Apportioning Emission Source-group Impacts among Individual Sources through Dispersion Modeling: Application to Prescribed Fires

Ran Huang, Momei Qin, Yongtao Hu, Armistead G. Russell, M. Talat Odman*

School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta GA 30332

Background and Objective

- Prescribed burning is a land management tool commonly utilized in the United States (U.S.) to maintain healthy ecosystems and to reduce the risk of catastrophic wildfires. Southeastern U.S. is the most active prescribed burning area.
- We forecast daily prescribed fire impacts using the Community Multiscale Air Quality (CMAQ) model and Decoupled Direct Method (DDM), a sensitivity analysis technique for computing sensitivity coefficients simultaneously while air pollutant concentrations are being computed. (https://forecast.ce.gatech.edu)
- The current forecast is for the impact of all prescribed burns combined. However, fire managers need to know the individual impact of each forecast burn. If an exceedance is forecast, burns with larger potential impacts can be deferred to another day.
- Considering there are hundreds of burns in a state like Florida or Georgia every day during the burning season, computing the impact of every single burn with CMAQ-DDM would require massive computational resources. Another approach is to partition the combined impact to individual burns using dispersion models.

Method

- We developed a new method to split the impact of a source group into its constituents: Dispersive Apportionment of Source Impacts (DASI).
- DASI uses the pollutant fields predicted by dispersion models downwind of each individual source to apportion the total impact of the source group predicted by the Eulerian CTM as follows:

$$s_{i,j}^p = \frac{m_{i,j}^p}{\sum_{p=1}^{N} m_{i,j}^p} \times S_{i,j}$$

s^p is the individual impact of source p as vertical column mass of pollutant (in µg),
m^p is the vertical column mass of pollutant from dispersion modeling of source p (in µg),
S is the source-group impact from Eulerian CTM as the vertical column mass of pollutant (in µg),
i and j are the horizontal column and row indices for the vertical column, and
N is the number of individual sources in the group.

- We simulated four prescribed burns (each one is 200 acres) forecast for April 27, 2016 (Figure 1): one isolated burn (ID01) and the other three clustered (ID02–ID04).

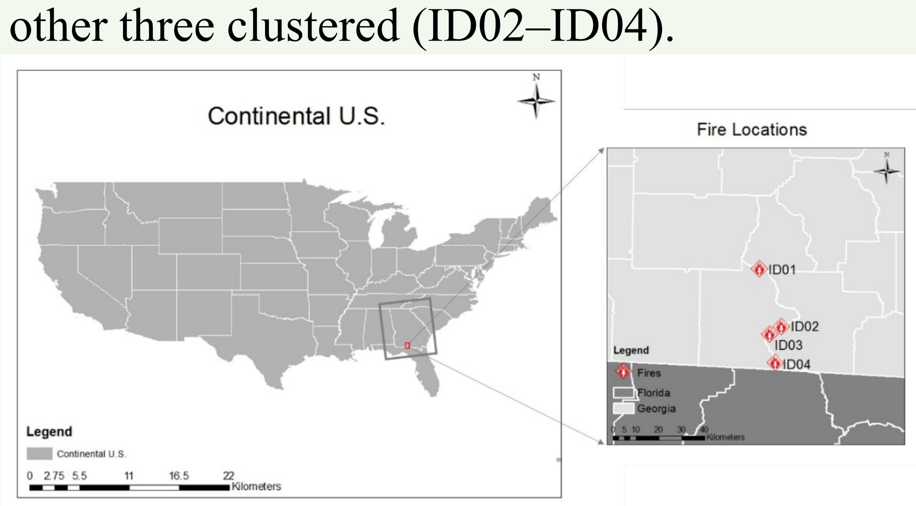

Figure 1. Modeling domain and locations of burns

- Models and configurations:
  Dispersion model: HYSPLIT 4 (Windows version)
  CTM: CMAQ v5.0.2 Resolution: 4km × 4km

Difference in Plume Distribution (Burn ID01)

- In HYSPLIT, almost all the mass is in the top two highest layers of the plume while in CMAQ-DDM the most concentrated layers are close to the ground (Figure 2). This difference in vertical plume distribution and the difference in the horizontal location of the largest concentration grid is mainly due to the difference in the dynamics of the two models.

