

THE STATE OF FEDERAL WILDLAND
FIRE SCIENCE: EXAMINING OPPORTUNITIES
FOR FURTHER RESEARCH & COORDINATION

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE,
AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

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**THE STATE OF FEDERAL WILDLAND
FIRE SCIENCE: EXAMINING OPPORTUNITIES
FOR FURTHER RESEARCH & COORDINATION**

TUESDAY, JUNE 29, 2021

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Committee met, pursuant to notice, at 10:06 a.m., in room 2318 of the Rayburn House Office Building and via Zoom, Hon. Zoe Lofgren [Chairwoman of the Committee] presiding.

**U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HEARING CHARTER**

*The State of Federal Wildland Fire Science: Examining Opportunities for Further Research
& Coordination*

**Tuesday, June 29, 2021
10:00 am EDT**

2318 Rayburn House Office Building and Online via Zoom

PURPOSE

The hearing will provide an opportunity to discuss the current state of wildland fire research, with a focus on how to improve understanding of on-the-ground conditions as well as how climate change is impacting wildfire risk. The Committee will also examine research gaps and additional federal coordination, investment, and engagement needed to improve wildland fire prediction, management, and post-fire response.

WITNESSES

- **Dr. Craig Clements**, Professor of Meteorology, Director of Wildfire Interdisciplinary Research Center, San José State University
- **Dr. Jessica McCarty**, Assistant Professor of Geography, Director of the Geospatial Analysis Center, Miami University
- **Mr. George Geissler**, State Forester and Deputy, Wildland Fire and Forest Health and Resiliency, Washington Department of Natural Resources
- **Fire Chief Erik Litzenberg (Ret.)**, Chair, Wildland Fire Policy Committee, International Association of Fire Chiefs

KEY QUESTIONS

- What are the major gaps in our understanding of fire weather forecasting, fire detection and monitoring, fire behavior, and other topics related to wildland fire research?
- How do federal science agencies and non-federal partners contribute to this research? How can collaboration and coordination be improved?
- What scientific information is most useful to fire managers? How can this information be made more accessible?
- How can we improve community engagement to improve wildfire preparedness and resilience?
- How does climate change impact wildfire risk, and how do wildfires contribute to climate change? How can this feedback loop be mitigated?
- How can we prevent catastrophic wildfires?

BACKGROUND

Fire is a natural phenomenon. In some environments, fire rejuvenates ecosystems by clearing dead material, returning nutrients to the soil, and supporting plant reproduction.¹ However, in recent

¹ <https://www.fws.gov/northeast/refuges/fire/firewildlife.html>

years, we have seen larger and more severe fires, longer fire seasons, and more destruction.² This has been brought about by a changing climate, more widespread development into the wildlands, and fire suppression practices over the past century that have resulted in a buildup of fuels.³ The shift over time to catastrophic infernos has undermined the benefits that can come with wildland fires and has instead presented the general public, businesses, and government at all levels with a growing threat to lives, public health, property, and financial stability.

In 2020, over 10 million acres in the U.S. burned due to wildfires. While wildfires occur in many parts of the country, California has been impacted the most by wildfires. In 2020, California saw over 4.1 million acres burned, which is more than double its previous annual record for acreage burned set in 2018. Furthermore, five of the six largest wildfires on record in California burned between August and September of 2020. Colorado's three largest fires on record also occurred in 2020. Wildfires in the U.S. are estimated to have cost \$16.6 billion and resulted in 46 deaths in 2020 alone.⁴

The ability to accurately anticipate, detect, monitor, and contain wildland fires is largely dependent upon the scientific information available and how accessible that information is to users. Similarly, the ability to predict and monitor fire weather, or weather conditions that affect the likelihood, magnitude, and movement of wildland fires and associated smoke, both in the short-term and seasonally, is an essential tool for fire managers. Factors such as wind speed and direction, temperature, humidity and chance of precipitation, and lightning activity influence fire danger.⁵

Fire managers also rely on the characterization of fuels on the ground—critical information that is obtained through remote sensing by satellites and aircraft, as well as surface observations. Fuels in the wildland-urban interface (WUI) are particularly difficult to accurately characterize as they include both natural vegetation and manmade structures. Fuels information is also important for safe and effective prescribed burns, as fire managers try to keep fire intensity low and minimize smoke exposure to nearby communities as much as possible.

CLIMATE CHANGE AND WILDLAND FIRES

Although natural variations in climate can influence the severity of different fire seasons, anthropogenic climate change is exacerbating the frequency and severity of wildfires. Climate change has led to increased global temperatures and more severe drought, thereby drying vegetation and intensifying fuel aridity. Fire-season fuel aridity is a key driver of wildfires. As temperatures rise, so does the vapor pressure deficit (a measure of the potential amount of water vapor the air can hold). Heightened vapor pressure deficit encourages more evaporation of water from fire-season fuels, ultimately leading to fuel dryness.⁶ This effect has been most pronounced in the intermountain western U.S. From 2000 to 2015, climate change effects on temperature and vapor pressure deficit contributed to 75 percent more of the forested areas in the western U.S. experiencing high fire-season fuel aridity, leading to approximately nine extra days, annually, of

² <https://www.pnas.org/content/113/42/11770>

³ <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019EF001210>

⁴ <https://www.ncdc.noaa.gov/billions/events/US/2020>

⁵ https://www.spc.noaa.gov/misc/NSWW05/16%20rhett_FWXProgram2005.pdf

⁶ <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019MS001790>

high fire potential over that period.⁷ Climate change's influences on fuel dryness have tremendously impacted recent fire seasons. Climate change has also been estimated to have increased U.S. wildfire area by about 4.2 million hectares (the combined size of Connecticut and Massachusetts) from 1984 to 2015. This growth in fire area has been calculated to be double the wildfire area had climate change been absent.⁷

Beyond worsening fire-season fuel aridity, climate change has the potential to increase thunderstorm prevalence throughout the U.S.⁸ In some parts of the U.S., climate change is predicted to increase lightning strikes from thunderstorms by as much as 12 percent per every degree Celsius of warming.⁹ This is a great cause for concern as lightning from thunderstorms can ignite dry fuels leading to wildfires.⁷ While much of this increase in lightning strikes will likely take place in the South, Northeast, and "Tornado Alley", lightning strikes will also become more common in the western U.S. due to climate change.⁹ As atmospheric carbon concentrations continue to contribute to a warming planet, wildfires in the U.S. will become deadlier and more widespread.

FEDERAL WILDLAND FIRE ACTIVITIES

Federal Wildland Fire Science

While federal land management agencies, in conjunction with state and local entities, are responsible for on-the-ground fire management, several federal science agencies provide crucial support services.

Environmental Protection Agency (EPA): The EPA's Air Climate and Energy (ACE) Research Program, within the Office of Research and Development (ORD), conducts research on air quality, emissions, and ecological and health impacts from wildfires. ORD also conducts wildfire research in its Safe and Sustainable Water Resources, Homeland Security, and Sustainable and Healthy Communities research programs. EPA researchers collaborate with the U.S. Forest Service (USFS) to assist with air quality information during wildfire events. EPA also maintains a national real-time ambient air quality data system (AirNow) that the public relies upon for air quality information during wildfires.¹⁰ Additionally, EPA's "Smoke Sense" app focuses on using crowdsourcing and citizen science to increase public awareness and engagement related to wildfire smoke health risks.¹¹

National Aeronautics and Space Administration (NASA): Through the Science Mission Directorate's (SMD) Earth Science Division (ESD), NASA develops and operates Earth-observing space satellites and conducts basic and applied research programs at its Centers and extramurally, through grants and cooperative agreements. NASA research, measurements, and data products improve scientific understanding of and inform decision-making and operational responses to wildland fire across the pre-fire (conditions, fuel, forecasting), active burn (ignition, behavior, smoke plumes, and tracking) and post-fire (soil, vegetation, and air quality conditions) phases. The ESD Applied Sciences program's Disasters element facilitates the transfer and translation of fire-

⁷ <https://www.pnas.org/content/113/42/11770.short>

⁸ <https://www.pnas.org/content/104/50/19719>

⁹ <https://europepmc.org/article/med/25395536>

¹⁰ <https://www.epa.gov/planandbudget/fy-2022-justification-appropriation-estimates-committee-appropriations>

¹¹ <https://www.epa.gov/air-research/smoke-sense-study-citizen-science-project-using-mobile-app>

related satellite data to inform fire management and air quality warnings from smoke plumes.¹² NASA's Fire Information for Resource Management System (FIRMS)¹³ distributes Near Real-Time active fire data to the USFS, partner agencies, and the general public within three hours of satellite observation from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) aboard each of the sun-synchronous polar-orbiting Terra and Aqua satellites and NASA's Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 satellites. At least nine of ESD's operating space-based missions collect data relevant to the pre-fire phase for vegetation and fire fuel conditions: Soil Moisture Active Passive (SMAP); Global Precipitation Measurement Mission (GPM); ECOSystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS); Ice, Cloud, and land Elevation Satellite-2 (ICESat-2); Global Ecosystem Dynamics Investigation Lidar (GEDI); Landsat; Terra; Aqua; and Suomi National Polar-orbiting Partnership (S-NPP). Two missions in development would also collect data relevant to fuel content and conditions: NASA-Indian Space Research Organization Synthetic Aperture Radar (NISAR, scheduled for launch in 2023)¹⁴ and the Soils, Biology, and Geology Designated Observable Mission (in study, anticipated for launch later this decade).¹⁵ The ESD also tests early versions of science instruments on board NASA research aircraft, including by observing active fires and post-fire environments. The Aeronautics Research Mission Directorate (ARMD) has a small research activity, the Scalable Traffic Management for Emergency Response Operations project (STEReO), exploring new ways to respond to disasters, including wildfires, using piloted and unmanned aircraft. STEReO will conduct a live flight demonstration of a wildfire event.

National Institute of Standards and Technology (NIST): Research at the NIST focuses on advancing measurement science, standards, and technology. The NIST Engineering Laboratory does work on fire prevention and control and research done by the Fire Research Division focuses in part on fires at the WUI. The research focuses on improving resilience in communities located at the wildland-urban interface, understanding the start of these fires, and preventing or reducing the ignition of structures located at the wildland-urban interface. NIST's Firebrand Generator is used for research to better understand the spread of fires from flame, contact, embers and thermal radiation. NIST research also helps identify structures at risk of ignition and fire spread as well as to inform the development of new coatings and materials to improve the resilience of these structures to ignition and fire spread. NIST conducts extensive research on past fires, including those at the wildland-urban interface, which helps identify vulnerabilities in structures lost to fire. Given its role in advancing measurement science and standards, NIST research on fires and fires at the wildland-urban interface helps inform and improve building and fire codes.

National Oceanic and Atmospheric Administration (NOAA): The National Weather Service (NWS) provides fire weather forecasts that range from short-term warnings to long-term seasonal predictions. NWS also provides "spot forecasts" that are important tools for both wildfire suppression and prescribed fire. Red Flag Warnings are issued to alert the public of an ongoing or imminent critical fire weather. Incident Meteorologists (IMETs), specially trained forecasters, are on the front lines alongside firefighters, constantly reassessing weather conditions and supporting

¹² <https://appliedsciences.nasa.gov/what-we-do/disasters/fires>.

¹³ <https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms>.

¹⁴ https://nisar.jpl.nasa.gov/files/nisar/NISAR_Applications_Fire.pdf.

¹⁵ <https://sbg.jpl.nasa.gov/>.

operational decisions that enable firefighters to be as effective and safe as possible.¹⁶ The National Environmental Satellite Data and Information Service (NESDIS) manages two satellite missions that are critical to NWS's ability to detect active wildfires and assess potential fire risk. The Joint Polar Satellite System (JPSS) is a constellation of satellites that orbits the Earth from pole-to-pole and across the equator to provide full global coverage twice a day.¹⁷ JPSS is not only capable of detecting active fires and smoke, but it is also able to discern fire temperature,¹⁷ enabling the NWS to determine the intensity of a fire. NOAA also employs the Geostationary Operational Environmental Satellites – R Series (GOES-R), which maintain geostationary orbit over the entirety of the U.S. and outlying territories.¹⁸ GOES-R can monitor fires every five minutes. It is also equipped with the Geostationary Lightning Mapper that detects and measures total lightning within a cloud—a useful metric for fire ignition risk.¹⁹ Observations from JPSS and GOES-R allow NOAA to analyze pre-fire conditions like drought and health of vegetation. Additionally, these satellite systems allow NOAA to observe burn scars after fires to create maps of areas that would be prone to post-fire landslides.²⁰ Information provided by JPSS and GOES-R improves NOAA's High-Resolution Rapid Refresh (HRRR) model, developed in the Office of Oceanic and Atmospheric Research (OAR), producing better smoke forecasts.²¹

National Science Foundation (NSF): The NSF supports foundational research focused on wildfire science through all of NSF's directorates. This includes research funded through the core NSF funding mechanism as well as special funding mechanisms such as NSF Grants for Rapid Response Research (RAPID). NSF also supports investments in research infrastructure such as the National Ecological Observatory Network (NEON), Natural Hazards Engineering Research Infrastructure (NHERI) and Long Term Ecological Research (LTER). Sensors from NEON help enable research projects at larger scales as well as the study of factors that increase fire hazard such as drought. NSF also collaborates with other Federal science agencies including NIST, NOAA, and NASA in support of wildfire research such as through the NSF-NIST Disaster Resilience Grants (DDRG) Program as well as the National Windstorm Impact Reduction Program (NWIRP). The Foundation also supports the National Center for Atmospheric Research (NCAR), a Federally Funded Research and Development Center (FFRDC) headquartered in Boulder, CO. NCAR supports research aircraft used in part for wildland fire studies and has remote sensing capabilities that are used for fire research. NCAR produces the daily National Fuel Moisture Database using data from a number of federal science agencies. Basic research supported by the Foundation in fields such as artificial intelligence and machine learning as well as the social, behavioral and economic sciences are also key to improving our understanding of wildfires. Between FY 2015 – FY 2020, NSF supported 237 awards totaling \$133.3 million in support of wildland fire research.

Federal Wildland Fire Interagency Coordination

The National Interagency Fire Center (NIFC) is a multi-agency support center for wildland firefighting that includes the Bureau of Land Management, the National Park Service, the U.S.

¹⁶ <https://www.noaa.gov/media-advisory/wildfire-season-and-fire-weather-resource-guide-for-reporters-and-media>

¹⁷ https://www.jpss.noaa.gov/mission_and_instruments.html

¹⁸ <https://www.goes-r.gov/>

¹⁹ <https://www.goes-r.gov/spacesegment/glm.html>

²⁰ <https://www.usgs.gov/news/post-wildfire-landslides-becoming-more-frequent-southern-california>

²¹ <https://rapidrefresh.noaa.gov/hrrr/>

Fish and Wildlife Service, the Bureau of Indian Affairs, and the USFS. NIFC facilitates information sharing and coordinates shared usage of firefighting supplies, equipment, and personnel among its member agencies.²²

The National Wildfire Coordinating Group (NWCG) provides national leadership to enable interoperable wildland fire operations among federal, state, local, tribal, and territorial partners. Its member agencies include many within at the Department of the Interior, along with the USFS the U.S. Fire Administration and a few non-federal organizations. The National Weather Service is an Associate Member of the NWCG.²³

Federal Wildland Fire Science in the Fiscal Year 2022 President's Budget Request

The President's Budget Request (PBR) for fiscal year 2022 (FY 2022) includes a \$15 million increase across NOAA to support research, operations, and observations to enable better fire weather forecasts and fire detection and management. The additional funding would also improve local communities' access to fire weather data, products, and services. \$7 million of the increase is for the fire weather program at NOAA's Office of Oceanic and Atmospheric Research. \$4 million is designated for NWS for its fire weather predictions, and \$4 million is for NESDIS to advance its fire weather priorities. The increase in NOAA funding is also intended to establish a new NOAA Fire Weather Testbed, facilitating coordination between NOAA line offices, the USFS other federal agencies, and non-federal partners.

The FY 2022 PBR for the EPA includes a \$30 million increase to the ACE Research Program that would include climate research on how extreme events, including wildfires, affect air quality, water quality and availability, and human health, with a focus on vulnerable communities.¹⁰

The administration's budget request for NASA for FY 2022²⁴ includes a \$9.8 million increase to the Earth Science Division's Applied Sciences program, provided "to initiate an Applications and Research Team focused on science-informed solutions and addressing climate impacts together with underserved communities." Within that effort, Applied Sciences "will initiate efforts to build resilience to environmental disruptions and climate risks" and "target specific activities on wildfires."

OPPORTUNITIES FOR FURTHER RESEARCH AND INVESTMENT

There remain ways to improve fuels, fire, and smoke management through science and coordination.²⁵ Further research of fire hazards and fire behavior in the WUI can help reduce the risk of fire dangers. Higher resolution – both spatial and temporal – data of fuels in the wildland can inform decisions to both reduce the risk of extreme fire and help managers anticipate fire behavior and spread. Additional research into smoke plume behavior may lead to improved public health outcomes and provide additional actionable information to fire managers. Scientists are also increasingly finding value in the development of artificial intelligence and machine learning. Ultimately, more data will require additional computing capacity and data storage.

²² <https://www.nifc.gov/about-us/what-is-nifc>

²³ <https://www.nwcg.gov/>

²⁴ https://www.nasa.gov/sites/default/files/atoms/files/fy2022_congressional_justification_nasa_budget_request.pdf

²⁵ <https://link.springer.com/content/pdf/10.1007/s40725-020-00127-2.pdf>

Chairwoman LOFGREN. This hearing will come to order, and, without objection, the Chair is authorized to declare a recess at any time. Before I deliver my opening remarks, I wanted to note that today the Committee is meeting both in person and virtually, and I want to announce a couple of reminders to the Members about the conduct of this hearing. First, Members and staff who are attending in person, and who are unvaccinated against COVID-19, need to stay masked throughout the hearing. Unvaccinated Members may remove their masks only during their questioning under the five minute rule. Or, of course, unvaccinated persons can also attend remotely. Members who are attending virtually should keep their video feed on as long as they are present in the hearing. Members are responsible for their own microphones, and please also keep your microphones muted, unless you're speaking. And, finally, if Members have documents they wish to submit for the record, please e-mail them to the Committee Clerk, whose e-mail address was circulated prior to the hearing.

I want to say good morning, and thank Chairwoman Johnson for agreeing to hold this hearing. She is in her district with the First Lady of the United States today, and I am honored to be able to the Chair this hearing on wildlife fire science, and I think it's very clear that in the 2021 fire season—we've already had that begin—it's on pace to be much worse than last year. Already over 100,000 more acres of the American wildland have burned than by this point in time in 2020. Firefighters in my home State of California are currently battling at least six large wildfires throughout the State. As a Californian, this is cause for alarm. In 2020 alone the U.S. saw record wildfires burn 10 million acres of land, over four million of which were in California. In 2018 Californian fires only burned two million acres. The warmer and drier conditions created by climate change have increased extreme wildfire conditions, with nine more days of higher—high fire potential added every year since 2000.

As the risk for catastrophic wildfire grows, so should our ability to forecast wildfires and to mitigate fire risk. Today's hearing presents an opportunity to discuss the current state of wildland fire research, and how we can use it to improve our understanding of conditions in the field. We'll also discuss gaps in the science, and identify opportunities for further Federal investment and coordination. Federal programs like the U.S. Drought Monitor are instrumental in helping our wildland managers prepare for worsening fire seasons. This is just one example of how enhanced coordination amongst science agencies with operational managers can lead to actionable science. With dedicated authorities and investments in wildfire science, we can develop additional capabilities for real time detection of fire ignition, and even deepen our understanding of wildfire fuels.

I was proud to co-sponsor an amendment with my colleague, Mr. Perlmutter, on wildfire resilience research funding at—in the *NSF for the Future Act*. It was great—it was a great start to what we can do to strengthen wildlife research, but we must do more. It's not right for Congress not to act to bolster our wildlife research, it's also dangerous. That's why I'm drafting legislation in this Committee to improve the understanding, prediction, and management

of wildland fires through robust research initiatives. This bill will also enhance Federal interagency collaboration and coordination to include science agencies in Federal wildland fire response. I hope this bill will also lead to our Federal science agencies working closely with fire managers to ensure that wildfire science can be operationalized to mitigate wildfire risk.

We are fortunate to have witnesses today whose testimony will inform this legislation. Joining us are academic researchers who use information provided by agencies like NOAA (National Oceanic and Atmospheric Administration), and NASA (National Aeronautics and Space Administration), and the EPA (Environmental Protection Agency) to build out America's wildfire research capacity, and we look forward to hearing from them about opportunities for areas of further investment in wildfire science. I'd also like to extend a warm welcome to Dr. Craig Clements, who is a professor at, yes, San José State University, located in my congressional district. Dr. Clements is the Director of San José State University's Wildfire Interdisciplinary Research Center, which is a leader in wildfire research. I look forward to hearing his testimony about the importance of supporting interdisciplinary wildfire research.

We're also fortunate to have with us today some of the bravest people facing the wildfire crisis, our first responders, forest managers, and firefighters, intimately understand which innovations best support on the ground needs. This hearing is a critical first step in creating a truly whole of government response to wildfire risks that connects research to operations. We're encouraged by the administration's emphasis on climate resilience and robust funding in the President's budget request for our science agencies to tackle extreme weather events. This leaves us ample room to work with appropriators to ensure funding levels in keeping with the magnitude of the wildfire challenges we face.

[The prepared statement of Ms. Lofgren follows:]

Good morning and thank you Chairwoman Johnson for holding this timely hearing on wildland fire science, and for allowing me to take the gavel.

It is clear: the 2021 fire season has already begun, and it's on pace to be much worse than the historic season observed across the West last year. Already, almost 200,000 more acres of American wildland have burned than by this point in time in 2020—a 10-year high. Firefighters in my home state of California are currently battling at least six large wildfires throughout the state. As a Californian, this is cause for alarm. In 2020 alone, the U.S. saw record wildfires burn 10 million acres of land—over four million of which were in California. In 2018, Californian fires only burned two million acres. The cycle of extreme heat and drought in the West have increased extreme wildfire conditions, adding nine more days of high fire potential every year since 2000.

As the risk for catastrophic wildfire grows, so should our ability to forecast wildfires and mitigate fire risk. Today's hearing presents an opportunity to discuss the current state of wildland fire research and how we use it to improve our understanding of conditions in the field. We will also discuss gaps in the science and identify opportunities for further federal investment and coordination. Federal programs like the U.S. Drought Monitor are instrumental in helping our wildland managers prepare for worsening fire seasons. This is just one example of how enhanced coordination among science agencies, and with operational managers, can lead to actionable science. With dedicated authorities and investments in wildfire science, we can develop additional capability for real-time detection of fire ignition, and even deepen our understanding of wildfire fuels. I was proud to cosponsor an amendment, with my colleague Mr. Perlmutter, on wildfire resilience research funding in the *NSF for the Future Act*. It was a great start to what we can do to strengthen wildfire research, but we must do more.

It is not just unwise for Congress not to act to bolster our wildfire research, it is dangerous. Throwing ourselves at each megafire is neither a near-term nor long-term solution. That is why I am drafting legislation in this Committee to improve the understanding, prediction, and management of wildland fires through robust research initiatives. This bill will also enhance federal interagency collaboration and coordination to include science agencies in federal wildland fire response. I hope this bill will also lead to our federal science agencies working closely with fire managers to ensure that wildfire science can be operationalized to mitigate wildfire risk.

We are fortunate to have witnesses today whose testimony will inform this legislation. Joining us are academic researchers who use information provided by agencies like NOAA, NASA, and the EPA to build out America's wildfire research capacity. We look forward to hearing from them about opportunities for areas of further investment in wildfire science. I would also like to extend a warm welcome to Dr. Craig Clements who is a professor at San Jose State University located in my district. Dr. Clements is the Director of SJSU's Wildfire Interdisciplinary Research Center, which is a leader in wildfire research. I look forward to hearing his testimony about the importance of supporting interdisciplinary wildfire research. We are also fortunate to have with us today some of the bravest people facing the wildfire crisis: our first responders. Forest managers and firefighters intimately understand which innovations best support on-the-ground needs.

This hearing is a critical first step in creating a truly whole-of-government response to wildfire risk that connects research to operations. We are encouraged by the Biden Administration's emphasis on climate resilience and robust funding in the President's Budget Request for our science agencies to tackle extreme weather events. This leaves us ample room to work with appropriators to ensure funding levels in keeping with the magnitude of the wildfire challenge we face. With that, I want to thank our witnesses for their time this morning. At this point, I would like to yield to the Ranking Member for any comments he may wish to make.

Chairwoman LOFGREN. With that, I want to thank our witnesses for their time this morning, and at this point I would like to yield to the Ranking Member for any comments he may wish to make.

Mr. LUCAS. Thank you, and I'd like to thank Chairwoman Johnson for holding this hearing, and Chairwoman Lofgren for presiding today. Today's hearing is timely as we enter the summer months, which have traditionally marked the beginning of wildfire season. However, I am sure many of my Western colleagues would agree that there is really not much of a true wildfire season anymore, with fires occurring year-round. Last year brought haunting images of devastating wildfires across the West. This year, unfortunately, could be even worse. The National Interagency Fire Center (NIFC) reports that the number of fires and acres burned to date are ahead of last year's figures. Given the ongoing drought covering much of the West, it's reasonable to conclude this year's wildfire statistics could be historic.

Wildfire is an important part of the ecosystem, and often occurs naturally. Many plant species rely on wildfire for their growth and regeneration processes, and many animal species look to recently burned lands for their habitat. However, lengthier drought, hotter temperatures, and poorly maintained Federal lands are all contributing to a greater frequency and intensity of wildfires across the country, and around the world, which is problematic. Additionally, the increased number of people who live in the wildland-urban interface (WUI), the area where residential neighborhoods meet wooded areas, has created the need for a different allocation of resources. While wildfires represent a threat to life and property, they also have devastating environmental impacts, ranging from polluted watersheds to increased carbon dioxide released into the atmosphere.

We tend to think of the West as being the most vulnerable to wildfire, but this is an issue for all of us. Resources spent combatting wildfire by our Federal land management agencies are resources that could be spent on revenue-generating recreational activities, and are a diversion of attention away from other local emergency response needs. Several agencies within our Committee's jurisdiction have a role in combatting wildfire, whether it's NASA providing Earth imaging data or NOAA's incident meteorologists helping firefighters plot the best path to fight an ongoing fire. Other agencies, such as NSF (National Science Foundation) and NIST (National Institute of Standards and Technology), engage in research on different aspects of wildlife behavior, and how we can better fireproof structures. But we must be certain that all the work of these agencies is carried out in a coordinated manner, and is being effectively put into operations by agencies such as the Forestry Service and the Department of Interior (DOI).

