Review of manuscript egusphere-2024-1485

A Multi-site Passive Approach 1 for Studying the Emissions and Evolution of Smoke from Prescribed Fires

The goal of this project is to study the emissions and evolution of smoke from prescribed fires and provide data to test model simulations.

From conclusion: *This data set will be used to assess models predicting the impact of prescribed fires on air quality to enhance the use of prescribed burning in land management practices by minimizing impacts on populations*

General Comments

This paper describes an observational study of prescribed fire smoke conducted at Fort Moore in southeastern Georgia, US. Prescribed fire regularly is used on Fort Moore and in the region where the Fort is located. The stated goal of the study was to measure and characterize "the emissions and evolution of smoke from prescribed fires and provide data to test model simulations". The project deployed one ground-level, fixed location air monitoring station at Fort Moore during the 2021 prescribed fire season. During the 2022 prescribed fire season (Mar – May), four additional ground-level, fixed location sites were established. The monitoring sites measured CO, PM2.5, BC, BrC, O3 and NOx. (However, the NOx measurements are not reported in the paper.) The study utilizes meteorological observations from a Remote Automated Weather Station (RAWS) located on Fort Moore, Hysplit model trajectories driven by high-resolution (1-km inner domain) WRF simulations, Fort reports on fire activity, and satellite observations of active fires to determine the fires impacting the monitoring sites and estimate smoke age.

The paper reports emissions as normalized excess mixing ratios (NEMR), the excess mixing ratios of PM2.5, BC, and BrC normalized to CO, as is commonly done in biomass burning studies. The study focused on smoke plume events, defined as periods when 20-minute average PM2.5 levels > 35 ug/m3 and 40-minute PM2.5 levels > 30 ug/m3. A total of 64 smoke events were recorded across all sampling sites over the 2021 and 2022 deployments. This smoke event number is a count of sampling site level events, e.g. in 2022 a single fire could result in 5 smoke events if the smoke impacted all 5 sampling sites and resulted in PM2.5 levels meeting smoke event thresholds. For smoke events < 1 hour in age the NEMR are taken as emission ratios (ER) which represent the composition of fresh smoke. If concurrent CO2 measurements are available ER can be used to calculate emission factors (EF). The authors compare their ER results with previous, examine the variability of NEMR with smoke age, and identify and discuss instances of ozone enhancement. The authors also provide a summary of daytime versus nighttime ER, i.e. smoke measured during day when fires are presumed to be active versus smoke measured at night when fires are likely to be less active and probably smoldering dominated.

The observational dataset reported in the manuscript may be valuable for evaluating smoke dispersion and air quality model simulations of prescribed fires. However, the presentation of the data is incomplete, and it is unclear what crucial ancillary data may or may not be available for model evaluation. I also have some concerns regarding the method used for assigning smoke age. employed. Additionally, I believe there is room for the authors to expand some on their analysis and discussion. Below, I elaborate on these comments and provide a few suggestions to the authors for strengthening the paper. Then I provide specific comments, followed by recommendations for technical corrections.

Study goal(s). What kind of models will be tested? The authors do not describe the types of models for which their study is intended to provide evaluation data nor how their study's observational dataset could be used to evaluate these models. The uses of the ambiguous target models are not discussed. In the introduction the authors need to address the following: what are the target model(s), what are these models used for, in what ways do these models need improvement and/or evaluation, and how will this study's observational dataset meet these model evaluation needs and potential lead to improved models. This information is crucial for determining how the study results meet the study purpose: "The goal of this project is to study the emissions and evolution of smoke from prescribed fires and provide data to test model simulations."

A critical component to making this data useful for model evaluation is knowing the fire ignition times and, when possible, the duration of active fire. Also, more specific info on the type vegetation and fuels that were burned and when the previousprescribed burns took place. This information can be useful in estimating fueling loading, which is needed for bottom-up estimates of emission fluxes which are need for model evaluation.

For fire events detected by MODIS/VIIRS, verifying that the preceding satellite overpasses had a clear view (not clouds) of the site but did not detect active fire, can help narrow the window of possible fire ignition time (e.g. Fig S7).

