USDA Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Rocky Mountain Research Station

Science You Can Use 101

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Smoke 101

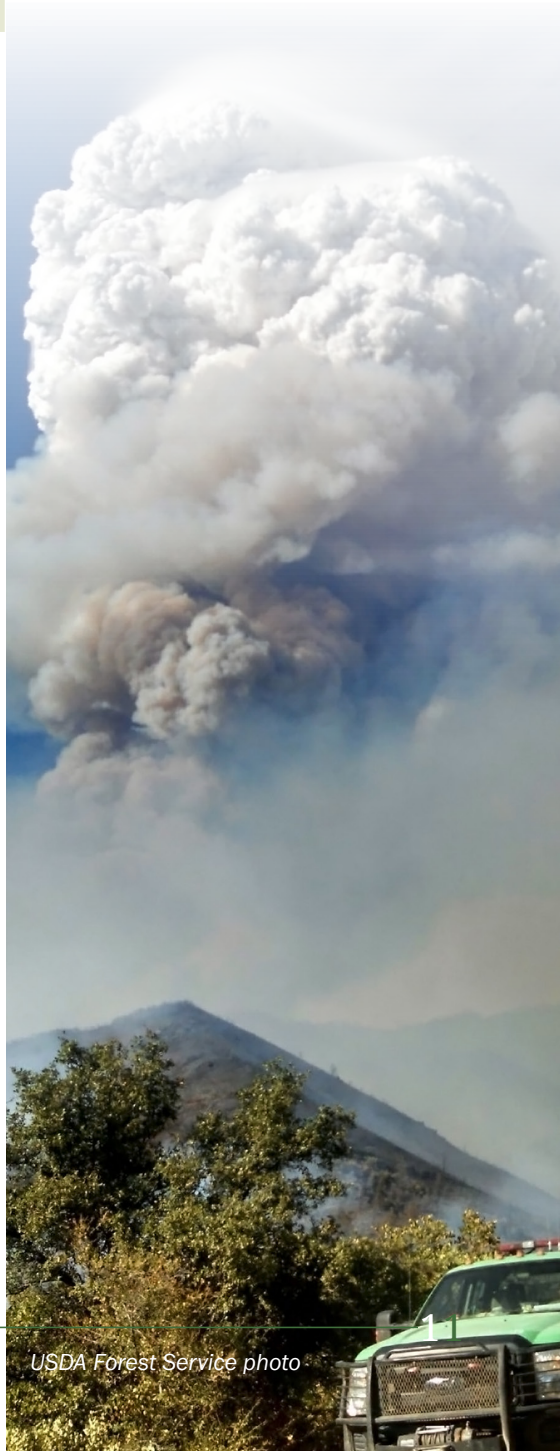
And Differences Between Wildfire and Prescribed Fire Smoke in the Western U.S.

An often-overheard phrase, “there is no future without smoke,” describes fire, and associated smoke, as an ecological process inextricably tied to Western forests. While fire can provide many benefits such as reducing fuels and renewing forests, smoke from fires poses a serious challenge to public health, land managers, and air quality regulators. So, can we reduce these challenges?

A State of the Science: Smoke Webinar was held in November 2023 where a panel of smoke experts addressed land managers’ key questions related to smoke. The most common question posed was, “What do we know about the differences between prescribed fire and wildfire?” The answer: While smoke from wildfires and prescribed fires varies greatly in composition and intensity, as well as patterns of movement, generally speaking wildfires produce more smoke than prescribed fires. Additional questions and their answers are captured here:

What Is Smoke?

Smoke is a byproduct of living and dead vegetation and organic soil, collectively referred to as fuels, consumed by fire. It is comprised of hundreds of gases and particles that are diverse in size, composition, and optical properties. **Smoke composition** is the combination of gases and particles and is described by emissions factors. **Smoke emission factors** quantify the yields of pollutants from the combustion of wildland fuels. For every ton of fuel consumed by fire, emission factors describe pounds of fine particulate matter (PM) and other air pollutants produced. Both short-term and long-term