I want to thank our witnesses for appearing before us today. I'm especially pleased to welcome George Geissler, who's currently the Washington State Forester. He previously was the State Forester of Oklahoma, and can speak to the impacts of wildfire in different parts of the country. I look forward to hearing his thoughts on where there are gaps in Federal research, how we can improve coordination among Federal agencies, and what actions we can take which would be the most beneficial to him, and all the on-ground wildfire responders. I know this is a busy period for him, especially given the record-breaking temperatures most of the West faced this past week, and I thank him for taking time to share his extensive experience with the Committee. With that, Madam Chair, I want to thank you, and I yield back.

[The prepared statement of Mr. Lucas follows:]

Thank you, Chairwoman Johnson, for holding this hearing. Today's hearing is timely as we enter the summer months which have traditionally marked the beginning of wildfire season. However, I am sure many of my western colleagues would agree that there is really not much of a true wildfire season anymore, with fires occurring year-round.

Last year brought haunting images of devastating wildfires across the West. This year unfortunately could be even worse. The National Interagency Fire Center reports that the number of fires and acres burned to date are ahead of last year's figures. Given the ongoing drought covering much of the west, it is reasonable to conclude that this year's wildfire statistics could be historic.

Wildfire is an important part of the ecosystem and often occurs naturally. Many plant species rely on wildfire for their growth and regeneration processes and many animal species look to recently burned lands for their habitat. However, lengthier droughts, hotter temperatures, and poorly maintained federal lands are all contributing to a greater frequency and intensity of wildfires across the country and around the world, which is problematic. Additionally, the increased number of people who live in the wildland-urban interface—the area where residential neighborhoods meet wooded areas—has created the need for a different allocation of resources.

While wildfires represent a threat to life and property, they also have devastating environmental impacts, ranging from polluted watersheds to increased carbon dioxide released into the atmosphere.

We tend to think of the West as being the most vulnerable to wildfire, but this is an issue for us all. Resources spent combatting wildfire by our federal land management agencies are resources which could be spent on revenue generating recreational activities and are a diversion of attention away from other local emergency response needs.

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cies such as NSF and NIST engage in research on different aspects of wildfire behavior and how we can better fireproof structures. But we must be certain that all the work of these agencies is carried out in a coordinated manner and is being effectively put into operation by agencies such as the Forest Service and the Department of the Interior.

I want to thank our witnesses for appearing before us today. I'm especially pleased to welcome George Geissler, who is currently the Washington state forester. He was previously state forester of Oklahoma and can speak to the impacts of wildfire in different parts of our country. I look forward to hearing his thoughts on where there are gaps in federal research, how we can improve coordination among federal agencies, and what actions we can take which would be most beneficial to him and all on-the-ground wildfire responders. I know this is a busy period for him, especially given the record-breaking temperatures most of the West faced this past weekend, and I thank him for taking the time to share his extensive experience with the committee.

Thank you and I yield back.

Chairwoman LOFGREN. The gentleman yields back, and, without objection, other Members who wish may submit opening statements to the record.

[The prepared statement of Chairwoman Johnson follows:]

In districts across the country, especially in the West, we are seeing more frequent and catastrophic wildfires destroying lives and property. These tragedies are only getting worse. Last year, over 10 million acres burned in this country at a cost of over \$16 billion. This year, wildfire season has already begun. With record temperatures and drought across much of the country, I fear how the season will progress.

We know that climate change is contributing to this growing threat. We also know that poor land management practices over the past several decades have allowed vegetation to accumulate—ripe for enormous infernos. Furthermore, as development creeps more into natural wildlands, more homes and businesses are put at increased risk.

Our federal science agencies provide critical support to fire managers. This includes the National Oceanic and Atmospheric Administration, NASA, the National Science Foundation, and others. These agencies advise fire managers on fire weather conditions, monitor fire behavior and smoke plumes, and perform related fire research and monitoring. But there is need for further investment and coordination of these research efforts.

Congress must ensure that communities and firefighters have as many tools as possible to address this growing threat. This Committee is focused on moving critical science forward in a collaborative way. This is critical for us to be prepared to manage wildfires in the safest and most effective ways possible. This is top of mind for many of the Members of this Committee.

In particular, my colleague from California, Ms. Lofgren, has devoted much of her time and attention to this matter. I am glad that Representative Lofgren is working to address the gaps in wildfire science through legislation. It is vital that the best available science is used to inform operational decisions on the frontlines of wildfires. It is also crucial that robust mechanisms for collaboration and coordination are put in place. This will ensure a unified approach to wildfire management across the federal government and with non-federal stakeholders.

Our expert witness panel includes those on the ground and those doing the critical research on wildfires. They will discuss the current state of wildfire science, but also what they need to do their work more effectively. I look forward to hearing their recommendations on how this Committee can help our country better respond to our growing wildfire risk.

Thank you.

Chairwoman LOFGREN. I'd now like to introduce our witnesses, all of whom are participating remotely. Our first witness today is Dr. Craig Clements. Dr. Clements is a Professor of Meteorology at San José State University, and the Director of the Wildfire Interdisciplinary Research Center. He leads research on fire weather, extreme fire behavior, fire/atmosphere interactions, and conducting wildland fire field experiments. Dr. Clements has over 20 years of experience in the meteorological field observations, and teaches

courses in fire weather, wildfire science, mountain meteorology, climate change, and meteorological instrumentation.

Our next witness is Dr. Jessica McCarty. Dr. McCarty is the Director of the Geospatial Analysis Center, and as of July 1 of this year, an Associate Professor of Geography at Miami University of Ohio. Dr. McCarty has more than 15 years' experience in applications of geospatial and data science to accurately quantify wildland and human-caused fire emissions, agriculture and food security, and land cover/land use change. She is the co-author—author of more than 30 peer reviewed journal articles, 12 peer reviewed conference proceedings, three book chapters, four technical reports, four data citations, and one NASA technology transfer.

Our third witness, as has been mentioned by the Ranking Member, is Mr. George Geissler, who is Washington State Forester, and he's the Deputy Supervisor for Wildfire and Foreign—Forest Health, having previously served in Oklahoma. He has almost 30 years of experience in natural resource and wildland fires, fire management, and 6 years of experience in structural firefighting as a volunteer in Idaho and New Mexico. He's a member of the Society of American Foresters since 1987, and a certified forester. He joined the Oklahoma Forestry Services in 2006. Before being named as State Forester, he served in a staff function to coordinate all forest management activities provided by the agency.

And our fourth and final witness today is Chief Erik Litzenberg, recently retired from his position as Fire Chief for Santa Fe County, New Mexico. Chief Litzenberg served the majority of his career in the city of Santa Fe Fire Department, completing his time in the city as Fire Chief and City Manager before returning to the county where his career began. Through 25 years of service he has also worked for New Mexico State Forestry, and is part of multiple incident management teams, and for many years owned Santa Fe Wildfire, which provided resources for large scale incident management and response.

As our witnesses should know, you will each have five minutes for your spoken testimony. Your entire written testimony will be included in the record of this hearing. When you have completed your spoken testimony, we will begin with questions. There will be, I believe, a little clock on your virtual screen that will count down your five minutes, and when your five minutes are up, we do ask that you sum up so that we can hear all the witnesses before votes are called. So first we will start with you, Dr. Clements.

**TESTIMONY OF DR. CRAIG B. CLEMENTS,
PROFESSOR OF METEOROLOGY
AND DIRECTOR OF THE WILDFIRE
INTERDISCIPLINARY RESEARCH CENTER
AT SAN JOSÉ STATE UNIVERSITY**

Dr. CLEMENTS. Good morning, Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, including San Jose State's representative, Congresswoman Lofgren, who is chairing this hearing today. Thank you for inviting me to provide testimony on this very important issue. My name is Craig Clements, and I serve as Director of the Wildfire Interdisciplinary Research Center at San José State University. I am honored to appear before the

House Science, Space, and Technology Committee for this hearing on “The State of Federal Wildland Fire Science: Examining Opportunities for Further Research Coordination”. My testimony will focus on fire weather and fire behavior research, and the need for additional Federal investment in wildland fire science. At the outset I’d like to thank Congresswoman Lofgren for advocating for increased wildfire investments across the Federal Government in her letter to the Biden Administration.

There is no doubt that wildfires are becoming larger and more severe in Western U.S. This is—this trend is projected to continue due to a number of factors, including 100 years of fire exclusion that resulted in increased tree density and dead fuel accumulation, and longer fire seasons, and changes in fire weather conditions caused by climate change. Now more than ever our Nation needs to increase investment in fire science to empower decisionmakers in addressing the complex challenges we face. While I won’t address all research gaps in wildland fire science today, I will focus on a few key aspects that I believe are important.

Fundamental mechanisms of wildfire spread are still poorly understood, especially in the context of extreme events. Additionally, we don’t have a good understanding what role fire atmosphere interactions play on fire spread, nor do we have the appropriate observations to tackle these questions. There is a wide gap between the need for high resolution data to understand fire behavior and the current capabilities of fire observation systems. In terms of observational needs, we need to start treating fire weather the same as we do other severe weather phenomena. We don’t have the same levels of funding or dedicated resources for fire weather as we do for severe storms or hurricane research. We need the equivalent of hurricane hunters for wildfire so that we can better see and sample the fire.

Additionally, we are missing the appropriate centers for critical observations. Specifically, we need publicly available, high spatial, and temporal resolution observations from both space and aircraft. These observations can’t just be a snapshot once or twice a day. They need to be continuous over the entire event. Comprehensive observational data sets that include fire weather, plume dynamic, smoke and fire behavior, are rare. The Fire and Smoke Model Evaluation Experiment, called FASMEE, which is a multi-agency program. Addresses these data gaps by capitalizing on high intensity prescribed fires, and this should be a national priority.

In terms of the prediction of fire behavior, investment is needed in operational, community-based, coupled fire atmosphere models, which are models that link the fire spread with the weather prediction forecast. These are the only models that can best predict how a fire can create its own weather. A community-based model is even more important because it allows researchers from any institution to not only use the model, but to also improve the model, and share it with other users. This is in contrast to models that are kept in-house and within one agency, institution, or National Lab that are not available for other agencies or institutions to use or contribute to. For example, the Open Wildfire Modeling Group facilitated development of the first community fire atmosphere model called WRF-SFIRE (Weather Research and Forecasting

Model-Spread Fire Model). This model has become a core forecasting system used by many institutions and agencies around the world. Further investment in this framework will improve our ability to better predict extreme future fire.

In terms of driving the science forward and promoting innovation, directed funding to agencies that support research and development in wildfire science needs to be a priority. A few Federal agencies are already leading wildfire research efforts, but these are not well coordinated. One exception is the Joint Fire Sciences Program (JFSP), that's had its budget reduced in half. Restoring its budget, and even increasing it, will benefit wildland fire science. Federal investment should also target competitive grant programs where—that academic institutions can apply for. For example, that National Science Foundation could develop specific wildfire funding programs across its directorates that would fund not only basic research, but also provide more mechanism for research within the social sciences. And finally, and most importantly, in my opinion, is the need to establish a national and sustainable fire weather research program. To date there's never been a dedicated program that funds both basic and applied research in fire weather, and this is critically needed. Thank you.

[The prepared statement of Dr. Clements follows:]

Written Statement of

Craig B. Clements, Ph.D.

Director, Wildfire Interdisciplinary Research Center
Professor of Meteorology, Department of Meteorology and Climate Science
San José State University, San Jose, CA

Before the House Committee on Science, Space, and Technology hearing on
“The State of Federal Wildland Fire Science: Examining Opportunities for Further Research &
Coordination”

June 29, 2021

I am a Professor of Meteorology and Director of the Wildfire Interdisciplinary Research Center and Fire Weather Research Laboratory at San José State University. In this testimony I present briefly on the current needs in wildfire and fire weather research and the funding requirements for improving our state of knowledge in these fields. Additionally, I will address some aspects of current technologies and provide an example of how the private sector has successfully developed new tools for fire management agencies. I will close with a summary of recommendations.

Background and the changing wildfire environment

Wildfire globally is becoming more challenging compared to just a few decades ago with many fires becoming larger and more severe, particularly in the western US. This trend is projected to continue into the future due to a number of factors including changes to fire weather conditions that are caused by anthropogenic climate change (Stravos, et al. 2014; Barbero et al. 2015). Fire seasons are getting longer and fire danger and critical fire weather conditions are increasing globally as well (Jolly et al 2015; Abatzoglou et al. 2019). Studies have also shown that increased air temperatures and drying of the atmosphere due climate change are driving more critical conditions in the fire environment (Parks and Abatzoglou 2020). This leads to impacts on fuel moisture content (FMC) which is the amount of water or moisture within a plant. As FMC within a plant decreases, flammability of the plant increases leading to increased ignition probability and faster rates of fire spread. Live fuel moisture content and fire weather are key drivers to high-severity fires (Parks et al. 2018). In addition to the climate impacts on fuels, forest management has also played a role in the increase of large and higher severity fires in the western US. Over 100 years of fire exclusion resulted in increased tree density dead fuel accumulation, and decreased forest structure heterogeneity magnifying the wildfire problem (Collins et al. 2017). It is clear that there is a pressing and immediate need for more research to address the changing wildfire environment. For example, many studies attributing changes in wildfire severity to climate change employ empirical indices that account for atmospheric conditions conducive to fire weather, such as air temperature and low humidity (e.g., Abatzoglou et al. 2019). However, a more comprehensive attribution requires dynamical modelling of wildfires that accounts for the coupling between atmospheric conditions, ecological conditions, and the fire behavior itself (Lloyd and

Shepherd, 2020). Furthermore, as catastrophic wildfires become more common, there is a need for more research to help develop improved understanding of future wildfires and their behavior. This involves the development of improved real-time prediction and forecasting tools.

Current state of federal fire weather research and forecasting

While there are many research efforts within various federal agencies that focus on wildfire, I will focus my testimony on programs that are aimed at fire weather research and wildfire prediction, which are mainly within the U.S. Department of Agriculture U.S. Forest Service (USFS) and partners. Research at the USFS is primarily driven by user needs and is mostly application focused. However, to some degree basic wildfire research is also conducted within the various USFS research laboratories and research stations and through partnerships with academic institutions who typically focus on more fundamental research.

Federal wildfire forecasting and prediction is generally addressed by the USFS which leads the nation in development of tools for wildfire risk and fire danger assessment. The National Fire Danger Rating System (NFDRS) is a system that is used throughout the nation to predict fire danger based on the environmental conditions. Current efforts are being made to improve its algorithms, to advance fine-dead fuel moisture and live fuel moisture models, and simplify fuel classifications (<https://www.firelab.org/project/national-fire-danger-rating-system>). NFDRS relates environmental conditions to fire operations and is the core tool used by fire agencies around the country. However, NFDRS is produced only once per day and not at a high spatial resolution as needed for forecasting fire risk at the community scale. As a result, investor owned utilities (IOUs) in California have been forced to develop their own fire potential indices to meet their requirements of Public Safety Power Shutoffs so that de-energization of circuits can be limited to small areas. Increasing both the temporal and spatial resolution of fire danger forecasts will be an improvement to an already critical tool for fire management.

Another key contribution of USFS fire weather research has been the development of various fire weather indices that are used to assess and predict weather conditions conducive to large wildfires. Many of these indices are still in use today (Fosberg 1978; Haines 1988). More recently the Hot-Dry-Windy index was developed in partnership between three USFS research stations and Saint Cloud State University (Srock et al. 2018).

Within the Research and Applications Laboratory at the National Center for Atmospheric Research (NCAR) efforts have been made to extend the functionality of the Weather Research and Forecasting (WRF) community NWP model to enable in-line simulations of weather conditions and fire behavior. New developments leverage the WRF-SFIRE model (Mandel et al. 2011) and improve the fire spread representation, the fuel characterization (Jiménez et al. 2018), as well as satellite-derived fuel-moisture data, and spotting potential to better predict fire progression and where the spot-fires are likely to ignite. These developments are being included in the community WRF-Fire model. Additionally, a new satellite-driven fuel moisture prediction system has been developed for better fire spread forecasts (McCandless et al. 2020).

Wildfire and fire weather research gaps

To address the major gaps in our understanding of fire weather and fire behavior, we need to think about and treat wildfires like other natural disasters and severe weather threats. Fire weather is the severe weather of the western US, yet there are very few resources aimed at monitoring these events like those dedicated to severe thunderstorms and hurricanes.

Core deficiencies in our knowledge are related to how wildfires create their own weather and how these coupled processes manifest on the fire line. We have limited understanding of how fire-atmospheric interactions affect fire spread. This is an area of research that has not been well funded and requires improved modeling capability using next-generation coupled fire-atmosphere models (e.g., WRF-SFIRE) and new capabilities in field observations which are also lacking.

Current efforts used for forecasting wildfire behavior need to focus on further development of community coupled fire-atmosphere prediction systems such as WRF-SFIRE (Kochanski et al. 2015; Mandel et al. 2011, 2014; Jiménez et al. 2018). This type of framework is community based allowing researchers from any institution to not only use the model but to also improve the model and share it with other users. This is in contrast to models that are kept in-house and within one agency, institution or national lab and are not available for other agencies or institutions to use, modify or contribute to. Community-based models provide buy-in from the entire community to further develop the model and make it better. For example, the Open Wildfire Modeling group (<http://openwfm.org>) facilitated development of the first community coupled fire-atmosphere model WRF-SFIRE, leveraging the community Weather and Research and Forecasting Model (Skamarock et al. 2019). This model has become a core fire forecasting system used by many institutions and agencies not only in the US, but around the world. Coupled fire-atmosphere models are the only models that can predict how a wildfire interacts with its environment and how the fire can change local weather conditions. Wildfire induced weather is responsible for some of the most extreme fire events in history, including the development of fire tornadoes (Lareau et al. 2018) which can form quickly and cause extreme rates of fire spread endangering firefighters and communities. Additionally, coupled fire-atmosphere models can predict smoke impacts at community scales more accurately than typical smoke prediction systems that run at coarse resolutions and are incapable of resolving small-scale processes critical in the context of plume dynamics and smoke dispersion.

In order to build better fire prediction tools, there is a critical need for new comprehensive observational datasets that include weather, plume dynamics and fire behavior observations (Clements et al. 2018). These data are rare, especially compared to the observational record for other atmospheric processes such as severe storms. This observational deficit stems from the logistical and safety challenges associated with sampling in the near-fire environment. One way to overcome these challenges is to capitalize on planned prescribed fires. For the last decade, prescribed fire experiments have focused on small, low-intensity fires in flat terrain and do not represent the high-severity wildfires of the western US. One exception to this is the Fire and Smoke Model Evaluation Experiment (FASMEE) (Prichard et al. 2019), which is an interdisciplinary and multi-agency program that is focusing on high-intensity prescribed fires to study fire behavior, smoke and plume dynamics, fire weather, fire ecology and fuels, and fire effects. A large coordinated effort is needed to address extreme wildfire with research needs at its

core. This program will build on the decades of research focused by many national agencies on low-intensity prescribed fire. The FASMEE project is one of the higher priority projects in wildfire science today and should be a national priority.

Fire weather data collection needs

Collecting routine meteorological data on wildfire incidents is challenging because many wildfires typically occur in remote areas with the exception of those burning in the wildland urban interface (WUI). We have not invested in monitoring the fire environment as we have for other severe weather phenomena. Many regions in the western US lack a sufficient coverage of surface weather stations, but this is improving with new networks being established in the last few years. California is unique because it likely has the most dense weather station network in the world as the IOUs there each have invested heavily in creating a network of surface weather stations that are installed on utility infrastructure and within each utility's territory. While surface weather data are critical for assessing near surface fire risk (temperature, humidity, and wind), it is the atmospheric conditions above the surface that are important in understating how fires may evolve especially in mountainous terrain where the atmosphere is more complex and associated with rapid changes that can impact a fire's behavior in a matter of minutes (Werth et al. 2011; Lareau et al. 2018). Additionally, fuel moisture observations are critical for both fire risk and fire spread prediction. These data are sparse and this is a major limitation that requires new observations of both live and dead fuel moisture for wildfire prediction improvement.

National Weather Service Incident Meteorologists (IMETS) who are assigned to large wildfire incidents can request the deployment of portable, remote automated weather stations to provide surface weather observations, but these stations are generally limited to just a few and it takes a minimum of a few days after the incident management team is established. Additionally, IMETS are equipped with modern upper-air weather balloon sounding systems that allow the collection of vertical profiles of the atmosphere when time permits. Generally, the IMET is already heavily tasked with providing detailed weather forecasts to the Incident Management Team and this takes up a majority of their time (<https://www.weather.gov/news/imet-articl>). There is a need for increased fire weather observations at large wildfire incidents to provide critical data to IMETS for fire weather and fire behavior forecasts.

During the last few years, San José State University has made a concentrated effort to collect new observations of fire weather and fire behavior at active wildfire incidents (Clements et al. 2018; Brewer and Clements 2019). Because of the inherent dangers of the wildfire environment, research teams are required to possess fire-fighter qualifications through either state or federal agencies to access the fire line. Being the only academic meteorological research team in the US with these qualifications, we have deployed to nearly 40 wildfires in California with our mobile Doppler lidar and radar assets. These new tools have provided first insights into the dynamics of plume-dominated wildfires and fire-atmosphere interactions at the large scale (Lareau and Clements 2016; 2017). Still yet, these observations are very limited and we need to capitalize on these early efforts and create a concentrated program to sample critical fire weather during wildfire events. It is only then that we will have the data necessary to not only better understand extreme fire behavior, but also develop the next generation of forecasting models.

We do lack the appropriate observational tools for fire characterization and reconnaissance—knowing quickly and continuously where and how a wildfire is spreading is a major gap in both our forecasting and suppression capability. This is also creates a major gap in our scientific understating of extreme fire behavior. Fire managers need to make decisions in timely manner and having high-resolution and continuous observations of the fire front position is required to ensure not only public safety, but also that of firefighters. Additionally, next-generation models need high-resolution infrared observations in order to predict where the fire will be in the next few minutes, hours, or days. While there is much emphasis on fire detection, that is not as much of a concern as having continuous high temporal and spatial resolution observations allowing to characterize the fire, its temperature, flame lengths, heat release, spotting potential, and rate of spread. Improved fire characterization is a core need for all wildfire science fields. These observations can be made using both satellites and aircraft including drones, but must have high pixel resolution (tens of meters or less), high temporal resolution (< 15 minutes) and be multispectral so that images are not saturated.

A summary of fire weather research needs was presented during San José State University's Fire Weather Research Workshops in 2019 and 2021 (<https://www.fireweather.org/2021-workshop>), where over 400 attendees participated from around the world. The workshops focused on the state of knowledge of wildfire prediction and fire weather research, with a strong emphasis on models and tools that can be adopted operationally.

Wildfire community resilience

The social component can be one of the more intractable factors in wildfire management. The exploding residential population in the WUI and increasing wildfire impacts (e.g., smoke, evacuation) highlights a need to promote fire-adapted communities and increase the pace and scale of risk-averting activities, like fuels management or defensible space, across socially distinct populations sharing the same landscape. Fire professionals, emergency officials, and community leaders can struggle with disaster management within an administrative unit in the WUI, like a fire district or county, because new residents from more urban areas with less fire-education move into high-risk spaces. Furthermore, community contexts and capacities are going to vary, and our wildfire adaptation tools and policies need to be adaptable to local-level needs and capacities in order to promote fire adaptation across landscapes. Integrating social data into our planning, model development, and conversations with managers and community members can help illuminate gaps in our fire resilience programs, more accurately plan for and respond to wildfire events in areas with a residential population, and better understand barriers to increasing the pace and scale of fuels management in WUI contexts. New modeling tools on the other hand can be helpful in prescribed burn planning and identifying most fire-prone communities.

Tools for fire management

There is prevailing evidence that fire managers often utilize decision support tools to gut check or validate the tactics they already intend to take or implement due to years of experience. However, the tide is shifting. Many managers identify that models are increasingly useful to them when responding to events under a changing climate as years of expertise is beginning to be challenged by new environmental circumstances. The public demand for information during a wildfire event

can also add additional stress to the fire management situation as agencies are expected to provide accurate and frequent information updates to a public that is attempting to time their evacuation to a variety of evacuation cues. Spatial data, models, and displays (e.g., dashboards, accessible websites) are important tools for both professional wildfire response under a changing climate and community/individual resident response during a wildfire event also under a changing climate. However, these tools must be integrated and adjusted to operational needs so that critical information can be extracted from multiple data sources and models easily and fast.

Wildfire research at academic institutions and the private sector

Traditionally, wildfire research at US academic institutions has been housed in forestry departments with a focus on fire ecology. There are a number of programs within engineering departments that study fire dynamics and combustion and some of these programs are focused on wildfire. In the last decade, much wildfire research in academia has focused on climate science and climate impacts on wildfire. There are few wildfire specific research programs at universities. Typically, only one or two faculty in any one department may have funded projects in wildfire research and many of these investigators are funded through specific directorates within the National Science Foundation focused only on a single aspect of wildland fire or through limited-scope Joint Fire Science Program grants. One gap in academia is the lack of programs focused on fire weather as most atmospheric science programs do not offer courses in fire weather or fire behavior. Exceptions to this are San José State University and the South Dakota School of Mines & Technology both of which offer specific courses in fire weather. Other programs occasionally offer fire weather as a special topics course.

In terms of technology development, few academic programs develop operational tools for wildfire applications as this typically remains within the scope of federal agencies. However, there are exceptions where model development at academic institutions is funded by federal partners and is then targeted for operational adoption. An example of this is the NASA Disasters Program which is funding operational deployment of coupled fire-atmosphere modeling for fire spread prediction and assimilation of satellite fire data. Another example is the Desert Research Institute partnership with the U.S. Forest Service to provide weather and climate data, both historical and operational, to inform various decision support systems.

Private industry, and in particular, the IOUs in California, are driving much of the wildfire science and technology development and is outpacing what is done at the federal level. This is due to the high demand placed on the utilities by regulatory agencies because of the inherent risks associated with utility infrastructure. These risks are driving innovation within all areas of the private sector and as a result the state of wildfire science has improved in just the last few years. For example, the California Department of Forestry and Fire Protection (CAL FIRE) have successfully adopted a new wildfire situational awareness and fire prediction system (<https://technosylva.com/>:https://www.wsj.com/articles/california-firefighters-tap-ai-for-an-edge-in-battling-wildfires-11601544600?reflink=desktopwebshare_permalink) that has also been implemented successfully in 9 other states. These technologies are being further improved by partnerships between universities and private industry.

Future efforts at universities need to focus on the interdisciplinary nature of wildfire. Not one department or college can address the wildfire problems facing the nation, but an interdisciplinary team that includes fire ecologists, engineers, meteorologists, and social scientists will be more successful. Interdisciplinary research centers are critically needed to advance our understanding of wildfire and push technology development forward. For example, a unique aspect of the Wildfire Interdisciplinary Research Center recently established at San José State University and something many academic institutions lack, is a strong social science component. Programs and products developed to assist in wildfire planning and management are often criticized for not matching the fine-scale nature of community or professional decision making, the tech savvy or access abilities of older WUI populations, or local needs. Integrating social science into the product development process, as well as integrating social science data into evacuation models and other tools, better allows for adopting the science innovations, and can provide a more realistic picture of our community needs and vulnerabilities and enhance our ability to promote local wildfire resilience and build up to the landscape level desired by national policies.

