Leveraging NASA Soil Moisture Active Passive for Assessing Fire Susceptibility and Potential Impacts over Australia and California

Nazmus Sazib, John D. Bolten, Iliana E. Mladenova

Abstract— **Wildfires are a major concern around the globe because of the immediate impact they have on people's lives, local ecosystems, and the environment. Soil moisture is one of the most important factors that influences wildfire occurrences and spread. However, it is also one of the most challenging hydrological variables to measure routinely and accurately. Therefore, soil moisture is significantly underutilized in operational wildfire risk applications. Thus, the aim here is to use a well-established operational soil moisture product to isolate the soil moisture-fire relationship and assess the utility of using soil moisture as a leading indicator of potential fire risk. We evaluated the value of remotely-sensed soil moisture observations from the Soil Moisture Active Passive (SMAP) sensor for monitoring and predicting fire risk in Australia and California. We quantified the relationship between observed fire activity and soil moisture conditions and analyzed the soil moisture conditions for two extreme fire events. Our findings show that fire activity is strongly associated with soil moisture anomalies. Lagged correlation analysis demonstrated that a remote-sensing based soil moisture product could predict fire activity with a 1-2 month lead-time. Soil moisture anomalies consistently decreased in the months preceding fire occurrence, often from normal to drier conditions, according to a spatiotemporal analysis of soil moisture in two extreme fire events. Overall, our findings indicate that soil moisture conditions prior to large wildfires can aid in their prediction and operational satellite-based soil moisture products such as the one used here have real value for supporting wildfire susceptibility and impacts.**

Index Terms— **Soil Moisture Active Passive (SMAP), Wildfire, Drought, Soil moisture**

I. Introduction

Wildfire is an increasing natural hazard with serious consequences which can impact ecological health, as well as jeopardize people's livelihoods, and security. Another unanticipated effect of wildfires is that their secondary effects, such as erosion, landslides, and changes in water quality, can be more damaging than the fire itself [1]. Wildfire, on the other hand, can sometimes be beneficial to the environment in other ways. For example, it contributes to overall global vegetation productivity and biodiversity, which in turn enables improvements in ecosystem health, such as assisting in the mitigation of weather extremes, including heat waves or droughts, or removing CO_2 from the atmosphere [2].

Because wildfires play such an important role in ecosystem health, many studies have been conducted to investigate the impact of climate conditions on fire occurrence, spread, and severity. Keeley et al. [3], for example, evaluated the association between fire activity and climate in central and southern California and found that summer temperatures were positively correlated with the number of fires in the central coast region, while autumn precipitation was negatively associated with fire occurrence in the south coast region. Fuller and Murphy et al. [4] investigated the spatial-temporal patterns of fire in the island of South East Asia between July 1996 and December 2001. When compared to geo-referenced climate and land-cover data from a variety of sources, the Southern Oscillation Index (SOI) in forested land-covered areas was found to be highly associated with fire counts. As expected, variations in precipitation also have a significant impact on the extent and severity of fires, as demonstrated in a study of the Gila National Forest in the southwestern United States [5].

Soil moisture, defined as the volumetric water content of the soil, is an important indicator of soil dryness and is considered to be a key variable that influences wildfire occurrence [2], [6]. In the specific context of the soil moisture-fire relationship, several studies have enhanced the understanding of the influence of soil moisture on fire activity. For example, Krueger et al. [7] demonstrated that large growing-season wildfires only occurred in conditions of low soil moisture. According to Yebra et al. [8], improving wildfire assessments entails using soil moisture as a proxy for fuel moisture, which is a key factor in wildfire ignition and spread. Westering et al. [9] investigated the relationship between snowmelt time and wildfire activity in the western United States and concluded that

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earlier snowmelt and increased soil dryness in the summer can be related with wildfire activity. Cooke et al. [10] examined the likelihood of wildfires and various soil moisture-based drought metrics derived from gridded meteorological data and simulated soil moisture data available from the North American Land Data Assimilation System (NLDAS-2) over southern Mississippi and noticed that soil moisture-based indices are strong predictors of fire occurrence in that region.

