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Carbon Emission Mapping from Disturbnaces in Canada and Alaska Using Synthetic aperture radar (SAR), Landsat and Lidar

By

Chinyere Ottah

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment
of the Requirements for the Degree Doctor of Philosophy
in Earth and Environmental Sciences

December 2023

Abstract

Wildfire is the major standing disturbance in Canada. The area burned in Canada over the years has continued to progress with climate change as well as carbon released due to fire mediated disturbances for the year 2023. Here, statistical models will be established between field combustion and remotely sensed data from Landsat imagery as well as other environmental and climate variables obtained from the GEE datasets to estimate carbon emitted from the 2023 wildfires in order to derive a combustion map for 2023. The combustion datasets described here can be used across local and global scale for fire combustion science. The combustion datasets which will be described here [github.com/ChinyereRuth/Canada-Carbon-emission-RDM] can be used for local to continental-scale applications of boreal fire science.

Keywords: Wildfire, carbon, spatial modelling, boreal forests

Contents

Acknowledgements

I am profoundly grateful to my dedicated supervisor, Dr. Alemu Gonsamo, whose unwavering guidance and support have been invaluable throughout my entire PhD journey. His expertise, encouragement, and commitment to excellence have significantly enriched my academic experience.

I extend my sincere appreciation to Dr. Anthonio Paeza for imparting his expertise and providing a comprehensive introduction to R and GitHub. His insightful teaching has equipped me with essential skills that have proven instrumental in my research endeavors.

Introduction

Worldwide, forests are vital carbon sinks and they store carbon belowground and aboveground. The boreal forest is the largest forest biome in the world and more than 20% of this zone is in Canada contributing to 8% of the world's forests (Brandt, 2009). Canada's boreal forests accumulate over 28 Pg of Carbon (Kurz et al., 2013) making them important global C reservoirs. A vast amount of Carbon has accumulated within this zone because of slow decomposition from cold temperatures and from their anoxic conditions (Kurz et al., 2013).

Although this zone has been known for a very long time be a C sinks, drier air temperatures attributed to climate change are now making them vulnerable to wildfire by enhancing drier fuels below and aboveground. Wildfire is currently the dominant disturbance impacting the boreal forest and accounting for vast amounts of C (Potter et al., 2023). Carbon loss is the release of particles, gasses and aerosols into the atmosphere. Wulder et al. (2020) estimated that about 1.79 Pg of biomass had been lost as a result of fire disturbance from 1985–2016. In addition to this, fire regimes are also changing, and these trends are projected to increase as climate change progresses Changes to fire regimes in Canada for an increase in area burned, fire intensity and fire severity leading to more carbon emission from fires aboveground and belowground. For example, over 17 Mha have burned just from the fires in 2023 alone in Canada. This is 5 times higher than the 2.37 Mha annual burn reported by Potter et al. (2023) in the past two decade. Changes in Canada's fire regime (fire frequency, intensity, burned area, ire severity) have the ability to convert some of these forest biomass C stocks to carbon sources and this ecosystem might not return to their original biomass carbon storage.

To understand the impact of fires on Canada's boreal forest where small fluctuations in temperature are already noted and projected to have significant effect on climate change (Phadnis and Carmichael, 2000), there is a critical need to estimate and understand the carbon loss from fire. This will not only help to improve carbon modelling and reporting but also provide mitigation measures for the areas where these trends are expected to be high.

There are two approaches to estimating carbon loss from fires. The first is the more traditional approach where the area burned, the fuel load (biomass consumed), the combustion completeness and the fraction of carbon are taken into account (French et al., 2011). The second approach is the remotely sensed method where statistical techniques are used to model combustion by establishing a relationship between field combustion and remotely sensed variables. For the more traditional approach of C emissions, a lot of uncertainties arises when accounting for fuel load and the combustion completeness as it differs from landscape to landscape (Hook et al.; Rogers et al., 2014)Hook et al., 2013). The latter is now used widely because of the availability of satellite imagery and the integration of field C measurements. Fuel load can be mapped with remote sensed observations and C loss information can be cover for a larger extent both

