DEVELOPMENT OF METHODS TO CONNECT EXPOSURE TO WILDLAND FIRE PARTICULATE EMISSIONS TO HEALTH OUTCOMES: A CASE STUDY FROM SAN DIEGO COUNTY, 2007

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1. INTRODUCTION

Particulate matter emissions from wildland fire smoke have been linked to a variety of acute human respiratory and cardiovascular health effects. In a project sponsored by the National Institute of Environmental Health Sciences Interagency Working Group on Climate Change and Health Initiative, physically based models of wildland fire emissions and atmospheric transport were linked to population health outcomes using syndromic surveillance data obtained during the 2007 San Diego County wildfires. The goal was to better forecast and prepare for air quality events caused by wildland fire under current and projected future climate conditions.

This paper and presentation include a review of the initial study that included creation of the smoke exposure maps and development of modeling methods to connect emissions of particulate matter from wildland fires to respiratory health outcomes as assessed from syndromic surveillance emergency department visit data (Figure 1). The status of new research is also reviewed here that is linking the exposure maps to health outcomes using the richer health data from California Department of Health Care Services (DHCS) Medi-Cal claims files from San Diego County.

The presentation further reviews the model developed in the initial study to forecast future fires based on regional climate model predictions, which shows wildland fire risk for the next 30 years to be similar to the present. Based on the outcomes of the future fire assessment, the respiratory health outcomes model was applied to realistic scenarios to demonstrate the use of the coupled emissions-transport system and statistical model for assessing potential future fire impacts.

This research serves as an example of how complex process-based models of fire emissions and smoke dispersion can be combined with a statistical modeling approach to determine realistic expectations of health outcomes and assess the impact fire could have on human health during past, current, and future wildland fire events.

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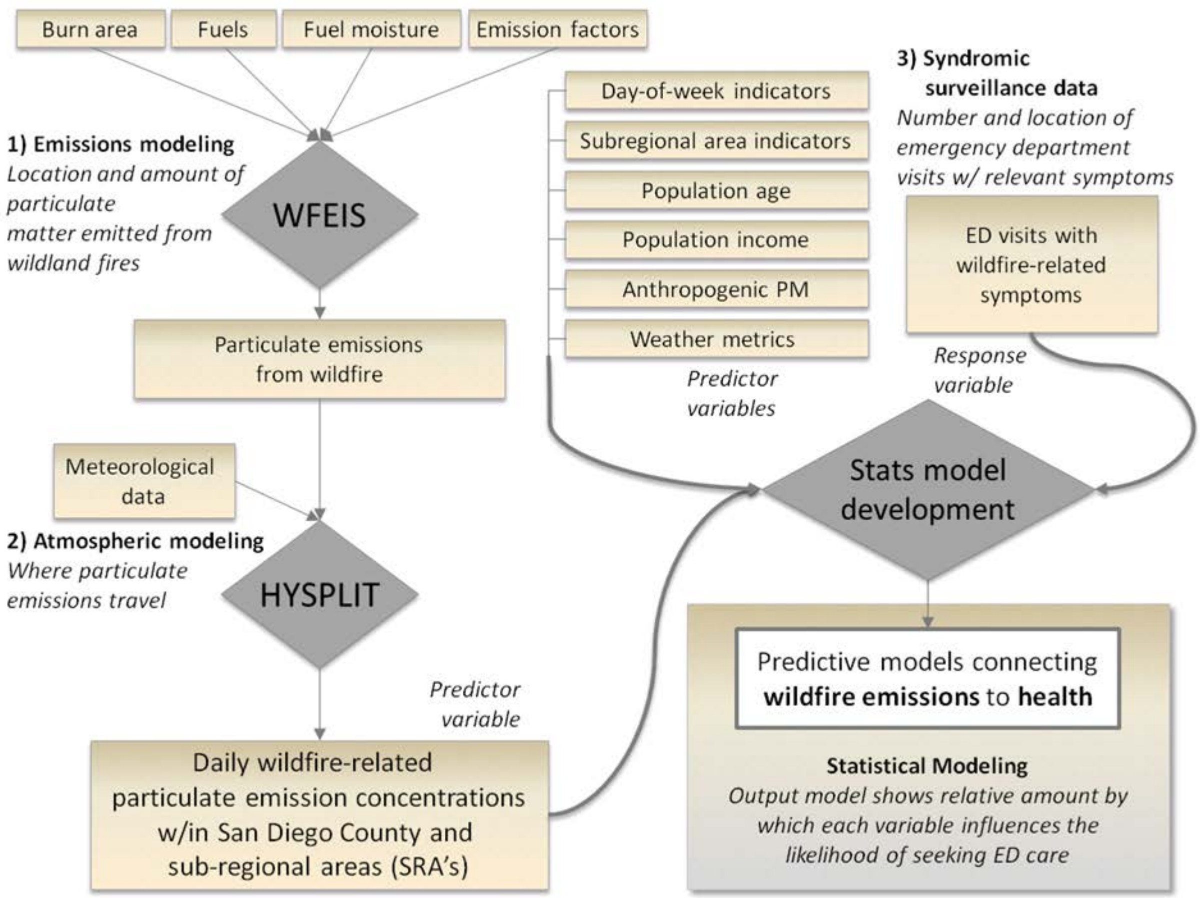