Due to the lack of in-situ based soil moisture data, many previous studies relied on model-based soil moisture information or secondary drought indices. In addition to the use of model-based soil moisture products, advances in remote sensing over the last two decades have enabled satellite-based microwave sensors to provide continuous, consistent, and timely information of soil moisture conditions. Aubrecht et al. [11] assessed the soil water index (SWI) developed from the Advanced Scatterometer (ASCAT) sensor and reported a high regional association between dry soils and detected fires. Jensen et al. [12] examined the satellite soil moisture from NASA's Gravity Recovery and Climate Experiment (GRACE) and the historical fire data from the USDA Forest Service in the U.S. from 2003–2012 and suggested that the GRACE's soil moisture correlated with wildfire activity. However, their study is limited by spatial resolution of the GRACE data and authors recommended using SMAP data to generate more accurate regional predictive fire maps. Sungmin et al. [2] investigated the association between soil moisture anomalies and large wildfire events around the globe between 2001 and 2018 over the humid and wet region and found soil moisture anomalies continuously decrease in the months prior to fire occurrence, often from above-normal to below-normal in both regions. Because the fire-moisture interactions vary between ecosystems and temporal and spatial scales, various drivers can play an important role depending on the local context. As a result, there are limitations to transferring findings from one location to another or generalizing conclusions from this global scale analysis to local scales. Ambadan et al. [13] investigated the performance of the remotely sensed soil moisture products derived from the Soil Moisture and Ocean Salinity (SMOS) data over the wildfire areas, across fourteen eco-zones in Canada and found that SMOS soil moisture products could be useful in spotting soil moisture anomalies near possible wildfire hotspots. One drawback of those studies is the quality of the satellite soil moisture product in high vegetation areas (e.g., forests), where the product can be influenced by considerable vegetation water content, which affects the computation of soil moisture climatology and soil moisture anomaly maps. To address these constraints, we employed data from NASA's Soil Moisture Active Passive (SMAP) satellite which collects L-band soil emissions that penetrate clouds and more easily pass through forest cover, resulting in enhanced soil moisture estimates. We demonstrate the value of readily available, satellite-based, near-surface soil moisture observations. Even though the spatial resolution of satellite-based remote sensing products is significantly coarser than in-situ based observations (i.e., on the order of 10s of magnitude), we argue that the value of satellite-based remote sensing can be realized in the regional perspective, increasing data record, and frequent overpass times that these data allow.

We analyzed the role of soil moisture in the occurrence of wildfires across fire-prone regions in Australia and California using satellite-based derivation of surface soil moisture and fire products. Wildfires in Australia have increasingly become larger and more frequent during the last several decades, contributing to greater environmental degradation, property damage, and economic losses. According to the USDA Forest Service report, the cost of fire suppression in the United States is predicted to increase to nearly $1.8 billion per year by 2025 [14]. We focused on these case studies of wildfire hotspots observed over various Australia and California regions to demonstrate the value of routine satellite-based soil moisture products for forecasting wildfire risk. In addition to temporal correlation analysis, we looked at the spatiotemporal evolution of soil moisture during major fire events. The findings from this study will aid in developing routine strategies for assessing the vulnerability of fire-affected areas, improving fire planning and resource management at the national and county levels.

II. Materials and Methods

Data:

The NASA Global Inventory Modeling and Mapping Studies (GIMMS) Global Agricultural Monitoring (GLAM) system provided the soil moisture data used in this study (https://gimms.gsfc.nasa.gov/). A well-established operational global soil moisture product was applied, which was generated by incorporating Soil Moisture Active Passive (SMAP) soil moisture observations into the two-layer Palmer model via a Kalman Filter (EnKF) data assimilation approach [15]–[17]. The Palmer Model used by the United States Department of Agriculture-Foreign Agriculture Service (USDA-FAS) is a water balance model driven by daily precipitation and minimum and maximum temperature data provided by the U.S. Air Force Weather Agency (AFWA) [18]. The AFWA dataset was derived using multiple sources, including remotely sensed observations and gauge data acquired from the World Meteorological Organization (WMO) [9]–[11].

The SMAP mission was launched by NASA in January 2015, and data collection began in late March 2015. The sensor monitors the Earth's soil moisture and freeze/thaw states twice a day, at approximately 6 a.m. and 6 p.m. local solar time, from a near-polar, sun-synchronous orbit. The current SMAP passive microwave data archive covers the period from March 31, 2015 to present [12]. SMAP offers a variety of soil moisture products based on these passive microwave observations each developed using a different algorithm. The baseline Level 2 (L2) SMAP SM product produced by the single-channel algorithm (SCA) and SMAP V-pol brightness temperature observations were used while integrating to the Palmer model. The GIMMS system offers various soil moisture products, including surface and root-zone soil moisture, soil moisture profile, surface and root zone-soil moisture anomalies at 0.25° spatial resolution. For this study, the surface soil moisture products (i.e., 0 - 1 inch depth) from 2015 to 2019 were used.

To assess fire activity, NASA's Moderate Resolution Imaging Spectroradiometer Active Fire (MOD14A1) product, which provides fire count, location, and radiation power, was used [19]. MOD14A1 is suitable for our study because it has global coverage, high data completeness, and is still operational, allowing real-time fire event analysis. The MODIS instrument is installed on both the Terra and Aqua platforms providing observations of the Earth's surface four times per day. The fire count product utilized here provides the number of fires in a pixel ranging from 0 to 30. The product utilizes MODIS 4- and 11-micrometer brightness temperature to identify the fire pixel [20], [21]. Fire activity throughout this study is characterized using the MODIS-based fire count product.