spatial and temporally. Typically, remote sensing estimates of C loss rely on statistical approach between field measurements of C loss and absorption properties from either active or passive sensors. Several studies have found a significant relationship between remote sensing observation and carbon combustion across the boreal forests (Veraverbeke et al., 2015). The difference normalised burn ratio along other environmental spectral inputs, topographic and climate variables are derived to explain C loss. For example, Rogers et al. (2014) was able to estimate the amount of below and aboveground carbon loss from fire disturbance in Alaska using dNBR and field combustion. Veraverbeke et al. (2015) using geospatial data and Environmental variables reported that elevation, the day of burning, Burn severity (dNBR) and tree cover were the drivers of carbon emission from boreal fires in Alaska. Similarly, Potter et al. (2023) related file combustion measurement with predictor variables of climate, fire weather indices, environmental variables and remotely sensed variables. He reported that the period where a larger fire year was witnessed and later season burning generally accounted for a higher mean combustion. Tree cover, elative humidity, Normalized Difference Infrared Index (NDII), and dNBR were the most important variable for aboveground combustion, while silt, slope, solar radiation, tree cover and sand were the drivers of combustion for belowground combustion.

Carbon emission mapping such as our studies here will allow for improving C emission accounting, modelling and reporting and also more accuracte prediction of C losses which is a very key importance discussion within the united nations framework accounting.

Most of the research modelling carbon emission from disturbances such as wildfire only looked at Alaska and sometimes a combintaio of Alaska and western Canada. This research will be the first to provide belowground, soil and aboveground C emissions for the entire Canada Here, we are looking at the carbon emission rom fire from the entire Canada considering that this year, Canada had the worst fire seasons compared to other years. It is therefore important to understand the C that has been released from this disturbance and mitigation measures that can be carried out to help this ecosystem recovered from his disturbance. And also, carbon emission modelling of Canada will help in improving Canada C loss emission report and modelling and also to understand the drivers of C emission within Canada's forests.

Methods

Study area

The study area (Figure 1) is Canada's forests region which comprises of boreal, great lakes, acadian, carolinian, subalpine, columbia, montane and coastal forest. Tree species within the zone are generally conifers such as black spruce, white spruce, Tamarack, balsam fir and jack pine while deciduous trees within the zone includes Aspen, balsam poplar and paper bitch. The climate of Canada's forest varies but it is mainly characterized by cold winters and short summer (Brandt, 2009), although we are beginning to observed more warmer winter due to climate change. The mean temperature in Canada's boreal forests ranges 10ºC- 20ºC and this varies from region to region (Zhang et al., 2019)
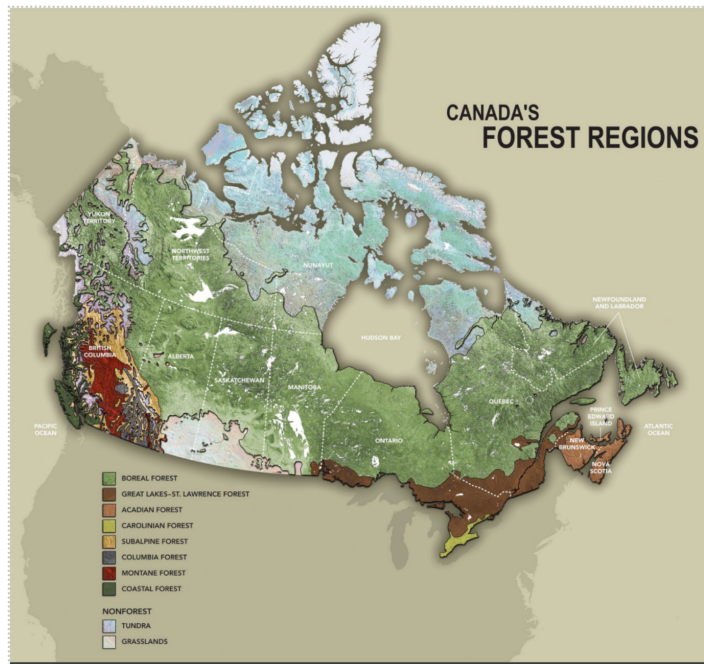

Figure 1: Canada's forests regions (Natural resource Canada)

Wildfire is the major standing disturbance within Canada's boreal forest and also other forest region with more than 2 Mha burn annually on average (Stocks et al., 2002) although this range varies from year to year.o determine areas that burned, a burned area map derived using a support vector machine learning algorithm will be used to identify area burned. To determine the areas that are primarily forests, a land cover map will be used to stratify the various land cover types. a land cover map will be used to stratify the areas of various landcover classes.

