Climatic Change
Particulate Air Pollution from Wildfires in the Western US under Climate Change
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Abstract:
Wildfire can impose a direct impact on human health under climate change. While the potential impacts of climate change on wildfires and resulting air pollution has been studied, it is not known who will be most affected by the growing threat of wildfires. Identifying communities that will be most affected will inform development of fire management strategies and disaster preparedness programs. We estimated levels of fine particulate matter (PM2.5) directly attributable to wildfires in 561 western US counties during fire seasons for the present-day (2004-2009) and future (2046-2051), using a fire prediction model and GEOS-Chem, a 3-D global chemical transport model.
Future estimates were obtained under a scenario of moderately increasing greenhouse gases by mid-century. We created a new term "Smoke Wave," defined as >2 consecutive days with high wildfire-specific PM2.5, to describe episodes of high air pollution from wildfires. We developed an interactive map to demonstrate the counties likely to suffer from future high wildfire pollution events. For 2004-2009, on days exceeding regulatory PM2.5 standards, wildfires contributed an average of 71.3% of total PM2.5. Under future climate change, we estimate that more than 82 million individuals will experience a 57% and 31% increase in the frequency and intensity, respectively, of Smoke Waves. Northern California, Western Oregon and the Great Plains are likely to suffer the highest exposure to wildfire smoke in the future. Results point to the potential health impacts of increasing wildfire activity on large numbers of people in a warming climate and the need to establish or modify US wildfire management and evacuation programs in high-risk regions. The study also adds to the growing literature arguing that extreme events in a changing climate could have significant consequences for human health.

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Title: Particulate Air Pollution from Wildfires in the Western US under Climate Change

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Abstract

Wildfire can impose a direct impact on human health under climate change. While the potential impacts of climate change on wildfires and resulting air pollution has been studied, it is not known who will be most affected by the growing threat of wildfires. Identifying communities that will be most affected will inform development of fire management strategies and disaster preparedness programs. We estimated levels of fine particulate matter (PM².₅) directly attributable to wildfires in 561 western US counties during fire seasons for the present-day (2004-2009) and future (2046-2051), using a fire prediction model and GEOS-Chem, a 3-D global chemical transport model. Future estimates were obtained under a scenario of moderately increasing greenhouse gases by mid-century. We created a new term “Smoke Wave,” defined as ≥2 consecutive days with high wildfire-specific PM².₅, to describe episodes of high air pollution from wildfires. We developed an interactive map to demonstrate the counties likely to suffer from future high wildfire pollution events. For 2004-2009, on days exceeding regulatory PM².₅ standards, wildfires contributed an average of 71.3% of total PM².₅. Under future climate change, we estimate that more than 82 million individuals will experience a 57% and 31% increase in the frequency and intensity, respectively, of Smoke Waves. Northern California, Western Oregon and the Great Plains are likely to suffer the highest exposure to wildfire smoke in the future. Results point to the potential health impacts of increasing wildfire activity on large numbers of people in a warming climate and the need to establish or modify US wildfire management and evacuation programs in high-risk regions. The study also adds to the growing literature arguing that extreme events in a changing climate could have significant consequences for human health.
Keywords: wildfire, climate change, air pollution, PM$_{2.5}$

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1 Introduction

Climate change has increased the frequency, intensity and spread of wildfires (Spracklen et al., 2009). In the coming decades, wildfires are anticipated to pose a growing threat (Interagency Working Group on Climate Change and Health, 2010), especially in the western US, where wildfires are common (Brown et al., 2004; Littell et al., 2009; Westerling et al., 2006). Smoke from wildfires contains large abundances of fine airborne particulate matter (PM$_{2.5}$) (Ammann et al., 2001; Dennis et al., 2002; Lighty et al., 2000; Sapkota et al., 2005). This pollutant is known to harm human health when produced by other sources (e.g., transportation, industry). While wildfires are estimated to contribute ~18% of the total PM$_{2.5}$ atmospheric emissions in the US (Phuleria et al., 2005), the contribution of smoke on days exceeding regulatory PM$_{2.5}$ standards is not known. Current literature on wildfires and climate change has been limited to estimates of future area burned (Balshi et al., 2009; Flannigan et al., 2005) and changes in the locations and intensity of wildfires (Fried et al., 2004; Krawchuk et al., 2009). A few studies have examined the impacts of increasing wildfire in the western US on regional levels of particulate matter (Spracklen et al., 2009; Yue et al., 2013), but no study has quantified which if any populations will experience increased smoke exposure. It is not clear, for example, what effect wildfires in remote regions of the western US will have on human health. There is thus a need to understand on fine spatial scales how levels of PM$_{2.5}$ generated specifically from wildfires affect present-day air quality, how these levels will change in the future under climate change, and which communities are anticipated to be most affected.