Data preprocessing:

The daily fire count data were aggregated up to generate total month count. Then, the monthly total fire data were re-gridded to 0.25° × 0.25° resolution in order to match the spatial resolution of the soil moisture data. The MODIS data are available through present, but the study focused on the 2015–2019 period to match the soil moisture datasets in our analysis. First, we used surface soil moisture and fire count data to explore their spatial and temporal variability over different regions across Australia and California. For each study region, annual total fire count and surface soil moisture were calculated using monthly data from 2015 to 2019. The variability of fire count statistics was summarized for major fire prone locations in Australia and California. To characterize the relationship between fire count and soil moisture, the fire count was compared to soil moisture with varying time lags. We computed Spearman’s rank correlation coefficient between fire activity and soil moisture anomalies to quantify the strength of the relationship between them. The Spearman’s rank correlation was chosen as the Pearson correlation has the tendency to underestimate or overestimate the significance of the relationship when the interaction is not linear [22]. Monthly standardized soil moisture anomalies were computed using the Z- score which were calculate using following equation:

$$Z_{score} = \frac{x_i - \mu}{\sigma}$$

where μ and σ represent mean and standard deviation values of the data for that month over all the years and xi is the data value for a given month in year i.

Fire events are fairly rare at local and daily scales, and hence, highly random in nature. Therefore, fire counts and soil moisture anomalies for each location in California and Australia were first averaged spatially and then averaged temporally across each month before performing the correlation analysis. Monthly lag correlation analysis was performed to identify any lags related with the highest correlations and to assess the predictability of fire danger based on the antecedent soil moisture condition.

Furthermore, soil moisture anomalies were investigated on a regional scale for the most recent fire episodes in Australia and California. The first case study focusses on the 2019–2020 bushfire in Australia, which occurred in the southeastern part of the country (New South Wales, NSW). This event is considered to be the most catastrophic in terms of burnt area and severity [23]. Similar analysis was performed over California, which experienced a record breaking number of large fires in 2020 [24].

III. Results

A. Spatial and temporal variability of fire count and soil moisture

The soil moisture conditions over Australian range from wet tropical conditions in the north through arid conditions in the interior to temperate sub-humid to humid conditions in the south. According to the fire count map, the most fire-prone areas are primarily in the country's north. Fires are also common in the southeastern parts of New South Wales and Victoria (Figure 1). The El Niño–Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) have a significant influence on the spatial variability of soil moisture over Australia. During the negative phase of the ENSO cycle, rainfall in northern and eastern Australia is reduced, which frequently results in drought conditions [25]. ENSO is also associated with higher land surface temperatures that last longer than the drought condition, resulting in higher evaporation and drier soils, which leads to increased fire activity [26], [27].

Analysis indicated substantial fire activity in the Queensland, Northern Territory and Western part of the country during all five years examined in this study (Figure 1). The Northern Territory's climate is primarily influenced by the annual monsoon, which is particularly moist from November to April and dry from April to October. As a result, plant growth increases during the monsoon season, leading to increased fuel accumulation and fire activity [27]. Rainfall in Western Australia becomes increasingly infrequent and episodic with distance inland, and significant plant production occurs only after major and sustained rainfall events. Extensive fires in the region occur only after prolonged and widespread rainfall when production and fuel accumulation are high. Furthermore, firefighting resources, equipment, and infrastructure are limited outside of the state's major cities and towns, as Western Australia's population density is below one person per square kilometer. This also means that wildfires in remote areas tend to be bigger and cover a larger area [28]. In 2019, there was a large bushfire in New South Wales and Victoria, which