Needed federal investment to grow innovation

There is an immediate need for a national and sustainable fire weather research funding program. Most fire weather research is funded by smaller contracts with agencies such as the U.S. Forest Service and the occasional award through NSF's Division of Atmospheric and Geospace Sciences. To date, there has never been a dedicated program that funds both basic and applied research in fire weather and this is critically needed. User inspired research, a different approach than basic and applied, is of high value because it is undertaken with an objective of informing decision making at the outset by developing and weighing alternatives and formulating and implementing decisions. Investment should also be made in programs that are not only conducting cutting edge wildfire research but are also heavily investing in and have a record of preparing a diverse workforce and training the next generation of wildfire scientists.

There is little need for duplication across agencies. A few federal agencies are already leading wildfire research efforts and spinning up new programs. But these are not well coordinated and not clear on how prioritization is determined or the extent that academic-government partnerships can be established. There are few true established partnerships today. These are important because as a step beyond the typical grant process, sustained partnerships allow for capacity building and interdisciplinary undertaking of the research. Leveraging already established programs will benefit the science community on a whole. There are already established federal programs that would benefit from increased investment including the interagency Joint Fire Sciences Program and the NASA Applied Science Wildland Fire Program, both of which have had their budgets drastically cut over the last few years. Increasing funding to these programs will provide more research opportunity to the wildfire research community. Additionally, the National Science Foundation could develop specific wildfire funding programs across directorates that would fund not only basic research but also provide more mechanisms for research within the social sciences. In order to further stimulate innovation in academia, increased federal investments need to be targeted for competitive grant programs that academic institutions can apply for. This investment needs to be separate from agency operational budgets.

Areas of improved coordination are also required to capitalize on current efforts being made within each agency. It is my understanding that coordination generally happens at a grassroots level where upper administrators are not aware of fostered collaborations. Partnerships are built on individual connections and common research interests with a goal of jointly building capacity and achieving actionable outcomes. In addition to partnerships, there are coordination efforts between agencies such as the 2012 Memorandum of Understanding between the U.S. Department of Agriculture U.S. Forest Service and the U.S. Department of Commerce National Oceanic and Atmospheric Administration that states both the USFS and NOAA have the authority to participate in collaborative research and development efforts in fire weather, fire behavior, fire danger, smoke and air quality forecasting, and fire-climate effects. The purpose of the MOU is to:

“provide a framework for implementing and expanding existing research partnerships focused on weather and climate and their effects on fire potential, fire behavior, fire danger, and fire smoke products that support improved fire management and firefighting decisions. The parties recognize the importance of connecting improved weather elements such as numerical models, data assimilation, surface based observing platforms, telecommunications and aerial and satellite observations to improving operational forecasts in support of safe, reliable and sustainable USFS land management and firefighting operations.”

This MOU directly addresses current research and development needs for improving wildfire and fire weather forecasting. However, no funding has been provided to support the research agenda outlined in this MOU. In order to leverage this coordination, federal investment must be allocated to these agencies to fund research outlined in the MOU. A mechanism for distributing funds to both agencies and external partners such as academic institutions will be needed to fast track this research.

Closing Remarks

It is clear that the coming decades will bring more catastrophic wildfire to the western US and managing this risk will require sustained investment in new science and technology. Wildfire and fire weather research requires more directed funding in order to address research gaps and encourage innovation within federal agencies and academic institutions. While this testimony is not exhaustive by any means, I have tried to illustrate priorities relative to fire weather research needs and potential areas for future investment. Below are a few key takeaways from this written testimony.

Summary of research needs and recommendations:

- Treat fire as a part of the earth system, and comprehensive coupled earth modeling approaches must be used to address issues related to wildfires and their impacts.
- Need improved understanding of how fire-atmosphere interactions impact fire behavior.
- Need further investment and development in operational coupled fire-atmosphere modeling systems (e.g., WRF-SFIRE). These tools should be operational across the US.

- Coordinated field measurement campaigns should focus on large high-severity fires (both prescribed fires and wildfires) to measure weather, plume dynamics, and fire behavior (e.g., FASMEE project).
- Enhance fire weather observations at wildfire incidents to support NWS IMETs and research.
- Improved fire characterization observations are needed at high spatial (< 50 meters) and temporal resolution (< 15 minutes) from both space and airborne platforms. Currently, these observations do not exist.
- Need higher temporal and spatial resolution forecasts of fire risk and this requires further investment in the National Fire Danger Rating System.
- Improve fuel moisture content observations for wildfire risk assessment and prediction.
- Establish a national and sustainable fire weather research funding program.
- Invest in already established wildfire engaged agencies rather than “reinvent the wheel.”
- Increase federal investments targeted for competitive grant programs that academic institutions can apply.
- Provide funding to the USFS-NOAA MOU to support its research agenda and provide mechanisms for partners to engage in research.

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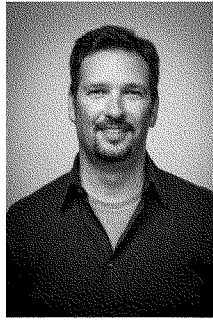
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Craig B. Clements, Ph.D.

Bio



Dr. Craig Clements is a Professor of Meteorology at San José State University and Director of the Wildfire Interdisciplinary Research Center. He leads research on fire weather, extreme fire behavior, fire-atmosphere interactions, and conducting wildland fire field experiments. Dr. Clements has over 20 years of experience in meteorological field observations and teaches courses in Fire Weather, Wildfire Science, Mountain Meteorology, Climate Change, and Meteorological Instrumentation. He received his PhD in Geophysics from the University of Houston, his MS in Meteorology from the University of Utah, and a BS degree in Geography from the University of Nevada, Reno. In 2012, Dr. Clements received the National Science Foundation's CAREER Award for his research on wildfire dynamics and fire weather. His current research focuses on obtaining meteorological measurements using state-of-the-art Mobile Atmospheric Profiling Systems such as Doppler Lidar and Radar at active wildfires in the western US and his research has been featured in PBS NOVA, Rolling Stone, The New York Times, Time, CNN, and Scientific American.

Chairwoman LOFGREN. Thank you very much, Dr. Clements. We will now turn to our next witness, Dr. McCarty. We're pleased to hear from you.

**TESTIMONY OF DR. JESSICA McCARTY,
ASSISTANT PROFESSOR OF GEOGRAPHY
AND DIRECTOR OF THE GEOSPATIAL ANALYSIS
CENTER AT MIAMI UNIVERSITY**

Dr. McCARTY. Thank you, Chairwoman Johnson, Chairwoman Lofgren, and Ranking Member Lucas, and distinguished Members of the Committee. I appreciate this opportunity to appear today to discuss research and coordination for Federal wildfire science. I am Dr. Jessica McCarty, and as of July 1 I am an Associate Professor of Geography at Miami University of Ohio. I have more than 15 years' experience in applications of satellites to quantify wildland and human-caused fires, and related emissions, including as a member of the 2019 NOAA/NASA FIREX-AQ (Fire Influence on Regional to Global Environments Experiment—Air Quality) Field Campaign. During my testimony, I will highlight the relationship between climate change and wildfires, options to reduce fire risk, solutions for satellite-based detection and monitoring, as well as Federal wildfire science collaboration. The opinions expressed in my testimony are my own, and do not represent views of Miami University.

As Dr. Clements has pointed out previously, climate change means warmer temperatures for the entire U.S., witnessed in the increased fire intensity and drier field conditions of the Western States. Climate change increases drought, leading to large stands of dry, and sometimes dead, trees. This accelerates the likelihood of extreme fires, even in our Eastern forests, like the 2016 Great Smoky Mountains Fire near Gatlinburg, Tennessee that burned over 17,000 acres and killed 14 people during an exceptional drought. Within the boreal and Arctic regions of Alaska, climate change will increase lightning activity, will trigger a transition from boreal forests to more fire-prone grasslands, and will dry out peatlands, causing long lasting underground fires that will span multiple fire seasons.

Wildfires contribute to climate change by being a source of carbon dioxide and other greenhouse gases. More frequent and intense wildfires now, and in the future, can potentially lower our forests' ability to capture carbon by reducing forest density and tree size. Research into mitigating future wildfire risks should note that mitigating any wildfire risk means reducing carbon emissions and preventing further warming. Since we cannot prevent lightning strikes, and as we work to limit warming, our remaining options are to reduce human-caused ignitions and to modify fuels.

Human-caused ignitions in the Western U.S. account for 84 percent of all wildfires. In a warmer and more flammable future, we must act to reduce arson, accidental fires, and the spread of open burning from agricultural fields to wildlands, and research in those areas will assist in those actions. Wildfire risks can be lowered through fuels reduction. This is most effectively done via prescribed burning, as well as working with indigenous fire practitioners to return cultural burning to the land. A community's tolerance for

smoke will often dictate when or if a prescribed fire occurs, and social science research into those community reactions is needed. The choice is ours, do we tolerate a few hours of smoke, or do we wait until we are forced to evacuate?

Space-borne fire detections often rely on 375 meter to one kilometer resolution polar orbiting satellites, which are overhead two to four times per day, as Dr. Clements mentioned. A higher resolution sensor, like the 30 meter Landsat, is only overhead every 16 days, but the pixel sizes are about the size of a baseball diamond. Geostationary systems, like NOAA's GOES-R series, have 0.5 to two kilometer pixels, so think three by three city blocks to 11 by 11 city blocks, but they capture images every five to 15 minutes. Improved wildland fire detection, monitoring, and research needs combined higher spatial and temporal resolution sensors. NOAA'S GeoXO gets us closer to such a system, but the first launch is currently planned for the early 2030's. We need this now. Being able to see new fire ignitions and fire spread every 15 minutes within baseball-sized—baseball diamond-sized grids would be a game changer for science, for fire management and incident command, and for public education and engagement, including improved warning systems.

Finally, I would be remiss not to mention as well the Joint Fire Science Program. The JFSP is a solutions-oriented Federal research collaboration that provides scientific funding for practical results. But the JFSP also funds and manages the Fire Science Exchange Networks. These 15 regional fire science exchanges provide the most relevant and current wildland fire science to Federal, tribal, State, local, and private stakeholders across all 50 States. Currently the funding for, and future of, the JFSP and the regional exchanges is in question. We should not reinvent the wheel when a functioning and successful Federal mechanism that collaborates with non-Federal partners at all levels already exists.

Thank you for giving me the opportunity to testify before you today, and I look forward to answering your questions.

[The prepared statement of Dr. McCarty follows:]

Testimony of Dr. Jessica L. McCarty
Assistant Professor of Geography and Director of the Geospatial Analysis Center,
Miami University
Co-Investigator, NASA FIREX-AQ

House Science, Space, and Technology Committee
U. S. House of Representatives
June 29, 2021

**Hearing on “The State of Federal Wildland Fire Science: Examining Opportunities for
Further Research & Coordination”**

Chairwoman Johnson (D-TX), Ranking Member Lucas (R-OK) and distinguished members of the Committee, thank you for the opportunity to appear today to discuss opportunities for further research and coordination as it pertains to federal wildfire science. My name is Dr. Jessica McCarty. As of July 1, I am an Associate Professor of Geography at Miami University of Ohio. I have more than 15 years’ experience in applications of satellite and geospatial science to accurately quantify wildland and human-caused fires and related emissions. I have led and contributed to fire fieldwork, most recently during the 2019 NOAA/NASA FIREX-AQ field campaign which measured atmospheric chemistry of smoke across the continental U.S. During my testimony, I will be discussing the relationship between climate change and wildfires, how to reduce fire risk, proposed solutions for satellite-based fire detection and monitoring, and how federal and non-federal partners can better collaborate and coalesce around existing programs. The opinions expressed in my testimony today are that of my own and do not represent views of Miami University.

Climate Change and Wildfires

Climate change means warmer temperatures for the entire U.S., which for many of our western states will cause drier fuel conditions and increase the likelihood of intense burning. For instance, wildland firefighters have historically been able to build fuel breaks during the night, when fires subside during the cooler temperatures. But climate change is increasing nighttime temperatures faster than daytime temperatures, potentially eliminating one wildland fire fighting strategy¹. Warmer temperatures from climate change also means snowpack melts earlier in the season, causing forests, soils, and plant life to dry out sooner – which is another way that climate change increases dry fuel conditions². As climate change increases droughts, rain patterns will no longer match the seasonal memories that we or the landscape have, leading to large stands of dead trees and increasing the likelihood of extreme fires even in our eastern forests - like the 2016 Great Smoky Mountains fire near Gatlinburg, Tennessee that burned over 17,000 acres and killed 14 people³ during an “exceptional” drought. Within the boreal and Arctic regions of Alaska, climate change will increase lightning activity, will trigger a transition from boreal

¹ <https://www.scientificamerican.com/article/one-climate-change-wildfire-risk-lurks-in-the-dark/>

² Abatzoglou & Williams (2016). <https://doi.org/10.1073/pnas.1607171113>.

³ <https://wildfiretoday.com/2016/12/05/analyzing-the-fire-that-burned-into-gatlinburg/>

forests to more fire-prone grasslands, and will dry out peatlands⁴ – causing long-lasting underground fires that span multiple fire seasons, often referred to as “Zombie fires”⁵.

Wildfires contribute to climate change by being a source of carbon dioxide (CO₂) and other greenhouse gas emissions. The California Air Resources Board estimates that approximately 117 million metric tonnes of CO₂ were emitted from wildfires in 2020⁶, which is 25% more than total annual fossil fuel emissions for the entire state⁷. Even still, more frequent and intense wildfires can potentially lower our forests’ ability to capture carbon in the future by reducing forest density and tree size.⁸

Mitigating future wildfire risk

Mitigating future wildfire risk means reducing carbon emissions and preventing further warming. As we cannot prevent lightning strikes, and we work to limit warming, our remaining options to reduce catastrophic fire risk “are to reduce human-caused ignitions and to modify fuels.”⁹ Human-caused ignitions in the western U.S. account for 84% of all wildfires while also increasing the length of fire seasons.¹⁰ In a warmer and more flammable future, with many landscapes currently running a fire deficit¹¹, we must act to reduce arson, accidental fires, and the spread of open burning from agroecosystems to wildlands.

Fire risk can be lowered through fuels reduction, most effectively via prescribed burning and working with Indigenous fire practitioners to return cultural burning to the land. In some landscapes, prescribed burning can be safely done throughout all seasons, while others require more risk management. In all cases, a communities’ tolerance for smoke will often dictate when or if a prescribed fire occurs. The choice is ours – do we tolerate a few hours of smoke in the off season every year or do we wait until the sky has turned red and we are forced to evacuate?

Improving fire detection and monitoring

Spaceborne fire detections used by the U.S. Forest Service relies on 1 km (MODIS) to 375 m (VIIRS) spatial resolution polar orbiting satellite systems that are overhead two to four times per day¹². A higher resolution satellite, like 30 m Landsat that is only overhead every 16 days but provides before and after fire assessments with pixels approximately the size of a baseball diamond. Geostationary systems, like NOAA’s Geostationary Operational Environmental Satellite (GOES)-R series, have 0.5 to 2 km resolution (ranging from three-by-three city blocks to 11-by-

⁴ McCarty et al. (2021; pre-print). <https://bg.copernicus.org/preprints/bg-2021-83/>.

⁵ Scholten et al. (2021). <https://doi.org/10.1038/s41586-021-03437-y>.

⁶ https://www3.arb.ca.gov/cc/inventory/pubs/ca_ghg_wildfire_forestmanagement.pdf

⁷ <https://news.mongabay.com/2020/09/off-the-chart-co2-from-california-fires-dwarf-states-fossil-fuel-emissions/>

⁸ Pellegrini et al. (2021). <https://doi.org/10.1038/s41559-021-01401-7>.

⁹ Flannigan et al. (2013). <https://doi.org/10.1016/j.foreco.2012.10.022>.

¹⁰ Balch et al. (2017). <https://doi.org/10.1073/pnas.1617394114>.

¹¹ Parks et al. (2015). <https://doi.org/10.1890/ES15-00294.1>.

¹² <https://firms.modaps.eosdis.nasa.gov/usfs/>

11 city blocks), but capture images every 5 to 15 minutes¹³. What is needed for improved wildland fire detection and monitoring are higher spatial and temporal resolution sensors. NOAA's Geostationary Extended Observations (GeoXO)¹⁴ is such a system, but the first GeoXO launch is currently planned for the early 2030s. We need this now. In my opinion, being able to see new fire ignitions every 15 minutes within 30 m baseball diamond-sized grids from geostationary satellites would be a game changer for science, for fire management and incident command, and for community education and engagement – including improved warning systems – giving us specific rather than general information.

Utilize existing partnerships to improve fire science collaboration and coordination

I would be remiss to not mention the Joint Fire Science Program (JFSP)¹⁵, established by Congress in 1998 and jointly funded by the Department of the Interior (DOI) and the U.S. Forest Service (USFS). The JFSP is a solutions-oriented federal research collaboration that provides scientific funding for practical results that improve wildland fire policy, management, and solutions at local, regional, and nation levels¹⁶. The JFSP funds and manages the Fire Science Exchange Network¹⁷. These fifteen regional fire science exchanges provide the most relevant, current wildland fire science information to Federal, Tribal, State, local, and private stakeholders within ecologically similar regions – across all 50 states¹⁸. Currently, the funding for and future of the JFSP is in question. NOAA¹⁹ and NASA²⁰ seek to and deliver applied wildland fire and smoke knowledge, science, data production, and satellite missions within the needs of the DOI, USFS, and join. We should not re-invent the wheel when a functioning and successful federal mechanism exists.

Thank you for giving me the opportunity to testify before you today. I look forward to answering your questions.

¹³ <https://www.goes-r.gov/#MissionDescription>

¹⁴ <https://www.nesdis.noaa.gov/GeoXO/>: the website details the partnership as “NASA will manage the development of the satellites and launch them for NOAA, which will operate them and deliver data to users worldwide.”

¹⁵ <https://www.doi.gov/wildlandfire/joint-fire-science-program> & <https://www.firescience.gov/>

¹⁶ <https://www.doi.gov/wildlandfire/joint-fire-science-program>

¹⁷ <https://southernfireexchange.org/about-us/jfsp-fire-science-exchange-network/>

¹⁸ https://southernfireexchange.org/wp-content/uploads/Consortia_map1.gif

¹⁹ <https://www.nesdis.noaa.gov/GeoXO/fire>

²⁰ <https://appliedsciences.nasa.gov/what-we-do/disasters/fires>

Dr. Jessica L. McCarty

Assistant Professor, Geography

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Miami University

Oxford, OH

Dr. Jessica L. McCarty is the Director of the Geospatial Analysis Center and as of July 1, 2021, an Associate Professor of Geography at Miami University of Ohio. She has a Bachelor of Arts in Geography and Spanish from Morehead State University, a Master of Arts and PhD in Geography from the University of Maryland in College Park, and is a 2005 awardee of the National Aeronautics and Space Administration (NASA) Earth System Science Graduate Fellowship. Dr. McCarty has more than 15 years' experience in applications of geospatial and data science to accurately quantify wildland and human-caused fire emissions, agriculture and food security, and land-cover/land-use change. She is the author/co-author of more than 30 peer-reviewed journal articles, 12 peer-reviewed conference proceedings, 3 book chapters, 4 technical reports, 4 data citations, and 1 NASA Technology Transfer. She is an invited contributor to the Intergovernmental Panel on Climate Change Expert Meetings on Short-Lived Climate Forcers (SLCFs), the Arctic Monitoring and Assessment Programme's Expert Group on SLCFs (an Expert Group of the Arctic Council), a Co-Investigator of the NASA FIREX-AQ field campaign, and a NASA Land-Cover/Land-Use Change Science Team member. Her published fire emission methodologies have been used by the U.S. Environmental Protection Agency for the U.S. Greenhouse Gas Inventory and National Emissions Inventory. Dr. McCarty is often an invited speaker on issues related to human-caused fires in the U.S. and fires in the Arctic, specifically black carbon and methane emissions, impacts of smoke on air quality, future Arctic fire regimes, and human-caused fires and fire management strategies. Dr. McCarty is an active member of the International Association of Wildland Fire and is currently serving as the invited Co-Chair of the Steering Committee for the 2022 Fire & Climate Conference.

Chairwoman LOFGREN. Thank you very much. We'll turn to our next witness, Mr. Geissler. We're looking forward to hearing from you.

**TESTIMONY OF MR. GEORGE GEISSLER,
STATE FORESTER AND DEPUTY FOR WILDLAND FIRE
AND FOREST HEALTH AND RESILIENCY
AT THE WASHINGTON DEPARTMENT
OF NATURAL RESOURCES**

Mr. GEISSLER. Good morning, Chairwoman Lofgren, and Ranking Member Lucas, and distinguished Members of the Committee. My name is George Geissler, State Forester and Deputy Wildland Fire and Forest Health for the Washington Department of Natural Resources (DNR). I am past president of the National Association of State Foresters (NASF), Chair of the NASF's Wildland Fire Committee, and a member of the Wildland Fire Leadership Council (WFLC). I appreciate the opportunity to speak with you today as the Committee examines opportunities for further research and coordination related to wildland fire science.

State forestry agencies, such as DNR (Department of Natural Resources), contribute a significant portion of the overall wildland fire suppression effort nationally in terms of resources, personnel, capacity, and funds. Each year State and local agencies respond to the majority, roughly 80 percent, of all wildfires across all jurisdictions, and State Foresters work closely with conservation districts, mayors, local and county governments, tribal and Federal partners across the U.S. to deliver forestry programs and wildfire protection on a national scale. We appreciate the work of this Committee to address this important issue, and in the interest of time, I will highlight the following recommendations for improving research and development efforts focused on supporting wildland fire management.

First, please support research and development on wildland fire behavior [inaudible] would benefit wildland fire response efforts that would be made accessible to the general public. We have [inaudible] services now, but there is a clear need for real time wildfire monitoring at the operational level to inform response. As an example, the National Hurricane Center uses many models as guidance in the preparation of official tracking intensity forecasts for hurricanes. Forecast models vary tremendously in structure and complexity. Similar tools would combine a collection or ensemble of wildfire models in real time to provide an advantage for wildland fire operations and better inform the public.

Second, please support the development of fire simulation models that incorporate the built environment as a fuel. Currently wildfire models encompass the wildlands and stop at the built environment to better determine future threats to communities in the WUI. Trees and grasses burn very differently from homes and our businesses. Please support research and development that enables remote tracking of all active wildfire suppression resources in real time. Wildfire management and suppression operations utilize a patchwork of communication networks to track resources. We need to develop a standardized system for accountability and tracking of

resources, and develop an implementation schedule for integration of the system into the interagency environment.

We need to improve the capacity for early detection and assessment of wildfires, particularly in rural areas. Oftentimes in many areas, including my own State of Washington, wildfires can go undetected for days, and we now rely more and more on citizens to report wildfires through typical 911 calls. More access to satellite technology and high performance infrared cameras would greatly improve early detection and assessment, and attacking wildfires early and when they're small is the key to reducing fatalities, injuries, loss of natural resource, property damage, and lowering our firefighting costs.

Also, we ask you prioritize the development of real time smoke modeling and decision support tools for wildland fire managers and local and regional public health officials. There are opportunities to leverage the resources of the EPA and Centers for Disease Control (CDC) to better understand the public health impacts of smoke on people, including our wildland firefighters. With many wildfires occurring in the WUI, there are more materials and chemicals in homes and in streets that burn and produce a very toxic environment.

We ask you provide research opportunities that will help inform the development and implementation of the next generation of national, State, and local codes and standards for addressing WUI issues and catastrophic wildfire risk. This research should utilize the best available science, and include the review of past wildfire losses. And, finally, we ask you develop a standard warning scale for wildfires that actually conveys the magnitude, or potential magnitude, of current, developing, and projected wildfire events. This scale, much like the Enhanced Fujita Scale for tornadoes, or the Richter Scale for earthquakes, would help convey the magnitude of the threat to the public, and could be used to improve evacuations and emergency preparations.

Thank you for the opportunity to appear before the Committee today on behalf of Washington's Department of Natural Resources and the National Association of State Foresters. Improvements in applied research and development technologies that support wildfire management will greatly enhance our collective ability to safely respond to wildfire, and better protect our communities and treasured natural resources. I look forward to answering your questions. Thank you.

[The prepared statement of Mr. Geissler follows:]

**Testimony of George Geissler, Washington State Forester
On Behalf of the National Association of State Foresters
Submitted to the U.S. House Committee on Science, Space and Technology
Tuesday June 29, 2021**

Good morning, Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee. My name is George Geissler, State Forester and Deputy, Wildland Fire and Forest Health/Resiliency, Washington Department of Natural Resources, Past President of the National Association of State Foresters (NASF), Chair of the NASF Wildland Fire Committee, and member of the Wildland Fire Leadership Council (WFLC). I appreciate the opportunity to speak with you today and submit written testimony as the Committee examines research and development related to wildfire operations.

NASF represents the directors of the state forestry agencies in all 50 states, eight U.S. territories, and the District of Columbia. State Foresters deliver technical and financial assistance to private land owners, along with protection of forest health, water and wildfire for more than two-thirds of the nation's forests, as well as partner with federal agencies through authorities like Good Neighbor Authority in managing and protecting the nation's federal forests. While the duties of state agencies vary from state to state, all share common forest management and protection missions and most have statutory responsibilities to provide wildland fire protection on all lands, public and private.

State Contribution

State forestry agencies contribute a significant portion of the overall wildland fire suppression effort nationally in terms of resources, personnel, capacity, and funds. Collectively, States reported spending \$1.9 billion on fire suppression, prevention, and mitigation in 2018, with \$1.4 billion spent on suppression alone. The overall federal cost of fire suppression for 2018 was \$3.1 billion. In 2018, there were 8,080 State personnel (including overhead and crews) mobilized through the National Interagency Coordination Center. Of those State personnel, 6,026, or nearly 75%, were mobilized to federal wildfires.¹ State forestry agencies also provide local governments and volunteer fire departments with access to fire and emergency response resources, which in 2018, included 93,656 firefighters, 91,940 fire engines, 2,851 dozers, and 620 aircraft. In 2019, 50,477 wildland fires burned nearly 4.7 million acres.² State and local agencies respond to the majority – 79% – of these wildfires across all jurisdictions.²

State Foresters work closely with Conservation Districts, Mayors, local and County Governments, Tribal and Federal partners across the US to deliver forestry programs and wildfire protection on a National scale. NASF is a key partner in the development and implementation of the National

¹ Statistics posted above were gathered from the Interagency Fire and Aviation Management Web Applications (FAMWEB) system, which includes the Situation Report and Incident Status Summary (ICS-209) programs. The statistics presented here are intended to provide a national perspective of annual fire activity but may not reflect official figures for a specific agency.

