Application of Low-cost PM Sensors to Prescribed Fire, Air Quality and Health Management

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HAQAST

NASA Health and Air Quality Applied Sciences Team (HAQAST)

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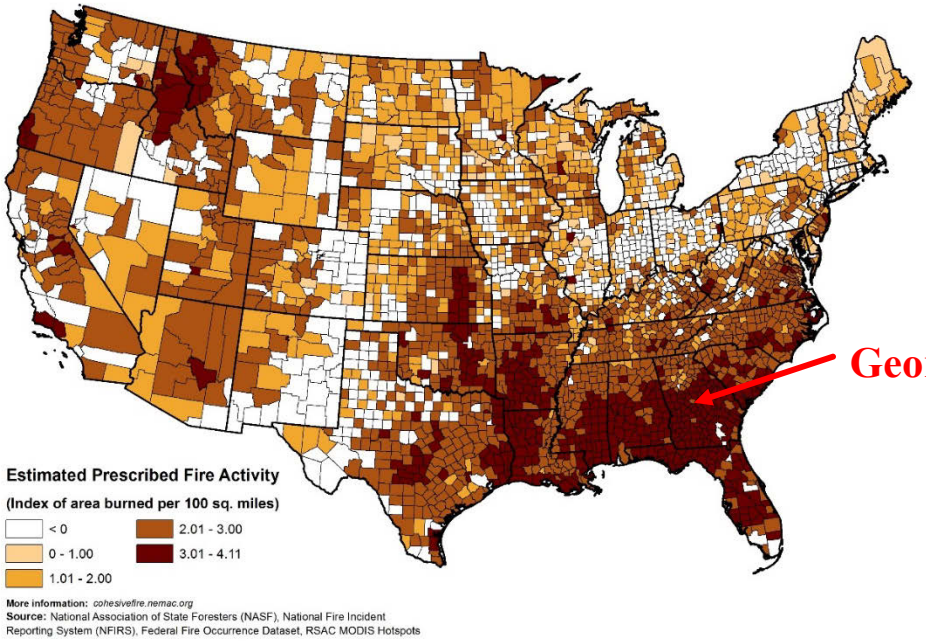
Collaborators & Stakeholders

- Susan O'Neill (USFS)
- Rish Vaidyanathan (CDC)
- Scott Goodrick (USFS)
- Fernando Garcia (NCSU)
- Yufei Zou (UW)
- Dan Chan (GaFC) – Prescribed Fire Management
- Jim Boylan (GaEPD) – Air Quality Management
- Chris DuClos (FlDH) – Health Management
- Cassandra Johnson (USFS) – Environmental Justice
- Leticia Nogueira (ACS) – Lung Cancer Survival
- Benjamin Jones (UNM) – Health Economics
- Eladio Knipping (EPRI) – Wildfire Liability

Prescribed fire is the largest source of $PM_{2.5}$ emissions in the southeastern U.S.

Prescribed fire improves native vegetation and wildlife habitat, controls insects and disease, and reduces wildfire risk.



2014 National Emissions Inventory (NEI) attributes 24% of all $PM_{2.5}$ emissions in the southeastern U.S. to prescribed fire.

HiRes-X: Operational forecasting of prescribed fire impacts for health, air quality and ecosystem mgmt.

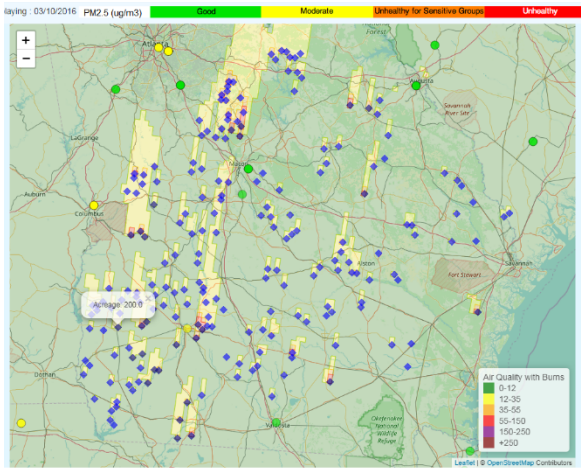
- Daily forecasts of prescribed-fire related air quality impacts to state agencies for prescribed burn and air quality management

https://forecast.ce.gatech.edu

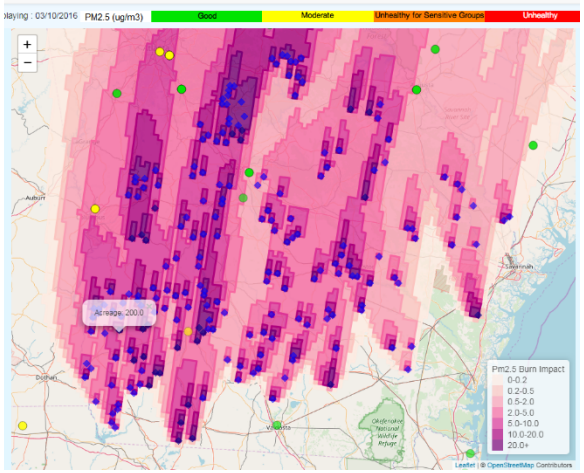
- Prescribed-fire related exposures to CDC and its partners for public health tracking and source-specific epidemiological assessments

https://sipc.ce.gatech.edu/SIPFIS/map/

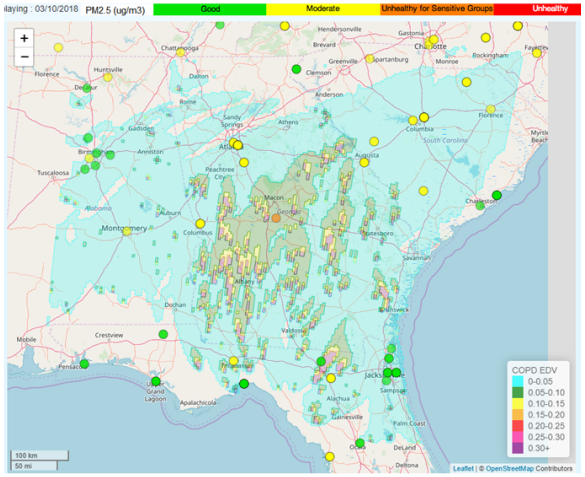
$PM_{2.5}$ Forecast



Burn Impact Forecast



Health Impact Forecast



- Odman, M. T., et al. (2018) *Atmosphere*, doi:10.3390/atmos9060220
- Hu, Y., et al. (2019) *IJERPH*, doi:10.3390/ijerph16111981

HiRes-X estimates health impacts based on smoke exposure epidemiological studies

Health burden:

$$\Delta H = H_0\left(1 - e^{-\beta \Delta c}\right)$$

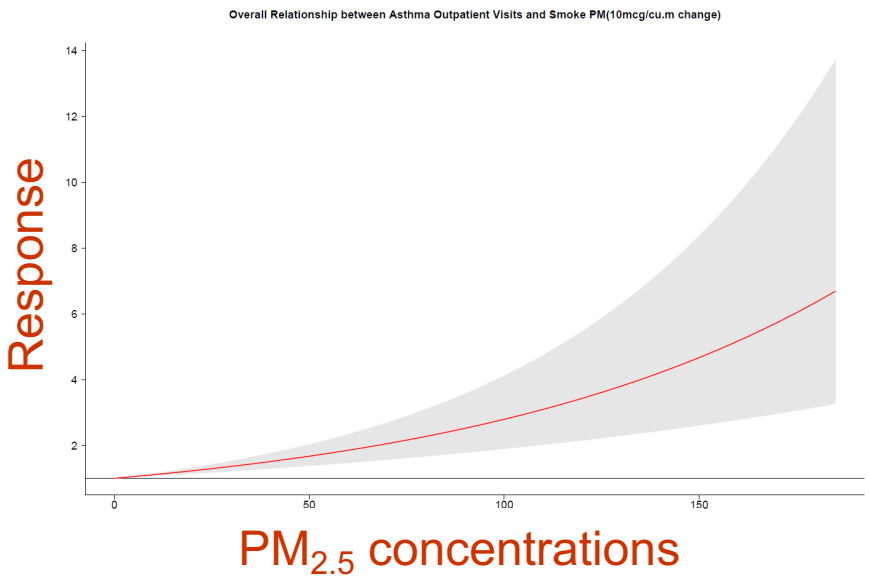
where

H_0 is baseline health rate

β is effect estimate coefficient (obtained from C-R function)