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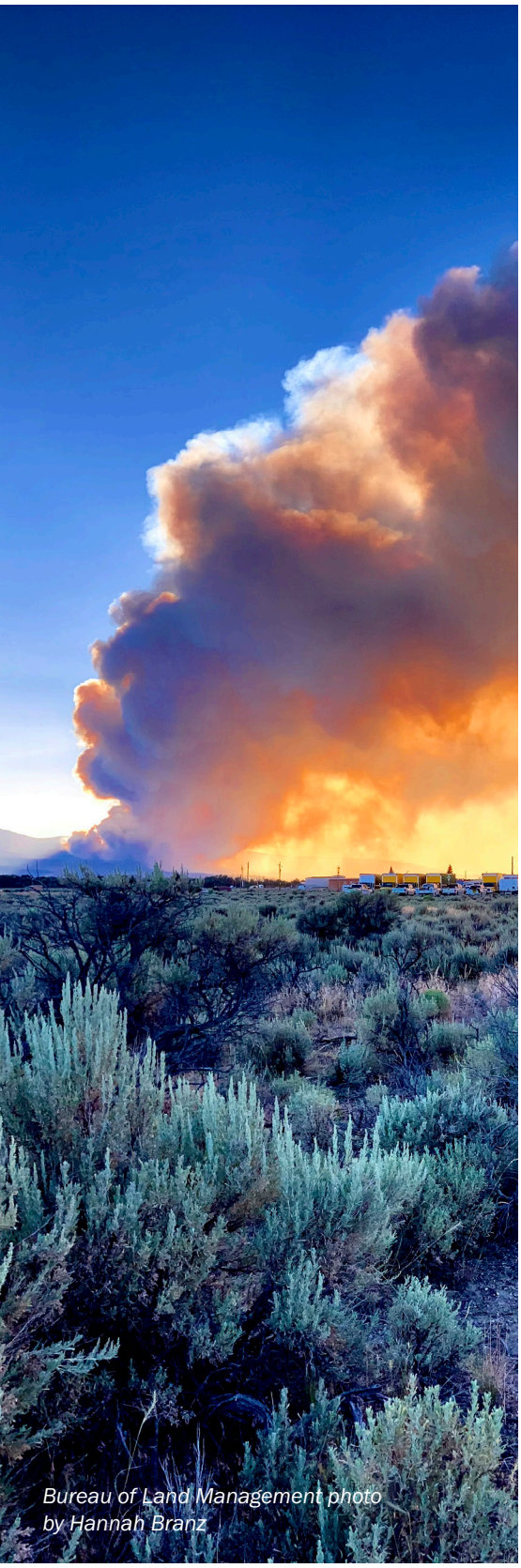


Bureau of Land Management photo by Hannah Branz

exposure to $PM_{2.5}$, particles with a diameter less than 2.5 microns, can have harmful health effects (U.S. EPA 2023). **Smoke emissions**, in contrast to composition, refers to the where, when, and how much of various pollutants are produced by wildland fire such as how much PM is produced by a given fire over a time period. Emissions of a specific pollutant are calculated by emissions factors and fuel consumption. Importantly, different amounts of fuel layers (i.e., litter, understory, canopy) burn depending on fire conditions, which translates to different mixes of emissions factors. **Smoke impacts** are the concentration of $PM_{2.5}$ (or other pollutants) experienced on the fireline, in a community, or at a location far from the wildfire. **Smoke dispersion** is the process by which the atmosphere mixes and transports particulates and other pollutants. Sometimes smoke will rise and disperse higher in the atmosphere during the heat of the day. In mountainous terrain, smoke will often settle into lower elevation areas with a nighttime inversion (a portion of the atmosphere in which temperature increases with altitude, inhibiting vertical mixing of air near the surface). Smoke is not static; it ages over time and creates different chemicals and impacts downwind.

What Do We Know About the Differences Between Wildfire and Prescribed Fire Smoke?

It is difficult to make generalizations about differences between wildfire and prescribed fire smoke. Both occur across a spectrum of fire intensities and conditions. Smoke varies with season of burning, intensity of burning, fuel conditions, and weather conditions, to name a few. Not all prescribed fires are low intensity fires and not all wildfires are high intensity fires. Some ecosystems require stand replacing fire to be ecologically significant and, in such a case, there may be little difference between a prescribed fire and wildfire. In ecosystems frequently burned at low intensities, a wildfire or prescribed fire in that system would likely also be of lower intensity.

