Air Quality and Health Burden of the 2017 Northern California Wildfires

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Introduction

The **October 2017 Northern California wildfires** were a series of fires that started burning in early October and spread across northern California. These fires killed 44 people and caused at least $9.4 billion in insured damages. The fires ignited during the late evening of October 8, when high northerly winds prevailed throughout much of northern California and gusts of up to 70 miles per hour were recorded. By October 14, the fires had burned more than 200,000 acres, and air quality impacts were widespread. In Napa, air quality reached the "hazardous" level by October 13, and unhealthy air quality indices were reported in many downwind Bay Area cities. Figure 1 is a NASA satellite image from October 9 showing the area affected by smoke plumes on that day.

This poster describes air quality modeling performed as an initial assessment of the effects of wildfire smoke on air quality and human health during the October 2017 Northern California wildfires. Using a modeling system that features FINN, WRF, SMOKE and CMAQ, we tried to reproduce pollutant concentrations observed during this incident and estimate the air quality impacts from wildfire emissions. Next steps will include refining wildfire emissions estimates and assessing human health impacts from the elevated pollutant concentrations.

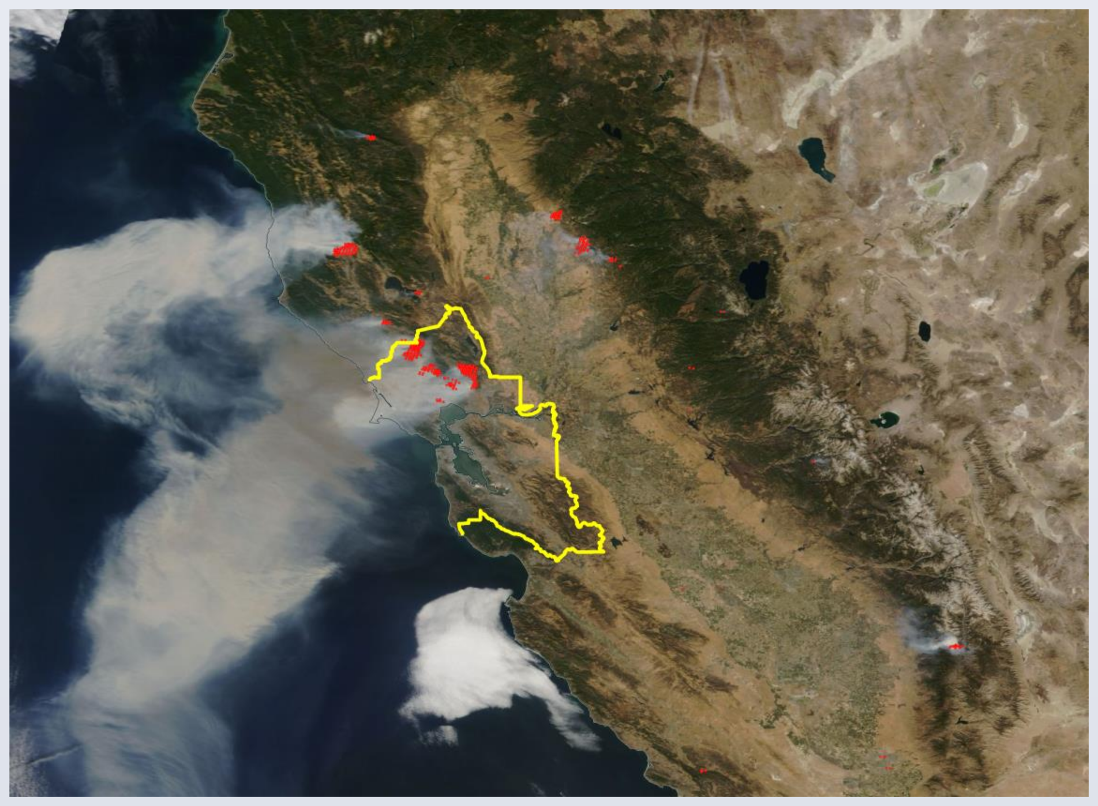

Figure1. NASA satellite image from October 9, 2017 (BAAQMD jurisdiction outlined in yellow).