Estimating the ambient levels of air pollution that can be attributed specifically to wildfire is challenging, even in the present-day. This difficulty arises because most pollutants, including
PM$_{2.5}$, have numerous sources in addition to wildfires. Air pollution data obtained from monitoring stations cannot distinguish between ambient levels of PM$_{2.5}$ from wildfires and PM$_{2.5}$ from other sources. In addition, monitoring data on PM$_{2.5}$ are temporally and spatially sparse. To overcome these difficulties, we used the chemical transport model GEOS-Chem. The PM$_{2.5}$ concentrations from GEOS-Chem can be classified according to emission source and the hourly, gridded results can fill in observational gaps. Simulated particulate matter in GEOS-Chem has been extensively validated against observations, including in the western US (Spracklen et al., 2007; Zhang et al., 2014).

We estimated wildfire-specific PM$_{2.5}$ levels in the western US in the present day (2004-2009) and in the future (2046-2051) under climate change using GEOS-Chem and a newly developed fire prediction model (Interactive Map: [journal url to be added - see: http://khannotations.github.io/smoke-map/, password: smokewavemap15]). For both the present day and the future, our goals were to: 1) estimate the concentration of wildfire-specific PM$_{2.5}$ and its contribution to total PM$_{2.5}$ and 2) identify communities and populations that are expected to experience high exposure to wildfire-specific PM$_{2.5}$.

2 Methods

The study domain was the western US (561 counties) (Interactive Map), where wildfire is a frequent natural disaster (Westerling et al., 2006). To estimate daily wildfire-specific PM$_{2.5}$ levels for the present-day (2004-2009) and the future under climate change (2046-2051) (Intergovernmental Panel on Climate Change (IPCC), 2001), we used GEOS-Chem v9-01-03 driven by assimilated meteorology from the NASA Global Modeling and Assimilation Office (GMAO) Goddard Earth Observing System (GEOS-5) product. The model was run with the
nested grid option, which uses the native GEOS-5 horizontal resolution of 0.5°x0.667° over North America. Boundary conditions are obtained from a 2x2.5 global GEOS-Chem simulation. The model includes black carbon and primary organic particles from wildfires, but not secondary organic particles, whose production in fire plumes is highly uncertain (e.g. Wonaschutz et al., 2011).

For wildfire emissions, we relied on a fire-prediction model (Yue et al., 2014; Yue et al., 2013). The fire-prediction model was developed by quantifying relationships between observed area burned and key meteorological variables. The model does not take ignition into account since wildfire-specific PM$_{2.5}$ is a strong function of area burned, not of ignition type. Here we extended the approach of Yue et al (2013) by estimating area burned at much finer spatial resolution (0.5°x0.667° in the present study vs. 4° x 5° in Spracklen et al (2009) and Yue et al. (2013)). As in Yue et al. (2014), we improved projections of area burned in California by including the effects of elevation, population, fuel load, and the Santa Ana winds. We built on the work of Yue et al. (2014) by using this improved characterization to calculate changes in wildfire-specific PM$_{2.5}$ in California.

We estimated present-day and future area burned by applying the fire-prediction model to simulated meteorological fields archived from an ensemble of 15 climate models in the Coupled Model Intercomparison Project (CMIP3) of the IPCC. For 2046-2051, the climate models follow the A1B scenario (Meehl and Stocker, 2007), which projects moderate growth of greenhouse gas emissions, representing a relatively conservative estimate of future warming due to increased greenhouse gases with balanced reliance on fossil and non-fossil fuels (Intergovernmental Panel on Climate Change (IPCC), 2001). The climate models show a large range in their projections of
key variables associated with weather conditions conducive to wildfires by the mid-century. We therefore used a multi-model approach: we first calculated the future change in area burned for each model separately and then determined median changes for the model ensemble (Yue et al., 2013). The predicted median increase from present day to future in area burned ranged from 10% to 170%, depending on the ecosystem (Yue et al., 2014; Yue et al., 2013).