The key difference between wildfire and prescribed fires is that prescribed fires are planned in advance. Managers have decision space to initiate a prescribed fire or wait for more favorable conditions to minimize smoke impacts. On a regional basis, numerous groups engaging in prescribed burning are able to interact and adjust cumulative smoke emissions and impacts. During a wildfire, however, there is little to be done about ambient smoke condition as a wildfire simply exists in the shared airspace.

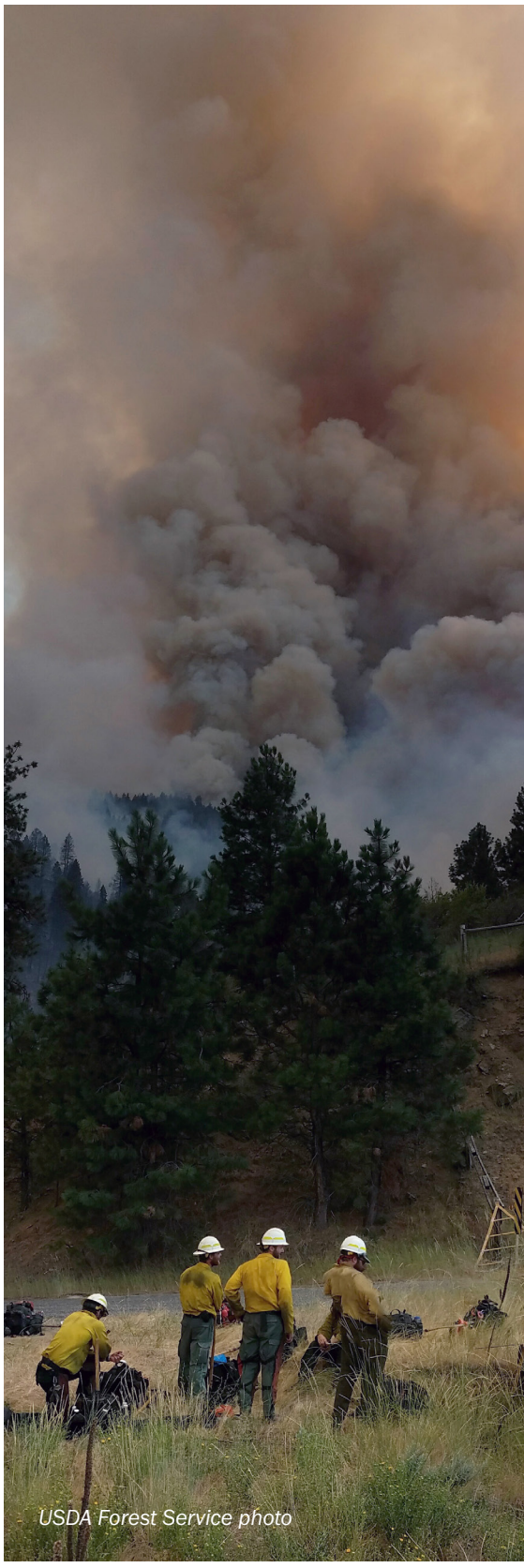
How Does Planning for Prescribed Fire Reduce Smoke Impacts?

Prescribed burning is an activity that is designed in advance to achieve desired conditions on the land, such as improving wildlife habitat or reducing fuels. While ecological outcomes associated with a wildfire or prescribed fire could be quite similar, the fundamental difference between the two is the decision to put fire on the ground. Before a prescribed fire, conditions must be acceptable from a safety perspective and able to support the desired end results. A burn prescription is developed and approved that considers smoke transport, weather, fuel conditions, and other factors needed to meet resource objectives. A smoke management plan is an essential component of a proper prescribed burn plan. Prescriptions are designed to minimize adverse effects to people, communities, and airsheds. They also are meant to ensure the results of burning yield desired effects including reducing fuels, improving wildlife habitat, and addressing other resource objectives. Prescribed fire planning relies heavily on science-based modeling that allows for consideration of multiple scenarios and tradeoffs.

Prescribed fires are planned and managed activities and there are fundamental choices to make including when and whether a prescribed fire will take place. For example, if a prescribed fire is burned later in the day, might winds be more favorable and less likely to bring smoke into a community? By considering scenarios and modeling conditions associated with planned prescribed fire, choices can be understood and made to minimize impacts to communities while still accomplishing the desired resource objectives.

