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Spatio-temporal and causal analyses of "black summer" fires based on remote sensing satellites

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Abstract. Wildfires are a common natural disaster that threatens the environment, the economy, the climate, and even human life. It is therefore important to monitor the occurrence of fires to understand how they start, what causes them, and how they can be better prevented. Fires occur throughout the year in Australia, and 2019-2020 saw an unprecedented 'black summer' of fires. These fires have caused tens of thousands of animal and plant deaths, massive property damage, and many casualties. Therefore, it is more meaningful to study a typical case like Australia as a research object. In this paper, by applying Arcgis to MODIS fire point data, it is possible to analyze them in time and space. The causes are also analyzed through the impact of Sentinel-2. The results show that the initial phase of the fires is from July to October 2019, peaking in December 2019 and starting to decline in mid-January 2020. Most of the fires were concentrated along the coastline, with fewer in the west. This is thought to be related to the classification of vegetation cover and rainfall in Australia.

Keyword: Wildfire, Remote Sensing, Australia, Modis.

1. Introduction

Forest fires have become more frequent in recent years. More than 1,000 new fires start every year around the world, and the size of these fires is increasing every year. As these fires become more frequent, they threaten forests and urban areas around the world, wreaking havoc on the environment, destroying valuable property, and often killing people [1]. It is therefore essential to understand how to manage catastrophic wildfires and reduce their social, economic, and environmental consequences, and how to effectively monitor and prevent them.

In the past, people have mainly relied on large-area detection using simple equipment such as Osborne fire detectors on fire lookout towers to detect wildfires [2]. The accuracy of this method is very low and can be affected by human fatigue and long-term monitoring conditions. In addition, surrogate sensors used to monitor flames require long measurement times to allow molecules to approach, and because the range of the sensors is small, a large number of sensors are required to cover the area [3]. This results in not only human costs but also material costs. The swift advances in remote sensing have opened up novel methods to oversee wildfires [4]. Satellite systems are a commonly utilized technology that may detect or observe active fire or smoke conditions in real or near-real time. Sensors that are visible, infrared, multispectral, or hyperspectral, are frequently used in these technologies. This method uses either powerful techniques or hand-crafted feature extraction to identify wildfires in their early

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phases and simulate the behavior of smoke and fires [5]. The Landsat satellite series, developed and launched by NASA, has moderate resolution and rich spectral information which can facilitate fire-damaged area recognition to provide benefits to forest fire monitoring. However, the drawback lies in the extended time resolution where continuous optical images cannot be procured.

Xulu et al. [6] utilized a BAM approach based on differential normalized burning ratio and Sentinel-2 pictures for monitoring of burn area after fires. Among them, a random forest classifier is used in BAM. Their research claimed to have detected burned sites with an average accuracy of around 97%. Furthermore, Seydi et al. [7] used Google Earth Engine and Sentinel-2 pictures from before and after the fire, and assessed the effectiveness of the BAM statistical machine learning approach. The study found they claimed that the random forest classifier had a 92% accuracy rate. Liu et al. [8] proposed dual-phase Landsat-8 pictures' new BAM index and automatic threshold approach. The research indicated this method has high accuracy.

Additionally, Roteta et al. [9] used Sentinel-2 and MODIS data sets in sub-Saharan Africa to construct a regionally tailored multi-temporal burning region methodology. Furthermore, Ba et al. [10] used a single MODIS image and a back-propagation neural network and spectral index, an approach for developing burn areas was constructed. Additionally, they assessed how well the suggested strategy worked in three separate Idaho, Nevada, and Oregon regions. Wozniak et al. [11] also created a system for autonomous combustion area mapping using medium-resolution optical Landsat photos [7].

This study aims to study the spatial and temporal distribution of fires in New South Wales (NSW). First, by using the MODIS satellite, fire point data in NSW from July 2019 to March 2020 was obtained. In terms of time research, each month is divided into the upper, middle, and lower 3 periods to study the initial stage, peak value, and attenuation of the fire. In terms of space research, the Sentinel-2B satellite is used to study the main distribution areas of fires. Finally, combined with land cover land use types and rainfall maps, the causes of fires were analyzed.

The purpose of this article is to share knowledge and lessons discovered from significant disasters in Australia with a global audience.

2. Materials and Method

2.1. Study Area

The area of this study is NSW in Australia, which encompasses the entire Australian Capital Territory (ACT). The total area is approximately 80.16 square kilometers. The climate of New South Wales is temperate, with a mild climate, four distinct seasons, and 240 days of sunshine each year. During the winter months, average temperatures hover around 10 degrees Celsius or higher and occasionally undergo spikes towards 30 degrees Celsius during the summer. Inland regions of New South Wales encounter extreme daytime heat and frigid nighttime temperatures, with coastal areas receiving comparatively elevated levels of precipitation.