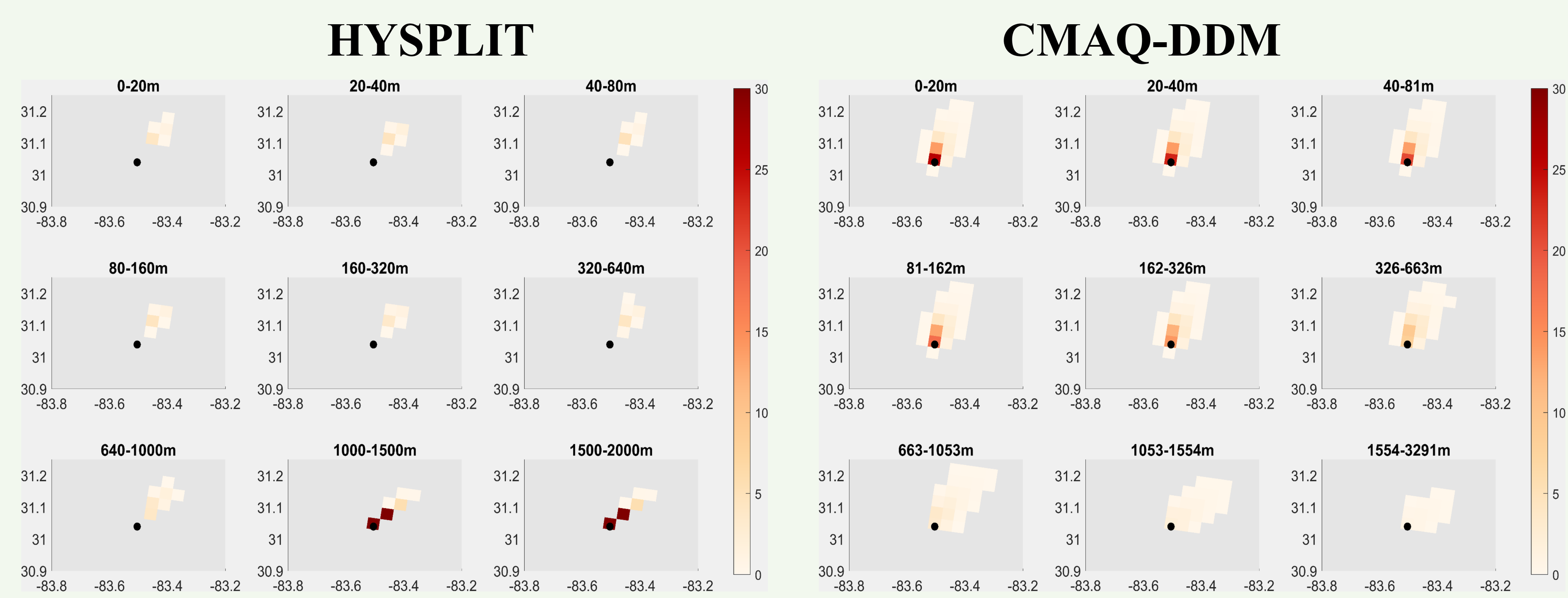

Figure 2. Different layer distributions of $PM_{2.5}$ from HYSPLIT and CMAQ-DDM

- In order to reduce the effect of the differences between the two models, the total vertical column masses are used in the formulation (Figure 3).

