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Viewpoint

Findings from Biomass Burning Field Campaigns Set Directions for Future Research on Atmospheric Impacts

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INTRODUCTION

The global extent of vegetation fires is modified by climate, land use change, and other factors and feedbacks. Fires are important for maintaining fire-adapted ecosystems, but they can also impact ecosystem properties and functions and hasten ecosystem conversion. Fires are also a major source of atmospheric trace gases and particulate matter (PM) that influence global air quality and climate. Fire emissions are highly variable, and their air quality and climate effects also depend on complex transport and post-emission chemical and physical transformations that are often poorly understood.

Here, we reflect on previous large-scale campaigns and consider future research that will advance the understanding of fires and their effects on both the atmosphere and the global environment. Atmospheric field campaigns that targeted fires and their emissions in tropical, boreal, and temperate ecosystems over the last half-century have significantly improved understanding of the chemistry and physics of fire emissions and smoke evolution and impacts (Figure 1).[1] These campaigns evolved in their sophistication and comprehensiveness, and have been complementary to laboratory studies, satellite measurements, and models, all of which have similarly advanced.

HISTORICAL CAMPAIGNS

Illustrating this evolution, the Southern African Regional Science Initiative (SAFARI 2000), featured extensive fuels and fire behavior research, evaluation of MODIS fire products, and instrumentation that was state-of-the-art at the time. In the 2008 Arctic Research of the Composition of the Troposphere from Aircraft (ARCTAS) study, the chemistry of boreal smoke plumes was measured. The 2013 Biomass Burning Observation Project (BBOP) and Studies of Emissions and Atmospheric Composition, Clouds, and Climate Coupling by Regional Surveys (SEAC^{4}RS) advanced the understanding of emissions and smoke evolution and aging from temperate wildfires and agricultural fires.

MODERN CAMPAIGNS

The Figure 1 campaigns documented characteristics of important global fire types but left open many questions regarding the effects of fuels and weather on emissions and the impacts of these emissions on air quality and climate both now and under future conditions. Two recent studies have made significant strides in addressing some of these gaps.

The NSF-sponsored Western Wildfire Experiment for Cloud Chemistry, Aerosol Absorption, and Nitrogen (WE-CAN)[3] campaign sampled wildfires during summer 2018 from a C-130 aircraft with state-of-the-art instrumentation that increased our understanding of the near-field evolution of nitrogen in smoke plumes; the impact of volatile organic compounds on ozone, PAN, and health; the evolution of smoke PM; and the impact of smoke on cloud properties and climate. WE-CAN also sampled aged smoke, which is improving our understanding of wildfire impacts on air quality, radiation, and cloud properties on longer time scales.

The NOAA/NASA Fire Influence on Regional to Global Environments and Air Quality (FIREX-AQ)[4] sampled wild, prescribed, and crop residue fires during summer 2019 using state-of-the-art instruments deployed on airborne, mobile, and ground-based platforms. These were coupled with thermal imaging, fuel data, burned area assessments, and evaluations of remote sensing detection efficiency for small fires, which account for most of the global-scale fire emissions. Many modeling, forecast, and analysis products for fire, fuels, air quality, and climate were intercompared and evaluated. Advances included evaluation of new emission factors, important insights into daytime ozone formation, PM and brown carbon evolution over extended temperature and time ranges, and a novel understanding of nighttime processing, both after dark and in dense daytime smoke plumes.

SATELLITE OBSERVATIONS

Satellite measurements of thermal radiation emitted by fires and changes in the albedo of burned areas underpin quantitative estimates of vegetation burned with global coverage. However,