Δc is fire impact on concentration

C-R function



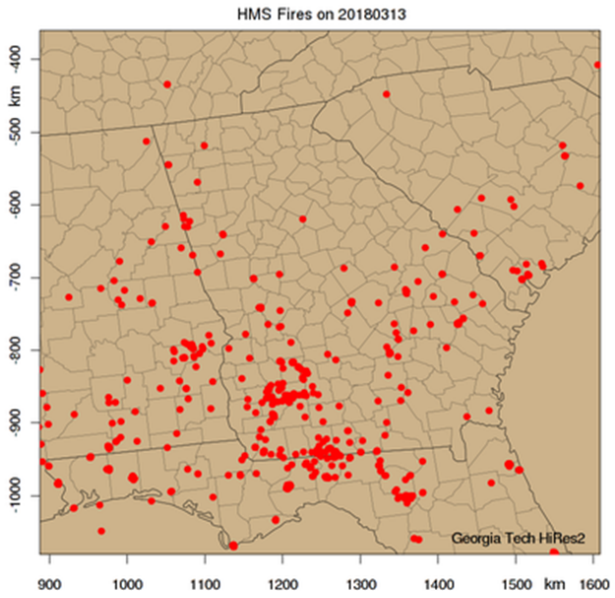
β = 0.008 for asthma ER visits

β = 0.006 for asthma hospitalizations

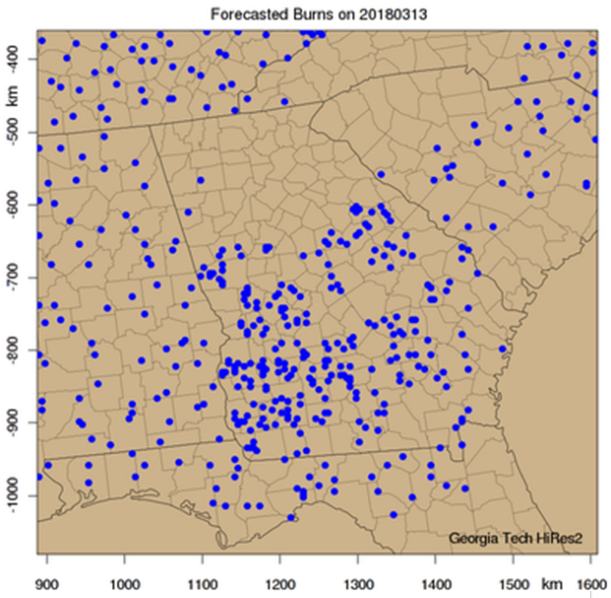
Prescribed fire activity forecast is based on weather forecast and historic fire patterns

- 2010-2016 burn permit data in Georgia (GA)
- 2015-2016 Biomass Burning Emissions Product data elsewhere
- County-specific Classification and Regression Trees in GA
- Meteorological burn/no-burn criteria in other states

