Extreme climate sparks record boreal wildfires and carbon surge in 2023

Lili Liang,[1] Shijing Liang,[1] and Zhenzhong Zeng[1,*]

[1]School of Environmental Science and Engineering, Southern University of Science and Technology, Shenzhen 518055, China

*Correspondence: zengzz@sustech.edu.cn

Received: December 18, 2023; Accepted: April 24, 2024; Published Online: April 25, 2024; https://doi.org/10.1016/j.xinn.2024.100631

Citation: Liang L., Liang S., and Zeng Z. (2024). Extreme climate sparks record boreal wildfires and carbon surge in 2023. The Innovation **5(4)**, 100631.

While human activities, such as the burning of fossil fuels, are the primary contributors to the increase in atmospheric CO_2 levels, large-scale wildfires can exacerbate this situation. In years with extensive and severe wildfires, additional carbon emissions can significantly perturb global carbon budgets,[1] thereby impeding existing endeavors to mitigate climate change. Notably, a recent investigation reported a notable surge in carbon emissions originating from boreal forests in 2021,[2] reaching an estimated 0.48 gigatons of carbon (Gt C). However, this record proved temporary. Figure 1 shows that by September 2023, the carbon emissions of boreal forests exhibited an unprecedented increase, primarily attributed to the Canadian boreal region, reaching 0.86 Gt C. The consequences extend beyond geographical borders, as wildfires occurring hundreds of kilometers away resulted in the worst air quality in New York and Chicago. The increasing severity of boreal forest wildfires is accompanied by growing public concern, suggesting the potential proximity to or crossing of a critical tipping point in the ecological functioning of boreal forests.[2]

RECORD-BREAKING CARBON EMISSIONS FROM BOREAL WILDFIRES IN 2023

According to the newly released Global Fire Emissions Database (v.4.1s), boreal carbon emissions in 2023, closely following 2021, exceed the 2000–2020 average by more than three standard deviations. Particularly alarming is the 10-fold increase in carbon emissions stemming from boreal North America compared to the 2000–2020 average (Figures 1A and 1B). Note that these fire emissions constitute a gross flux of carbon into the atmosphere, including those inherent to natural disturbance-recovery cycles, those intensified by changes in climate, CO_2, and N fertilization, and those linked to land use and change. Regarding the global carbon budget, only emissions associated with intensified fires due to climate-related factors should be considered in the terrestrial CO_2 sink component.[1] Therefore, the unprecedented increase in boreal wildfires and the consequential dynamics in carbon emissions not only pose threats to ecological well-being in the affected areas but also have significant ramifications for global carbon budgets.

