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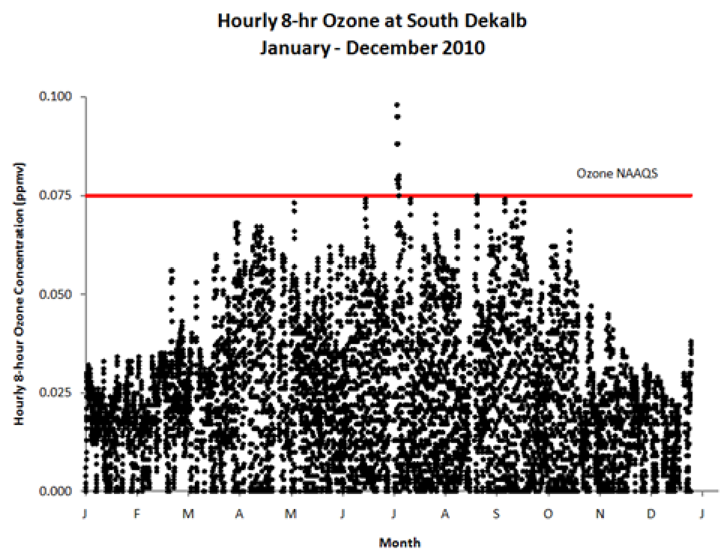
Forecasting the air quality impacts of prescribed burns: 2015 burn season in Georgia

AQAST Workshop at Georgie Tech
August 28, 2015

Dynamic AQ management has potential benefits.

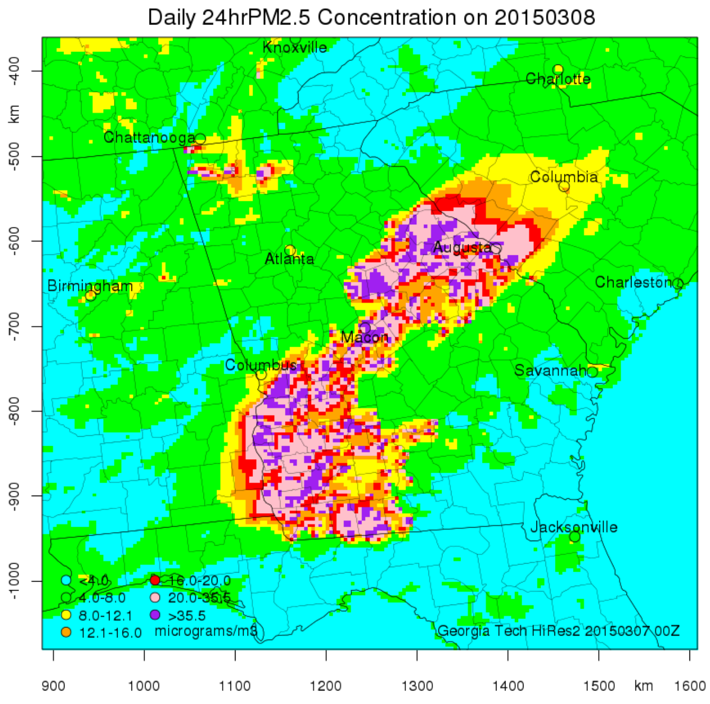


- Dynamic air quality management can:
  - not only moderate the potential impacts of emissions on AQ,
  - but also moderate AQ constraints that now limit emissions.

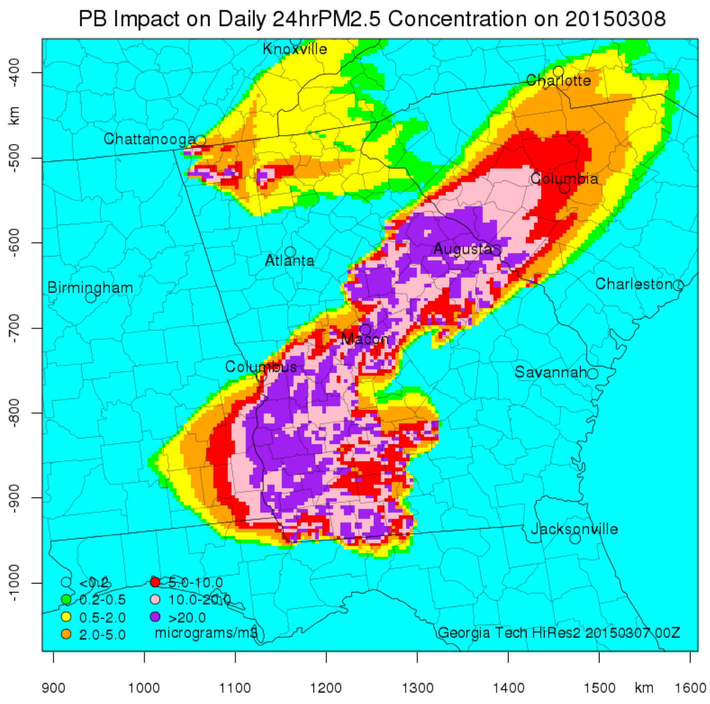
Prescribed burning can yield to dynamic management easier than other sources.

- Burn/no-burn decisions are made daily: a permit is issued.
- Our objective is to forecast AQ impacts of PB as a basis for dynamic PB / AQ management.

$PM_{2.5}$

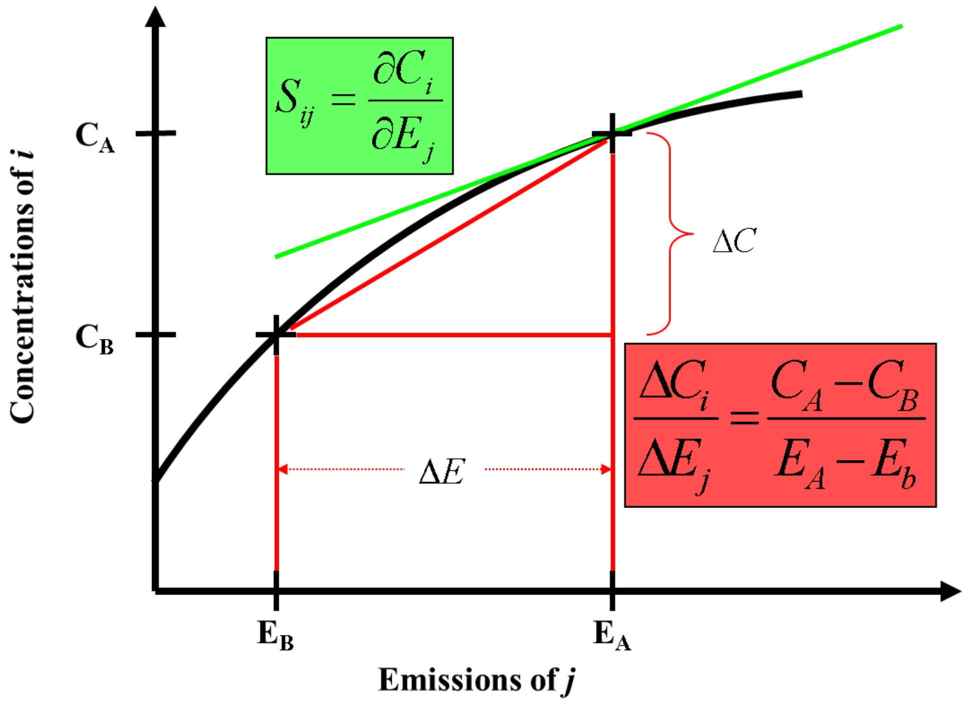


Prescribed Burn Contribution



(The scales for $PM_{2.5}$ and PB contribution are different)

Accurate forecasting of PB impacts requires forecasting of their emissions.



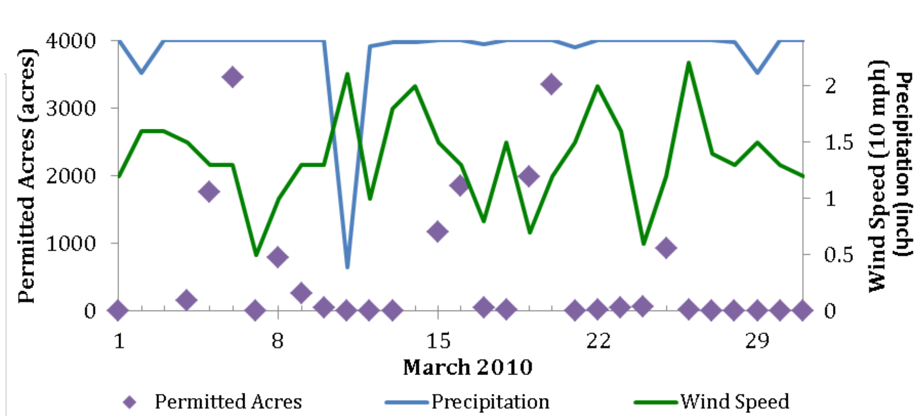
- Sensitivity is the local change in pollutant concentration due to a change in PB emissions.
- PB impact can be approximated as:

$$\Delta C_i \approx S_{ij}^{(1)} \Delta E_j$$

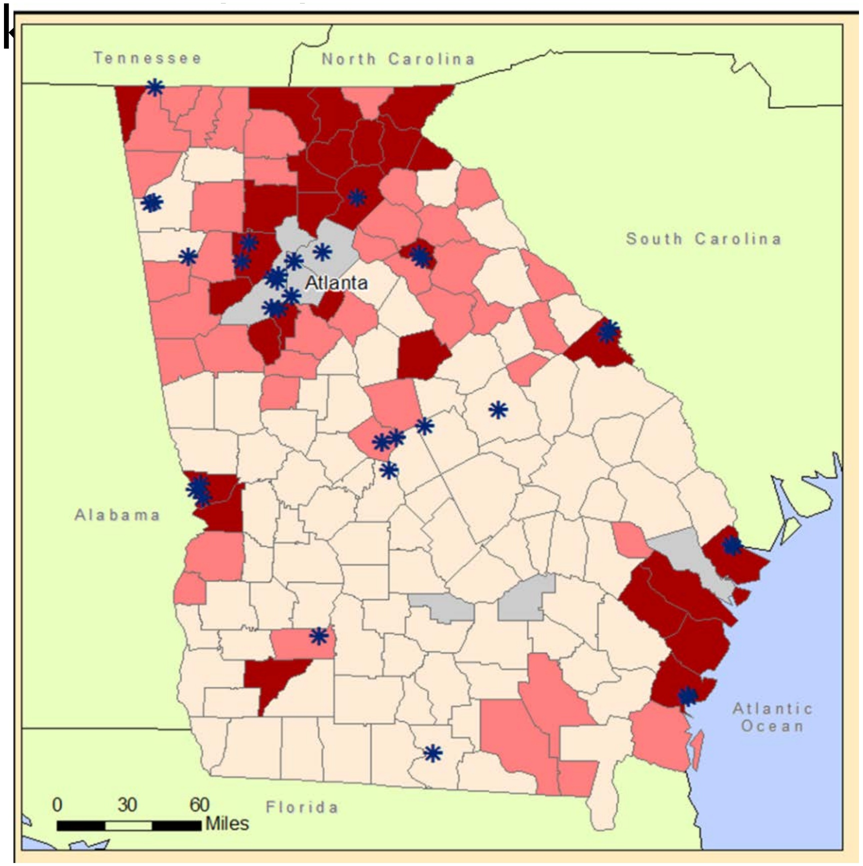
- Since we are using first order DDM, it is desirable to estimate baseline PB emissions accurately.

Challenges with forecasting prescribed burn emissions include: When & where?

- There is a relation between burns and weather.
  - No burns when it rains,
  - Nor when it is windy.



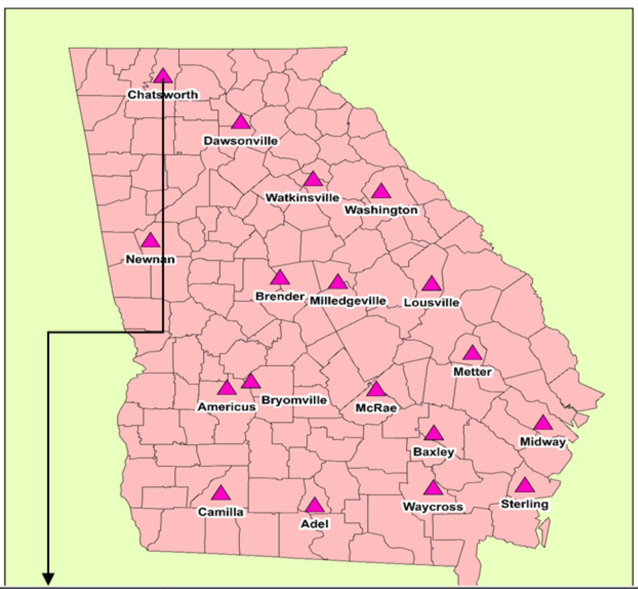
- The locations of the lands treated by PB are known.



We built a decision tree model using fire weather data and burn permit data.

- There are 18 fire weather stations in Georgia.

