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Evaluation of the Effects of Wildfires in Siberian Forests Based on Satellite Data for 1996–2023

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INTRODUCTION & AIM

Wildfires are the most significant factor that affects the boreal ecosystems of Siberia. Up to 1% of the forested area is exposed to wildfires annually in Siberia, which accounts for a significant proportion of post-fire damage to the boreal forests of the world.

The problem of fire consequences monitoring such as tree stand loss, long-term changes in the thermal regime of soils, and direct emissions of carbon is very important for the region.

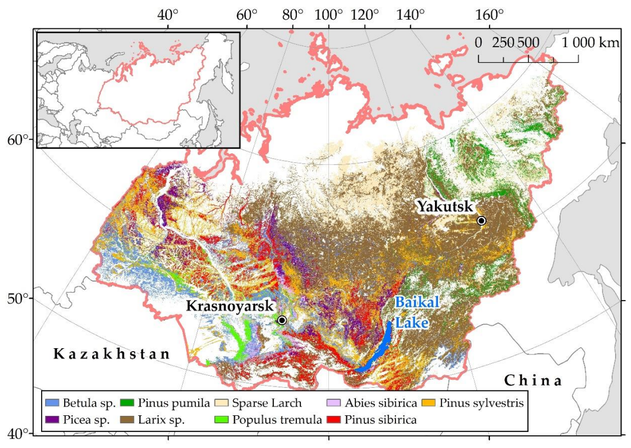
Considering the climate changes, a further increase in burned areas in Siberia is predicted.

We investigated the following issues:

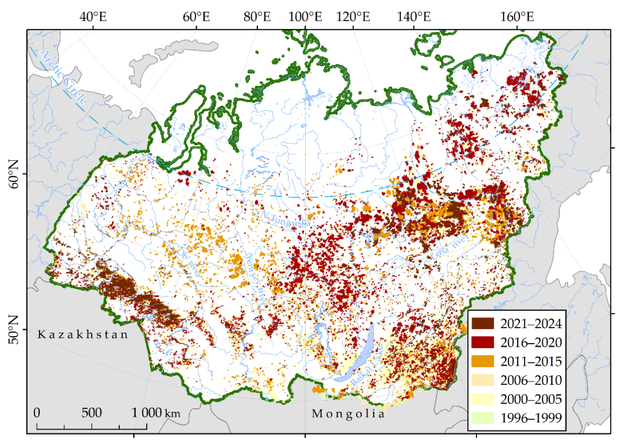
i) Annual burning of Siberian forest accounting dominant tree species;
ii) Wildfire impact and proportion of the high-intensity and stand-replacement fires in Siberia;
iii) Dynamics of high-intensity burning in Siberian forests in terms of Fire Radiative Power (FRP) over the past two decades;
iv) Direct fire emissions variation and trends accounting for fire intensity from FRP data.

METHODS

Siberia covers 9.7×10^6 km^2 between 50–75 N and 60–150 E. This is more than 50% of the area of Russia. The area of Siberian forests is estimated at 6.0×10^6 km^2 , which is about 70% of Russian forests.



Territory of Siberia. Main Siberian forest types



Spatial distribution of wildfires in 1996–2024. Only burned areas >2500 ha are shown

Remote sensing is the most effective technique for controlling large-scale processes caused by wildfires in Siberia.

Our study used fire data from the satellite monitoring geospatial database (Institute of Forest SB RAS, Krasnoyarsk, Russia) for 1996–2024. Fire intensity was ranged based on the Fire Radiative Power (FRP) technology from the standard MODIS active fire products (MOD14/MYD14).

Dominant forest types corresponding to fire polygons were obtained using the “Vega-service” (Database of the Institute of Space Research RAS, Moscow, http://pro-vega.ru/maps/).

To estimate annual carbon emissions from wildfires in Siberia, we categorized levels of fire intensity for individual active fire pixels based on fire radiative power data and then used the Seiler–Crutzen method (1980), by accounting for fire intensity in terms of FRP (Ponomarev et al., 2021).

We also estimated the proportion of stand-replacement fires using forest loss maps obtained from the Global Forest Change dataset developed in University of Maryland (Hansen et al., 2013, https://glad.earthengine.app/view/global-forest-change). We defined a stand replacement fire as a fire followed by tree cover loss detected from Global Forest Change product using spatial and temporal thresholds.