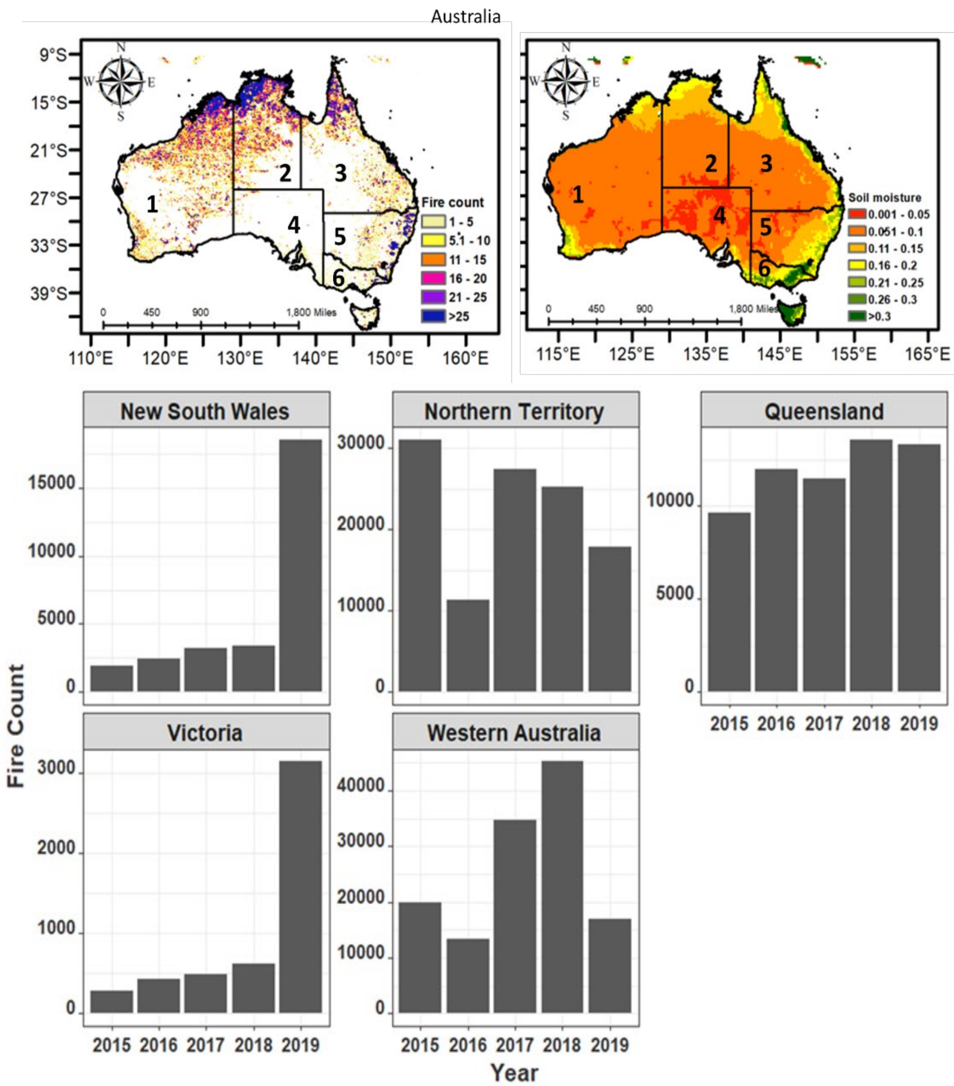

Figure 1: Spatial variability of fire count and surface soil moisture (top) and annual variation of fire count (bottom) for different provinces over Australia for the period of 2015-2019. The locations of each province of Australia (1: Western Australia, 2: Northern Territory, 3: Queensland, 4: South Australia, 5: New South Wales (NSW), 6: Victoria) are also indicated.

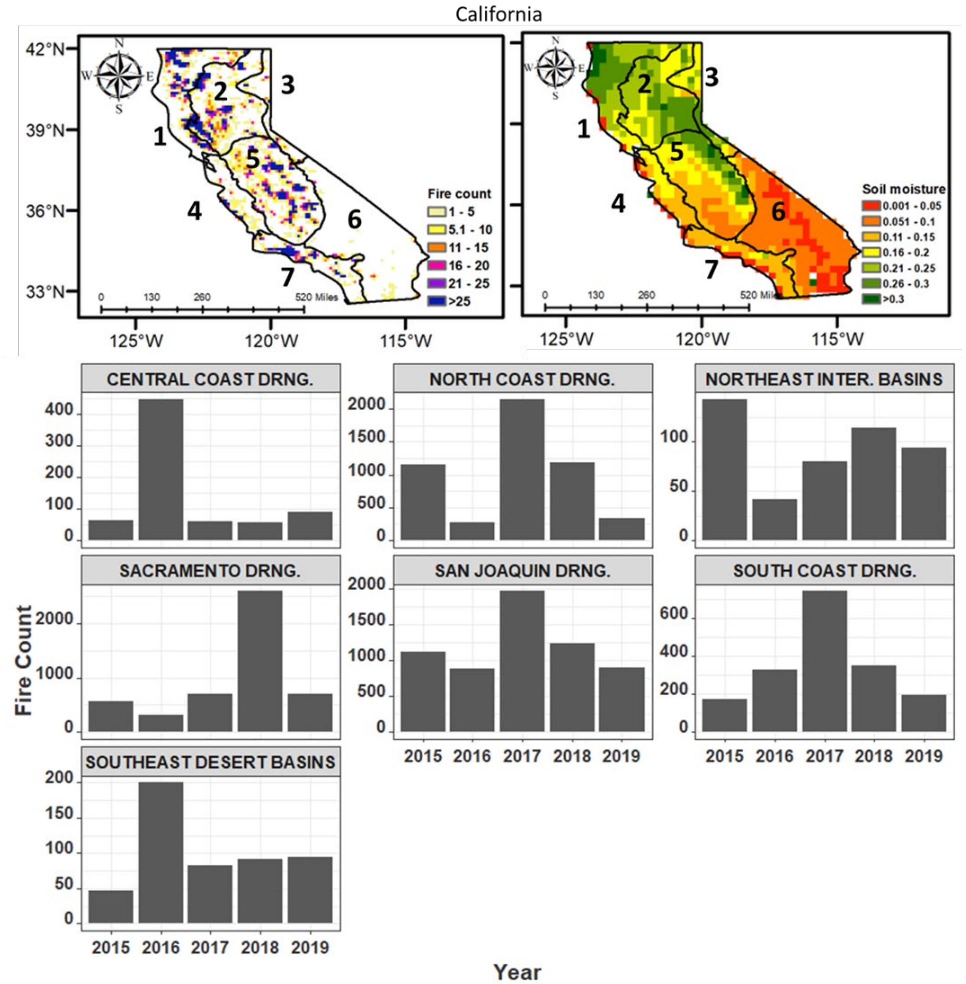

Figure 2: Spatial variability of fire count and surface soil moisture (top) and annual variation of fire count (bottom) for different climate divisions over California for the period of 2015-2019. The locations of each climate divisions of California (1: North coast, 2: Sacramento, 3: Northeast interior, 4: Central coast, 5: San Joaquin, 6: South coast, 7: Southeast desert) are also indicated.