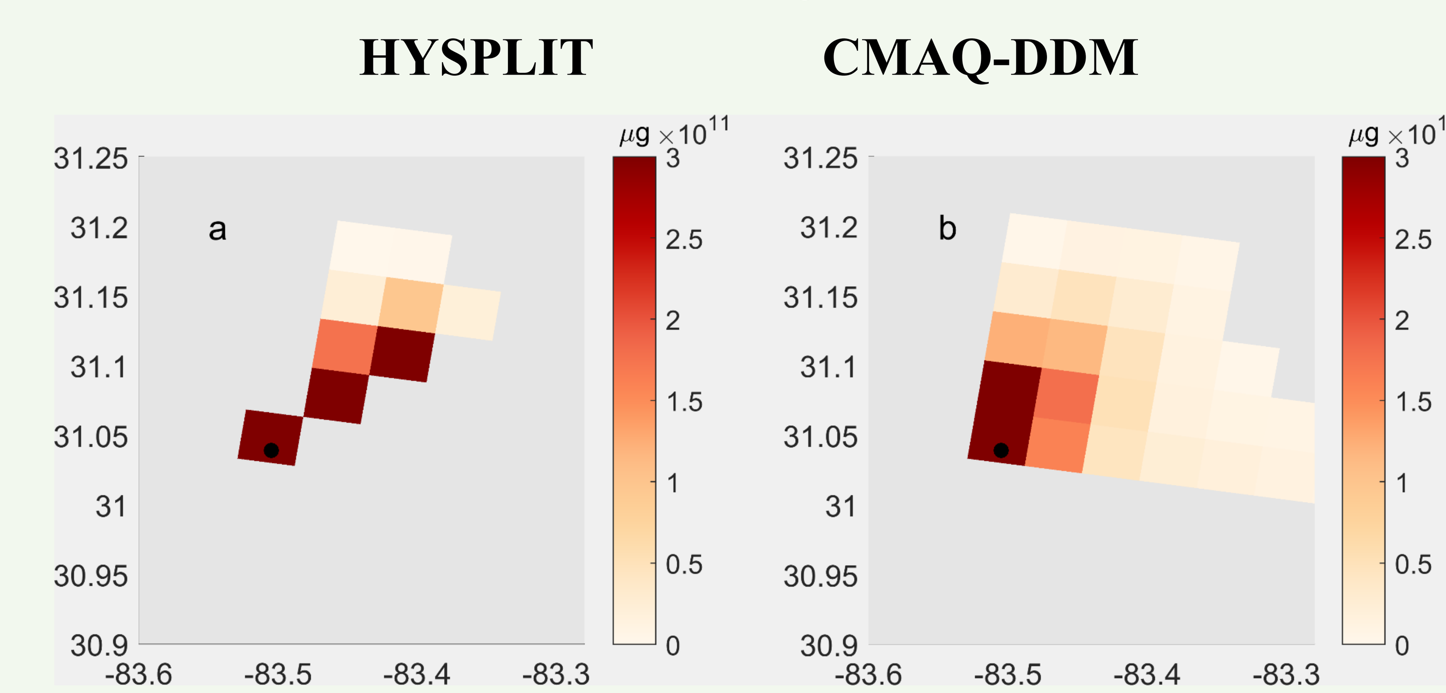

Figure 3. Vertical column mass of $PM_{2.5}$ for ID01 from HYSPLIT and CMAQ-DDM

- The highest concentration grid in HYSPLIT is downwind of the burn location, while in CMAQ-DDM, it is the grid where the burn is located.
- The horizontal extents of the plumes are also different. In this case $\sum_{p=1}^{N} m_{i,j}^p$ in Equation 1 can be zero for certain i,j for which $S_{i,j}$ is non-zero. Since this would lead to a division by zero, it is necessary to match the horizontal extent of the plume in the dispersion model with the one in the Eulerian CTM. This can be achieved by applying artificial diffusion to the column mass fields from the dispersion model. The following equation is applied iteratively to all $m_{i,j}^p$ until no $\sum_{p=1}^{N} m_{i,j}^p$ is zero for non-zero $S_{i,j}$:

$$m_{i,j}^{p\,*} = m_{i,j}^p + D\left(m_{i-1,j}^p + m_{i,j-1}^p - 4m_{i,j}^p + m_{i,j+1}^p + m_{i+1,j}^p\right)$$

D is non-dimensional artificial diffusion coefficient.

Acknowledgement and Contact Information

- This research was funded by the U.S. Environmental Protection Agency (Grant # RD8352170) and the Joint Fire Science Program (Project ID 16-1-08-1).
- For more information contact Talat Odman (*odman@gatech.edu*).

Nonlinear Interaction of Plumes (Burns ID02–ID04)

- The difference between the combined fire impacts on $PM_{2.5}$ and the sum of individual fire impacts from CMAQ-DDM is less than 1.3 µg/m³ (5%). This shows there is little non-linear interaction among the fire plumes.