Figure 1. Initial Project Overview.

2. MODELING EXPOSURE TO WILDLAND FIRE PARTICULATES

A comprehensive set of burn area, fuel loading, and fuel moisture data were incorporated into the Wildfire Emissions Information System (WFEIS; http://wfeis.mtri.org)(French et al. 2014) to produce PM emissions estimates on a daily basis at a scale of approximately 30 m spatial resolution. The input datasets totaled over 14,000 wildfire burn polygons with a cumulative area of 14,464 km^2 distributed across 1,700 dates from 2003-2008. The total output emissions across the entire study area and time period amounted to 188,000 metric tons PM_{10}.

Atmospheric transport trajectories of PM emissions originating from wildfires from the HYSPLIT model (Draxler 1999; Draxler and Hess 1998) were spatially aggregated to produce daily wildfire emissions concentration values by zip code and sub-regional area within San Diego County. Air quality data from in situ California Air Resources Board (CARB) sensors were used to calibrate emissions model inputs. An example result from the atmospheric dispersion model is shown in Figure 2, depicting PM plumes moving west from their wildfire origin towards the Pacific

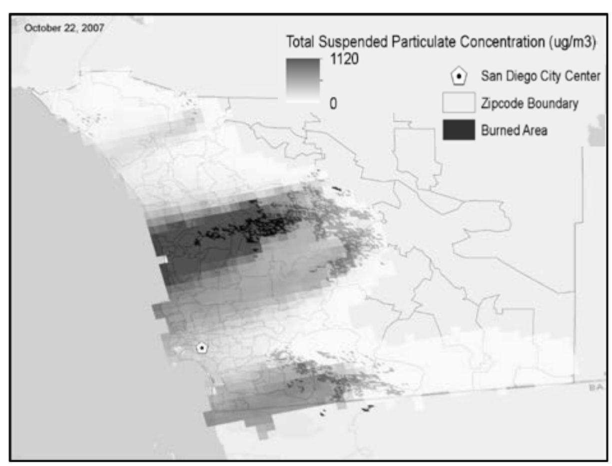

Figure 2. Gridded concentrations of particulate matter from wildfire as output from the HYSPLIT atmospheric transport model for the peak day of burning in the study.

coast on the peak day of wildfire burning during the study time period, October 22, 2007.

As reported in Thelen et al. (2013), peak county-wide average concentrations of fire-produced $PM_{2.5}$ during the October-November 2007 period was modeled to be more than 400 µg/m^3, while average peaks in some sub regions exceeded 500 µg/m^3, and station-measured concentrations in the time period were as high as 475 µg/m^3. Compared with modeled region-averaged anthopogenic $PM_{2.5}$ of no more than 2.5 µg/m^3 for the same time period, it is clear that fire-derived PM dominated the signal in the time period of these fires.

3. STATISTICAL MODELING OF WILDLAND FIRE HEALTH OUTCOMES

The smoke concentration maps created for the San Diego region were used to determine smoke exposure to assess the impact of wildland fires on respiratory health. The maps were used in the initial study reviewed by Thelen et al. (2013) and in a new assessment underway using Medi-Cal records.

3.1 Connecting Smoke Exposure to Syndromic Surveillance Respiratory Health Data

The statistical model connecting particulate matter concentrations from wildland fire to syndromic surveillance data on respiratory health is based on a generalized additive modeling (GAM) approach, with the addition of environmental variables and lagged effects. Smoke exposure was determined from modeled smoke concentrations with an added cumulative lag effect that was determined using a half-Gaussian weighting of the 3 days prior to seeking care. A full review of the modeling effort is provided in Thelen et al. (2013) with a short summary here.

Input datasets to the respiratory effects model cover four categories: (1) atmospheric particulates, (2) syndromic surveillance health data records, (3) environmental conditions, and (4) demographic stratification variables. Two levels of geographic aggregation were considered; the first aggregation combines the full set of zip codes in the San Diego County study area and the second merges zip codes into six sub-regional areas.