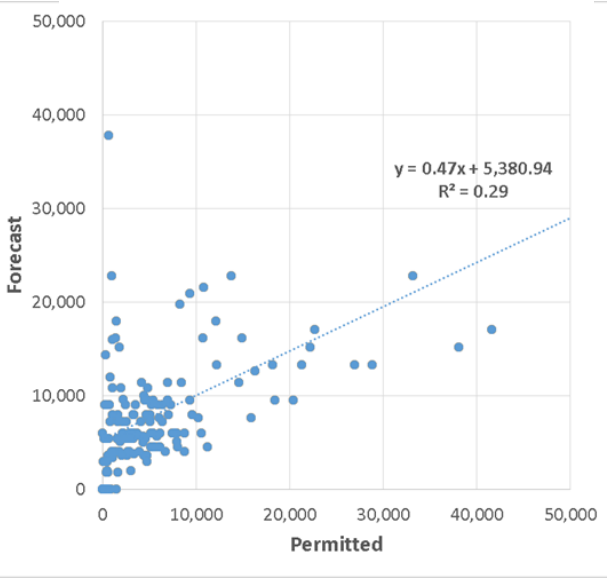
HMS Fire Detections



HiRes-X Burn Forecast

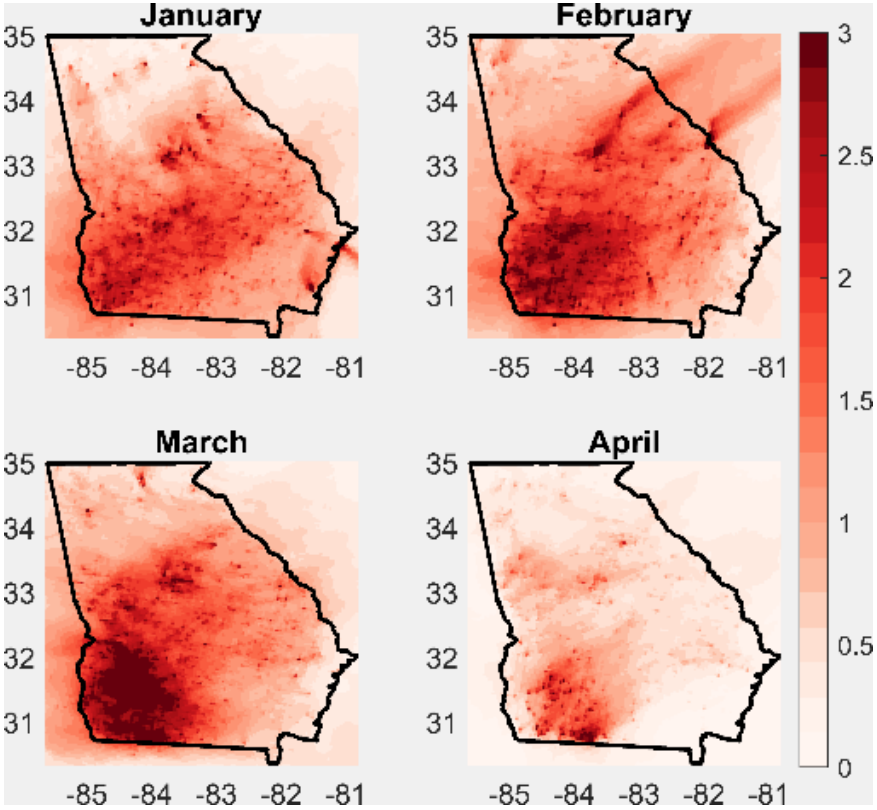


Forecast vs. Permitted Burn Areas

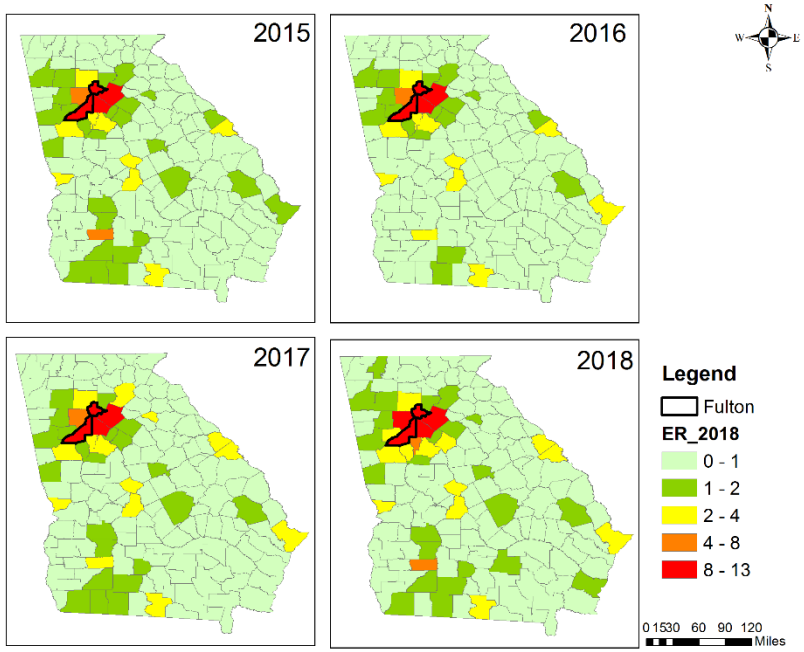


HiRes-X can also be used for retrospective analysis with actual fire data

- Huang, R., et al. (2019) *IJERPH*, doi:10.3390/ijerph16132312

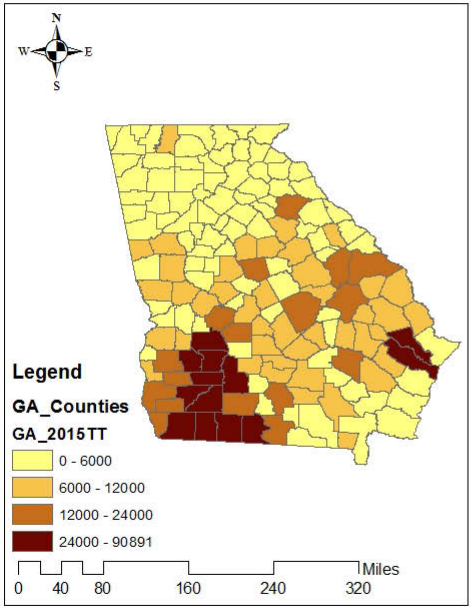


2015 Rx fire impact on $PM_{2.5}$ (µg/m³)

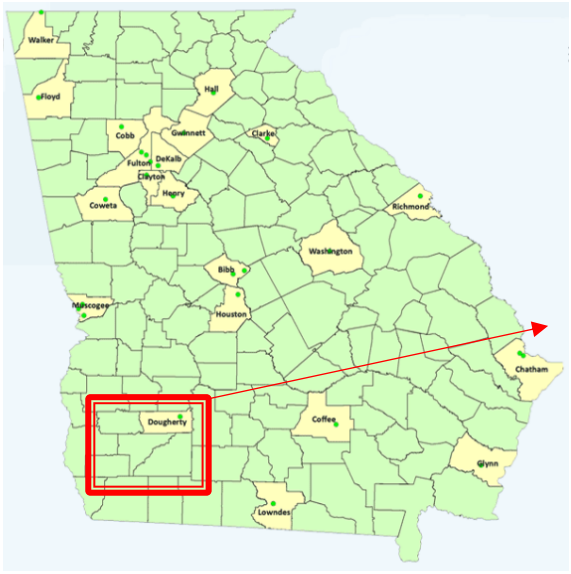


Estimated asthma-related ER visits due to Rx fire by county in Georgia from 2015 to 2018 for the first four months of the year.

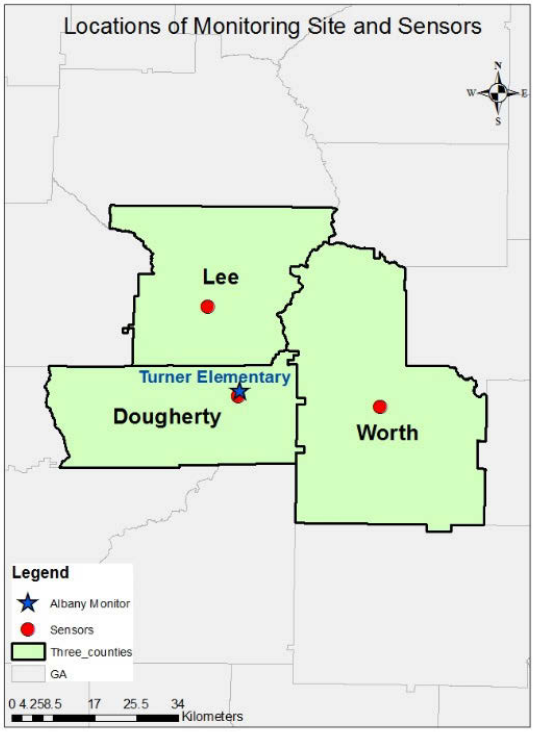
Low-cost sensors deployed at smoke impacted areas of Southwest GA



Burned area
(2015 permit data)

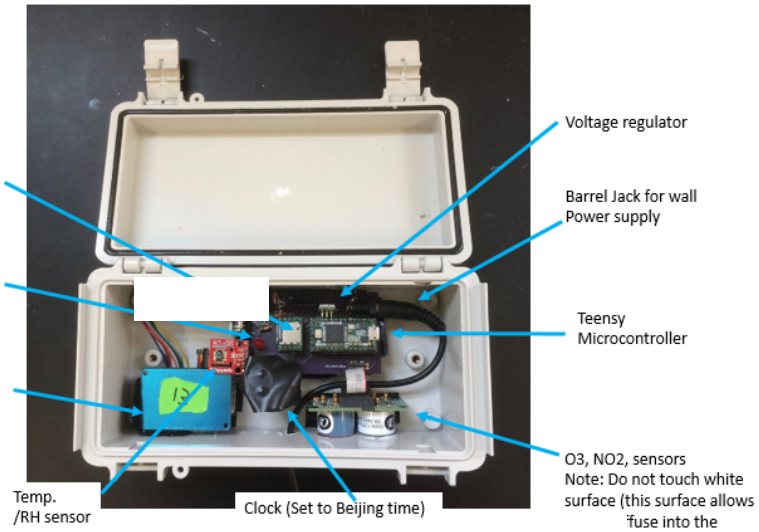


$PM_{2.5}$ Monitoring Sites in GA
Counties shaded in yellow have $PM_{2.5}$ monitoring sites