Is it possible to obtain more detailed information from Fort Moore on the prescribed fire events such as ignition time, ignition method, ignition duration, unit area? This information would be very useful, perhaps even necessary, to use the smoke event observations for model evaluation, which is the stated goal of this project.

Data collected. It is quite unfortunate the study did not include CO_2 measurements. High quality CO_2 mixing ratios can be easily measured using LiCOR CO_2 instruments. These instruments are inexpensive, easy to maintain and operate, and are designed for extended duration, unattended atmospheric measurements as were conducted in this study. CO_2 measurements are used to calculate modified combustion efficiency, MCE (Urbanski et al. 2022) an index of the relative mix of the flaming and smoldering emissions in a smoke sample. MCE is widely used to compare burning conditions between emissions studies, between fires, and temporally for individual fires. MCE can be very useful in understanding why ER vary among different studies or different fires within study. The lack of MCE measurements somewhat limits what can be learned from this study and how the finding might be applied in modeling studies. Further, CO_2 measurements would have allowed for calculations of emission factors, EF (Urbanski et al. 2022) (The long-term background CO_2 measurements would have allowed the authors to account for diel and seasonal variations in background CO_2.) Having EF would have enabled a more comprehensive and enlightening comparison of the current study with previous studies. Further, EF are needed for bottom-up emission flux calculations that are input to smoke dispersion and air quality models. To use the study dataset in smoke dispersion or air quality models, the authors will need to estimate, based on other studies, what the EFCO are in order to derive EFPM2.5 and EFBC for calculating emission flux rates of these pollutants. Also, for simulating O3 or SOA formation processes, VOC emissions profiles are needed. MCE can be very is useful for estimating VOC emissions when EF for VOC were not measured. The authors will be unable to do this easily due to the absence of CO2 measurements.

Even without CO2 measurements, the study has solid potential to improve understanding and modeling of emissions and smoke transport for prescribed fires in the Southeastern US. However, the description and inventory of data available for this study is incomplete and the presentation needs to be improved. This needed to better demonstrate how the study addresses the study goals of elucidating emissions and evolution of smoke from prescribed fires and providing data for model evaluation.

Additional data. The following ancillary data would be of great value, and in some cases is necessary, to utilize the smoke measurements for a robust evaluation of smoke dispersion or air quality models.

Fort More fires, if available:

- Burn unit – Area of unit burned, centroid of burn unit or burned area polygon, forest/vegetation type and fuel type information, including if mechanical fuel treatments were conducted on site, and date of or time since previous prescribed fire.
- Burn conditions - ignition start time, ignition method, and end time of ignition, and fuel moistures

Satellite data – MODIS/VIIRS overpass times, number of active fire detections per pass and FRP for all fires that impacted the monitoring sites. Including overpass that did not record an active fire but occurred during the time-period in which a fire generated emissions that impacted monitoring sites is useful as well along with cloud cover info from imagery or RAWS and Colombus airport observations.

Smoke age – the reported smoke age needs to be clarified as discussed below in specific comments. However, once clarified, including the estimated emission time or time window for each smoke event would be of great use in addition to estimated smoke age alone.

I recommend the authors compile expanded tables in the supplement that includes as much of the above information as possible for each smoke event.

Specific Comments

L28-42: See the surveys of prescribed fire use prepared by the Coalition of Prescribed Fire Councils and the National Association of State for specific info on acres of prescribed fire use in the Southeastern US (https://www.stateforesters.org/newsroom-category/publications/) :

2021 Survey

2020 Survey

2018 Survey

L43-52: The authors should provide background on the use and air quality impacts of prescribed fire in the Southeast US. See for example: Afrin & Garcia-Menendez, 2020; Larkin et al., 2020; Bian et al., 2020.

L53: “Both wildfires and prescribed fires emit a large variety of gases and particulates (Liu et al., 2017b; Burling et al., 2011).”

Update references with Gkatzelis et al. (2024); Permar et al. (2021) (wildfire) and Travis et al. (2023) (prescribed fire).

L56: “PM2.5, (particulate matter with aerodynamic diameter of 2.5 micrometers or smaller), is directly emitted as primary particles and also formed from condensation of emitted gases and their oxidation products, where a major component is secondary organic aerosol (SOA) (Liu et al., 2016; May et al., 2014).”

