State of the Science FACT SHEET

Fire Weather

Wildfires and weather

Wildfires are a common occurrence across the United States in all seasons, but especially in the summer and early autumn. These fires can be initiated many different ways with both natural and human causes. The number of acres burned in the western United States and Alaska has markedly increased since the early 1980s (Fig 1), and is projected to further increase in those regions as the climate warms, with profound changes to certain ecosystems. Wildfires threaten forest and grass lands, housing and communities, aquatic and soil ecosystems, and air quality both near to and far from the fires. In the last 30 years, there have been 18 wildfire events with losses exceeding $1 billion dollars, with 8 of those events happening in the last decade.

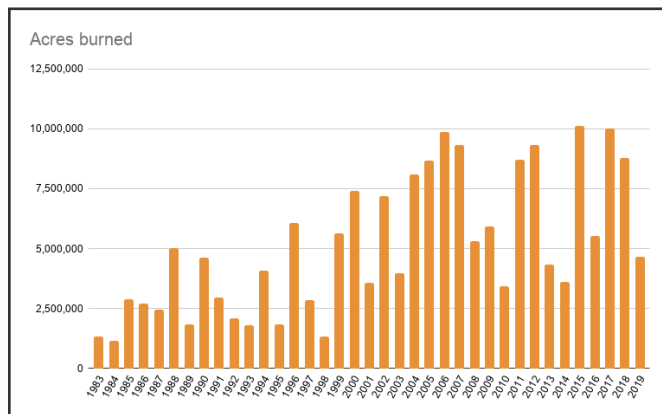*Figure 1: Total acreage burned in wildfires within the United States (data from the National Interagency Fire Center).*

Weather has long been recognized as having both an influence on fires and being affected by fire. For example, strong winds and above-average temperatures coupled with very dry air and surface conditions are associated with elevated likelihood that fires will rapidly spread, and thus these meteorological conditions are important for fire behavior forecasting. Similarly, a thick smoke plume can modify the weather downstream from a fire due to the large reduction in solar energy reaching the surface by the smoke itself.

Wildfire presents multiple challenges for the emergency management community who must: (1) identify new fires, (2) describe how an existing fire is growing spatially over time, and (3) forecast where the smoke from the fire will travel and how it will impact both the weather and the air quality as it moves. Each of these is a unique forecasting challenge, and NOAA's measurement and modeling capabilities play an important role in all three.
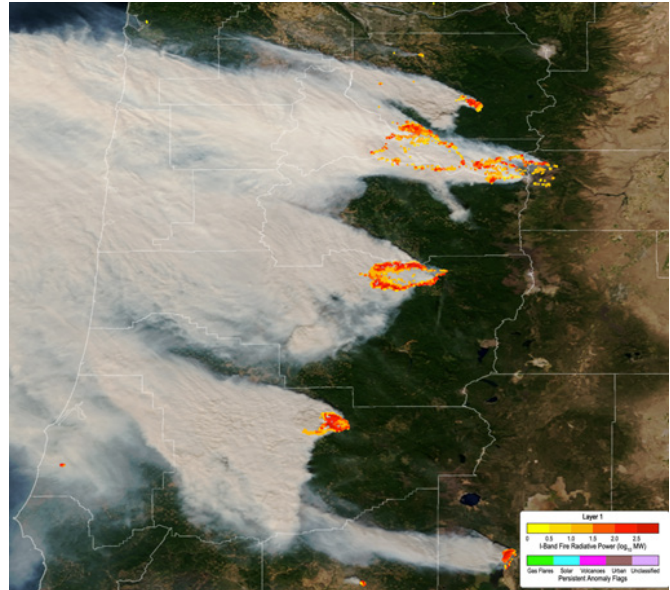

Figure 2: Joint Polar Satellite System (JPSS) image of smoke and fire location / intensity over western Oregon on 7 September 2020.

Satellite observations

NOAA's operational polar-orbiting and geostationary satellites provide critical observations that are used both to identify the initiation of new fires and monitor the growth and behavior of existing fires (Fig 2). NOAA researchers are investigating how to better use these satellite observations to characterize the surface conditions, including vegetation dryness, which is an important parameter that correlates with how large the fire could become and how much smoke it will emit. Furthermore, these observations are used to evaluate the surface conditions after the fire is extinguished, as these burn scars present significant risks in future heavy rain events for flash flood forecasts. As these satellite observations are hindered by the presence of clouds and aerosol layers, NOAA researchers are investigating new methods to detect fires and their properties in spite of non-optimal viewing conditions.