² National Interagency Fire Center, Historical Wildland Fire Summaries, pg. 8. Last accessed March 4, 2020 at https://www.predictiveservices.nifc.gov/intelligence/2019_statsumm/intro_summary19.pdf.

Cohesive Wildland Fire Management Strategy (Cohesive Strategy), which provides the roadmap for interagency wildland fire management across the country and allows diverse stakeholders to work collaboratively using the best science to achieve resilient landscapes, fire-adapted communities, and effective wildfire response. NASF is also a key partner and member of the WFLC, an intergovernmental committee of Federal, State, Tribal, county, and municipal government officials convened by the Secretaries of the Interior, Agriculture, Defense, and Homeland Security dedicated to consistent implementation of wildland fire policies, goals, and management activities. The Council provides strategic recommendations to help ensure policy coordination, accountability and effective implementation of Federal wildland fire management policy and related long-term strategies through collaboration.

Our Nation's Forests and Wildfire

Fire is a natural phenomenon for nearly every forest ecosystem in this country. Fire has shaped the occurrence and distribution of different ecosystems for centuries, simultaneously impacting the human and natural communities that live in and around those forests. Over the past century, a culture of fire suppression has unfortunately removed the natural role of fire from many fire-dependent landscapes. This culture, combined with less active forest management in many areas, has led to the build-up of hazardous fuels to historic levels. In our attempts to manage wildfires away, we've inadvertently made our forests more prone to catastrophic wildfire.

Federal, State, and local fire managers have learned the critical role of hazardous fuels management in mitigating wildfire impacts. Solely focusing on wildfire suppression and ignoring proactive forest management does not lead to fewer wildfires in the long run; the fuel continues to build up to the point where eventually wildfires become unmanageable. The task for wildfire managers is to manage the risk to communities and ecosystems in both the short- and long-terms by implementing a coordinated and science-based program of fuels reduction, fire suppression, and community planning.

Hazardous fuels reduction has two main components: prescribed fire and silvicultural treatments, such as "thinning." Both activities have a beneficial impact on mitigating wildfire emissions by reducing combustible material in the woods and allowing fire to play its natural role in the ecosystem. In many parts of the country, especially on federal lands which have not seen regular management, forest stands are too dense to conduct prescribed fire and thus forest thinning is a crucial first step in managing hazardous fuels. Following a harvest treatment, prescribed fire can be an important tool to maintaining the investment of a more healthy and resilient forest and minimizing the risk of catastrophic wildfire.

Wildland fire response is one of the most challenging facets of our jobs. As State Foresters, we believe we need to be doing significantly more hazardous fuels reduction across all ownerships – public and private and across this country. We are committed to continue working towards this goal. Such treatments allow us to put fire on the landscape at times and under conditions that minimize impacts, including smoke emissions. These treatments reduce fuel loading in the forests, so that when wildfires inevitably occur, they burn with less intensity, reduced spread, and fewer smoke impacts on communities and firefighters.

Where forests of different ownerships exist in close proximity to each other, it is critical that decisions about suppression and fuels treatments get made in a collaborative and cooperative way. This is especially true for federal lands on which fire management has a direct impact to adjacent state and private lands and/or communities.

The Role of Research and Development in Wildfire Mitigation and Operations

Research and Development (R&D) plays a critical role in supporting wildland fire management efforts and improving technology used to support all phases of wildland fire management. Research can produce valuable information and applications that support wildland fire management and help land managers better understand fuels and wildfire behavior. Wildfire management is inherently a partnership effort between federal, state, local, and volunteer agencies and departments. All of these entities stand to benefit from coordinated R&D efforts that support the science and technology needs of Federal, State, tribal, and local governments, and also private land owners, by delivering applied research that better informs efforts to mitigate wildfire risk and foster resilient, adaptive ecosystems to mitigate the impacts of climate change.

Forest Service R&D has played a vital role in U.S. wildland fire management and response programs since the early 1900s and continues to develop new knowledge and products that support evolving fire management and response needs in the context of the growing complexity of fires in the United States. Forest Service R&D contributions that have changed the way fire managers in the United States and other countries manage and respond to wildland fires have been numerous. Here are three examples of how investments in wildfire R&D efforts provide support to all phases of wildfire management.

The Incident Command System (ICS) provides the common management structure that all wildland firefighters and support personnel work under when they come together and respond to an unwanted wildland fire or other incidents. The ICS was developed as part of the Riverside FireScope Research, Development, and Applications (RD&A) program in the 1970s and has been used since its inception in Federal fire response. Over time, the system has been adopted by emergency responders around the world and, in 2001, as a result of the important role it played in the 9/11 response, ICS became the management structure used to manage all natural and human-caused disasters in the United States.

The National Fire Danger Rating System (NFDRS) is used by wildland fire managers to assess seasonal progression of fire danger, allocate firefighting assets, determine use restrictions, and communicate fire risk with the public.

Fire behavior prediction systems that use the Rothermel (1972) model are used by Federal agencies and others to predict fire behavior on wildland fires. This model is employed as the core of many fire behavior and decision-support applications that rely on fire spread prediction.

The Joint Fire Science Program

The Joint Fire Science Program (JFSP) was established by Congress in 1998 as an interagency research, development, and science application partnership between the U.S. Department of the Interior (DOI) and the Forest Service. Program oversight is provided by a governing board, which includes representatives from five DOI agencies and the Forest Service with diverse backgrounds in R&D, fire management, and land management. JFSP supports research, tool development, and science application related to the following specific emphasis areas defined by Congress: fuel inventory and mapping; fuel treatment scheduling and risk assessment; fire effects and behavior; monitoring and evaluation; restoration of fire-adapted ecosystems; postfire stabilization, rehabilitation, and restoration; remote sensing; and developing and integrating research information for local land managers.

The JFSP is a program many state forestry agencies find tremendously valuable, providing the data we need to rate fire danger, make seasonal wildfire forecasts, and cost effectively reduce the risk of wildfire through fuels management and prescribed fire. In addition to helping state forestry agencies prepare for wildfire events, the JFS program also generates scientific data used to manage smoke from wildfires and develop remote sensing tools for wildfire management.

The 15 regional Fire Science Exchanges funded by the JFS program provide trusted, science-based information to land managers and owners throughout the country, that in turn, enables sound policy and on-the-ground decision-making related to wildfire, ecosystems, and hazard risk reduction. The Fire Science Exchange Network distinguishes itself from other federally supported wildfire research programs in its emphasis on direct application. Members of the network convene workshops, field tours, webinars, and conferences, and in many states, work directly with wildfire managers to ensure management needs and questions are met and answered with scientific research.

As this Committee examines opportunities to improve research and coordination around Wildland Fire Science, we point to the JFSP as model for federal agencies to engage in coordinated efforts that deliver applied research to land managers.

Research Informing Fuel Treatments and Active Management

America's federally managed forestlands face serious threats. Entire landscapes are experiencing deteriorating health and uncharacteristic ecological change as a result of insects and disease, catastrophic wildfire, and other forest health stressors. Forest health threats know no boundaries and there is an urgent need for more active management on these landscapes in order to protect both public and privately-owned forests and the communities that depend upon them. State Foresters are responsible for protecting the health and socio-economic benefits of forest resources within their jurisdictions; what happens on federal forests has a direct bearing on their ability to fulfill those responsibilities.

Intentional management is necessary to improve the resilience of federal forest lands. In regions with a mixture of ownerships, the prerequisite for success is landscape-level coordination, which includes the full participation of federal partners.

A great example of this interagency cooperation leading to on-the-ground decision-making related to wildfire, ecosystems, and hazard risk reduction—informed by research and develop—is the Nenana Ridge Experimental Fuels Treatment Research Project, funded by the Joint Fire Science Program. This project was designed to quantify the effects of fuels reduction treatments on fire behavior and post-fire vegetation dynamics in Alaska black spruce forests. Mechanical (e.g., shearblading) and manual (e.g., thinning) fuel treatments are commonly used by Alaska fire managers and agencies for mitigating fire risk. However, prior to this experiment, there was little documentation of the actual effect of different fuel treatments on fire behavior. The Nenana Ridge project began in 2006 with preparation of eight 1-acre treatment blocks with two controls, and a prescribed burn was conducted on five blocks in June of 2009. The primary objective of the project was to characterize the effectiveness of the treatments in reducing fire intensity. Fire-proof digital sensors and video cameras were used to document the burn, in addition to measurements of vegetation, fuel beds, and fuel moistures, which allowed scientists to compare fire behavior between control plots and fuel treatment plots. All treatments that burned resulted in significant reductions in fire intensity and spread.

This study was the first of its kind testing the effect of four fuel treatments on fire intensity in the boreal forests of Alaska. The anecdotal ($n = 1$) evidence suggests that all treatments significantly reduced fire intensity. The thinning treatment modified fire behavior while maintaining an aesthetic that closely matched the original forest stand; it also led to the lowest peak heating rates and was the most effective in stopping fire spread. The shear-blade treatments produced the lowest air temperatures with some indication that grass loads that could develop in years subsequent to the treatment could facilitate fire spread across the entire treatment area.

Subsequent fuels treatments in Alaska were tested by wildfire during the Eagle Trail (2010), Funny River (2014), Card Street (2015), and Nenana Ridge (2015) fires. In all documented cases the Alaskan fuel breaks changed fire behavior as the fire moved through untreated wildland fuels as an active crown fire and dropped to a surface fire in the treatment areas.⁵

I would like to highlight an example of an Alaska fuel break project which resulted in a successful burn out operation on the Shovel Creek fire near Fairbanks in the summer of 2019. The fuel break was created using shear blade by dozers and a windrow/burn treatment. The shear-blade work was done in the winter of 2007. Burning of the windrowed piles was accomplished in late fall 2009 after curing for a few years. The curing of the fuels was a smoke management technique to lessen smoke impacts during the burning as the cured fuels combust more completely and quickly. The line is over 22 miles in length and runs along a ridge between the outskirts of Fairbanks and open country to the north of town.

[This operation secured the north flank of the Shovel Creek Fire](#), which was a Type I incident, and protected over \$187.5 million in private property. This is a conservative estimate as it only includes parcels in the Level III and II evacuation areas. The costs were covered by a combination of State Fire Assistance Wildland Urban Interface (WUI) grants, which are awarded through a competitive process with emphasis on hazard fuel reduction, information and education, and

⁵ Final Report: Evaluating the Effectiveness of Fuel Treatments in Alaska JFSP Project 14-5-01-27
https://www.frames.gov/documents/alaska/docs/little_et_al_2018_EvaluatingEffectivenessFuelTreatmentsAlaska_jfsp-14-5-01-27.pdf

community and homeowner action, American Recovery and Reinvestment Act (ARRA) stimulus funding and other funds, following the large 2004 and 2005 fire seasons.

And every state has ongoing efforts to improve the resiliency of our forests and provide opportunities for our firefighters by implementing and evaluating effectiveness. In a recently published research paper, scientists evaluating fuel treatments across all lands found that not only was burn severity significantly lower within the footprint of past fuel treatments than in untreated forest but in Washington.⁶

- Fuel reduction treatments that combined mechanical thinning from below with post-harvest broadcast burns were particularly effective.
- Placement of fuel reduction treatments mattered. Burn severity was significantly lower in fuel treatments positioned on leeward slopes (sheltered from wind, and typically drier and warmer than windward slopes).

With each fuel treatment and with each fire, we learn, and we get better.

Opportunities for Improving Wildland Fire Research and Development

We appreciate the work of this committee to address research and development needs related to wildfire. Accordingly, we offer the following recommendations for improving research and development efforts focused on supporting wildland fire management:

- There is a need for improved wildland fire behavior modeling, including for the wildland urban interface (WUI) that can provide wildland fire response efforts with real-time wildfire modeling and be made accessible to the general public. We have good predictive services but there is a clear need for active, real-time wildfire modeling that can be used at the operational level to inform response efforts. As an example, the National Hurricane Center (NHC) uses many models as guidance in the preparation of official track and intensity forecasts for hurricanes. Forecast models vary tremendously in structure and complexity. Similar tools that would combine a collection (or “ensemble”) of wildfire models in real-time would provide an advantage for wildfire operations and better inform public orders for evacuations.
- Federal, state, tribal and local agencies should collaborate to improve fire-modeling and communications by providing real-time and realistic fire behavior information to resources engaged in wildfire suppression operations.
- We need support in the development of fire simulation models that can incorporate the built environment as a fuel. Currently, wildfire models encompass the wildlands and stop at the built environment, our communities. We need models that include the built environment in these models to better determine future threats to communities in the WUI.

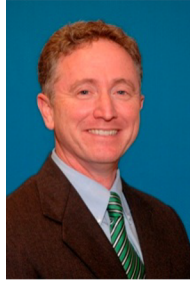
⁶ Prichard, Susan J., Nicholas A. Povak, Maureen C. Kennedy, and David W. Peterson. 2020. Fuel treatment effectiveness in the context of landform, vegetation, and large, wind-driven wildfires. *Ecological Applications* 00(00):e02104. 10.1002/eap.2104

- We need to be able to remotely track the location of active wildland fire resources and display the location of each fire resource on real-time maps. Wildfire management and suppression operations utilize a patchwork of communication to track resources. We need real-time dissemination of information.
 - The Android Team Awareness Kit (ATAK) provides an example that should be considered for broader use to support the complex communication and coordination needs of the multi-jurisdictional responders. <https://www.dhs.gov/science-and-technology/news/2017/11/17/snapshot-atak-increases-situational-awareness-communication>
- We need to improve our capabilities for early detection and assessment of wildfires, particularly in rural areas. Often times, wildfires can go undetected for days. More access to satellite technology and high-performance infrared cameras would improve our abilities for early detection and assessment. Attacking wildfires when they are small is the key to reducing fatalities, injuries, loss of homes, and cutting federal fire-fighting costs.
- We need technical assessments from qualified entities to ensure that states have adequate baseline systems necessary to capture and analyze data. This assessment should include identifying any state deficiencies in necessary equipment and provide solutions for improving state data collection systems.
- We need to prioritize the development of smoke modeling and decision support tools for local and regional public health officials. We also need operational smoke models that can be used in real time by fire managers. There are opportunities to leverage the Environmental Protection Agency and Center for Disease Control to better understand the public health impacts of smoke, and also the impacts to our wildland firefighters. With many wildfires occurring in the WUI, there are more materials and chemicals in homes and in the streets that burn and produce a toxic environment.
- We need to provide research opportunities that will help inform the development and implementation of the next generation of national codes and standards designed to address issues in the modern WUI and impacts from catastrophic wildfire utilizing the best available science and review of past wildfire losses.
- We need to develop a standardized warning scale for wildfires that conveys the magnitude or potential magnitude of the current, developing, or projected wildfire event.
 - This scale, much like the Saffir-Simpson scale for hurricanes or the Richter scale for earthquakes, would help convey the magnitude of the impending threat to the public. This could be used included as part of the evacuation process.

Conclusion

Thank you for the opportunity to appear before the Committee today on behalf of the Washington Department of Natural Resources and the National Association of State Foresters. Wildland fire

response is one of the most challenging facets of our jobs. We appreciate the work of this committee to address research and development opportunities related to wildfire operations today and for its continued support on this important issue. Improvements in applied R&D and technologies that support wildfire operations will enhance our collective ability to safely respond to wildfire and better protect our communities and treasured natural resources. NASF and I stand ready to assist the Committee in finding ways to address the challenges we all face as the wildland fire problem continues to grow and consume larger and larger portions of our state and federal budgets. The scale of wildfires and their community impacts far outpace current efforts to prevent them and mitigate the damage they cause. Substantial increases in active forest management and fuel treatments across all landscapes and ownership boundaries are needed in the areas at greatest risk for unwanted wildfire. Without an increase in coordinated forest management, wildfires will continue to pose a threat to the nation's forests, destroy our cherished communities, and irrevocably alter American landscapes.

George L. Geissler, CF

George L. Geissler is Washington's State Forester and Deputy Supervisor for Wildfire and Forest Health.

Mr. Geissler is a native of New Orleans. He received his Bachelor of Science degree in Forest Management from Louisiana State University and a Master of Business Administration degree from Harvard University. He has almost 30 years of experience in natural resource and wildland fire management, and six years of experience in structural firefighting as a volunteer in Idaho and New Mexico. He is a member of the Society of American Foresters since 1987 and a Certified Forester.

Mr. Geissler began his career with the United States Forest Service on the Boise National Forest as both a wildland firefighter with the Boise Hotshots and a silviculturalist on the Idaho City Ranger District.

He left the USFS in 1988 to become Corporate Forester for Central and Southwest Services (an electric utility holding company based in Dallas, TX) where he directed forest management activities on 475,000 acres of company owned timberlands and vegetation management on company electrical system infrastructure located in the US, Brazil and England.

In 1997 Mr. Geissler left Central and Southwest to establish Forestry West LLC, in New Mexico. Forestry West quickly established itself in natural resource management including forest management, community wildfire protection planning, and wildland fire planning and prevention.

He joined Oklahoma Forestry Services in 2006. Before being named as State Forester he served in a staff function to coordinate all forest management activities provided by the agency.

Mr. Geissler joined the Washington State Department of Natural Resources in May of 2018 and serves in the capacity of State Forester and Deputy Supervisor for Wildfire and Forest Health.

Mr. Geissler is the former President of the National Association of State Foresters and is a member of the Wildland Fire Leadership Council.

Mr. Geissler is married to his wife Bea. They have two children and four grandchildren and reside in Olympia, Washington.

Chairwoman LOFGREN. Thank you very much. And now for our final witness, Chief Litzenberg, we'd be pleased to hear from you.

**TESTIMONY OF FIRE CHIEF ERIK LITZENBERG (RET.),
CHAIR OF THE WILDLAND FIRE POLICY COMMITTEE
AT THE INTERNATIONAL ASSOCIATION OF FIRE CHIEFS**

Chief LITZENBERG. Good morning, Chairwoman Johnson, Chairwoman Lofgren, and Ranking Member Lucas, as well as Members of the Committee. I am Erik Litzenberg, recently retired Fire Chief from Santa Fe County Fire Department. I currently serve as Chair of the Wildland Fire Policy Committee of the International Association of Fire Chiefs (IAFC). I appreciate the opportunity today to discuss the state of Federal wildland fire science and the future. Wildland fires are now an all year threat to every State, and, as my previous panelists, as well as Members of the Committee, have stated, the statistics continue to rise. This year probably looks to be the worst on record. Local fire departments are on the front lines. We prepare our communities for fires, and are often the first to respond. We help evacuate communities. When the fire is over, we help communities recover, and address threats that often follow, such as flooding, debris flows, and landslides.

While Federal agencies like the U.S. Forest Service and FEMA (Federal Emergency Management Agency) play the most visible role in responding to wildland fires, Federal research agencies, like NASA, NOAA, NIST, and NSF provide tools to help prevent and fight future wildland fires. They currently provide research and tools such as fire weather prediction, satellite imagery, predictive fire analysis, research on building codes, community fire prevention, post-fire analysis, and studies of major catastrophic fires—greater Federal research into satellites, climate, and technology can revolutionize preparedness and response. As we adapt to new technology, like unmanned aircraft systems (UAS), we can provide the incident commanders on scene with a host of new tools. Most importantly, we can develop an integrated picture. This will allow us to effectively save lives and property in the face of a growing wildland fire problem.

As Federal researchers focus on the national wildland fire problem, I'd like to highlight some emerging fields of research and technology for them to consider. Ground-based airborne and satellite remote sensing systems can provide an integrated early warning system and better picture of the incident. Satellites can identify fires in low density areas and near critical infrastructure. Also, remote sensing can be used to provide information about fuels and droughts. Fire mapping can be used to prevent and mitigate wildland fires. These maps can guide hazardous fuels and other mitigation projects. They also can provide real time and interactive maps to assist incident commanders during a fire. Remote sensing data and risk maps can be used to provide predictive analytics. This information can be used to identify at-risk areas and focus community preparedness and mitigation efforts. The UAS provides several capabilities. They can hover over a fire to track its progress, infrared cameras can be used to identify hot spots, and they can provide a wealth of real time data to the firefighters in the field.

The development of a firefighter location tracking system would be a game changer. The creation of a practical firefighter tracking tool could improve firefighter safety and reduce the number of deaths and injuries that occur each year. The IAFC recommends that the U.S. Forest Service, FEMA, NOAA, and NIST work with the Wildland Fire Leadership Council to develop a standard warning system for wildland fires. Much like the Richter Scale for earthquakes, a standardized warning system would help emergency managers and the public act as a fire develops. Federal agencies should develop a standardized data collection system. This includes uniform formatting and methodology to capture and report wildland fire data, including information about mitigation, prevention, and post-recovery efforts.

Effective communication systems are the glue that link all of these opportunities together. Unfortunately, we're still facing problems with coverage and interoperability. It will be crucial to address this problem to take advantage of the new tools under development. I would like to highlight FirstNet's role in focusing on building out a nationwide public safety broadband network. These capabilities offer potential, but they must be integrated effectively before incidents occur and on scenes, so the Federal agencies should work with the Forest Service and Department of Interior, but they should also work with State, tribal, territorial, and local partners. There are opportunities like WFLC and NIFC (National Interagency Fire Center) to have these discussion. In addition, they should work with non-governmental organizations, such as the IAFC. Prioritization of at-risk communities can guide community preparedness like the IAFC's Ready, Set, Go Program. In addition, the National Fire Academy, IAFC, and other educational and media organizations can partner with Federal researchers to get information and technology to the practitioners.

The wildland fire problem is a national challenge. The IAFC looks forward to working with the Committee to mobilize our resources for this fight. Thank you for the opportunity to testify today.

[The prepared statement of Chief Litzenberg follows:]



**The State of Federal Wildfire Science:
Examining Opportunities for
Further Research & Coordination**

Statement of

**Fire Chief Erik Litzenberg, Ret.
Santa Fe County Fire Department**

presented to the

**COMMITTEE ON
SCIENCE, SPACE & TECHNOLOGY**

U.S. House of Representatives

June 29, 2021

INTERNATIONAL ASSOCIATION OF FIRE CHIEFS
4795 MEADOW WOOD LANE, SUITE 100W • CHANTILLY, VA 20151

Good morning, Chairwoman Johnson and Ranking Member Lucas. I am Fire Chief Erik Litzenberg, recently retired from the Santa Fe County Fire Department and current Chair of the Wildland Fire Policy Committee of the International Association of Fire Chiefs (IAFC). I appreciate the opportunity today to discuss the state of federal wildland fire science and opportunities for further research and coordination.

The IAFC represents the leadership of over 1.1 million firefighters and emergency responders. IAFC members **are the world's leading experts in firefighting, emergency medical services, terrorism response, hazardous materials (hazmat) incidents, wildland fire suppression, natural disasters, search and rescue, and public-safety policy.** Since 1873, the IAFC has provided a forum for its members to exchange ideas, develop best practices, participate in executive training, and discover diverse products and services available to first responders.

America's fire and emergency services are the only organized group of individuals who are locally situated, staffed, trained, and equipped to respond to all types of emergencies. There are approximately 1.1 million men and women in the fire and emergency service – consisting of approximately 300,000 career firefighters and 800,000 volunteer firefighters – serving in over 30,000 fire departments around the nation. They are trained to respond to all hazards ranging from earthquakes, hurricanes, tornadoes, and floods to acts of terrorism, hazardous materials incidents, technical rescues, fires, and medical emergencies.

Wildland fires are a growing area of operations for local fire departments that are located in rural locations, the wildland-urban interface (WUI), and more developed areas. Last year was one of the worst fire seasons on record. According to the National Interagency Fire Center, there were 58,950 fires totaling more than 10.1 million acres burned.¹ These fires resulted in federal suppression costs of almost \$2.3 billion.² As the American population grows more into the WUI, fires in these areas are proving to be very costly and most challenging to federal, state, tribal, and local authorities.

Research Needs of Local Fire Departments

Local fire departments are at the front lines of these wildland fires. They are the first on scene for eighty percent of fires, regardless of whether they occur on federal, state, local, private, or tribal lands. As such, it is vital that they work with state, tribal, and federal officials to prepare for wildland fires and respond to them. Federal research agencies, such as the National Science Foundation (NSF), National Institute of Standards and Technology (NIST), and National Aeronautics and Space Administration (NASA) can play a role in improving the preparedness and response to wildland fires.

Currently, these agencies do provide some assistance with wildland fires. The NSF has funded research into the flow of sediment and how it can affect post-fire mudslides. In addition, it has funded programs to predict the size of wildland fires and produce predictive fire analysis. The **NASA's earth-**observing satellites can detect fires, track the smoke from fires, provide

¹ Wildfires and Acres, National Interagency Fire Center, <https://www.nifc.gov/fire-information/statistics/wildfires>.

² Suppression Costs, National Interagency Fire Center, <https://www.nifc.gov/fire-information/statistics/suppression-costs>.

information about burn scars to the earth, and provide this information to local fire managers. The NIST has produced comprehensive studies of the 2018 Camp Fire and other major incidents and educated the fire and emergency service about lessons learned regarding how fires progress through communities. The NIST also has produced research supporting community mitigation efforts and the use of these efforts and building codes to reduce fire damage.

These federal efforts are appreciated by local fire departments. However, there are a number of opportunities for further federal scientific research that can help firefighters as they battle major wildland fires. Unmanned aircraft systems, machine learning, and remote sensing all offer opportunities for improving the response to wildland fires and reducing the costs to life and property.

The following are some fields for future focus to improve the nation's wildland fire response:

- Remote Sensing: It is easiest to suppress fires as soon as they are identified. While there are ground- and air-based remote sensing systems, NASA, the National Oceanic and Atmospheric Administration (NOAA), and other federal agencies can provide a satellite-based component to help better identify fires. For example, a satellite-based system can identify fires in low density areas near critical infrastructure. Local fire departments can **then be informed of these fires and work to extinguish them.** In addition, NASA's Earth-observing satellites should be able to provide better information about droughts and help target community preparedness efforts. In addition, federal, state, tribal, and local officials can do a better job of utilizing ground- and air-based remote sensing systems to identify the location and growth of fires.
- Fire Mapping: Risk mapping is an important tool for preventing and mitigating wildland fire incidents. These maps identify possible risk characteristics to guide mitigation projects, including hazardous fuels removal projects. Federal agencies can provide assistance in developing more accurate risk maps. In addition, the development of real-time and interactive maps would provide critical assistance to incident commanders during active wildland fire incidents.
- Predictive Analytics: The NASA and the other federal agencies also may be able to combine remote sensing and risk maps to develop tools for predictive analytics. Predictive analytical tools could help federal, state, tribal, and local jurisdictions to identify at-risk areas and focus on wildland fire prevention, community preparedness and mitigation activities.
- The Use of Unmanned Aircraft Systems (UAS): Drones and other UAS provide several important capabilities to the wildland fire arena. UAS can hover above a fire and track its progress for long periods of time. Infrared cameras on UAS can be used to identify hot spots at night. By combining aerial surveillance with fire maps and predictive analytics, an incident commander may have a greater understanding of the fireground and be able to make better informed decisions to save life and property.

