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Dynamic Data-driven Research on Forest Fire Behavior Overview

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ABSTRACT

In recent years, under the combined effects of climate change and El Niño, extreme weather has been occurring frequently, and natural disasters of all kinds have been increasing. Forest fire is the first of the three major natural disasters in forests, to reduce the possibility of starting forest fires, reduce the damage caused by forest fire disasters, as well as to predict the development trend of forest fires and fight them scientifically, we should systematically and scientifically grasp the law of forest fire occurrence and development. This paper analyses the various influencing factors affecting the behavior of forest fires and classifies meteorological factors and the moisture content of combustible materials as dynamic factors, and topographical factors and other factors of combustible materials except moisture content as slow-change factors. The research on dynamic data-driven forest fire behavior in recent years is reviewed, the advantages of dynamic data-driven technology for simulating fires are analyzed, the constraints of the technology are indicated, and the future development trend is shown.

KEYWORDS

Forest fire behavior, dynamic data-driven.

1. INTRODUCTION

In recent years, the combination of climate change and El Niño has led to extreme weather events and an increase in natural disasters, with catastrophic forest fires breaking out in Chile at the beginning of the year 2024, torrential rains in California, and persistent drought in Spain. Forest fires are the first of the three major natural disasters in forests, and they occur every year around the world, increasing in duration, severity, and impact. [1] In 2023, Canada experienced one of the most destructive forest fires on record; in Australia, a forest fire broke out between July 2019 and February 2020 that lasted nearly six months and caused irreversible damage to ecosystems and biodiversity, in addition to significant property damage and human casualties. The high-latitude Siberian region has also been heavily affected by global warming, and in recent years the region has continued to experience extreme heat that has led to several large-scale forest fires.2021 Russia's Siberia experienced one of the hottest and driest summers since meteorological observations began, and the extreme heat triggered forest fires that lasted for months in Siberia.[2] The extreme heat triggered forest fires in Siberia that lasted for months. The "10.17" major forest fire in Xintian County lasted for about 8d, covering a total area of 5129.8hm^2, the largest fire in Hunan since the founding of New China, and affecting an area of 928.62hm^2, with a loss of 64,800m^3 of affected forests, and direct economic losses of 26,196,900 yuan. The direct economic loss was 26,196,900 yuan.[3] The direct economic loss was 26.1969 million yuan. The hazards of forest fires are huge, burning trees, destroying understorey resources, destroying wildlife habitats, causing animal deaths and even extinction, and causing casualties and financial losses.[4] . To reduce the likelihood of forest fires, reduce the damage caused by forest fires, predict the development trend of forest fires, and fight them scientifically, we should systematically and scientifically grasp the law of forest fire development.

2. SIGNIFICANCE OF FOREST FIRE BEHAVIOR RESEARCH

Fire behavior in a broad sense represents the totality of a series of interlocking processes of fire from ignition, development, and propagation, up to attenuation and extinguishment, and in a narrower sense, fire behavior represents the intensity of a fire after a certain period, the rate of fire spread, the length and depth of the flame and so on.[5] The fire behavior In simple terms, forest fire behavior represents the various characteristics of combustible material during the entire process of combustion, but due to the wide range of objective conditions affecting forest fires and the unpredictability of forest fires, every forest fire is unique.

Forest fire behavior studies the changes in forest fires in time and space, implying quantitative and qualitative transformations. Parameters describing fire behavior include fire spread rate, fire intensity, heat released per unit area, fire intensity, flame height, spread shape, fire area, etc. Fire spread rate, fire intensity, fire intensity, etc. indicate quantitative changes in the combustion reaction, and these quantitative changes lead forest fires into different stages of development. Among them, spreading speed, fire intensity, and flame height are important indexes in the research process of forest fire behavior, and people always designate the suitable fire-fighting plan, select the suitable fire-fighting equipment, and decide to fight the fire directly or indirectly by hand according to the spreading speed, fire intensity and flame height. Once a forest fire occurs, timely prediction of the status and trend of fire behavior is of great significance for the effective organization of fire fighting and reduction of fire losses.[6] The following are some examples of the most important factors that can be taken into account in the prediction of fire behavior

