Application of MODIS Data-Based Forest Fire Monitoring and Assessment

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Abstract. Forest fires are uncontrollable fires that spread freely within forest land, causing significant harm and damage, and thus its monitoring and assessment are crucial. There is a wide range of applications of MODIS data in forest fires aspect, but they are mainly targeted to solve regional problems. This study addresses MODIS data technology and examples of its application to forest fires in the Heilongjiang, Australia, Fujian Province, and Daxinganling Mountains, confirming its potential for monitoring and assessing forest fires. MODIS images and fire products contribute significantly to the usefulness and accuracy in the dynamic identification monitoring of forest fires and accurate determination of the ignition place due to their high resolution, excellent calibration, and positioning processing. MODIS and its corresponding product datasets can also be used to construct multiple vegetation and associated indicators to acquire vegetation area changes and to analyze the damage caused by forest fires. It is the ideal data source for monitoring and assessing forest fires.

Keywords: Forest fire, Remote sensing, Monitoring, Assessment, MODIS data.

1. Introduction

Forest fires are uncontrollable fire acts that spread freely within forest land, causing harm and damage to forests, forest ecosystems, and people. It alters soil microbes, reduces forest area, and significantly threatens biodiversity. At the same time, forest fires emit large amounts of carbon dioxide (CO2) gas, hastening global warming and negatively impacting global ecosystems [1-3]. Van Der proposed that between 1997 and 2001, fires are assumed to contribute to approximately two-thirds of the change in atmospheric CO2 and aerosols, and that increased CO2 causes changes in transpiration while rising concentrations of fire-generated aerosols reduce the amount of solar radiation reaching the ground [4].

In a world where ecology is highly valued, the dangers of forest fires are of global concern. Forest fire monitoring and assessment are crucial due to the significant risks and the severe damages. There are numerous ways to monitor and assess forest fires. Aerial circle mapping, data statistics, ground survey, and remote sensing image methods are applied to estimate forest fire areas, with data statistics and remote sensing image methods mostly used to estimate large-scale forest fire areas [5]. The former method is labor- and money-intensive and therefore is not appropriate for estimating the size of forest fires on a large scale. Contrastly, remote sensing satellites have significant advantages in monitoring and evaluating the size of forest fires due to their quick imaging time and extensive coverage. Among these, the utilization of MODIS data is escalating progressively. Tang et al. used four MODIS bands to monitor forest fires: near-infrared, mid-infrared, and thermal infrared. Based on the MODIS 7 band, they proposed a direct discrimination method for high-temperature fire points and a comprehensive threshold discrimination method for non-high-temperature fire points [6]. He et al. conducted a comparative study with historical fire traces using active fire points extracted from MODIS and discovered that the 8+9 bands extracted from MODl4A1 were suitable for fire monitoring, with an agreement of up to 0.83 when compared to site survey data [7].

There is a wide range of applications of MODIS data in forest fires aspect,but they are mainly targeted to solve regional problems. This study covers the principles of MODIS at the outset, analyzes a few representative cases, and then, based on those analyses, discusses how it can be used to track and rate forest fires.

2. Principle of MODIS

MODIS (or Moderate Resolution Imaging Spectroradiometer) is a crucial instrument on the Terra (formerly EOS AM-1) and Aqua (formerly EOS PM-1) satellites and is one of the most important optical remote sensing instruments in use today. With ground resolutions of 250 m, 500 m, and 1000 m and 36 spectral channels covering the electromagnetic spectrum from 0.4 μm to 14.4 μm, it provides global coverage observations every one to two days. It is intended to give measurements of large-scale global dynamics, such as variations in the amount of the Earth clouds covering, radiation balance, and processes taking place in the oceans, on land, and in the lower atmosphere. Both the polar satellites TERRA and AQUA are in Sun-synchronous orbits, with TERRA transiting in the morning and AQUA in the afternoon of local time. Regarding time update frequency, the MODIS data on TERRA and AQUA are compatible, and when combined with the evening transit data, a minimum of two daytime updates and two nighttime updates per day may be acquired for receiving MODIS data. For real-time Earth monitoring and emergency response, this frequency of data updates is extremely valuable practically [8].

The MODIS sensor has considerably greater fire monitoring capabilities than other sensors because its instrument characteristics were created with fire monitoring in mind [9]. Compared to other remote sensing tools, MODIS provides the following benefits for applications involving fire: benefits in the detection and diagnosis of flames of high sensor sensitivity and quantitative precision; having numerous channels available for fire detection prevents not only saturation issues but also enables qualitative and quantitative investigation of the nature of the fire; capacities for precision positioning. Existing research has used MODIS fire detection methods based on the spectral properties of the mid and long infrared channels, fire mask data products, and assessing fire damage by combining its bands to obtain information like NDVI vegetation indices. The specific method generally needs to be determined by the magnitude of the study, the subject, and the actual conditions of the study location.