2.2 Field data

Field combustion area

To estimate the amount of C loss across Canada's major disturbances, Field combustion measurements for the year 2014 and 2015 as shown in Figure 2 were acquired from a number of publications that carried out combustion measurement within Canada's boreal forests and published online as a single database (Walker et al., 2020a).

This field measurements resulted in 456 plots and were used with other predictor variables to estimate C loss from Canada 's boreal forest fires.
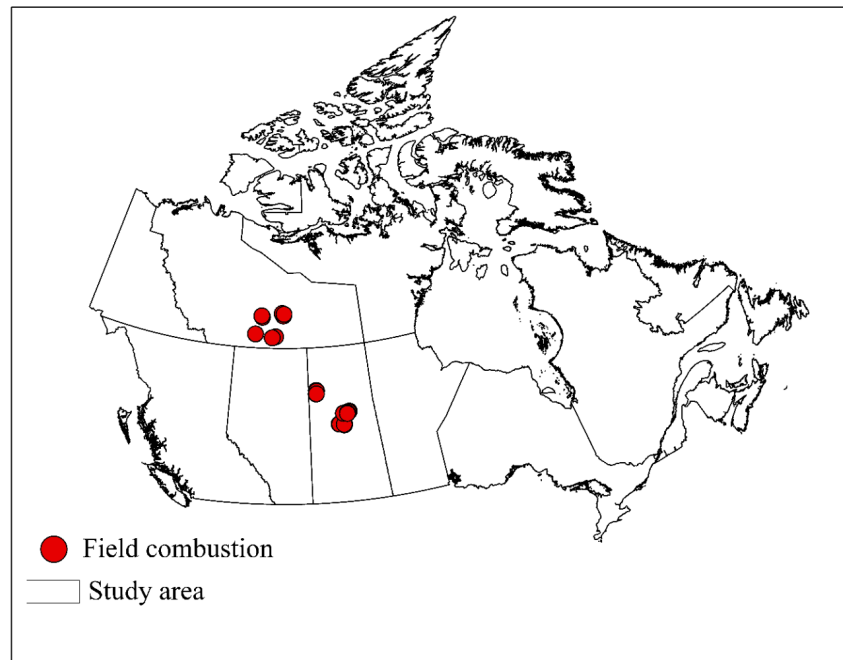

Figure 2: Field combustion area

Burned-area, harvest and insect disturbance mapping

Disturbnace map across the entire sty area will be drive using a random forest approach where we integrated different spectral indices, spectral bands and environmental variables. A threshold value established from literature and other filed collected disturbance site will be used on the final disturbance product to identify each disturbance types(fire, harvest and insect infestation) within Canada's forests.

Combustion models

Predictor variables

Field combustion measurements for aboveground and belowground C loss was obtained from Walker et al. (2020) and related to gridded environmental, fire severity and remotely sensed variables of combustion (Figure 3).
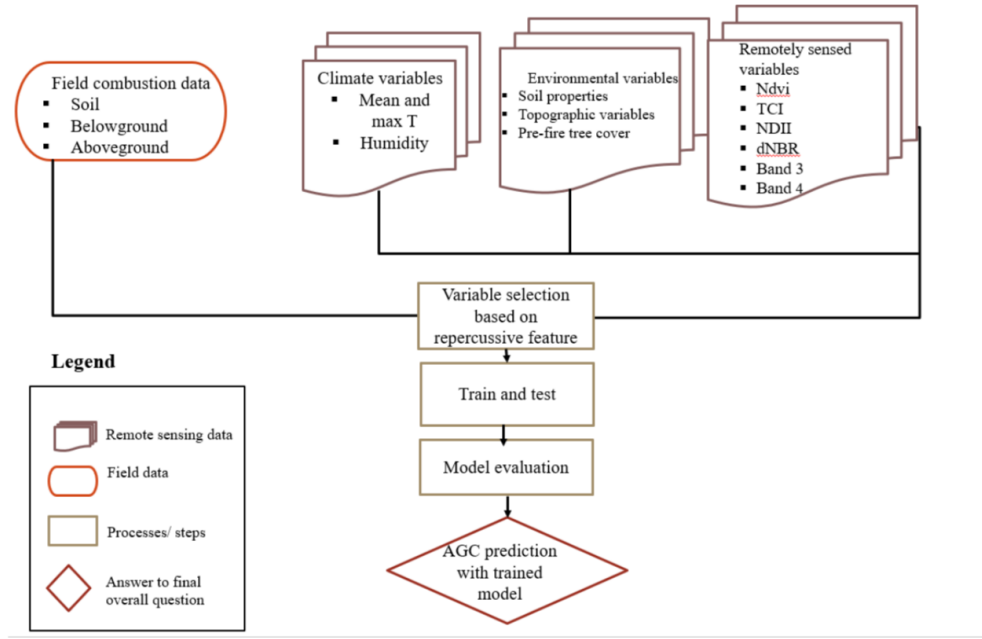

