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DETAILED ANALYSES OF EMISSIONS FROM PEAT COMBUSTION ACROSS BIOMES

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SUMMARY

The multifaceted impacts of fires in peatlands have attracted global attention and concern in recent years. Documenting the nature and effects of combustion products from peatlands has been a particularly active area of work, although detailed analyses of emissions are still needed. Our research includes a focus on the chemical composition and the physical and optical properties of particulate matter emissions from peatland fires. We will present detailed emissions work conducted across a wide range of peatland fuels from boreal, subtropical, and tropical peatland ecosystems. Although many similarities exist, we will highlight important differences in combustion emissions observed across the climatic range of our fuel sources and describe some of their implications. Also, we will discuss some of our initial efforts to address challenges facing future emissions research, such as proposing criteria by which to prioritize fuels for detailed emissions analysis.

Keywords: *fire; smoldering, emissions, carbon, atmospheric science*

INTRODUCTION

With carbon stocks rivaling those of Earth‘s atmosphere (5-6 x 10^{17} g; Gorham 1994, Page *et al.,* 2011), the organic soils in peatlands represent one-fifth to one-third of the planet‘s terrestrial organic carbon. The importance of these ecosystems in the global carbon cycle is therefore highly significant, despite peatlands occupying only 2-3% of the Earth‘s terrestrial surface (Yu 2012). The significance of peatlands includes economic, agricultural, and ecological values, and this study relates to the multi-scale importance of fire in peatlands from the standpoint of carbon, climate, and air quality.

Peatlands generally accumulate organic carbon due to wet conditions under which decomposition is slower than biomass production. Therefore, fire in these ecosystems is a very infrequent occurrence, with naturally-ignited fires (*i.e.,* from lightning) recurring only on the order of every 100-1000 years in many of the tropical, temperate, and boreal biomes. When fires do occur, they can be categorized generally into two types: surface fires, which burn aboveground vegetation and, due to high soil moisture, are characterized by short duration, low intensity, and low to moderate severity; and ground fires, which occur during periods when soil moisture is sufficiently low to permit fires to become established in the organic soils of peatlands (Watts and Kobziar 2013). These ground fires, where smoldering combustion of peat soils can result in considerable loss of soil via combustion over extended periods (Rein *et al.,* 2008), and the effects from their emissions, are the focus of this study. (Here, the term ―peatland fire" is used to refer to the smoldering ground fires that occur in peatlands.)

At local scales—at the site of a peatland fire and within a distance of 100km, the extended duration of these fires, their production of smoke during nighttime when winds are generally calm, and the difficulty of extinguishing them lead to health concerns from their impacts on air quality (Rappold *et al.,* 2011). At global scales and over long time scales, emissions from peatland fires are a concern for their potential to contribute to global climatic change, both because of the magnitude of emissions and the nature of those emissions. For example, the infamous 1997-1998 fires in Indonesia were estimated to have released carbon emissions equivalent to 13-40% of annual fossil fuel emissions for that year (Page *et al.,* 2002). Also, previous studies have identified smoldering as a major contributor of aerosols and particulates compared to flaming combustion, owing to less efficient combustion and lower temperatures encountered during smoldering (Hadden 2011). Peatland fires can emit up to six times more aerosols per unit carbon consumed than flaming grassland fires (Page *et al.,* 2004). While much is known about the gaseous emissions, the properties and climatic impacts of particulate matter from these fires is an understudied topic. Since the identification of optical properties of aerosol organic carbon (OC) from combustion two decades ago, increasing efforts have focused on the enhanced potential of radiative forcing impacts of aerosol emissions from wildfires (See *et al.,* 2007). These organic compounds, which strongly absorb solar radiation in the low-visible and UV wavelengths, are called brown carbon (BrC; Gyawali *et al.,* 2009, Chakrabarty *et al.,* 2010, Moosmüller et al., 2009) or black carbon (BC). Black carbon (BC) aerosol has been identified as the major light-absorbing and warming agent, influencing radiative forcing directly by as much as 17 ± 30 W/m^2 after a flaming boreal fire (Oris *et al.,* 2013; Randerson *et al.,* 2006). The implications are that not only do peatland fires potentially contribute to altered climate, but that the nature of their emissions cause these fires to have a greater impact on climate per unit of carbon emitted than do other types of wildland fires. Furthermore, the contribution from smoldering combustion of organic soils to global releases of terrestrial carbon to the atmosphere may increase under scenarios of warming and drying climatic conditions (Solomon *et al.,* 2007). However, science still lacks a good understanding of the nature and properties of emissions from peatland fires, especially in regards to the variation that may exist among the emissions from fires in different peat biomes.