Generally, Do Wildfires Produce More Smoke Than Prescribed Fires?

While there are knowledge gaps in this area, generally speaking wildfires produce more smoke than prescribed fires. The conditions under which a fire is occurring affect the partitioning of fuel carbon between carbon dioxide (CO_2), which is the product of complete combustion and incomplete combustion that produces carbon monoxide (CO), $PM_{2.5}$, and other carbon-containing pollutants. Overall, wildfire conditions tend to favor a less complete combustion process. As a result, smoke emission factors including $PM_{2.5}$, CO, and pollutants of concern (such as formaldehyde and benzene) are greater for wildfires than prescribed fires on average. In Western forests, for each ton of fuel consumed, wildfires produce approximately twice as much $PM_{2.5}$ as compared to prescribed fires in comparable ecosystems. In addition to having larger pollutant emission factors, wildfires consume more fuel per acre burned compared with prescribed fires. Due to the



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combination of higher fuel consumption and larger emission factors, wildfires produce greater amounts of pollutants than prescribed fires on a per acre burned basis.

Estimates of nationwide pollutant emissions from prescribed fires have large uncertainties since there is no consolidated system for recording prescribed activity across the United States. However, based on prescribed fire activity data collected by federal and state agencies, it is known that in the West, prescribed fires produce only around one-tenth of the $PM_{2.5}$ emitted by wildfires. For example, the U.S. EPA National Emission Inventory estimated that in the West in 2017, $PM_{2.5}$ emissions wildfires were around 1,111,000 tons compared with 94,000 tons from prescribed fires (US EPA 2017).

A specific example of how prescribed fire treatments could reduce the air quality impacts of a wildfire is given in the Comparative Assessment of the Impacts of Prescribed Fire Versus Wildfire (CAIF) report. CAIF used case studies to estimate the potential impact that prescribed fire treatments may have had on the pollutant emissions and air quality from two wildfires. The study found that for the largest wildfire considered, the Rough Fire, planned prescribed fire treatments may have reduced $PM_{2.5}$ emissions by 20 percent and resulted in an approximate 40 percent reduction in excess respiratory- and cardiovascular-related emergency department visits and hospital admissions, and premature deaths. The Rough Fire occurred in California from July 31 to October 1, 2015 and burned ~150,000 acres.