Research on forest fire behavior at home and abroad: due to the close connection between the types of forest fires and forest fire behavior, the early research is mainly on forest fire classification; the research on forest fire spread, one of the three major indicators of fire behavior, is also the mainstream direction, mainly on the establishment of the forest fire spread model; the use of physical and mathematical tools to reveal the nature of the forest fire behavior, and the establishment of a physical model in line with the actual situation is undoubtedly the direction of development in the future, and there is a tendency to develop towards the direction of spatial computational simulation and simulation. The use of physical and mathematical tools to reveal the nature of forest fire behavior and thus establish a realistic physical model is undoubtedly the future direction of development, and there is a tendency to develop in the direction of spatial computational simulation of forest fires.[7] The development of physical and mathematical tools to reveal the nature of forest fire behavior and to establish realistic physical models is undoubtedly the direction of future development.

3. FACTORS AFFECTING THE BEHAVIOR OF RINGING FOREST FIRES

There are many factors and complex mechanisms that influence forest fire behavior, which is sensitive to changes in land growth, combustible hazards, weather and wind conditions, and topography.[8] The factors that dominate changes in forest fire behavior are weather and wind. The factors that dominate changes in forest fire behavior are meteorological factors, combustible factors, and topographic factors. In the short term, because meteorological factors and moisture content of combustibles can change significantly, is categorized as a dynamic factor. is categorized as a slow-change factor because topographic factors and combustibles other than moisture content can change to a lesser or significant extent over long periods.

3.1. Dynamic factors

3.1.1. Meteorological factors

Meteorological factors are the main elements influencing the spatial and temporal dynamics of forest fires. Forest burning is based on combustible materials, and climate change accelerates the loss of water from combustible materials, thus affecting the development of fire behavior[9]. Climate change affects the occurrence of forest fires in two time scales: first, in a longer time scale, climate change affects climate zones, causing vegetation zones to move, which in turn affects the accumulation and distribution of combustibles; second, in a shorter time scale, the rapid changes in meteorological factors have a direct impact on fire risk, fire behavior, etc., and meteorological factors such as air temperature, precipitation, relative humidity, wind, etc., directly affect the occurrence and development of forest fires. temperature, precipitation, relative humidity, wind, and other meteorological factors directly affect the occurrence and development of forest fires. [10][11] The second is that rapid changes in meteorological factors over short time scales have a direct impact on fire risk and behavior.

The occurrence of forest fires is closely related to temperature. When combustibles are in a hot environment, it becomes easier for combustibles to reach their ignition point because the hot combustibles will become drier and easier to burn. Temperature changes can be divided into daily, monthly, and yearly changes, the highest daily temperature is often used to determine whether a forest area has the possibility of fire. When the temperature reaches 12℃, the number of forest fires starts to increase; above 15℃, forest fires occur frequently; when the temperature is higher than 20℃, forest fires can occur in large numbers; when the temperature is below 5℃, even if a fire breaks out, it burns slowly; when the temperature is below 0°C, forest fires rarely occur.[12] .

The relative humidity of the air affects the ease with which forest fires can occur. The ratio of the actual water vapor pressure in the air to the saturated water vapor pressure at the same temperature is the relative humidity of the air, which varies with the temperature, decreasing when the temperature increases and increasing when the temperature decreases, and thus must have a maximum and a minimum value during the day. Normally, when the relative humidity of air is >75 percent, forest fires do not occur; when it is between 55 and 75 percent, forest fires may occur; when it is <55 percent, forest fires are likely to occur; and when it is <30 percent, forest fires are very likely to occur and may be particularly significant.[12] .

Precipitation is the main factor determining the relative humidity of the air and the dry humidity of combustibles, which depends on the amount of precipitation at a time and the period between precipitation, precipitation enhances the water content of combustibles, especially dead combustibles, which increases in a large amount, and increases the soil water content, which extinguishes burning forest fires or keeps the forests free from fires[9,12]. Therefore, in the rainy season forest fires hardly occur, while in the dry and dry seasons, the sharp decrease in precipitation leads to a significant decrease in the moisture content of the vegetation, and when the moisture content of the vegetation and the soil decreases to a certain level, the combustible materials in the forest floor become extremely flammable, with the potential for high-energy fire behavior, and life and property are exposed to huge losses.

