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EDITORIAL

The Innovation Geoscience

2023 Canadian wildfires produced extreme CO_2 emissions

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Received: January 9, 2025; Accepted: November 21, 2025; Published Online: November 22, 2025; https://doi.org/10.59717/j.xinn-geo.2025.100176

Citation: Xiang W., Ouyang C., An H., et al. (2025). 2023 Canadian wildfires produced extreme CO_2 emissions. *The Innovation Geoscience* **3**:100176.

In recent years, with the global warming, the area burned by wildfires in boreal forests has increased significantly. Extreme wildfire severity has increased across the boreal forest biome, resulting in the release of vast quantities of greenhouse gas (GHG) emissions previously sequestered in above- and below-ground biomass reserves and deep organic soils such as peat, exacerbating global climate chang.[1,2] In 2021, the scale of boreal forests wildfires broke the highest record since 2000[1] and in 2023 the record was broken again, and the scale of the wildfire was about four times that of 2021.[3] The international community has formulated international conventions such as the Paris Climate Agreement, which set the goal of limiting the temperature rise to 1.5°C by the end of the 21st century and estimated the remaining global carbon emissions that need to be controlled to achieve this goal.[4] The carbon emissions generated by the Canadian wildfires in 2023 have already had a huge impact on the achievement of this goal. It is necessary to accurately estimate Canada's wildfire emissions and analysis the causes of wildfire growth and the distribution characteristics of combustion emissions. Which can help the government formulate targeted policies based on wildfire characteristics, understand and mitigate future extreme wildfire events. Byrne et al.[5] has previously estimated the carbon emissions from wildfires in Canada from May to September 2023 on the basis of inverse modelling of satellite carbon monoxide observations, which was an extreme number. This commentary estimates carbon dioxide emissions from wildfires in Canada for the entire year of 2023 based on the GFED and GFAS databases. We believe that the results based on the GFED database are more reliable and are basically similar to the estimates of Byrne et al.[5] In addition, we analyze the spatial patterns of carbon dioxide emissions distribution and extreme wildfire events, and intuitively illustrate the adverse impact of Canada's 2023 wildfire emissions on global climate warming from the perspective of carbon dioxide. This can help us gain a deeper understanding of the current situation and develop scientific countermeasures.

CANADIAN WILDFIRE CO_2 EMISSION ESTIMATION RESULTS

Byrne et al.[5] estimate that carbon emissions from the 2023 Canadian wildfires were about 674 TgC based on the basis of inverse modelling of satellite carbon monoxide observations, accounting for 26.7% of global wildfire carbon emissions in 2023 (global wildfire carbon emissions in 2023 were 2524 TgC, data from GFED 4.1s), which is an extreme amount.[5] However, simply publishing the estimated carbon emissions figures may not be intuitive and sufficient for us to clearly understand that extreme wildfires are a serious situation facing the global atmosphere at this stage. Therefore, we estimated Canada's wildfire CO_2 emissions in 2023 based on the Global Fire Emission Database 4.1s (GFED 4.1s) database, the Global Fire Assimilation System (GFAS) database, and the data from Natural Resources Canada (https://cwfis.cfs.nrcan.gc.ca/home), and compared them with data from 2000 to 2022. Based on the daily monitoring results provided by Canada Fire Monitoring, Mapping, and Modeling System (Fire M3), it is believed that the results estimated based on GFED 4.1s are closer to reality