USDA Forest Service photo by Andrew Avitt

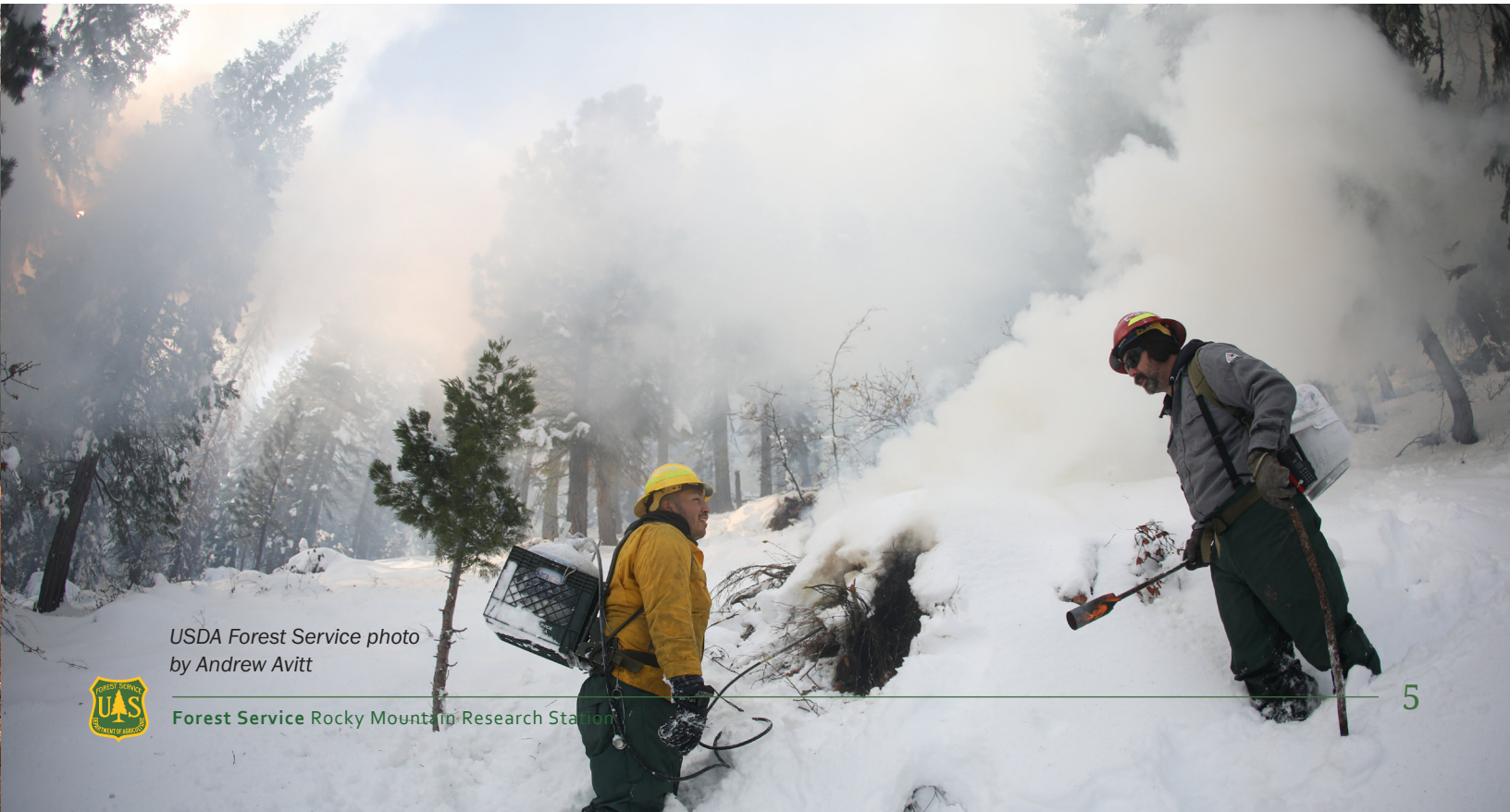
In addition to CAIF, a recent study concluded that increasing prescribed burns in northern California and the Pacific Northwest could provide large benefits for much of the Western United States by reducing future wildfire smoke (Kelp et al. 2023).

How About Pile Burning and Smoke?

Slash piles that result from thinning or other forest management activities are burned when conditions are favorable for fire containment (such as snow on the ground) and smoke dispersion, just like prescribed fire. Pile construction and pile components affect smoke that results from burning piles. For example, inclusion of soil or wet material changes the way piles burn. One study found that dry slash piles emit only about one quarter of the $PM_{2.5}$ that is produced by wet piles. A pile that is constructed with larger materials on the bottom that is lit from the top can form an air curtain reducing the amount of smoke from a pile (and can yield biochar when coals are quenched before turning to ash).

How Are Maintenance Treatments Likely to Affect the Amount of Smoke?

After over a century of fire exclusion in Western forests, fires have more material to consume than fires in these systems historically. Despite forest thinning projects, downed wood, shrubs, organic soil, and litter are byproducts and naturally occurring fuels that can still produce substantial amounts of smoke when burned. These fuels can



