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Emissions from southeastern U.S. Grasslands and pine savannas: Comparison of aerial and ground field measurements with laboratory burns



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HIGHLIGHTS

- PM_{2.5}, BC, BrC emission factors were marginally higher from ground vs air samples.
- BC and BrC emission factors increased with modified combustion efficiency.
- EC emission factors were over 40% lower than BC values.
- Laboratory testing showed lower PCDD/PCDF emission factors than field testing.

GRAPHICAL ABSTRACT



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ABSTRACT

Emissions from prescribed burns of a managed longleaf pine (*Pinus palustris*) forest and grass/savanna fields in western Florida were measured by simultaneous aerial and ground sampling. Results were compared with measurements made in an open burn laboratory test facility using biomass gathered from the same stands. Measurements included polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), particulate matter (PM_{2.5}), elemental carbon (EC), organic carbon (OC), black carbon (BC), brown carbon (BrC), polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs). The flaming phase (high modified combustion efficiency) was characterized by high levels of BC and BrC yet low levels of VOCs. In general, ground-based measurements of PM_{2.5}, BC, and BrC reported marginally higher emission factors than those measured in the plume by aerostat (balloon)-lofted instruments. The optically-determined BC emission factor was approximately ten times higher than many previously reported results. Simultaneous BC and EC measurements showed that EC values were, on average, 42% lower than the BC values, lending uncertainty to the common use of EC measurements as a BC surrogate. PAH emission factors were indistinguishable across the sampling scenarios, while PCDDs/PCDFs saw a significant decline in the laboratory testing. Limited distinctions in particle-related emissions between aerial and ground measurements

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suggest sampling bias between these methods. Emission factor distinctions between laboratory burn simulations and field tests appear primarily related to lower combustion efficiencies in the latter, perhaps due to higher biomass moisture or surface wetness.

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1. Introduction

Wildfires and prescribed burns generate a variety of emissions that can cause adverse health effects for humans, contribute to climate change, and decrease visibility. Prescribed burns are prevalent in the Southeast U.S. to reduce fuel buildup, improve the habitat for animal and plant species, minimize spread of disease, and reduce the risk of wildfires. Measuring air emissions and deriving emission factors from prescribed burns are important because they provide data to better understand effects of fire on air quality, as the emission factors are used in national emission inventory calculations, air climate change models, and risk assessments. Wildland fires are one of the largest sources of particulate matter in the U.S.A (U.S EPA Average annual emissions, all criteria pollutants, June 2012). Light-absorbing carbonaceous aerosols known as black carbon (BC) are considered to be one of the major contributors to the global climate change (Ramanathan and Carmichael, 2008). Elemental carbon (EC), sometimes used interchangeably with BC despite measurement by different means (thermal-optical versus optical/aethalometer), is an indicator of combustion extent. The light-absorbing organic matter aerosols referred to as brown carbon (BrC) are possible global warming agents (Alexander et al., 2008; Andreae and Gelencser, 2006; Kirchstetter et al., 2004) that are starting to get more attention. Volatile organic compounds (VOCs) from combustion such as benzene, and semi-volatile organic compounds such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), include pollutants with properties that are toxic, carcinogenic, bio-accumulative, and persistent in the environment.

Measuring air emissions from actual field burns is challenging due to variation in plume height, changes in wind direction, and safety for sampling equipment and personnel, all of which may limit the time the sampling equipment can spend in the plume. Emissions can be measured in the field by aerial or ground based sampling platforms or, alternatively, in laboratory test facilities using fuels from the landcover of interest. Aerial measurements are important when plumes are lofted and when ground-based sampling may create a bias toward measuring less intense fire behavior, including the, smoldering phase of the burn, which could strongly influence emission factor estimates. Laboratory measurements are utilized when field measurements are impractical or costly and when species-, phase-, and condition-specific burn data are desired.

Emission sampling is typically separated into flaming (good combustion) and smoldering (poor combustion) phases, as each has reasonably distinctive emission factors. Samples gathered at distance from the flame front may be a mix of both flaming and smoldering combustion phases as the flaming stage and post-flame smoldering emissions are mixed and entrained into the plume. Aerial measurements are more likely to generate a composite sample of flaming and smoldering emissions than would be produced from point source measurements on the ground. Collection of ground based samples may be biased toward the smoldering phase because they are more amenable to safe sampling and equipment survival than intense flaming phases. In addition,

convective mixing of the plume is limited potentially segregating heavier particles from gases. Further, the ground-sampled sampled pollutants may have less aging and are less likely to have been affected by atmospheric chemistry such as formation of secondary organic aerosols (Cubison et al., 2011). Evidence for differences between emissions sampled from airborne and ground-based platforms was observed for hydrocarbons and oxygenated organic species by Burling et al. (Burling et al., 2011). Methods for aerial and ground measurements were demonstrated during three southeastern U.S. prescribed burns (Aurell and Gullett, 2013). Initial reporting of concurrent application of these aerial- and ground-based measurements (Strand et al., 2015) showed little difference in a variety of pollutants, but only single aerial samples were available for comparison.

Due to their small size and controlled combustion conditions, laboratory tests can have the advantage of allowing both species-specific studies and separate measurements of different combustion phases. Comparability between laboratory and field emission data has been demonstrated for African savanna fires (Christian et al., 2003) and extensively covered by Yokelson et al. (Yokelson et al., 2012). Differences observed in laboratory versus field emission factors have been attributed to higher modified combustion efficiency (MCE, $\Delta\text{CO}_2^*(\Delta\text{CO} + \Delta\text{CO}_2)^{-1}$) values in laboratory burns (Christian et al., 2003) of African savanna fuels. When they account for MCE, laboratory-based emission data predict emission factors within 15% of the field values.

Work reported here, part of a comprehensive study to develop a fire and fuels dataset (Ottmar et al., 2013), aims to elucidate whether differences exist in multipollutant emission factors derived through concurrent aerial and ground sampling as well as laboratory combustion tests using fuel from the same field sites. Potential differences would need to be further explored in order to understand the causes of these biases and to guide further sampling for determination of accurate and representative emission factors.

2. Experimental section

2.1. Sampling method and instrumentation

A light-weight instrument package termed the “Flyer” was attached to a helium filled, tethered aerostat (4.3 m in diameter) mounted to an all terrain vehicle (ATV). A second identical Flyer was mounted on an ATV approximately 2 m above ground level. The use of the aerostat and Flyer instrumentation with the ATV has been described in detail elsewhere (Aurell and Gullett, 2013; Aurell et al., 2011). In summary, the instrumentation on the Flyer consisted of: non-dispersive infrared for continuous measurement of carbon dioxide (CO_2) (LICOR 820, LICOR Biosciences U.S.A), light-scattering photometers for continuous $\text{PM}_{2.5}$ (DustTrak 8520, DustTrak DRX, TSI Inc. U.S.A), micro aethalometers for BC and BrC (AE51, AE52, Aethlabs, U.S.A), SUMMA canisters for VOCs, CO_2 , and carbon monoxide (CO) (Columbia Analytical Services – CAS, U.S.A.), batch sampling of $\text{PM}_{2.5}$ onto a 47 mm in diameter Teflon filter (pore size 2 μm), batch sampling onto quartz filters for EC, OC, and TC measurements, and batch sampling of PCDDs/PCDFs onto a

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