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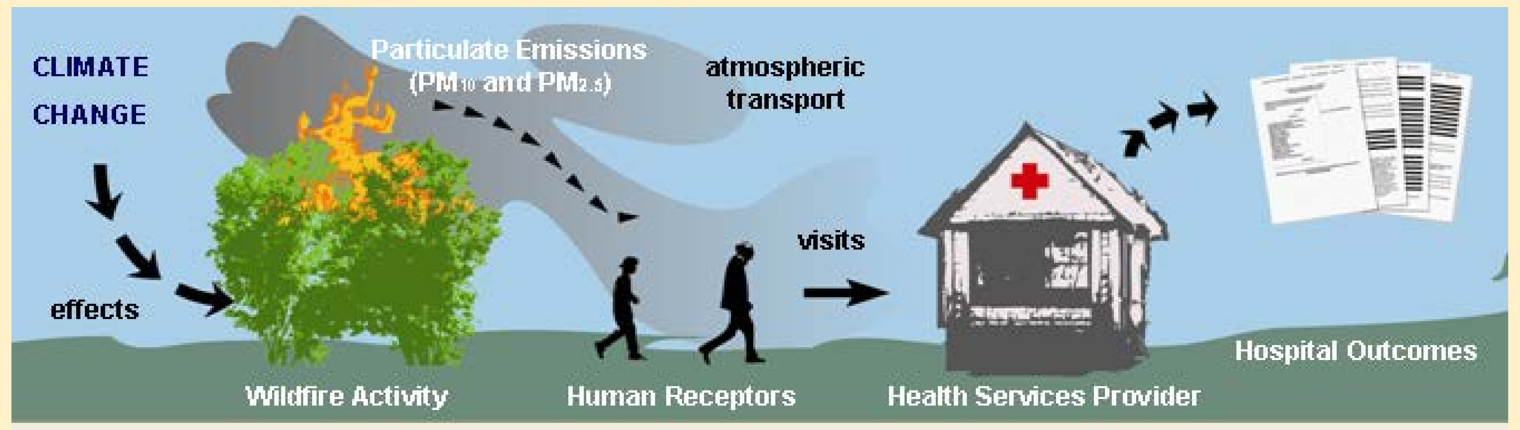
A part of the research presented was supported through grant #1-RC1-ES018612 from the National Institute of Environmental Health Sciences, under the NIEHS Interagency Working Group on Climate Change and Health Initiative

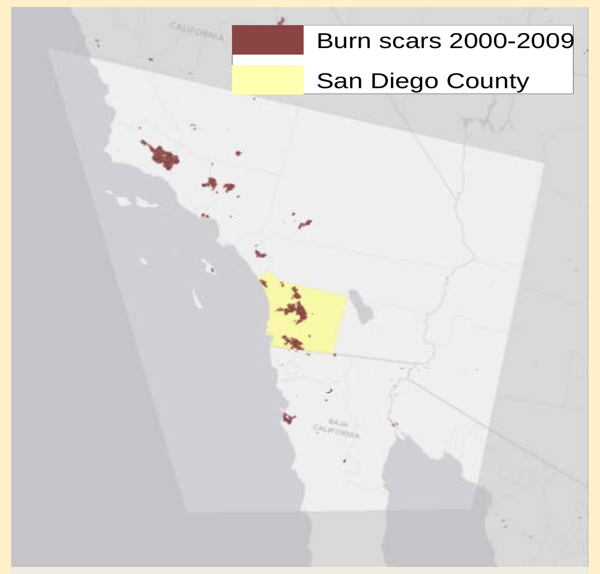
1. Introduction

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.