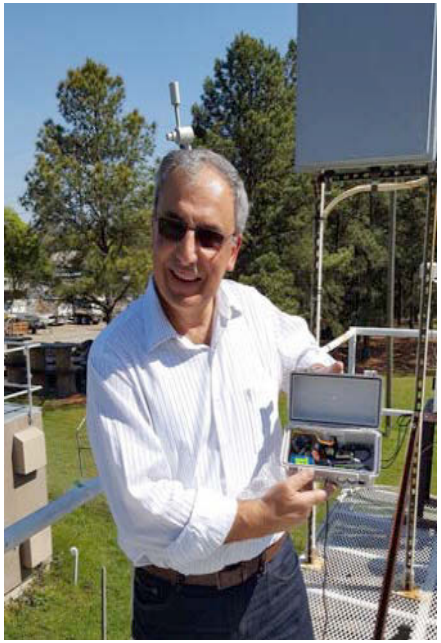


GA EPD site at Turner Elementary, Albany, GA (13095007)
BAM

The low-cost PM sensor is Plantower PMS 3003



Plantower PMS 3003



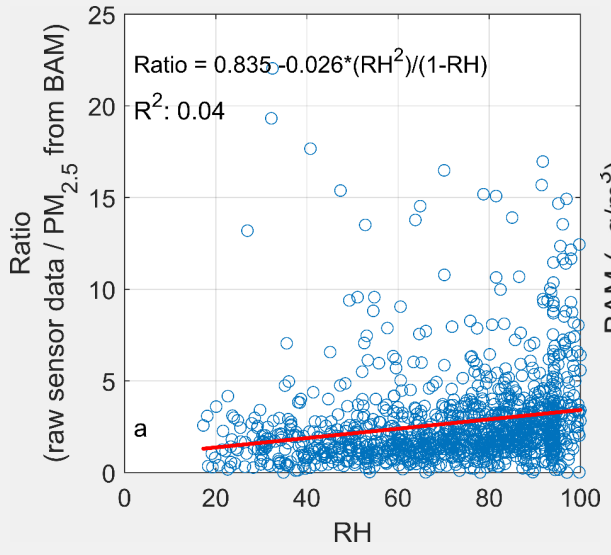
- PM sensor costs $17. Box total cost is ~$300.
- The Plantower PMS 3003 sensor uses an optical method to measure PM_1, $PM_{2.5}$ and PM_{10}.
- It converts particle number concentration, based on laser scattering principle.
- The sensor performance was better when ambient $PM_{2.5}$ was higher

(Zheng, T., et al. (2018) *Atmos. Meas. Tech.*, DOI: 10.5194/amt-11-4823-2018)

Low-cost PM Sensor Calibration: Remote vs. Local

Remote

RH correction calibration



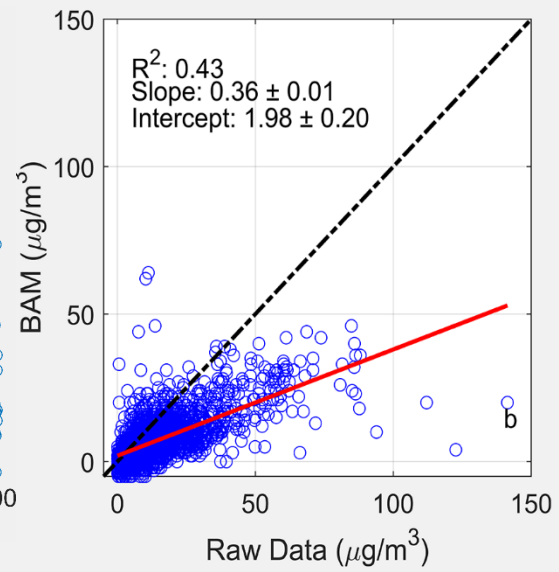
RH correction factor

$$= \frac{\text{Raw Sensor } PM_{2.5}}{\text{Reference } PM_{2.5}}$$

$$= a + b \times \frac{RH^2}{1 - RH}$$

Local

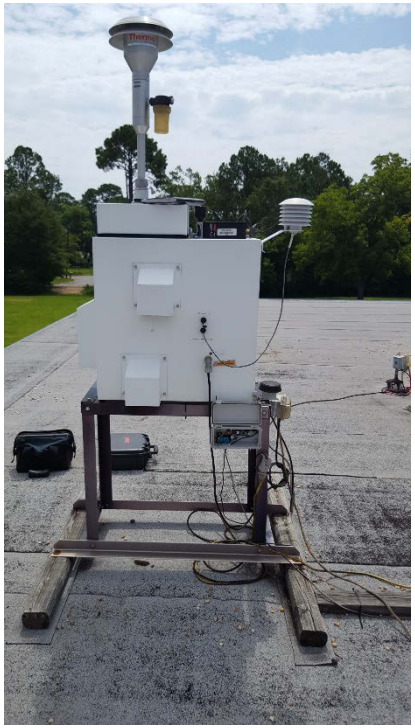
Linear regression calibration



Calibrated data

$$= 0.36\ \text{RawData} + 1.98$$

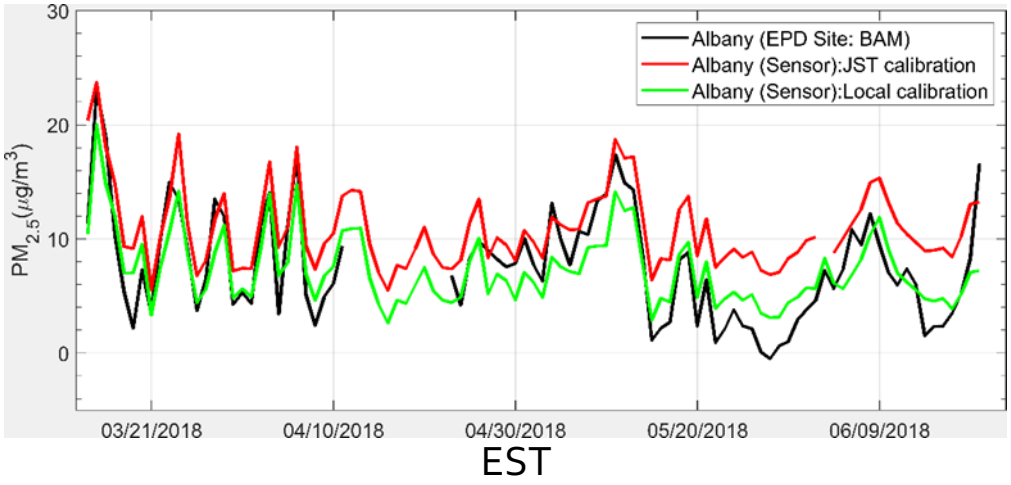
Sensor vs. BAM $PM_{2.5}$ at EPD's Albany site (hourly, March 14–June 20, 2018)



BAM: Smart heater controls RH to the setpoint of 35%

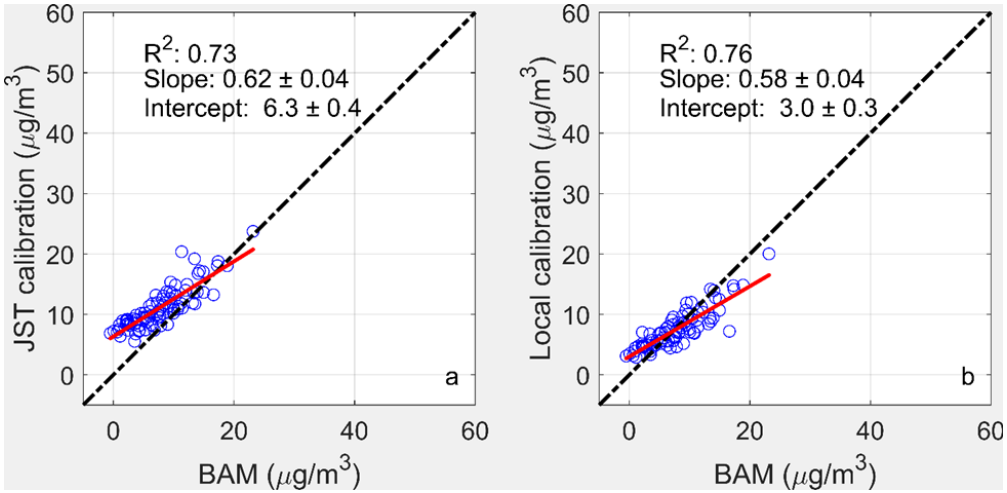
RH data: Southwest Georgia Regional Airport (Distance: 13 km)