Fire Weather Stations

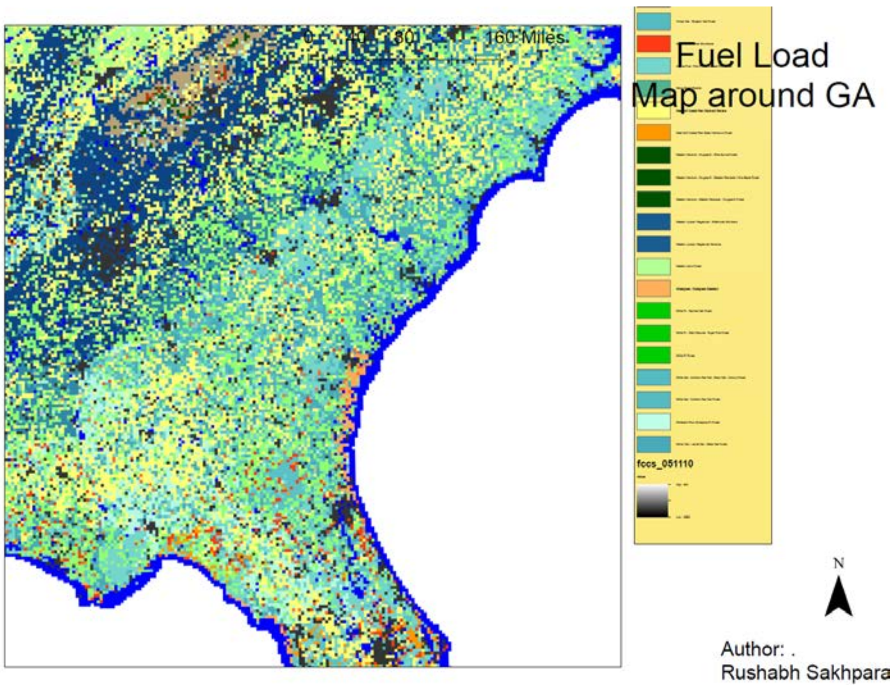


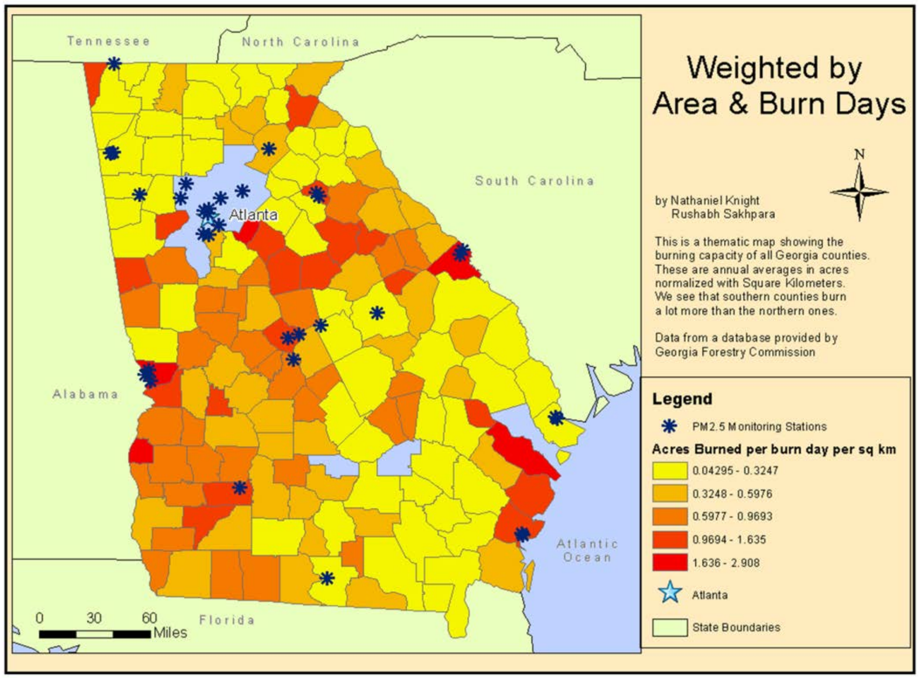
Chatsworth, Ga			Observed NFDRS-88 at 1300 EST Jul 20 2015					
RH (%)	IC	BI	Class Day	KBDI	Wind (mph)	Mx_Wind (mph)	Rn24 (inch)	Dur (Hr)
54	18	22	2 Moderate	359	S 2	S 9	0.29	2
Sow	Temp (°F)	Td (°F)	Tmax (°F)	Tmin (°F)	RHMax (%)	RHMin (%)	HrbGF	WdyGF
0	94	75	92	72	97	58	12	12
1-Hour	10-Hour	100-Hour	1000-Hour	X1000	Herbaceous	Woody	SC	EC
8.0	8.0	16.0	19.9	18.8	84.8	120.7	5	16

- Predictor variables
  - 21 fire weather predictor variables
  - Temp, RH, WS, Rain duration, Season, and some other fire meteorology variables
- Training dataset: 2010-2014 burn permit and observed fire weather data
  - Matched weather with burn permits in the county of the monitor
  - Single, statewide CART model
- The model uses the fire weather forecast to predict whether tomorrow will be a burn day.
  - Burn day defined as >70 acres countywide
  - If burn day in central monitor's county, burn day in the entire fire district.
  - Each county is assigned its own annual average burn day acreage
  - Burns assigned to lands of known burners or forested areas

Other challenges of forecasting PB emissions are: What and how much?

- We are using FCCS fuel load maps.
  - Satellites can provide more up-to-date data.
- From the permit data, we derived average burn area per burn day for each of the 159 counties in Georgia.





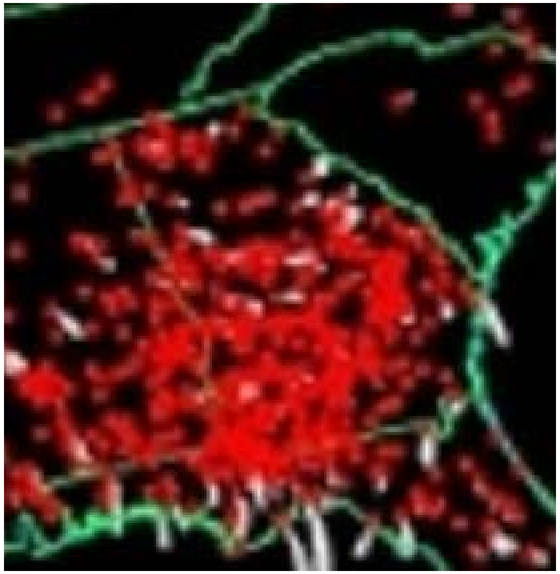
Overview of the Method for Forecasting Prescribed Burn Impacts on Air Quality

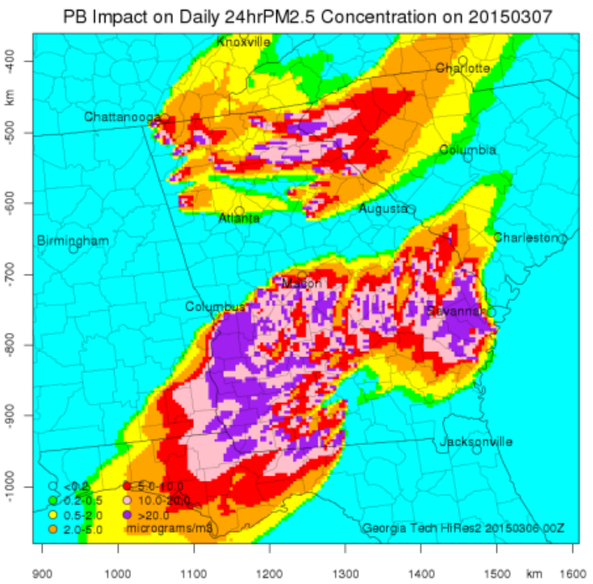
- Forecast burns from weather and burner information
  - County average for burn area
  - Burner type (institutional, commercial or small) for location within county
- Estimate emissions for forecasted burns
  - FCCS fuelbed maps for fuel loads
  - Fuel moisture observations for fuel consumption
  - Emission factors for Southeast USA fuels
- Estimate vertical distribution of emissions
  - Plume rise calculations (Briggs, 1975) for fraction below/above PBL height
- Forecast impacts of PB emissions on O_3 and $PM_{2.5}$
  - Hi-Res2 with DDM-3D (1^{st}–order) for tracking PB emissions
  - Currently statewide, by fire district and by county in the future.

Satellite fire & smoke analyses can be used for evaluation of PB forecasts.

- We compare our forecast qualitatively to the Hazard Mapping System Fire and Smoke Analysis by NOAA.
- We give each day's forecast a rating based on the agreement in location and density of fires.

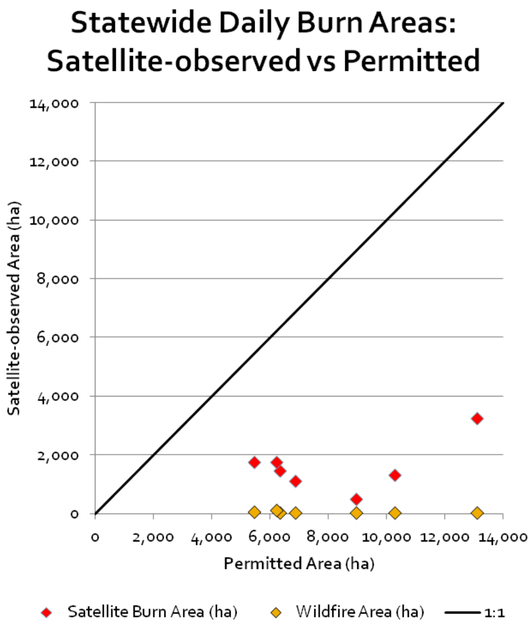
February 13, 2015: rated very good

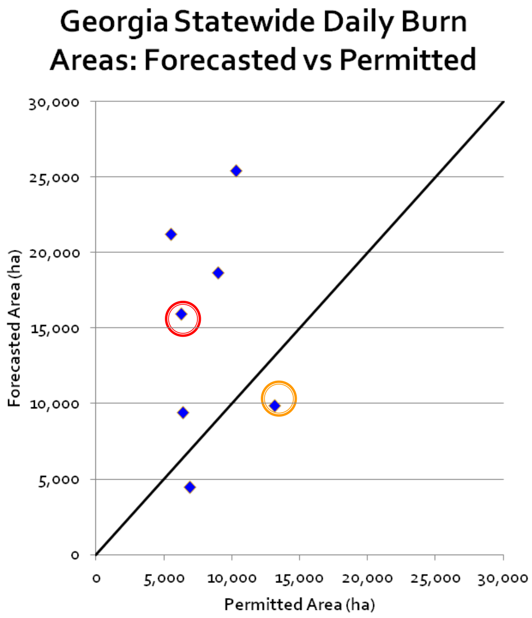




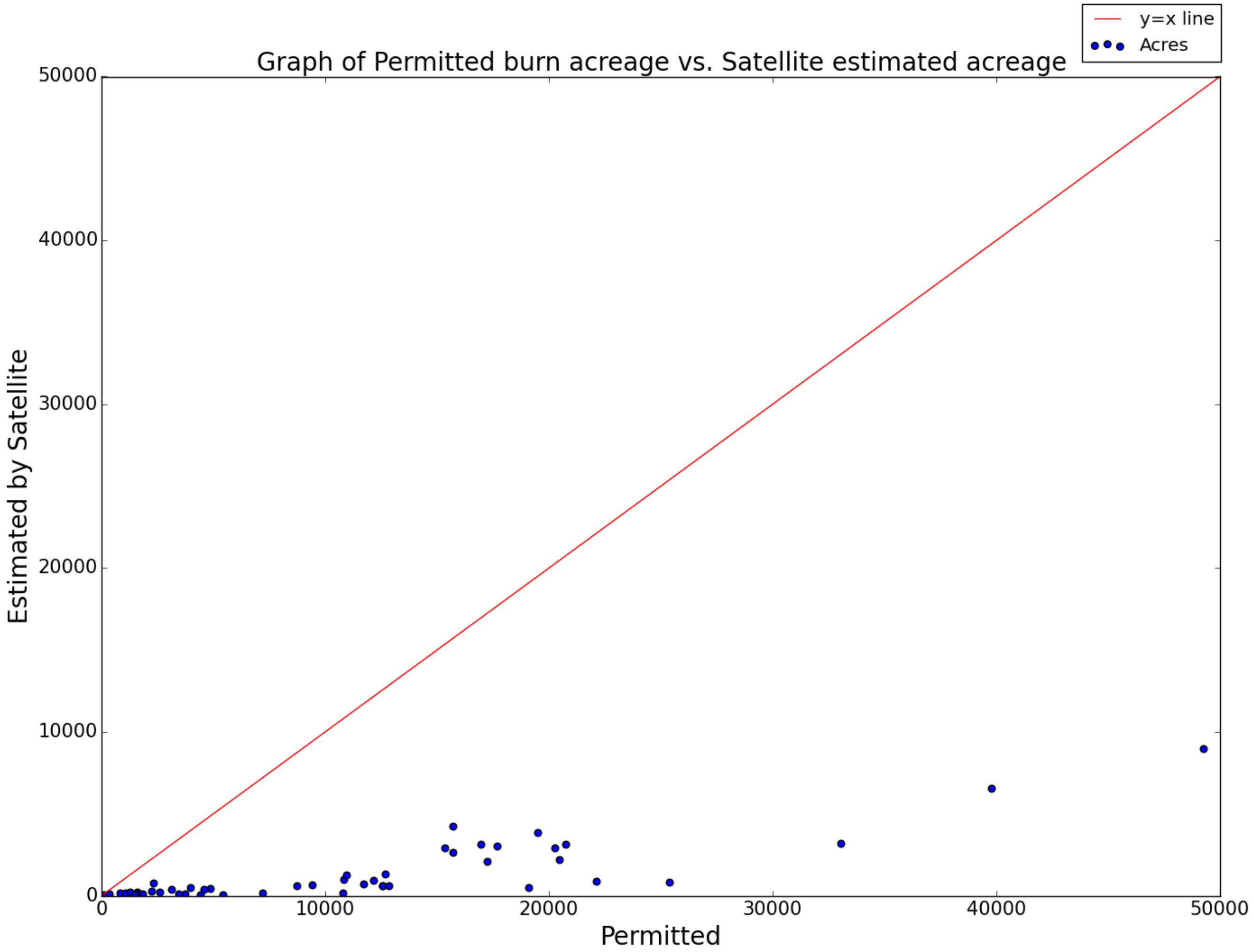
Burn areas from satellites and permitted burn areas can be used for evaluation.