Finally, we calculated both non-wildfire and wildfire-specific PM$_{2.5}$ in GEOS-Chem. Following Yue et al. (2013), we used estimates of biomass burned derived from the median area burned (present day and future), together with emission factors for carbonaceous species (Andreae and Merlet, 2001). The transport and lifetime of PM$_{2.5}$ is calculated online in GEOS-Chem using GEOS-5 meteorology. Output from GEOS-Chem consisted of 24-hour averages of PM$_{2.5}$ during the fire season (May-October) for the present day (2004-2009) and at mid-century (2046-2051).

We estimated PM$_{2.5}$ levels using three GEOS-Chem simulations: 1) “all-source present-day PM$_{2.5}$,” defined as total PM$_{2.5}$ levels, including from wildfires and all other sources; 2) “non-fire PM$_{2.5}$,” defined as present-day PM$_{2.5}$ levels excluding the contribution from wildfires; and 3) “all-source future PM$_{2.5}$,” defined as future PM$_{2.5}$ levels from wildfires and all other sources. The “non-fire PM$_{2.5}$” simulation used the same model setup as the “all-source present-day PM$_{2.5}$” simulation, except wildfire emissions were turned off. Non-fire sources for PM$_{2.5}$ in the model include transportation, industry, and power plants (Querol et al., 2004). Future PM$_{2.5}$ levels from non-fire sources could differ significantly from present-day levels due to many factors, including technological changes and climate change (Tai et al., 2012). For this study, in order to isolate the influence of climate change on wildfire PM$_{2.5}$, we assumed that future non-fire PM$_{2.5}$ concentrations are the same as in the present day. Grid-level wildfire-specific PM$_{2.5}$ levels in
both the present day and future were therefore calculated by subtracting the “non-fire PM$_{2.5}$” concentrations from the “all-source” PM$_{2.5}$ concentrations. Using this method, a small portion (~2%) of wildfire-specific PM$_{2.5}$ concentrations were negative and were set to zero. Wildfire-specific PM$_{2.5}$ was zero on days when no smoke traversed a given grid cell. Daily county-level wildfire-specific PM$_{2.5}$ levels were estimated as weighted averages from gridded exposure estimates using as weights the area of each grid cell within a county. Daily county-level estimates of all-source PM$_{2.5}$ were calculated using the same method.

To characterize prolonged air pollution episodes from wildfires, we defined the term “Smoke Wave” (SW) as ≥2 consecutive days with wildfire-specific PM$_{2.5}$ > 98$^{\text{th}}$ quantile of the distribution of daily wildfire-specific PM$_{2.5}$ values in the modeled present-day years, on average across the study area. We emphasize that SWs do not define wildfire events; we use this term to characterize the air pollution episodes resulting from one or multiple wildfire events. Based on this definition, we classified each day in each county during the study period as a SW day or non-SW day. We also defined the length and intensity of a SW as the number of days in the SW and the average levels of wildfire-specific PM$_{2.5}$ during SW days, respectively. We estimated the length of a SW season as the number of days between the first and last SW day in a fire season. Sensitivity analysis included alternate SW definitions for intensity. Similar approaches have been used in studies of heat waves (Anderson and Bell, 2011). Unlike previously applied measures of wildfire-specific PM$_{2.5}$, which focused on seasonal or monthly means (Yue et al., 2014), the SW concept can capture the high concentration, sporadic, and short-lived characteristics of wildfire-specific PM$_{2.5}$. Such characteristics are of great value to epidemiological studies. We estimated and compared SW characteristics for the present day and the future.
We created a Fire Smoke Risk Index (FSRI) for each county for the present day and a separate FSRI for each county for the future. The FSRI combined information on the number of SWs per year, average SW intensity, and average SW length (Supplementary Table A.1). FSRI values ranged from 0 to 5, with 0 representing the lowest level (no SWs in that county in that time period) and 5 representing the highest level of wildfire-specific PM$_{2.5}$ based on the combined metrics of frequency, intensity, and length of SWs.