Description of the Modeling System

Three nested WRF domains were used: 36-km (91x95 grid cells); 12-km (157x151 grid cells); and 4-km (190x190 grid cells). Outputs from the NCEP North America Mesoscale (NAM) 12-km modeling system were used as the first guess. WRF Version 3.8 was run with the following key options:

- Morrison (two moments) microphysics
- RRTM short- and long-wave radiation scheme
- Modified Kain-Fritsch scheme with trigger function based on PDFs
- Pleim-Xiu Land Surface Model and ACM2 PBL scheme
- Surface-layer Revised MM5 Monin-Obukhov scheme
- Analysis and Observation FDDA were applied

Anthropogenic, biogenic, and wildfire emissions were processed using the Sparse Matrix Operator Kernel Emissions (SMOKE) tool. Anthropogenic emissions included in the base case modeling were obtained from in-house data and the California Air Resources Board. Biogenic emissions were developed using SMOKE's implementation of the Biogenic Emission Inventory System (BEIS) v.3.61. Details about fire emissions processing are provided in the next section.

CMAQ version 5.2 with offline plume rise and biogenic emissions was used. The CMAQ model was configured as followings:

- SAPRC07 Chemical Mechanism
- AERO6 Aerosol Module
- CCTM Science Modules: Driver WRF; Horizontal advection YAMO; vertical advection WRF; horizontal diffusion MULTISCALE; vertical diffusion ACM2

Fire Emission Processing

Fire emissions were derived from the Fire Inventory from NCAR (FINN), which is a daily fire emissions product for atmospheric chemistry models. FINN emissions estimates are based on satellite observations of active fires, land cover databases, and emission factors. Figure 2 gives a summary of FINN-based estimates of total acres burned (left) and daily $PM_{2.5}$ emissions (right) from the fires that occurred during this episode.

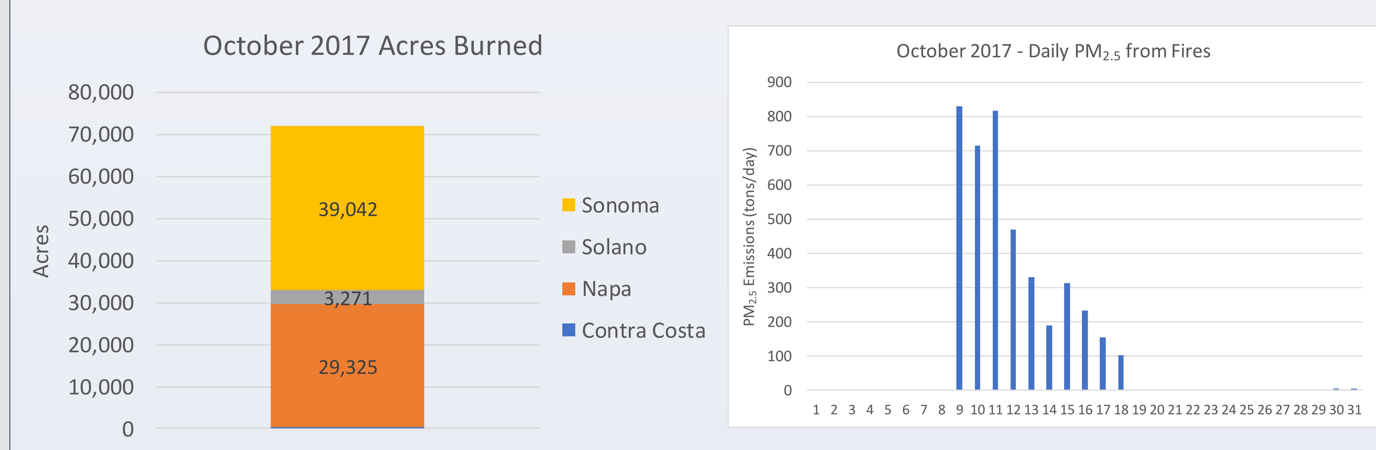

Figure 2. Fire emissions summary from FINN

An EPA methodology was used to add a heat flux parameter for estimating plume rise, and the FINN estimates were then processed through SMOKE to generate CMAQ-ready fire emissions inputs. Initial plume rise estimates calculated by SMOKE from fire size and heat flux placed significant emissions at 500 to 800 m. However, this plume rise was likely overestimated given the extremely high winds and volatile atmospheric conditions. In addition, the FINN-based $PM_{2.5}$ emissions were likely underestimated since structure fires and car fires were not accounted for. Therefore, sensitivity tests were designed to evaluate alternative plume rise and emissions estimates for wildfires. Four CMAQ runs were conducted:

- A base case run with anthropogenic and biogenic emissions only (no fire emissions)
- A run that included default fire emissions allocated to all 28 model layers, and with significant emissions at 500 to 800 m (FIRE01)
- A run that limited fire emissions to the first 4 model layers, or a maximum height of about 115 m (FIRE02)
- A run with fire emissions doubled to account for structure/car fires and plume rise limited to the first 4 model layers (FIRE03)