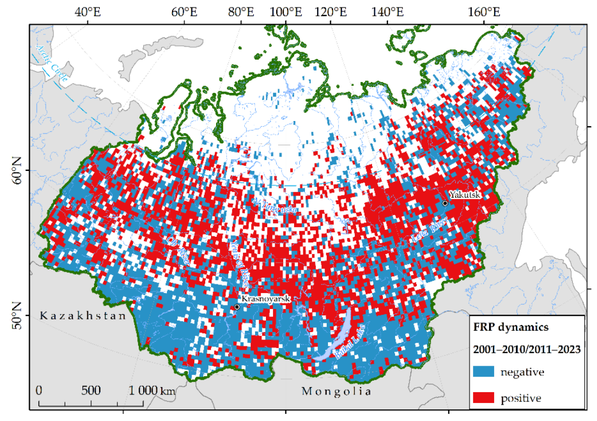
RESULTS & DISCUSSION

We found that during 1996–2023, Siberian forests experienced about 15.48±2.33 thousand fires per year, which is about 11.34±2.88 Mha of burnt areas annually. Considering fire intensity, we estimated the stand-replacement fire area in Siberia as approximately 1.0 Mha, and this value has the potential to surpass 3.0 Mha by 2050, given the current trends in burning regimes and fire intensity.

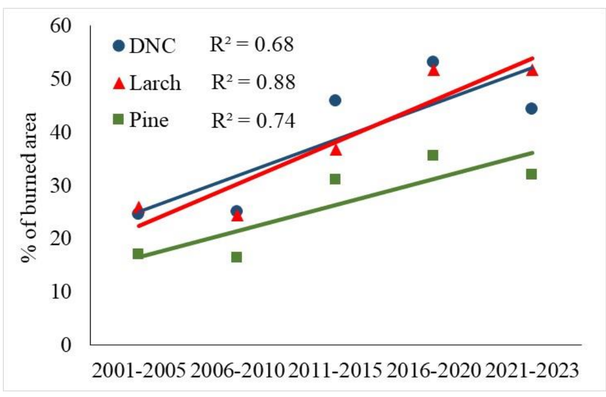
Forecast of the area of stand replacement fires in Siberia

№	Vegetation types	Stand-replacement fires, Mha/year	
		until 2021	until 2050
1	Larch (*Larix sibirica, L. gmelinii, L, cajanderi*)	0.52	1.65
2	Larch sparse (*Larix sibirica, L, cajanderi*)	0.25	0.79
3	Pine (*Pinus sylvestris*)	0.11	0.33
4	Dark coniferous (*Pinus sibirica, Abies sibirica, Picea obovata*)	0.07	0.24
5	Tundra vegetation, Siberian dwarf pine (*Pinus pumila*)	0.034	0.12
Total:		0.98	3.13

Over the past two decades of 2001–2023, a growth trend in high-intensity fires was typical for a significant part of Siberia (~30% of the total area), mainly in larch-dominated forests (>60° N) and in the tundra (>67° N).

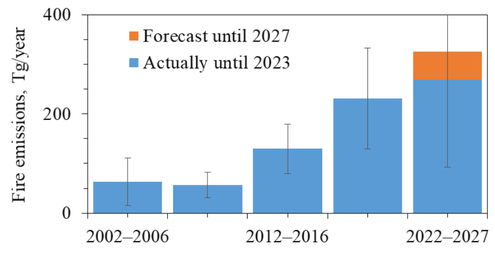


Change in fire intensity in terms of increase/decrease of total FRP values



Proportion of stand-replacement fires

We also found significant increasing trends in stand-replacement fires for main forest types of Siberia (R^2 = 0.68–0.88, p < 0.05) with the proportion of stand replacement burning reaching 40–50% in Larch and Dark Coniferous (DNC) stands.



Dynamics of fire emissions in Siberia

Direct fire emissions have been rising from 60.0±25.8 Tg/year in the early 2000s up to 296.0±102.0 Tg/year during the 2020–2023 seasons due to increases in both wildfire area and the proportion of high-intensity fires (Ponomarev et al., 2023).

CONCLUSION

Under climate change conditions in Siberia, the proportion of high-intensity fires is growing, determining a significant impact on the forests, and, consequently, on the emissions of carbon-containing compounds. In the near future, carbon sinks may be suppressed by annual fire emissions, resulting in a positive carbon balance in ecosystems.

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