accounted for a significantly larger than normal area fire activity. (Figure 1). Satellite fire detection in New South Wales and Victoria were more than four and five times higher than the previous year, respectively. Despite large wildfires in southern Queensland, fire counts in Queensland remained consistent with previous years, owing to the state's total fire activity being dominated by savanna fires in northern Queensland, which are a natural part of these ecosystems (Figure 1).

In the case of California, significant wildfires were observed throughout northern and southern California, with the exception of the southeast desert regions, where large areas of sparsely vegetated desert ecosystems inhibit large fires (Figure 2). California's diverse climate, combined with a wide range of vegetation cover and topography, has a significant impact on the spatial pattern of its wildfires. Furthermore, population growth and geographic development have an impact on fire regimes because of their effects on fuel availability and continuity [9]. Fire counts differ noticeably across climate divisions. For all these years, fire counts have been higher along the North coast, in Sacramento and the San Joaquin region, with some exceptions on the south coast (Figure 2). While estimating the mean soil moisture values, we considered each month of the year (wet and dry periods) rather than the dry season (when the majority of fires occur) which results in a high fire count in higher soil moisture regions (e.g., North coast). The hot spring and summer temperatures, as well as the dry soil moisture condition during and before fire seasons, are the primary drivers of wildfire activity in North coast, Sacramento, and San Joaquin regions. Southern California's Mediterranean climate, extreme winds in autumn, and frequent drought conditions, on the other hand, further contributed to frequent and severe wildfires [29].

B. *Correlation between fire count and soil moisture*

In general, negative correlation coefficients were found between soil moisture anomalies and fire count, especially when the soil moisture preceded or is concurrent with the fire count, indicating that fire is more likely to occur in drier soil moisture conditions (Figure 3). Dry soil moisture conditions increase fuel flammability because fuel moisture is depleted not only by a prolonged lack of rainfall but also by moisture out flux (loss) from vegetation into the atmosphere [30]. The correlation values varied considerably with lag time, showing a tendency for high correlation values with shorter lags and low correlation values with longer lags. The negative correlations also varied by region, with the southeastern part of the Australia having a higher negative correlation than the northern part. Some of this variation can be explained by ecosystem-climate connection. Ecosystems in the northern, monsoonal tropics experience prolonged annual wet and dry seasons, whereas those in southern, temperate regions experience severe drought on a multi-decadal cycle, which alters the soil moisture status and thus directly affected fire activity [31]. The southern part of the country typically has plenty of fuel, but extended periods of dryness or drought are required to dry out the fuel before it can be burned. This has significant effects on the flammability of the fuels and the fire in these areas can be attributed to the weather conditions [27].

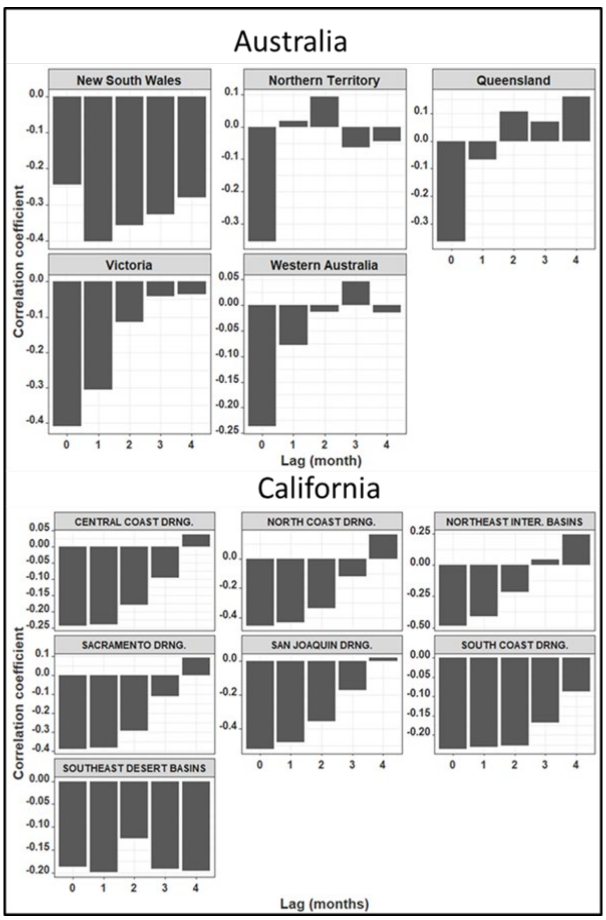

Figure 3: Correlation coefficient between fire count and surface soil moisture anomalies for different lag times over Australia and California.