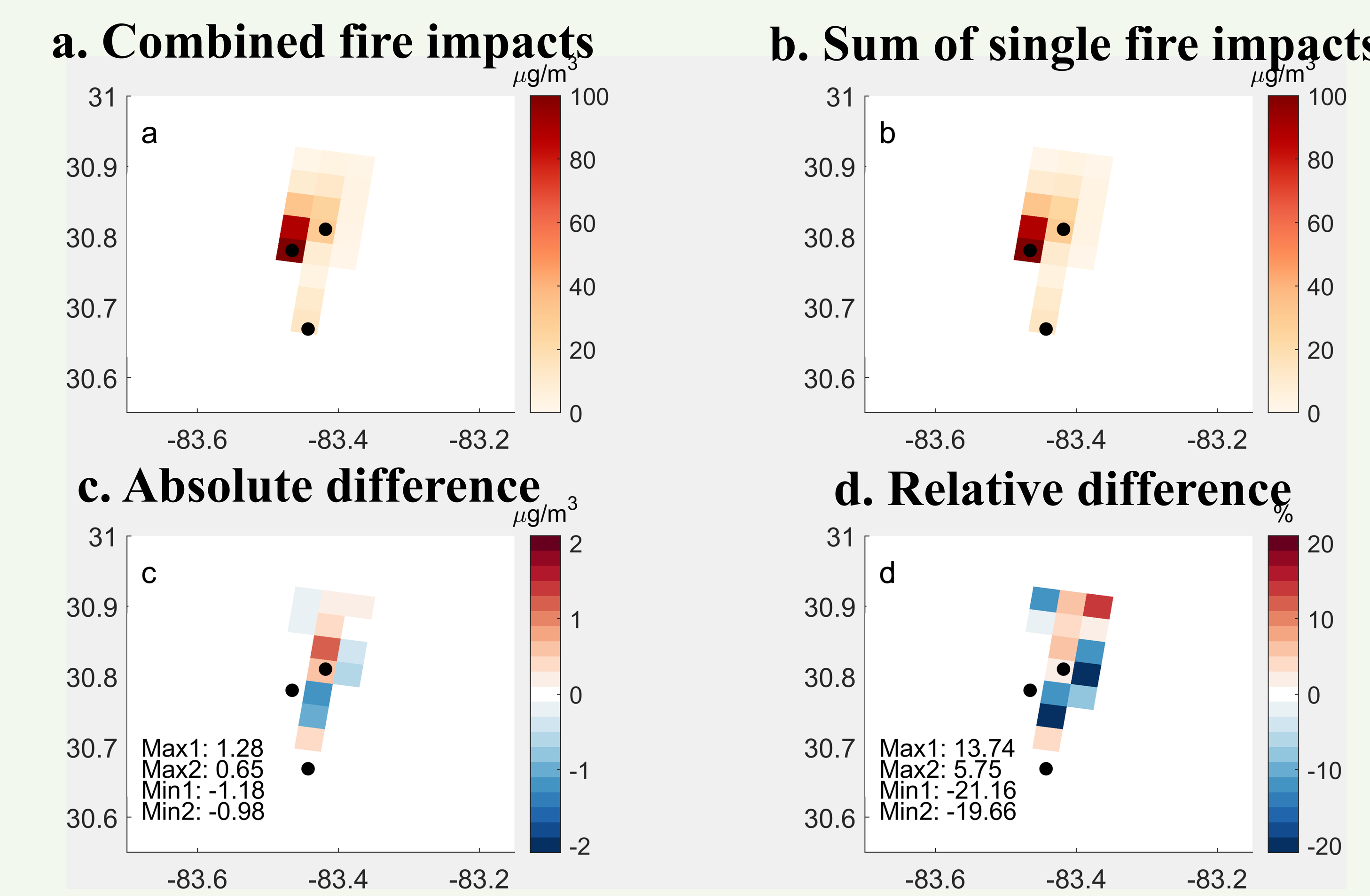

Figure 4. Comparison of the summation of individual burn impacts with the combined impact from CMAQ-DDM and the difference between those two

Evaluation: Comparison to Single Burn Impact (Burn ID03)

- For burn ID03, which has the largest impact of the three clustered burns, the difference between the split fire impact and single CMAQ-DDM impact is quite small with the absolute difference less than 2 µg/m³ (Figure 5).

