MEMBERS FORUM

Using Soil Moisture Information to Better Understand and Predict Wildfire Danger

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Wildfires have significant impacts on communities and ecosystems around the world, and over the past decade (2011–2020), more than 1.5 million hectares of land has burned in the U.S. on average each year (National Interagency Fire Center, 2021). Meanwhile, federal fire suppression costs have increased dramatically, topping US$3 billion in 2018. Additional costs are borne by the affected communities in the form of lives lost, structures destroyed, decreased business and tax revenues, increased respiratory illnesses, and increased water pollution (Roman et al., 2020). These costly effects of wildfire could be reduced through fuel load reductions accomplished by more widespread use of prescribed fire (Kolden, 2019). Yet both prescribed fire management and wildfire preparedness and response efforts need more accurate and timely approaches for estimating fire danger. Soil scientists and other researchers are now exploring how fire danger rating systems could be improved, and our understanding of fire behavior advanced, through incorporation of soil moisture information.

Soil moisture provides a key link between traditional "fire weather" observations, such as air temperature, relative humidity, and wind speed, and the characteristics of the vegetation fuel bed, such as fuel moisture content and fuel loads. These dynamic fuel bed characteristics strongly influence wildfire occurrence and severity and can be challenging to

There are strong and growing lines of evidence that soil moisture information can help us better understand and predict wildfire danger. Photo courtesy of Adobe Stock/наталья саксонова.

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monitor at relevant spatial and temporal scales. Meanwhile, soil moisture monitoring capabilities have been steadily improving due to the growth of in situ networks and dedicated satellites (Ochsner et al., 2013). The increasing availability of soil moisture information is creating significant opportunities to quantify the relationships among soil moisture, fuel bed conditions, and wildfire occurrence and to use that knowledge to improve models for fuel moisture content, fuel loads, and fire danger.

A fire manager supervises a prescribed fire near a soil moisture monitoring station in a tallgrass prairie ecosystem at the Marena, OK In Situ Sensor Testbed. Soil moisture data can help identify hazardous fuel conditions as well as optimal conditions for fuel treatment and post-fire restoration. Photo courtesy of Jeff Basara, University of Oklahoma.

Researchers and Fire Managers Convene

Recognizing these opportunities, more than 200 soil moisture researchers, fire researchers, fire managers, ecologists, and government personnel registered for a one-day online symposium (https://bit.ly/3njq1MY) held on 6 May 2021. The objectives of the symposium were to provide researchers and fire managers an opportunity to connect with others, learn about ongoing research in this area, and discuss ways to move forward with new research and end uses. Invited speakers discussed current trends and status of: (1) wildfire hazard rating; (2) relationships between remotely sensed soil moisture and wildfire; (3) use of soil moisture models for fire danger assessments; and (4) linkages among in situ soil moisture measurements, fuel bed characteristics, and wildfire. Breakout groups and a panel discussion focused on key remaining questions and next steps.

Through these interactions, participants highlighted the need to present the science in a readable and actionable way for fire managers. Increased partnership between researchers and decision-makers was identified as one key strategy to help meet this need, so that soil moisture information can better fit into existing workflows and decision processes. Such partnerships likely require iterative conversations that may be difficult to sustain via typical grant-funded research projects, which tend to be too short lived to bring research into practice. At the same time, recent increases in wildfire-burned areas across the U.S. (Burke et al., 2021) have increased the stress on fire managers and limited the time and energy available for incorporating new research results into fire management processes. New federal investments are necessary to further develop this promising research area and to integrate the knowledge produced into existing fire danger rating systems and associated fire management tools and workflows.

The symposium's speakers, panelists, and participants also emphasized the need to go beyond observational studies of the strong correlations between soil moisture and wildfire to more in-depth studies that quantify the underlying mechanisms operating in the soil-plant-atmosphere-fire nexus. Such mechanistic studies require intensive, in situ time-series measurements of not only soil moisture, but also fuel moisture contents and fuel loads, properties which typically require time-consuming, destructive, manual sampling of both live and dead vegetation. Further enhancement and geographic expansion of existing fuel moisture databases and development of dynamic fuel load databases may be necessary to support deeper understanding of the mechanisms linking soil moisture and wildfire.

Looking Deeper at Soil Moisture—Wildfire Relationships

The potential influence of soil moisture on wildfire behavior has long been recognized, beginning with the Keetch–Byram Drought Index (Keetch & Byram, 1968), a soil moisture surrogate that continues to be widely used by wildfire managers and scientists today. But for decades, the limited availability of soil moisture observations with sufficient duration and spatial extent severely restricted progress towards understanding soil moisture—wildfire relationships. This has begun to change in the current era of new

Wildfire damage from the Valley Fire of 2015 in Middletown, CA. Photo courtesy of Flickr/Matthew Keys.

sources of soil moisture measurements, which started with the advent of large-scale in situ soil moisture monitoring networks in the late 1990s and continued with the launch shortly thereafter of satellite missions capable of remotely sensing soil moisture. When the resulting data records reached sufficient duration, we began to get our first solid evidence for the strong relationships between wildfire and soil moisture measured via remote sensing (Chen et al., 2013) and in-situ networks (Krueger et al., 2015).

Since then, we have entered a phase of accelerating growth in our understanding of soil moisture—wildfire relationships and of the mechanisms driving those relationships. We now know that in situ soil moisture relates differently to wildfire probability during the growing season than during the dormant season (Krueger et al., 2016) and that in situ soil moisture measurements can better predict large growing-season wildfires than the Keetch–Byram Drought Index (Krueger et al., 2017). We also learned how soil moisture observations can provide an effective indicator of fuel moisture content and curing rate for grassland vegetation (Sharma et al., 2020) and dead fuel moisture content in Sierra Nevada forests (Rakhmatulina et al., 2021). In situ soil moisture measurements have also proven valuable for improving predictions of grassland fuel loads (Krueger et al., 2021), which is significant given the fact that grasslands account for a large portion of the area burned worldwide each year.