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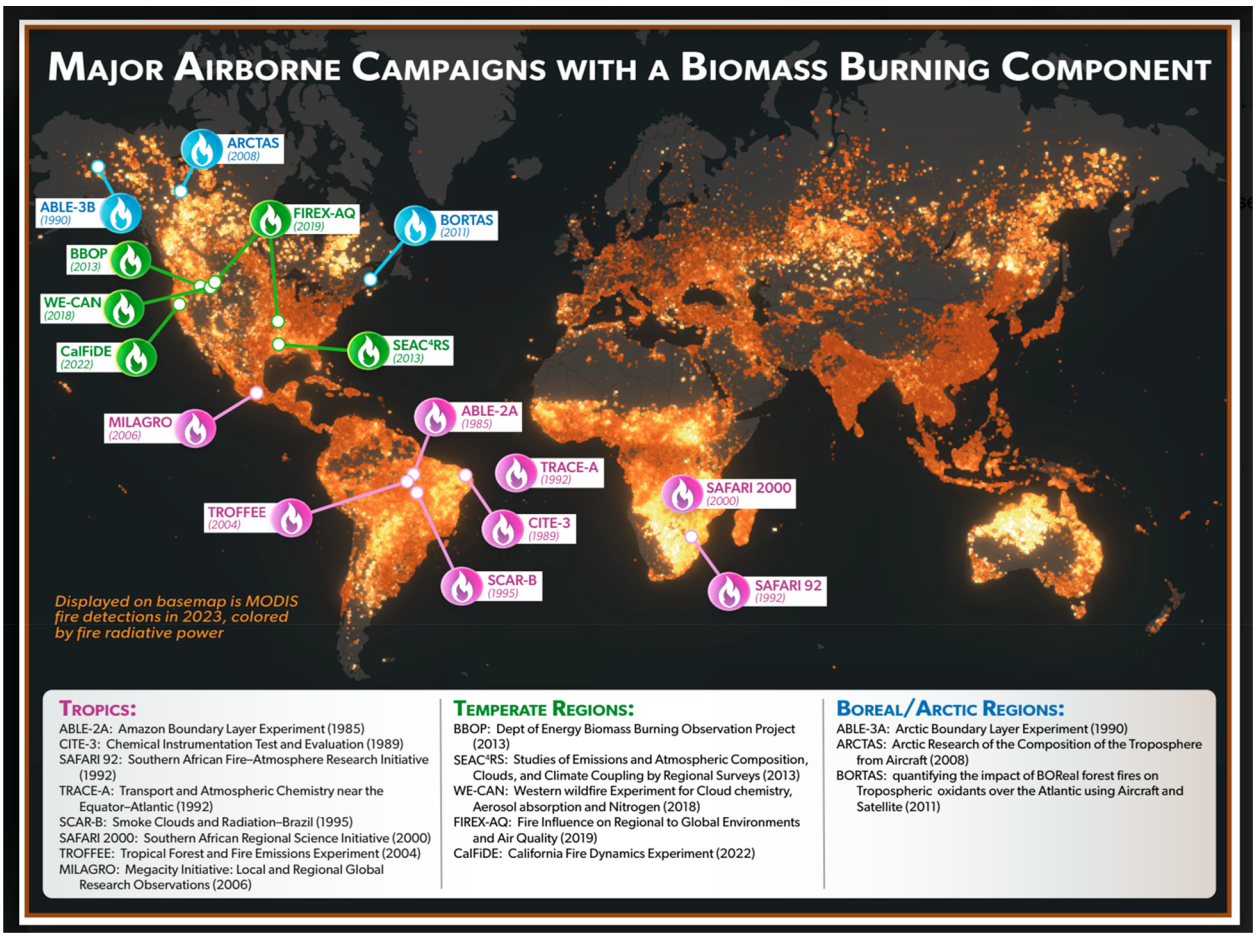

Figure 1. MODIS fire detections colored by fire radiative power illustrate the widespread occurrence of fires. Locations of major airborne campaigns with a biomass burning focus are shown and colored by type of ecosystem. For estimates of the amount of biomass burned, see for example van der Werf et al.[2]

each product misses a fraction of the fires. Satellites can also yield information on fuel loading and conditions and variables that impact fire behavior and severity, combustion efficiency, and the amount of fuel burned. Constituents of smoke observed by satellite include CO and aerosol optical depth. Linking the latter to the type and mass of PM emitted requires ancillary information, some of which can be measured from aircraft. Remotely measured CO columns are used with inverse modeling to estimate emissions, and studies have also used this approach for PM, CH_4, and CO_2. Many important smoke constituents and properties are observed from space, including NO_2, HCHO, CHOCHO, HONO, PAN, ozone, plume height/depth, and the aerosol absorption Ångström exponent, which can be used to estimate brown carbon content.

LOOKING FORWARD

The above studies and analyses provided critical insights and helped clarify some priorities for future research. Comprehensive, multifaceted approaches that enhance understanding of the chemistry and physics of fire emissions along with their amounts, timing, location, and post-emission processes have greatly increased the value of recent large-scale campaigns and will be essential in the future. Ancillary measurements requiring more attention include weather and fuel characteristics, cloud interactions, and topographical influences on smoke transport. Careful coordination between airborne campaigns, high-resolution satellite observations, and both near- and far-field ground-based measurements inform all types of observations: e.g., vertical profiles from coordinated aircraft flights and Lidar, and satellite data, provide critical context for intensive ground-based observations of near-surface impacts. Future campaigns would benefit greatly from the inclusion of a ground-based team focusing on weather and fuels and comparison to remotely sensed properties. Studies in areas where geostationary satellite observations including fire radiative power (FRP) are available have enhanced potential to improve our understanding of total annual burning and seasonal and diurnal cycles in emissions production along with correlations to FRP.

