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Editorial

Overview of the Georgia Wildland-fire Simulation Experiment (G-WISE)

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The readership of *ACS ES&T Air* is undoubtedly familiar with the profound impacts of wildland-fire smoke on air quality and climate. It may be less familiar with the crucial role that wildland fires play in maintaining the ecological health of many forest types (McLauchlan et al., 2020). Wildland fires are generally categorized into wildfires and prescribed fires. On one hand, wildfires are unplanned wildland fires that occur either naturally or due to accidental or malicious human ignition. On the other hand, prescribed fires are wildland fires that are ignited intentionally to rejuvenate fire-dependent ecosystems in a controlled manner and to prevent larger-scale wildfires by consuming highly ignitable fuels (Kolden, 2019). This important utility of prescribed fires has recently received increased recognition both in the United States and globally (Molina-Terren et al., 2016; Hiers et al., 2020; Peterson et al., 2022; Li et al., 2025). However, the perspectives of U.S. regional wildland-fire specialists indicate that smoke emissions are often a barrier for the implementation of prescribed fires (Peterson et al., 2022).

Central to the discourse on the utility of prescribed fires and the development of sound prescribed-fire science is understanding how smoke production in a prescribed fire differs from smoke production in a wildfire in the same region (Hiers et al., 2020; Peterson et al., 2022; Jaffe et al., 2020). To further this understanding, the Georgia Wildland-fire Simulation Experiment (G-WISE) was conceived as a collaborative experimental effort, aimed at elucidating smoke production in prescribed fires and wildfires, with a focus on linking smoke production to fire behavior, in terms of both emission quantities and intensive physicochemical properties. This Editorial provides an overview of key aspects of the experimental design of the first G-WISE campaign (G-WISE-1), which was conducted in October and November 2022 at the U.S. Forest Prescribed Fire Science Laboratory on the campus of the University of Georgia in Athens, GA. This Editorial also provides background context as an introduction to continued research outputs from G-WISE-1 and future G-WISE campaigns. Papers published from G-WISE-1 have covered topics that include aerosol optical properties (Glenn et al., 2024; Sun et al., 2024; McQueen et al., 2024), hygroscopicity and emissions of surface-active organics (Deegan et al., 2025), and emissions of micronutrients (Zeng et al., 2024). Papers currently under review or in preparation cover topics that include emission factors of carbonaceous aerosol, secondary organic aerosol formation potential, volatility distributions of organic aerosol, chemical transformation due to photochemical aging, toxicity of fresh and photochemically aged smoke, among others.

■ BIG PICTURE IMPETUS FOR G-WISE

There is an abundance of published laboratory studies on biomass-burning emissions that aim to understand smoke production in wildland fires. Among the most influential in developing an understanding of smoke from an atmospheric chemistry perspective have been the campaigns at the Fire Science Laboratory in Missoula, MT, including the four Fire Lab at Missoula Experiment (FLAME) campaigns that took place between 2006 and 2012 and the Fire Influence on Regional to Global Environments Experiment (FIREX) in 2016. Those campaigns provided valuable insights into various smoke-related questions, such as emission factors of key smoke constituents from a large number of globally relevant biomass fuels (McMeeking et al., 2009; Sekimoto et al., 2018), chemical transformation of smoke emissions due to atmospheric aging (Ahern et al., 2019; Tkacik et al., 2017; Hennigan et al., 2011), and aerosol optical properties (Saleh et al., 2014; McClure et al., 2019; Pokhrel et al., 2016). G-WISE builds on that existing scientific knowledge base and technical expertise to further advance the science of smoke. Specifically, the experimental design implemented in G-WISE allows for systematic exploration of the effect of variability in combustion conditions inherent in wildland fires on key smoke properties that are important for quantifying its effect on public health and climate. Those include emission factors, secondary organic aerosol formation potential, aerosol light-absorption properties, hygroscopicity, toxicity, among others. As further elaborated below, dissecting the effect of combustion conditions on smoke production is crucial when comparing smoke production in wildfires to that in prescribed fires.