Simulation Results

The CMAQ simulation period was from October 3 - 20, 2017, which allows for sufficient spin-up time before the fires started. The base run without fire emissions predicted clean conditions, as expected. The FIRE01 run underestimated $PM_{2.5}$ significantly over the San Francisco Bay Area, especially at the Napa monitor, where 24-hr average $PM_{2.5}$ was underestimated by as much as 160 μg/m³. The FIRE02 run with all fire emissions allocated to the first 4 model layers improved the model results, but $PM_{2.5}$ was still significantly underestimated. $PM_{2.5}$ predictions from FIRE03 run, which doubled fire emissions and limited plume rise to the first 4 model layers, displayed good agreement with observations at four Bay Area monitors: Napa, Vallejo, Sebastopol and West Oakland (Figure 3).

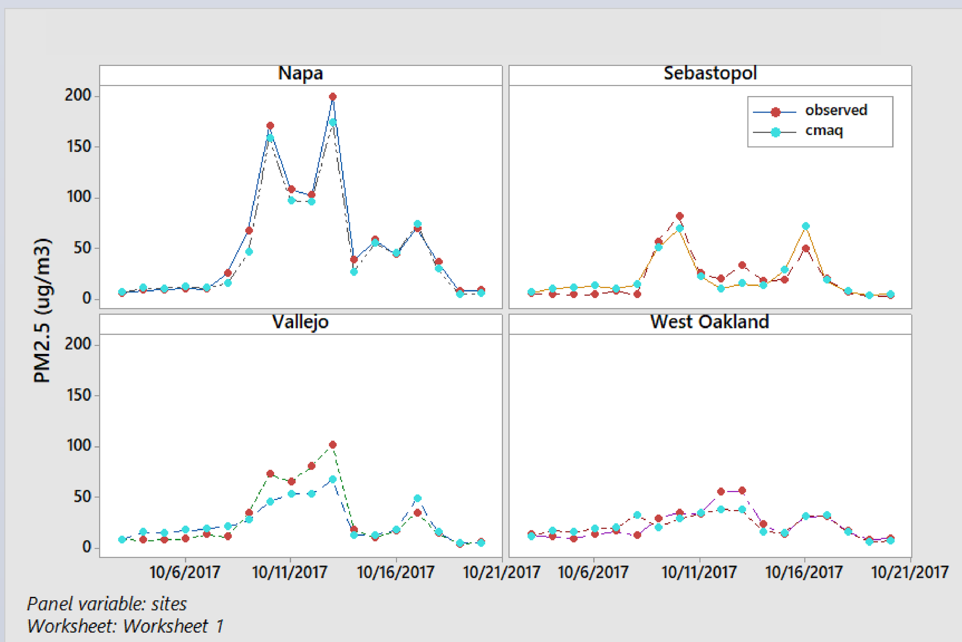

Figure 3. CMAQ and observed 24-hour $PM_{2.5}$ at representative sites.

Simulation Results (continued)

Though the CMAQ FIRE03 run generally captured 24-hr average $PM_{2.5}$ concentrations at representative monitors during the fire period, issues remain with the modeling results that continue to be investigated.

For example, on October 13, the fire smoke spread from the northeast and "fumigated" the entire Bay Area (Figure 4, right). A plot of 24-hour $PM_{2.5}$ concentrations from run FIRE03 (Figure 4, left) shows that CMAQ produced smoke coverage that was similar to the satellite image. The "hot spots" with high $PM_{2.5}$ concentrations correlated to key fire locations. However, the simulation results also showed that $PM_{2.5}$ was underestimated at most Bay Area monitors. In addition, the clean conditions with low $PM_{2.5}$ in the Point Reyes Peninsular area indicated that a lack of easterly flow could be an issue in the simulation.