Local calibration performed better than remote calibration with RH correction



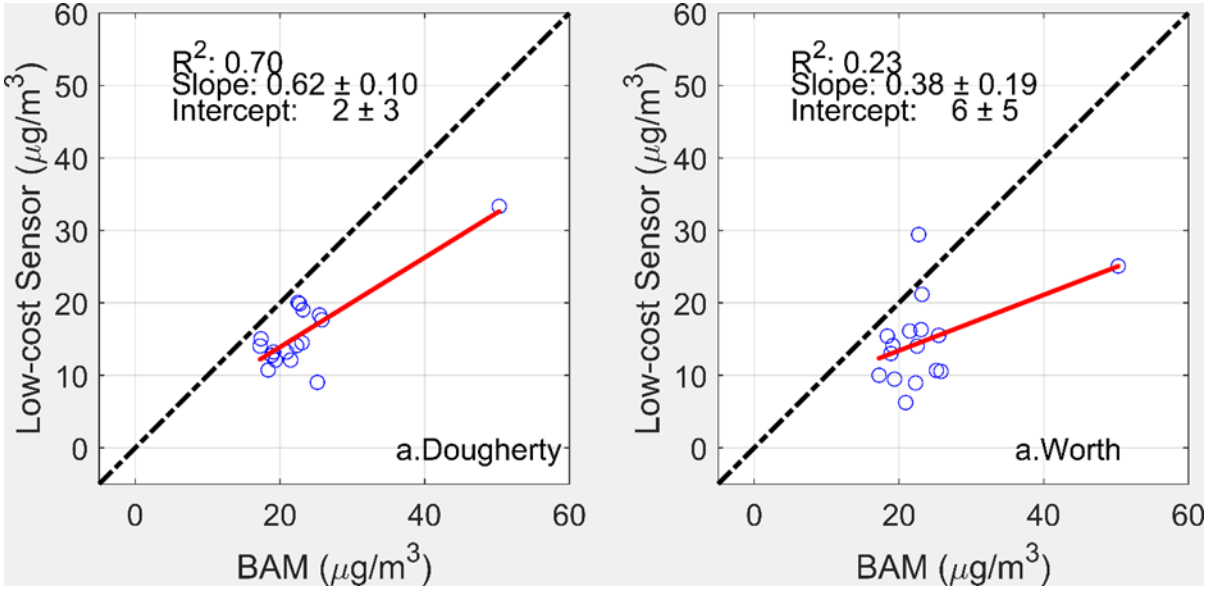
Daily $PM_{2.5}$ concentrations from low-cost sensor using different calibration methods and BAM at GA EPD site in Albany (March 14–June 20, 2018)

Remote calibration **Local calibration**

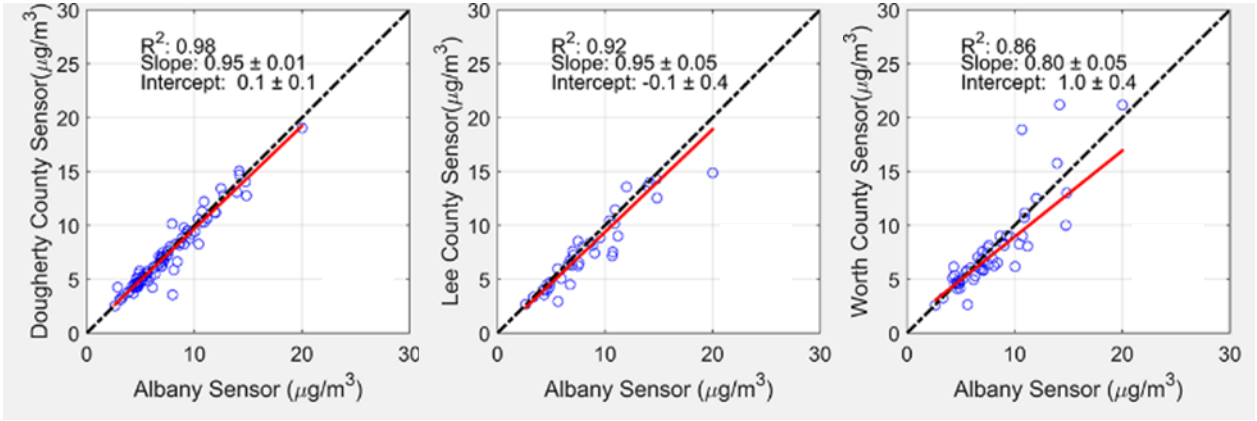


Comparison of the daily $PM_{2.5}$ concentrations from collocated low-cost sensor with those from BAM at GA EPD site in Albany (March 14–June 20, 2018)

Sensor data show spatial variation in Prescribed Fire impacts on $PM_{2.5}$

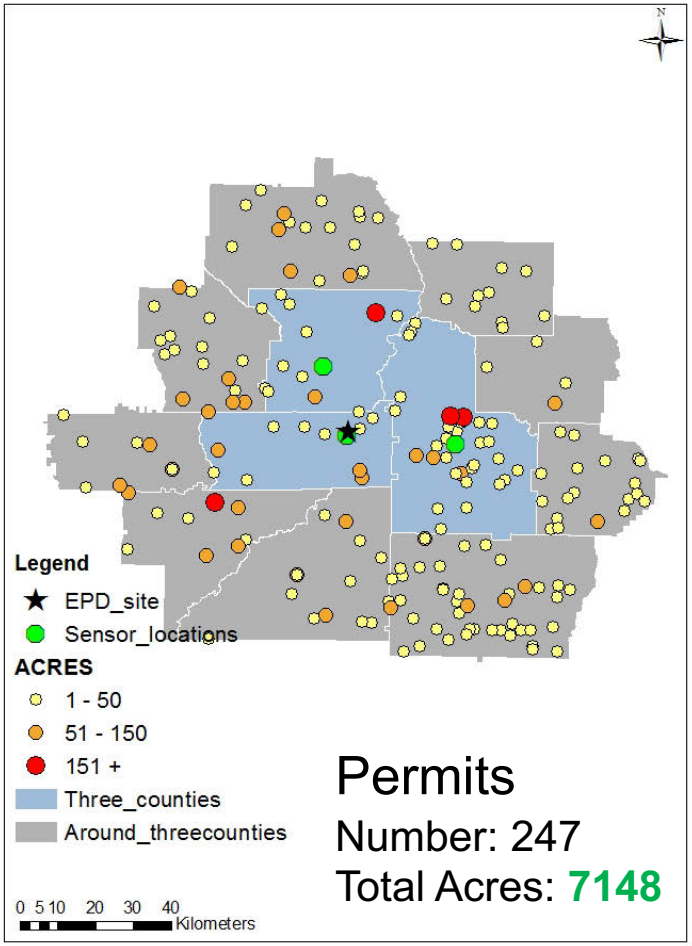


Comparison of daily $PM_{2.5}$ concentrations between low-cost sensors and BAM with a cut-off at 95th % of BAM observation