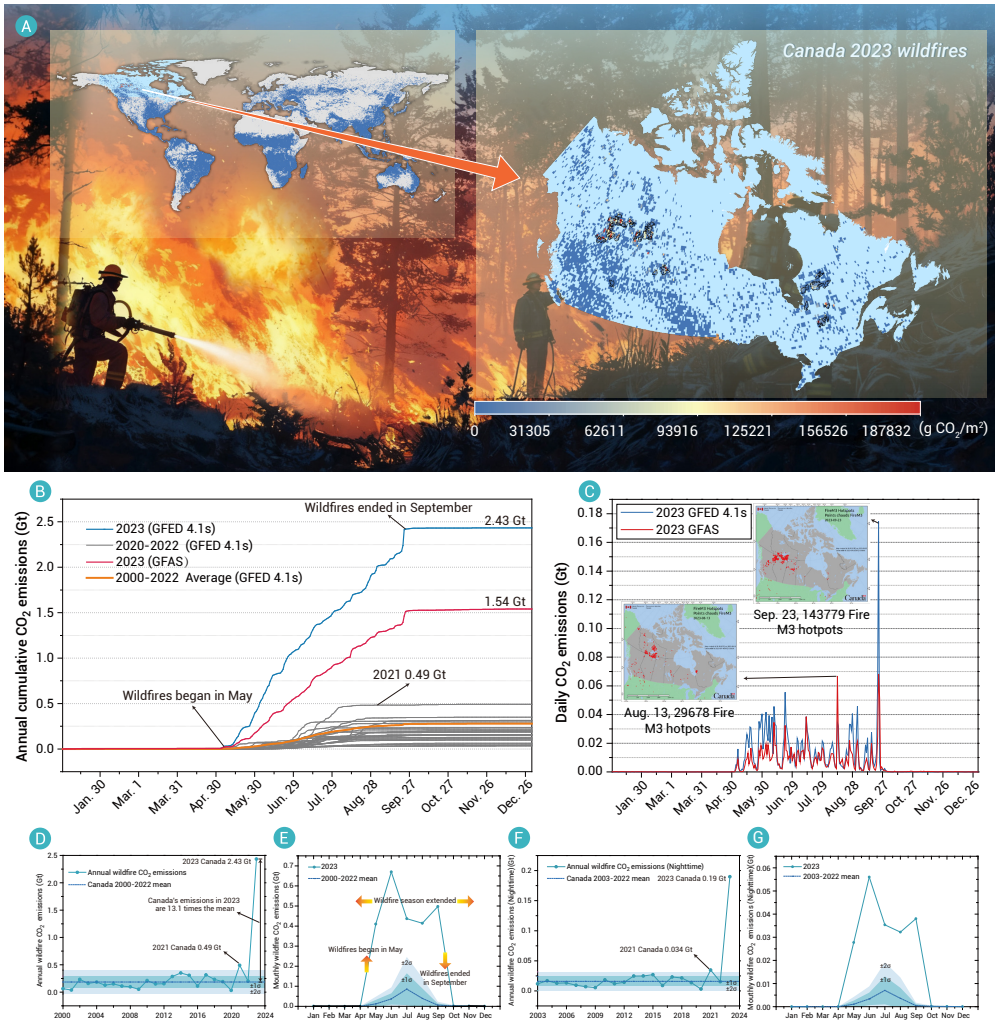

Figure 1. (A) Distribution of global wildfire CO_2 emission intensity (g $CO_2 \cdot m^{-2}$) in 2023 (The accompanying figure is Canadian wildfire CO_2 emission intensity, with the black curves circle the top 20 extreme wildfire areas in Canada in 2023). (B) Annual cumulative CO_2 emission curve for wildfires in Canada from 2000 to 2023. (C) Daily CO_2 emission curve for wildfires in Canada, 2023. (D) and (E) are Canada wildfire CO_2 annual and monthly emissions, respectively; shading indicates one and two standard deviations from the 2000 to 2020 mean. (F) and (G) are Canada wildfire CO_2 annual and monthly nighttime emissions, respectively; shading indicates one and two standard deviations from the 2003 to 2020 mean (Nighttime is set as UTC 6:00-15:00 according to the wildfire area. Since there is no GOES data from 2000 to 2002, it is not included in the calculation).

(Figures 1B-C). The annual emission intensity distribution is shown in Figure 1A, the strongest area reached 0.19 (t $CO_2 \cdot m^{-2}$), and most of these high emission intensity points occur in areas with larger scale fire events, while some small-scale fire areas have relatively lower emission intensity. In addition, the fires were distributed over a wide area. Except for the Nunavut region in northern Canada, wildfires were distributed almost throughout the country (Figure 1A). The 2023 Canadian wildfires resulted in 2.43 Gt of CO_2 being emitted into the atmosphere, with large areas of fire burning from May to September (Figures 1B-C). The total CO_2 emissions from wildfires in 2023 were 13.1 times that of the calculated mean for the period 2000-2022, showing an extremely abnormal increase (Figure 1D), consuming 0.61% of the world's remaining CO_2 budget, seriously affecting the subsequent remaining carbon emission plans (CO_2 emissions budget from 2023 to 2050 required to limit global temperature rise to 1.5°C (50% achievement)). We exported nighttime CO_2 emissions, which also showed an unusual increase (Figure 1F). From the distribution of emission time in a year, the phenomenon of large-scale fires starts earlier in 2023. The emission was the highest in June 2023, with CO_2 emissions reaching 0.67 Gt. The monthly mean emission peaked in July from 2000 to 2022, while the monthly emissions peaked in June during 2023 and remained at a high level from May to September (Figures 1E & G). From the seasonal characteristics of fires, it shows a trend of earlier start of the fire season and prolonged duration.