Figure 3: method to map C emissions from disturbance

The predictor variables of combustion used in this study was selected first by spanning across the literature and also discussing with experts and also further validated with a selection from random forests.

Climate variables   Climate variables used in this study was obtained from Climate NA. Climate NA provides monthly, seasonal and yearly gridded climate data. This data was used to generate climate impact of C combustion within Canada's boreal forests.

2.4.3 Environmental variables   Aboveground combustion from fire depends on a lot of top tree influence. The environmental variables that we will use for this research includes elevation, Soil properties, slope, aspect, and pre-fire tree cover. The elevation data will be obtained from the Advanced Spaceborne and Thermal Emission and Reflectance Radiometer Global Digital Elevation Model (ASTER GDEM), and then slope and aspect will be derived in ArcGIS or R USING THE DEM.

Prefire tree cover plays a huge factor and influences below and aboveground combustion. Tree cover influences biomass fuel for burning and it is also a measure of tree stand. Studies have found out that tree cover correlates with C loss (Rogers et al., 2014). The pre-fire tree cover used in this study will be obtained rom Sexton et al et al. (2013) for the year201 and it will serve as the pre- fire tree cover for our combustion model

The differenced normalised burn ratio (dNBR) assess changes in fire impacted vegetation using the near and shortwave infrared reflectance (Key & Benson, 2004). dNBR will also be included as a predictor variable as studies have found out the dNBR correlates significantly with biomass loss. Spectral bands of Landsat 1- 9 wil be downloaded from the USGS and the NIR and SWIR band s will be used for deriving NBR (NIRSWIR)/(NIR + SWIR). dNBR will be computed as the difference between pre-fire and post fire NBR.

2.4.4 Remotely sensed variables   Remotely sensed variables used for this studies were all derived from Landsat 7 and 8. This include Landsat band 1 -9, the normalised differenced vegetation indices(NdVI), the topographic wetness index, Tasseled cap indices, and the Landsat dNBR

Results

```
## tibble [467 x 12] (S3: tbl_df/tbl/data.frame)
## $ AGC       : num [1:467] 171.6 278.7 254.3 74.5 192 ...
## $ AGCprefire: num [1:467] 602 888 1684 187 1397 ...
## $ B3        : num [1:467] 0.0293 0.0289 0.0372 0.042 0.0222 ...
## $ B5        : num [1:467] 0.0625 0.0567 0.0797 0.1555 0.0551 ...
## $ B6        : num [1:467] 0.0718 0.1082 0.1496 0.1436 0.0747 ...
## $ Gness     : num [1:467] 0.0346 0.0488 0.0332 0.0132 0.0205 ...
## $ Max_T     : num [1:467] 24.7 24.7 24.7 24.7 24.7 ...
## $ Mean_RH   : num [1:467] 64.9 64.9 64.9 64.9 64.9 ...
## $ Mean_T    : num [1:467] 9.43 9.43 9.43 9.43 9.43 ...
## $ dNBR      : num [1:467] 0.316 0.526 0.635 0.207 0.531 ...
## $ Canopcover: num [1:467] 34 32.5 15 14.5 26 23 38.5 41 58 29 ...
## $ GDEM      : num [1:467] 291 279 305 292 302 254 269 258 211 221 ...


## Mean Absolute Error (MAE): 205.7412


##          B3          B5          B6       Gness       Max_T     Mean_RH      Mean_T
##     3432168     4442350     2935600     3240675     2283578     1573098     5324778
##        dNBR   Canopcover        GDEM
##     3674875     6739883     4901051
```