- Firefighter Location Tracking: The development of firefighter location tracking is a major goal of the fire service research agenda. While there are efforts to track firefighters in buildings, it remains important to be able to track firefighters in the middle of major wildland fire incidents. These systems will have to be lightweight to address the challenges of responding the fires in remote areas and be able to broadcast signals over long distances in rugged terrain. Ideally, these tracking systems will be able to provide basic health information to identify when firefighters may need to take time for rehabilitation during major fires.
- Uniform Data Collection: The IAFC recommends that the federal agencies develop a standardized data collection system, including formatting and methodology to capture and report wildland fire data. This data should include mitigation, prevention, and post-fire recovery efforts. Without a standardized system, it is hard for incident commanders and emergency managers to review information, compare it, and make the appropriate decisions based on the federal data.
- A Standard Warning System for Wildland Fires: The IAFC recommends that FEMA, NOAA and NIST work with the Wildland Fire Leadership Council (WFLC) and emergency management agencies to develop a standard warning wildland fire scale that relates to the magnitude of current and expected wildland fires. This scale would be similar to a Richter scale for earthquakes or the Saffir-Simpson scale for hurricanes and could relate the magnitude of the pending threat to communities. In addition, this standardized warning system would help communities plan for evacuation.
- Interoperable Communications: Interoperable communications remain a challenge on the fireground during wildland fires. In some cases, mobile devices may not get coverage and radios may not be interoperable between neighboring jurisdictions. As the amount of data available to an incident commander broadens to include interactive risk maps, images for UAS, and location information about wildland firefighters, it is important that the incident commander can access this information and distribute it to the personnel in the field. I would like to recognize the First Responder Network Authority's (FirstNet) efforts to create a nationwide public safety broadband system that will operate even during rural wildland fires. We urge the federal agencies to work with FirstNet to ensure that information like National Weather Service fire weather reports can be broadcast through FirstNet to the incident commanders and firefighters on scene.

Improved Federal, State and Local Coordination

The opportunity to link UAS surveillance; interactive real-time fire maps, information about firefighter location; and predictive analytics together through a seamless interoperable communications system would transform response efforts on the WUI fireground. However, these technologies must be integrated and coordinated through the federal, state, tribal, and local members of the incident management team. The federal research agencies can work with the U.S. Department of Agriculture and the U.S. Department of Interior to start planning how to integrate future technology into wildland fire operations. In addition, these agencies should accelerate their discussions with the National Interagency Fire Center and WFLC to begin

outreach to federal, state, and local stakeholders about how to develop and adapt technology for the wildland fire arena.

It is important to point out the role that research can play in preventing and mitigating wildland fires too if it is shared with state and local stakeholders. If federal remote-sensing resources can identify areas where there is localized drought or infestation by the bark beetle, they can work with state foresters and local communities to expedite hazardous fuels removal and community preparedness activities. The IAFC manages the Ready, Set, Go! (RSG) Program in partnership with the U.S. Forest Service. RSG helps communities in the WUI through local emergency response agencies to become involved in preparation, mitigation, and being ready to evacuate early and safely when a wildland fire strikes. Predictive analytics would help the RSG! Program focus on those communities most at risk of severe wildland fires and hopefully reduce life and property loss. In addition, research at NIST can be shared with standards developing organizations like the National Fire Protection Association and International Code Council to develop robust wildland codes to mitigate the risk to both communities and individual homeowners.

Professional associations and educational organizations, like the IAFC, also play a role in disseminating the results of applied research to the fire service community. On April 29, the NIST joined with the IAFC and U.S. Fire Administration to present the findings from their comprehensive analysis of the Camp Fire in a webinar for fire service leaders. This webinar included lessons learned for fire spread, fire behavior, community evacuation, and responses to structural fires caused by wildland fires. As federal research agencies develop technology and more scientific analysis of the growing wildland fire problem, they can partner with organizations like the IAFC to get their conclusions to practitioners in the field.

Conclusion

I thank the committee for the opportunity to testify today about the federal research into the wildland fire problem. Across this nation, local fire departments are first on scene to respond to this growing problem. The federal research agencies can conduct research and adapt technology **to transform the nation's preparedness for wildland fires. The key is to bridge the gap between** the federal lab or a federally funded research partner and the local incident commander and firefighters in the field. This gap can be closed by close coordination with state, tribal and local officials through organizations like the NIFC and WFLC. In addition, the federal agencies can work with professional nongovernmental organizations like the IAFC to educate practitioners on the results of such research and ways to adapt and integrate technology on the fireground. The IAFC looks forward to working with you to address this issue.

Biography of Fire Chief Erik Litzenberg, Ret.

Erik Litzenberg recently retired from his position as fire chief for Santa Fe County, New Mexico. Chief Litzenberg served the majority of his career in the City of Santa Fe Fire Department, completing his time in the city as fire chief and city manager before returning to the county where his career began. Through 25 years of service, he has also worked for New Mexico State Forestry and as part of multiple Incident Management Teams, and for many years owned Santa Fe Wildfire, which provided resources for large-scale incident management and response.

Chief Litzenberg holds a master's degree in public administration from the University of New Mexico and a master's degree in security studies from the Naval Postgraduate School. He is a doctoral candidate in sports administration. He represents local government as the chair of the International Association of Fire Chiefs' Wildland Fire Policy Committee and as a principal member of the Wildland Fire Leadership Council. Chief Litzenberg has authored multiple articles and textbooks on fire service and organizational leadership, community risk reduction, and the wildland-urban interface. He enjoys training for and participating in triathlons, and lives in Santa Fe with his wife and children.

Chairwoman LOFGREN. Thank you very much for your testimony, and to all the witnesses for your testimony. At this point we will give Members of the Committee an opportunity to ask questions of our witnesses for about five minutes, and I will begin with myself.

You know, my constituents, and the constituents of many of us on this Committee, have been dealing with severe wildland or mega fires in recent years. In fact, the wildland fires has grown from a season to really all year round. We had fires in California in the winter. And, you know, in a way I think about—yes, they're wildland fires, but they also impact urban areas. I'll never forget visiting Santa Rosa in 2017, a little town, not in the middle of a forest, and the fire came in and destroyed 5 percent of the housing in that suburban community. Going to a suburb and all the houses are gone, the shopping center is burned down. Going, you know, with Representative Thompson, who represents that area, to other areas of his district that just was burned. And the fire in Paradise 2018. Doug LaMalfa represents that area. The fire swept through, and the entire time—town was also destroyed. So obviously we have important steps to take.

I'm interested in how we can enhance collaboration and coordination across the Federal Government, along with, you know, the operational stakeholders on the front line. So, Dr. Clements and Dr. McCarty, as academic researchers who rely on Federal data and resources, where should the Federal investment in wildfire science be most urgently directed? First you, Dr. Clements.

Dr. CLEMENTS. All right, thank you. So I think that funding these programs across all the agencies, particularly—

I think what we really need to focus on is research focus so we can get better information, in terms of better tools. And so having new tools will allow us to build what we need, in terms of sensor systems, because we're lacking of sensor systems, and also the fact that we need more platforms. Like was stated earlier was the fact that we need better satellite technology, so I think investment in a lot of satellite development would be really beneficial to the entire wildfire science community.

Chairwoman LOFGREN. Dr. McCarty, do you have anything to add on?

Dr. MCCARTY. I would just add that we also need to think about, as we develop these tools, that we communicate them with the public in an effective way, and we also integrate their input. I think a lot of time when we think about wildfire risk, and reducing wildfire risk, we forget that people are the main cause of fires still, and the more that we are transparent and open with the public the better they will understand the risk and potentially act as good citizens to reduce that risk in the future. And that includes social science research, public health research, as was mentioned by some of the other witnesses. Thank you.

Chairwoman LOFGREN. Are there opportunities for Federal investment or direction that could have positive impacts in the short term, and how long do we think it will take for the longer term investments to have realized impacts? Dr. McCarty, and then Dr. Clements.

Dr. MCCARTY. So for satellite development, these things take a while. NASA's decadal surveys are a decade long for a reason. But

oftentimes it's the funding and the priority that limits the advancement of these systems and implementation. And I agree also with Federal investment in the Wildland Fire Leadership Council would also be needed so that it can interact with the incident command and the commanders on the field, and NIFC, as well as other agencies. And that's a short term, you know, high risk, high reward investment that could be done quickly within an offseason to see if that implements better in the next fire season.

Chairwoman LOFGREN. Dr. Clements, anything to add on that?

Dr. CLEMENTS. I think one thing that could happen quickly is that restoring the Joint Fire Science Program budget would allow researchers to just engage quickly, because that program actually funds things faster than a lot of Federal agencies. The timing between proposal submission and project start is really quick, and so that could be one way to just jump start a lot of research quickly.

Chairwoman LOFGREN. Dr.—Mr. Geissler and Chief Litzenberg, I don't have much time left in my five minutes, but do you have anything to add to what's been said already?

Mr. GEISLER. Thank you. There is one statement I'd like to make, and I totally agree with the comments of my colleagues here on the panel, and I would like to emphasize the application of that science also. There's a lot of really good work that's ongoing that will require just a little bit of funding, and maybe increased collaboration between State, local, and Federal agencies, and we could get this technology to the ground, to the firefighters, where it's going to make a difference. And so that interaction and collaboration I find is just something that we should foster and support as much as possible.

Chairwoman LOFGREN. Thanks.

Chief LITZENBERG. And I will add that echo for all three panelists, and I'll emphasize what George Geissler just said about integration. There are places where this integration is already happening effectively. And as science and data is created, it'll be important to get this to the boots on the ground, to the practitioners. And Wildland Fire Leadership Council and the National Interagency Fire Center, that integration is happening already, so small investments can be leveraged significantly.

Chairwoman LOFGREN. Thank you very much. My time has expired. I'd like to recognize the Ranking Member, Mr. Lucas.

Mr. LUCAS. Thank you, Madam Chair. And, George, I think we've worked together long enough I can call you George—you mentioned in your testimony about, of course, listing several areas, about how the Committee could fill gaps and address shortfalls, and the Chairwoman very appropriately went down that. Could you expand for a moment, thinking about from the Committee's perspective, prioritizing those? Where particularly, George, if you had the ability to give us guidance, how would you prioritize one, two, three, four, if you don't mind?

Mr. GEISLER. No, I'd be glad to. Thank you, Representative Lucas, and yes, you can call me George anytime.

Mr. LUCAS. Thank you.

Mr. GEISLER. The priorities—what we're looking at—and, I mean, I am very aware of a lot of the satellite technology and some of the early work that's been going on. In fact, in my time with

Oklahoma Forest Service we were working closely with a severe storms lab, doing early detection and notification modeling. And I know that while there's long term implications, and development of the resource, currently there's a lot of opportunity just to get that on the ground right now, working with local agencies.

The other piece that I would really like to emphasize is the firefighter and resource tracking. This is a safety issue, and there are a number of different systems that are out there right now, and to be able to monitor and track our resources in real time, ensuring that we are putting them in the best places possible, ensuring that we're utilizing them effectively, and especially monitoring them to ensure that they are safe, and that we are tracking, and know that they're all going home, I think that that's just absolutely critical for us, and we could make the changes that are necessary there. It's a standardization process and an implementation process that really needs to occur.

And the last one, though, for me, is very much a—I know that there's a lot of work here, but it is something that I would sink my money into if I had to, and that's the discussion around real time smoke modeling, and continuing the decision space around that. Smoke is probably the greatest public health issue related to wildland fire, and knowing what that—implications are, being able work with the public to improve public health and firefighter health, in fact, I think is just part of that mission. And the CDC and EPA, along with several other regional smoke agencies, are doing some amazing work, and to kind of foster that even further would be a tremendous asset to us all.

Mr. LUCAS. You know my district, George, literally from the northeast corner of the State to the southwest corner, the northwest half of Oklahoma, and weather forecasting's very critical to my farmers, because it's decisions about when to plant, apply fertilizer, harvest, utilize prescribed burns to help maintain—

Mr. GEISSLER. Right.

Mr. LUCAS [continuing]. The health of our rangelands. And one of the ways that my neighbors and my spouse engage in decision-making is using Oklahoma's Mesonet system, which provides up to the minute weather data. How did you utilize the Mesonet data when you were State Forester of Oklahoma? And along with that, while you're thinking about it, do you believe that such a system should be emulated in other States to help benefit, prevent, and fight large scale wildfires?

Mr. GEISSLER. Yeah, the Mesonet system that Oklahoma has is such a unique resource for firefighters. We can watch in almost real time weather pattern changes, wind changes. I remember distinctly my fire chief counting down a wind shift to people in the field, telling them when it was going to occur, and he hit it within minutes, because we were watching it all with—on a screen. When I worked in other parts of the country, especially if you go to places like here in Washington State, we struggle because there's so many microclimates and not enough monitors. And—but to be able to do that, to be able to talk to folks in real time, and do the prediction that folks that have all of that data, like the Mesonet, that—what the Mesonet system provides was just unbelievably valuable to us in that environment, especially an environment that, the type of

fuels Oklahoma has, it's a rapidly changing fire scenario. They're very quick, fine fuels, and you have to know the wind very, very effectively to do it.

In other parts of the country, when I got—get out I do sometimes wax nostalgia about Mesonet, and having something to that effect across the United States would be amazing. And I think fire—any fire manager that works in Oklahoma is always thrilled by the app that we can easily download on our phones and do all of that. So it's an excellent tool, I agree.

Mr. LUCAS. Absolutely, the ability to protect both citizens' lives and their property. And I know there have been many occasions, as you've kind of alluded to, when volunteer fire lines—members had been moved in a hurry because they couldn't survive where they were. An amazing system. With that, I thank you, George, and I yield back, Madam Chair.

Chairwoman LOFGREN. Thank you very much. The gentlelady from Oregon is now recognized, Ms. Bonamici.

Ms. BONAMICI. Thank you so much, Chair Lofgren, and thank you to Chair Johnson and Ranking Member Lucas for holding this hearing today, but especially thank you to our witnesses for bringing your expertise. I represent Northwest Oregon, and this past weekend the Pacific Northwest faced a record-breaking heat wave, with temperatures exceeding 100 degrees for multiple days. In fact, it was 115 degrees at home yesterday. These dangerous temperatures, combined with a thin snowpack and below average precipitation, are really raising alarms about our upcoming wildfire season. In fact, we have already seen a 6,200 acre fire on the Confederated Tribes of Warm Springs Reservation in Central Oregon. Fortunately it's been mostly contained, but Oregonians have become all too familiar with wildfires in recent years.

Over Labor Day weekend just last year rare powerful winds and very dry conditions resulted in unprecedented wildfires across the State. Approximately a million acres burned. Lives were lost, homes and communities were destroyed. Hazy skies and smoky conditions made the air quality in Portland comparable to some of the most polluted places on the planet. Thank you, Mr. Geissler, for highlighting the health hazards of smoke.

Now, our communities are really on the front lines of the climate crisis, and wildfires are yet another example of the need for comprehensive and bold climate action, so I want to ask you, Dr. Clements, you said we need to treat wildfires like other natural disasters and severe weather threats, and in your testimony you noted the deficiencies in our understanding of how wildfires create their own weather, and how fire atmospheric interactions can affect spread. So how would improving our understanding of fire weather help to mitigate or respond to wildfires, and how can Congress better direct Federal agencies to conduct this important research?

Dr. CLEMENTS. Thank you. So, yeah, the fire weather gap—knowledge gap is really in—is a problem because we just don't put those resources to fire weather, like I mentioned thinking about the hurricane hunters. We don't have those resources for fire. Now, we have suppression resources, very—you know, tons of suppression resources. One thing we can do is we can instrument suppression aircraft with these tools, with the science tools. I've been advo-

cating this in—for a while now, and it wouldn't be that hard, because everything would be automated, and we could actually just get all the information in real time.

So harnessing the current platforms that are surrounding fires is really important, and I think what we're missing is that we can't—you know, when we go to—so, for example, my team, we go to active wildfires in California with Doppler radar and Doppler lidar, and we're the only team in the U.S. that can do that. There are no observations on active wildfires. It's not like there's storm chasers chasing fires. We're the—this small team, and we get just a little bit of information here and there. We need to change that concept and make it more of a priority, where we're actually supporting the incident meteorologists of the National Weather Service on these big fires.

In addition, I think we could support—funding could be directed to NOAA for this type of infrastructure to support the incident meteorologists. You know, they're tasked with forecasting very high resolution, using models, but they don't have the observations on the fire, and some of these fires are so remote that we don't have the observations. In California—

Ms. BONAMICI [continuing]. I don't want to cut you off, but I want to try to get in another question. Thank you so much.

Dr. CLEMENTS. Yeah, sorry.

Ms. BONAMICI. I just want to ask—

Dr. CLEMENTS. Yeah.

Ms. BONAMICI. —Chief LITZENBERG, last year I joined my colleagues on the Select Committee on the Climate Crisis in releasing our bold science-based plan to reach net zero emissions no later than mid-century, and net negative thereafter. The plan represents the first significant legislative proposal to address the need for climate resilience investments, including investing in wildfire risk mapping systems that integrate relevant data from Federal agencies, States, and partners. So in your testimony you noted the importance of risk mapping and real time interactive maps, so what are the implications of the expansion of the wildland urban interface without high resolution mapping, and how could better maps, including parcel level data, better inform planning and response decisions?

Chief LITZENBERG. Thank you for that question, Congresswoman. So that is the key to what we do, getting good data, and putting it in a way that's usable not only to our responders, but to those in the community who are working on the team that's doing prevention, doing mitigation, trying to make our communities safer. And as we have seen hotter, drier conditions, the risk areas have expanded. I will say that—and I said it in my testimony as well—one of the keys to me, and my profession, and my representation as a responder, is that that data becomes available as real time as possible to those that are on the ground doing the work. So there's application in both prevention and mitigation, and predictive analysis, and incident command, and real time situational awareness.

Ms. BONAMICI. Thank you so much. My time has expired. I yield back. Thank you, Madam Chair.

Chairwoman LOFGREN. Thank you very much. Mr. Posey is now recognized.

Mr. POSEY. Thank you, Madam Chair. I really appreciate you hearing all this. Mr. Geissler, the *Proceedings of the National Academy of Sciences* issued a report entitled "Human Presence Diminishes the Importance of Climate in Driving Fire Activity Across the United States". This report is significant because it found that climate was significantly less important where humans were more prevalent, suggesting that human influences override, or even exceed, the effect of climate change on fire activity. And, Madam Chair, I'd ask unanimous consent to submit this report for the record?

Chairwoman LOFGREN. Without objection.

Mr. POSEY. Thank you so much. Based on your experience, to prevent fires, should our limited resources be focused more, or specifically on what and how, we are building in fire zones rather than the broader topic of climate change? Mr. Geissler, I appreciate your response.

Mr. GEISLER. Thank you, Congressman, I appreciate that. Actually, the—when we talk about fire and fire prevention, I—one of the earlier panelists mentioned the greatest numbers of fires are caused by humans. Whether it be a spark or a campfire, we use the old Smokey Bear message of Only You. Bottom line, though, is with development in wild and urban areas, we're getting more people, and so you have more opportunities for fires to occur. It's not that they're not trying to prevent it, but it's just greater opportunities.

In fact, in my own State of Washington, the west side, while it does have forests that typically have a longer duration between fires because of the fuels types, that's where our biggest population is, and we are seeing significant fires there. But at the same time, if you look at our forests, and our forest resiliency, climate has had an impact on that also. And so, combining with the—both challenges, that why a lot of what you see happening right now is an emphasis on working toward healthier forests, greater resiliency in those forests, and making them more for—fire adaptive.

So for me it's really a two prong approach. There is the long term of we have to get our fuel situation under control, we have to be able to keep our landscapes resilient, whether it's a forest or a rangeland, but at the same time there's an education process and a prevention process which we have to get people to be aware of what they're doing, be able to prevent those fires, and then, in our planning efforts, ask people—move into these beautiful areas, we have to get those areas better prepared for the interactions and the fires that will inevitably come.

Chairwoman LOFGREN. And I lost, so—I—can you hear us?

Mr. GEISLER. I cannot hear you anymore. Or I cannot hear the Congressman.

Mr. POSEY. How about that? Is this better?

Mr. GEISLER. That's better, sir. Thank you.

Mr. POSEY. I'm asking if you'd be kind enough to explain why we need to include our "built communities", those where we have built homes, roads, businesses, and schools, in fire simulation models?

Mr. GEISLER. Easily, because, as we see the roads and the homes being put into these areas, our models currently just look at it as a continuous layer of fuels. Basically, we look at it as trees

and grasses. Homes and businesses, structures, all of these things change the fire behavior, change the way that fire acts on the landscape. Having that information, knowing how the reaction of the fire is going to be, or the actual behavior of the fire's going to be when it hits these communities, is something that will better inform our firefighters, and make them work safer, and be able to suppress the fires a lot easier.

Mr. POSEY. Very good. Thank you, Mr. Geissler. Madam Chair, I see my time is about to expire. I yield back. Thank you.

Chairwoman LOFGREN. Thank you very much. Mr. Bera of California is now recognized.

Mr. BERA. Thank you, Madam Chairwoman, and the Ranking Member. Obviously this is a hugely important issue for us in California. If I think about why I love the State of California, you know, from hiking in the back country as a Boy Scout when I was growing up to, you know, hiking in the Sierra Nevadas and, you know, the Feather River, et cetera, camping out there, a lot of those places I've experienced are now scarred by forest fires. And, you know, I'm going to ask a series of questions, and I'd ask the witnesses to keep their answers short and tight so I can get through a number of these.

I want to make sure I understand, you know, on the sensing side, this—you know, I've heard a number of the witnesses talk about how we just haven't allocated the satellite resources necessary. Because I don't think it's a technology issue. I think, you know, we have infrared sensing devices, we have the ability to put satellites in space so they're constantly monitoring areas 24/7. We have drone capabilities that could, you know, surveil, you know, these areas. So I want to make sure I understand, it's not a technology issue, it's a resource allocation issue, if I get that correct. And maybe, Mr. Clements, is that, you know, an accurate sense?

Dr. CLEMENTS. Yeah. So let's—we can use Cal Fire (California Department of Forestry and Fire Protection) as an example. Cal Fire has adopted the latest science and software package available, and it allows to track resources, firefighters, it puts the fire prediction model in there, and so it's the state of the science, and it's actually been very successful. So that information gets some DOD (Department of Defense) satellites, fireguard data—so they could map it, but those data aren't really applied to the research community. But yes, the resources—it's a resource issue. Cal Fire's already adopted it, and it's very successful. They have a new system, and it's for the whole State, and it's a really good model that should be used nationally.

Mr. BERA. Great, fantastic. So I think that that's something we as a Committee could work on in a bipartisan way. Question for Mr. Geissler. You know, one area that I've worked on over the years is—we have allocated resources to better forestry management, et cetera, but for years we would do this thing called fire borrowing, where we would take those resources, and then we would actually spend them to fight the fires. I know we've tried to address the issue of fire borrowing. I suspect we could do more on the forestry management side to mitigate some of these forest fires, is that correct?

Mr. GEISSLER. Yes, sir. The fire borrowing issue was actually helped tremendously by some legislation that occurred a couple of years ago. Really the emphasis right now needs to be to take that—those dollars and really force them onto the ground, and making sure that they are being put into the highest priority areas that we have. A lot of times, when we're doing forest management, I call them random acts of conservation, where a lot of is kind of spread across the landscape, and prioritizing the funds, making sure that they get to the ground, is something that we should all emphasize and work harder on.

Mr. BERA. OK, great. And, again, we were able to pass that legislation in a bipartisan way, so I think this is another area where we could work together as Democrats and Republicans, you know, to really make sure we're actively managing our forests, and mitigating some of these fires. Mr. Litzenberg, let me ask you a question. You know, 4 or 5 years ago I had two of my local fire chiefs, you know, who happened to be up in Washington, DC. visiting, and, you know, just serendipitously they started talking about the stresses that we're putting on our firefighters, and, you know, since then I've talked to a number of—I represent a suburban/urban community, but a lot of our firefighters rotate up into the hills to supplement Cal Fire, and help with these—so they're almost constantly working during fire seasons.

And, you know, we put together a piece of legislation called the *Heroes Act* a few years ago, which had passed out of the House and this Congress, really identifying—trying to address the pressures and stress that are leading to firefighter suicide, firefighter PTSD (post-traumatic stress disorder), et cetera. You know, if you could, you know, just quickly comment on the stresses that the men and women are under, both urban and suburban, but also the folks that are in the Forestry Service?

Chief LITZENBERG. Congressman, I really appreciate that question, because, yeah, the stresses on our work forces at any level, all levels of government, and private sector, is significant, and they are full range, from behavioral stressors all the way through physical stressors. The more that you ask from a workforce that's already strapped, the longer you ask them to serve in terms of hours in a day, or in terms of weeks and months in a year, and the more exposures you give them to smoke and human suffering, the greater stressors they have. So we've always appreciated investments and solutions, but we are only just beginning to discover the effects that these stresses have on our response force. They are significant.

Mr. BERA. Well, great. And we passed that legislation out of the House in a bipartisan. Let's hope the Senate takes it up and sends it to the President's desk. Thank you, and with that, I'll yield back.

Chairwoman LOFGREN. Thank you. Ms. Kim of California is now recognized.

Mrs. KIM. Thank you, Chair Lofgren, and Ranking Member Lucas, for holding this hearing. I want to thank the witnesses for being with us today too. Unfortunately wildfires in my district, and the rest of California, where Congressman Ami Bera and I are from, we seem to be more prevalent every year. And with 85 percent of California in extreme drought, the problem of longer wild fire seasons has been exacerbated by the dryness of our landscape

and the record-breaking temperatures. And adding insult to injury, the wildfire smoke and ash negatively impact our air quality and drinking water. And I hope we can work in a bipartisan manner to better coordinate our Federal efforts in predicting wildfires and adopt cutting edge solutions to detect fires as soon as they start.

Mr. Geissler, I represent California's 39th District, where we have, unfortunately, seen the devastating effects of wildfires not only in my communities, but across the State of California. So how can we ensure coordination between Federal, State, and local communities to share available information and tools to better predict and respond to wildfires?

Mr. GEISLER. Thank you for that question, Congresswoman, I appreciate it. The one thing that I will emphasize is that you really should be proud of the national system and—that we do have currently. They—the interaction that we have between Federal, State, and local agencies is something that actually other countries come to try to duplicate. But there's always room for improvement. Getting to common operating systems, being able to share data, being able to share and communicate effectively, is really some of the items that, if we can address those, it is—it's critical.