For the present day and future, we estimated the number of persons residing in each county, using Integrated Climate and Land Use Scenarios (ICLUS v1.3) Population Projections (US Environmental Protection Agency, 2011) for the A1B scenario. Specifically, for the present day, we estimated the number of persons in each county using the 2005 values, and for future years we used 2050 population projections from ICLUS. To estimate the size of populations for children and the elderly in each county in the future, we combined US Census survey estimates for children (<18 years of age) and the elderly (>64 years of age) in 2005 (US Census, 2005) with nationally representative population growth rates for each age group (US Census, 2012). We also used county-level 2010 Census data to indicate which counties have a high fraction of populations (e.g., by race, poverty, age) that are potentially vulnerable to health effects from PM$_{2.5}$ (Liu et al., 2015).

We created an interactive map visualizing county-level SW characteristics (number of SWs per year, length of SWs in days, and intensity) and county-level FSRI values for the present day and under climate change (Interactive Map). The map also ranks counties in each state by total number of SWs over the 6-year period, total number of SW days, average length of SW in days, average SW intensity (wildfire-specific PM$_{2.5}$), FSRI for the present day and future, and the difference between future and present-day FSRI values. These features in the map therefore
highlight which counties experienced the highest wildfire-specific PM$_{2.5}$ (as indicated by SW characteristics and FSRI) in the present day and the future, regardless of population. The map also includes county-level population size and population density for the present day and the future. This feature of the map can be used to identify counties suffering the highest exposure to wildfire pollution based on both exposure to wildfire-specific PM$_{2.5}$ and number of people affected. The general public and policy makers can use this map to examine the present and future fire smoke exposure risk in states and counties of interest.

3 Results

**Wildfires as a source of PM$_{2.5}$ in the present day:** In western US counties during wildfire seasons in the years 2004-2009, we found that wildfires are an important source of total ambient PM$_{2.5}$. Wildfire contributed on average 12.0% of total daily PM$_{2.5}$ in the 561 counties (Figure 1). On days with total PM$_{2.5}$ exceeding regulatory standards for daily PM$_{2.5}$ (35 μg/m$^3$), 71.3% of total PM$_{2.5}$ could be attributed to wildfires, based on an average across counties (Supplementary Figure A.1).

**Wildfire-specific PM$_{2.5}$ levels under climate change:** Under climate change, the average wildfire-specific PM$_{2.5}$ level for the years 2046-2051 was estimated to increase approximately 160%, and the maximum wildfire-specific PM$_{2.5}$ level was estimated to increase by >400% (Supplementary Table A.2, Supplementary Figure A.2, Interactive Map).

**Smoke Waves and their characteristics in the present day and under climate change:**
Supplementary Figure A.3(a) shows the number of SWs in each county over 6-year periods in the present day and in the future under climate change. SW characteristics differ by region.
Overall for both the present day and the future analyses, northern California, the Pacific Northwest, and forests in the northern Rocky Mountains experienced more SWs than other areas. SWs in these counties also tend to last longer and have higher intensity. These counties are heavily forested with abundant fuel to drive SWs. Counties in the northern Rocky Mountains are also strongly affected by SWs as they are located downwind of fires in dense forests. Overall, climate change is anticipated to increase the frequency, intensity, and length of SWs (Table 1, Supplementary Figure A.3). We estimated that the frequency (number of SWs/year) will increase from an average across counties of 0.98 SWs/year (range 0-4.00/year) in the present day to 1.53/year (0-4.83/year) under climate change in the 2050s. Twenty counties free from SWs in the present day are anticipated to experience at least one SW in the future 6-year period under climate change. The average SW intensity (wildfire-specific PM$_{2.5}$ level) is expected to increase an average 30.8% and the length of the SW season is estimated to increase by an average of 15 days.

The estimated changes in SW characteristics related to climate change appeared spatially heterogeneous (Interactive Map). Among the 561 counties, 55.6% (312 counties) are anticipated to face more intense SWs in the future, 19.3% to have less intense SWs, and 25.1% to have no change in intensity. We estimated that most counties in the forests of the northern Rocky Mountains and coastal counties will experience a 10-40 μg/m$^3$ increase in SW intensity (wildfire-specific PM$_{2.5}$) under climate change, while eastern Rocky Mountains counties will have less intense SWs (Figure 2a). More than 40% of counties are anticipated to have longer SWs under climate change (Figure 2b). Counties in the Rocky Mountains are more likely to have prolonged SWs under climate change compared to the present day. The 20 counties with fewer future SWs were primarily located in northern California and northern Nevada. More than 60% of counties...
are anticipated to face more SW days under climate change (Figure 2c), 6.8% to have fewer SW days, and 32.2% to have no change. The change in the number of SW days and change in number of SWs (Figures 2c and 2d) had similar spatial distributions. Although we estimated that a small number (6.8%) of counties will have fewer SW days under climate change, the future SWs were generally estimated to have higher average intensity. We estimated that more than 62.5% of counties, mainly in northern Rocky Mountains, Colorado, and southern California, will face extended fire seasons, by as much as 69.5 days (Figure 2e).