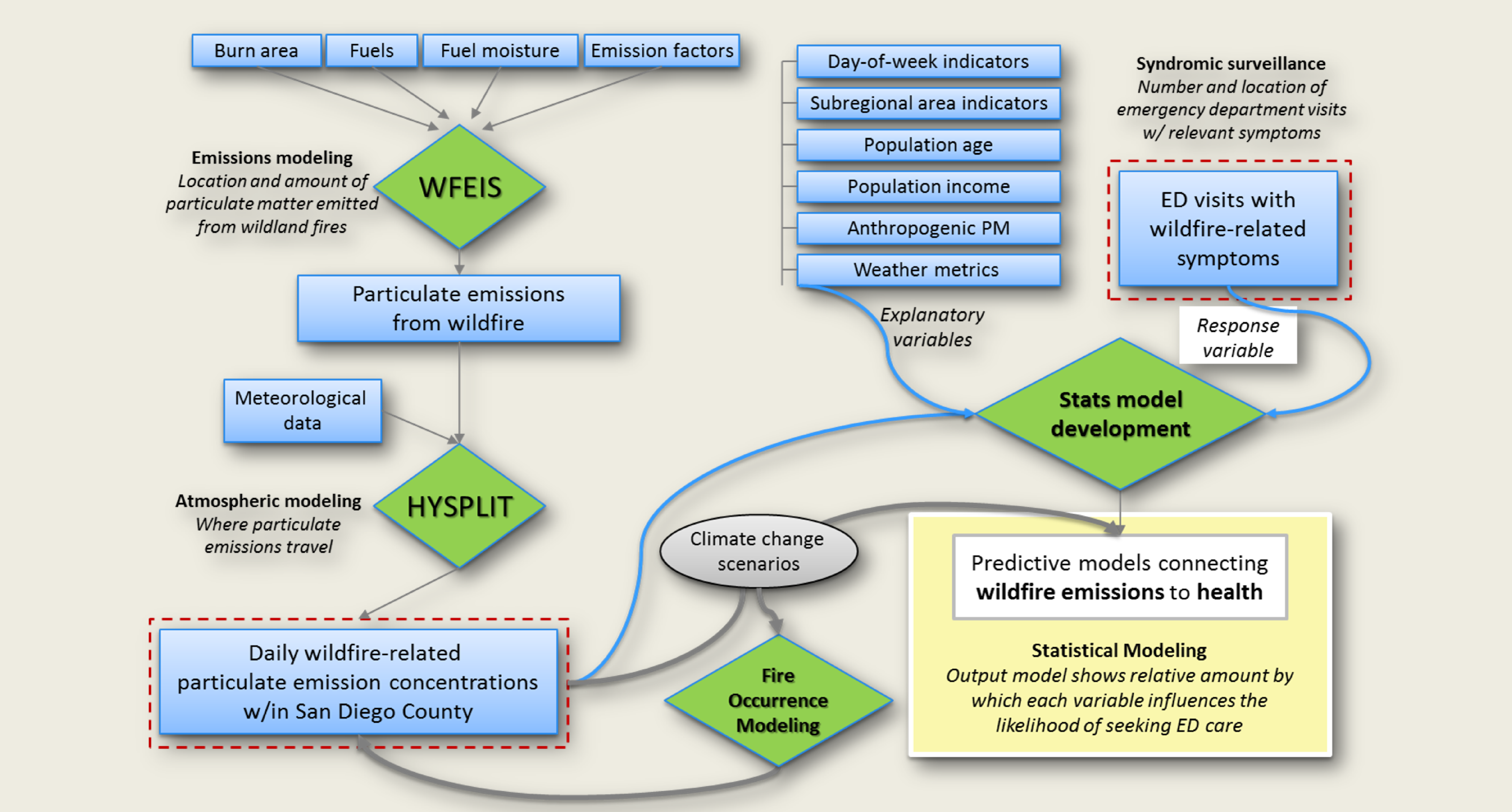
Above: Climate change will affect air quality conditions from wildland fires that are detrimental to respiratory health

- **Review of the initial study**
  - **Smoke exposure maps**
  - **Modeling methodology development to connect emissions of particulate matter from wildland fires to respiratory health outcomes**
  - **Forecast future fires based on regional climate model predictions**
- **Status of new research linking the exposure maps to health outcomes**
- **Respiratory health outcomes model applied to realistic scenarios**



Above: The study area, with San Diego County highlighted in yellow.