- We compare our forecast quantitatively to:
  - Burn area and emissions provided by the Biomass Burning Emission Product of NOAA.
  - Burn areas permitted by the Georgia Forestry Commission

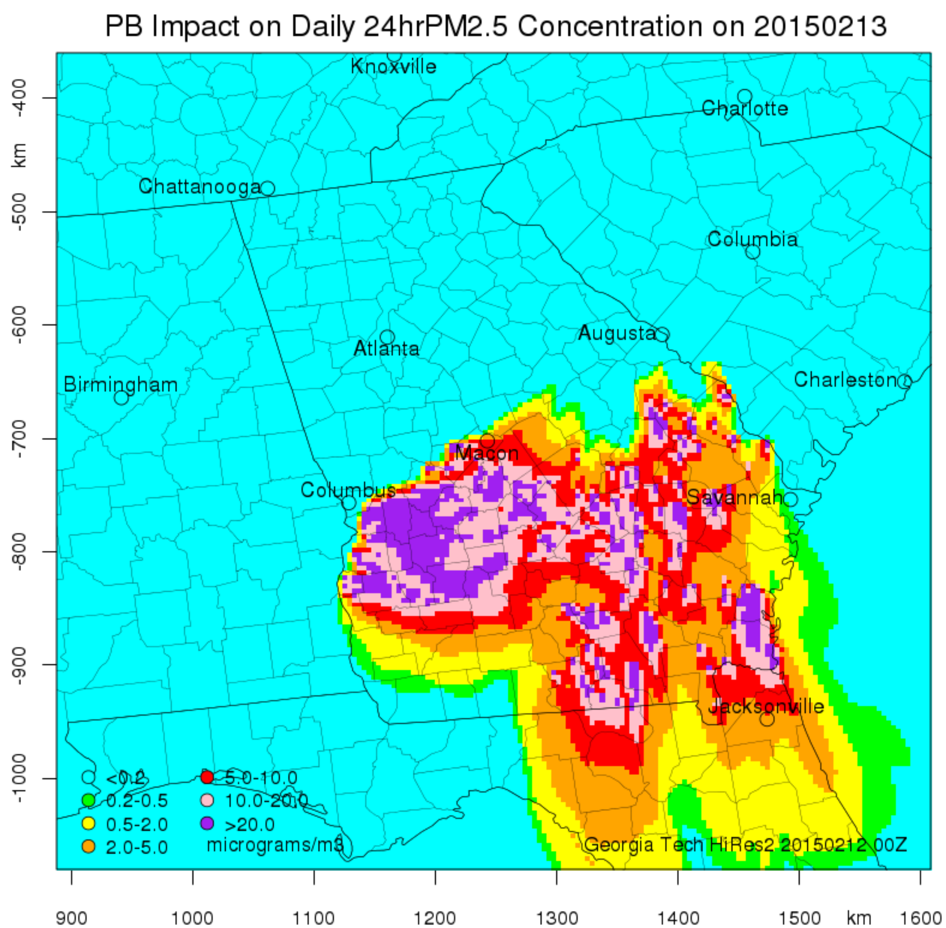




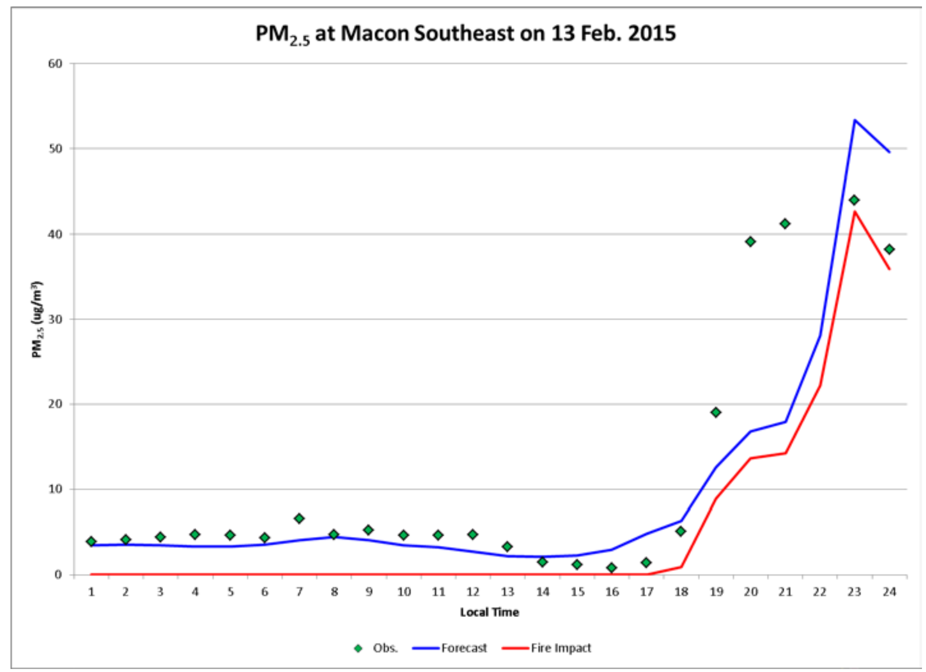
Satellite-derived burn areas are 3-5 times smaller than permitted burn areas.



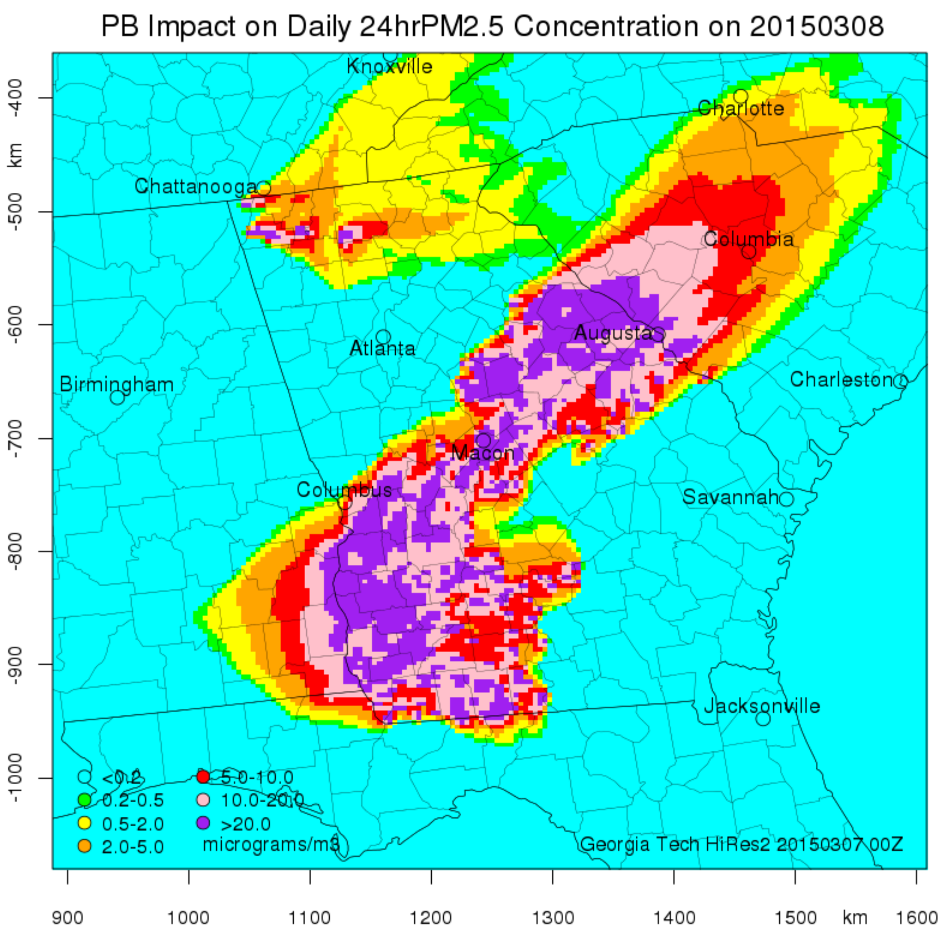
Ground-level $PM_{2.5}$ observations can be used for evaluating the impact forecast.



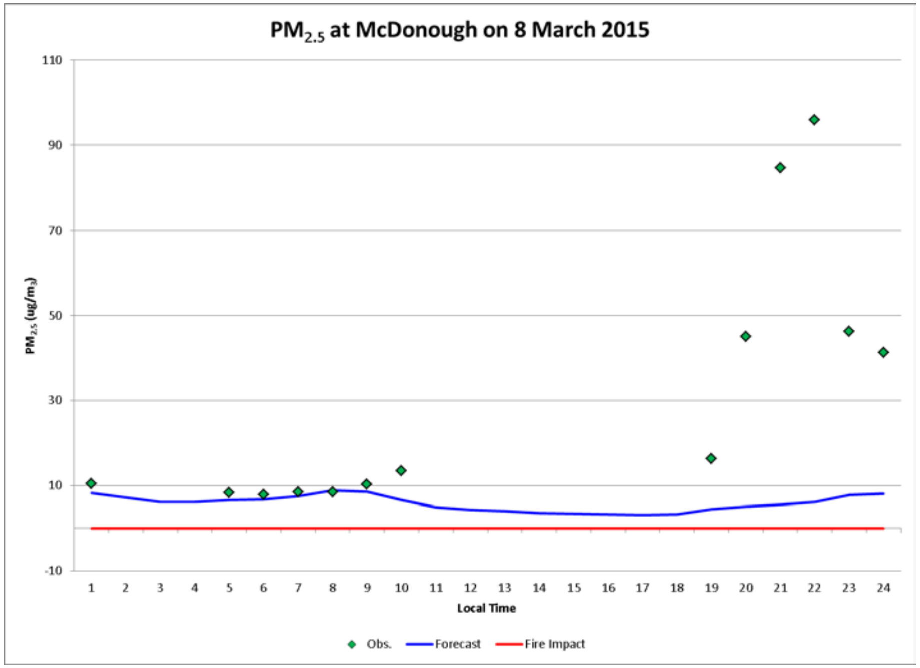
A hit (true positive)



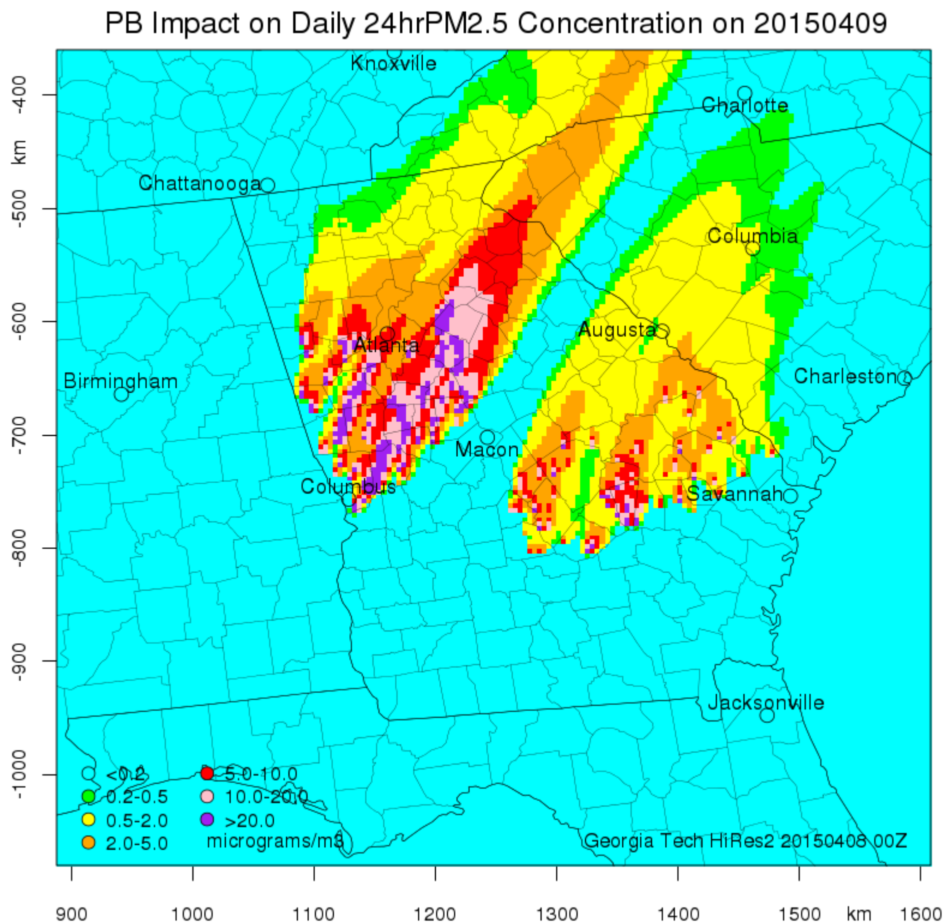
There are cases where the burn forecast can be improved.