In a series of studies, we have conducted detailed analyses of particulate emissions from the combustion of peats found in multiple climatic regions where peatlands occur, in order to compare the chemical, physical, and optical properties of these emissions.

METHODS

Peat samples were collected from three locations: Siberia, Russia, and Alaska, USA (intended to represent boreal and arctic ecosystems), and Florida, USA, (representing temperate-subtropical biomes). These samples were burned at moisture levels approximating those found during droughts and under which peat soils will support combustion. Samples were burned at the DRI biomass combustion facility within insulated containers to simulate field conditions in which surrounding peat soils provide insulation, trapping heat and gases near the site of smoldering combustion. Aerosol emissions were characterized for optical properties with three-wavelength photoacoustic spectrometer and nephelometer (Droplet Measurement Technologies, Inc., CO).

We compared the optical properties of peat samples collected in three biomes at multiple moisture levels to determine whether peat source or fuel moisture content was more important to emissions optical characteristics. Aerosol absorption and scattering coefficients, measured at three wavelengths (405, 532, and 870 nm) were analyzed for single scattering albedo (SSA) and absorption Ångström coefficients (AAC) (405-870 nm).

RESULTS

As expected, low molecular weight Polycyclic aromatic hydrocarbons (PAHs), such as naphthalene, methylnaphthalenes, are mostly present in the gas phase, while high molecular weight PAHs (*e.g.* retene, dimethylphenanthrene) are present in the particle phase (Figure 1). The chemical analysis of emissions constituents revealed similar levels of many compounds compared to needles from Ponderosa pine (*Pinus ponderosa*); a well-characterized fuel from the western U.S. However, all three peat fuels produced considerably higher emissions in the particle phases compared to either pine needles or *Bromus tectorum*; a fine grass that burned rapidly and efficiently in tests (Figure 1).

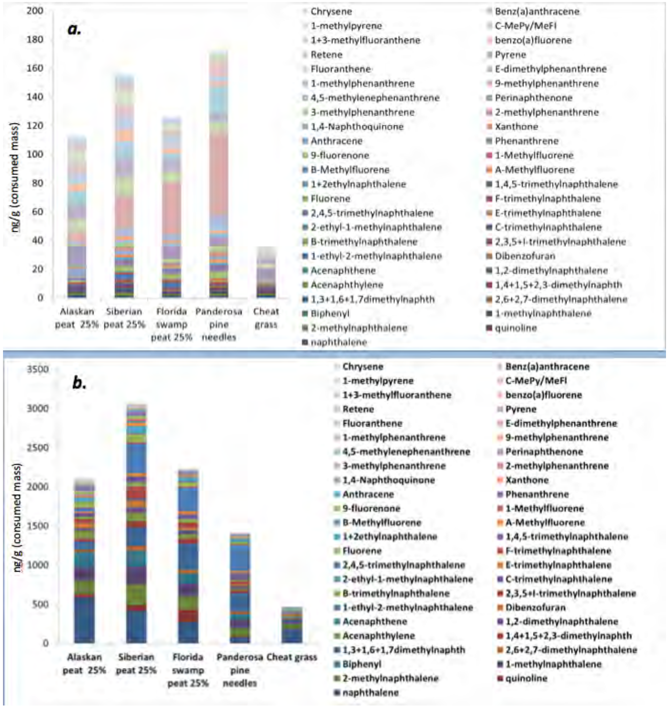
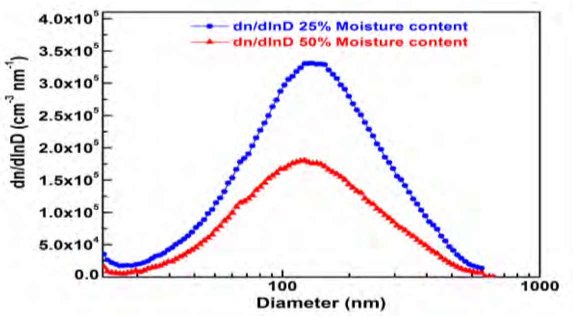


Figure 1 (left): Constituents of gaseous-phase (*a*) and particle-phase (*b*) emissions from Alaskan, Siberian, and Florida peat samples, as well as Ponderosa pine and cheatgrass, two wildland fuels found extensively throughout the western United States which burn primarily in the flaming phase.

Figure 2 (below): Particle size distributions from smoldering combustion of Alaskan peat at two different moisture contents (25% and 50% by mass dry weight). This graph illustrates the effect of moisture content on particulate emissions seen in all three peats.