Daily modeled emergency department (ED) visits are shown in Figure 3 along with actual ED

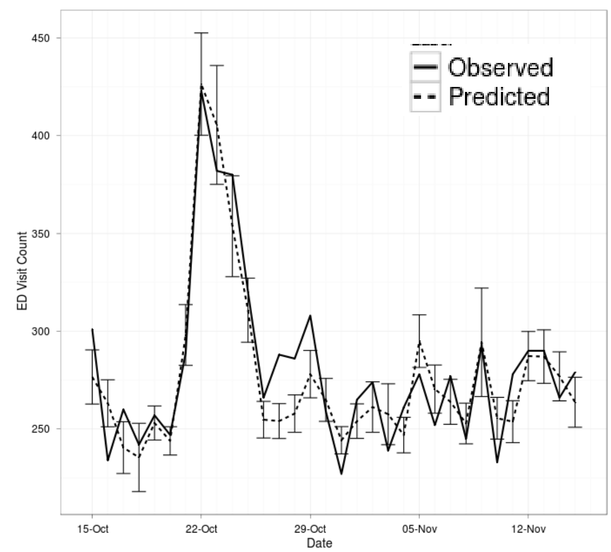

Figure 3. Comparison of emergency department (ED) visits observed versus predicted by the statistical model for the time period directly before, during, and after the October 2007 fires. The San Diego County-wide model is shown. Results for each sub region are similar.

visits as collected by the San Diego Aberration Detection and Incident Characterization (SDADIC) system (Johnson et al. 2005). The spatially explicit syndromic surveillance data available from SDADIC allowed an aggregated assessment of outcomes, as shown in Figure 3, and spatially-specific comparisons, which were done within the six sub regions defined for this study. The sub-regional analysis provided a way to control for other confounding factors, such as geographic location, which is a determinant of exposure due to varying smoke concentrations as well as other environmental variables, and socioeconomic factors including age and income. Complete results of this study, including a review of the impacts of non-smoke variables on health outcomes, is reported in the publication (Thelen et al. 2013).

3.2 Assessing Outcomes from Smoke Exposure using Syndromic Surveillance

The initial analysis connecting smoke exposure to ED visits derived from syndromic surveillance data resulted in a predictive model that showed that the additive effect on the odds of seeking emergency care due to wildfire smoke ranged from 41% for the full San Diego County region to 72% for sub regions (See Thelen et al. 2013). Further analysis with additional data sets is underway to explore the value of various health data and indicators and develop additional quantitative avenues on predicting health outcomes during wildfire events such as the 2007 San Diego fires.

3.3 Relating Modeled Smoke Concentrations to Health Outcomes in Medi-Cal Populations

Extending analysis of smoke concentration outputs previously used to connect respiratory outcomes captured in syndromic surveillance of emergency room data in San Diego County is now being applied to a different and richer dataset of Medi-Cal (California Medicaid) patients. The exposure maps will be used to characterize the burden of large wildfire events on public health, assessing respiratory, cardiovascular, and other health outcomes in vulnerable populations and impacts to the public health care system in outpatient visits, emergency and urgent care visits, and hospitalizations. Studying Medi-Cal beneficiaries will allow analysis of a population with concentrated vulnerability factors, including low-income (a factor recognized to increase vulnerability to climate change), children, pregnant women, seniors, adults with disabilities, and persons with chronic diseases.

We are using exposure outputs from the 2007 San Diego wildfire from coupled models of particulate matter emissions and atmospheric dispersion to estimate daily average $PM_{2.5}$ levels calculated by ZIP code, as described previously

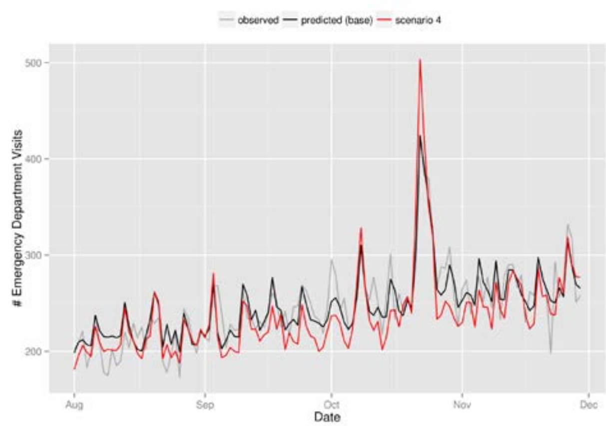

Figure 4. Emergency department (ED) visits across the study time period (August 1 to December 1) for San Diego County. Gray shows observed values; black shows predicted values according to the GAM; red ("scenario 4") shows a "worst case" scenario wherein wildfire TSP data is increased to levels modeled from 2003 fire season and temperature and relative humidity values are modified according to conditions predicted under doubled-CO_2 climate change scenarios.