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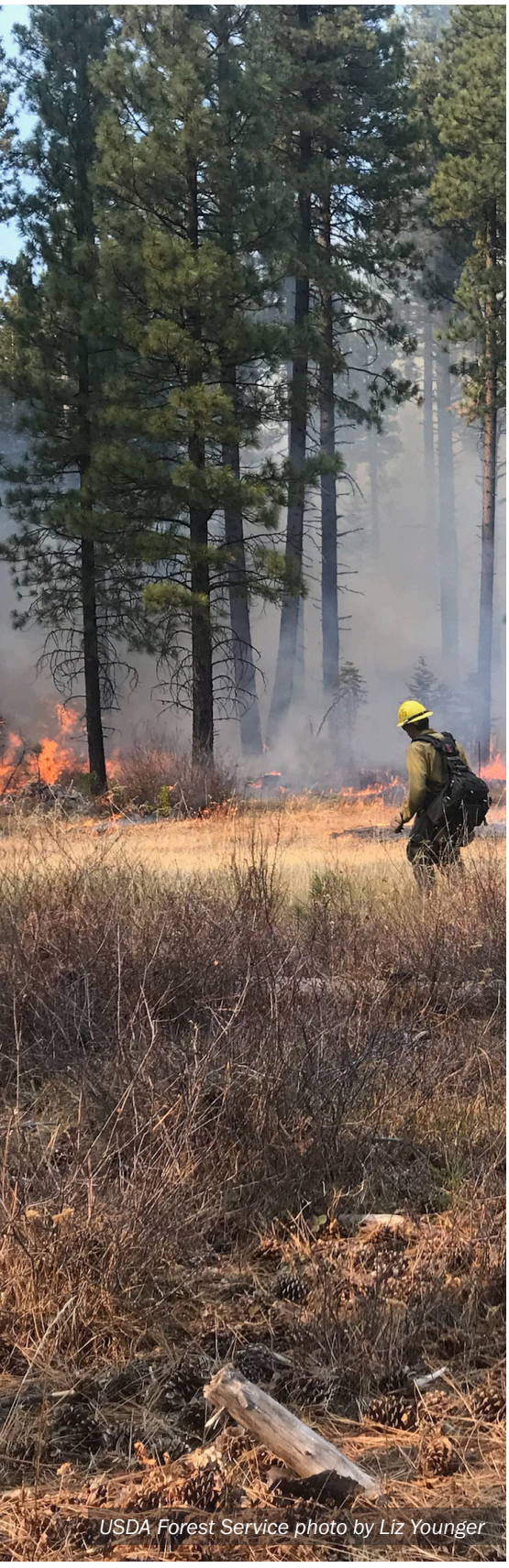

USDA Forest Service photo by Liz Younger

be consumed in wildfire or prescribed fire. By not prescribed burning landscapes and by suppressing naturally occurring fires, we are deferring an inevitable future with smoke.

There is light at the end of the tunnel when it comes to fires and smoke. Fires and smoke will become more manageable provided we keep burning landscapes. Once landscapes transition to repeated maintenance burning and treatments, fire behavior and smoke will lessen. Maintenance fires refer to a second, third, or beyond fire in a given location. These maintenance fires will burn fine wood, needles, and duff making the amount of smoke more manageable.

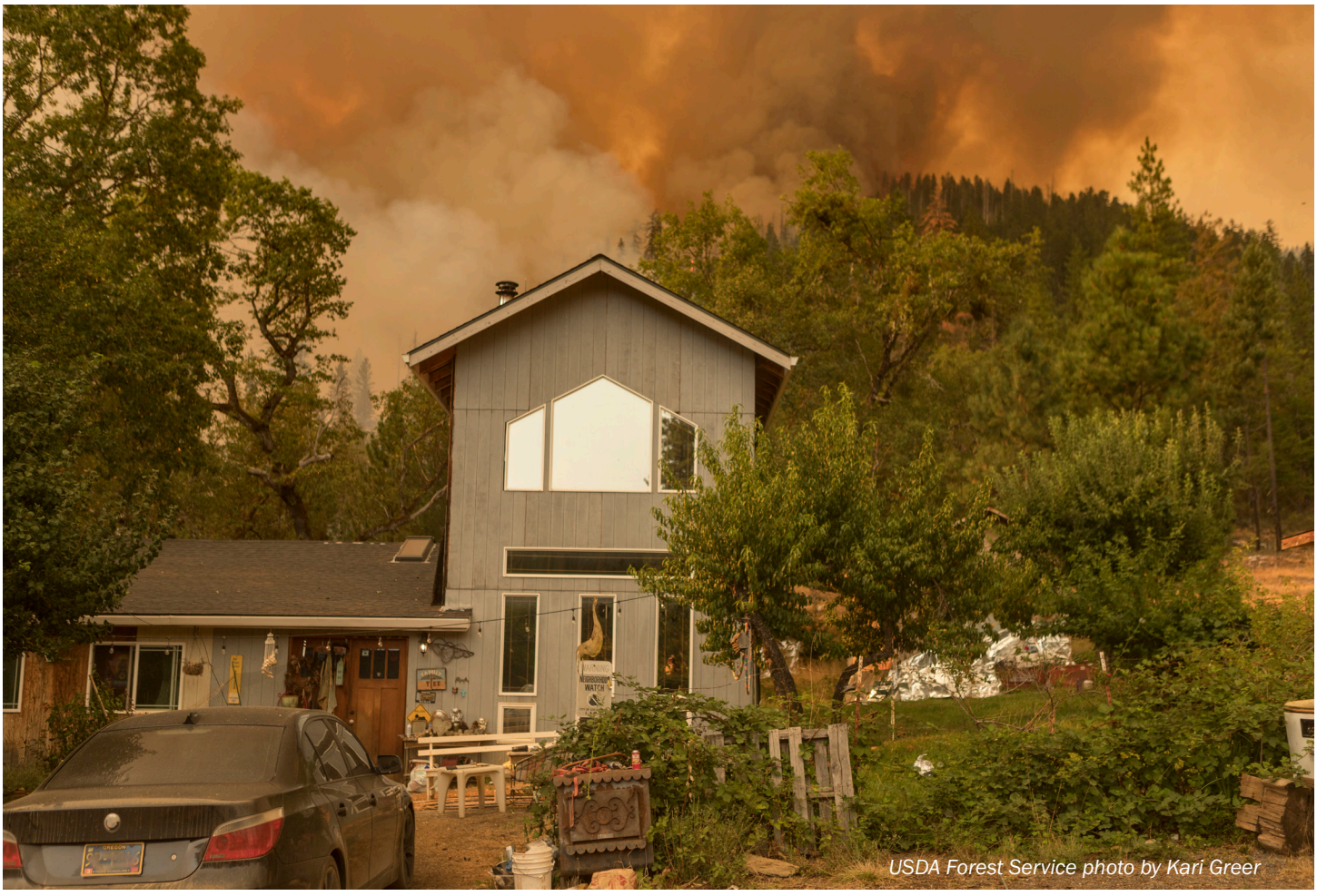
How Can Modeling Help Us Understand Smoke?