Needs revision. 1) SOA is not always a major component of aged biomass burning PM or necessarily the primary fate of emitted organic gases and 2) the volatile nature of organic PM must be mentioned, especially the fact that both primary and secondary PM can evaporate, reducing PM as a plume ages.

L59-61: “PM2.5 exposure has been linked in many epidemiological studies to serious health problems such as respiratory, cardiovascular, and neurological diseases, as well as increased risk of adverse birth outcomes (Liu et al., 2015; Reid et al., 2016; Naeher et al., 2007).”

Recommend one or two newer sources and perhaps a couple studies related specifically to wildland fire smoke and maybe even prescribed fire smoke.

L63-71. This section could use some cleaning-up. E.g., brief overview of active fire detection, burned area, and FRP to estimate fire location, burned area, fuel consumption, and emissions.

L72-L74: "Aircraft (fixed wing and helicopters) and more recently drones are commonly used in airborne studies of wildland fires (Decker et al., 2021b; Cubison et al., 2011) and have been deployed for prescribed burning studies (Yokelson et al., 1999; May et al., 2014; Pratt et al., 2011)."

Recommend UAS references, e.g. Aurell et al 2021; 2023

L79-86: See Fiddler et al 2024 and refs therein re: FIRE-EX AQ ground-based mobile emissions measurements.

L87-91: Authors should note there are several studies where wildfire smoke fortuitously impacted atmospheric chemistry labs or pre-existing monitoring locations, see as example Selimovic et al. 2019. Also consider noting that regulatory air monitoring sites, despite their limited measurement suites, can be very valuable in studies of smoke impacts (see any of several pubs by Dan Jaffe from U Wash.).

L104-116: This is a very good description and informative background on the Fort. Is it possible to include a description of tree species that dominate the uplands and bottomlands? Also, is prevention of wildfires the primary purpose of prescribed burning or are there also ecological objectives e.g., restoration/maintenance of longleaf pine, etc.?

L138-139: "Calibration of CO analyzers was performed before and after each field study using a 100 ppm CO in air standard purchased from nexAir (Memphis, TN)"

100 ppm seems quite high for ambient air monitoring. Did you verify the instrument precisions, accuracy, and stability (e.g. pre- and post-burn-period) with CO standards typical of ambient air and the CO levels observed in the smoke events during your study?

L140-142: "O3 was measured using an ultraviolet (UV) photometric analyzer (Thermo Fisher Scientific Inc, model 49C, Franklin, MA)"

Is this an instrument found to have artifacts in smoke impacted environments? See: https://research.fs.usda.gov/treesearch/63344

L151-152: "The TEOM is a US-EPA approved instrument for measuring the mass concentration of ambient PM2.5 and PM10 (Liu et al., 2017a)."

Please note TEOM model number. Also, I believe the authors mean that the TEOM used may also be used for Federal Equivalent Method (FEM) regulatory measurements: https://www.epa.gov/sites/production/files/2019-08/documents/designated_reference_andequivalent_methods.pdf

L153-154: "The sample air is preconditioned to a temperature of 50 °C to remove liquid water interferences."

Please confirm that these are typical/recommended operating flow temperature. Interesting considering Pagonis et al. (2023) who found that when smoke samples were "heated to 40–45 °C in an airborne thermal denuder, 19% of lofted smoke PM1 evaporates"

L161-162: "Regional hourly PM2.5 mass was reported at two Environmental Protection Division (EPD) sites."

Please note the PM2.5 measurement techniques employed at these regulatory monitoring sites.

L179: Can the authors cite a good BrC review for the readers?

L178-195: Why not use 370 nm for BrC determination? What have previous studies done?

L228-229: "Also, small or relatively cool fires may not be detected, especially when there is significant cloud coverage or thick smoke"

The authors should note that for prescribed understory burns in forests, the focus of this study, a continuous, thick forest canopy may also obstruct satellite detection.

L217-230: It's unclear why they need active fire detections to identify location and timing of prescribed fires on the base. Did the authors not have access to the location, size, start and end times of prescribed fires conducted on the base during their study?