3. Application of MODIS date in recognition of forest fire points

One application of MODIS data for forest fire monitoring is to recognize forest fire points, and this study takes two cases to discuss the use of MODIS data for forest fire points recognition in the Daxinganling Mountains of Northeast China in August 2002 and fires in Heilongjiang Province from 2006 to 2010.

3.1. Case in the Daxingan Mountains, Northeast China

In order to validate the level 1B data and test and examine the MODIS fire detection algorithm based on the spectral properties of the mid and long infrared channels, Liu et al. undertook dynamic monitoring of abrupt fires in the Daxinganling, Northeast China.

Based on Planck's equation, Liu et al. displayed the blackbody radiation spectrum at various temperatures. Channels 1, 3, 4, 21, and 31 were chosen to convert the obtained images into bright temperature values to clarify the processing and the extraction of the ignition point, while channels 4μm and 11μm were chosen to obtain a more distinct image element of the ignition point. The study then thresholds the bright temperature maps acquired for channels 21 and 31, transforming the radiant brightness values of channels 21 and 31 into bright temperature values before analyzing each threshold and identifying the fire locations.

The study compared the processed data and fire points with the precise fire point locations that could be found from satellite images of fires in the northern Daxinganling at that time to assess the suitability of MODIS data for monitoring forest fires. The study concluded that MODIS is useful for monitoring forest fires because of its high spatial resolution, greater temporal resolution, strong radiometric resolution, wide bandwidth resolution, good calibration, and positioning.

The study still has some flaws. Some areas that appeared to be heavily smoke-filled on satellite cloud maps were not included in the experimental fire sites, which Liu hypothesizes may be because the smoke in these locations obscured the energy of the fire sites on the ground and was not detected by the sensors. These areas may be smothered areas with different fire intensities, temperatures, and radiation rates than open fire areas, which may have been disregarded in the calculations of the study data. Finally, these areas may be smothered areas with different fire Surface fires can be detected under the monitoring conditions used in the study, but subsurface fires might not be. The lack of field data might potentially cause bias in the results [9].

This study provides some reference value for MODIS data in monitoring forest fires since its data sources and formulae are dependable and scientific.

3.2. Case in 51 major forest fires in Heilongjiang Province from 2006 to 2010

Jiao et al. utilized Landsat-TM/ETM+ to verify the precision of the forest fire area estimated by the MODIS fire product, MOD14A2 (Terra). Jiao's analysis employed high probability fire pixels with an error of under 30% at the provincial scale out of the nine different types of pixels in the MOD14A2 product. To gather fire area data for each year, the researcher utilized ArcGIS GIS software to conduct spatial analysis, including reclassification and regional statistics.TM images of 7, 4, and 3 band combinations were then used as a comparison.

The results indicate that at the individual fire scale, forest fires smaller than 3.72 km2 are not suitable for fire area estimation using MOD14A2 products due to their low spatial resolution. However, the MOD14A2 fire product adds checks to exclude false alarm signals (solar flicker, coastal zone exposure) from fire point identification, which to some extent boosts the accuracy of fire point identification. The annual fire area accuracy of the fire product is above 86%, demonstrating that it is a very efficient source of information for identifying yearly fire areas in Heilongjiang Province.

The quantitative Kappa indices were significantly more significant than the positional Kappa indices and the standard Kappa indices, according to the analysis of the Kappa indices, demonstrating that the annual fire area in Heilongjiang Province as determined by MOD14A2 fire products and TM remote sensing imagery was essentially the same. However, it was discovered that there were some inaccuracies between the two when comparing the location Kappa indices of the TM imagery and the MODIS data. A possible explanation for the inaccuracy is that the fire data' erroneous spatial position or the disparity in spatial resolution between TM and MODIS caused it [10].

The study used significant data and assessed for statistical significance to establish that the MOD14A2 fire product is a valid and reliable estimate of the yearly forest fire area.

4. Application of MODIS data on vegetation cover changes

Many studies have applied MODIS data to establish vegetation indices such as the NDVI to get vegetation area changes to evaluate the devastation caused by forest fires. The following two studies are identified and discuss their use in assessing forest fires: the damage to vegetation cover and subsequent recovery from large-scale forest fires in southeastern Australia in 2019-2020, and the assessment of the change in forest area in the hilly southern mountains from the 2004 forest fires in Fujian Province.