Renewed attention to understudied regions that account for most of the global fire emissions such as tropical and boreal areas, peatlands, Australia, and sub-Saharan Africa is required. Measurement of actual exposure to smoke in ground-based campaigns and synthesis of these data with health impact metrics over prolonged periods across diverse communities are needed in many regions, particularly in the wildland urban interface where nonvegetative fuels can burn. Integrating emerging measurement technologies (e.g., unmanned aerial vehicles) and modeling approaches (e.g., machine learning) and expanding monitoring networks has potential to significantly leverage our understanding of the role of fire in the Earth system.

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■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsestair.4c00276.

Extended reference list for both historical and modern field campaigns (PDF)

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Notes

The authors declare no competing financial interest.

Biographies

Kelley Barsanti is a Scientist III in the Atmospheric Chemistry Observations and Modeling Laboratory at the NSF National Center for Atmospheric Research. Her research interests in wildland fire science are the culmination of undergraduate studies in environmental biology, graduate studies in environmental science and engineering, and a lifetime spent in fire-impacted regions. Her research has been particularly focused on the diversity of gas-phase organic compounds emitted from fires, their chemical and physical transformations in the atmosphere, and their effects on air quality. To that end, she recently published a comprehensive global biomass burning emission factor database, NEIVA, with several unique features to facilitate the use of recent data in models (https://egusphere.copernicus.org/preprints/2024/egusphere-2024-633/). She is working on the development and codevelopment of community tools and resources that will serve a more diverse and expansive group of users and facilitate greater impact of ongoing wildland fire research efforts. She acknowledges the contributions of all of the excellent graduate students and postdocs that she has worked with in these endeavors, as well as the inspiring mentors and colleagues, including her coauthors on this Viewpoint.

Steven Brown received a Ph.D. in physical chemistry from the University of Wisconsin—Madison. He came to the NOAA Aeronomy Laboratory (now the Chemical Sciences Laboratory) in Boulder, Colorado in 1997 as an NRC postdoctoral fellow, was a Research Scientist with the Cooperative Institute for Research in Environmental Sciences at the University of Colorado from 2000−2005, and has served as a federal Research Chemist since then. He holds an adjoint professor appointment in the chemistry department at the University of Colorado, also in Boulder. He currently leads the Atmospheric Remote Sensing Program, and the Tropospheric Chemistry Program, a group that conducts field measurements to understand atmospheric composition with applications in air quality and climate. His major research theme at NOAA has been the chemistry and impacts of nitrogen oxides in the Earth's atmosphere, with an emphasis on nighttime chemical cycles. He has also led the development of high sensitivity optical instrumentation for laboratory and field studies of atmospheric trace gases and aerosols.

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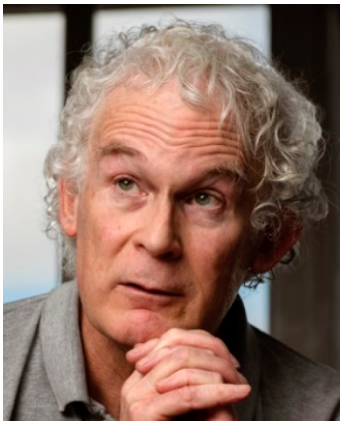

Robert Yokelson, a former wildland firefighter and initially a University of Montana forestry major, received a Ph.D. in Chemical Physics in 1991 from Yale University where he located and described excited states of O_2. His introduction to atmospheric chemistry was at the NOAA Aeronomy Laboratory (now the Chemical Sciences Laboratory) where he studied the photochemistry and kinetics of stratospheric ozone depletion as a postdoctoral fellow from 1991−1993. Since then he has led a 100% soft money research program at the University of Montana mainly focused on using emerging technology to learn about global fire emissions, smoke evolution, smoke impacts on air quality and climate, previously undersampled sources and compounds, etc., with an aim to improve models of local−global atmospheric chemistry. He emphasizes the need to also consider ecosystem impacts of fire, the use of fire for land management or household energy, etc. Along with using COTS instruments, his group built FTIR-based systems for airborne, on- or off-road ground-based, and other applications and deployed them around the globe (Alaska to Zambia, Brazil to Borneo, all over CONUS, etc.). He has helped advance new MS and aerosol approaches within his group and via small−large, ground−air collaborations with other scientists.

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