■ SMOKE PRODUCTION IN WILDFIRES VERSUS PRESCRIBED FIRES

A majority of wildfires occur during drought periods or dry environmental conditions, which render the fuels more susceptible to ignition. Prescribed fires, however, are carried

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out within a defined "prescription window", which refers to igniting a fire when the fuels, environmental conditions, and available operational resources are favorable for achieving management objectives and maintaining control of the fire. Objectives include reduction of hazardous fuels, vegetation management, and minimizing smoke exposure in neighboring communities. A key determinant of the prescription window is the moisture content of the fuels, which is dictated by environmental conditions (temperature, vapor pressure deficit, and days since rain). In general, the moisture content of the fuels is required to be neither too high, to ensure efficient fuel consumption and fire spread, nor too low, to avoid high-intensity fire behavior that can lead to ignition of heavy fuels and containment issues. Moisture content is therefore an important differentiator between drought-induced wildfires and prescribed fires (Ottmar, 2014). It affects the availability of the various fuel components for combustion (Prichard et al., 2017), which is especially important for regions where the forest floor contains duff, a layer of partially decomposed biomass that forms over decades as a consequence of extended periods of fire exclusion. In regions that contain duff, the prescription windows are designed to avoid duff ignition. However, duff can become dry enough to be available for combustion during droughts and can thus be consumed in wildfires (Ottmar, 2014; Prichard et al., 2017). Due to its compactness and relatively low carbon content, duff combusts less efficiently compared to recently senesced fuels. Consequently, in a region that contains duff, a drought-induced wildfire (which consumes duff) produces smoke that is drastically different from that produced by a prescribed fire (which does not consume duff) in the same region.

■ G-WISE EXPERIMENTAL APPROACH

In G-WISE-1, our aim was to investigate how differences in moisture content between wildfires and prescribed fires affect combustion conditions and smoke production, with particular emphasis on the presence or absence of duff. To that end, we implemented an experimental approach that involved (1) simulating wildfires and prescribed fires in a laboratory setting, (2) developing a quantitative measure of combustion conditions for predicting smoke production, and (3) designing an experimental matrix that allowed for systematic investigation of the effects of environmental conditions and fuel-bed characteristics on combustion conditions and smoke production.

Simulating Wildland Fires in the Laboratory. We leveraged the control provided by laboratory experiments to isolate key variables that affect smoke production in wildland fires, which cannot be achieved in field measurements, while striving to make the burns as realistic as possible in a laboratory setting by considering three aspects. First, we constructed fuel beds that replicated the average proportions, mass loadings, and three-dimensional (3D) structures of fuel beds as observed in the field (Loudermilk et al., 2023). The fuel beds featured recently senesced surface fuels, including fine fuels (forest litter) and woody fuels (sticks and branches). Some of the fuel beds also featured a layer of duff underneath the surface fuels. Second, the fuel beds had an area of 0.5 m^2, consistent with the scale of a "wildland fuel cell" unit (Hiers et al., 2009). This scale was chosen to allow the development of fire behavior that captures most of the variability in fire energy release reported in field observations of wildland fires (Loudermilk et al., 2012). The rationale is that capturing the variability in fire energy release also captures the variability in smoke production. Third, we conditioned the moisture content of the fuel beds to realistic levels. We considered both relatively low moisture contents, which simulate drought-induced wildfires, and moisture contents close to the midpoint of the prescription window for the southeastern United States, which simulates prescribed fires. It is important to note that the mismatch in moisture content between laboratory experiments and actual wildland fires has been identified as a major drawback of laboratory experiments (Warneke et al., 2023) and has been hypothesized to be an important contributor to the discrepancy in smoke production between laboratory experiments and field measurements (Yokelson et al., 2013).

Fuel-bed characteristics (proportions of different components, mass loading, and 3D structure) in conjunction with environmental conditions (particularly manifested as moisture content) govern fuel availability, combustion conditions, and, ultimately, smoke production. Therefore, considering the aspects detailed above is a key feature of our experimental approach to approximate realistic smoke production. This is most critical for fuel beds that contain duff. Duff has a compact structure that limits air–fuel mixing, leading to oxygen-deprived combustion. Furthermore, duff ignition in wildfires is typically predicated on the ignition of surface fuels. Therefore, in order to simulate smoke production in a wildfire that involves duff ignition, (1) the laboratory fuel bed should maintain the same 3D structure (compactness) of duff as in the field, (2) the laboratory fuel bed should include surface fuels in addition to duff, and (3) the combustion process should be initiated by igniting the surface fuels first and allowing flame propagation from the combustion of surface fuels, which creates hots spots that induce duff ignition. A laboratory experiment that does not maintain the 3D structure of duff and burns it directly without surface fuels would likely fail to replicate realistic combustion conditions and associated smoke production from duff burning in a wildfire. In prescribed fires, duff is typically too moist to be available for combustion. However, even though it does not ignite, duff acts as a heat sink that can affect the combustion conditions of the surface fuels. Therefore, to perform a laboratory experiment that accurately simulates smoke production in a prescribed fire for a region that contains duff, duff should be featured in the fuel bed despite it being unavailable for combustion.