L243-251: Unfortunate all TEOM were not inter-compared as this can identify an outlier unit. Collocation at an ambient air monitoring site is a good way to gain an additional check instrument performance.

L275: Should provide definition of 'peaks' here.

L277-281: For 2022, please also note the number of days on which when PM smoke events were observed.

L282: "We focus on the larger smoke plumes…"

This should be rephrased. The focus is on smoke events with PM peaks of > 35 ug/m3 for 20-min mean and > 30 ug/m3 for a 40-minute mean. Such events could result from a plume "small" in volume (or a fire "small" in size) but concentrated due to location of fire, transport conditions, and emission production rates.

L289 – 290: For comparison, please note the correlation between PM2.5 and CO, BC, and BrC for no-event periods. Also, clarify if non-events data points include all observations during the entirety of the measurement periods.

L295-296: "When a smoke plume is identified the goal is to link it to a specific burn area and determine the transport time."

This is also important for using the dataset to evaluate smoke transport/dispersion models.

L296-297: "…we had limited beforehand information on the timing and location of planned burns."

Does the research team have access (after the fact) to the location (burn unit centroids), unit area, and ignition time of the burns? This is critical information that should be easily obtained from the Fort's land management / fire management team.

L352-358. **Smoke age determination. It is unclear how to interpret the smoke age.**

This needs to be clarified.

For the example given in Fig. 5, the duration of the three smoke events are 8 hours, 14 hours, and 8 hours. For all three events, there are changes in wind speed and direction of the 8 -14 hours of the events. Why were the trajectories shown in Fig 5. initiated at the times selected? The trajectory start times relative to the start of each smoke event are ~ 2:40 h 4/7, ~0 h on 4/7, and ~3 h on 4/8. Also, temporally, what wind observations were used in the Fig 5 analysis? Given the long duration of the events and accompanying variability of the winds, the smoke age will vary over the event. If the authors want to report the average smoke age for the events, the age should be based on some temporal averaging across the events' durations. The authors need to describe what exactly they believe their "smoke age" is intended to represent.

L364: "The substantial difference between modeled and observed winds suggests that relying on the wind vector based on observed winds is more reliable in this instance."

Please provide reasoning for this statement. The mere existence of a substantial difference between the two methods does not suggest the observed wind method is more reliable than the model wind method.

Did the authors consider using the Colombus airport receptor site as an additional comparison of the observed wind and hysplit model approaches to some age?

Also, comparison of the WRF model winds versus the Colombus airport wind observations may provide some insight the model performance.

L368-373: Forest canopy can have significant effects on winds (see Mallia et al. 2018; Huang et al. 224)

L415-420: In instances like this, when the source fire is very close to the receptor, transport near the surface may be heavily influenced by fire – atmosphere interactions. It is very possible that neither the RAWS (located some distance away) or the WRF simulations will be a good indicator of atmospheric flows this close to an active fire.

L420-435: The authors should note that the emission production rate and fire convective energy/plume rise would also be expected to have a large impact on the concentration measured downwind. In the case of the April 4, 2022, nighttime event it is likely the smoke was produced by a mostly smoldering fire and released into the atmosphere with very little convective energy and was trapped in the shallow PBL.

L430-432: “The much higher PM2.5 mass concentrations measured on April 4, 2022 suggests that the trailer received a more direct smoke hit on that day than on February 11, 2022 or February 12, 2022, despite the fire being closer on February 11 and having a very similar distance to the one detected on February 12.”

L459-460: “The ages of the smoke detected based on wind vector analysis were 266, 296, 330 and 480 minutes, for the various trailers”

Are the differences in smoke age between the trailers consistent with the observed difference in the smoke arrival time?

L480-502:

The ERPM2.5 reported in Yokelson et al. 2011; Yokelson et al. 2009; Akagi et al. 2012, and Burling et al. 2011 were based on nephelometry measurements. Later analysis of aerosol mass spectrometer data taken on some of the same flights (May et. al 2014), found that nephelometry-based measurements did not provide a reliable measure of PM2.5. I recommend removing these datasets from your discussion. Doing so may impact your assessment of differences between airborne & ground-based measurements on prescribed fires.