A lot of times it's just the difference between two computer systems, or literally the links that we might be able to get through broadband that prevent some of the sharing. And so it sounds kind of basic, the need, but the willingness and the ability to do it is there. A lot of times it is just making sure that the connections are made, whether it be introducing two people literally just doing that, all the way to making sure that our systems link together and operate effectively.

The system that was just described, that Cal Fire had, is absolutely amazing. And it's in test, and it has been doing some great work. Part of the basis of that is its ability to start communicating across jurisdictional authorities, and that's what we're all looking for, is that ability to effectively share all of these resources that we currently have.

Mrs. KIM. So NOAA has matched the processes of designing in the next generation of satellites in a split. So have any of your colleagues engaged with NOAA in designing these satellites to improve wildfire detection abilities? If not, what advice would you give to NOAA to help make the future satellites released more effective in wildfire detection and prevention?

Mr. GEISLER. So I will say that I am unaware if any of my colleagues have worked directly with NOAA over satellites. I will tell you that in my past life I was able to work with the National Severe Storm Labs in Norman, Oklahoma, and I know that the interaction between the National Weather Service and State agencies is very strong, and we utilize a lot of that satellite technology, and that there have been conversations about how effectively those could be used at the NOAA level also. But I'm unaware of anyone that is speaking directly to them. But I do agree it's a huge opportunity for us all.

Mrs. KIM. So you're familiar with the experimental high resolution rapid refresh smoke model? Have you had input on the development of any of these models, and, in your opinion, what further

research and development is needed to make existing models more effective?

Mr. GEISLER. You know, a lot of input has been really coordinated through the Wildland Fire Leadership Council, where we do have all of the partners at the table. So you not only have State Foresters, but you also have mayors, and other members of the various levels of government really having those discussions. So it's a really powerful forum to kind of discuss the needs and where we go forward.

So going into the future we're really looking, again, to try to enforce that, and try to get more of the outreach. There's a very recent memo even, in fact, between CDC and EPA discussing wildfire smoke, and actually being able to address all of the research and coordination that was there, and all of that was actually made possible through the interactions that we've had at that Wildland Fire Leadership Council. So, again, I—it sounds like I'm a broken record related to potentially solving a lot of these problems, but there's basic funding we need for research, but then there's also just the social science of communication, and then effectively making sure that we share resources across the table.

Mrs. KIM. Thank you very much. I see my time is up, so I yield back.

Chairwoman LOFGREN. Thank you. Ms. Stevens is now recognized.

Ms. STEVENS. Thank you, Chair Lofgren, for presiding over today's hearing, and thank you to our witnesses for your incredible written and spoken testimony. Your written testimonies in particular were quite inspiring, and I really enjoyed reading them.

In Michigan, during this month alone, the National Weather service has issued multiple red flag fire warnings throughout the State, and in particular last year we saw fire outbreaks in Northern Michigan. And, Dr. Clements, in your testimony you focused on programs that are aimed at fire weather research and wildfire prediction. Could you tell me more about the types of climate smart investments in research that are needed for better—for us to better understand the influences of wildfire on weather, and vice versa?

Dr. CLEMENTS. Yeah. Thank you, Congresswoman, for the question. I think one focus—what I mentioned earlier would be this coupled fire atmosphere modeling tool, because it's the only tool that actually allows the atmosphere to drive the fire, and then the fire itself to drive the atmosphere, and that's where we get our most dangerous fires, is when we have big plumes, and you can't predict where that fire's going to go. So investment into high resolution coupled fire atmosphere models is critical.

And, like I mentioned earlier, it's used in—so Greece, it's their national model. They have already adopted it. National Center for Atmospheric research is also building on that model. So these are the kind of tools I think that we really need to invest in. In addition, it also predicts smoke at very high resolution, and so you can tell a community what the smoke concentration's going to be in an hour, tomorrow, or the next day. So that's where I would really focus a lot of investment, in terms of on—

Ms. STEVENS. Well—and do you have recommendations, or any examples that you know of, of how the Federal Government is

working across agencies to forecast and predict these fires and better inform and protect the public?

Dr. CLEMENTS. Well, yeah. So, in terms of national, we have the National Fire Danger Rating System, which allows us to understand what the fire risk is, and so that goes across the Nation. That's a U.S. Forest Service product. But it needs to be a little bit more higher resolution, in terms of forecasting certain areas. For fire behavior research, it's agency specific. We don't really have a fire behavior prediction system at a national level.

Chairwoman LOFGREN. You're muted.

Ms. STEVENS. I muted myself? OK. And then another major priority for many of us, including myself, on this Committee has been the effort to strengthen our STEM pipeline to ensure that we have trained scientists and engineers who are ready to help address the 21st century challenges that are before us. And, Dr. McCarthy and Dr. Clements, are there skills from the fire management side of this work that you believe would benefit the STEM workforce, or relate to activities with STEM workforce training, and how would you recommend those skills to be transferred?

Dr. MCCARTY. Sure. I'll begin with that. So I'm not from Ohio, I'm actually from Eastern Kentucky, and, funnily enough, I'm married to a man from Michigan. My daughter was born in the UP (Upper Peninsula), so I know a lot Appalachian Eastern forest fire and—but I started, actually, as an undergrad working for the Daniel Boone National Forest and learned a lot of technical skills. And, as a first generation student, that was really important for me as a pipeline into graduate school at the University of Maryland to have that applied workforce—working on fire risk modeling within an eastern forest because of Southern Pine Beetle infestation.

And that was one of the reasons that I was able to get a graduate assistantship from a small school in Appalachia, was because I had worked on these types of on the ground management STEM skills in computing and data science. And so I didn't come from, you know, a very prestigious undergraduate institution, though it is great, and so that helped me in that pipeline. So I do think that throughout, holistically, the wildfire science community, this is a good way to get anyone from anywhere, you know, whether they're, you know, a woman or a man, non-binary, to get involved, because we are welcome. This is a problem, you know, across all 50 States. So I would just say that, and turn it over to Dr. Clements.

Dr. CLEMENTS. Real quick. So, yeah, at San José State we created a new Wildfire Sciences minor, and so that'll allow us to bring students from a diverse background into our field to give them some toolsets that they can take to—like, if they're a business major, or if they're a psychology major, they'll be aware of the wildfire problem, in addition to fire weather training that is very critical for meteorologists to have, which is something that we're also doing, and is a need around the Nation. Thank you.

Ms. STEVENS. Great. Thank you so much.

Chairwoman LOFGREN. The gentlelady's time has expired, and we'll turn now to Mr. Feenstra.

Mr. FEENSTRA. Thank you, Chairman Lofgren and Ranking Member Lucas, and thank you to all our witnesses for your testi-

mony, and sharing your extensive research and your experience with us. This question is for Mr. Geissler.

In 2020 Iowa experienced 126 wildfire incidents that burned almost 2,200 acres. These fires can jump from burning grasslands to agricultural fields, wreaking financial devastation for our farmers. What is the current state of understanding as to how a forest or a grass-based wildfire interacts with spreads across agricultural land? What research questions remain to be answered in this domain?

Mr. GEISLER. Thank you, Congressman, for that question. There is a lot of work that is actually ongoing relative to the interaction between agricultural croplands and wildland fire. For most wildland fire managers, we actually utilize a lot of agricultural croplands because, at certain times, they are the most irrigated spots on the planet, and we are able to use them and—as fire control. But as you know, and others on the Committee know, at various stages of the crop cycle, you’re going to have conditions where crops can be damaged, or that the fuels that are remaining on the ground can carry a wildfire.

So basically a lot of the types of fuels that we’re seeing on the ground do fit within some of our existing models. They need to be fine tuned somewhat to—as far as the local conditions, and a lot of the local agencies do some of that work in-house just to correlate the types of agricultural crops that they’re currently seeing on the ground relative to the standard fuels models that we have. But there is probably some ongoing work that could happen there, and especially where it comes into crop protection going forward.

Mr. FEENSTRA. All right. Thank you. And I’ve seen that a lot with our corn crop in the fall, and soybeans, when we’re ready to harvest, and a spark is set off by a combine or whatever, and we have a lot of devastation. I have one other question for you. Iowa is also home to numerous lakes and rivers, which are important for recreation, economic activities for my constituents. When discussing wildfires we commonly focus on the damage and destruction due to the flames and vegetation, and to the manmade infrastructures. However, I’d like to ask, what consequences can high intensity and high heat wildfires have on watersheds, and what additional research do we need to better understand these impacts?

Mr. GEISLER. I’m actually very glad you brought that one up. Post-fire recovery is something that a lot of us within the Wildlife Fire Leadership Council and within the community are really looking to—how do we better—do a better job of this. Right now, if you look at resources that are available, the Forest Service does have what they call Burn Area Response Units, BAR teams, that can evaluate and look to those areas to determine what are going to be the impacts, how do we recover? More specifically a lot of that revolves around impacts to water quality, as well as vegetation recovery.

The resources available at the State and local level are very limited. And, in fact, in most cases, a lot of that does not get done. But when you have the effects of a catastrophic wildfire, or one that removes a significant wildfire, or one that removes a significant portion of the vegetation, obviously that’s going to have an impact on water quality downstream. And so the idea of what we

need to do, how we address it, is all being discussed right now. I know that the National Sciences groups are actually coordinating through USGS (United States Geological Survey) and others. We're trying to come to a better way to effectively address these issues following some of these fires.

And it does not matter if you're working in a mountainous terrain, where a lot of people think it is more significant, or more visible, I should say, but on all aspects of watersheds, if you have these kind of damaging fires, you can impact the water quality.

Mr. FEENSTRA. Yeah. I really appreciate that information. We see that in Iowa quite a bit, where all the sudden you have the buffer strip gets burned away, and you have significant erosion, and there's really not a lot to stop that until the next spring, and sort of the grass grows back, or vegetation grows back, so it's always a concern for me. So I thank you for your responses, and thank you to all of the testimony of each one of you, and I yield my time back. Thank you.

Chairwoman LOFGREN. Thank you. Ms. Stansbury is now recognized.

Ms. STANSBURY. Thank you, Madam Chairwoman, and thank you so much for holding this important hearing this morning. I also want to thank especially Chief Litzenberg for being here this morning from Santa Fe County, which is from my home State in New Mexico. Thank you for your service, and to all of our local, State, county, Federal, and tribal firefighters. Thank you for your work on the front lines protecting our communities. And I also want to thank you for sharing your expertise this morning.

So I think it goes without saying that addressing wildfire is not only a matter of protecting our public safety, and the ecological well-being of our forests and our communities, but in New Mexico it's also a matter of national security because a significant number of our forestlands also abut on our National Laboratories, and our Federal military installations as well. But it's also the single largest threat to water and drought resilience in New Mexico, and much of the West as well, as well as our future climate adaptation and economic security. And, as was noted by Chief Litzenberg's testimony, we're already spending billions of dollars a year at the Federal, and local, and tribal levels to both suppress fire and fight fires across the West.

So one of the things that I wanted to talk a little bit about today is our forest science. So we focused a lot here today on remote sensing, fire weather, warning systems and hazards, but one of the most significant and important ways that we can address and mitigate the catastrophic fires that are affecting the West is through forest management, and this is especially true in New Mexico, where a lot of really exciting climate and forest management science is happening. So we're seeing a lot of really incredible partnerships between our tribes and pueblos, our local county officials, nonprofit organizations like the Nature Conservancy, our National Laboratories, who are doing really exciting, complex modeling around forest dynamics, carbon sequestration, soil, and ways in which we can actually target our forest treatments.

And, in fact, one of the things that's most exciting to me about have Chief Litzenberg here this morning is that he was intimately

involved in these activities in what is called the Santa Fe Fire Shed Program, which is a collaborative of all of these different programs, and so my question is actually for our Chief. Mr. Litzenberg, I wonder if you could talk a little bit about the Santa Fe Fire Shed efforts, and share with us how the science was leveraged, and partnerships were leveraged, and how we might scale this exciting collaborative model across the West.

Chief LITZENBERG. I sure can, Congresswoman, and, again, very much appreciate that question, because it is near and very dear to me. The Santa Fe—the Greater Santa Fe Fire Shed Coalition is a very successful collaboration, and it was built from the ground up around the premise that if you bring the right people to the table, much like you have, I think, on this panel, who can put their two cents into the mix, you often get a product that's much better than a single person or a single organization could've come up with.

And in that coalition we have all levels of government, we have nonprofit, we have scientists, we have people from the labs, and we even have people who don't necessarily agree with what we're doing. And we have regular meetings to talk about how do we make our watershed and our forests healthier and safer, and ultimately protect our communities, both for recreation, for life safety, and prevent the large fires, and those things that—we've talked about the smoke, we've talked about the post-fire debris. They've got huge destructive potential to not only primary effects, but secondary and tertiary effects.

And anything you can do to research and create data on those things that are modifiable, and toss them into a room where smart minds can think together and come up with solutions, much like the Santa Fe Fire Shed Coalition, I think replication of that across the West and the Nation is much in order. Thanks for asking that question.

Ms. STANSBURY. Thank you, Chief Litzenberg, and I would really encourage my colleagues—I know many in the fire community are very familiar with these efforts in New Mexico, but it's a really exciting model, and the Rio Grande Watershed efforts that are being put into restoring our forests are really a model for the Nation. And, finally, I just want to say that there's a coupled opportunity, while we're talking about fire mitigation, to talk about carbon sequestration. A recent study by the Climate Alliance in New Mexico showed that reforestation of burned catastrophic fire areas has a huge potential to help capture carbon, so I really think that that's an important part of the science that we need to be introducing into the conversation. And with that, Madam Chairwoman, I yield back. Thank you so much.

Chairwoman LOFGREN. Thank you very much. Now the gentleman from California, Mr. Obernolte, is recognized.

Mr. OBERNOLTE. Thank you very much, Madam Chairman, and thank you to all of our panelists. I represent a very fire prone and very rural section of the Western United States, and so the prevention of these wildfires is of critical importance to the people that I represent, and I know a lot of the people in this room share that concern.

One of the things that I was struck by in the testimony from all four of our witnesses is the inadequacy of the current satellite data

that we're getting, both in terms of geospatial resolution and in terms of temporal resolution, and, frankly, I had no idea that it was still this bad, to be talking about geospatial resolution of a kilometer, and temporal resolution of only one or two frames per day is clearly not going to be adequate to generate the kind of wildfire models that we need to predict wildfire behavior, and certainly is not going to be as useful as it could be to be able to give early warning when a new wildfire starts. So that's what I'd like to ask some questions about.

And I probably could pick any of the panelists, but, Dr. McCarty, I was struck by your testimony about this. Can you talk a little bit about what the prospects are for improved satellite imaging, if we have anything in the pipeline, and in particular maybe talk about the fact that—I know that we're talking about geostationary satellites mostly here, but the state-of-the-art in satellites now is low Earth orbit satellites, which might solve your spatial resolution problems also. Is there some prospect that we could use some of the assets that we have to solve this problem?

Dr. MCCARTY. Yes, and thank you, Congressman, for that question. I do think that we have a lot of work going on at NASA, at NOAA, I know NIST even had a small workshop around this a few years ago, of data fusion, of thinking about how to, you know, intercorporate various polar orbiting satellites, including low Earth orbit, and some of our commercial platforms, as well as our open source geostationary, to provide better temporal resolution. It's more complicated with spatial resolution because you just kind of have to accept the data as it is, how it was engineered. If it was engineered at 10 kilometers, it's 10 kilometers, and you just have to take that location, and then compare it to something that's 10 meters in resolution.

We've also had, in the last 10 years, and, you know, much credit to NASA, USGS, and NOAA for their collaboration with the European Space Agency (ESA), with the Indian Space Agency, with the Japanese Space Agency, in trying to improve some of our other collaborations so that we have open source access to their platforms, and are developing, you know, kind of a cross-pollination coordination.

And, to be fair, sometimes our satellite systems are developed because they are meeting the needs of the community, and not just the fire community. Often they're—they need to meet agriculture and food security, they need to meet biodiversity and forest management. They need to think about water quality, as well as the atmospheres and the lithospheres as well, and so sometimes what we need for fire will get maybe pushed to the end, or at least the resolution will be downgraded a bit because there are these other components that also need to be captured in the same platform. And so I do think that NOAA's GeoXO, which is in collaboration with NASA, is one way to move forward. They did hold a workshop last summer with local, State, and Federal level fire researchers and practitioners and management to get their input on that. But even that system, which was—an RFP (request for proposals) was issued, and two contractors were selected earlier this spring, its highest resolution will be half a kilometer.

And so, really, we need to think about, you know, setting an agenda where the—we want spatial resolution that is helpful both tactically and strategically for fire management. And if I—I will return to you for—if you have further questions.

Mr. OBERNOLTE. Well, thank you. I completely agree. I'm horrified that we don't have access to higher resolution data than that. And as a scientist myself I can tell you there's no way you can create meaningful prediction models based on that. And, as you say, we've got all of these high speed aerial assets now for fighting the fires, it would be very helpful to have real time information about when the fire started and where. So I'm hopeful that we in Congress can help you to solve this problem and get access to this higher resolution data, because then we can, as you say, take the next step, work with the National Science Foundation, and catalyze some more research into this topic. But I see my time has expired. Thank you to all of our panelists, and I yield back, Madam Chair.

Chairwoman LOFGREN. Thank you. Dr. Foster is recognized.

Mr. FOSTER. Thank you, Madam Chair. Dr. Clements, in your testimony you stated your team has deployed to nearly 40 wildfires in California with specialized equipment, including mobile Doppler, lidar, and radar assets, and that these tools have provided a lot of insights into the dynamic of plume-dominated wildfires, and how the fires and the atmosphere interact with each other on the large scale. You know, back in my district in Illinois, last week we had some tornadoes, and it was amazing, when you looked at the data that was available in real time for—from lidar system and Doppler radar. The—my wife and I basically, you know, came to a—got into a safe area, turned on the TV, and we could watch the tornado vortex as it moved across neighborhoods just south of my house.

And so I was wondering—you know, I'm very interested in the technological developments and sensors, particularly cost reduction, that would help us have a much higher density of sensors on there. And so, in regards to that, you know, roughly—the equipment that you deploy, how much does it cost, if you just had to buy another one of those?

Dr. CLEMENTS. Thank you for your question, Congressman. So the radar is a special radar. It's a K-band, it's custom made. It's not that expensive. It's about 600, \$700,000—

Chairwoman LOFGREN. OK.

Mr. CLEMENTS [continuing]. Not including the truck and all that stuff, and that's probably a relatively low cost, high resolution Doppler radar. The lidars are even less expensive. They're about \$350,000. And so, you know, these aren't super expensive instruments, but to set up a network of those, it would be somewhat costly. Now, the advantage of also the lidar is it allows us to look at vertical wind profiles, which is really critical in downslope windstorms, and understanding the onset of critical wind for fire weather, particularly in California, with the public safety power shutoffs, and so there's a need for those.

Just to get back to the surface weather station discussion, California has more surface weather stations than any other place on the planet because of the utilities. They've invested a lot into meteorological data for their modeling. And so I think we can down—get the costs down if we build more instruments, or we can use

new engineering technologies to build these instruments better and cheaper. So there is a way to use it. In addition, we also have the National Radar Network for the—NOAA Radar Network that we use for wildfire observations as well. So there's a lot of things that we can do.

Mr. FOSTER. Yeah. I think one of the things we have to get better at as a nation is making high tech stuff cheaper in large quantity, and I think you might be able to bootstrap this if there was just an agreement that we're going to employ—deploy, you know, hundreds, thousands, tens of thousands of equipment like you deploy all over the country, and you might find the cost curve goes down pretty sharply.

Is there a consensus on the types of data points and the collection assets that you'd like? I know you mentioned ground-based stations. You know, you can imagine drone swarms that come in over fires, maybe just more investment in satellites, or maybe more investment in just the inventories of all the consumables that are on the ground? Is there an agreement on what you'd really like, or is that something that's under discussion?

Dr. CLEMENTS. Well, I think in terms of the fire weather community, we're probably in agreement that we need more atmospheric observations, but then we also need to understand what the fire's doing at every instant. One technology that's coming out, small radars that are cheaper that you can put on power poles or utility assets, so that way you can scan everything, versus just the National Radar Network. So using smaller radars that are getting more cost effective could be a really good asset in the future.

Mr. FOSTER. All right. And could someone say a little bit about the collaboration—the state of collaboration, particularly with DOD? You know, I don't think I'm giving away any national security secrets to say that we spend a lot of time looking for infrared flares for various purposes. And so I was wondering, do you hit a roadblock where you say, well, you know, we could give you information, but then we don't want the bad guys to know we have this capability, so we won't tell you, or is there really a pretty good collaboration in real time when there's a serious fire hazard?

Dr. CLEMENTS. Well, I guess I could take that from my knowledge. What I know is that there's a fireguard product that maps the fire in real time for fire agencies. Those data are not publicly available, but the technology's—is there, so, you know, increasing that collaboration could be very useful—or using that technology in a more public framework would be beneficial to the research community.

Mr. FOSTER. OK. That sounds like it could be a job for Congress. The other possible collaboration might be insurance companies. Do they look at detailed fire modeling to come up with their insurance rate on—rates on a house-by-house level? Are they big players in this?

Dr. CLEMENTS. Yeah. We're working with some insurance companies now, as well as the utilities. I mean, there's so much investment needed in a better understanding of the fire problem, and so insurance companies are definitely interested in the risk, for sure.

Mr. FOSTER. OK. Thank you. My time is up, and yield back.

Chairwoman LOFGREN. Thank you. Mr. Webster is recognized.

Mr. WEBSTER. Thank you, Chair. Thank you for holding this meeting. Chief Litzenberg, you mentioned some items or fields of future focus in your report, and things like remote sensing, or fire mapping, things like that. Which of those would be the highest priority?

Chief LITZENBERG. Congressman, thanks for that question. It is a tough one for me to answer because, in my view, all of these are somewhat related. And—so if you're asking for a priority, it is a difficult one. I can say that the creation of a sensing network—I'll go back to the discussion I had a few minutes ago about Santa Fe Fire Shed Coalition. Part of the success of that is a lot of viewpoints. And, to me, you get a better view when you're getting a lot of viewpoints, whether it's social science, or whether it's technology and data. So the more we can create a sensor network that is both ground-based and up to the satellites that integrates and gives us real time forecasting and mapping, that, to me, is a huge priority.

But that actually falls into some of the other priorities, like putting that data in a single useable place, where all levels of government are sharing data significantly, using that data to create situational awareness in real time for boots on the ground, and ultimately a network of communication that links all of these priorities together. Again, in summary, it's hard for me to prioritize because they work together, but that's probably how I would do so, in—since you asked me to do so.

Mr. WEBSTER. Thank you for that. Last week we had the new NASA Administrator, Senator Nelson, and he was here, we were talking about collaboration, and how much is there, and how it's working and so forth. He was pretty confident that it was a lot of collaboration, at least from NASA in the areas of hurricane tracking, and firefighting, floods, so forth. My question would be, this whole idea of remote sensing, should there be, or are there already, ways where that information is being coordinated and communicated to local and State foresters in communities to improve prevention of—and also mitigation in the area of forest fires? Do you know anything about that?

Chief LITZENBERG. Congressman, I can give you my opinion from being somebody at the local level. I've always had the impression that that data exists, and that it should be reachable. And in places where there are good relationships it often is, but it is really dependent on the caliber of those relationships. There are places nationally—we've referenced Wildland Fire Leadership Council, we've referenced National Interagency Fire Center—where integration is happening, and I think it's happening well and thoroughly. But it's not always getting down to the community level, where decisions about prevention and mitigation can be made appropriately, and it's potentially a huge place for future improvements.

Mr. WEBSTER. Well, that's something we're going to have to work on. I yield back.

Chairwoman LOFGREN. Gentleman yields back. Mr. Sherman of California's recognized.

Mr. SHERMAN. Thank you. I want to thank the Committee for having this hearing. I take it personally, having been evacuated from my home just a couple of years ago with the Saddle Ridge Fire, representing a city that goes right up against the city limits

of Los Angeles. Mr. Geissler, in your written testimony you note that the buildup of hazardous fuels on many of our public manage—publicly managed lands are at historic levels, and you further note that past management activities have actually made our public lands even more vulnerable. How can research improve the maintenance issues so as to reduce the likelihood of fires like those we've seen in California?

Mr. GEISLER. Thank you, Congressman, for that question. And, you know, as you said, our forests and landscapes are really at a point where their resiliency is questionable in many places. Science and research has really been doing a lot of work relative to how we best turn the corner on these landscapes. There's always ongoing research related to fuels and what is on the ground. There's a lot of work within FIA, the Forest Inventory and Analysis, world where essentially we're learning more and more about what the conditions are, what the state of our forest is, so that we can better address the issue that's there. And the—I will say the Forest Inventory and Analysis Program through the Forest Service is one of those things that is kind of an unsung hero, providing us a lot of longstanding data information related to how our forests and landscapes have changed over time.

So it's there. It's ongoing below the surface, and it does not get a lot of notice from those of us that are outside of the community. But making sure that we have effective funding for Forest Inventory and Analysis, and then programs like the Joint Fire Sciences Program that helps coordinate the research utilizing some of that data is really some of the critical needs.

Mr. SHERMAN. Thank you. Firefighters, emergency officials, Dr. Clements, you indicated how they and community leaders can struggle with disaster management. Wildfire season is increasingly becoming year-round. Our firefighters are being asked to work impossible hours in hazardous conditions. Dr. Clements, how can we better use scientific modeling and the enormous amount of data that have been collected to better predict the number of firefighting personnel that we will need?

Dr. CLEMENTS. Thank you for your question, Congressman. So that's a difficult question. So what we can do in the future is, using some of these state-of-the-art fire prediction models to look at what we should expect, how big are these going to be, given, you know, changes in wind, changes in temperature, and fuels. And so that could give us an idea of what resources and suppression needs are going to be required in the future. So that's one way to use some of these new models that are very high resolution to look at what those needs could be in the future.

Mr. SHERMAN. Thank you, and I also want to take a minute to thank the Appropriations Subcommittee for funding a project, or recommending the funding of a project, in my district to replace invasive and highly flammable shrubs with native and fire-resistant shrubs right there in the area of the Sesnon and Saddle Ridge Fires that we've suffered through in recent years. I thank you for your comments, and I yield back.

Chairwoman LOFGREN. The gentleman yields back. Dr. Baird is recognized.