4.1. Assessment of the impact of forest fires on vegetation cover in Australia

Qin et al. used different MODIS products, including the 50-m PALSAR/MODIS forest map in 2010, MODIS active fire data (2010-2020), divided fire areas into fire-affected and non-fire-affected grids for data processing, and used equations to build models to assess changes in vegetation structure and function. The spatial optical, thermal, and microwave images were analyzed, and the fire was evaluated using four vegetation indices (VIs): leaf area index (LAI), solar-induced chlorophyll fluorescence (SIF), and total primary production (GPP), and above ground biomass (AGB).

Qin discovered the SMOS L-VOD-based AGB dataset to be suitable for analyzing AGB's spatial and temporal fluctuation over several years in forest grid cells across Australia. LAI, VIs, GPP, and L-VOD attained their lowest levels in January 2020 and since then have quickly recovered to pre-fire levels. This implies that in both fire-affected and non-fire-affected parts of Australia, there was a significant loss of forest canopy with natural forest vegetation in 2019 and a quick and broad recovery in 2020. The contribution of climate to the loss of plant AGB in forested regions (0.11 Pg C) was somewhat larger than that of fire (0.09 Pg C), suggesting the severe impact of record high temperatures and drought on forest AGB dynamics. Both fire and climate caused these AGB losses. By January 2021, the annual AGB of 366 forest grid cells had recovered to 1.36 Pg C, a more excellent rating than in January 2019 (1.29 Pg C), and the results suggest that the recovery of vegetation in 2020 contributed the most to the recovery of AGB. Above-average annual precipitation from fire-adapted eucalyptus forests and moderate La Niña in 2020 bolstered the recovery of vegetation cover, productivity, and AGB.

Small-scale AGB variations could not be determined well because the L-VOD data used in the study had a coarse spatial resolution of 25 km. Qin et al. believe that the high-resolution satellite that will be launched later will be able to solve this problem [11].

The area of vegetation covered before and after the hill fires in Australia is calculated by the research using a substantial amount of data and formulae, which are of the high reference value.

4.2. Case in hilly mountainous areas of Fujian Province

Zhang et al. developed a technical method for fire area assessment based on the portrayal of 250 m resolution MODIS data in the fire area. They evaluated 35 forest fire samples and used scatter plots of MODIS near-infrared channel reflectance and normalized vegetation indices before and after the fire, combined with pseudo-color composite images of the fire area.

The approximate geographic extent of each fire region was first determined based on visual recognition from a total of 70 MODIS photos taken during each forest fire. The area of the fire area measured by CH2 reflectance in the near-infrared band was close to the overfire area from the ground survey from the assessment of 35 forest fires in Fujian Province in 2004, whereas the area of the fire area measured by NDVI was close to the deforested area from the ground survey. A more accurate evaluation of the forest's post-fire area is possible thanks to the methodological error of the CH2 reflectance and NDVI values from MODIS data in the fire region, which may be found to be within 15 hm2, or around 3 pixels in MODIS imaging.

The authors emphasize that the MODIS data must be as recent as feasible after the fire to maintain the experiment's accuracy because of the south's quick plant growth and recovery. Additionally, the researcher assumed that by including the topographic data in the data processing, the error might be further decreased due to the steepness of the mountainous terrain [12].

By using scatter plots to pick ROIs and selecting many fires with good dependability, the study could get results that were both scientifically valid and had low mean square deviations.

5. Conclusion

This study discusses the fundamental concepts of MODIS and how it is used in monitoring (e.g., determining the location of the fire) and evaluating (e.g., vegetation area change) forest fires. It presents numerous representative case studies, analyzes them, and concludes to arrive at the findings presented below.

Processed MODIS imagery and MODIS fire products can offer a significant portion of usability and accuracy when monitoring forest fires dynamically and identifying fire points because of their high resolution, good calibration, and positioning processing. When combined with additional satellite imagery with a similar spatial resolution to MODIS, errors can be minimized. Because of the several characteristics of the fire sites and the smoke produced when the forest burns, the accuracy of the data under investigation may be lowered.

To construct multiple vegetation and associated indicators that may be compared over time to acquire more precise answers about the particular vegetation area decrease and later recovery, MODIS, and its corresponding product datasets can be used to analyze the damage caused by forest fires. The images needed for the study must be taken as soon after the fire as possible, owing to the swift growth of vegetation, while subsequent launches of higher resolution sensors can further improve the precision of forest fire evaluations.

It is concluded that MODIS data provides an accurate source of information for tracking forest fires and estimating the harm they inflict. If this technology is used properly, it can be served as a useful tool for real-time monitoring of forest fires, assisting in the creation of relief guidelines, and studying ecological reconstruction after a disaster, but also assist in addressing issues such as global warming and the planet's overall ecosystem. With the significant environmental issues, our world is experiencing, and this is obviously of great importance.

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