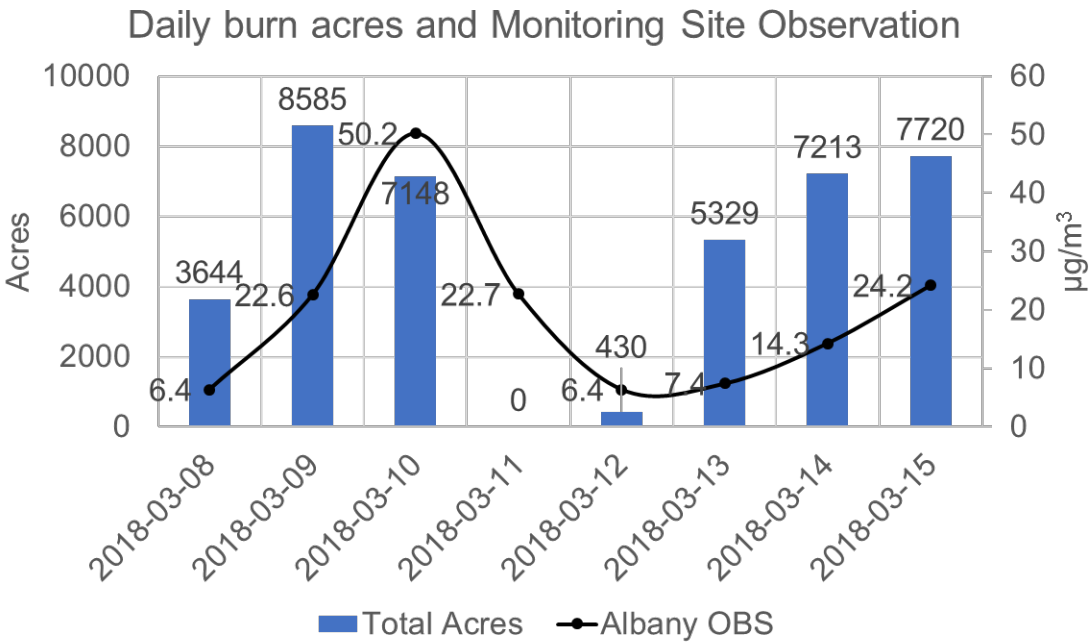
Orthogonal regression of daily $PM_{2.5}$ concentrations between low-cost sensors (vs. sensor at Albany EPD site)

A $PM_{2.5}$ exceedance was detected by Albany EPD monitor on March 10, 2018



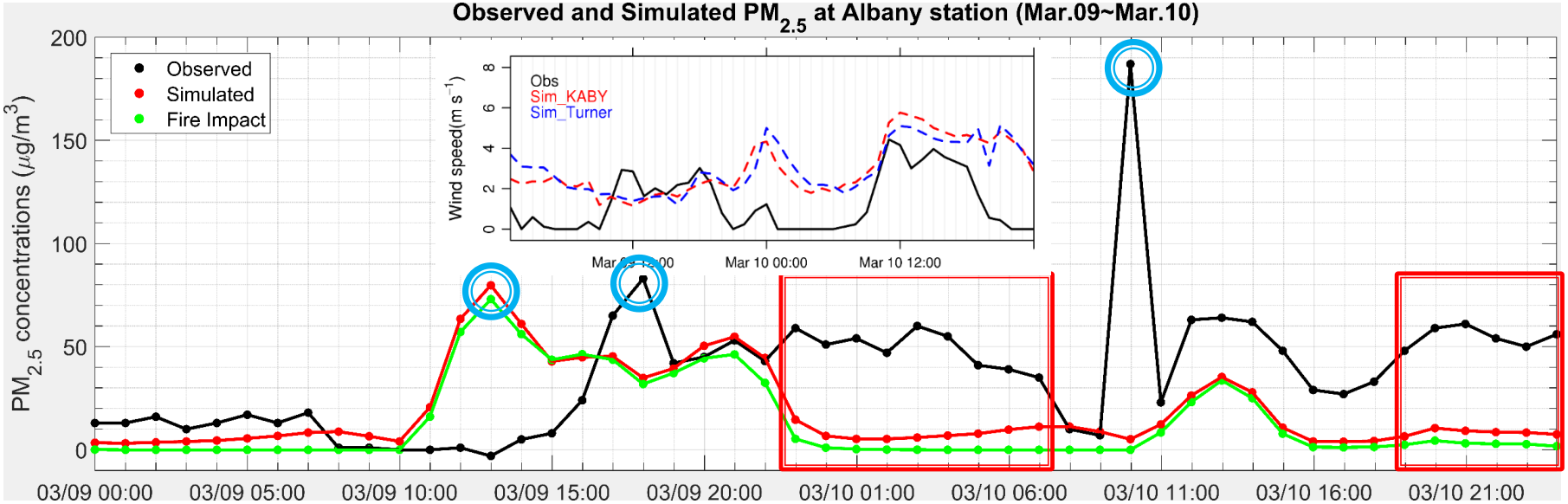
Southerly winds

Albany EPD Daily $PM_{2.5}$: 50.2 µg/m³



- Simulation period: March 8–15, 2018
- Models: WRFv3.6, CMAQv 5.0.2, DDM
- Fire emissions: BlueSky, all fires start at 11 am (EST), and last 3 hours

Evaluation of simulated $PM_{2.5}$ and fire impact at Albany EPD site: March 09–10



March 9th:

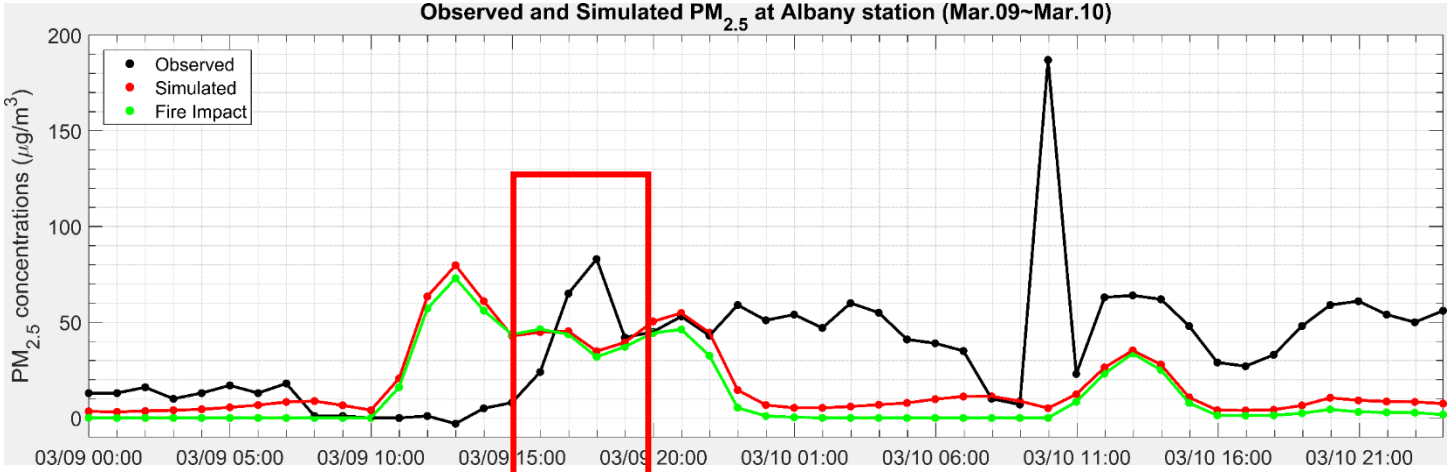
- Peak concentration level captured, but timing missed in the simulation. This may be due to fire start/end times.