Variable Importance
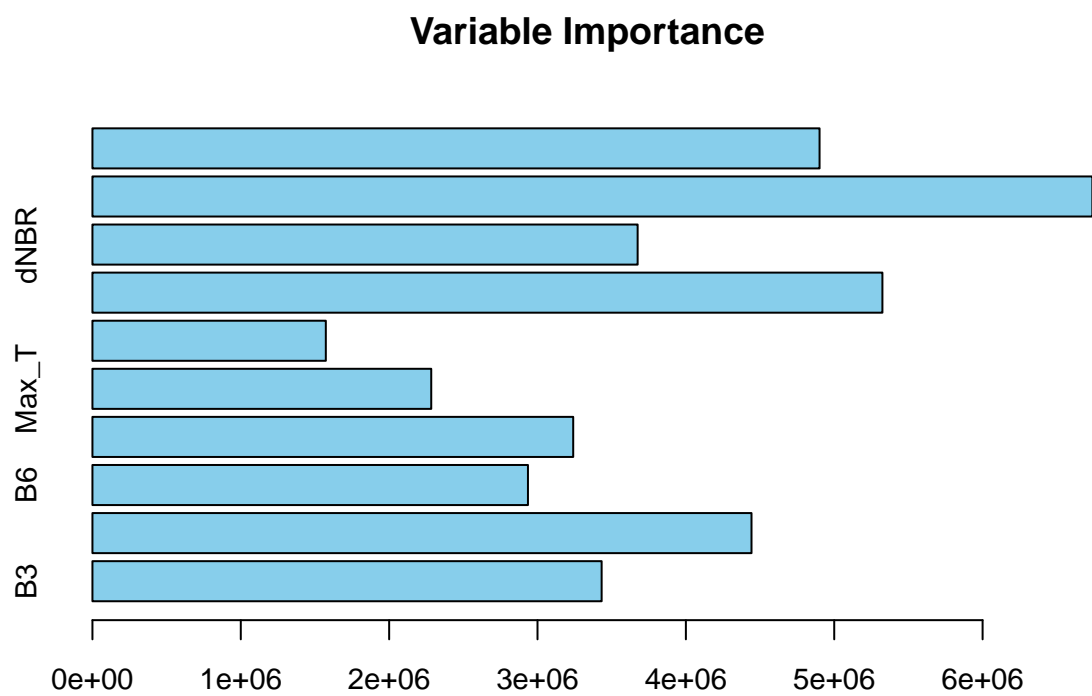

```
## R-squared: 0.3838116
```

Discussion

the purpose of the discussion is to summarise your major findings and place them in the context of the current state of knowledge in the literature. When you discuss your own work and that of others, back up your statements with evidence and citations. - The first part of the discussion should contain a summary of your major findings (usually 2 – 4 points) and a brief summary of the implications of your findings. Ideally, it should make reference to whether you found support for your hypotheses or answered your questions that were placed at the end of the introduction. - The following paragraphs will then usually describe each of these findings in greater detail, making reference to previous studies. - Often the discussion will include one or a few paragraphs describing the limitations of your study and the potential for future research. - Subheadings within the discussion can be useful for orienting the reader to the major themes that are addressed.

Conclusion

The conclusion section should specify the key findings of your study, explain their wider significance in the context of the research field and explain how you have filled the knowledge gap that you have identified in the introduction. This is your chance to present to your reader the major take-home messages of your dissertation research. It should be similar in content to the last sentence of your summary abstract. It should not be a repetition of the first paragraph of the discussion. They can be distinguished in their connection to broader issues. The first paragraph of the discussion will tend to focus on the direct scientific implications of your work (i.e. basic science, fundamental knowledge) while the conclusion will tend to focus more on the implications of the results for society, conservation, etc.

Waiting for the command to add the references. . .

Appendix(ces)

documentation of the data used in this project

\# Specification Table

Subject	Geography, Environmental Science, Remote Sensing, Computer Science, Climate studies
Specific subject area	Tree Carbon in boreal forests, Remote Sensing modelling, Environmental Science climate processing
Type of data	Raster data (Tif file type)
	Excel data (CSV)
	Code files (html)
Method of data acquisition	Predictor and Explana tory data were acquired online
	Field combustion data was acquired: The ABoVE Fire Emissions Database
	USGS Earth Explorer: Landsat 8 band 1-9
	GEE Climate variables: Precipitation, humidity, minimum and maximum temperature.
	ASTER DEM: Digital elevation
Data format	Processed
Description of data acquisition	Field combustion dataset were acquired from the above fire emissions derived from Potter et al. 2023 [^1^].
For prediction of Carbon emissions, we used different covariate layers:	• Time-series 2014 and 2015 : USGS Landsat bands [^7^], Optical vegetation indices, GEE Climate variables (Humidity, precipitation, mean, min. and max. air temperature, ASTER DEM
Location of data source	Landsat bands: [^2^]
	GEE climate dataset: [^3^]
	ASTER DEM: [^4^]
Accessibility of data	The predicted carbon emission dataset will be found at 30 m resolution in the following repository [^5^] : Repository name: Chinyereruth Data identification number: Still in progress Direct URL to data: Still in progress Detailed code associated with the data analysis is available from the Github repository [^5^]