Characteristics of the top 20 extreme wildfire events in Canada in 2023

The single large-scale burning events in Canada in 2023 were becoming extreme. We conducted a detailed analysis of Canada's top 20 largest wildfire events, revealing the main characteristics of Canada's extreme wildfire events from multiple perspectives, including surface cover, burn ratio, and nighttime burning emissions. The largest single fire event burned an area of 1.3×10^6 hectares, which is almost the area burned by wildfires in Canada in the whole year of 2022. The forest cover percentage of the top 20 extreme wildfire events reached 52.1%, among which the wildfire events with the highest forest cover percentage reached 75.7%, which is almost a typical northern forest fire (the Non-Vegetated Land ratio includes invalid areas such as cloud cover, so the ratio of other areas may be higher). The total nighttime CO_2 emissions from wildfires in 2023 were 7.8% of the daily emissions, which is almost the same as the level from 2003 to 2022. The distribution of nighttime emissions is worth noting, as higher nighttime emissions often occur in large-scale fires, with local nighttime emission proportions as high as 17%. Even though the nighttime temperature and air humidity are not conducive to the spread of wildfires, a high proportion of nighttime fires still occur. The large-scale burning of extreme fires makes it more difficult to extinguish fires at night, which also promotes the occurrence of large fires that last all night. Some severe overnight fires also appear to be becoming more frequent during extreme wildfire events. This may be the driving force of fire spread by global warming and drying. In addition, we generated delta normalized burn ratio (dNBR) and relativized delta normalized burn ratio (RdNBR) of the top 20 extreme wildfire events based on the Google Earth Engine (GEE) platform, found that the dNBR of most fires have a positive correlation with the CO_2 emission intensity values. What's more, the higher the CO_2 emission intensity of the fire, the more obvious its linear relationship with the burn dNBR, which may provide new ideas for rapid assessment of large-scale and high-severity fire events. The code how we deal with the raw data in detail can be accessed in zenodo (https://doi.org/10.5281/zenodo.14044571ome).

SUMMARY

The scale of the Canadian wildfires in 2023 is unprecedented. Firstly, the burned area is almost ten times the average level in Canada in previous years. Secondly, the scale of single fire events shows a more extreme trend. The largest single fire area is almost the area burned by wildfires in Canada in the whole year of 2022. In addition, higher proportions of nighttime CO_2 emissions were found in areas with large fires, which may be an abnormal signal of frequent all-night burns. On the other hand, our findings on the relationship between dNBR and CO_2 emissions may provide new approaches to quickly assess the fire hazard when a large-scale fire with a high burning intensity occurs. Although the linear relationship found now is not particularly obvious, if more basic data support is provided, combined with vegetation cover data and other information to establish a detailed data regression logic, it may become a method for quickly assessing large-area fire images in the future. Overall, the impact of Canada's 2023 wildfires was huge, increasing extreme wildfire events in Canada pose a significant risk on global climate budgets, compromising GHG emissions reductions targets. Therefore, comprehensive analyses of the causes of wildfire growth and the distribution characteristics of combustion emissions, should be prioritised in environmental policy and management to reduce the frequency of wildfire occurrence, control the speed and scale of wildfire spread, and achieve a reduction in wildfire emissions.

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FUNDING AND ACKNOWLEDGMENTS

This research is funded by the Sichuan Science and Technology Program (2025YFNH0009), West Light Foundation of The Chinese Academy of Sciences (xbzg-zdsys-202401), Postdoctoral Fellowship Program of CPSF (GZC20232570). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

AUTHOR CONTRIBUTIONS

Conceptualization: Wen Xiang, Chaojun Ouyang. Data curation: Wen Xiang. Funding acquisition: Chaojun Ouyang. Methodology: Wen Xiang, Chaojun Ouyang, Huicong An, Da Wei. Supervision: Chaojun Ouyang. Visualization: Wen Xiang. All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

Chaojun Ouyangis an Editorial Board member of The Innovation Geoscience and was blinded from reviewing or making final decisions on the manuscript. Peer review was handled independently of this member and their research group. The other authors declare no conflicts of interest.