CanadaFire2023: Burned Area Mapping Datasets and Benchmarks for Canadian Wildfires in 2023

Zilong Zhong
School of Earth, Environment & Society
McMaster University
Hamilton, Canada
zhongz30@mcmaster.ca

Alemu Gonsamo
School of Earth, Environment & Society
McMaster University
Address
gonsamoa@mcmaster.ca

Abstract

In 2023, wildfires burned record-breaking areas in Canada, resulting in significant carbon loss, exacerbating climate change, and underscoring the need for relevant datasets and machine learning methods for effective and efficient analysis [5]. To understand the fire development processes and assess the climate impact of this natural disaster, burned area mapping datasets are essential for generating high-quality burned scar maps, enabling a comprehensive analysis of the 2023 wildfires, particularly given the vast expanse of Canada. To this end, we propose the CanadaFire2023 dataset, which includes burned area mapping data collected from multiple satellite platforms, namely, Landsat-8, Landsat-9, and Sentinel-2, specifically focused on these wildfires in the recorded history of Canada. To our knowledge, this is the first dataset specifically focused on burned area detection related to the unprecedented 2023 Canadian wildfires, using individual satellite imagery. We also trained four deep learning models—FCN, U-Net, multiscale ResNet, and SegFormer—for burned area mapping and evaluated the mapping performance using binary segmentation metrics, demonstrating that these datasets can serve as benchmarks for the research community studying wildfires and their environmental consequences. The CanadaFire2023 dataset could facilitate downstream applications such as disaster management, carbon emission estimation, and climate change mitigation.

1 Introduction

Canada possesses about 28% of the world's boreal forest and roughly 25% of its peatlands, thereby storing a significant amount of carbon across various biomes in North America. Over the past six decades, burned areas from wildfires have doubled in Canada due to global warming and climate change [9], and this trend poses a threat to the carbon sink of aboveground biomass and organic soils, [13]. The 2023 Canadian wildfires, partially driven by early snow-melt and abnormal drought, [8] are unparalleled in terms of burned areas and climate impacts. This event has attracted significant attention from governments, society, and academia, emphasizing the need for wildfire monitoring, disaster management, and climate change mitigation. However, few datasets are available for burned area mapping, which is the foundation for climate analysis caused by wildfires. This motivates us to answer two questions: *How can we create burned area mapping datasets from different Earth observation platforms? How can we establish machine learning benchmarks for the task of burned area detection?*

As a result of increasing temperatures and climate change in recent years, wildfires have become more prevalent all over the world, leading to the development of multiple wildfire-related datasets to support the understanding and analysis of this natural disaster [11, 6, 2]. For example, Ribeiro et al. created a novel dataset collected by a UAV and trained a 3D U-Net model for segmenting wildfire-burned areas.

38th Conference on Neural Information Processing Systems (NeurIPS 2024).

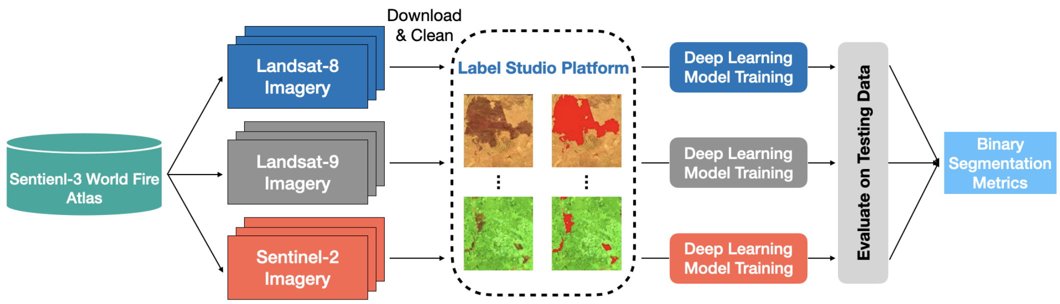


Figure 1: Framework for creating the CanadaFire2023 datasets. The workflow involves: (i) generating burned area annotations and (ii) recording semantic segmentation metrics (such as precision, recall, and F1-score) for deep learning benchmarks across three satellite imagery datasets.