In general, the correlation between soil moisture anomaly and fire count varied according to California's climate divisions. In the northern part of the states (e.g., North coast drainage), we found a higher average correlation between fire count and soil moisture anomalies than in the southern parts of California (e.g., South coast drainage). In the Central and South Coast, the relationship between fire count and soil moisture anomaly was relatively weak. This is likely due in part to the fact that the fire-climate relationship in these regions are strongly altered by anthropogenic activity such as ignitions, suppression, and land cover [32], [33].

Previous studies have found similar pattern of association between soil moisture anomalies and fire activity in Australia and California. For example, Beth and Brown, [34] found strong correlation between the short term Palmer Drought Severity Index and the number of wildfires and acres burned in the Western U.S. Riley et al. [35] also noted the association between short-term drought indices and fuel moisture content, the primary drivers of wildfire in the Western USA. Ehsani et al. [36] examined the relationship between recent wildfires, various hydro-climatological variables, and satellite-retrieved vegetation indices, concluding that the lack of precipitation before the wildfire prevented the soil from having enough moisture to supply demand and paved the way for the spread of fires. Our correlation analysis indicates that the soil moisture - fire link gets stronger during the pre-fire season, which is particularly essential for determining the next season's wildfire events. The lagged relationship between soil moisture and fire demonstrates that remotely sensed soil moisture can be used for the prediction of fire at 1-2 months lead-time, which is essential for early warning and mitigation.

C. Spatial response of soil moisture and fire activity during major fire events

Of the study areas, the most recent bushfire season (2019-2020) in Australia was the most severe in terms of burnt area and intensity, resulting in 33 deaths, the destruction of over 3000 homes, and the annihilation of approximately one billion animals, including several endangered species [23]. The potential for fire activity is clearly visible in drier-than-usual soil moisture conditions in the preceding months. Soil moisture anomaly values indicate that all hot spot fire regions experienced droughts with magnitudes ranging from -0.25 to -2.0 during the 2019–2020 bushfire season (Figure 4). During November and December 2019, New South Wales and Victoria experienced significant rainfall deficits as a result of a very strong positive Indian Ocean Dipole (IOD) [37]. The impact of the period's low rainfall had been exacerbated by a record high-temperature anomaly of nearly 1 °C above normal since 2003 [36]. The increased temperature elevated evapotranspiration demand, resulted in drier soil moisture conditions, which further increased the dryness of the vegetation and set the stage for the faster wildfire spread. The number of fires and burned areas of the Victorian bushfires was the largest in the state's history, resulting in over a million hectares burned, over 400 houses destroyed, and five people killed. Due to significant rainfall deficit, Victoria experienced below-normal soil moisture conditions during the 2019-2020 bush fire season, particularly along the coast and in the foothill forests of

Gippsland. Combined with above-average temperatures, resulted in an increase in surface fuel loads and higher flammability in live vegetation [23].

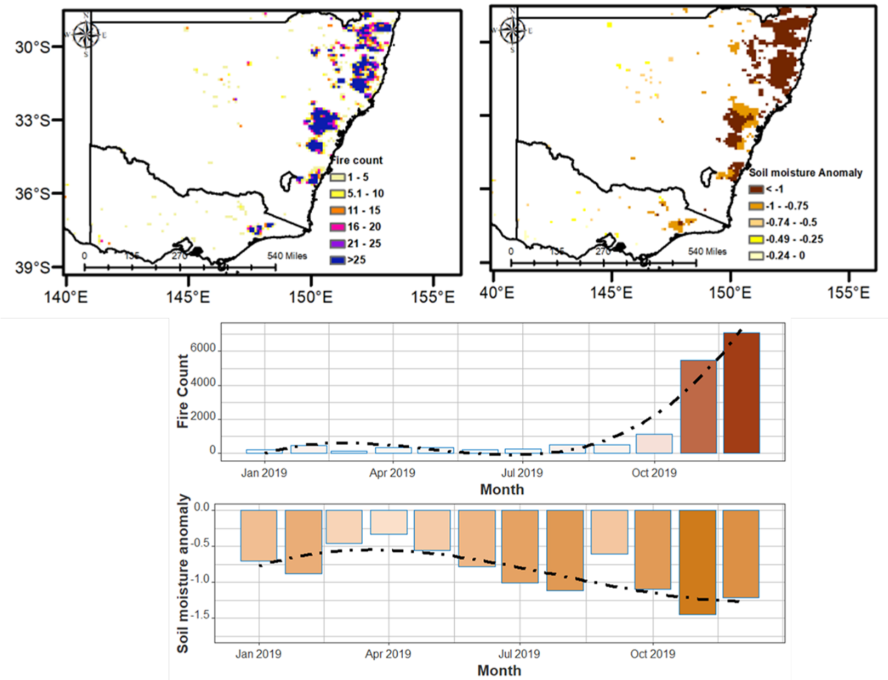

Figure 4: Spatial distribution of observed fire counts (top-left) and soil moisture anomalies (top-right) over New South Wales, Australia for the November-December 2019. Time series of monthly soil moisture deviations from average conditions (anomalies) and observed fire counts over New South Wales, Australia from January 2019 to December 2019 (bottom).