Fire Smoke Risk Index (FSRI) in the present day and under climate change: FSRI was designed to summarize overall wildfire risk based on duration, intensity, and frequency of SWs. The percent of counties at each level of the FSRI are shown in Supplementary Table A.3 for the present day and in the future under climate change. We estimated that the number of counties with the highest wildfire smoke risk (FSRI of 5) will increase from 22 (3.9% of 561 counties), in the present day, mostly in coastal Oregon and coastal northern California, to 97 (17.3% of 561 counties) under climate change, expanding to western Oregon, northwestern California, Idaho and western Montana (Figure 3, Interactive Map). These maps also highlight counties with children, elderly, or those living in poverty comprising more than 25% of the population, and counties with populations that are more than 50% non-white. Of the 137 counties with FSRI of 0 in the present day, we estimated that 20 counties will face at least one SW in the future (FSRI ≥1), primarily in southwestern Nevada, eastern Utah, and northern New Mexico. The regions estimated to suffer the highest increase in wildfire smoke risk are central Colorado, southeastern Idaho, southern Montana, and eastern Washington (Supplementary Figure A.4, Interactive Map).

Number of individuals expected to experience SW under climate change: We estimated that approximately 57 million people were affected by at least one SW during in the study region for
the present-day 6-year period (2004-2009). In the future (2046-2051), with climate change as modeled under the A1B scenario and with population growth, more than 82 million people are likely to be affected by at least one SW, an increase of 43.9%. The changes in SWs, combined with demographic trends, are anticipated to result in 7 million more children and 5.7 million more elderly people affected by SWs under climate change compared with the present day (Supplementary Table A.4).

4 Discussion

To our knowledge, this is the first study to estimate daily ambient levels of wildfire-specific PM$_{2.5}$ at the county scale across the western US and to map the frequency and intensity of wildfire-PMM$_{2.5}$ episodes (SWs) in the present day and in the future under climate change. We introduced the concept of a Smoke Wave, defined as ≥2 consecutive days with high levels of wildfire-specific PM$_{2.5}$, which uniquely summarizes the frequency, duration, and intensity of air pollution from wildfires. Our study demonstrated that SWs are likely to be longer, more intense, and more frequent under climate change, which raises health, ecological, and economic concerns.

Wildfire-specific PM$_{2.5}$ can impose economic burdens by impacting medical care, tourism, and property values, and costs of forest suppression. It can cause ecological damage and also affects visibility, which can impact transportation, aesthetics, and tourism (Hystad and Keller, 2008). Increased wildfire activity damages property and raises suppression and recovery costs (Flannigan et al., 2009), creating new challenges for wildfire management. Suppressing a large fire can require thousands of firefighters (Dombeck et al., 2004). During 2000-2002, US federal agencies spent over a billion dollars to suppress wildfires, and this expense has grown over time due to increased burned areas (Dombeck et al., 2004).
SWs are likely to be especially deleterious to human health (Delfino et al., 2002; Hänninen et al., 2009; Moore et al., 2006) because of exposure to very high levels of PM$_{2.5}$. We also estimated that substantial populations of elderly, children, people living in poverty, and non-white individuals will be exposed to SWs; these populations may be the most vulnerable to the health risks related to exposure to PM$_{2.5}$ from wildfires. Our results, which identify regions and populations of high risk, can aid decision makers in wildfire management, public health, and climate change policies to mitigate the occurrence and associated consequences of wildfires.