A large-scale Mediterranean wildfire modeling dataset with a spatial resolution of 1 km, covering the period from 2006 to 2022, has been released for two purposes: wildfire danger forecasting and burned area estimation [6]. Gerard et al. present a multi-temporal U.S. dataset from 2018 to 2021 that focuses on active wildfire spreading, utilizing its unique time series structure [2]. Similar to our dataset, an Indonesian burned area mapping dataset of Landsat-8 satellite images is introduced, and a U-Net model is trained on it to detect burned areas [10]. Although these datasets all focus on wildfires or burned area mapping, our CanadaFire2023 dataset differs in three ways. First, to the best of our knowledge, CanadaFire2023 is the first dataset comprising individual imagery collected by three satellite-mounted sensors, specifically focused on the 2023 Canadian wildfires, which had substantial environmental and climate impacts. Second, CanadaFire2023 contains not just one but three datasets collected from three different satellite sensors, respectively. Lastly, CanadaFire2023 has a much higher spatial resolution than existing burned area mapping datasets. Specifically, the Landsat-8 and Landsat-9 datasets have a resolution of 30 meters, while the Sentinel-2 dataset has a resolution of 10 meters.

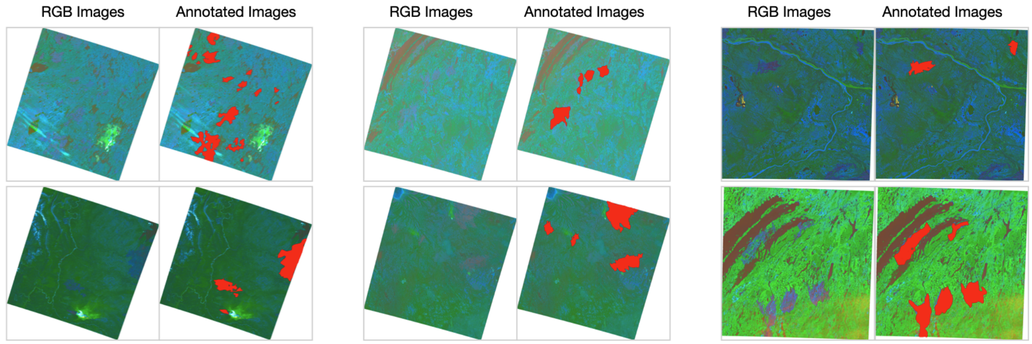
Recent years have witnessed progress in the task of burned area mapping with the rapid application of machine learning models in remote sensing and environmental tasks [1, 15, 3]. In 2015, Alonso-Canas et al. proposed a global burned area detection algorithm using MERIS imagery and MODIS active fire data from 2006 to 2008. Later, Hawbaker et al. developed an automated method to detect burned areas on Landsat imagery for the conterminous U.S. [3]. More recently, Zanetti et al. put forward a burn severity index thresholding approach using multispectral satellite imagery for burned area mapping. Inspired by this pioneering work, we aim to first build a burned area mapping dataset focusing on the 2023 wildfires in Canada using satellite imagery from three multispectral platforms (Landsat-8, Landsat-9, and Sentinel-2) and then create three corresponding benchmarks to train and evaluate the effectiveness of deep learning models. Specifically, we use semantic segmentation baseline models, including FCN [7], U-Net [12], multiscale ResNet [4], and SegFormer [14]. In addition, we present our framework to create the CanadaFire2023 dataset and showcase an example of mapping the burned areas across Canada for the 2023 wildfires, which could be of great value for carbon emission calculation and climate impact assessment.

2 Framework

As shown in Fig. 1, the framework for creating the burned area mapping dataset CanadaFire2023 across three satellite platforms primarily involves three steps. First, we identify the areas of interest using data from the Sentinel-3 World Fire Atlas[1] to efficiently select satellite imagery containing burned areas in Google Earth Engine. Second, we download the selected images and remove unsatisfactory imagery, due to clouds or smoke. Third, we manually annotate the satellite imagery using a labeling platform called Label Studio[2] based on visual interpretation by human experts.

[1]See: `https://s3wfa.esa.int/`

[2]See: `https://labelstud.io/`



(a) Landsat-8 **(b) Landsat-9** **(c) Sentinel-2**

Figure 2: Annotation samples from the CanadaFire2023 dataset across three satellite imagery sources using Label Studio: (a) Landsat-8, (b) Landsat-9, and (c) Sentinel-2. The Red, Green, and Blue channels are used for visualization. For each dataset, the two images on the left are the visualized satellite images, while the two images on the right are the corresponding annotated images, where the red areas indicate labeled burned areas.

After establishing the three CanadaFire2023 datasets, the associated deep learning benchmarks involve three stages. Initially, we train four baseline deep learning models using the training data on the three datasets, respectively. The deep learning framework we adopted is PyTorch. Subsequently, we generate burn scar maps using trained baseline deep neural networks on the testing data for each dataset. Finally, we record the corresponding binary segmentation metrics (precision, recall, and F1-score) for all baseline models across the three annotated imagery datasets.