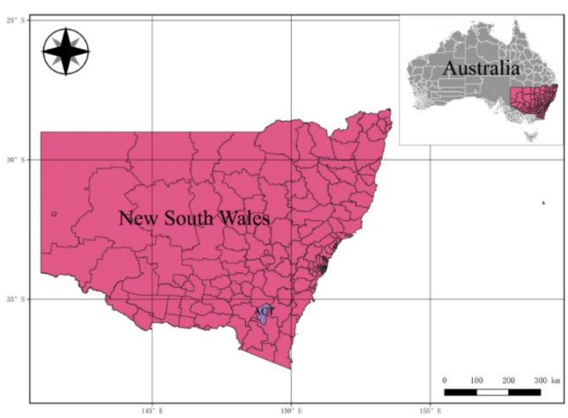

Figure 1. Location of New South Wales in Australia

Australia has a long history of coping with bushfires. The bushfires that occurred in Australia in 2019 were called the ‘Black Summer Bushfires’. Nearly all regions and territories in Australia were impacted by it [12]. But the brunt of the fires fell on the stretch of coastline from southern Queensland to South-Eastern Victoria in South Australia [6]. That had varying degrees of impact on commerce, agriculture, industry, and tourism: a total of 3100 houses were destroyed, 79% of which belonged to New South Wales, and insurance costs were estimated to be as high as 10 billion Australian dollars [13]. Most of the local national parks, forest reserves, and World Heritage areas have been extensively infiltrated by fires. A total of 190,000 hectares of forest have been burned, and 17,000 hectares have been burned in New South Wales. This resulted in the death of 100 million animals and the extinction of some species, and Australia’s biodiversity and species communities were severely affected [13]. In addition, the fire directly caused the death of 33 people, 25 of whom were in New South Wales. In the weeks after the fire, 417 people died due to air pollution caused by the fire [14].

2.2. Data Source

This study utilized optical satellite imagery from Sentinel-2, which is a part of the worldwide multispectral observations service of the European Space Agency (ESA). The Sentinel-2 mission comprises two satellites, Sentinel-2A and Sentinel-2B, with a temporal resolution of five days. The Multispectral Instrument (MSI), the primary sensor of Sentinel-2, is based on the push-scan principle and has spatial resolutions that range from 10 (m) to 60 (m) and 13 spectral bands.

In addition, this study employed Moderate Resolution Imaging Spectroradiometer (MODIS) satellites to analyze the spatial and temporal distribution of fire points and land cover classification. MODIS is a key instrument used in NASA’s Earth Observing System (EOS) Terra and Aqua missions, comprising 36 spectral bands, of which 20 are reflective solar bands and 16 are thermal emission bands. MODIS observations and data products have facilitated the analysis of significant geophysical and environmental parameters of the Earth’s land, oceans, and atmosphere, along with the effects of both natural and anthropogenic influences on the Earth’s climate and its evolution over time [15].

The geographical coordinate system employed for all maps is the World Geodetic System 1984 (WGS 1984) reference.

2.3. Method

The MODIS data were processed with Arcgis to produce specific fire point data for the first and second half of each month, from which the start, peak, and burnout of the fires were determined. This is then combined with Sentinel-2 satellite imagery to produce the fire point distribution map, which shows the spatial distribution status of the fires.

Finally, the Sentinel-2 data is classified using QGIS, and the satellite images before and after the fire are compared to check the approximate area burned.

3. Result

3.1. Time Analysis

Time analysis of the fire point data from the 27 datasets concluded that there has always been a history of bushfires in the Australian region and that the Black Summer bushfires had a distinct onset, peak, and extinction phase.

This is shown in Figure 2: the fire started to burn in October, with an outbreak in late August and September that was successfully contained. Fire activity peaked in November, with 11,343 fires burning in the middle of the month, and then declined to 4,191 fires in the second half of the month after containment. The number of fires increased again in December, reaching a peak of 15,884 for the whole burning period. The lowest number of fires in December was 10,146 in mid-December.

The ‘black summer’ began in January. After the first half of January, the decline was quickly halted when the number of fires was reduced to around 2350. By mid-February, the number of fires had been reduced to about 50 per decade.

