INTRODUCTION

Beginning October 8-9, 2017, a series of wildfires in N. California resulted in:
- 8,400 buildings destroyed, 100,000 displaced, 185 hospitalized, 45 dead
- PM$_{2.5}$ concentrations reached highest levels recorded to date in the region
- ~7.2 million people living in the Bay Area exposed to unhealthy air

Exposure to wildfire smoke increases respiratory illness and symptoms and risk of hospital admission for respiratory disease$^4$. Due to this health risk and an increased frequency of wildfires$^2$, it is important to develop accurate methods for estimating the air quality and health impacts of wildfires.

Geostatistical methods exist to combine modeled & observed concentrations to estimate air quality over a region$^2$, but these methods have not been applied to intense natural events like a wildfire. This research has two primary goals:

1. Map PM$_{2.5}$ during the Oct. 2017 wildfires, fusing together observed & modeled PM$_{2.5}$ concentrations.
2. Use the PM$_{2.5}$ map to estimate the acute health impact of the Oct. 2017 wildfires, specifically the attributable respiratory hospital admissions. Future work will extend this approach to more health endpoints and pollutants.

MAPPING METHODS

Four steps were used to fuse observed & modeled PM$_{2.5}$ over CA during the entire fire period:

1. Constant Air Quality Model Performance$^3$-corrected CMAQ (CC-CMAQ) model
2. Simple space/time (s/t) kriging on log-PM$_{2.5}$ observations from FRM/FEM monitors – Flat Mean Trend (MT) removed
3. Simple s/t kriging on log-PM$_{2.5}$ observations from FRM/FEM & temporal monitors – Informed MT removed
4. Fusion of CC-CMAQ model & log-PM$_{2.5}$ observations from FRM/FEM & temporal monitors – Informed MT removed

Each step was evaluated through a leave-one-out cross-validation. The Mean Squared Error (MSE) and R$^2$ values were calculated using the 163 monitoring stations as the validation set.

Constant Air Quality Model Performance$^3$ - CMAQ model

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ACUTE HEALTH IMPACT

Objective

Conduct a health impact analysis of the Oct. 2017 wildfires for multiple acute health endpoints, using respiratory hospital admissions as an example.

Data & Methods

The rate of respiratory hospital admissions attributable to wildfire PM$_{2.5}$, given a log-linear relationship, is:

$$\Delta f = \beta \cdot \left( 1 - e^{-x \cdot Y_{FRM/FEM}} \right)$$

- $x$ (µg/m$^3$) - mean PM$_{2.5}$ concentration at a s/t location, provided by the PM$_{2.5}$ estimates
- $Y_{FRM/FEM}$ (background concentration of PM$_{2.5}$ at a s/t location, the average PM$_{2.5}$ in CA in 2017: 9.9 µg/m$^3$

The average admission rate, 0.65 hospital respiratory admissions per 10,000 people per day$^5$.

A composite MT in space and time is removed from the CMAQ model & log-PM$_{2.5}$ observations from FRM/FEM monitors – in the Central California region PM$_{2.5}$ concentrations increase in CMAQ R$^2$ (0.410 to 0.452), MSE (0.730 to 0.679). Two MTs are used:

1. Step 1 - the CAMP Method, which evaluates and corrects the CMAQ model by:
   - Accounting for the non-linear and non-homoscedastic relationship between CMAQ modeled and observed PM$_{2.5}$ data$^6$
   - Correcting errors in CMAQ model estimations by modeling the mean ($\mu$) and variance ($\sigma$) of the observed value as a function of the given model value across the model domain$^6$

Bayesian Maximum Entropy (BME) Framework

Step 2 - the BME framework uses modern spatiotemporal geostatistics to combine general knowledge with site-specific knowledge to create estimates of PM$_{2.5}$ at unmonitored locations$^6$. A composite MT in space and time is removed from the data to characterize systematic structures and trends over space and time$^6$. Two MTs are used:

1. Flat S/T Composite MT – Assumes that each s/t location has its own unique MT of PM$_{2.5}$ observations across space & time$^6$
2. Informed S/T Composite MT – Assumes that each s/t location has its own unique MT of PM$_{2.5}$ observations across space & time

Step 4 - To fuse the CC-CMAQ model with the log-PM$_{2.5}$ data, the BME framework treats observed data as “hard” and modeled data as “soft”. Unlike hard data, soft data:

- Influences only the site-specific knowledge
- Includes a variance, where modeled PM$_{2.5}$ ($\hat{y}$) with lower variance ($\sigma$) have more influence$^6$

Estimates of PM$_{2.5}$ on Oct. 10, 2017

1. CC-CMAQ Model
   - MSE: 0.331 (log-µg/m$^3$)$^2$
   - R$^2$: 0.452 (log concentration)

2. S/T kriging FRM/FEM Observations, Flat MT
   - MSE: 0.182 (log-µg/m$^3$)$^2$
   - R$^2$: 0.661 (log concentration)

3. S/T kriging FRM/FEM & Temp Obs, Informed MT
   - MSE: 0.139 (log-µg/m$^3$)$^2$
   - R$^2$: 0.740 (log concentration)

4. Fused CC-CMAQ + FRM/FEM & Temp Obs, Informed MT
   - MSE: 0.144 (log-µg/m$^3$)$^2$
   - R$^2$: 0.730 (log concentration)

REFERENCES

Acknowledgements

Special thanks to NASA HAQAST Tiger Team for funding, Sean O’Neill & Minghui Diao for leading the Tiger Team, & BAAQMD for the model runs

RESULTS: AIR QUALITY MAPS

Findings

- CC-CMAQ leverages benefits of CMAQ’s knowledge of atmospheric physics and chemistry while correcting for errors in modeled PM$_{2.5}$
- Reduction in CMAQ MSE (0.703 to 0.331 (log-µg/m$^3$)$^2$)
- Increase in CMAQ R$^2$ (0.410 to 0.452 (log-µg/m$^3$)$^2$)
- Use of temporary station data, while not FRM/FEM, improves accuracy of PM$_{2.5}$ estimates by increasing the coverage of surface observations
- Removing an informed MT improves accuracy of the PM$_{2.5}$ estimate, using knowledge that each location had a unique PM$_{2.5}$ trend during the fires

Limitations & Future Work

- Validation set for cross-validation MSE and R$^2$ is limited to observed data
- Investigation inclusion of satellite data to further improve PM$_{2.5}$ estimate
- Create maps for additional wildfire smoke pollutants (NO$_x$, NO$_2$) for the entire fire period

Fig. 3. Estimates of PM$_{2.5}$ on Oct. 10, 2017 from FRM/FEM and CC-CMAQ.