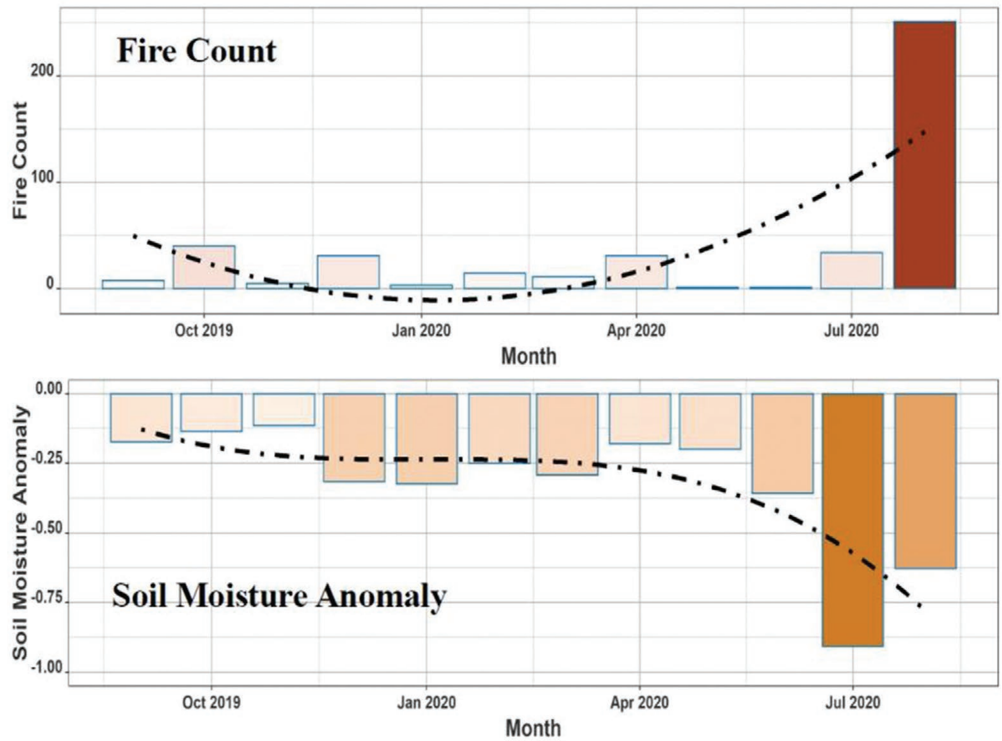
Underlying the dynamic soil moisture values are relatively static but influential soil properties. These properties provide a natural integrator of precipitation variability (Chikamoto et al., 2015), and thus detailed soil-mapping approaches have also shown value for fire prediction (Levi & Bestelmeyer, 2016, 2018). In addition, there is a rapidly expanding body of knowledge resulting from studies linking remotely sensed soil moisture to wildfire. Those studies have shown how remotely sensed soil moisture can be used to estimate fuel moisture content and to predict wildfire extent from regional to global scales (Chaparro et al., 2016; Jensen et al., 2018; Lu & Wei, 2021; O et al., 2020; Rigden et al., 2020; Thomas Ambadan et al., 2020). Taken together, there are strong and growing lines of evidence that soil moisture information can help us better understand and predict wildfire danger.

Next Steps

Towards that end, some symposium participants expressed interest in forming working groups to move the research forward. Already one such group has formed and is working on an interdisciplinary review paper to summarize the rapidly growing body of research, broaden the community of researchers aware of and engaged in this line of research, and make a convincing case for more widespread use of soil moisture information in operational fire danger rating systems. Symposium participants also expressed interest in a follow-up meeting to build momentum and sustain progress. Currently, the U.S. Forest Service is organizing one such meeting to be held in spring 2022 in collaboration with USDA-ARS. That meeting is intended as a step toward developing a framework for improved forest soil moisture monitoring across the U.S. Two potential topics are the enhancement of monitoring infrastructure in the nation's forests and grasslands and how to best synthesize that data into a dashboard to provide quick interpretations for land managers.

Another key next step discussed by symposium participants is to effectively integrate and leverage the increasingly diverse sources of soil moisture information from land surface models, in situ networks, and satellites. Each of these information sources has associated strengths and limitations, and objective methods for blending soil moisture estimates from these sources are still being developed (Zhang et al., 2021). There is a clear need to evaluate how such blended products can be effectively used to estimate fuel moisture, fuel load, and wildfire danger. Meanwhile, the development of soil moisture models designed specifically for application in wildfire danger rating systems is another key area in need of more research.

Recordings of all the presentations at the symposium, "Using Soil Moisture Information to Better Understand and Predict Wildfire Danger: A Symposium for Researchers and Fire Managers," are available online (https://bit.ly/3njq1MY). We encourage all interested researchers and fire managers to contact the authors of this article or the symposium speakers to share your ideas and to join us in the effort to better understand and predict wildfire danger.



Researchers from NASA's Goddard Space Flight Center used data from the NASA Soil Moisture Active Passive (SMAP) satellite to track the correlation between soil moisture conditions and wildfire susceptibility in the 2020 California wildfire season. The top chart shows the number of fires detected in northern California from September 2019 through August 2020 while bottom chart shows how the soil moisture deviates from average conditions over the same time period (also known as soil moisture anomalies). These data show that dry soil conditions in July 2020 may have led to more fires occurring in August. Source: NASA GSFC Hydrological Sciences Lab, John Bolten, Nazmus Sazib.

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continued on page 31