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Effects of Forest Fires on Diurnal Land Surface Temperature in Boreal Forests

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Abstract: *Wildfires are the most prevalent natural disturbance in Canadian boreal forests, which could cause postfire land surface temperature change (ΔLST) through biophysical processes. Here, we used multiple remote sensing products and spatial GIS analysis methods to investigate the fire-induced daytime and nighttime LST change over Canada's boreal forest from 2004 to 2017. We further examined the differences of ΔLST among three forest types. We found a pronounced asymmetry in diurnal ΔLST, characterized by daytime warming in contrast to nighttime cooling. The differences in the effects of forest fires on diurnal surface temperature were also exhibited among three forest types. The effect of wildfires on diurnal surface temperature is more significant in evergreen forest areas than in deciduous forest areas. These results also revealed that species composition has a strong influence on the climate effects of fire in boreal regions.*

Keywords: *Forest Fires, ΔLST, Boreal Forests*

1. Introduction

The vast boreal forests are the largest terrestrial biomes on Earth, accounting for about 30% of the world's forest cover (Veraverbeke et al., 2017). Forest fires are the most critical disturbance to boreal forest dynamics, controlling the flow of carbon and energy fluxes and having positive and negative feedback effects on climate (Rogers et al., 2013). Through the exchange of energy and water, boreal forests play an essential role in regulating the regional and global climate (Bonan et al., 2008). Satellite observations have revealed that forest loss due to forest fires account for about 15% of global forest loss, and these forests are concentrated in the high northern latitudes (Liu et al., 2019). Canadian boreal forest fires typically kill most of the overstory trees, trigger a century-long vegetation succession, and have significant impacts on land surface temperature (LST) (Randerson et al., 2006, Rogers et al., 2013).

Fire regimes are expected to change further with the anticipated climate warming. Statistical data show a long-term increasing trend in burned area in Canada (Stocks et al., 2002). According to the Canadian Climate Centre's fire climate scenarios, the incidence of forest fires is increasing rapidly, with a 25% increase by 2030 and a 75% increase by the end of the century (Wotton et al., 2010). Wotton et al. (2017) suggests that the challenges of wildfire management in Canada in the 21st century include not only dealing with the increasing number of fires, but also the increasing number of high-intensity crown fires. Therefore, it is very valuable to study the effect of forest fire on land surface temperature comprehensively.

Previous studies have found that the main biophysical process controlling fire-induced LST change (ΔLST) is the change in albedo (Δα) and the change in evapotranspiration (ΔET). (Liu, et al., 2018, Rogers et al., 2013). However, most of these studies investigated the change of daily mean LST (Rogers et al., 2015), and paid less attention to explore the daytime and nighttime LST changes separately. Nonetheless, a few studies have found that a diurnal asymmetry exists in the postfire LST change (Zhao et al., 2021, Liu et al., 2019). Despite this progress, there remains little information on whether the difference of forest type might influence the diurnal LST change.

Here, we use multiple remote sensing products and spatial GIS analysis methods to investigate the fire-induced daytime and nighttime LST change (ΔLST, i.e., the fire-induced difference between the LST one year after fire and that one year before fire) over the Canada boreal forest from 2004 to 2017. In addition, we further examine the differences of diurnal ΔLST among three forest types.

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2. Data and Methods

Three satellite-data products derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) were used in this study. This MODIS-Collection consisted of products for the burned area (BA), LST, and land cover type (LCT) at various resolutions. For BA data, the monthly MCD64A1 product was used, which covered the period 2004-2017 at a spatial resolution of 500 m. For LST data, we used the monthly MYD11C3 product, with a period of 2003-2018 at a spatial resolution of 0.05 °. For the LCT data, we used the 0.05 ° spatial resolution MCD12C1 product along with the International Geosphere-Biosphere Programme classification scheme.

Monthly pixel-level BA was first integrated into annual pixel-level BA and then aggregated into Percentage of burned area (PBA) at 0.05 °spatial resolution (i.e., the number of burned pixels divided by the number of pixels within the 0.05 ° grid. Note that, only the 0.05 ° grid cells with PBA>0.2 were included in our analysis.

The fire-induced LST change is based on Equation 1

$$\Delta LST_y = \Delta LST_{y+1} - \Delta LST_{y-1} \tag{1}$$

where y is the year of forest fire occurrence. For a given burned pixel, the fire-induced (ΔLST) is the change in LST between the years previous and subsequent the fire (ΔLST).

3. Results

3.1. Changes in the daytime and nighttime surface temperatures following fires in Canada

In most areas, the annual LST (T_{max} and T_{min}) increased significantly during the day (mean ΔT_{max} = 0.699 ±1.649 K) and decreased slightly at night after forest fires (mean $\Delta T_{min} = -0.107 \pm 1.202$ K) (Fig.1 and 2). The LST response to fire also exhibits pronounced spatial patterns (Fig.1). According to the statistics, about 64.5% of areas showed a daytime warming effect, whereas only 35.5% of areas showed a daytime cooling effect. Fire-induced daytime land surface warming is more significant in the western part of Canada, and surface cooling is more significant in the central part (Fig.1a). For the ΔT_{min}, we found that about 52.9% of the areas showed a cooling effect, in which 47.1 % showed a warming effect (Fig. 1b). Fire-induced nighttime land surface warming is more significant in the western part of Canada, and surface cooling is more significant in the eastern part of Canada.