The expansion and spread of forest fires depend on the action of wind. Wind accelerates the evaporation of moisture from combustible materials, making them dry and more flammable, which leads to a rise in fire danger levels and a significant increase in the occurrence of forest fires. At the same time, it constantly replenishes the oxygen needed for the combustion reaction, accelerating the combustion process, in addition, by changing the state height and state of thermal convection, increasing thermal advection, and promoting the spread of forest fires; addition, the stronger the wind, the stronger the atmospheric turbulence, which often results in "flying fires".[13] The stronger the wind, the stronger the atmospheric turbulence, often resulting in "flying fires".

In addition to considering meteorological factors such as temperature, precipitation, relative humidity, wind, etc., we should also be aware of the impact that extreme weather events such as El Niño/La Niña can have on forest fires. Zhang Xiaoyu[14] By studying the effect of El Niño/La Niña events on forest burnability in the Daxinganling region, we found that El Niño/La Niña events of different intensities have a significant effect on the average daily maximum temperature and precipitation during the fire danger period in the Daxinganling region, and also affect the spatial variability of the fire weather indices: during the entire fire danger period of El Niño and La Niña years, the average probability of burning is significantly higher than that of normal years, and the simulated overfire area of each overfire area for each combustible type was higher than in normal years.

3.1.2. Moisture content of combustibles

Moisture content is an important indicator affecting the combustibility of combustible materials, forest combustibility refers to the conditions conducive to forest combustion, forests are ignited by the ease of fire, as well as after the ignition of combustion state (fire type) and combustion rate (fire intensity) of the combination.[15] The moisture content of the combustible material is a measure of its moisture content. The moisture content of combustible material is the percentage of water per unit mass of completely dry combustible material, which is the most important combustible material characteristic and plays a decisive role in determining the occurrence or otherwise of forest fires and related fire behavior indicators. Research has shown that it is almost difficult to have a forest fire when the moisture content of surface fine combustibles exceeds 35%, and it is also difficult to have a crown fire when the moisture content of live combustibles (branches and leaves) exceeds 130%.[16] The water content of combustibles is a major factor in forest fires. The moisture content of combustible material is the main indicator for forest fire prediction and forecasting, and accurate prediction of moisture content can improve the accuracy of forest fire prediction and forecasting.[17] Accurate prediction of moisture content can improve the accuracy of forest fire prediction and forecasting. The moisture content of combustible materials affects the spread of underfire, and sudden changes in moisture content may trigger the transition from underfire to open fire.[18] The water content of combustible materials has an impact on the propagation process of negative ignition.

The water content of combustibles is divided into the water content of living combustibles and the water content of dead combustibles, and the water content of forest combustibles varies from species to species and from period to period of the same species due to a combination of factors. Meteorological factors are the first to dominate the water content of combustibles, especially for dead combustibles. The water content of live combustibles shows dynamic changes in a day under the influence of changes in the relative humidity of the air, the water content of live combustibles reaches the highest in the morning when the relative humidity of the air reaches the maximum, and as the relative humidity of the air gradually decreases due to the increase in air temperature, the water content of live combustibles gradually decreases, and the water content of live combustibles is the lowest at the highest daily temperature, which is the time when most of the forest fires in the past occurred. Combustible moisture content and precipitation are also closely linked, with high moisture content in the rainy season and low moisture content in the dry season. In the rainy season, the precipitation is sufficient, the temperature is more favorable, the vegetation grows faster, and its water content is higher; in the dry season, the precipitation is extremely scarce, the relative humidity of the air is low, and the plants are mostly in a dormant or slow-growing state in this period, and their water content is lower. The plant part of the death, the processing of nutrients, and the water cycle is suspended, its water only gradually evaporates, until the "wind dry" until the dead plant maintains the cells, cell space fibers, and other organic structures, these structures in the water is changing with the weather.[19] The moisture in these structures varies with the weather. The water content of dead combustibles has a similar pattern to that of living combustibles, with higher water content during the high relative humidity of the air daily or the rainy season and, conversely, with lower water content; unlike living combustibles, the water content of dead combustibles is almost entirely determined by the relative humidity of the air during the dry season. In addition, there is a relationship between the change in water content of combustibles and altitude. The water content of combustibles on the forest floor is higher at lower altitudes and shows a clear tendency to decrease as the altitude rises.[20] The water content of forest surface combustible material is higher at low elevations and shows a clear trend of decreasing with increasing elevation.

