earth System Model (CESM) using an unprecedented fine scale (31 x 31 mile [50 × 50 km]) with the new Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP) climate projections. We have incorporated into the model a complex fire parameterization (Li et al. 2012) directly coupled with the climate projections to better predict future areas burned and fire emissions, including changes in biogenic emissions and vegetation. We also take into account projections in anthropogenic emissions (figure 2).

Our approach of using a high-resolution global model is preferred to downscaling climate projections to drive a regional model because: (1) CESM is producing self-consistent and fully coupled simulations, where the climate dynamics drive natural emissions, including also fire emissions, and is directly linked to air quality; (2) the 31- x 31-mile (50- × 50-km) resolution is comparable to that of many regional models; and (3) CESM is also accounting for changes in fire emissions from regions outside the United States, such as Mexico and Canada, to simulate air quality over the United States.

With this project, we aim to quantify potential changes in fire occurrence and severity resulting from changes in climate in the mid-21st century, develop global daily averages of area burned and fire emissions at 31- x 31-miles (50- × 50-km) for the mid-21st century to be used in future regional modeling studies, and quantify future contributions from fires to ambient levels of $PM_{2.5}$ and ozone over different regions of the United States. The research project will be finalized September 2016.

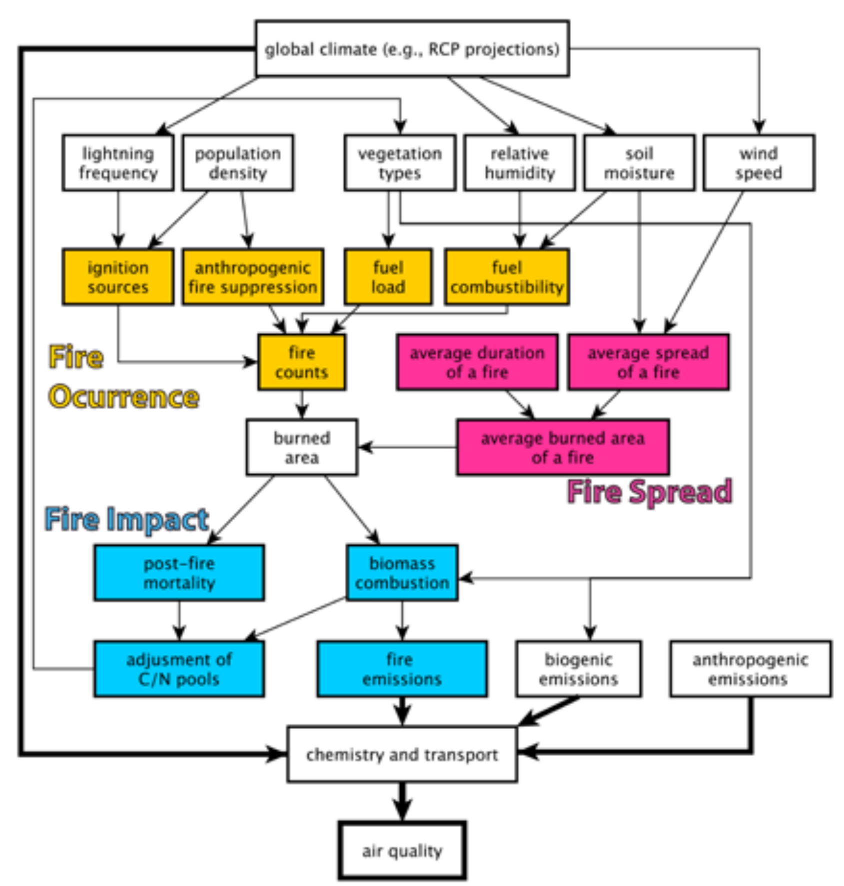

Figure 2. *Diagram of our modeling approach to project fire smoke impacts on air quality due to climate change. The fire parameterization used in the study is depicted in the flow chart and summarized as fire spread, occurrence, and impact. Thin lines connect mainly the elements of the fire parameterization and thick lines connect main items of the modeling system. Flowchart adapted from Li et al. 2012.*

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