Smoke research

The amount and chemical composition of the smoke wildfires emit depends strongly on the fire temperature and the fuel composition and moisture content. NOAA researchers are studying smoke and its chemical composition combining data from field campaigns with chemical modeling studies. This research is also investigating how wildfire smoke contributes to the concentration of small particulate matter (called PM2.5) that has a big impact on human health and hence air quality, how the chemical composition

of smoke evolves over time, how fires impact harmful trace gas concentrations such as carbon monoxide and ozone, and how these trace gases and smoke particles move through the atmosphere and affect weather and climate. Additionally, research continues on new ways to observe smoke properties, such as using the new dual polarization capability of the NWS operational weather radar network or in-situ observations from Uncrewed Aerial Systems (UAS).
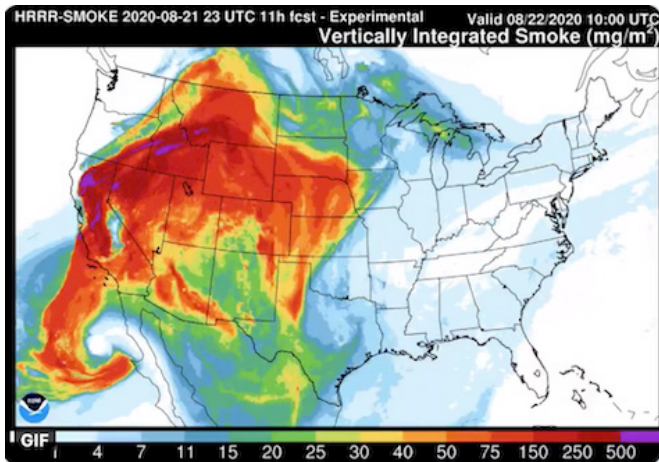

Figure 3: A forecast of the vertical amount of smoke over the U.S. continent on 22 August, 2020. These experimental products are part the effort to create a unified full- chemistry air quality and weather forecasting system as part of the UFS.

Prediction

As smoke moves away from the fire location, it impacts the weather through its interaction with radiation and clouds and subsequent modifications of the earth system. NOAA researchers have developed different models that are used to characterize source / receptor relationships, and to represent the interactions among smoke, clouds, precipitation, and solar energy to provide improved weather, smoke, and PM2.5 forecasts (Fig 3). These modeling systems rely heavily on observations from NOAA's satellites, and other NOAA observations such as trace gas (e.g., carbon monoxide), solar radiation, and aerosol optical depth (a measure of the total amount of smoke overhead) to evaluate the accuracy of these model predictions and improve them. These modeling teams are working on improved smoke and chemical representations that can be included in NOAA's next generation Unified Forecast System (UFS), which is used operationally by the National Weather Service (NWS) to provide both short-term and longer-term weather and air quality forecasts for the nation.

Longer-term weather and climate forecasts are also important for understanding the possible impact of fires. Research has shown that changes in climate have greatly influenced fire weather in the western U.S. and increased the risk and extent of wildfires by creating warmer drier conditions and increased drought, resulting in a longer fire season. Natural ocean cycles like El Niño / La Niña can

alter regional temperature, wind, and precipitation patterns during the normal fire-season. A warmer and longer dry season could amplify the potential for lightning over dry fuels which could ignite new fires. NOAA researchers are working to improve subseasonal-to-seasonal (S2S) forecasting systems (like the UFS) and comprehensive Earth system models to provide useful ocean and climate information related to fire weather, thereby allowing fire and forest managers to more effectively prepare for the coming fire season. NOAA researchers are also incorporating fire dynamics in fully coupled global Earth system models to improve understanding of the various natural and human factors contributing to fire ignition and intensity while accounting for the interactions with clouds and other climate variables.

Future work

Artificial Intelligence (AI) and Machine Learning (ML) devices are offering new ways to improve fire weather forecasts. NOAA researchers are using ML approaches to identify fires more quickly in satellite images, provide improved estimates of the vertical injection height of the smoke from fire intensity observations, improve fire outlooks by integrated AI/ML methods with improved S2S model forecasts, and deliver more computationally efficient methods to represent chemical and radiative transfer processes.

Ultimately, the goal of these research efforts is to improve the ability to provide timely and accurate fire weather forecasts from operational entities such as the NWS Weather Forecast Offices (WFOs), the NWS Storm Prediction Center (SPC), and other federal, state, and local agencies. Currently, the SPC and WFOs work together to issue outlooks and hazard products for situations where critical fire weather conditions and dry fuels coincidently exist and therefore a high likelihood of extreme fire behavior should an ignition occur. NWS fire weather meteorologists take advantage of modeling advancements to produce high spatial resolution site specific meteorological forecasts, precisely defined for the landscape topography and impacts of a wildland fire or prescribed burn project. Fire weather forecasts are used primarily for the safety of incident personnel and the public, and are also critical for strategic and tactical wildland fire management decisions that span the lifetime of the incident. The WFOs also provide watches when wildfire smoke could impact the air quality in their region. These operational entities benefit strongly from advances made by NOAA research teams. However, all new research products require testing and evaluation in a formalized future Fire Weather Test Bed to fully characterize the impact of these new products on forecast services provided by the NWS.