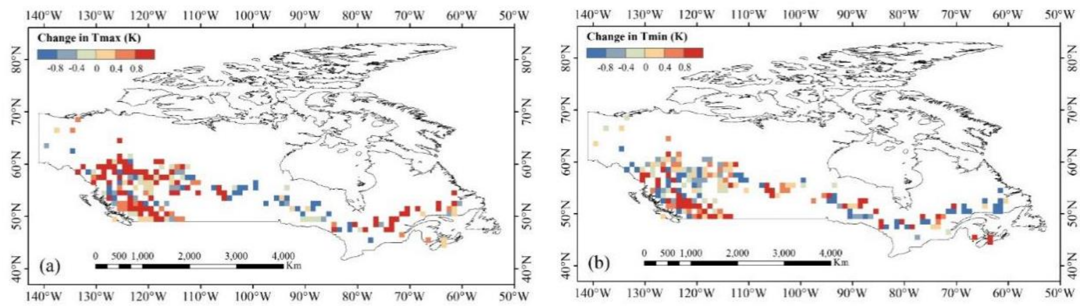

Figure 1: Changes in daytime and nighttime surface temperature (LST) per year after forest fires: (a) Change in T_{max} (K), (b) Change in T_{min} (K). Original analysis was made at 0.05 °resolution but results are aggregated to 0.5 °in this figure for display purposes.

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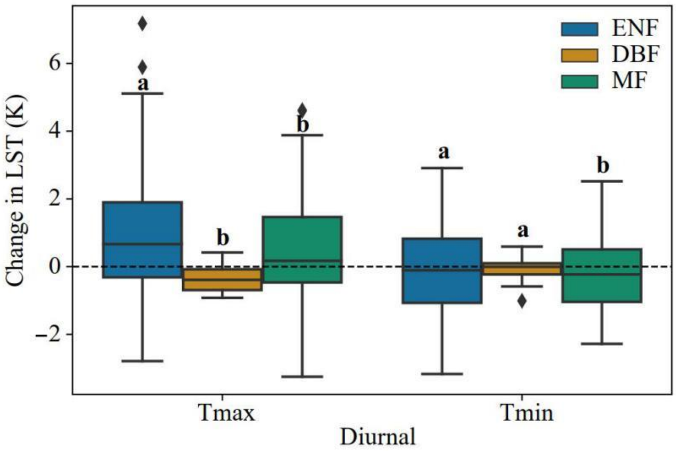

Figure 2: Effects of forest fires on daytime and nighttime surface temperature in different forest types. The symbols a, b, c, and d represent significant differences ($p < 0.05$) among different seasons determined by analysis of variance (ANOVA).

3.2. Changes and differences in surface temperature of different types of forests after fire

Fig.2 presents the fire-induced LST change for different forest types, such as ENF, MBF, MF. There was a significant increase in daytime LST for ENF after the forest fires (mean ΔT_{max} = 0.789 ± 1.633 K), while there was only a slight decrease in nighttime LST (mean ΔT_{min} = −0.076 ± 1.202 K). On the contrary, for DNF, both of ΔT_{max} and ΔT_{min} following fire show consistent cooling effects (mean ΔT_{max} = −0.416 ± 0.402 K, mean ΔT_{min} −0.075 ± 0.405 K). For the MF, forest fires produced a marked increase of daily T_{max} (mean ΔT_{max} = 0.462 ± 1.757 K, and an overall small decrease in T_{min} one year after fire (mean ΔT_{min} = −0.276 ± 1.041 K).

4. Discussion

Boreal forest dynamics is primarily driven by wildfire, which is the key ecosystem process shaping the physical and biological attributes of this biome over most of its range (Hayes et al., 2011). However, most of these studies have focused on the relationship between forest fires and daily mean LST change (Rogers et al., 2013), and there is a lack of studies on the influence of diurnal temperature (Zhao et al., 2021). Our results revealed the effects of forest fires on diurnal LST in Canada boreal forests. We found that boreal forest wildfires have a warming effect on daytime LST and cooling effect on nighttime LST one year after fire across boreal forest types. The differences in the effects of forest fires on diurnal LST were also exhibited among three forest types, suggesting that species composition has a strong influence on the climate effects of fire in boreal regions.

In accordance with previous studies, our results indicate that boreal forest fires produce an annual daytime warming effect one year after fire (Zhao et al., 2021). The changes in albedo and evapotranspiration are the potential causes of the warming (Liu et al., 2019). Rogers et al. (2015) found that reduced summer albedo caused by surface charring following fire might have increased LST. However, Zhao et al. (2021) proposed that the albedo decrease in summer only caused a slight increase in average summer net shortwave radiation but LE decreased more sharply one year after fire in North American Boreal Forest. They believed that the reduction of ET is primarily responsible for observed postfire daytime warming.

Our results reveal that postfire nighttime ΔLST is dominated by surface cooling in Canada boreal forest. There are two possible explanations for this phenomenon. Firstly, the destruction of vegetation caused by fire can reduce roughness-generated turbulence, which could otherwise bring heat from the air aloft to the surface during the night (Schultz et al., 2017). Therefore, the damage of forest canopy by fire can reduce the coupling between the near-surface air and the land surface at night, contributing to postfire surface cooling. Secondly, previous studies have found that boreal forest wildfires generally increased postfire albedo during winter, spring, and fall (Liu & Randerson, 2008). Postfire daytime energy absorption is reduced compared to the prefire state among the three seasons. As a result, energy release during the night is also reduced and this indirectly contributes to nighttime cooling.

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5. Conclusion

In this study, we analyzed the changes in the daytime and nighttime surface land temperature (ΔLST) in the Canadian region after forest fires based on various observations acquired by MODIS products and compared the differences of ΔLST in three forest types. We found that Canada boreal forest wildfires have a warming effect on daytime LST and cooling effect on nighttime LST one year after fire. The differences in the effects of forest fires on diurnal surface temperature were also exhibited among three forest types. The effect of wildfires on diurnal surface temperature is more significant in evergreen forest areas than in deciduous forest areas. Our results revealed that species composition has a strong influence on the climate effects of fire in boreal regions.

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