March 10th:

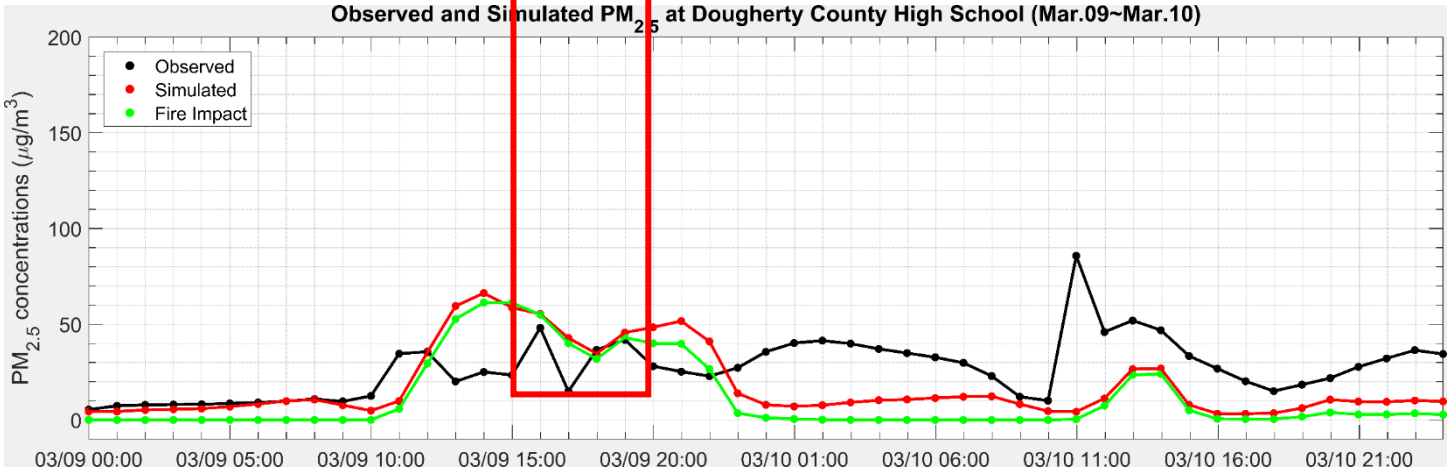
- Nighttime concentrations underestimated in the simulation. This is due to a systematic bias in WRF that overestimates nighttime wind speed.
- Peak missed in the simulation.

4-km grid-resolution simulations cannot capture the spatial variation of fire impact