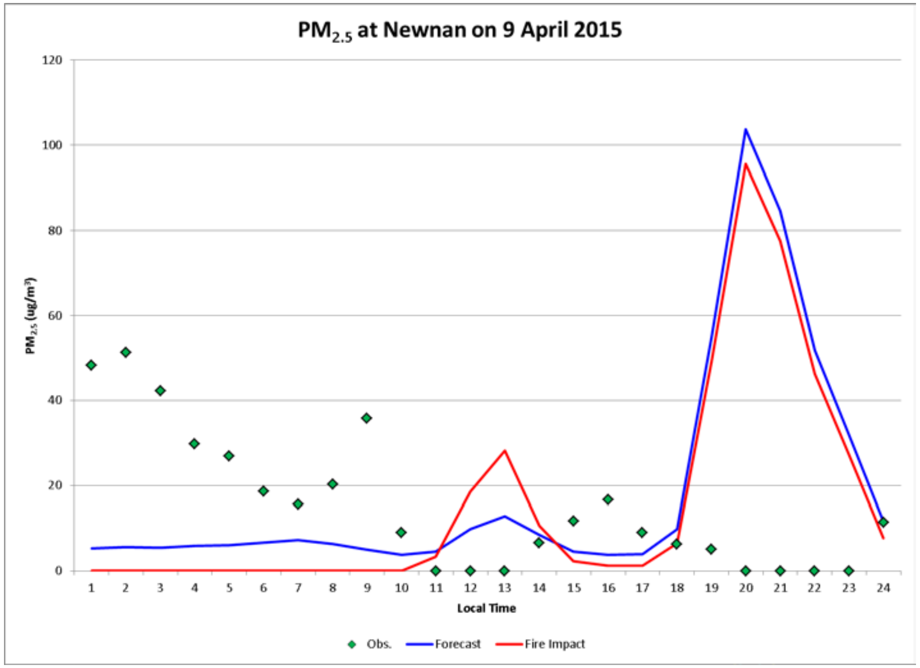
A miss (false negative)

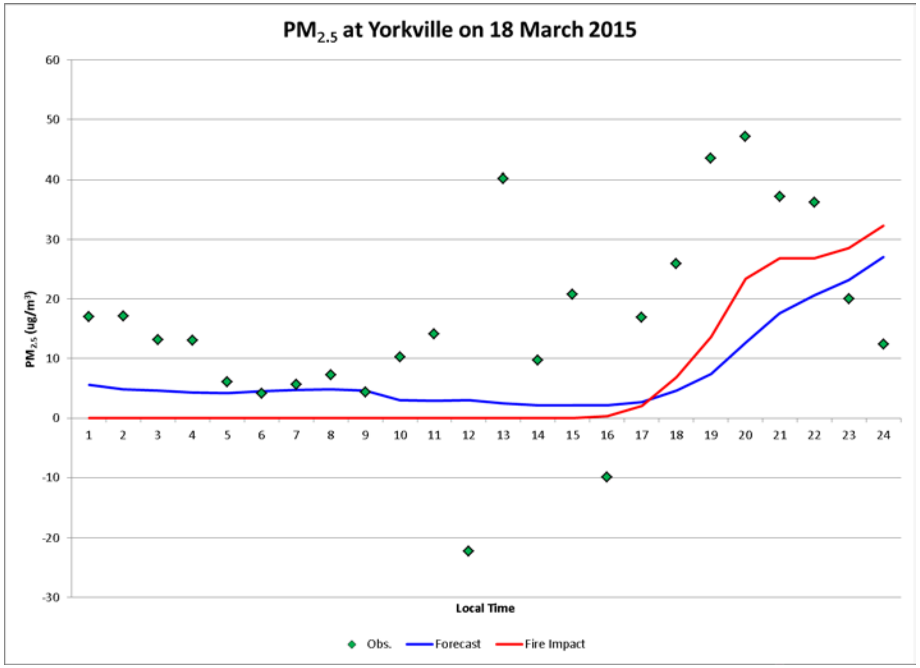


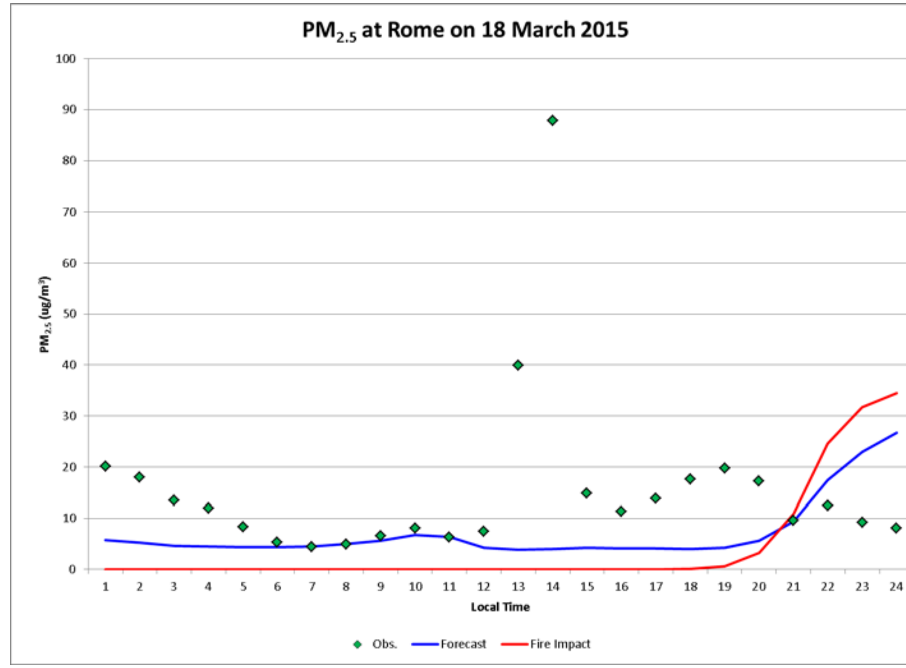
Each case must be analyzed carefully.

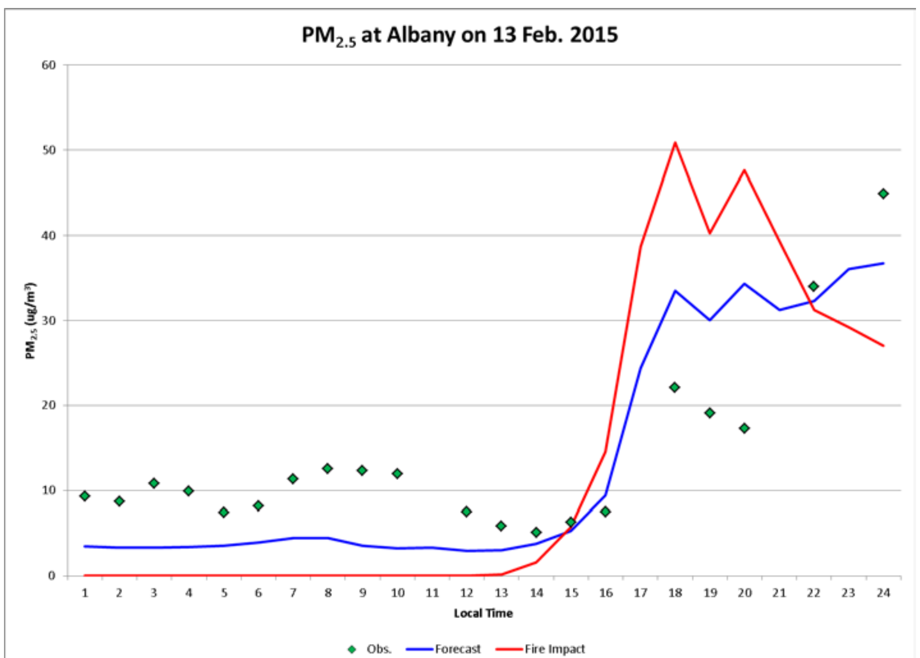


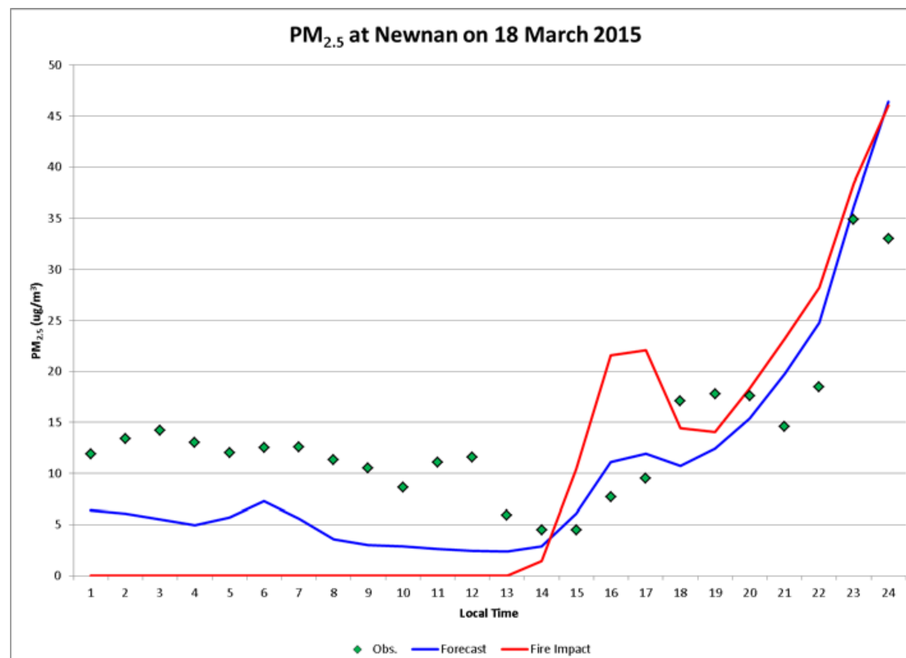
A false alarm (false positive)

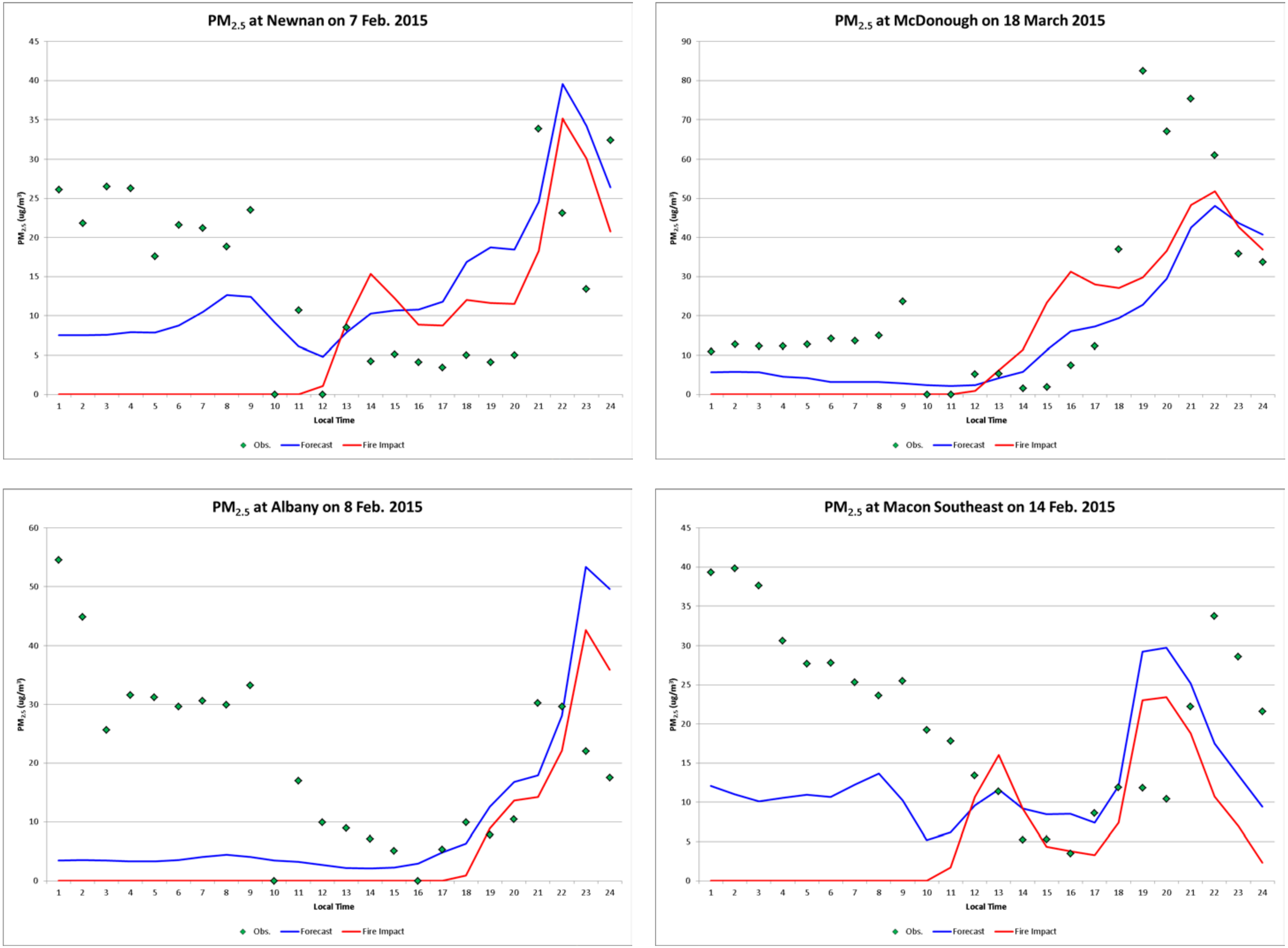



PM$_{2.5}$ at Yorkville on 18 March 2015
PM$_{2.5}$ (ug/m^3)
Local Time
Obs.
Forecast
Fire Impact