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



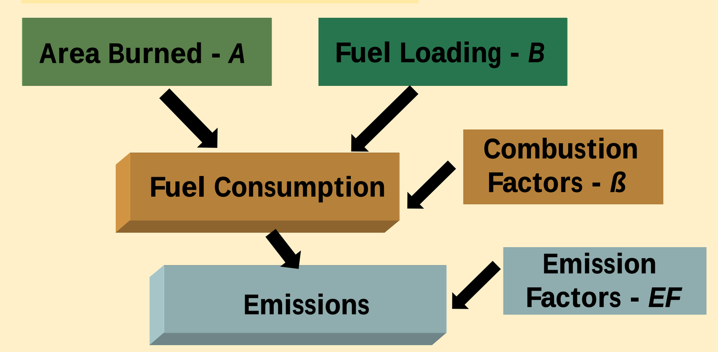
2. Modeling Exposure to Wildland Fire Particulates

Smoke concentrations were modeled using a combined emissions-transport model.

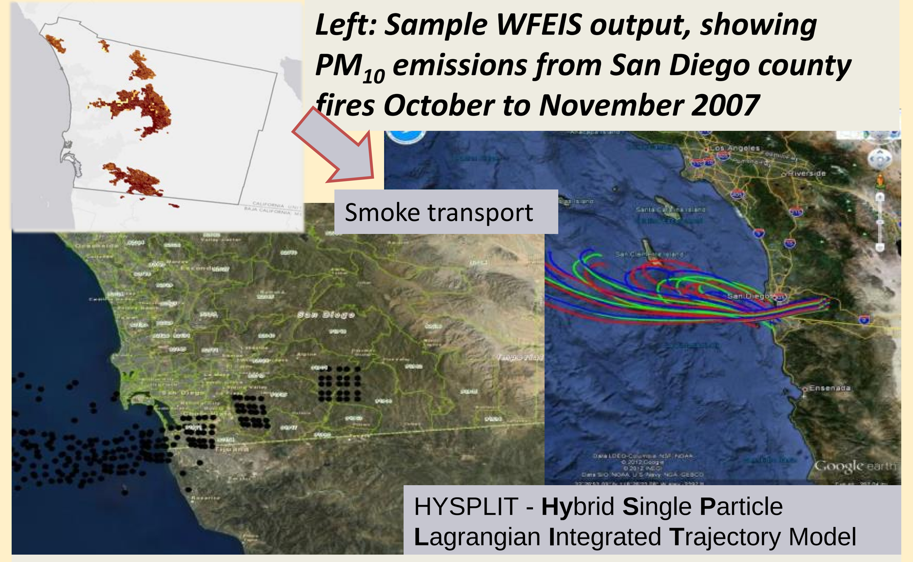
The Wildfire Emissions Information System (WFEIS) combines burn area, fuel loading, and fuel moisture to produce PM emissions estimates (*see French et al. 2014*)

- Input:
  - Datasets with > 14,000 wildfire burn polygons
  - Cumulative area of 14,464 km^2
  - 1,700 dates ranging from 2003-2008
- Model:
  - WFEIS (http://wfeis.mtri.org)
  - Fire progression maps
  - 30-m fuels FCCS
  - PythonConsume
- Output:
  - 188,000 tonnes PM$_{10}$