Scientists have been working to understand how smoke behaves by modeling the entire fire event chain from from fuel consumption and emissions to plume development and atmospheric transport to on-the-ground impacts downwind. In wildfire events, the amount of fuel consumed, and hence smoke emitted, and the location and timing of the emissions are typically beyond the control of management teams. Therefore, smoke models rely on satellite observations to predict wildfire smoke emissions. In contrast, for prescribed fires more information is available about fire behavior and expected smoke because of the planned nature of the activity. Based on the terrain and expected weather, fire managers usually know what fuel will burn and how intensely these fuels are expected to burn. This knowledge provides valuable input for smoke models and enables fire managers to better understand the atmospheric conditions required to disperse the smoke into the atmosphere and minimize potential impacts.

What Should I Know About Smoke and Public Health?

Smoke, whether from wildfire or prescribed fire, is a serious threat to human health. $PM_{2.5}$ is the primary pollutant of concern in smoke and is a regulated air pollutant under the federal Clean Air Act. The severity of health impacts from smoke depends on both the concentration and duration of exposure. Exposure to smoke—concentration and duration—in a given area is related to how much vegetation is being burned (tons per acre), where the fire(s) is occurring, the plume dynamics of the fire(s), and the atmospheric conditions that determine smoke dispersion and transport. In wildfire situations, short periods with very highly concentrated smoke levels are common. In prescribed fires, these concentrations are typically much lower. In recent years, many communities in the West have experienced long, smokey summers, a traumatic mental experience for many residents in addition to physical health issues.

The planned nature of prescribed fires provides opportunities to reduce smoke exposure by individuals and communities. Information about expected smoke dates and communities likely to experience smoke can be shared in advance of a prescribed fire. Daily activities can be adjusted for planned smoke. For example, one can alter exercise timing, intensity, or setting. Indoor spaces can be adapted for smoke including by closing windows and use of air filters. The U.S. Environmental Protection Agency and USDA Forest Service scientists developed the AirNow Fire and Smoke Map to help the public understand current and predicted smoke conditions.



USDA Forest Service photo by Kari Greer

Further Reading

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This piece was written by Nehalem Clark, Shawn Urbanski, and Scott Goodrick, all with USDA Forest Service Research and Development, and is based on peer-reviewed literature and information shared during the State of the Science: SMOKE Webinar.

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