3.2. Retardation factors

3.2.1. Topographical factors

Terrain factors and the role of the wind are similar, showing that the spread of uphill fire with the wind is similar to the speed, and intensity; downhill fire with the wind is similar to the slow speed, and fire intensity is small. Uphill fire flame with the slope of the burning change is presented as a small slope of slow combustion, with the increase in the slope of the flames of the jitter and the large slope when the wall of intense burning[21] that often forms high-intensity fires on steep slopes of ridges. Because of the topography and the distribution of vegetation, the rate of spread, fire intensity, etc., is much faster and higher on the sunny slopes of high mountains than on the shady slopes. Still, the fire is extinguished as soon as it spreads to swampy areas[22].

3.2.2. Combustible factors

Combustibles are the basic elements on which the act of burning occurs. Forest combustibles can be defined as all living and dead organic material within a forest that has the potential to burn and release energy.[23] Combustibles are classified according to their potential fire behavior and are divided into four main categories: grassland, shrubs, trees, and logging sites.[24] The combustibles are generally divided into four categories: grassland, shrubs, forests, and logging sites, and can be divided into small combustibles (hay, branches, leaves, needles, etc.) and (stumps, branches, twigs, branches, etc.) according to their weight. The type of combustible material affects the ease of catching fire. Small combustible material (easy to lose water and be ignited, most forest fires are caused by the ignition of small dead combustible material, thus developing and expanding. Heavy combustibles contain more water, the surface area to volume ratio is small, not easy to ignite, but contain high energy, is to support the transformation of low-intensity fire to high-intensity fire energy source. The type of forest fire is often determined by the type, configuration, and structure of the combustible material. Surface fires often occur in grasslands, thickets and deciduous broad-leaved forests, and underground fires may occur in places where the soil is rich in humus and peat, and canopy fires are likely to occur in evergreen coniferous forests and evergreen broad-leaved forests.

4. DYNAMIC DATA-DRIVEN RESEARCH ON FOREST FIRE BEHAVIOR

Due to the complexity of forest fire mechanisms and high experimental difficulty, the research and development of forest fire behavior is slow. However, there are many factors affecting the spread of forest fires, and it is the result of a combination of factors. Static forest fire simulation cannot combine real-time fire data to provide feedback and control of the system, and the simulation results often have a large gap with the real situation, which is less useful for the rational deployment of firefighting forces and the reduction of losses.[25] The dynamic data-driven application system technology paradigm. The dynamic data-driven application system technology paradigm was first proposed by the Natural Science Foundation of the United States (NSF) in 2000. This is a new simulation application model, which organically combines simulation and experiment, so that the simulation can dynamically receive measurement data from the actual system and respond to it during the operation process, and the simulation results can also dynamically control the operation of the actual system and guide the measurement. In recent years, some scholars began to carry out research on forest fire based on dynamic data-driven technology, mostly for the simulation of the spread of forest fire, with the efforts of many scholars, many of the spread of forest fire models have been put forward, accompanied by several excellent simulation software for the spread of forest fires, but any can not be approximated to the real fire process, there are shortcomings.