Particle size distributions counted from emissions of smoldering peats indicated an effect of moisture level on particulates, with drier samples emitting more aerosols in the 100nm size class (Figure 2). Compared with reported values for many other common wildland fuels, emissions from the four peats measured in this study displayed similar values for single scattering albedo, with values in the 0.9-1.0 range at 405nm (Figure 3). However, observed values for absorption Ångström coefficients (405-870 nm) were substantially higher for peats than for other fuels. Furthermore, our observations appear to indicate that as moisture content of a peat sample decreased, AAC values for their emissions increased.



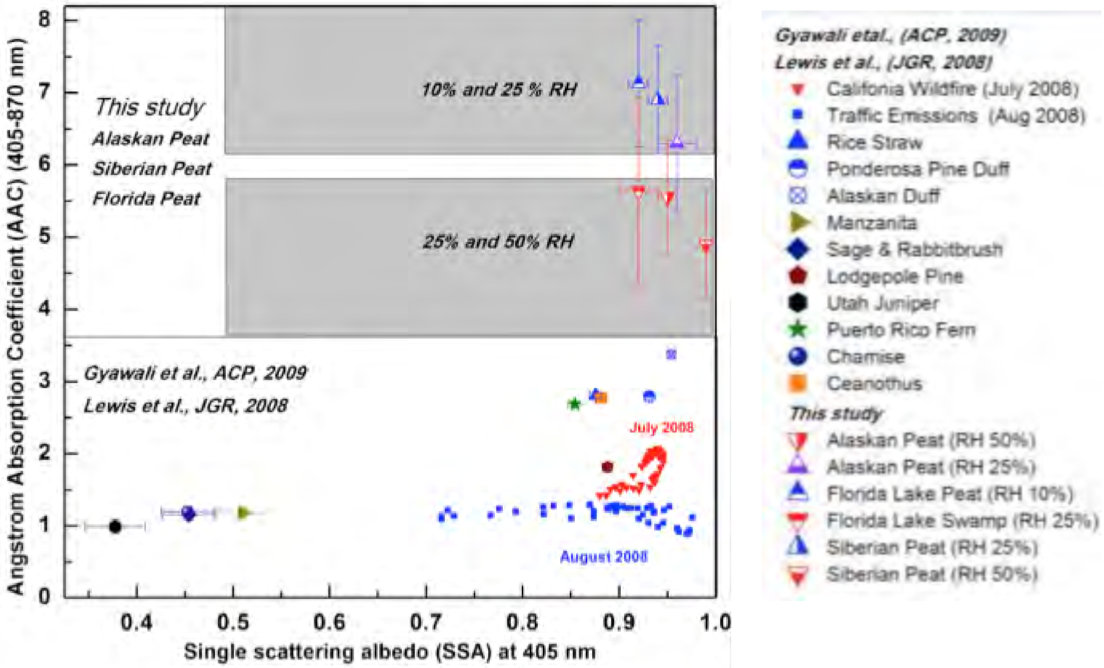


Figure 3: Optical characteristics of peat emissions examined in this study compared with those of other fuels measured by Gyawali *et al*. (2009) and by Lewis *et al*. (2009).

DISCUSSION

Our findings show that BrC from smoldering peat fires in the Boreal region could give rise to significant absorption in the shorter wavelengths and ultraviolet regions of the solar spectrum. This strong absorptivity of the aerosols could drive the net forcing values in the positive (warming) over bright surfaces. The common understanding has been that BC constitutes the light-absorbing aerosol type from boreal forest fires (Randerson *et al.,* 2006) while OC are light scattering in nature and help offset the BC warming effects. However, our results show that OC could further amplify the warming effects of BC over this region, especially since 47% of incoming solar energy is distributed between 400 nm and 700 nm.

CONCLUSION

This study highlights the importance of evaluating optical properties of particulate emissions from peatland fires from various sites under different moisture contents, because understanding the effects of location and moisture on emissions characteristics could potentially enhance the accuracy in the predicted radiative forcing contribution from peat fires and other biomass emissions. We plan to expand our analysis to include more sites and environmental parameters, in order to better characterize the impacts of peatland fires on the global climate. Objectives for these future efforts will be 1) to link understanding of terrestrial carbon emissions from peat/smoldering fires with radiative forcing so that we can better understand the mechanisms driving climate change; 2) to understand how emissions species partitioning may change due to varying environmental factors; and 3) to eventually couple models of emissions and forcing potential with climate change scenarios downscaled to biomes where large deposits of organic soils occur.

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