Our use of GEOS-Chem produces total PM$_{2.5}$ data with better temporal resolution and spatial coverage than monitoring data. Our wildfire-specific PM$_{2.5}$ estimates have finer spatial resolution than previous wildfire prediction models and incorporate improved predictions of area burned for California. The finer resolution used here leads to more accurate representation of the location of emissions and yields PM$_{2.5}$ exposure estimates at the county level, which are useful for policy purposes. The improved predictions in California account for the irregular terrain in that state and the influence of the Santa Ana winds, factors which are typically not well captured by climate models (Yue et al., 2014). Previous studies linking climate change and wildfire activity in the western US focused on trends in monthly or seasonal mean area burned or carbonaceous aerosol (Spracklen et al., 2009; Yue et al., 2013). In contrast, our study focused on daily PM$_{2.5}$, a metric relevant to human health as documented by numerous epidemiological studies and literature reviews (e.g. Dominici et al., 2006; Liu et al., 2015). By providing new information on the potential health consequences of future wildfires, our study can guide decision makers in developing policy responses and protecting population health.
There are several limitations in this study. Our results may underestimate wildfire-specific PM$_{2.5}$ under climate change, as our fire prediction model did not incorporate the possibility that fire suppression in the western US might lead to an unnatural accumulation of forests, thereby providing fuel that may increase the probability of very large fires (Marlon et al., 2012; Schoennagel et al., 2004). The model also did not include changes in vegetation due to climate change or to CO$_2$ fertilization, which may result in faster growth of vegetation. Future work could also estimate levels of wildfire-related ozone to develop a comprehensive assessment of wildfire’s impact on air pollution. Work is needed in other regions that experience frequent wildfire events, such as the Canadian boreal forests, the Brazilian Amazon, and Southeast Asia (Liu et al., 2015). Future investigations are needed to estimate the health, ecologic, and economic consequences of wildfire smoke using source-specific air pollutant data, and to develop policy frameworks in response to these consequences, especially given anticipated increases in wildfire activity under climate change.

Communities identified in this study as at risk of suffering intense wildfires in the future would benefit from the establishment or modification of public health programs and evacuation plans in response to climate change. Projections of wildfire-specific pollution could aid development of forest management programs, climate change adaptation plans, and community preparedness. Our results will advance understanding of the impacts of climate change on wildfire, and aid in the design of early warning systems, fire suppression policies, and public health programs.
Conflict of Interest: The authors declare that they have no conflict of interest.

References


Figure Legends

Figure 1. Fraction of PM$_{2.5}$ attributable to wildfires by county during fire seasons (May-October) in the present day (2004-2009), on all days (left panel), and on the subset of days that had total PM$_{2.5}$ > 35μg/m$^3$ (NAAQS threshold; right panel).

Figure 2. Difference in SW characteristics in the future (2046-2051) under climate change and in the present day (2004-2009) during fire seasons (May-October). Positive changes (in warm colors) indicate increases under climate change, while negative changes (in cool colors) indicate decreases under climate change. Panels show (a) average intensity of SW; (b) average length of SW; (c) total number of SWs during a 6-year period; (d) total number of SW days during the 6-year period; and (e) average length of the SW season.

Figure 3. FSRI during fire seasons (May-October). Panel (a) is for present day (2004-2009) and panel (b) is for future (2046-2051) under climate change.

Supplementary information

We prepared one document of supplementary material including four tables and four figures supporting the paper.
Figure 1. Fraction of PM$_{2.5}$ attributable to wildfires by county during fire seasons (May-October) in the present day (2004-2009), on all days (left panel) and on the subset of days that had total PM$_{2.5}$ > 35μg/m$^3$ (NAAQS threshold; right panel).
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Figure 3. FSRI during fire seasons (May-October) in the (a) present day (2004-2009) and (b) future (2046-2051) under climate change.
Tables

**Table 1.** Summary Statistics for Present Day (2004-2009) and Future (2046-2051) Smoke Waves (SWs) During Fire Seasons (May-October).

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<th>No. counties with SW (N=561)</th>
<th>SW days/year</th>
<th>SWs/year</th>
<th>SW intensity (μg/m$^3$)</th>
<th>SW length (days)</th>
<th>Length of SW season (days)</th>
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<td>Present</td>
<td>424</td>
<td>3.13 (2.93)</td>
<td>0.98 (0.8)</td>
<td>15.9 (6.6)</td>
<td>2.95 (0.7)</td>
<td>14.0 (13.4)</td>
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<td>Future</td>
<td>440</td>
<td>4.91 (3.45)</td>
<td>1.53 (1.0)</td>
<td>20.8 (8.9)</td>
<td>3.08 (0.5)</td>
<td>29.0 (18.2)</td>
</tr>
</tbody>
</table>

Data are presented as average across counties (standard deviation).
Click here to access/download
Supplementary Material
LIU_mapping paper supplemental Dec 2015.docx
References