(Thelen et. al, 2013). Exposure-linked health data are used to evaluate medical encounters in the fire period relative to control periods. To assure findings can inform public health practice, exposure is treated as a categorical variable, based on Air Quality Index thresholds developed by USEPA which are currently used as a basis for public health decisions. Total medical encounters are evaluated, as well as those related to respiratory and cardiovascular indices described previously (Delfino et al. 2009). Comparison periods are based on matched day-of-week selections within a close time period of the same summer (Hoshiko et al. 2010).

To screen for health impacts beyond the more well-studied outcomes of respiratory and cardiovascular endpoints, we developed a list of diagnoses that could be caused or exacerbated by wildfire smoke, evacuation, or other stress related to a large, disruptive wildfire event. Medical encounters will be screened for codes that increase during the fire period. In this hypothesis-generating activity, statistical approaches to adjust significance testing for multiple endpoints will be employed to identify those health effects with sufficient evidence to merit further investigation.

This study protocol was approved by California's Department of Health Care Services Data and Research Committee and Committee for the Protection of Human Subjects.

4. MODELING RESPIRATORY HEALTH OUTCOMES IN A CHANGING CLIMATE

The initial project included development of a model to forecast future fires based on regional climate model predictions, which shows wildland fire risk for the next 30 years to be similar to the present; San Diego County will experience approximately two extreme fire seasons each decade to 2040.

In addition to this analysis of fire season forecasting, another analysis used the trained GAM model that was developed as part of the initial project to evaluate respiratory health impacts under a set of "what if" scenarios. For example: what if San Diego County experienced a more extreme fire season than in 2007? Or: what if the fires had occurred in weather conditions predicted under climate change scenarios?

For the first scenario (increased emissions), 2003 wildfire TSP data was used because it shows a 1-day peak that is 47% higher than that modeled for 2007. Under these conditions, the model predicts an 8.4% increase in 1-day peak ED visits.

For the second scenario (climate change), the 2007 air temperature and relative humidity data used to train the model was modified (+4° C, -2% respectively) according to conditions predicted under doubled-CO_2 scenarios (doubled relative to the start of the century; roughly corresponding to IPCC's A1B and B2 emissions scenarios for 2100). Under these conditions, the model predicts an increase of ~10% in 1- and 5-day peak ED visits but a ~4% decrease in total ED visits across the entire August 1 to December 1 study period.

A "worst case" scenario (Figure 4) was also examined in which both 2003 wildfire TSP and doubled-CO_2 conditions were applied. In this scenario, the model predicts a 19% increase in 1-day peak ED visits, 8% increase in 5-day peak visits, but a 4% decrease in total ED visits across the entire study period. The projected decrease in visits outside of fire periods is a result of non-fire effects, as reviewed in data presented in Thelen et al. (2013).

This type of analysis can be useful for emergency preparedness and public health applications. Additionally, this analysis has implications for the effect of climate change on the emergency preparedness and public health.

5. CONCLUSIONS

Applying advanced statistical methods allows a better understanding of the influence of wildfire emissions and smoke exposure to public health. While it is obvious that wildland fire produces negative respiratory health conditions, quantification of the outcomes can be difficult. Improved geophysical modeling of smoke concentrations, improved assessment of cumulative exposures, and advanced statistical modeling has provided distinct results documented in the initial study of the 2007 San Diego wildfires. The project allowed San Diego County to improve syndromic surveillance capacity and infrastructure through the addition of new hospitals to the local syndromic surveillance system.

Further assessment with a richer dataset from Medi-Cal, and development of additional smoke exposure maps will provide more ways to quantify outcomes that can be used in assessing future possibilities. Since fire is well known to be increasing in the Western US and other regions, these studies can be used to quantify potential health outcomes and improve expectations of health impacts possible under a changing climate and fire regime.

The research team is hoping to expand this approach to other time periods and fire-affected regions to better understand how wildland fire events relate to health outcomes and to improve region-specific preparedness plans.

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Acknowledgement: A part of the research presented was supported through grant #1-RC1-ES018612 from the National Institute of Environmental Health Sciences, under the NIEHS Interagency Working Group on Climate Change and Health Initiative.