PM$_{2.5}$ at Rome on 18 March 2015
PM$_{2.5}$ (ug/m^3)
Local Time
Obs.
Forecast
Fire Impact


PM$_{2.5}$ at Albany on 13 Feb. 2015
PM$_{2.5}$ (ug/m^3)
Local Time
Obs.
Forecast
Fire Impact


PM$_{2.5}$ at Newnan on 18 March 2015
PM$_{2.5}$ (ug/m^3)
Local Time
Obs.
Forecast
Fire Impact



PM$_{2.5}$ at Newnan on 7 Feb. 2015
PM$_{2.5}$ (ug/m^3)
Local Time
Obs.
Forecast
Fire Impact
PM$_{2.5}$ at McDonough on 18 March 2015
PM$_{2.5}$ (ug/m^3)
Local Time
Obs.
Forecast
Fire Impact
PM$_{2.5}$ at Albany on 8 Feb. 2015
PM$_{2.5}$ (ug/m^3)
Local Time
Obs.
Forecast
Fire Impact
PM$_{2.5}$ at Macon Southeast on 14 Feb. 2015
PM$_{2.5}$ (ug/m^3)
Local Time
Obs.
Forecast
Fire Impact

Lesson learned: the burn forecast needs improvement.

We use the F1 score for evaluating the burn forecast models.

- F1 Score: Harmonic mean of precision and recall

$$\frac{Precision \times Recall}{(Precision + Recall)/2}$$

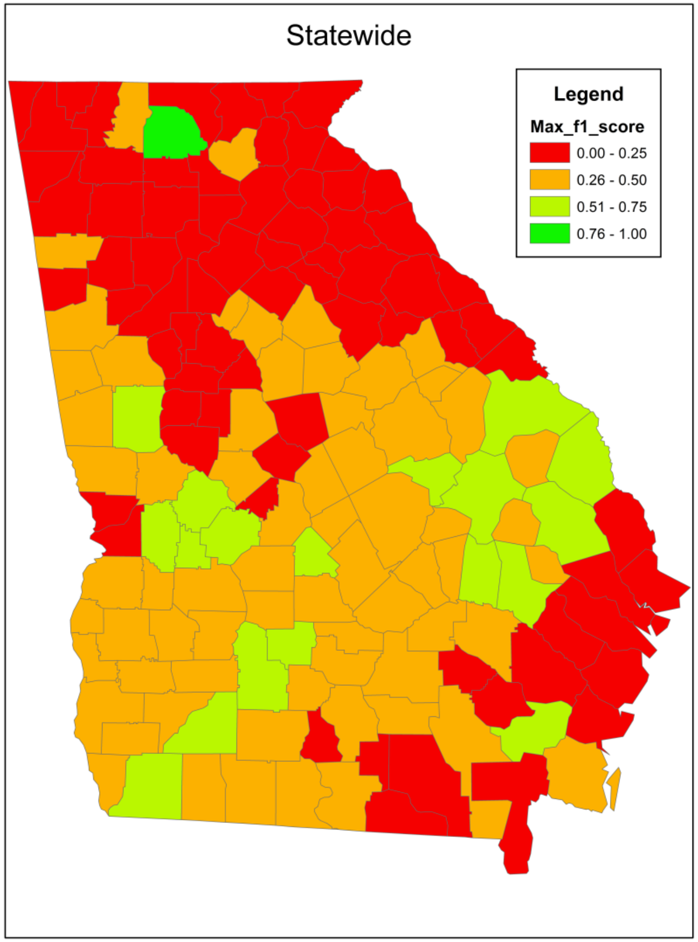
- Precision

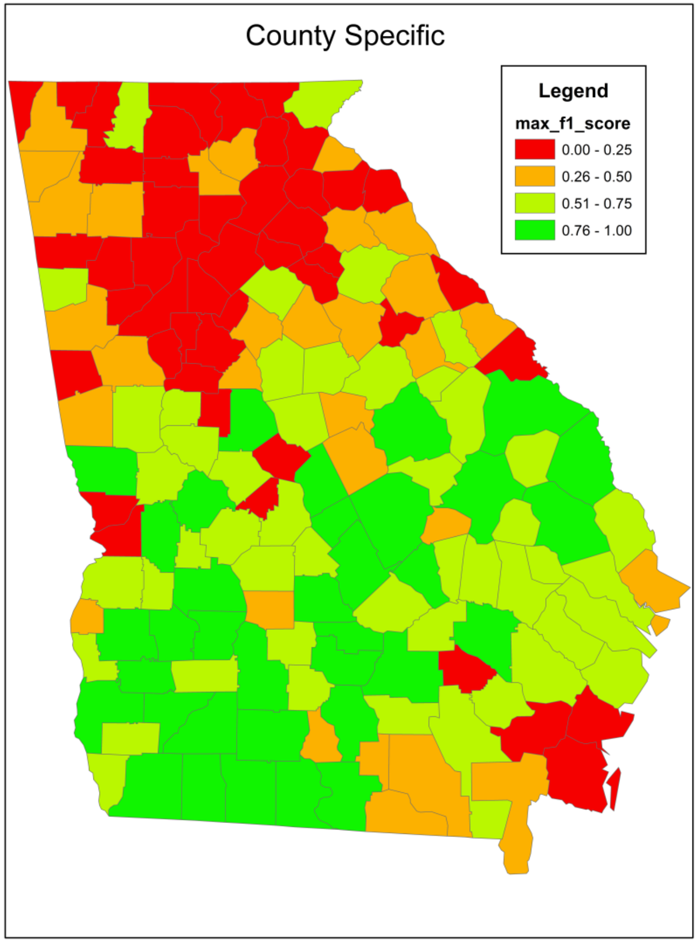
$$\frac{True\ Positives}{True\ Positives\ +\ False\ Negatives}$$

- Recall

$$\frac{True\ positives}{True\ Positives\ +\ False\ Positives}$$

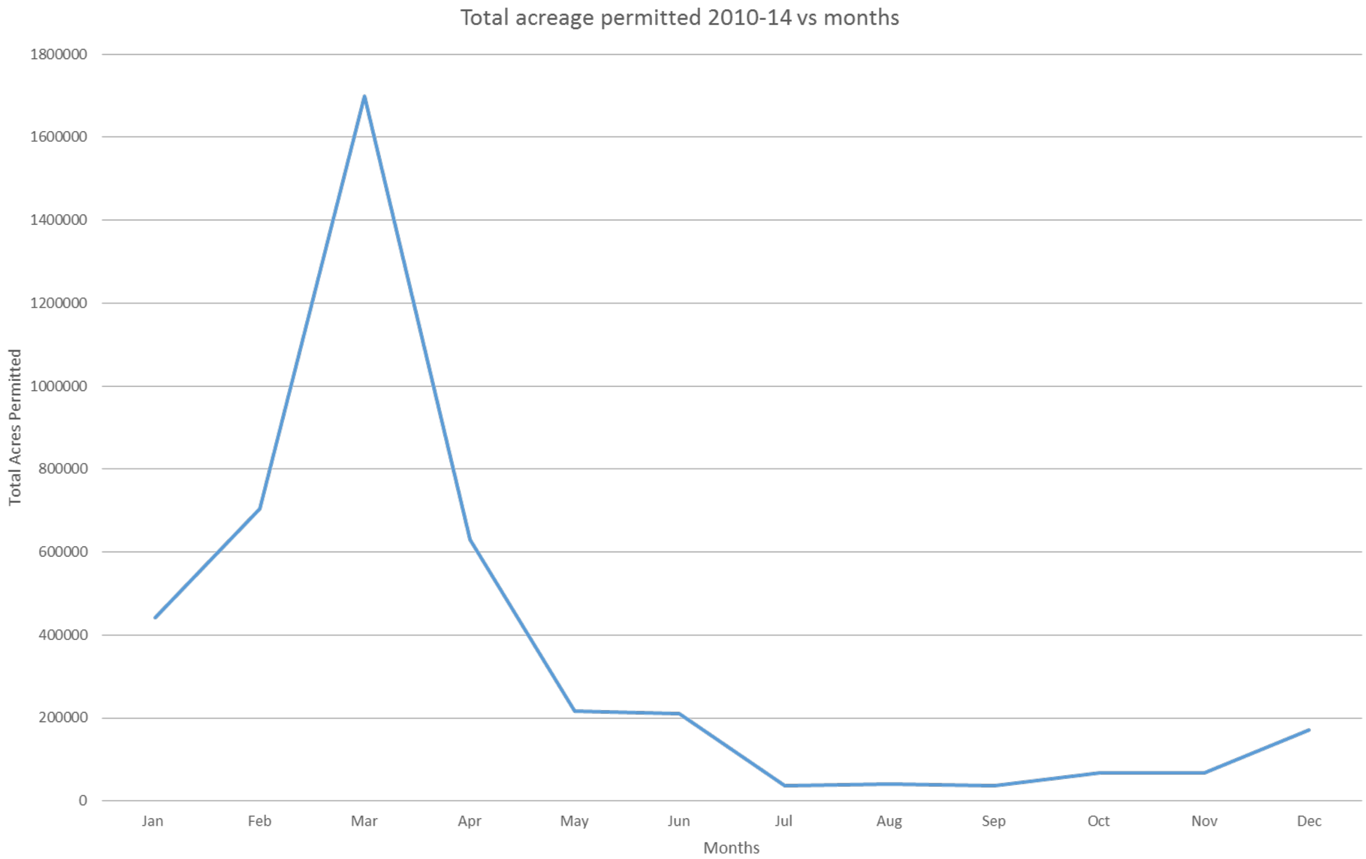
County-specific models perform much better than a single, statewide model.





Lesson learned: intra-annual variation of burn acreage is very large.

- Monthly average burn day acreage should lead to better burn impact forecast performance.



Summary & Conclusions

- Forecasting PB impacts is potentially one of the most beneficial applications of source impact forecasting for dynamic AQ management.
- We have started PB impact forecasting with our HiRes2 system (https://forecast.ce.gatech.edu).
- We are forecasting burn emissions for accurate forecasting of the burn impacts.
  - County-specific regression models will yield much more accurate burn forecasts than the statewide model we used so far.
- Evaluation of the forecasted PB impacts is difficult.
  - The satellites do not see the low intensity prescribed burns.
  - There are only a handful of PB impacts at the ground monitoring sites.

Acknowledgements

- US EPA

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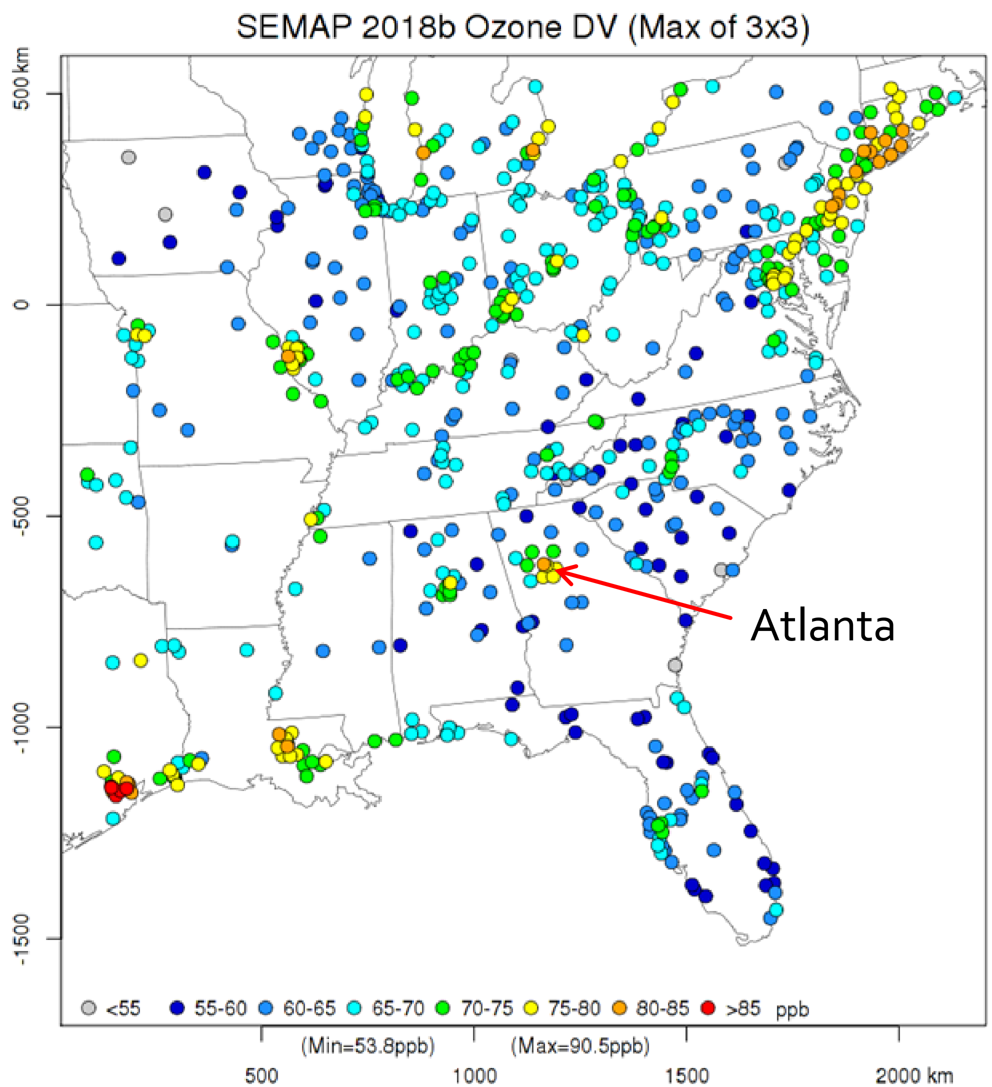
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # RD83521701