Driven by dynamic data, foreign scholars have done a lot of research in the field of forest fire simulation and modeling. Benali[26] et al. used the generalized likelihood uncertainty estimation (GLUE) method to adjust the parameters in the forest fire spread rate model against the background of seven forest fires that occurred in Portugal between 2003 and 2005 and compared the predictions of FARSITE before and after the adjustment to the processed results of historical satellite observations. Méndez-Garabetti[27] et al. used a data-driven approach with multiple overlapping solutions for forest fire simulation, using Firesim as a forest fire simulator, through the Evolutionary Statistical System. Island Model (ESS.IM), where the parameter set is represented by individuals in different populations of a given size, is searched using a parallel evolutionary algorithm, and the predictions are corrected using statistical analysis. Valero[28] et al. used the Rothermel fire spread rate model and the Huygens diffusion model for forest fire simulation, using fireline boundary data from extracted thermal infrared images of forest fires as observations, constructing a cost function, and iterating until convergence to search for the optimal parameter combinations that would maximize the similarity between the observations and the simulation results. Cardil [29] et al. used firefighter's logged fire monitoring data as a reference for the predictions of the forest fire model Wildfire Analyst were calibrated using an adjustment factor for the rate of spread of forest trees, and the value of the adjustment factor that minimized the simulation error was determined by the least squares method. Rochoux M[30] Reading fireline locations from infrared images of controlled burning experiments while simulating the fire spread process using the Rothermel model and the level set method, using optimal linear unbiased estimation to estimate the parameters of combustible moisture and combustible particles surface area-to-volume ratio in the Rothermel model for calculating the rate of spread of forest fires, and adjusting the simulation results with the new estimates to improve the accuracy of the predictions.

In China, the study of forest fire simulation and modeling based on dynamic data is a relatively new direction. Some scholars have conducted some research, but it is yet to be in-depth. Tang Chun[31] researched a UAV real-time dynamic data-driven forest fire spread simulation optimization system to improve the accuracy of forest fire spread simulation through real-time monitoring of forest fire occurrence, which has important theoretical and practical significance for scientific fire decision-making and forest fire prevention work. Zhou Guoxiong et al.[32] A dynamic data-driven forest fire spread model based on DEVS modeling is proposed by combining a dynamic data system and discrete event system specification model, and the model is applied to the simulation of a forest fire in a mountainous area, which has a high degree of real similarity. Xindan Gao[33] Based on the basic idea of the dynamic data-driven application system, the theory and implementation method of the dynamic data-driven application system was studied by taking forest fire spreading as an object. The peripheral fire line of the fire field was taken as the state parameter of forest fire spreading and development. The temperatures around the fire line and the fire field were taken as the assimilation parameter between the system model and the real-time data. The principle of collecting the temperature of the fire field and the method of implementation of the system measurement model were investigated. Zhou Yufei[34] A dynamic data-driven forest fire spread adaptive simulation prototype system was established, and a forest fire in the border area of Fengning, Hebei, and Huairou, Beijing was simulated by using Wang Zhengfei model and Rothermel model at the same time, which demonstrated the basic simulation implementation process of dynamic data-driven forest fire spread simulation. Qian Lan[35] The influence of wind, the main meteorological factor of forest fire spread, on the correction effect of the ensemble Kaman filter algorithm is studied, and the position of the fire line is taken as a parameter to be corrected, and given the problem of inaccurate prediction of the FARSITE fire line caused by the deviation of the input of the initial fire position, the ensemble Kaman filter algorithm is used to assimilate the real fire line data to carry out the dynamic correction. Correction.

5. CONCLUSION

Static forest fire simulation and the real fire difference, based on dynamic data-driven technology to simulate the fire is closer to the real forest fire, but also able to show the dynamic process of forest fire behavior, the basic idea is to use dynamic data to correct the simulation of the fire, and now dynamic data-driven research on the behavior of the forest fire is mainly the simulation of the spread of the forest fire. The use of dynamic data-driven technology in forest fire needs to be built on a real and effective database, especially real-time forest fire monitoring data, but the collection of these data, the deployment of measurement instrumentation, especially real-time transmission and processing of data for the current stage of the very difficult, which is also one of the core issues restricting the development of this technology. The forest fire spread simulation model and the adjustment of model parameters based on dynamic data need a lot of experience accumulation, and a long period, while the reality of forest fire development is rapidly changing, real-time fire spread samples are extremely difficult to obtain, coupled with the impact of other factors, such as human behavioral factors interfering with the (fighting, ignition), which makes the selection of fire simulation model has become very difficult to adjust the parameters with the actual fire field is very different. the actual fire scenes are vastly different. At this stage, the simulation of forest fire behavior based on dynamic data is still based on a more ideal state, how to be closer to the actual forest fire process which is the trend of future research and development.

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