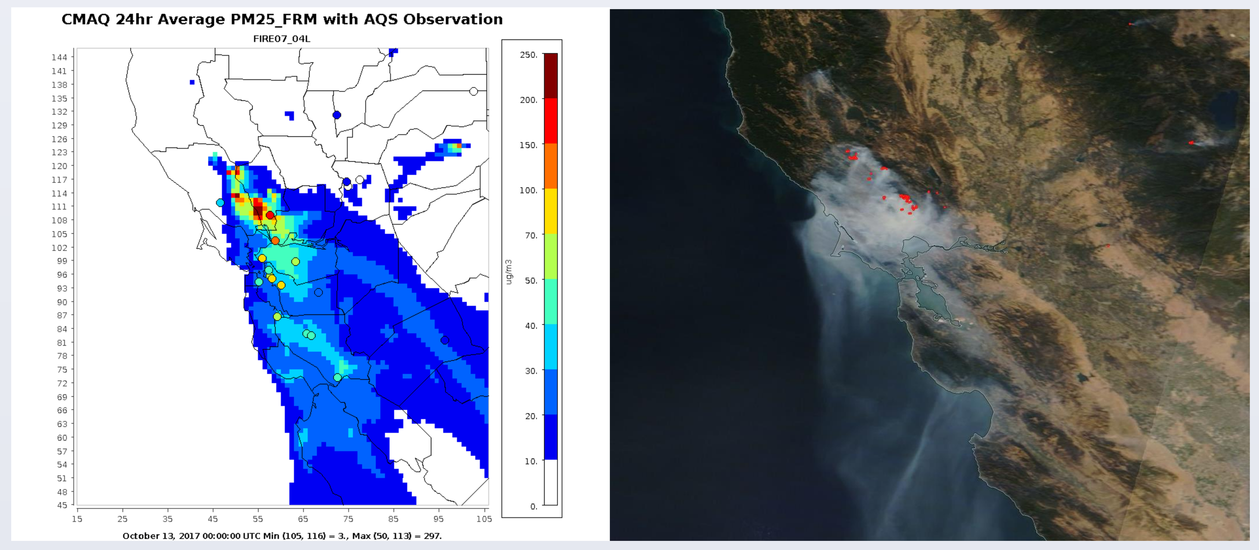

Figure 4. CMAQ 24-hour $PM_{2.5}$ with observations (circles) (left), compared to NASA Satellite image from October 13, 2017 (right).

Challenges and Future Work

The CMAQ modeling system delivered an impressive result at near-fire locations like Napa and Sebastopol and, on some days, generally reproduced smoke coverage defined by satellite images. However, $PM_{2.5}$ concentrations were underestimated at most Bay Area monitors, especially monitors in the central and western part of the Bay Area (see Figure 4). This underestimation is highlighted more clearly in Figure 5, which compares the average of 24-hour $PM_{2.5}$ concentrations across 16 Bay Area monitors to corresponding averages from CMAQ for grid cells that contain the monitors. In addition, the timing of high and low $PM_{2.5}$ concentrations from CMAQ is also slightly off compared to the observations. To improve model performance, we plan to:

- Refine the fire emission inventory with more accurate fire locations, diurnal profiles of fire emissions, and smoke plume rise using data and techniques from MODIS, VIIRS, GOES-16-Fire Detections, Fire Radiative Power, etc.
- Investigate and improve meteorological model performance

In addition, we plan to conduct a health impact analysis to assess the increased risk of morbidity and premature mortality from respiratory and cardiovascular diseases due to the wildfire-induced pollutant exposure.

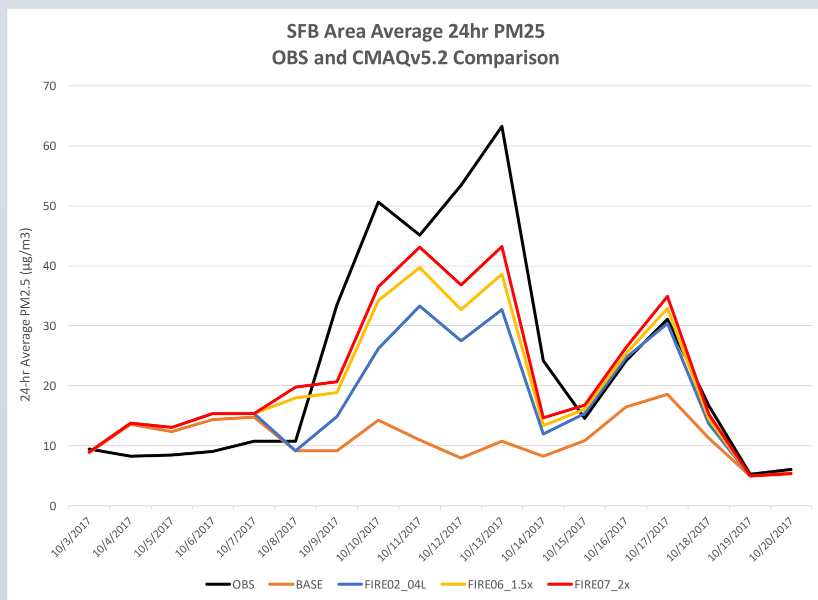

Figure 5. Average CMAQ and observed 24-hour $PM_{2.5}$ over the San Francisco Bay Area.

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