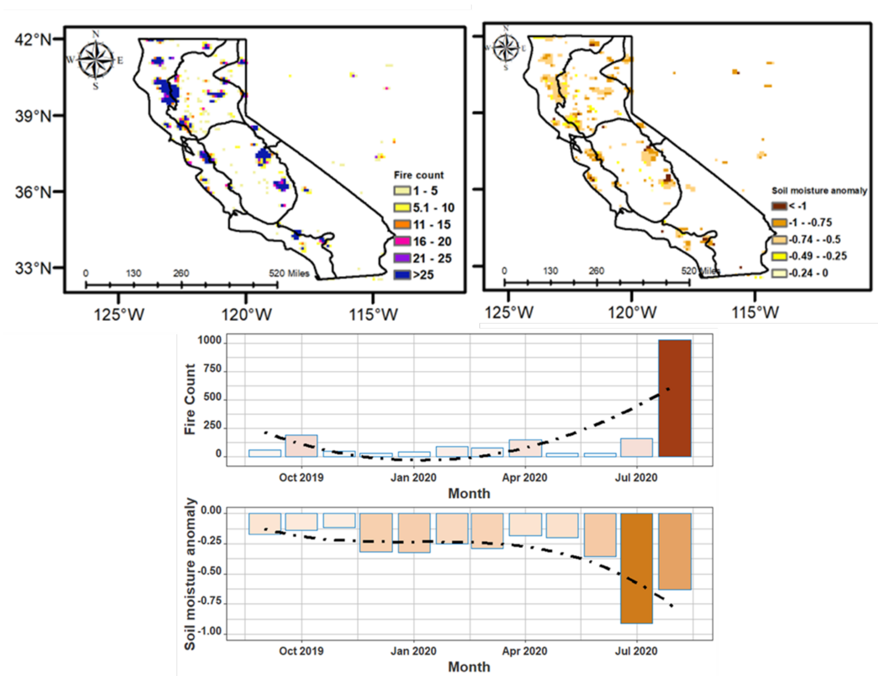

Figure 5: Spatial distribution of observed fire counts (top-left) and soil moisture anomalies (top-right) over California for July-August, 2020. Time series of monthly surface soil moisture deviations from average conditions (anomalies) and observed fire counts over Northern California from September 2019 to August 2020 (bottom).

The 2020 fire season in the western United States was staggering: over 2.5 million ha burned, including over 1.5 million ha in California (3.7% of the state), due in part to five of the six largest fires in state history [38]. As expected, the soil moisture anomalies and observed fire counts show an inverse trend, with dryer soil moisture conditions generally associated with increased fire activity. The time series analysis of fire count data revealed a higher number of fire activity during August 2020 (Figure 5). The fire count map was mostly consistent with the soil moisture anomaly map, following the premise that fires were more likely to occur in drought-affected areas. Lower precipitation and record-breaking heat waves in mid-August caused severe drought and a large amount of fuels for wildfires across northern California. In general, soil moisture anomalies were negative during the two notable fire events. This suggests that satellite-based observations are capable of capturing valuable fire-relevant information for this region. Even at a relatively coarse spatial scale (i.e., 0.25°), the observed trend in soil moisture anomalies has a significant relationship with fire activity. However, not all dry soil moisture conditions lead to a high number of fire activity. The relationship also depends on the length and intensity of the meteorological and agricultural drought (i.e., a deficit of soil moisture). Furthermore, the coincidence of low soil moisture and high temperatures is important in determining the number of fire activity [39].

IV. Discussion

It is well understood that soil moisture conditions can serve as a proxy for wildfire fuel accumulation and fuel moisture conditions. Therefore, properly measuring and observing soil moisture is of critical for understanding the fire-soil moisture relationship and developing strategies that leverage remote sensing-based approaches that could be employed in a strategic, operational framework. We examined the impact of regional soil moisture trends on fire activity in fire-prone areas in Australia and California during the notable wildfire seasons of 2019 and 2020, as well as demonstrated the utility of satellite-based coarse resolution soil moisture for assessing future fire risk. As expected, soil moisture has value in explaining fire occurrence across different provinces in Australia and California. Our lag correlation analysis revealed that the fire-soil moisture relationship was stronger during the pre-fire event, which is critical for forest fire early warning systems. More importantly, by isolating the fire count–soil moisture lag correlation, we demonstrated the value of soil moisture as a leading indicator for wildfire risk. The magnitude of the correlation indicates a higher possibility of fire occurrence due to drought conditions. Areas with a higher negative correlation, such as New South Wales and Victoria, are more prone to fire activity due to drier soil moisture conditions. The current and previous month's soil moisture conditions had a significant correlation with fire activity in most of the fire prone regions in Australia and California, which could be related to land cover type. The dominant land cover type in those regions is forest, which has deeper root systems that allow access to the water below the surface, resulting in slower drought response. In the northern part of Australia, however, only concurrent soil moisture is likely to influence wildfire occurrence. This is due, in part, to the fact that those areas are dominated by grassland, where roots are shallow and respond quickly to dry soil moisture conditions [40].