Mr. BAIRD. Thank you, Madam Chair, and Ranking Member Lucas, for holding this hearing. I always learn something in this Committee, and so I really appreciate the professionalism and the expertise of our witnesses, and I thank them for being here today. I'm going to continue on a little bit with the conversation my colleague Mr. Webster was having, and so my questions are going to be to the—Chief Litzenberg, as well as to Mr. Geissler. But, Chief, you mentioned in your testimony you highlighted that collaboration among local fire departments with Federal research, and working with NSF, NIST, or NIST, and NASA needs to further grow to improve the Nation's wildfire response. And then you followed that with eight fields of future focus on this matter, such as remote sensing, fire mapping, and others. So, in that context, then I want to extend my question to be how can we use these tools that you mention there to really increase the active forest management and the implementation of fuel treatments? Because I think those have a real impact on being able to prevent many of these wildfires. And so, with that, Chief, if you would care to comment, I would appreciate that.

Chief LITZENBERG. Thanks for the question, Congressman. And, yeah, I'll give you my perspective, again, as a local responder, and I think my perspective is probably shared by many responders and fire chiefs. I said it a few minutes ago, and I'll say it again, I do believe that there is a lot of data that's being created, and a lot of very smart people, many of whom are here today, who are doing great things around fire science, and often the missing link is how do I, as a community responder, how do I, as a Fire Chief, get that data in a place that's useable, and then use it to do prevention and mitigation primarily?

I often look at communities, and we have the term fire death communities now, but I often look at communities as an organism, much like a human, and if you look at your body over the years, you've counted on somebody to get data about you, whether it's doing brain scans when you've got a headache, whether it's looking at your heart when you have chest pain, you know, evaluating your blood. And you get data points, and then you have somebody who looks at those data points, and gives you a recommendation, and what do you do about that? And what do you do, in terms of prevention, to make sure that the ultimate effect is not catastrophic on your body?

Communities and ecosystems are no different, and we're creating data points, and, in my opinion, what we really need is a place where that data is collected in one single place, where everybody is dumping everything that they're learning into a single place, and then there's somebody, or a committee, or a group, or an organization, much like a doctor, who's telling me, as a local community, what do I do with that data? How can I make my forest healthier? How can I make community safer, and ultimately how can I provide public safety to those who want to live safely within the urban interface?

Mr. BAIRD. Thank you. Mr. Geissler, would you care to add to that?

Mr. GEISSLER. Yes, and I—and Chief Litzenberg really hit the nail on the head. It's the availability and the utilization of all of

this data that is being created, and making sure that we have the ability to share it across the various jurisdiction. And it has happened in some places. I can give you an example of—within my own State where we utilize data from Federal, State, and local, who we have come together, and are sharing it across jurisdictional boundaries to develop a forest health strategy for our State, prioritizing all of the landscapes across all jurisdictions. And that is in collaboration with the U.S. Forest Service, State agencies, and locals, and it ties back to our forest health management, and then we also have used it on our wildfire strategy that we're building out. But it takes a lot of interagency discussions, and it takes an environment where there's a shared mission on how we need to address, or what the end goal should be. And that, again, much like Erik said, is—I—a lot of folks are—organizations are essentially working on their own and discovering things, and that leads to sometimes reinventing wheels, and—to the point of getting it all to one location, getting the information on how this can be used, collected, analyzed, and then sent out and communicated is just absolutely critical.

Mr. BAIRD. Thank you very much. And I'm out of time, so I yield back, Madam Chair.

Chairwoman LOFGREN. Thank you very much. Mr. Beyer is recognized.

Mr. BEYER. Thank you, Madam Chair, very much. This is fascinating stuff, and I'd like to start with Dr. McCarty, because the—NASA's—the Space and Aeronautic Subcommittee of this Committee held a few—hearing a few weeks ago on NASA climate science work, and we heard an awful lot about the growing commercial remote sensing industry's ability to support NASA's earth science activities, but primarily through data buys. But the hearing also identified questions about commercial data transparency, accessibility, license restrictions, that could have implications for free and open access to federally funded earth science data. So what are your perspectives on the opportunities and challenges of commercial remote sensing data sets in wildfire research?

Dr. MCCARTY. Thank you for the question, Congressman. I mean, commercial data is proprietary, and so when we—and I, you know, full disclosure, have been a NASA-funded PI who has access to those commercial data buys, but they must be in the regions in which my—the project that I tentatively, you know, applied for has been selected. And so if I—for instance, for FIREX-AQ, which was a partnership between NOAA and NASA, I was on the NASA side, I was able to look at commercial data sets, and still I'm able to look at commercial data sets, for regions and fires that we flew the DC-8 through the smoke plumes. But if I wanted to expand that to other States where we didn't fly, that would not necessarily be permitted. I would need to go back, and request, and ask why.

I would also say that the commercial data is of high quality. It's definitely an add-on. It's one of those data fusion products we want to include. It requires a high level of computing, and data science, and coding skills to implement. Our NASA and NOAA Earth observation products are often some of the best in the world. They're plug and play in a lot of ways, and our commercial data sets are not quite there, but that's not necessarily their business model, so

they haven't been given the right incentive, stick or carrot, to develop those products. They would be something that would fill in that gap if we want multiple—daily-imagery. But to really get at some of the fire weather, you need kind of, like, a living—a weather system, a geostationary system, where you're getting something every 15 minutes, half hour.

Mr. BEYER. All the time, yeah. Let me ask a larger, more existential question. It seems that fire science has changed an awful lot since I was a kid. Smokey the Bear—I was impressed that we heard that 78 percent, or 84 percent, are still human caused. But back then, no fires, and we—and then later on I served for a number of years on the House National Resources Committee, where my—some of my friends were like, we need to do much more forestry, because we have to clear out all the trees, and that way they won't burn down. And then you had our most recent President talking about raking the forests in Norway. Where exactly are—and I know climate change has complicated all of this immensely. And you—there—I know you have projects with prescribed fires, but is there a larger scientific sense of how best to manage forests yet, with respect to fires?

Dr. MCCARTY. We have, I would say, a coalescing convergence. There's always more—science is, you know, frustratingly like that, there's always more to know. However, what we have learned are—you know, North America's a fire adapted ecosystem. Many of our natural areas are adapted to burn, and so to function they must burn. The fire will come, as Steven Pyne, the fire historian, has shown time and time again. Prescribed burning is one of those forest management techniques—like you were saying, there were no fires, right? Well, that's because there was active fire suppression. We're now in a fire deficit, where we have many of our wildland areas that aren't having enough fires, and so we need more prescribed burning. And that's when we talk about indigenous burning, prescribed burning.

And we have some systems that burn too much, in—close to our WUI, close to our agricultural systems, but some of rangeland systems need to be burned more, and so it becomes this very complex—what I like to call a patchwork quilt of what the ecosystem really looks like, and so management and science has to really view that complexity, and that includes our fuel systems. Not just thinking of it as all grasses, having buildings, and so on and so forth. Back to you.

Mr. BEYER. Madam Chair, with the—Chief Litzenberg, do you have anything to add in the last 20 seconds?

Chief LITZENBERG. I think that was a solid answer, and I agree entirely. Nothing significant to add.

Mr. BEYER. Great. I look forward to the science continuing to evolve. Thank you very much. I—Madam Chair, I yield back.

Chairwoman LOFGREN. Thank you, and the gentleman from Texas, Mr. Weber, is recognized.

Mr. WEBER. Thank you, Madam Chair. This will be for Mr. Clements, to start with. The State with the most fires, is that data readily available?

Dr. CLEMENTS. Yeah. Those data are nationally compiled, and so it can be easily accessed, generally.

Mr. WEBER. Did I understand, in your exchange with Bill Foster, I thought you said the data wasn't a given. And what data was that? Do you remember that exchange?

Dr. CLEMENTS. No. I don't think that was—

Mr. WEBER. OK. Then I'll go to Mr. Geissler. Do we have—you had a discussion with Daniel Webster. Do we have enough inter-agency interaction, and is there somebody that tracks that, and how successful that's been?

Mr. GEISLER. I—we have exceptional interagency cooperation at both the national, regional, and State levels. There—we have a lot of discussions among the State foresters, the emergency managers, on how we can improve it, along with our Federal partners at FEMA, and the USDA (United States Department of Agriculture), Forest Service, and DOI, and others. The collaboration revolves around the National Interagency Fire Center in Boise, as well as the Wildland Fire Leadership Council, and we really try to go through what is an ongoing continuous improvement kind of cycle with relation to that.

The—all of the agreements that are in place, in fact, whether it be a master agreement between Federal agencies and States, or numerous State-to-State or State-to-local agreements, all usually have some form of an assessment piece that's involved in it, whereby we take a look at how it's working, and try to improve on that.

Mr. WEBER. Has there been a discussion about whether or not if you widen the rights of ways in some of these heavily forested areas, that that would reduce some of the wildfires?

Mr. GEISLER. Those typically are occurring at the local and State level as we do our wildfire prevention planning. You know, there's a lot of work that, even within your home State of Texas, with the community wildfire preparedness planning, whereby you take and look at a community and determine what would be the best way to mitigate the risk of—to that community, as well as mitigate the risk to the natural resources around it. And those are all part of kind of a process that's utilized that we try to get done, obviously, before the fire gets accomplished. Texas, in fact, has an excellent program that they're utilizing in order to have those discussions.

And, to your point, I mean, a lot of it occurs all across the United States, across all levels of government, and within the local communities, and even private citizens. A lot of it—but a lot of it involves just giving a framework of how to get it done, and that's where a lot of funding and research could be utilized just on the social sciences side of how we get this information better understood and accepted by our public, as well as funding on facilitation and process in order to get these things done. If there's a place where we say we need to really accelerate on a curve, that is one place that you could point to.

Mr. WEBER. What State would you say has the most wildfires?

Mr. GEISLER. I think the last time we checked it was—I think if you look at sheer numbers it was California. But, to the point of Dr. Clemens, all of that information is readily available through the National Interagency Fire Center, as we all report our fires up through the systems that are involved to answer that—

Mr. WEBER. Follow-up question to that is would most of those fires have been caused by utility companies? I think one of the questions I had—we talked about insurance—and some of the testimony earlier about insurance companies were extremely interested, energy companies, power companies were extremely interested. Would you agree that those—well, not the insurance companies, but maybe the utility companies, lines sparking together in high wind areas, for example, is that probably the major cause of, for example, California's fires?

Mr. GEISLER. Actually, the major cause is humans. We do sometimes very foolish things, whether it be dragging a chain when we're towing a trailer, or lighting campfires. The Smokey Bear message that we talked about earlier still applies in many cases. And the causes that you're talking about, they do occur. You know, I'm not going to deny that we don't have equipment sparking with utilities, but we are working with the utilities, trying to best figure out ways to minimize that risk that's out there. But if you ask for the—purely what is the biggest cause, it's you and I, essentially, when you look at the cause data.

Mr. WEBER. So are you saying this world would be a really good place if it wasn't for the humans?

Mr. GEISLER. Well, we interact with our environment and change it all the time, and I think us being better aware of what we can do to prevent that would be a much better place. Sometimes we don't think about what we're doing, and it takes just some simple awareness to really make us take that extra step. Most people don't realize that they can cause a spark mowing their lawn and set a fire that easily until it happens to them. And we really do want them to understand, and want everybody to understand, the risk that you're taking, and how you can help us.

Mr. WEBER. Well, I thank you for that. I appreciate your indulgence, Madam Chair. I yield back.

Chairwoman LOFGREN. Gentleman yields back. Jerry McNerney is recognized.

Mr. MCNERNEY. Well, thank the Chair, and I want to thank the witnesses. You know, this is really important to me, to my district, to people in the western part of the country. I won't be able to be as entertaining as Mr. Weber in my questions, but I'll proceed anyway.

Dr. Clemens, thank you again. In your testimony you mentioned that we need more coupling of ecological conditions, atmospheric conditions, and general fire behavior for models to more accurately identify climate change's impact on modern wildfire dynamics. Can you elaborate a bit more on how Federal science agencies can be helpful in promoting this type of research?

Dr. CLEMENTS. Thank you for your question, Congressman. Yeah, so, a lot of this—these couple atmosphere fire models are—they're kind of—they're becoming operational, but they're not national, and they are very high computing—they take a lot of high computing resources. You need supercomputing centers to run these models. It's not that they can't be done, but you just need the resources, so funding centers to do that, or funding teams to run those models operationally for regions would be probably the best way to invest into getting those models operations.

Mr. MCNERNEY. Thank you. Chief Litzenberg, the Federal science agencies have limited or no role in the Federal—with the Federal agencies that coordinate Federal fire response. How would you recommend Federal science agencies be better incorporated into Federal fire—wildfire response efforts?

Chief LITZENBERG. Congressman, thanks for that question. I believe that the best way to be integrated is to use existing mechanisms, because there are mechanisms that are used, that are used successfully. Perhaps they could even be improved in this avenue, but they're already there. The Joint Fire Science Program is one that's taking good science, putting it in a place that's usable to practitioners. The Wildland Fire Leadership Council, and the National Interagency Fire Center, are also places where integrations are occurring, and all we really need to do is put a focus on new and existing research, and how it can be used and applied toward emerging issues.

Mr. MCNERNEY. Thank you. Dr. Clements again, in your testimony you talk about both the importance and difficulty of collecting routine meteorological data on wildfire incidents. Do you think there's a role for Federal science agencies to play in collecting more of this data?

Dr. CLEMENTS. Yes, I do. I think that we could—like I mentioned before, instrument aircraft, we could deploy more resources. Right now the National Weather Service Incident Meteorologist Program, which is, like, over 50 meteorologists that go to active wildfires and other disasters around the country, they deploy, and they can request surface weather stations, but it takes a while to get those stations in place because they have to be driven out from a location and set up in the field. And so we could potentially have other types of technology, wind profilers, Doppler radar networks, that are higher resolution that could be either deployed rapidly, like in a storm chasing manner, or through teams that are already established with the incident command team, or the fire incident. So, yeah, I think the Federal Government could actually play a big role.

It's just like hurricane hunters. We have those aircraft that go sample those hurricanes, to collect the meteorological data, but we don't have that for wildfire. And it's the same type of information that we need to better model and predict what the fire's going to do, and how the atmosphere is playing a role on that fire's spread.

Mr. MCNERNEY. And data standardization would be helpful too, I imagine.

Dr. CLEMENTS. Yeah, we have to have standards in the data as well. Particularly in some of the, like—the remote sensing data, because a lot of these images that you can get from, like, private vendors is saturated, and so that means that it's, like—you're not getting the accurate temperature, you're not really seeing what the fire's doing. You're seeing kind of a blob on an image. So having better data standards would be improvement for what we have currently.

Mr. MCNERNEY. Well, as co-Chair of the House Artificial Intelligence Caucus with my colleague Mr. Gonzales, one of the areas that I'm interested in is how AI (artificial intelligence) can be used in wildfire response. Chief Litzenberg, can you respond to that?

Chief LITZENBERG. You know, I can do my best to respond to that, as the non-scientist for the practitioner side. Anything that we can use to take existing information and create it in a usable fashion, for those of us who are actually doing the boots on the ground practitioner work, to me, is a bonus. And if that includes the use of AI, then I say we're in. That's something that should be explored into the future.

Mr. MCNERNEY. Thank you. Madam Chair, I'm going to yield back, then.

Chairwoman LOFGREN. The gentleman yields back. Mr. Gonzalez is recognized.

Mr. GONZALEZ. Thank you, Madam Chair, and thank you to our panel for being with us today, and sharing your perspectives. Mr. Geissler, I want to start with you, and I want to talk about tree spatial patterning. So I'd like to get your thoughts on this. New research indicates that trees in spatial patterns are more fire resistant than those uniformly or evenly spaced. Should we be encouraging more managers to adopt spatial reforestation, or is more research and testing of this method required?

Mr. GEISLER. Thank you for the question. I'm not as familiar with the latest research in this that has come out. I can tell you, only from a fire manager's perspective, that obviously, changing the spatial relationship among stems or trees in a forest, obviously changes fire behavior characteristics. But then, along the same lines, I do know that in our Southern States, where we do a lot of intensive silviculture related to, like, plantation forestry, those actually have created issues in the past because of the nature of the change in fuel spread. So I would have to do a little bit more research to give you a solid answer on that, and I'm willing to follow up with you on it.

Mr. GONZALEZ. Great. Thank you. And my next question was how can Federal science agencies assist in these efforts, so I guess I'd turn it back to you. Maybe it's just we need more research on it, but I'll let you answer.

Mr. GEISLER. Well, you know, and, again, as this type of research comes out, the modification of fuel profiles in general, whether it be through spatial changes between trees or the removal of lighter fuels, and percentages related to that, all of that stuff is—are items that foresters and natural resource managers are looking at all the time. Not just from the standpoint of fire management, but also from the standpoint of just pure forest health and resiliency, to other things like insects and disease.

So, you know, obviously, increasing and improving the research availability is always important, as well as—I'm going to kind of always tie back to the making of that research and information available to the practitioners on the ground. And sometimes that—it requires more of a social scientist to come up with how to get that best across. But I agree that more work is needed.

Mr. GONZALEZ. Thanks. And then a somewhat related question, perhaps. Obviously, the United States isn't the only country that's dealing with wildfires. There's been high profile issues with wildfires across the globe in various ways. What learnings, if any, can we take from how this is managed in other parts of the world

that we should be applying to how we deal with wildfires in the U.S.?

Mr. GEISSLER. There's actually a continuous sharing along those lines also. Even within my own State we partner with our fellow firefighters in British Columbia, Saskatchewan, and others on the Canadian side, as we share resources across the border all the time. And there's obviously discussion of the tools that we use, be it—everything from how we manage our firefighter safety to the tactics that we're utilizing.

You've obviously—or should've heard of where we bring firefighters in from other countries, and even the Forest Service has gone to other countries like Australia. And, through all of those, we have a sharing environment. That is one of the foundational elements within the wildland firefighting community, is to maintain that learning environment as we go and use different tools and techniques. And there's the Wildfire Lessons Learned Center and others that actually helps to disseminate this information.

So the experience of, again, getting the right people in the room with the shared experience that I believe Erik spoke to earlier, you get a lot of people in the room talking about the same thing, and you can come up with some fairly amazing ideas. And we have made changes to our systems, and tweaked our processes, in order to get better just because of the experiences that we've had with our fellow firefighters from other countries.

Mr. GONZALEZ. Thank you. That's very helpful. I appreciate your testimony and responses, and I'll yield back.

Chairwoman LOFGREN. Gentleman yields back. Mr. Casten is recognized.

Mr. CASTEN. Thank you, Madam Chair, and thank you to our witnesses. Dr. Clements, I'd like to start with you, and one of the things that's always sort of struck me as the hardest thing to deal with on climate change sociologically is that there's all these nonlinearities, and we just do a bad job of anticipating accelerating trends. Obviously that contributes to the increasing numbers and severity of wildfires that we've seen, but if you look just at wildfire science, as you try to predict what's going to happen over the next 5, 10 years, are there major nonlinearities that are either feedback loops making it worse, or that might damp it, with respect to wildfire science, that we should be thinking of on the expectation that we're probably not anticipating those things very well either?

Dr. CLEMENTS. Yeah. Thank you for your question, Congressman. Yeah, so, in terms of climate change and feedback loops, as we change—as the environment gets warmer, we're going to change the fuel structures, we're going to change our landscape so that can impact, maybe for the better at times, different types of fuel structures so we can convert some—after fire we can convert some forest to maybe grasslands, and that could lessen extreme fire, but it can make it more ignitable as well. So there are feedbacks. It's not really my expertise, so I could look into that a little bit more and get back to you.

But I think one thing that we need to consider, in terms of climate change, is that these trends—you know, the predictions are—you know, we have to continue to look at attributions, you know, what's really causing all these things. We know it's climate change,

we know it's forest management, we know it's climate induced drought, and weather, so—but we can still put more science into fine tuning what those attributions are, in terms of what's going to happen in the future. We could use high resolution modeling in a different state, so we can use 2050 climate scenarios, and model what fires are going to look like then. That's something that we're planning on doing, so that could be one way to kind of diagnose the changes.

Mr. CASTEN. I'm sorry to interrupt, but I've got to get two more questions. Dr. McCarty, you had mentioned in your comments about, you know, we're seeing wildfires in places like the Smoky Mountains that we haven't thought about before. With these trends, are there areas or types of fires that you think are going to be more likely in the future that we need to be thinking about and preparing for?

Dr. MCCARTY. Sure. Thank you for that question, Congressman. In fact, the Eastern Forest used to be called the Asbestos Forest by many professional foresters because they said that they wouldn't burn, but that is, in fact, not actually—that was not true, it's just they have a longer fire return interval. So we will expect, as the Southeast becomes hotter and drier, particularly in our upland areas, that fire risk will increase. And this is a WUI question, a wildland urban interface question. We've had a lot of people move in to places like Asheville, you know, Knoxville, Tennessee, even parts of West Virginia, and, you know, in Pennsylvania, so we're going to see more fire risk.

The other thing is to think about, you know, NIFC reported that in 2019, just in terms of burned area, total acres burned, the State with the most wildfires is Alaska. And so Alaska is some—is a State we need to have on our minds, as wildland fire scientists, because in the future we will see more Arctic fires, we will see more boreal fires. Those fire regimes are accelerating. And, in fact, we will see more of our organic carbon soils burn, and then burn through the winter, and reignite in the spring. And that's just a continuation of fire seasons, and that is a, you know, a very—a different type of fire management. And I do think the Alaskan Forest Service and the Alaskan Fire Consortium is a very professional and outstanding group, and they are trying, through research and science, to figure out how to work these new challenges in the future.

Mr. CASTEN. Wow.

Dr. MCCARTY. Thank you.

Mr. CASTEN. So last question, with the little time I've got left, is really for any of you who feel comfortable answering this, and it's a little beyond this Committee. Lael Brainard, who's the—on the Fed Board of Governors in January said the scientific evidence for climate change is unequivocal, but the magnitude of climate-related financial risks are highly uncertain, and among those are wildfires, and she noted that more than 70 percent of the losses from natural disasters are uninsured, and warned of the potential to create abrupt repricing events.

I spent a lot of time on the Financial Services Committee thinking about how our financial system is at stress from this, and, of course, we've had some conversations about, you know, if you were

an investor in PG&E (Pacific Gas and Electric Company), you may feel that directly from the wildfire damage. As you think about where there are big exposures to private capital from wildfires, any major concerns? And I realize this is more of a financial question than a scientific question, but you can't separate the two. They're all linked. Anybody want to comment on that?

Dr. MCCARTY. I will just say that maybe perhaps the thing we should think about is that a lot of Americans, their capital—much of their money is wrapped up in home ownership, and property ownership. And in many of our Western States, and of course in our Eastern States, and Midwestern States, as they've become more fire prone, then suddenly the likelihood that you lose your home, or it becomes uninsurable, increases, and that is just a huge loss to private capital. And you can only imagine what that would do to our economy, and to our GDP (gross domestic product), and just health of our population. And so that is something that's hard to predict and hard to imagine into the future, but is a direct financial loss.

Mr. CASTEN. Thank you. I'm out of time, and I yield back.

Chairwoman LOFGREN. Gentleman yields back. Mr. Kildee is recognized.

Mr. KILDEE. Thank you, Madam Chair. I really appreciate you recognizing me, and I do appreciate the Chair holding this important hearing. And thanks to the witnesses for your testimony. I come from Michigan. In fact, the northern part of my district is home to the Huron Forest, which is 737 plus acres over 70 miles. It's named after a Native American tribe that's local to our region, and the forest landscape is highly prone to seasonal fires. It's dominated by jack pines. Jack pine needles are highly flammable. Those seasonal fires are actually part of the life cycle of the forest. Pine cones from those jack pines containing seeds only open as a result of a fire. And the Kirtland Warbler, which is a great little songbird, only breeds in those young jack pines. So, as a result of logging in the forest, the warbler's habitat was, at one point, nearly completely destroyed. That little bird was almost completely extinct.

50 years later, due to prescribed burns, and the protections put in place by the *Endangered Species Act*, the Kirtland Warbler was successfully removed from the endangered species list. And now each year literally thousands of tourists come to that part of rural Michigan to see the Kirtland Warbler. And so it's not just a little bird, it's a really important part of what makes that place so great, so interesting, and so attractive to people who come from all over the country just to see that rare bird.

So in the forest we have to have these prescribed burns to maintain and control wildfires, but this year, as part of a prescribed burn, an uncontrolled forest fire broke out and burned about 5,000 acres of that forestland. Climate change has contributed to these fires. Due to climate change the forests are drier, the air is less humid, winds are stronger and more sustained, and it makes it hard to control these controlled burns, these prescribed burns. So, thankfully, no people or structures were damaged, but this is the kind of threat that we face.

So I'm just curious, and I guess I would ask the panels—the panelists, perhaps Mr. Geissler and Chief Litzenberg, for this Huron

Forest that I represent, or other forests across the country that do use prescribed burns to maintain forest health, as climate change increases the intensity of weather, what do we need to be doing, what do you suggest we do, so that we can maintain control of these sorts of fires, and ensure that we ignore—avoid a controlled burn—prescribed burn like this getting out of control like the one we saw in the Huron Forest? So——

Chief LITZENBERG. So—yeah.

Mr. KILDEE. Go ahead.

Chief LITZENBERG. Go ahead.

Mr. KILDEE. Go ahead, Mr. Geissler. You want to start, and then maybe the Chief could comment?

Chief LITZENBERG. Sure.

Mr. GEISLER. Thank you. And, actually, what I was going to let you know is that, you know, the idea of—like the jack pines situation, a lot of that revolves around the potential need for stand replacement fires even to truly manage that landscape, which we don't do because of the risk when you have prescribed burns. And that's why a lot of what you're seeing, and the type of work that's being done, is on a more cyclical basis, and maintaining the trees at different stages.

But the one piece that I wanted to make sure that everyone understood is that when a prescribed burn is planned, a plan is actually developed, and what it does is it not only is the objectives of how the burn will be occurring, and what the end result needs to be, but it's usually very specific on humidity, wind direction, wind speed, and others. I think that a lot of it, like you said, is making sure we do good planning, and that we follow the plan exactly, and then if there are issues, even if they're minor, learn from those.

In addition to that, a lot of the research that we've talked about throughout this hearing helps to feed that—those plans, and the knowledge that we have to develop them. So, again, I wanted to just kind of bring up how a prescribed burn can be done, and just the need for additional research and information to feed those.

Mr. KILDEE. Thank you. Chief, you have thoughts on this?

Chief LITZENBERG. Yeah. Thank you, Congressman. I'll say it briefly. So what you just described is the social phenomenon we call fire adaptation, and it goes have an effect in our ecologies as well. Back in—hundreds of years ago we decided we've got to suppress everything, and all of a sudden we had a bigger issue than we had in the past. And now we're realizing you have to control these fuels, you have to control risks, and it's healthier for forests. The more we can get information about the fuels, and the more we can get information about weather to use for our planning, the better our planning will be.

And I'll just say one last thing, which is, luckily, our organizations have evolved as well, and the science that our organizations, and the tactics that our organizations are using to manage these forests, are also getting better. So continuing to invest in those organizations and our workforces can't be overstated.

Mr. KILDEE. I thank you very much. And, Madam Chair, I thank you for the extra time. I yield back.