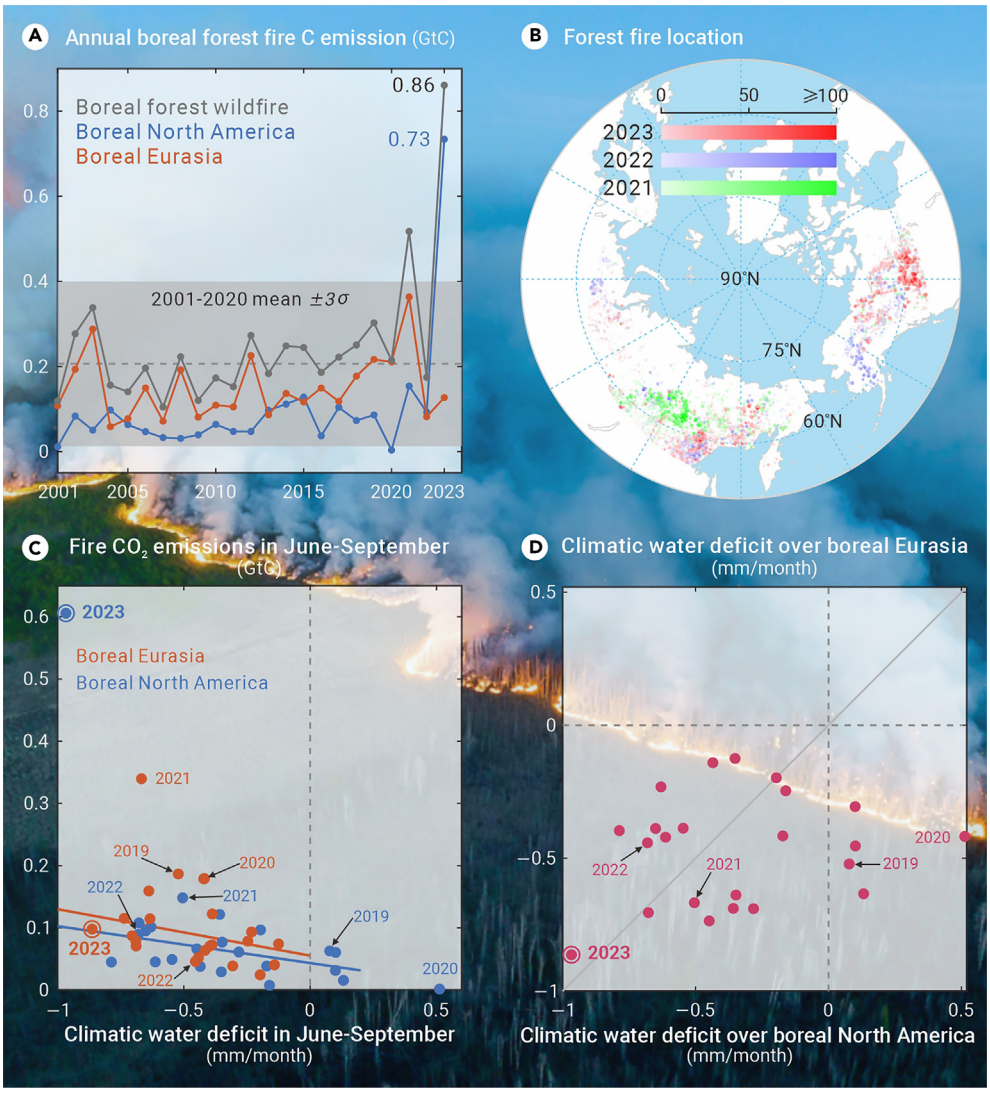

Figure 1. Boreal forest fire map, historical carbon emissions, and corresponding climatic conditions

(A) Annual boreal forest fire carbon emissions from Global Fire Emissions Database until September 29, 2023. (B) Forest fire locations from 2021 to 2023 (MCD14DL) with fire records detected and resampled to 0.1° grid cells. (C) Relationship between fire carbon emissions and tree area-weighted climatic water deficit during the fire season (June to September) from 2001 to 2023. According to the robust regression, the significance (*p* value) is 0.07 for boreal North America and 0.17 for boreal Eurasia. The average tree area from 2001 to 2021 (MOD44B) was considered. (D) Relationships between the tree area-weighted climatic water deficits in boreal North America and boreal Eurasia from June to September. Background photo of wildfires in British Columbia, Canada. Source: BC Wildfire Service. Copyright Province of British Columbia. Used with permission.

Lightning and extreme hot and dry climatic conditions have been identified as the main drivers of boreal forest wildfires.[2,3] Building upon this foundation, our analysis focused on the complex relationship between carbon emissions from boreal wildfires and the tree area-weighted climatic water deficit during the dry season (June–September) following Zheng et al.[2] The findings show that the year 2023 was characterized by an exceptionally low climatic water deficit in boreal regions during the dry season. Importantly, this discovery closely agrees with prior propositions linking boreal wildfires to droughts and severe water deficits (Figures 1C and 1D). The correlation between the observed decrease in climatic water deficits and the heightened incidence of boreal wildfires highlights the pivotal influence of water availability on wildfire dynamics within these ecosystems.

In evaluating the sensitivity of fire carbon emissions to climatic water deficits, linear regression suggested that boreal Eurasia may exhibit higher sensitivity than boreal North America, conforming with the hypothesis of Zheng et al.[2] However, regression may not be applicable to a system with a potential tipping point. Despite the seemingly stable fire carbon emissions of North American boreal forests until 2022, early signals indicate underlying vulnerabilities: the 5-year standard deviation in North America significantly increased over time, culminating in a significant increase in 2023. This indicates an unstable resilience and the accumulation of climatic impacts leading to a severe event. In contrast, boreal Eurasia shows no significant increase in the 5-year standard deviation. A more plausible scenario is that both Eurasia and North America may exhibit distinct sensitivities to climate change. However, determining which region is more sensitive remains challenging, underscoring the urgency of monitoring both areas as boreal forests approach critical tipping points, irrespective of their geographical location.