I also recommend including Travis et al. (2023) in this discussion as the study includes many Southeastern U.S. prescribed fires.

L498-502: The discussion of aerosol mass from evaporation of semi-volatile aerosol particle components is important. It should be noted that plume dilution can also lead to evaporation, perhaps offsetting the cooling effect of a lofted plume (e.g. May et al. 2013; May et al. 2015; Sinha et al. 2022). I encourage the authors to consult these studies as well as Pagonis et al (2023) and consider expanding this discussion.

For fresh smoke, BC to PM2.5 ER and NOx to PM2.5 ER would be interesting as they may provide information about fire behavior, e.g. yields of BC and NOx per unit mass of fuel consumed would be lower for smoldering dominated fire compared with flaming dominated fires.

The April 21, 2022, event seems very interesting. What about FRP? Fuel type? Burning conditions? Can the authors expand the discussion of this event?

L547-548: "…PM2.5 mass concentration NEMR consistently increases with physical age ($r2=0.65$), evidence of secondary aerosol formation through a photochemical process that directly involve O3…"

This doesn't provide evidence that the process resulting in increased PM2.5 NERM results from a photochemical process that **directly involves O3**. Please propose a mechanism and/or site appropriate studies to support this statement.

L550 – 577:

The ERPM2.5 reported in Yokelson et al. 2011; Yokelson et al. 2009; Akagi et al. 2012 were based on nephelometry measurements. Later analysis of aerosol mass spectrometer data taken on some of the same flights (May et. al 2014), found that nephelometry-based measurements did not provide a reliable measure of PM2.5. I recommend removing these datasets from your discussion. Please refer to May et al. 2014 re: the aerosol emissions originally reported in the Akagi et al. 2012 study.

Please include Garofalo et al. (2019) and Pagonis et al. (2023), these papers are very relevant to this discussion.

L581-583: "Satellite images do not show any visible differences in vegetation between the forested areas burnt on and off the base. Additionally, no further information regarding the fuel types in the off-base lands could be obtained."

Please note what satellite imagery was used. Also, the authors could consult recent vegetation maps (e.g. LANDFIE, https://www.landfire.gov/) which may provide a more sophisticated assessment of the vegetation (e.g. forest type) and potential fuel loading (https://www.landfire.gov/fuel) than is possible from visual inspection of imagery by a non-expert.

L604-612: It *may* be worth including the lab study of Selimovic et al. (2018) in this discussion, something for the authors to consider.

615-616: "The method was successful in capturing a significant number of smoke events (64)."

Include the number of days on which smoke events were successfully measured.

617: change 'determined' to 'estimated' (the two methods used at times yielded very different smoke age estimates)

L617-618: Would be useful to include the number of fires for which smoke events were measured.

Figures

Maps need scale bars!

Figure 1. Nice figure, but please add scale bar.

Figure 3. Regression line in missing in panel b.

Figure 10. Since wind vector and hysplit are on same scale (as they should be) maybe use just one set of labels (smoke age) for the x-axis. Is the ozone enhancement plotted versus wind vector age or hysplit age? Please clarify in caption.

Supplement

Fig. S6. Was all or most of the area within the burn units (gray shaded polygons) burned? Please add a scale bar to 6a. What is the native and displayed resolution of the Colombus airport and PCSG school monitoring sites? In tables S3 & S7, please state the reason for the missing CO observations.

Table S8. Please clarify in table heading that listed overpass times are local time.

Technical:

L132: suggested text change to: "used as a tracer of smoke movement and dispersion". Also, it may be worth noting that CO is used as a standard tracer of combustion sources in atmospheric chemistry studies.

L334: "from the northwest, west, and southwest" change to "westerly" ?

L614-615: "We describe a ground-based measurement method for characterizing smoke from prescribed fires based on continuous monitoring at multiple sites for an extended period in a regularly burned region."

Suggest changing 'ground-based measurement method' to 'ground-based observational study'

L620: maybe change "conservative parameter" to "conserved co-emitted species"?

L629: "indicating combined secondary O3 and particle mass formation" change to "indicating the formation of O3 and secondary organic aerosol"

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