The WFEIS model



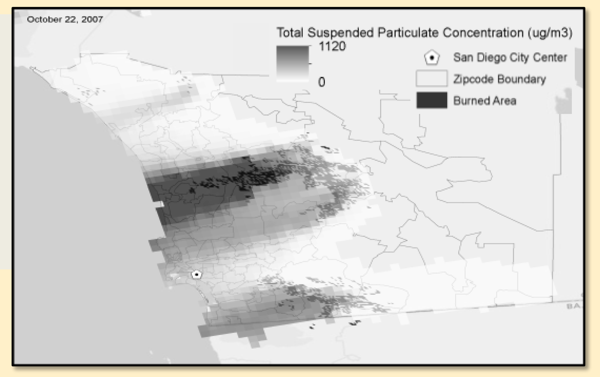
Atmospheric transport trajectories of PM emissions from the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model were spatially aggregated to produce daily wildfire emissions concentrations by zip code and by sub-regional area. Air quality data from California Air Resources Board (CARB) were used to calibrate emissions model inputs.



Left: Sample WFEIS output, showing PM$_{10}$ emissions from San Diego county fires October to November 2007

Above: Atmospheric transport modeling, using WFEIS and HYSPLIT.

Right: An example result from the atmospheric dispersion model



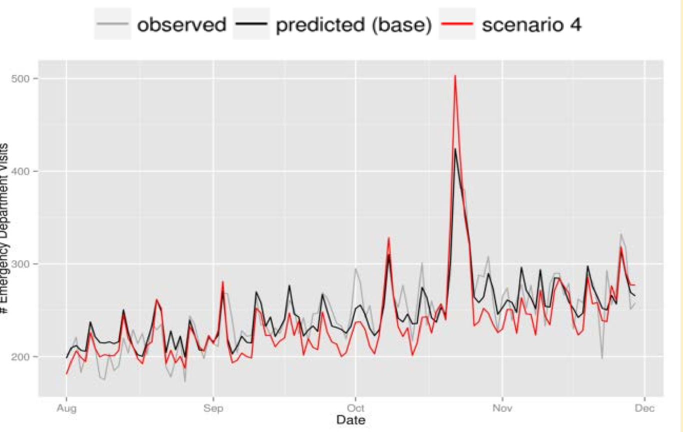
- Peak county-wide average concentrations of fire-produced PM$_{2.5}$ > 400 μg/m^3
- Average peaks in some sub regions exceeded 500 μg/m^3
- Station-measured concentrations in the time period were as high as 475 μg/m^3.

4. Modeling Respiratory Health Outcomes in a Changing Climate

Using the trained GAM model (see part 3) we evaluated respiratory health impacts under a set of "what if" scenarios.

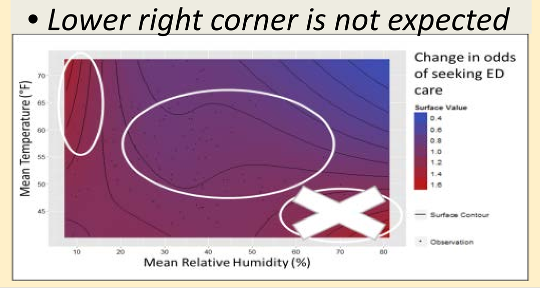
Regional climate model predictions showed wildland fire risk for the next 30 years to be similar to the present; San Diego County should experience approximately two extreme fire seasons each decade to 2040.

Right: Emergency department (ED) visits across the study time period (August 1 to December 1) for San Diego County. red 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.



Below: Bivariate interaction function for temperature and relative humidity

- *Center: the odds of seeking ED care decrease (most typical)*
- *Corners: Odds of seeking care increases*
- *Lower right corner is not expected*