VALUE OF DATA

- The map provides the amount of carbon emission from trees from Canada's boreal forests, using statistical methods such as regression and machine learning. • The map will support research on Carbon emission models, and climate change assessment and can be used to inform climate and fire scientists on carbon accounting and reporting, and also recommend measures to reduce carbon emission footprints. It can also be used to compare carbon emissions from other boreal forest zones. • The methods that will be outlined and code that will be provided can also be replicated in other locations and zones to derive carbon emission maps.

Data Description

Predictors will be provided within the domain of the boreal forest in a folder called the "carbon-emission-modelling-2023.zip". Carbon emitted from each province will be named according to its geographic location (i.e. 059E_14N corresponds to 59E to 60E, 14N to 15N). The "pronvince_carbon_emission_2023.Tif"file will contain carbon emissions for each province within Canada and the "Canada_Carbon_emission_2023.tif"file contains the final carbon emission map for the entire Canada . The detailed code associated with this project will be found in the Github repository (https: //github.com/Chinyereruth/carbon-emission), allowing for the prediction applied here to be replicated. In addition, the code used for this folder will be found in "carbon-emission-Canada-2023- code. Rmd" which will be located in the main GitHub repository folder.

Table 1 Files used in the study for wildfire carbon emission modelling in Canada for the year 2023

File description	File name
Predicted Carbon emitted for Canada 2023	Carbon-emiss-Can__ JanDec_2023-30m.tif
Minimum temperature for Canada 2023	Min-temp-Can__ JanDec_2023-30m.tif
Maximum temperature for Canada 2023	Max-temp-Can__ JanDec_2023-30m.tif
Soil data for Canada 2023	Soil-Can__ JanDec_2023-30m.tif
NDVI data for Canada 2023	NDVI-Can__ JanDec_2023-30m.tif
Tree cover for Canada 2023	Treecov-Can__ JanDec_2023-30m.tif
DEM for Canada 2023	ASTER-dem-Can__JanDec-2023-30m.tif

Experimental Design, Materials and Methods

Training data

I used a compilation of field carbon combustion data obtained from the ABoVE Fire Emissions Database (n=500). This field combustion data that were collected across Alberta, Saskatchewan, Manitoba and North Western Territories.

Covariate layers

Combustion measurements that were obtained from ABoVE fire database were related to covariates of remotely sensed variables for fire severity, elevation, soil and climate.

Climate variables

Climate data for minimum and maximum temperature were obtained from Climate ClimateNA using the GEE climate hub portal for the year 2023. The climate data used here provided the climate point estimate in degrees Celsius which was imported in the spatial environment. The data upscaled to a 30 m grid. This helped to capture the climate impact on vegetation, fuel loads, and fuel moisture, which affect combustion losses.

Environmental variables

I used a variety of environmental variables. This includes soils, topography and vegetation category. The soil data was gotten at 250 m resolution but this was upscaled. Topographic variables that will be derived include aspect in degrees, elevation (m), and slope at a 30 m pixel size.

Remotely sensed variables

Here, I derived various remotely sensed vegetation indices from Landsat, and this includes NDVI, the normalized difference infrared index (NDII) and the dNBR. All images used were atmospherically and geometrically corrected using the correction and geometric tool in R.

Model training

For the model training, remotely sensed variables, climate and environmental variables were used. Areas of clouds, cloud shadows, and snow were extracted out using an extraction function in R.

Spatial carbon modelling

The results from this research are still in progress. Preliminary results are displayed here.

Ethic statement

This study did not use human subjects, experiments carried out on animals, and did not also acquire any data from social media platforms.

Data availability

Carbon emission modelling from wildfire disturbances in Canada at 30 m resolution for the year 2023 will be available at Github/ChinyereRuth/carbon-emission.

Insert content for additional tables here.

Appendix B: additional figures

Insert content for additional figures here.

Appendix C: code