Our paper demonstrates that soil moisture is significantly related to wildfire activity. However, no wildfire danger models currently incorporate soil moisture due to the lack of adequate operational dataset [41]. This study demonstrated the utility of an operational SMAP-based soil moisture product, which can guide wildfire managers on how to use this data when assessing wildfire danger in Australia, and California. We also investigated the spatial pattern of soil moisture anomalies during extreme fire events in Australia and California, and noticed that the spatial soil moisture anomalies map corresponds to the fire hot spot regions. 2019 rainfall was 40% below average on a national level, making it Australia's driest year since records began in 1900 [37]. Our SMAP-based soil moisture anomalies also revealed more severe drought conditions over New South Wales and Victoria, which affect both the rate of vegetation growth and its dryness during 2019-2020 extreme bush fire events. Dry soil moisture conditions are associated with fires, but fires can also reduce soil water availability and have a negative impact on crop health and production. As a result, our current method of identifying fire-prone areas can assist local governments and emergency response agencies in better anticipating and preparing for an active fire season, as well as tracking the potential impact of fire on crop production.

Our findings are consistent with previous research. For example, Chaparro et al. [39] investigated the relationship of forest fires with soil moisture and temperature patterns in the Iberian Peninsula and the Balearic Islands and found that most forest fires burned in drier and hotter soils than the yearly averaged conditions in the Iberian Peninsula. Jensen et al. [12] quantified the relationships between pre-fire-season soil moisture and subsequent-year wildfire occurrence by land-cover type and concluded that larger fires occur more frequently when soil moisture is low. Ambadan et al. [13] investigated soil moisture anomalies prior to the onset of each wildfire occurrence in Canada between 2010 and 2017 across 14 eco-zones and concluded that soil moisture products could be useful in identifying wildfire hotspots.

We have built upon these previous studies and focused on a satellite-only approach, leveraging remotely-sensed, SMAP-based soil moisture data. Soil moisture was found to be an important variable in drought detection and fire risk assessment, paving the way for the use of remotely-sensed soil moisture data in early warning systems preventing forest fires. However, there is still much work to do on this topic - multiple sources of remotely-sensed based soil moisture data are available, and the choice of data source can have an impact on the fire-soil moisture relationship, as well as the application of these data and how they are integrated into a fire detection decision support framework. Here, only soil moisture condition was considered among a multitude of factors that cause wildfires. Therefore, other factors such as precipitation, land surface temperature, vapor pressure deficit, wind, as well as other non-climate variables such as topography, soil type, vegetation type, and vegetation dynamics could be taken into consideration to further outline the role of satellite based soil moisture products for predicting fire activity. It should be noted that the results of this analysis are not intended to be an exact prediction of actual fire occurrence and severity. Rather, they assess the relationship between an operational satellite-based soil moisture product and wildfire, specifically the sensitivity of fire occurrence to pre-season soil moisture conditions. It is envisaged that the main findings of our study will encourage the improvement of existing models and support leveraging SMAP and similar satellite-based remote sensing soil moisture instruments for improved wildfire forecasting and prediction.

V. Conclusion

Understanding the wildfire-soil moisture relationship is critical for better wildfire management practices and developing more effective forecasting and mitigating strategies of wildfire occurrence. This potential translation from data to actionable information is particularly important for developing operational applications, which will aid in mitigating the effects of fire events on the environment, agriculture, and human activities. This becomes even more evident when considering the extreme cases of wildfire in Australia and California during 2019 and 2020 fire seasons, respectively. Obviously, there were strong relationships between soil moisture anomalies and fire, but the nature of those relationships varied depending on geographic location, vegetation type, and climatic zone. Over the southeastern part of Australia, negative correlations between fire and soil moisture anomalies were observed to be stronger than in the northern part of the country. Our lagged correlation analysis confirmed the ability of soil moisture to predict fire activity with 1 to 2 months lead-time, which could be used for wildfire early warning and monitoring. Our analysis also demonstrated that remote sensing-based soil moisture data could help explain the observed spatial and temporal clustering of wildfires, which can be useful in identifying wildfire-prone areas. To this end, this relatively straightforward analysis gives a clear indication of the value of satellite-based soil moisture observations for helping identify wildfire risk and provides a strong foundation for further studies and decision support system design targeting regional wildfire modeling, prediction, and analysis.

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