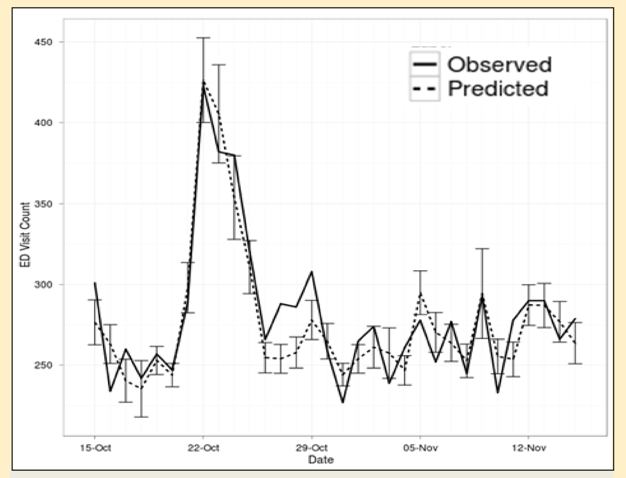


3. Statistical Modeling of Health Outcomes

Connecting Smoke Exposure to Syndromic Surveillance Respiratory Health Data

The smoke concentration maps for San Diego (see part 2) were used to determine smoke exposure and the impact of wildland fires on respiratory health.

$$\mathrm{logit}(p_{ij}) \equiv \log\left(\frac{p_{ij}}{1-p_{ij}}\right) = \beta_0 + \sum_{k=1}^{n} \beta_k x_{ij} + \sum_{m=1}^{n} f_m(x_{ij})$$



Above: Comparison of emergency department (ED) visits observed versus predicted by the statistical model for the time period of fires.

$Wildland\ fire\ PM_{10}$
I_{Monday}
$I_{Tuesday}$
$*I_{SRA3}$
$*I_{SRA6}$
$*Age < 24$
$*Income > 50k$

$s(Anthropogenic_{PM2.5})$
$te(Temp_{min}, RH_{mean})$

Tested but excluded:
- Other Weekday Offsets
- Other Weather Metrics
- *Other SRA offsets
- *Mean Elevation
- *Housing Density
- *Population Density

Odds Effects of Significant Terms:

	San Diego County Model		Subregional Area Model	
Term	Observed Data Range	Estimated Odds Effect Range[1]	Observed Data Range	Estimated Odds Effect Range[1]
Adj. r-Squared	**0.75**		**0.617**	
Percent Deviance Explained	**76%**		**75%**	
Intercept	-9.45	7.9e-5	-7.87	3.8e-4
Wildland fire PM$_{<10}$	0 - 412.31	1 - 1.43	0 - 623.47	1 - 1.72
I_{Monday}	(0, 1)	(1, 1.17)	(0, 1)	(1, 1.17)
$I_{Tuesday}$	(0, 1)	(1, 1.07)	(0, 1)	(1, 1.07)
I_{SRA3}	NA	NA	(0, 1)	(1, 0.52)
I_{SRA6}	NA	NA	(0, 1)	(1, 1.19)
Income >50k	NA	NA	0.31 - 0.55	0.25 - 0.08
Age <24	NA	NA	0.32 - 0.41	1.77 - 2.06

[1] GAM with binomial distribution and logit link

- All terms are significant at the 1% level ($p < 0.01$).
- Maximum estimated effect on the odds of seeking ED care from *wildland fire PM$_{<10}$* is **43%** change for San Diego County model and **72%** change for the Subregional model (linear effect).

NEXT STEPS: Relating Modeled Smoke Concentrations to Health Outcomes in Medi-Cal Populations

The exposure maps are now being applied to a different and richer dataset of Medi-Cal (California Medicaid) patients:

- to characterize the burden of large wildfire events on public health;
- for a population with concentrated vulnerability factors, including low-income, children, pregnant women, seniors, adults with disabilities, and persons with chronic diseases;
- assessing respiratory, cardiovascular, and other health outcomes in vulnerable populations;
- impacts to the public health care system in outpatient visits, emergency and urgent care visits, and hospitalizations.

To assure findings can inform public health practice:

- exposure is treated as a categorical variable, based on Air Quality Index thresholds developed by USEPA;
- 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).

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.

Presented at the 14th Annual CMAS Conference, October 5-7, U North Carolina-Chapel Hill

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