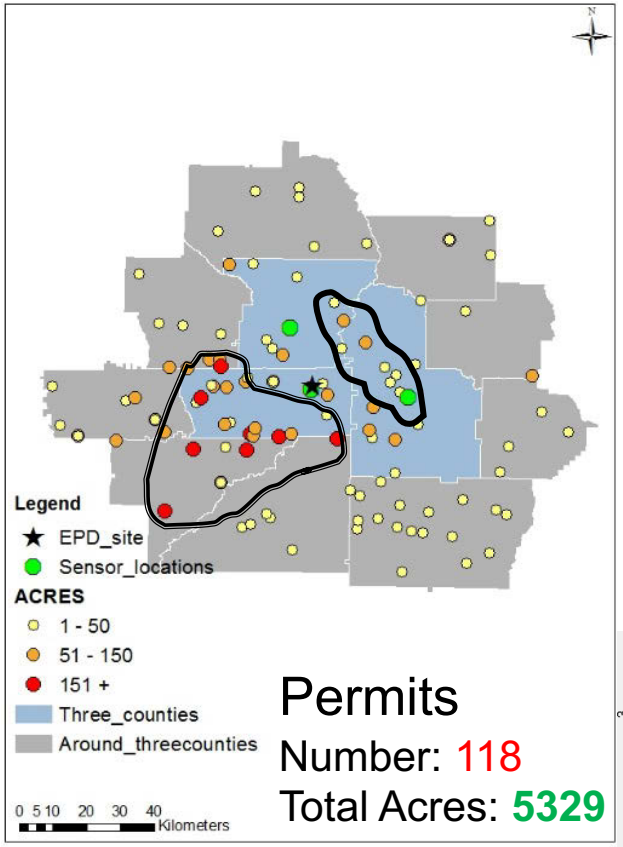
Albany EPD site



Dougherty County HS



March 13

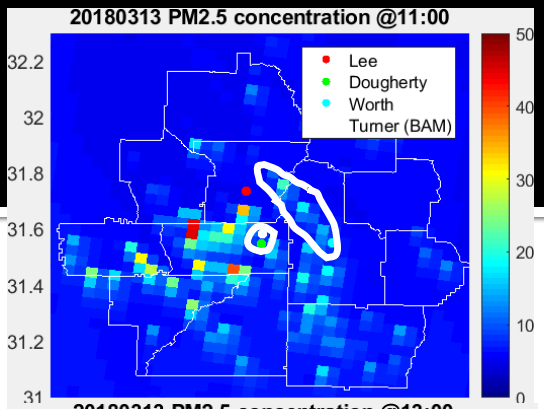


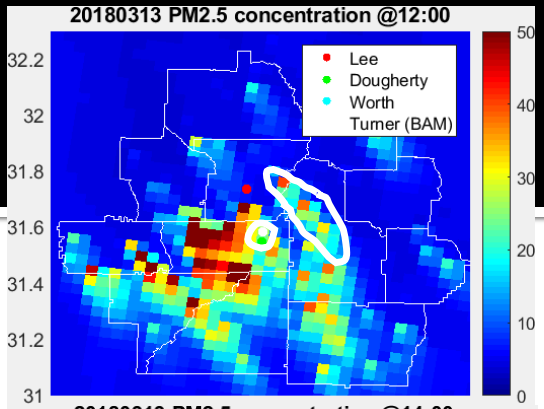
Permits

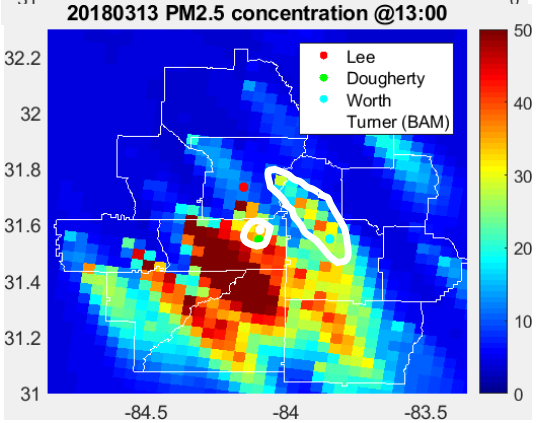
Number: 118

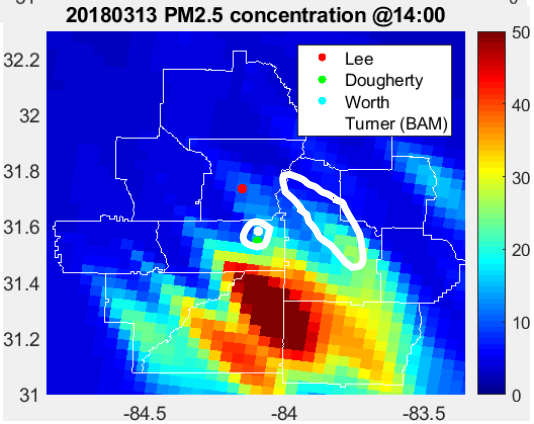
Total Acres: 5329

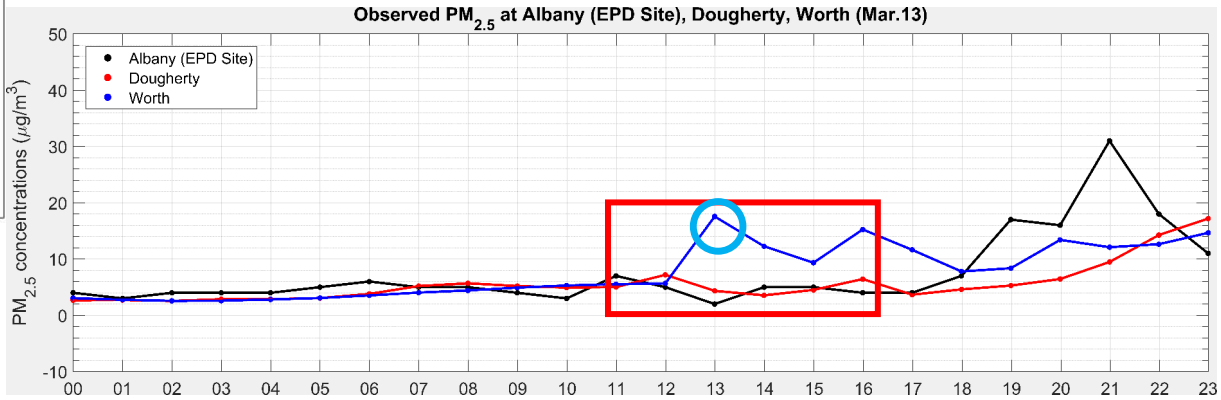
Northwesterly winds



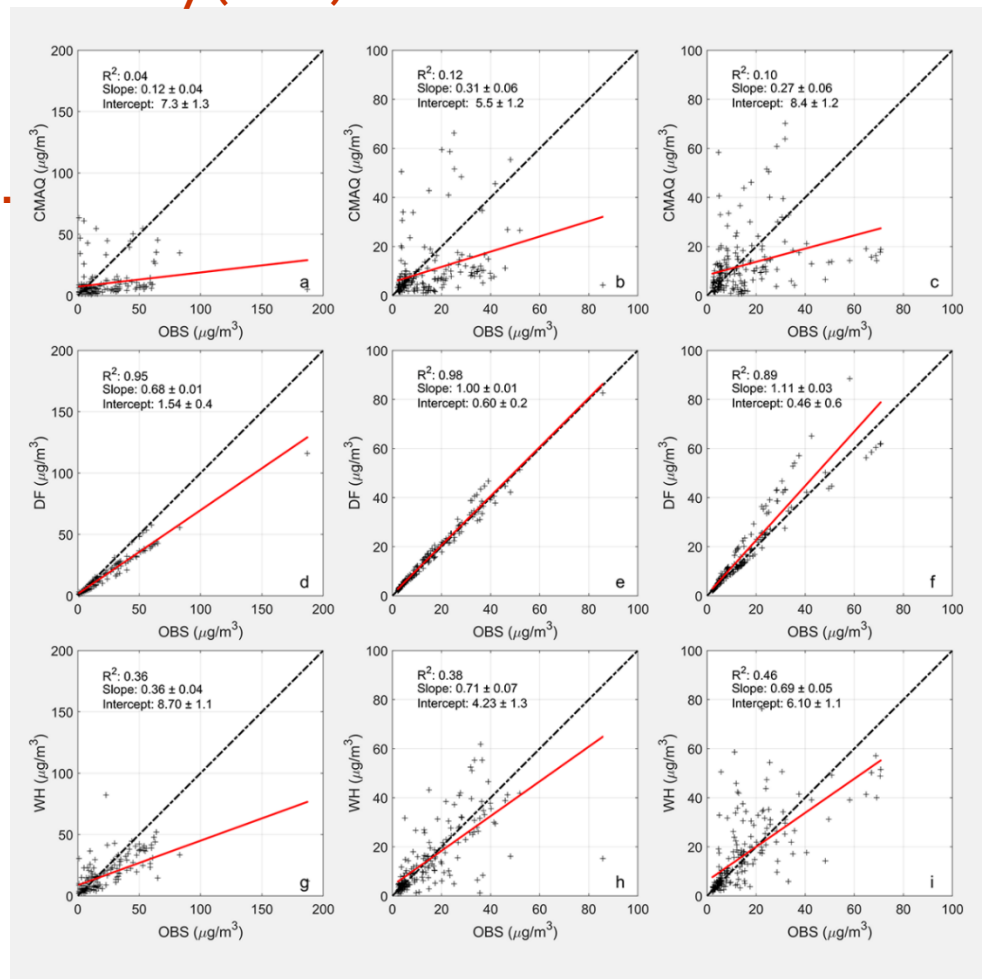


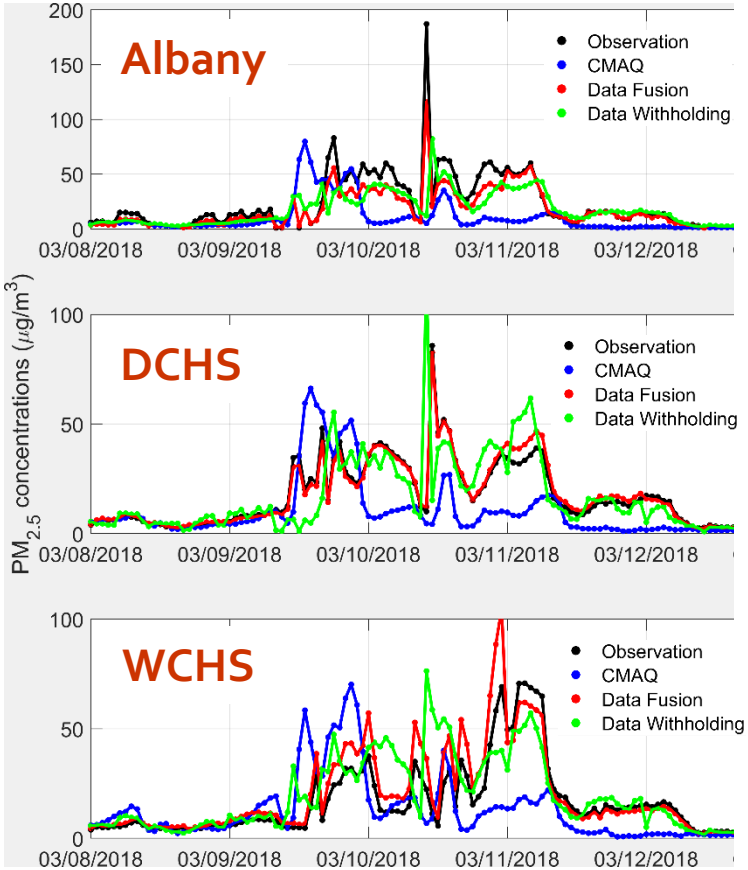






Fusion of low-cost sensor data improves simulated $PM_{2.5}$ fields





Conclusions

- Due to the shortage of monitoring sites in Southwestern Georgia, the severe impact of prescribed fires on local air quality and public health may be missed.
- $PM_{2.5}$ concentrations in Southwestern Georgia are not homogeneous; the spatial variation cannot be captured with 4-km resolution model simulations.
- Finer resolution together with better knowledge of start and end times of the burns could improve the simulations. However, the uncertainties in wind speed and direction would still limit the accuracy.
- Low-cost sensors could be used to detect prescribed fire impacts and provide spatial and temporal information missed by the simulations.

Year 3 Progress Update, PI Russell

HiRes-X: … Extension of Operational … Smoke Impacts Forecasts for Health …

- Enhance HiRes-X to forecast health impacts
  - Further expanded for forecasting health impacts from prescribed (Rx) fires especially on vulnerable population in the Southeast; disseminated through website https://sipc.ce.gatech.edu/SIPFIS/map/
- Develop a new source apportionment method
  - Developed a novel method DASI (Dispersive Apportionment of Source Impacts) to efficiently predict individual fire impacts; 1 paper submitted
- Analyse obs. from low-cost PM sensors network
  - Demonstrated low-cost sensors can improve the detection of Rx fire smoke impacts and the quality of data fusion for assessing exposures to Rx fire smoke
- 6+ academic presentations and 3+ talks to stakeholders

Tiger Team Participation

- TT Fiore: Supporting Regional Haze Planning
  - Conducted 2016 annual simulations for 12km CONUS with CMAQ/CAMx; performance evaluation done for IMPROVE network
- TT Neu: Estimating U.S. Background O_3
  - Developed CONUS spatial estimates of background O_3 with two methods: CMAQ modeling and machine learning using obs.
- TT O'Neill: Air Quality and Health Burden of 2017 California Wildfires
  - Modeling and health burden analysis of the wildfire; 1 paper published
  - Co-I Odman edited a special issue of *Int. J. Env. Res. Pub. He.* on "Air Quality and Health"

5 papers published
1 paper submitted
3 in prep