Of course, G-WISE cannot simulate high-severity wildfires that consume whole canopies. However, it is important to note that despite the prominence of these high-severity wildfires in public discourse and media due to their large-scale destructive effects, a majority of areas consumed by wildfires occur at low and moderate severities (Reilly et al., 2017) and typically consume only surface fuels and duff (if available). For the sake of completeness, we should mention that G-WISE-1 did not simulate the consumption of small live fuels (shrubs) that occurs in some prescribed fires. Live fuels will be considered in a future campaign.

Linking Smoke Production to Combustion Conditions. We used infrared thermography to retrieve the fire radiative power [FRP (MW)] and burn-integrated FRP, or fire radiative energy [FRE (MJ)]. FRP is commonly utilized to characterize fire behavior in wildland fires via both ground and aircraft measurements. Furthermore, FRE has been shown to be correlated with fuel consumption (Wooster et al., 2005) and total aerosol emissions in laboratory experiments (Free-

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born et al., 2008) and has been used to develop top-down emission inventories (Ichoku and Ellison, 2014). In G-WISE-1, we extended the utility of FRE to derive a quantitative measure of combustion conditions by defining normalized FRE [FRE_{norm} (MJ/kg)] as FRE divided by the dry mass of the fuel bed (Glenn et al., 2024). FRE_{norm} can be considered as an effective radiative heating value of the fuel bed, where the larger FRE_{norm} is associated with more efficient, high-temperature, more flaming combustion and a smaller FRE_{norm} is associated with less efficient, low-temperature, more smoldering combustion. We test the hypothesis that FRE_{norm} can be used to link key intensive physicochemical properties of smoke emissions (e.g., light-absorption properties, relative abundance of elemental carbon and organic carbon, and potential to form secondary organic aerosol) to combustion conditions.

Experimental Matrix. G-WISE-1 featured a two-dimensional experimental matrix that involved varying the fuel-bed (1) dry composition and mass loading by using fuels collected from three ecoregions in Georgia (Piedmont, Coastal Plain, and Blue Ridge) that are representative of forests in the southeastern United States (Mitchell et al., 2014) and (2) moisture content to represent either prescribed fires or drought-induced wildfires. The Piedmont and Coastal Plain fuel beds contained surface fuels only, whereas the Blue Ridge fuel bed also contained a duff layer underneath the surface fuels. We note that duff exists in some parts of both Piedmont and Coastal Plain. However, one goal of G-WISE-1 was to contrast fuel beds with and without duff, and the choice to have duff only in the Blue Ridge fuel bed was arbitrary (it could have been Piedmont or Coastal Plain). By design, prescribed fires exclude duff ignition, which we replicated in our experiments. Specifically, even though the Blue Ridge fuel beds contained duff, the high moisture content rendered the duff unavailable for combustion under prescribed-fire conditions. However, the duff was dry enough to combust under wildfire conditions, leading to drastic differences in smoke production between the prescribed-fire and wildfire conditions for the Blue Ridge fuel bed.

As we write this Editorial, preparations for G-WISE-2 are underway. G-WISE-2 will feature a more elaborate experimental matrix designed to probe the effects of various fuel-bed characteristics and environmental conditions on smoke production in greater depth, including fuel compactness, fuel mass loading, wind speed, and variable moisture content within the prescription window. The major goal of G-WISE-2 is to test a promising hypothesis that emerged from G-WISE-1: Can the complex multidimensional interactions between variable fuel-bed characteristics and environmental conditions be collapsed onto a single dimension of combustion conditions for the purpose of predicting smoke emission factors and physicochemical properties?

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Notes

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