- NASA (Air Quality Applied Sciences Team)
- Georgia Environmental Protection Division
- Georgia Forestry Commission

Supplement

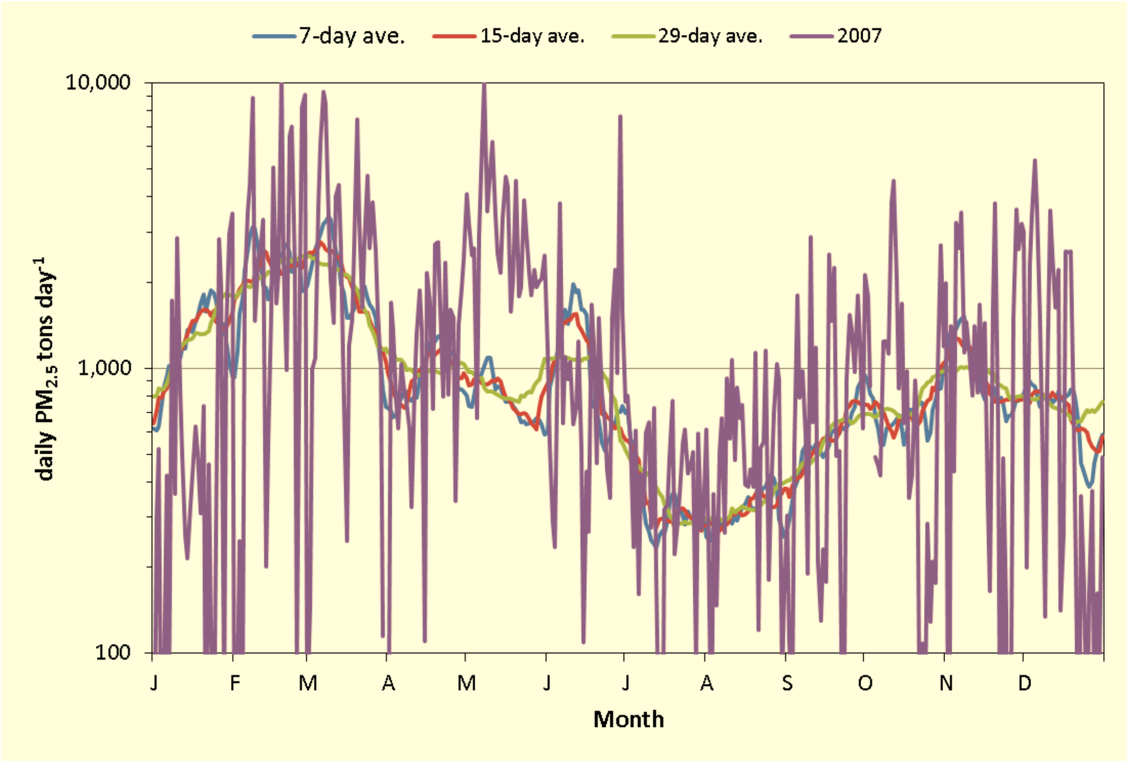
Traditional air quality (AQ) management is mostly "static."

- Emission control strategies are designed to make projected design values meet the standards.
  - A design value is a long-term statistic that describes the air quality status of a given location.
  - Air quality models are used to project design values into the future.



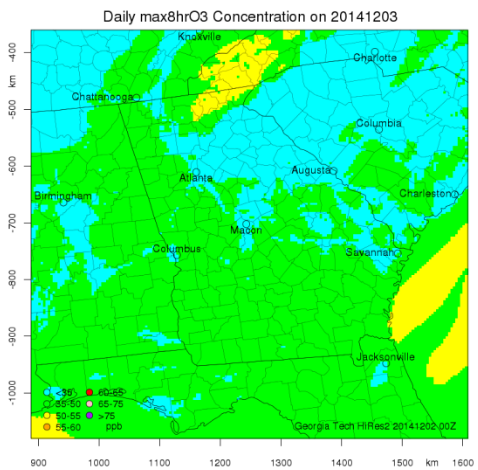
Prescribed burn impacts are underestimated in "static" air quality management.

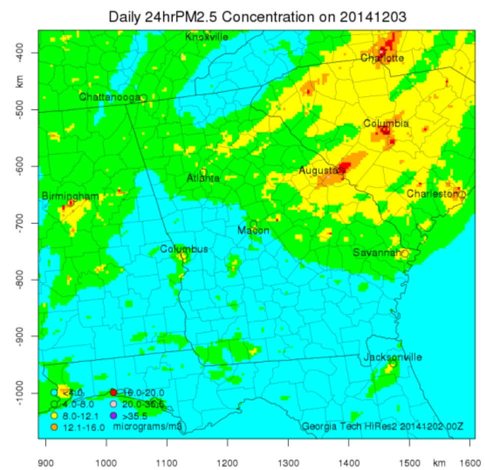
- Averaging in time reduces the maxima of fire emissions.
- What is modeled is smaller fires more frequently over larger areas.



Air quality forecasting helps reduce exposure to air pollutants.

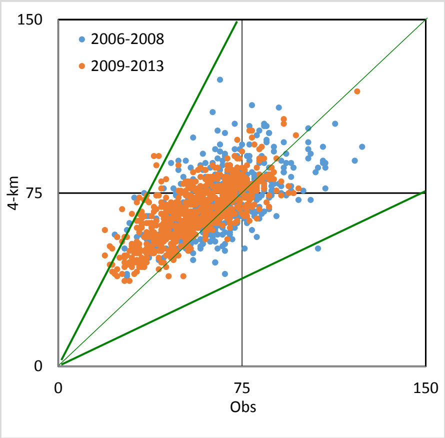
- With our Hi-Res system, we have been forecasting air quality in Georgia since 2006.





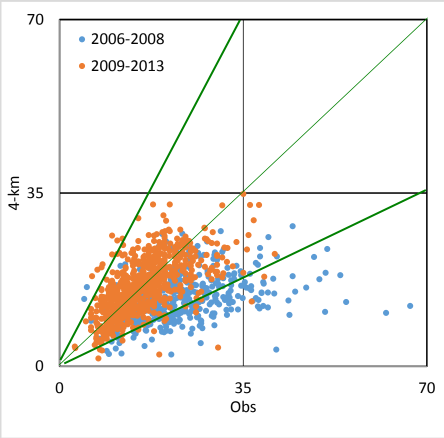
Ozone

MNB	20%
MNE	25%



$PM_{2.5}$

MNB	-10%
MNE	32%



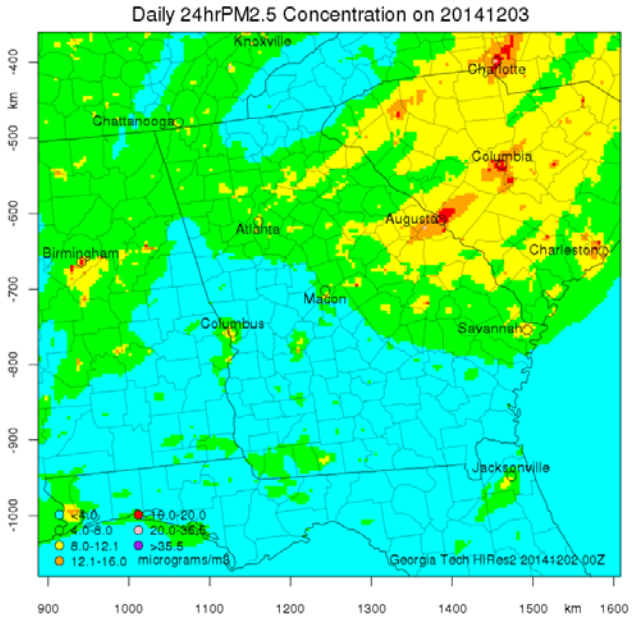
Sensitivities of air quality to different emission sources can be calculated by DDM.

- Hi-Res air quality forecasting system is updated with latest versions of its components:
  - WRF3.6
  - CMAQ 5.0.2 with SAPRC07TC mechanism
    - AERO6 aerosol module
    - Inline BEIS biogenic emissions
    - Inline 3-D point source emission processing
  - Emissions projected from 2011 NEI
- CMAQ 5.0.2 is equipped with the Direct Decoupled Method, DDM-3D, sensitivity analysis tool.

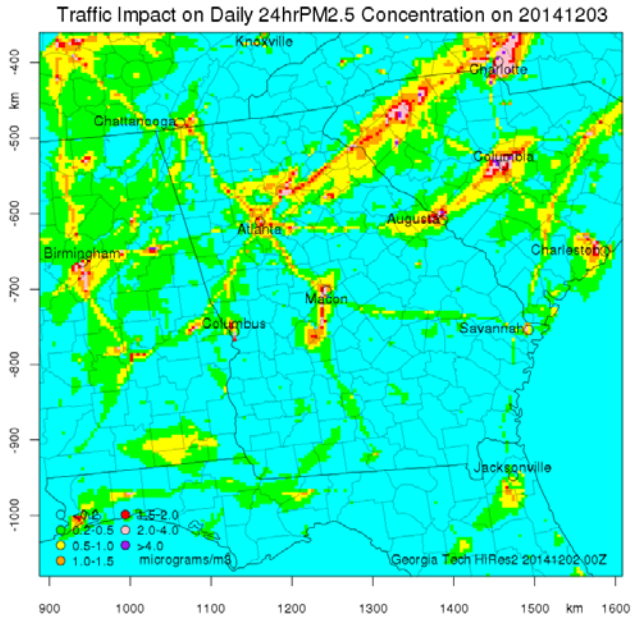
Forecasting source impacts in addition to air quality can facilitate dynamic management.

- With our updated system, Hi-Res2, we are now forecasting traffic, power plant and prescribed burn impacts to O_3 and $PM_{2.5}$ (https://forecast.ce.gatech.edu).