Chairwoman LOFGREN. Gentleman yields back. Ms. Wild is recognized.

Ms. WILD. Thank you, Madam Chair. I appreciate it. And thank you for this very interesting and informative hearing. The recent extreme heat in the Pacific Northwest is obviously concerning for many reasons, not the least of which is the safety and health of the communities, but it's deeply troubling that we are seeing such a mix of limited water, dry lands, and unusually high temperatures this early in the summer. I know I'm not saying anything that you don't already know. The terrible fires we saw last summer across Western States, and the lingering environmental and economic devastation highlight the importance of our scientific enterprise in informing us of climate risk and climate related disasters.

The U.S. has a number of Earth-observing satellite-based platforms that provide useful data for wildland fire science, but we also rely on assets from European and other international partners. Dr. McCarty, I'm interested to know, to what extent are relevant European and international partner data coordinated with United States data, and how can we further utilize available international data?

Dr. MCCARTY. Well, thank you for that question. I will say, as I'm not at NASA headquarters (HQ), some of this I can't speak to. I will try to reply back in writing. There are high level interactions between NASA HQ and, of course, ESA, and other international space agencies. Our researchers on the ground, including places like the U.S. Forest Service Geospatial Technology and Application Center in Salt Lake City tried to utilize Sentinel products, the Sentinel II, which is kind of Landsat-like, but higher spatial resolution and higher temporal resolution. It's overhead every 3 to 5 days, depending on clouds.

And some of our synthetic aperture radar data, which is at a 10 meter resolution, from ESA are now being implemented to try to look at both fire monitoring, fire detection, but also mapping—better mapping fuels, fuels conditions, including things like where peatlands are, soil moisture and fuel moisture condition. And so, in the research community, these products are being developed, and are being, you know, put forward to some of our Federal level operational centers. And, of course, the more that we can do that in our data fusion process, the better the data is for our agencies and for our firefighters on the ground.

Ms. WILD. OK. Thank you. And, Chief Litzenberg, can you go into some more detail about the proposal to develop a standard warning fire scale similar to the Richter Scale for earthquakes? I'm particularly interested in how it would be beneficial for firefighters, but of course the public as well.

Chief LITZENBERG. I sure can, Congresswoman. Thanks for the question. So, much like the Saffir-Simpson Hurricane Wind Scale, we could develop a scale for forecasting the threat of a wildland fire. This type of warning system would require coordination between NOAA, the U.S. Forest Service, the U.S. Department of Interior, and State, tribal, territorial, and local officials, pretty much everybody across the board. It would provide a standardized warning system to let communities and responders know what type of resources might be required, respond to a fire, what action should be taken, such as sheltering in place or evacuating. A lot of the catastrophic issues we've seen during fires are in the movement of

people, and obviously that is, for all of us, the No. 1 value. And the more we can communicate with people what to expect, the better our response system will be.

Ms. WILD. Thank you so much, I think there's great promise there. And, Dr. McCarty, did you want to comment on that at all? If not, I'll yield my time.

Dr. MCCARTY. Yes, I think this is a great idea. In fact, if you compare some of our fire warning systems to some of our international colleagues, often our fire warning system is seen as hard to interpret because it kind of looks like a color—a rainbow speedometer, essentially, and we would need that. And there's a lot of social science and public health research, including built environment research, that could be done that will help implement such a warning system so it does communicate the right thing to the people on the ground so that that's not causing problems for our wildland firefighters.

Ms. WILD. Thank you very much. With that, Madam Chair, I yield back.

Chairwoman LOFGREN. Thank you. The gentlelady yields back. Mr. Perlmutter is recognized.

Mr. PERLMUTTER. As the last questioner. So I want to follow up on Ms. Wild's questions. To Dr. McCarty and Chief Litzenberg, we were talking about satellites, and coordinating with the Europeans and others, obviously the Canadians. What steps have been taken—you said that NOAA is a number of years away from really having satellites to monitor these fires, but can we monitor them with some of our military assets, our intelligence assets? And I'm saying we—sometimes in Colorado, obviously, we had big fires last year, and we had to call in the National Guard to assist our firefighters. Can we call in some of our space assets? Have you—either of you heard about that?

Dr. MCCARTY. Yes. I mean, the project I know about is Fireguard. I'd actually like to defer to Dr. Clements because he has worked with the data. I have not needed to work with that in my lab, and so I just know about it. Dr. Clements, would you like to comment on that?

Dr. CLEMENTS. Well, thank you. I haven't actually been able to work with the data, because it's not available for the research community. I've seen examples of it, and so that's really all I know. And when we do deploy to wildfires, we know it's there. We know that the FBANs, or fire behavior analysts, are getting access to that, at least on some of these big incidents. So it's available, but I have not been able to work with those data.

Mr. PERLMUTTER. Chief Litzenberg, have you had any experience using some of our other assets besides—that we might have available through the military or the intelligence community?

Chief LITZENBERG. Congressman, I have not personally had a lot of experience with that, but I'll add to what Dr. Clements just said. A lot of what is available, when it is available, is when large incident management teams are in place. And, unfortunately, the vast majority of incidents across the Nation, a large incident management team is not put in place. It's managed by local responders, whether they're from local government, or from the State, or from the Forest Service. So the more that we can get that information

that's useable to all, the better we will be. I have not personally had that experience.

Mr. PERLMUTTER. OK. Let me ask this question. So, Dr. McCarty—or to any of the panelists—last year one of our fires, called the East Troublesome Fire, which is the second largest we've had ever, the thing that was most disturbing about it, it was growing at about four or 5,000 acres a day, and then in 1 day grew by 120,000 acres. And we lost some lives, and it was up in a very—it was part of Rocky Mountain National Park and—near Grand Lake. I mean, how can we use science to predict when there's going to be an explosion like that in terms of fighting wildfires?

Dr. MCCARTY. My quick answer to that is, in addition to these fire weather models that Dr. Clements has mentioned, we actually do need better higher resolution—not just fuels mapping, but fuels conditions, down to the hour. This could be used by incident command, and then that would tell us where would we likely see these types of explosive forest fires. And again, you know, Mr. Geissler has mentioned working with British Columbia, they had a similar situation in 2017, and they are—the Canadian Forest Service is working toward a similar process, so I will defer to the other panelists.

Mr. PERLMUTTER. Yeah. Mr. Geissler, could you follow up on that, and kind of explain your experience?

Mr. GEISSLER. Yeah, actually. As was said, I—there are a number of monitoring systems that are looking at fuels and other predictive data in order to give us that heads up. The Mesonet that Representative Lucas talked about has fuels data in real time is—as a part of it, so we were able to actually look at the moisture content and fuel typing at all of these sites across the State at any given moment. And so what it does is it allows the fire manager to anticipate.

You know, just this past year we had a wind event which took us from a slow fire season to our historic fire season in a matter of a couple of days, and a lot of that really came down to—we knew that the wind event was going to occur, but being able, while the wind event was ongoing to have that ongoing realization of changes, would've been another assistance. So there are various systems that are in place that allow this prediction to go, but they just don't have the coverage to really give a national or a regional picture. They're highly isolated at this point.

Mr. PERLMUTTER. OK. Thank you. My time's expired. I yield back.

Chairwoman LOFGREN. The gentleman yields back, and I believe we have no additional Members available to ask questions. So, before we bring this hearing to a close, I want to thank the witnesses for the time they spent with us today, their expertise, their testimony. It's been enormously helpful to us as we think about what further steps we should take here in the Science Committee.

The record will remain open for two weeks for additional statements from Members, or any additional questions the Committee may ask of the witnesses. And we do ask, witnesses, if we have questions, if you could please answer them, if possible, within that two week period, that we would be enormously grateful. So at this

point the witnesses are excused with our thanks, and this hearing is now adjourned.

[Whereupon, at 12:35 p.m., the Committee was adjourned.]

Appendix

ADDITIONAL MATERIAL FOR THE RECORD

Human presence diminishes the importance of climate in driving fire activity across the United States

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Growing human and ecological costs due to increasing wildfire are an urgent concern in policy and management, particularly given projections of worsening fire conditions under climate change. Thus, understanding the relationship between climatic variation and fire activity is a critically important scientific question. Different factors limit fire behavior in different places and times, but most fire-climate analyses are conducted across broad spatial extents that mask geographical variation. This could result in overly broad or inappropriate management and policy decisions that neglect to account for regionally specific or other important factors driving fire activity. We developed statistical models relating seasonal temperature and precipitation variables to historical annual fire activity for 37 different regions across the continental United States and asked whether and how fire-climate relationships vary geographically, and why climate is more important in some regions than in others. Climatic variation played a significant role in explaining annual fire activity in some regions, but the relative importance of seasonal temperature or precipitation, in addition to the overall importance of climate, varied substantially depending on geographical context. Human presence was the primary reason that climate explained less fire activity in some regions than in others. That is, where human presence was more prominent, climate was less important. This means that humans may not only influence fire regimes but their presence can actually override, or swamp out, the effect of climate. Thus, geographical context as well as human influence should be considered alongside climate in national wildfire policy and management.

climate change | wildfire | human influence | land use | fire management

The adverse effects of increasing wildfire on human assets, and altered fire regimes on ecological integrity, are becoming a worldwide concern (1), especially in the wake of recent “mega-fire” events in some regions (2), which have resulted in enormous loss of human lives and properties (e.g., refs. 3–6). Most of these large fire events are driven by extreme weather conditions combined with prolonged drought; and escalation in fire activity is widely attributed to climatic factors and global warming (7–11). Furthermore, projections suggest that fire extent, frequency, and intensity could skyrocket in upcoming decades due to warmer temperatures and drier fuels (12, 13), although there is inherent variability and regional variation (14).

Climate is often considered the primary factor controlling fire regimes, either directly by controlling weather conditions or indirectly via primary productivity and fuel conditions (15–17). However, evidence of burn patterns over millennia suggests that both climate and human activities have strong controls and that, at times, one control may override the other (18–20). Human influence on fire is also well documented in studies of contemporary fire patterns, where fire management activities and land use change have been implicated (21, 22), as well as the role of humans in changing the pattern, season, and frequency of fires through human-caused ignitions (23–27).

Given the enormity of values at risk, understanding the relative role of climate and other factors driving fire activity, and the potential for fire regimes to change as a result of these drivers, is a critically important scientific question. The issue is complex

because different factors limit fire behavior in different places and times, and for different reasons. However, despite recognition that fire-climate relationships vary geographically (28–31), many analyses and future projections are conducted across broad spatial extents (e.g., refs. 32–34).

While broad-scale studies are critical for understanding general patterns, analyses using data that span large environmental or latitudinal gradients may potentially confound spatial and temporal relationships and thus result in overly general conclusions about trends and drivers (11). This masking of regional variation was recently evidenced in a study in California, where statewide analyses of historical fire-climate relationships masked patterns that were only apparent via separate analyses conducted within smaller, climatically homogenous subregions (35). Another information gap in our understanding of fire-climate relationships results from a geographical bias of research conducted in the western United States (e.g., refs. 13, 17, 25, and 30–33), where ecosystems, climate, and fire regimes differ substantially from those in the eastern United States (e.g., ref. 36) or other parts of the world (e.g., ref. 37).

Despite growing recognition that fire-climate relationships and trends vary geographically, the reasons for these differences have never been systematically explored across broad landscapes. One possibility is that landscapes vary in the biophysical characteristics that lead to different fire regimes, resulting in different responses of fire to climatic variation. In northwestern North America, fire activity was highest in areas with moderate-intermediate precipitation and temperature conditions, where fuel abundance and moisture conditions were frequently sufficient to be favorable for fire (25). Pausas and Ribeiro (16) also

Significance

Projections of worsening wildfire conditions under climate change are a major concern in policy and management, but there is little understanding of geographical variation in fire-climate relationships. Our analysis relating climate variables to historical fire activity across the United States showed substantial variability in the importance of different seasonal temperature and precipitation variables and of climate overall in explaining fire activity. Climate was significantly less important where humans were more prevalent, suggesting that human influence could override or even exceed the effect of climate change on fire activity. Although climate change may play a significant role in altering future fire regimes, geographical context and human influence should also be accounted for in management and policy decisions.

Author contributions: A.D.S., J.E.K., and A.H.P. designed research; A.D.S., A.H.P., and K.F. performed research; A.D.S. and J.E.K. analyzed data; and A.D.S. and J.E.K. wrote the paper.

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found support for an intermediate fire-productivity relationship globally, which they suggest may result in varying effects of climate change on future fire activity. In another western US study, low precipitation and warm temperatures led to increased area burned in most forested ecoregions; however, moist seasons before the fire season were most important in fuel-limited arid provinces because prior-season precipitation facilitated biomass growth (30).

Krawchuk and Moritz (15) distinguished between conditions-limited and resource-limited fire regimes, and this dichotomy was used to explain geographically varying effects of climate change on projected future fire regimes in Mediterranean ecosystems (38). Keeley and Syphard (35) further distinguished ignition-limited systems in which annually both climate and fuel conditions are conducive to large fire events, so that fire events are dependent on timing of anthropogenic ignitions. Although human activities clearly affect the timing, extent, seasonality, and location of fire (27), area burned and ignition frequency are not always correlated (35, 39). Humans also influence fire regimes indirectly—for example, via management or land use decisions that alter the fuel patterns on the landscape—and the effect of fire policy change has been shown to mediate fire-weather relationships over time in southern France (40). Nevertheless, given that a major means by which humans influence fire is via changes in frequency, it has remained unclear whether or where human influence would be strong enough to alter or override the influence of climate.

To better understand the broad-scale nature of fire-climate relationships, and how and why they vary, we developed statistical models relating seasonal temperature and precipitation variables with historical annual fire activity for 37 different regions across the continental United States. By developing separate but parallel models, we were able to then assess geographical variation in the role of climate in explaining fire activity across different land ownership types and climatological regions spanning the entire continent. We stratified historical spatial fire occurrence data for lands administered by three federal agencies, the National Park Service (NPS), US Forest Service (USFS), and Bureau of Land Management (BLM), across 17 National Ecological Observatory Network (NEON) climate regions, known as NEON domains, spanning a period of ~40 y (Fig. 1). We additionally evaluated fire-climate relationships using a contemporary (~20 y) dataset [national interagency Fire Program Analysis, Fire-Occurrence Database (FPA FOD)] that included fire records spanning all public and private land ownership types and thus covered a much larger land area than the federal data, albeit for a shorter time span (Fig. 2).

After exploring the independent effects of each climate variable on fire activity, we performed multiple regressions considering all

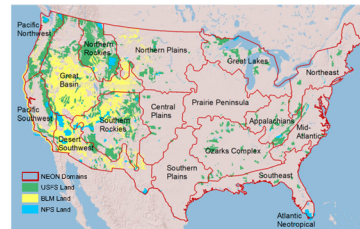


Fig. 1. Geographical distribution of federal lands across NEON domains in the continental United States.

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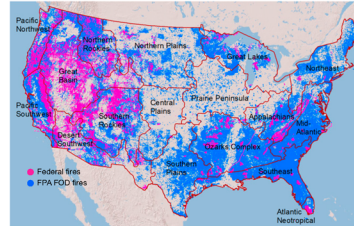


Fig. 2. Occurrence locations for fires on federal lands only (1972–2010) and for all fires (1992–2010) across NEON domains in the continental United States.

possible variable combinations and calculated the total variance explained for the best-supported fire-climate model in each region. We then related the variance explained, as a metric of the overall importance of climate on fire, to a range of biophysical and human factors that we hypothesized could explain differences in the strength of the fire-climate relationships. The overarching questions were, how do fire-climate relationships vary geographically, and why are these relationships more important in some regions than others?

Fire-Climate Relationships Varied Geographically in the Importance and Strength of Different Seasonal Climate Variables

There was wide geographical variation in the independent influence of seasonal temperature and precipitation variables on annual fire activity, not only across NEON domains but also across federal agencies (Fig. 3), as well as in comparison with the full-region analyses using FPA FOD data (Fig. 3). There were no strong patterns across latitudinal or longitudinal gradients, but the influence of prior-year precipitation was generally most important in western regions, except for a clear contribution to fire activity in the Appalachian, Mid-Atlantic, and Northeastern regions. Temperature variables were more important than precipitation variables in NPS lands versus USFS lands, but the effect of temperature versus precipitation was more equally, yet unsystematically, distributed across BLM lands and full NEON domains. In terms of seasonal importance, spring and summer temperature and precipitation variables overall explained more independent variation in fire activity than autumn or winter variables.

The results of the multiple-regression analyses showed that the average variance in fire activity explained by climate for the 37 federal regions was 29%. Climatic variables explained ≥50% variation in fire activity in five regions (Table S1), only one of which was located in the eastern United States, the Appalachian region on USFS lands. Here, fire activity was primarily explained by low precipitation in all seasons except for summer, plus high spring temperature. The other four regions with the strongest fire-climate relationships were the Southern Rockies on NPS lands, the Pacific Southwest on USFS lands, and the Great Basin and Northern Rockies on BLM lands. In all four of these regions, prior-year precipitation was among the variables included in the top-supported models, and the relationship was negative for all but the Great Basin where it was positive. Maximum summer temperature was the other variable that was included in all four of the western regions with the strongest fire-climate relationships, and maximum spring temperature was additionally important in the Southern and Northern Rockies.

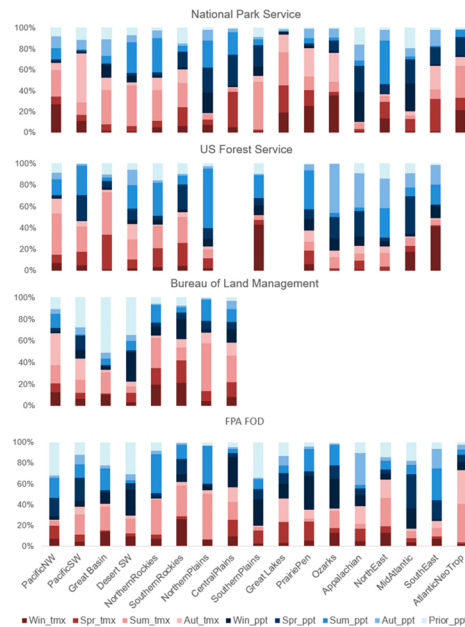


Fig. 3. Hierarchical partitioning results showing the percentage of independent variation in fire activity explained by seasonal temperature and precipitation variables for NPS, USFS, and BLM lands and for all public and privately owned lands using the FPA FOD. Aut, autumn; NW, Northwest; ppt, mean precipitation; PrairiePen, Prairie Peninsula; Spr, spring; Sum, summer; SW, Southwest; tmx, mean maximum temperature; Win, winter.

In the multiple-regressions using the FPA FOD data, the average variance in fire activity explained by climate was 42%, and in these data, there were six regions where climate explained >50% of the variation in annual fire activity (Table S2). These regions were either in the Southeast, Midwestern United States (Northern Plains, Prairie Peninsula, Ozarks Complex), or western United States (Northern Rockies, Great Basin). For these regions, high summer or winter temperatures were consistently important in the western regions and the Northern Plains, whereas hot spring and summer maximum temperatures were more important in the Prairie Peninsula or the Southeast. Low spring or summer precipitation was also important in these regions.

The Importance of Climate Overall Varied Across Regions

The overall strength of fire-climate relationships varied substantially across the continental United States, both in terms of longer-term federal fire records and the shorter-term, more spatially comprehensive FPA FOD fire data (Fig. 4). Although climate variables explained >50% of the variation in fire activity in some

regions, as described above, 10 of the 37 regions in the federal analysis and four of the regions in the FPA FOD analysis had adjusted R^2 values signifying $\leq 15\%$ of the variance in fire activity could be explained by climate.

Human Presence Was the Only Factor to Significantly Explain Differences in the Strength of Fire-Climate Relationships

Of the 10 different variables we explored to explain the variation in the strength of fire-climate relationships, none were statistically significant at $P \leq 0.05$ except for the anthropogenic variables (Table 1 and Figs. S1 and S2). In the federal data, regions in close proximity to either roads or developed areas had weaker fire-climate relationships; and in the FPA FOD data, regions with a higher mean human population and proportion of developed land had weaker fire-climate relationships.

Discussion

Seasonal climate variation has played a significant role in explaining annual fire activity across the continental United



Fig. 4. Proportion of variance explained by top-ranking multiple regression models of seasonal climate influence on annual fire activity for (A) federal lands and (B) NEON domains in the continental United States.

States, but the relative importance of different variables, in addition to the overall importance of climate, varies substantially depending on geographical context. Why climate explains more fire activity in some regions than others is best explained by human presence. That is, in regions where human presence is more prominent, the importance of climate is lower on average. This suggests that, not only can humans influence fire regimes, as has been documented, but their presence can actually override, or swamp out, the effect of climate. This has serious implications for national fire policy and management as we move forward in this era of rapid global change.

Humans can affect wildfire patterns in a number of ways, from starting fires to managing fires (e.g., prescribed fire or fire suppression) and via changes in the abundance and continuity of fuel through land use decisions. For example, humans alter native vegetation through agriculture, urbanization, and forestry management practices. Although their geographical subdivisions were coarser than those used here, regions where lightning-started fires dominated in a recent nationwide analysis (27) show some alignment with areas here where fire-climate relationships were stronger, largely in the interior, northwestern part of the country.

Nevertheless, although human-caused ignitions predominate across most of the country, there are also regions like the interior Southeast where fire-climate relationships were relatively strong but the cause of ignitions was nevertheless dominated by humans.

This suggests that human influence goes beyond just starting fires, and there is some combination of factors that leads to a dampening of the effect of climate on fire activity. This may be due to effective lengthening of the fire season (27), or starting fires in areas where naturally occurring fires are rare. On the other hand, fragmentation of fuels via land use and urban development may interrupt the spread of fires that would otherwise occur in a less human-dominated landscape. In this case, the climatological factors that might otherwise lead to fire spread are overridden by human-created landscape patterns. This dual effect of humans either increasing fire where it would not otherwise occur, or decreasing it where it would occur, may be why the overall amount of fire in a region was not significantly related to the importance of climate. A couple of other studies performed at smaller extents also suggest that human influence [i.e., suppression policy (40) or land use (33)] in addition to fuel quantity or quality (31, 33) can potentially mediate or dampen fire-climate relationships across different temporal scales.

Table 1. Bivariate regression results for models exploring regional and anthropogenic biophysical characteristics' relation to variance explained by climate on annual fire activity

Variable	Coefficient	R ²	P value
Federal data			
Precipitation	-0.00005	0	0.35
Temperature range	0.02	0.00	0.31
Elevation	0.00005	0.02	0.17
Slope	-0.0005	0.00	0.89
Forest biomass	-0.003	0.00	0.41
Vegetation	0.286	0.06	0.07
Distance to road	0.00002	0.20	0.002
Distance to developed	0.000002	0.07	0.05
Proportion of area burned	-1.12	0.00	0.65
Proportion of number of fires	-0.06	0.03	0.15
FPA FOD data			
Precipitation	-6	0	0.96
Temperature range	-0.004	0	0.69
Elevation	0.0001	0.01	0.29
Slope	0.013	0.02	0.28
Forest biomass	-0.0005	0.00	0.68
Vegetation	0.21	0.00	0.41
(log) Population	-0.18	0.19	0.04
Proportion developed	-2.99	0.20	0.03
Proportion of area burned	0.72	0.00	0.51
Proportion of number of fires	4.4	0.00	0.91

One of the most consistently important variables for explaining strong fire-climate relationships was prior-year precipitation, which is similar to other studies (e.g., refs. 28, 30, and 35). This relationship is often found in grasslands and savannas where fire activity is fuel-limited. High precipitation appears to have a dampening effect on current-year fires but leads to high fuel loads in subsequent years, and the production of fine-fuel biomass that dries by the following year is conducive to fire spread (41). In forested ecosystems, this relationship has been shown to be present in forest types with herbaceous understories and absent in ones with understory fuels comprising litter and other downed material (42).

An important caveat to this study is the fact that the variance explained for the differences in strength of fire-climate relationships was not particularly high, and there was substantial variability in the data (Figs. S1 and S2). Therefore, despite evaluating the role of climatic or topographic variability, or variation in vegetation or forest biomass, differences in strength of fire-climate relationships may be due to additional factors. For example, temperature or precipitation patterns may be less variable in some regions than in others, meaning there is less annual variability in fire activity due to these variables. Another reason may be that the fire-climate models do not include essential factors such as localized fire-weather events, long-term drought, or lightning density, nor do they account for variable interactions or more complex variable combinations.

The record of fire history was only available spatially since the 1970s, and a longer-term history could have provided a more robust analysis. However, fire-climate relationships do vary over long time scales (33, 35, 40), and the findings here are representative of the most current conditions. These results thus provide important insight on contemporary drivers of fire activity across a time when climate has already been changing rapidly (43).

Climate change may indeed be a concern for those areas with strong fire-climate relationships. However, our results suggest that, in some areas, anthropogenic factors diminish the influence of climate on fire activity. Thus, to effectively understand how and where fire regimes may change in the future, anthropogenic factors must become a larger part of the conversation relative to national fire policy and management. In addition to incorporating anthropogenic factors such as land use into future fire projections (44), it will also be important to consider alternative management decisions in the context of human development. For example, land use or conservation planning decisions have the potential to alter fire risk to structures as well as biodiversity outcomes (45, 46). Further work on fire prevention strategies is another important avenue for future fire management and is likely to play very different roles on different landscapes.

Materials and Methods

To develop our historical fire data, we assembled a comprehensive point-based spatial database of more than a million fires on federal agency lands. The more contemporary database beginning in 1992, the national inter-agency FPA FOD (47), provides more spatially extensive data that span all public and private lands. (See *S1 Text* for additional details on data sources, assembly, and modeling.)

We used monthly PRISM 2.5 arc-minute historical climate data (www.prism.oregonstate.edu) to derive and extract seasonal climate means to relate to annual fire data for NEON regions and for fire locations within those regions from 1972 to 2010. We defined winter as December through February, spring as March through May, summer as June through August, and autumn as September through November.

To quantify the relative and geographically varying importance of different climate variables in explaining fire activity, we used a hierarchical partitioning algorithm available in R (*hier.part* package, version 1.0-4 in R) (48, 49). Hierarchical partitioning, via a hierarchy of regression models using all combinations of explanatory variables, calculates the percentage of independent influence of each variable on the response, with or without its joint influence via other variables. Thus, it avoids issues of multicollinearity and provides a discrete quantification of relative variable importance. In addition to quantifying variable importance, we also developed multivariate models for the regions to account for the overall importance of climate in explaining annual fire activity. For every region, we selected the best-supported model, recorded the variables, and calculated the adjusted R² as a measure of total variance explained by climate.

To identify potential factors explaining the variation in strength of fire-climate relationships, we summarized a range of biophysical and human variables (Table 1) across the geographical extent of each region and related them to the adjusted R² values described above using bivariate linear regressions.

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