IMPLICATION OF BOREAL WILDFIRES IN LOCAL CARBON CYCLE AND GLOBAL CARBON BUDGET

To grasp the carbon cycle and manage forests effectively, a comprehensive understanding of the carbon dynamics of ongoing boreal wildfires, encompassing both postfire and prefire stages, becomes imperative. In terms of postfire processes, a thorough examination of long-term cycles is essential for understanding the ongoing carbon dynamics in boreal burned areas. To ensure robust results, researchers should utilize historical data while closely monitoring the evolution of boreal wildfires. Regarding prefire stages, identifying specific conditions and driving mechanisms underlying extreme wildfires is crucial for refining strategies to mitigate carbon emissions associated with detrimental boreal forest wildfires. The emergence of overwintering fires, also known as "zombie fires," poses a unique challenge, as they persist through winter, hidden beneath snow cover and undetectable through traditional remote sensing methods. Their ability to smolder and reignite under favorable conditions contributes to prolonged carbon emissions and emphasizes the need for enhanced monitoring and management efforts.

Within the framework of the global carbon budget, the attribution of boreal forest wildfires must distinguish between fires integral to natural disturbance-recovery cycles and those exceeding acceptable severity levels due to climate change. Traditionally, wildfires are regarded as carbon-neutral processes,[4] which involve the combustion of aged trees with significant carbon emissions, concurrently fostering vegetation growth. However, it is important to acknowledge that the unprecedented severity and frequency of recent boreal wildfires introduce complexities not considered in previous research. As uncertainty persists regarding the long-term assessment of the disturbance-recovery cycle and the existence of a tipping point in the boreal ecosystem, recent extreme boreal wildfires provide an opportunity for comprehensive long-term investigation.

COMPREHENDING BOREAL WILDFIRE-CLIMATE FEEDBACK AMID GLOBAL CHANGE

Wildfires not only bear the influence of climate change but also actively contribute to it.[5] To better predict boreal wildfires and their climatic consequences, a thorough assessment of the interplay between boreal wildfires and climate feedback during both pre- and postfire processes is needed. On the one hand, climate change induces changes in precipitation, temperature, and other factors, determining the frequency and severity of boreal wildfires. Conversely, boreal wildfires release substantial amounts of black carbon, carbon dioxide, and other greenhouse gases, causing complex radiative transfer processes and potentially contributing to further climate change. Moreover, changes in land cover resulting from wildfires impact biogeophysical processes, altering the surface albedo and thus influencing the broader feedback loops between fires and climate.

To combine the assessment of the global carbon cycle and future climate risks, the advancement of earth system models for realistic wildfire integration is key. This refinement covers factors such as ignition sources, fire spread patterns, the influence of vegetation types on fire behavior, etc. Bridging this gap requires a focused push toward incorporating real-time observational data, satellite imagery, and ground-based measurements to enhance the reliability of simulated fire processes. Additionally, the development of Earth system models highlights the collaborative efforts among researchers and institutions from diverse fields. This perspective not only enhances our understanding of the role of wildfires in the Earth system but also informs effective decision-making to maintain the objectives of the Paris Agreement within reach.

CONCLUSION

Amid the escalating boreal wildfires this year, which greatly exceeded historical norms, this study underscores the urgent need to comprehend and respond to the potential tipping point of boreal ecosystem functioning and the global carbon budget. By analyzing fire locations, carbon emissions, and climatic conditions, we can identify a potential shift in the boreal ecosystem. The relationship between fire carbon emissions and climatic water deficits reveals nuanced interactions. These findings emphasize the urgency for comprehensive evaluation, integrating pre- and postfire carbon dynamics, climatic feedback, and realistic wildfire processes in Earth system models, which is crucial for accurate future climate risk assessments and effective mitigation strategies.

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ACKNOWLEDGMENTS

This study was supported by the start-up fund provided by National Natural Science Foundation of China grant no. 42071022 (NSFC) and the Southern University of Science and Technology (no. 29/Y01296122). We thank the principal researchers and teams for all the datasets and data analysis methods used in the study.

DECLARATION OF INTERESTS

The authors declare no competing interests.