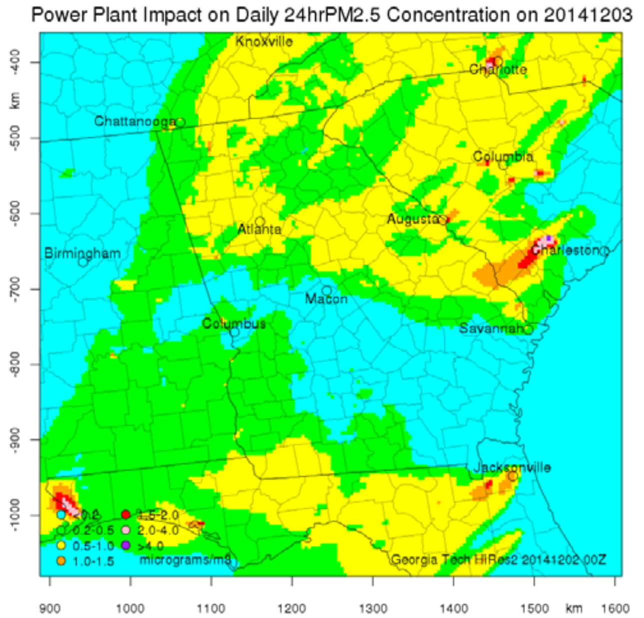
$PM_{2.5}$



Traffic Contribution



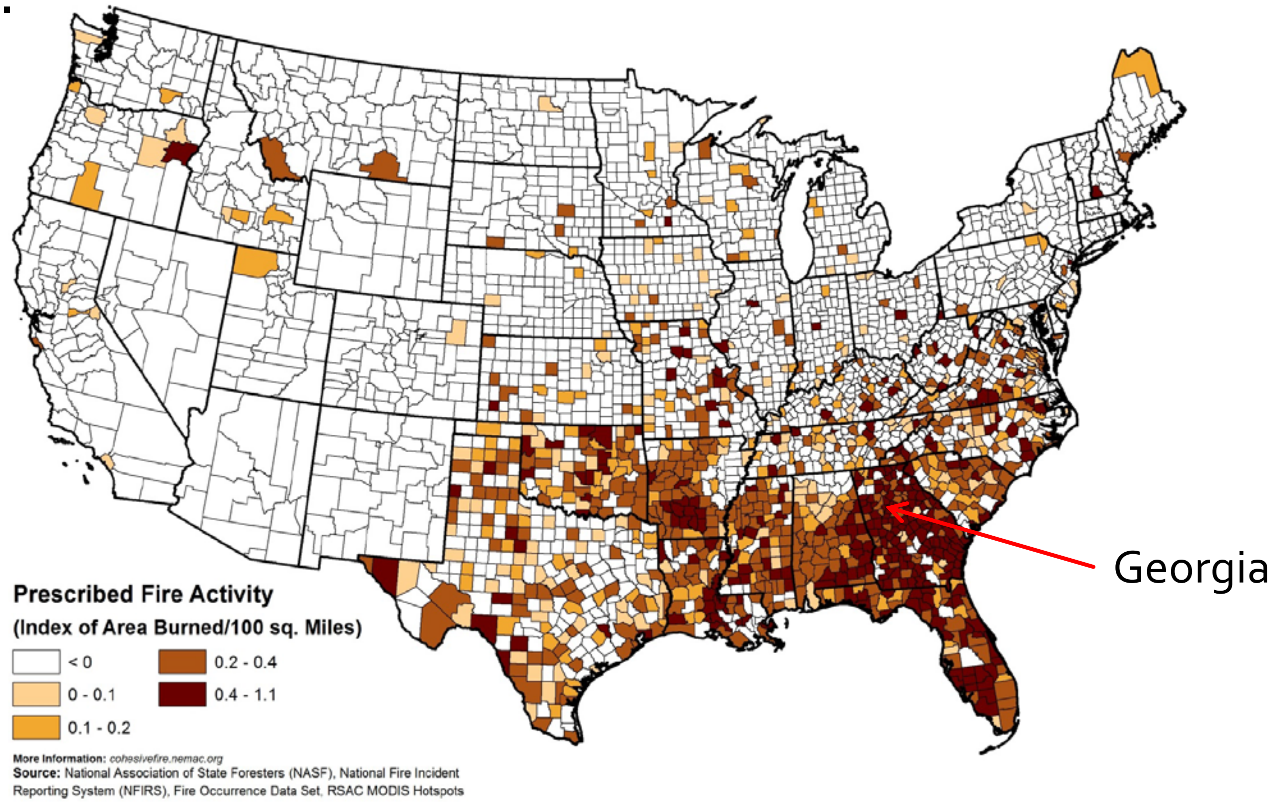
Power Plant Contribution



(The scales for $PM_{2.5}$ and the contributions are different)

Prescribed burning (PB) is a preferred land management tool in Southeastern USA .

Prescribed burning (PB) is practiced to improve native vegetation and wildlife habitat, control insects and disease, and reduce wildfire risk.



However, prescribed burning contributes to air pollution.

Low intensity fire: trees do not burn

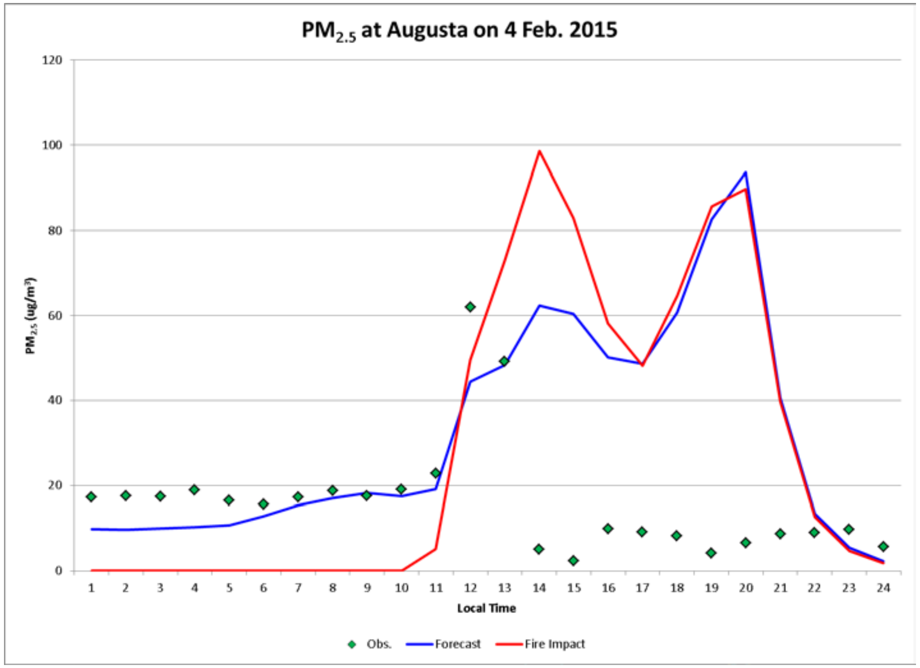
Nonetheless, a large smoke cloud is generated.

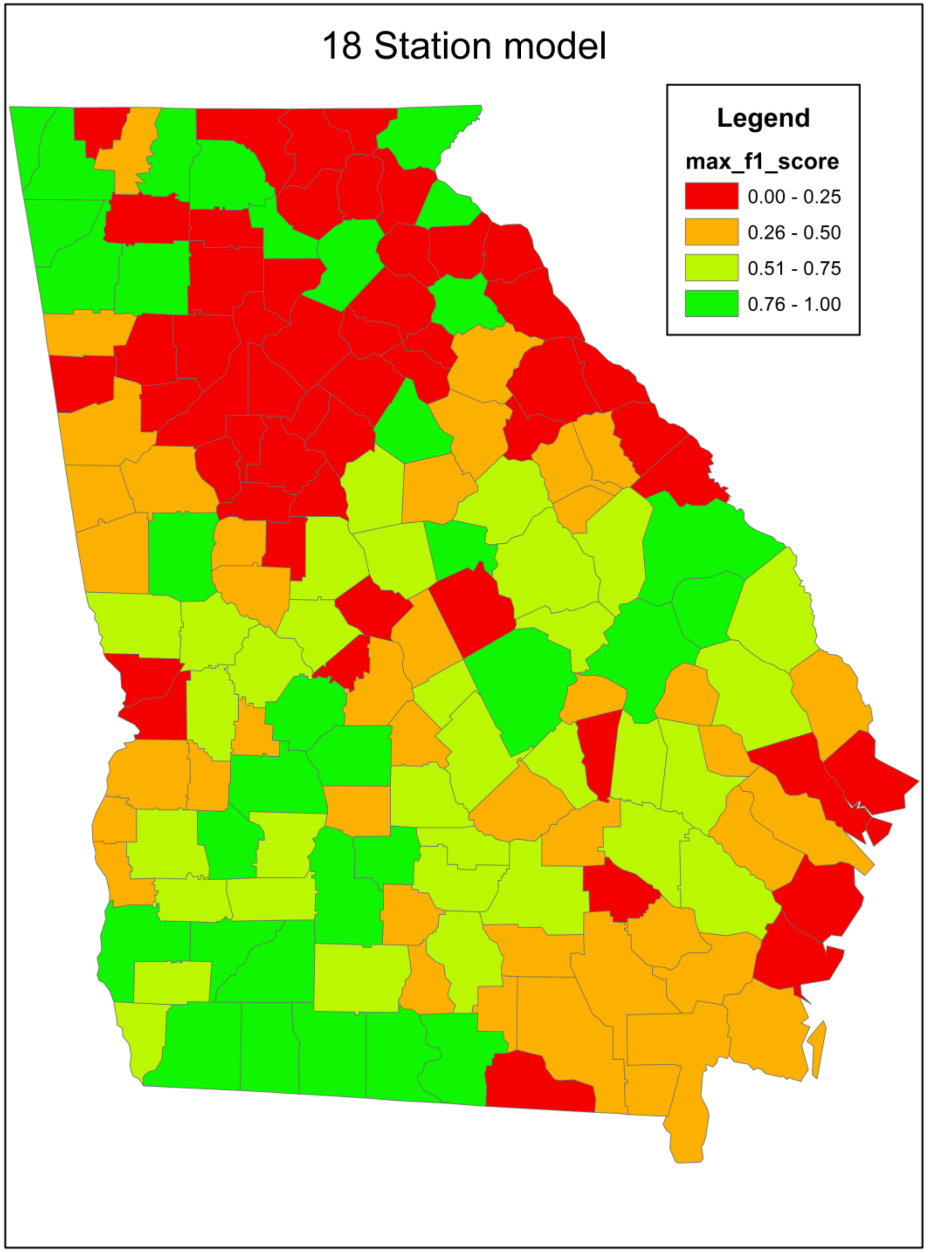
US EPA 2011 National Emission Inventory reported that 15% of PM2.5 emissions in the USA (840 Gg) are attributable to prescribed burning.

Example Forecast

- November 21, 2014
- "Burn day" (assumed) in pilot district **Flint North**
- Burn location randomly assigned
  - Acreage based on historical burn data
- Forecasts of PB Impacts on $PM_{2.5}$ and O_3

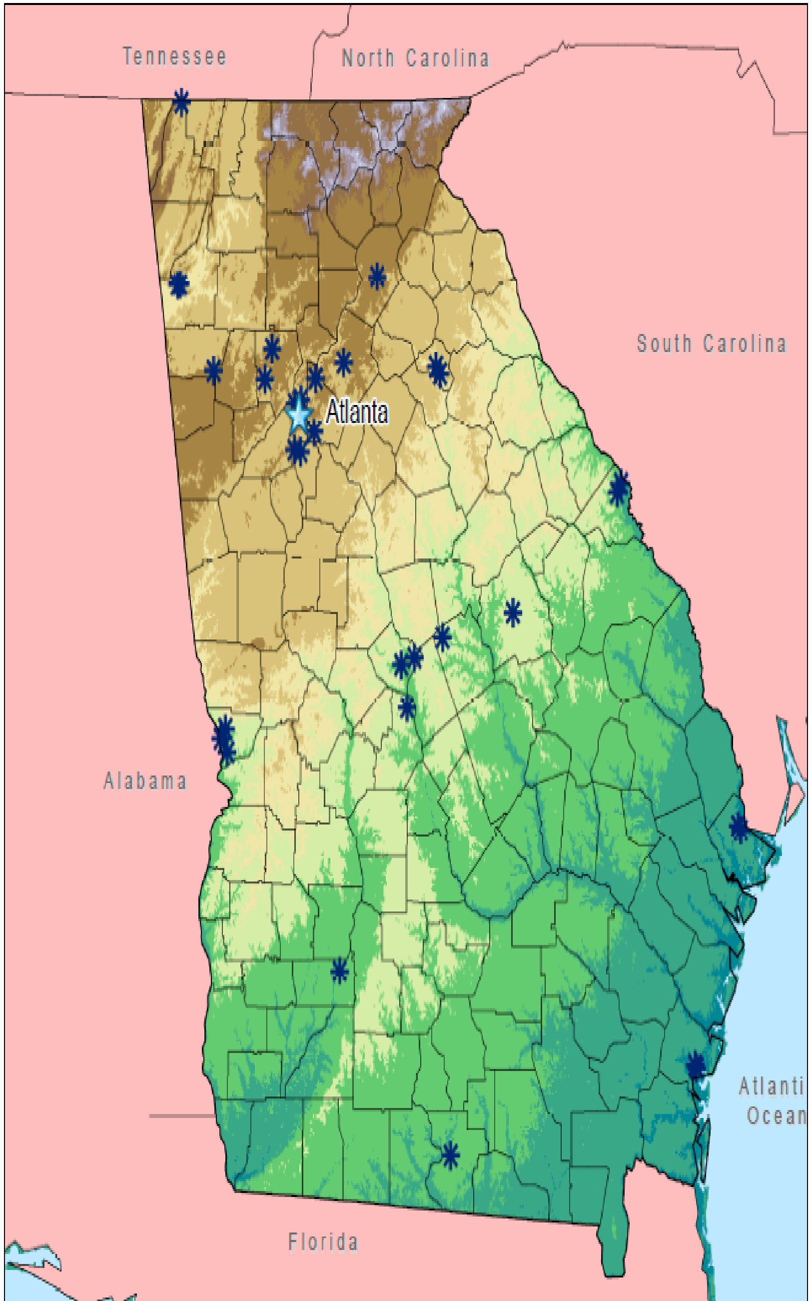
Ground-level $PM_{2.5}$ observations can be used for evaluating the impact forecast.