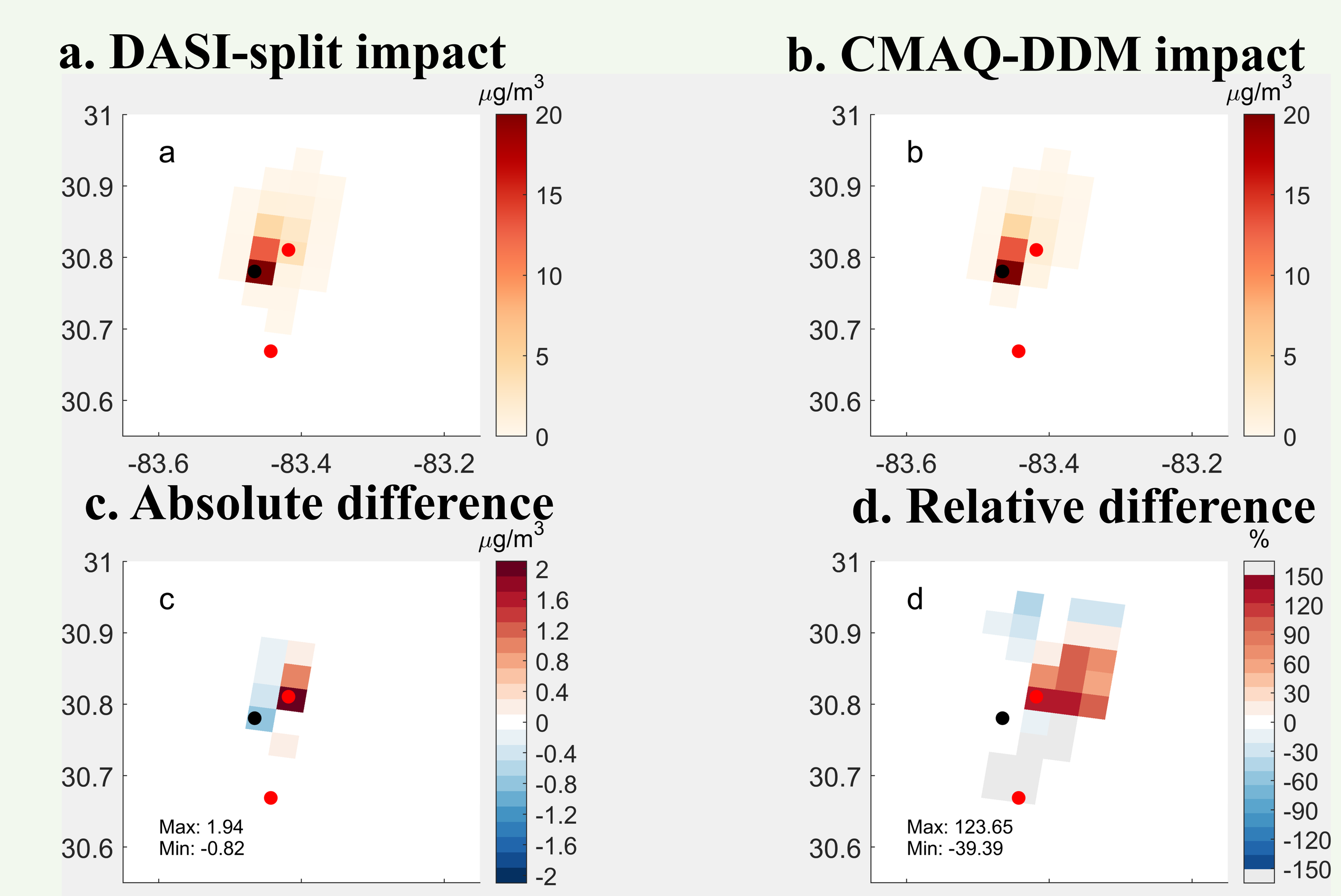

Figure 5. Comparison of the individual fire impact from DASI with the single burn impact from CMAQ-DDM

Conclusions

- A new source apportionment method (DASI) has been developed for prescribed fire impacts. DASI works well with fires that have small non-linear interactions.
- DASI could help land and air quality managers to quickly identify prescribed burns with the largest impacts on air quality and public health.