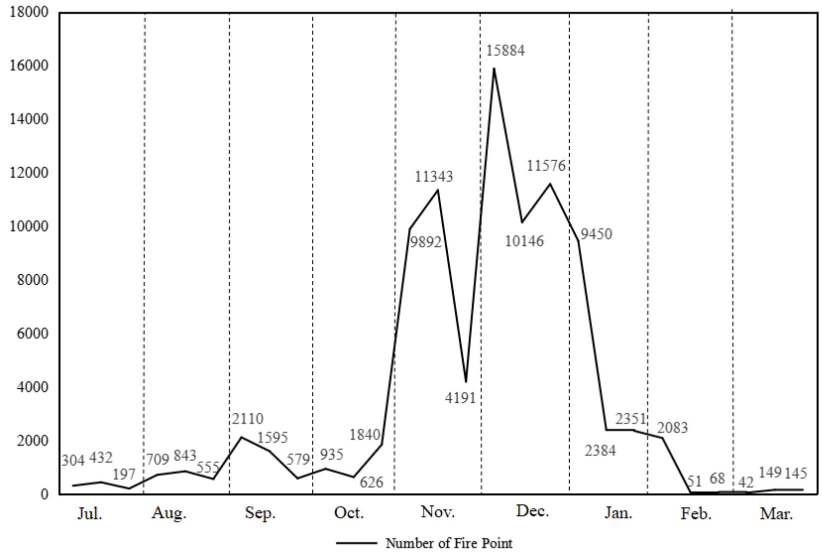

Figure 2. Fire point data in Australia

3.2. Spacial Analysis

The distribution of fires across NSW is shown in Figure 3. Most fires occurred in the south-east along the coastline.

Specifically, in the initial phases of the fires, the area burned between July and October 2019, shown in Figure 3(a), was concentrated in northeastern NSW, immediately adjacent to Queensland. It was diffuse, radiating from northeast to southwest into central NSW. During the period of fire peak, from January 2019 to early January 2020, the distribution of fire points is shown in (b), with a significant decline in fires in central NSW, but severe fires along the eastern coastline. During the period of fire decline, from mid-January to the end of March 2020, the distribution of fire points is shown in Figure3 (c), with fires along the coastline largely under better control, with a small number of fires occurring in areas other than the west, but at low densities, and fires along the south-eastern corner of the link to Victoria not yet under effective control, and with significant signs of burning in the ACT.

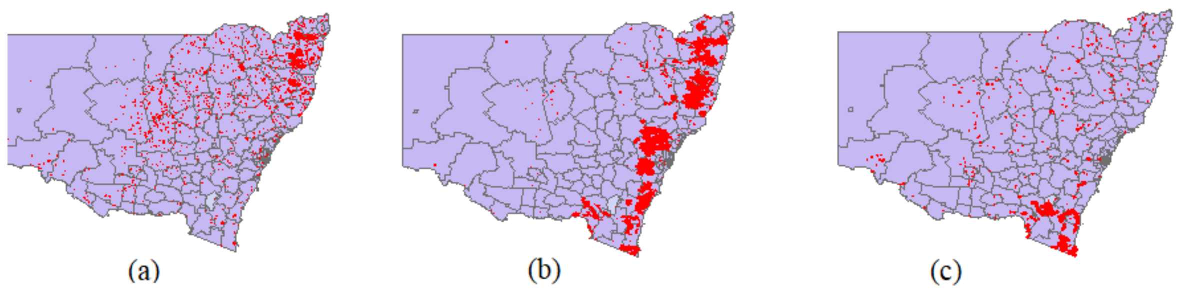

Figure 3. Spatial distribution of New South Wales fires at initiation (a), peak (b), decay (c)

4. Discussion

In 2019, the Australia Capital Territory (ACT) and much of eastern Australia experienced drought. Following spring rains, vegetation cover changes significantly across much of ACT from January. The drought is limited to western New South Wales, but vegetation growth is higher in other parts of New South Wales (NSW). The rainfall has eased dry conditions in central western NSW and boosted green growth by increasing vegetation cover along the NSW and Victorian coasts [12].

The devastating bushfires, maybe triggered by the climate and occurring between July 2019 and March 2020, were the result of a long-lasting drought in eastern Australia leading to a lack of moisture in bush fuels and prolonged high temperatures. Additionally, a succession of dry lightning storms contributed to the severity of the fires. In total, the fires burnt an excess of 11 million hectares of land in Australia, with the largest impacted area being New South Wales at 6.2%, making it the most significant recorded bushfire disaster in history [16].

Therefore, fire season started early, with drought affecting 1% of the state and dry and warm conditions persisting across the state.

5. Conclusion

And spatially, in the early stages of the fires, the area burned between July to October 2019 was concentrated in northeastern NSW, immediately adjacent to Queensland. There were also scattered fires in central NSW, but not at high densities. During the peak of the fire season, from January 2019 to early January 2020, there was a marked decline in fires in central NSW, but severe fires along the eastern coastline with very high fire point densities. During the period of fire decline from mid-January to the end of March 2020, fires along the coastline were largely well controlled, with a small number of low-density fires in all but the western region, fires along the south-eastern corner of the state connecting to Victoria were not yet effectively controlled, and signs of significant burning began to appear in the Australian Capital Territory (ACT).

This study aims to provide a spatial and temporal analysis of fires, which can provide a better understanding of the whole fire process, which will be useful for prevention and management in the future. Based on this study, further impact comparisons can be made, such as NDVI to look more specifically at vegetation changes. Air pollution can be monitored to study its effects on the atmosphere and human health.

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