18 Station model
Legend
max_f1_score
0.00 - 0.25
0.26 - 0.50
0.51 - 0.75
0.76 - 1.00

Georgia Slope



Legend

Elevation, GA US

Meters

- -47 - 0
- 1 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 900
- 901 - 1,200
- 1,201 - 2,009

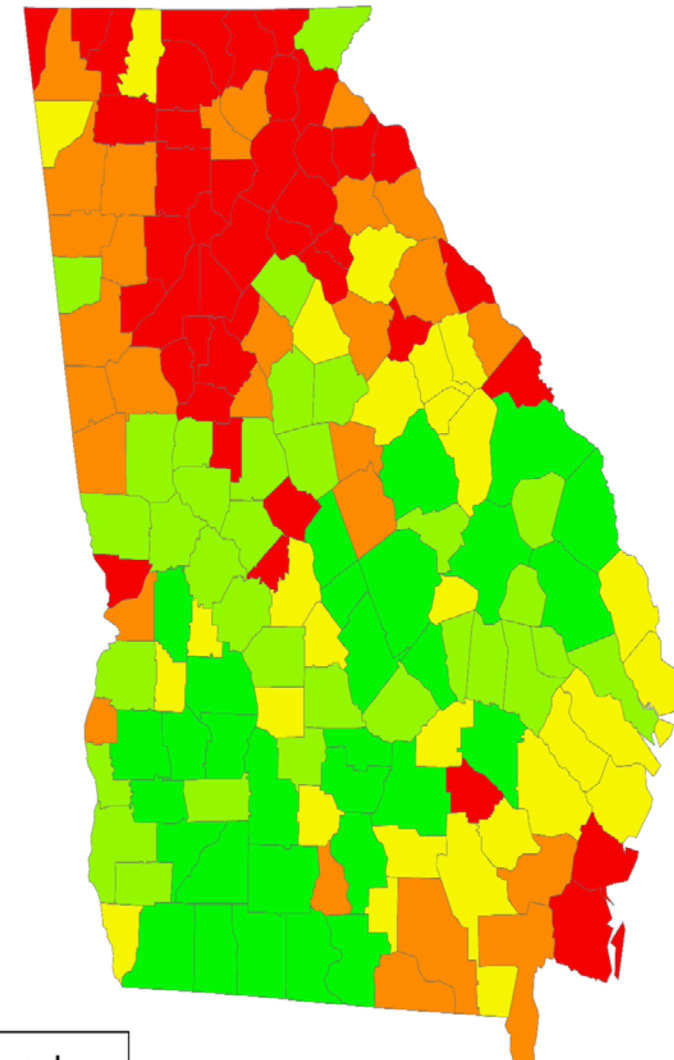
N

by Nathaniel Knight
Rushabh Sakhpara

Data from the
National Land Cover Database
2006 (U.S.) - zone 10
(Data Basin Dataset)

0 30 60 Miles

F1 Score

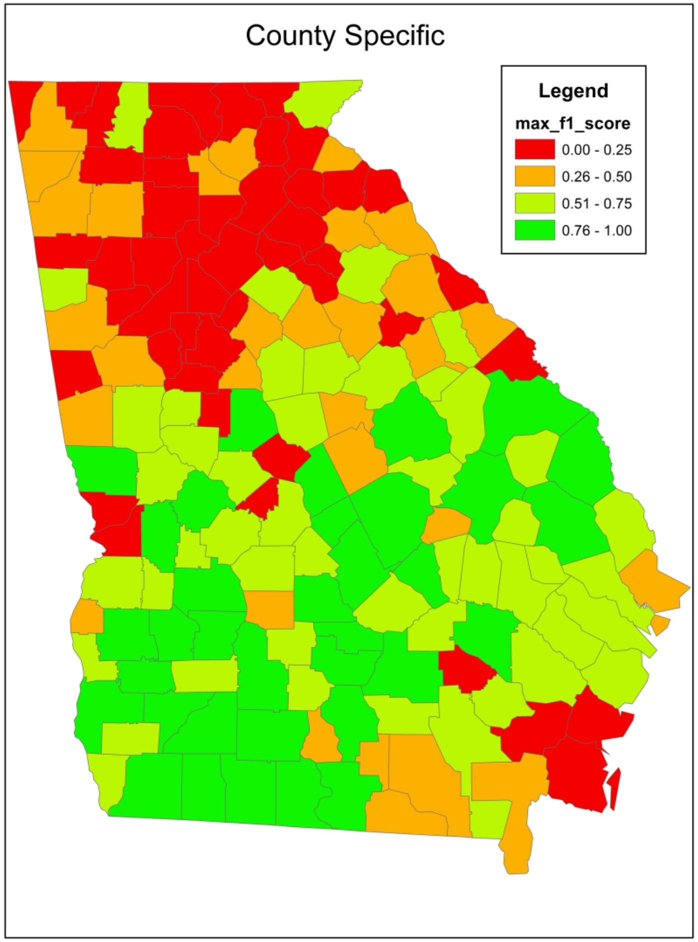


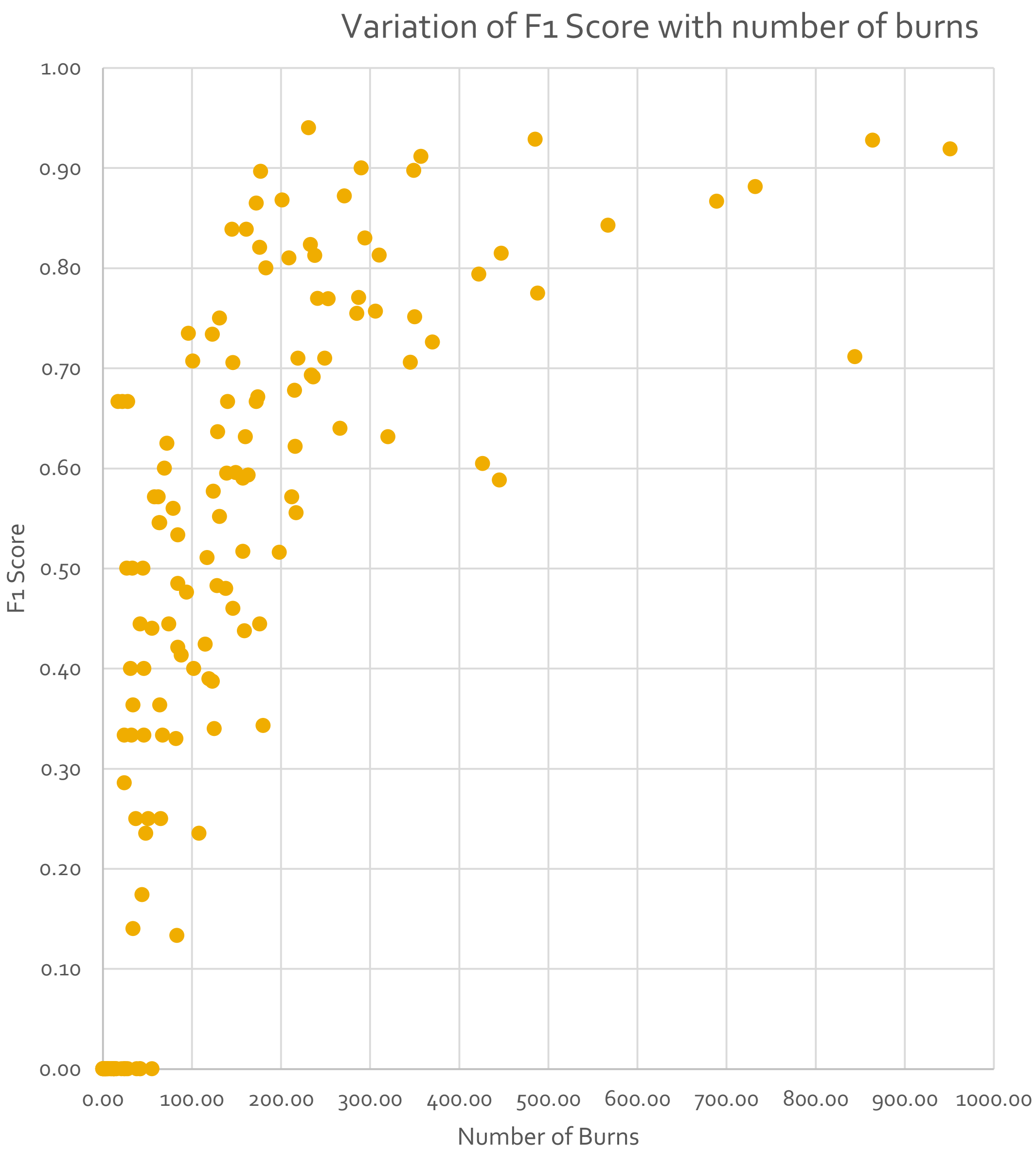
Legend

Max F1 Score

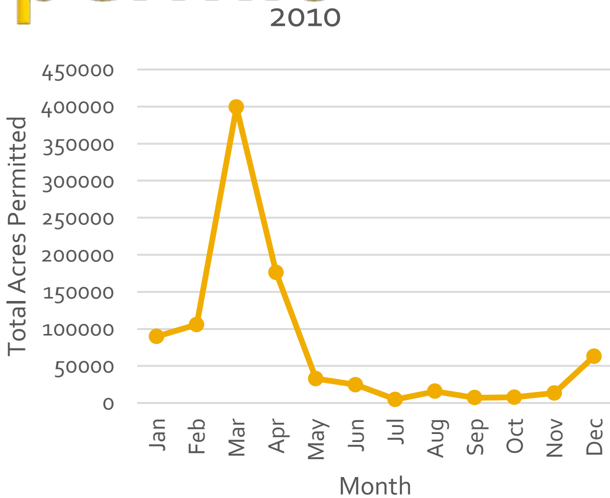
- 0.000000000 - 0.17
- 0.18 - 0.44
- 0.45 - 0.62
- 0.63 - 0.77
- 0.78 - 0.94

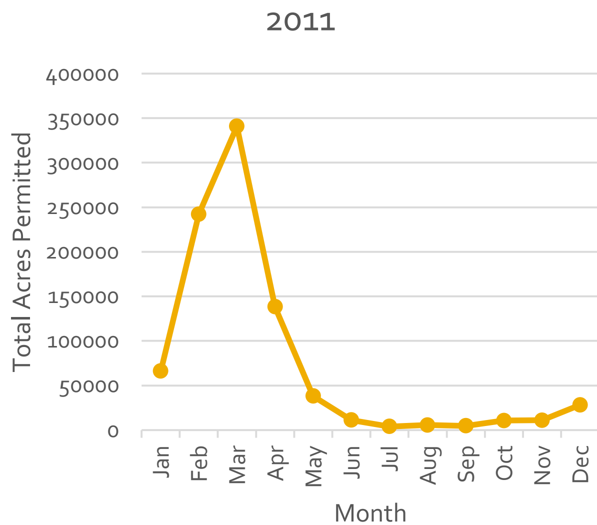
N

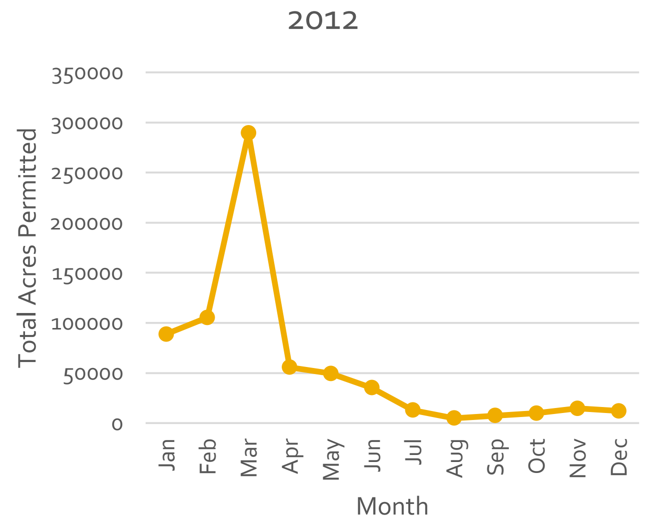

County Specific
Legend
max_f1_score
0.00 - 0.25
0.26 - 0.50
0.51 - 0.75
0.76 - 1.00

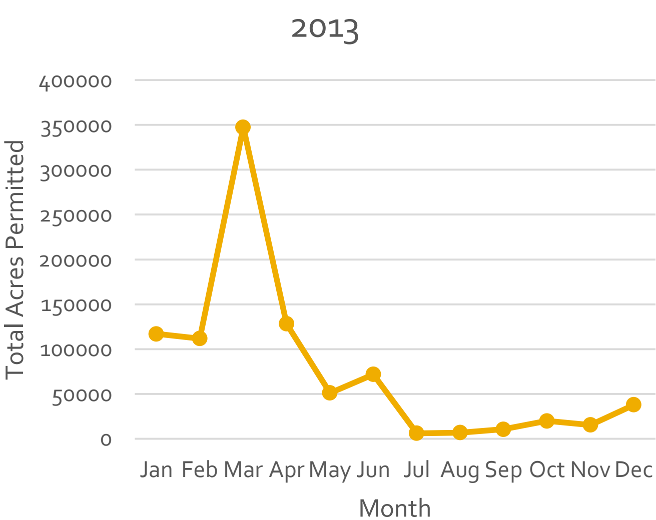

Variation of F1 Score with number of burns
F1 Score
Number of Burns
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
800.00
900.00
1000.00

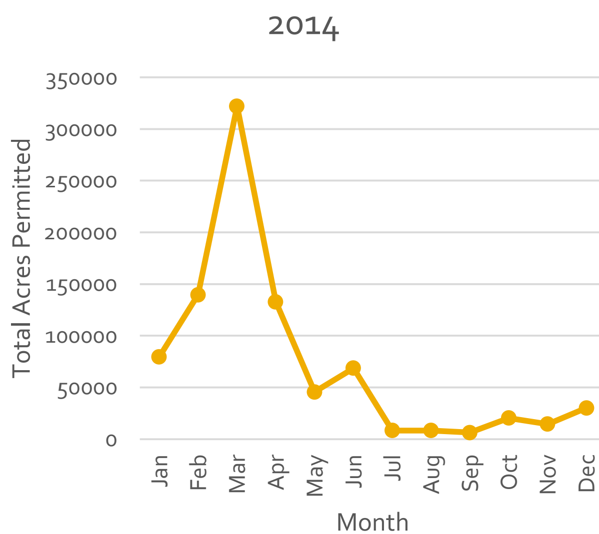
Monthly variation of burn permit











Assigning burn p

- Monthly avera