3 Datasets and Benchmarks

As shown in Fig. 2, CanadaFire2023 contains three subsets: Landsat-8, Landsat-9, and Sentinel-2. The Landsat-8 dataset consists of 305 images of 30-meter resolution, the Landsat-9 dataset comprises 272 images of 30-meter resolution, and the Sentinel-2 subset includes 828 images of 10-meter resolution. All imagery was collected between May 1 and November 1, 2023, covering almost all burning events across Canada during that period. Each Landsat-8 or Landsat-9 image covers an area of about 185 km $\times$ 185 km, while each Sentinel-2 image covers roughly 290 km $\times$ 290 km. For each dataset, 80% of the images were randomly selected for training, and the remaining 20% were used for evaluation.

3.1 Satellite Imagery Datasets

The active fire data from Sentinel-3 are first used to identify areas of interest. Then, CanadaFire2023 is manually annotated using Label Studio, which is an open-source platform for multiple labeling tasks. After downloading the imagery from the three data sources, we process them by normalizing the values for each layer to between 0 and 1. To account for the severity of burned areas caused by the 2023 Canadian wildfires, we generate the Normalized Burn Ratio (NBR) using satellite imagery. The NBR can be calculated using the formula: $\text{NBR} = \frac{\text{NIR}-\text{SWIR2}}{\text{NIR}+\text{SWIR2}}$, where NIR represents the Near-Infrared band and SWIR2 denotes the Shortwave Infrared 2 band. Furthermore, we introduce NDWI to account for water bodies that often have a dark color in satellite imagery, which appear similar to burned regions. The Normalized Difference Water Index (NDWI) can be calculated using the formula: $\text{NDWI} = \frac{\text{Green}-\text{NIR}}{\text{Green}+\text{NIR}}$. We then stack NBR and NDWI as additional features on top of each training sample. Therefore, there are nine layers in each input satellite image, including Aerosol, Blue, Green, Red, NIR, Shortwave Infrared 1 (SWIR1), SWIR2, NBR, and NDWI. Afterwards, four baseline deep learning models are employed to identify burned areas on the stacked 9-layer data for the three datasets, respectively.

Model	Landsat-8			Landsat-9			Sentinel-2		
	Prec.	**Rec.**	**F1-score**	**Prec.**	**Rec.**	**F1-score**	**Prec.**	**Rec.**	**F1-score**
FCN [7]	70.2	66.1	68.1	68.5	65.3	66.8	65.4	62.7	64.0
U-Net [12]	80.3	77.8	**79.0**	74.5	71.9	73.2	71.2	68.6	69.9
multi-ResNet [4]	78.9	76.5	77.7	81.2	78.6	**79.9**	77.8	75.3	**76.5**
SegFormer [14]	75.5	72.3	73.9	77.0	74.2	75.6	76.2	73.5	74.8

Table 1: Quantitative results in Precision (%), Recall (%), and F1-score (%) for four deep learning baseline models across three burned area mapping datasets of CanadaFire2023.

3.2 Deep Learning Baseline Models

The four classic deep learning models used to create benchmarks are FCN [7], U-Net [12], Multiscale ResNet [4], and SegFormer [14]. These models were selected because they have proven to be effective for semantic segmentation tasks across various datasets, including Earth observation datasets [10, 11]. We trained each model for 200 epochs on each dataset, using the Adam optimizer to guide the training process. We used three metrics to evaluate the effectiveness of the deep learning models for burned area mapping: Precision, Recall, and F1-score, which are standard indices for binary segmentation tasks. F1-score is the primary metric because it balances precision and recall. As shown in Table 1, Multiscale ResNet achieved the best burned area mapping performance for the Landsat-9 and Sentinel-2 datasets, while the classic U-Net attained the highest F1-score for the Landsat-8 dataset. Although these results are used to assess burned area mapping performance, the best-performing models are likely to produce better burned area maps for the 2023 wildfires across Canada, thereby enabling more accurate climate impact assessments and more effective disaster management.

3.3 Contribution to Climate Impact Assessment

The CanadaFire2023 datasets could generate non-trivial benefits for various tasks, such as wildfire analysis, forest management, and climate impact assessment. First, it can provide datasets to train burned area mapping models for local regions or across Canada, as the datasets cover almost all biomes that could be affected by wildfires. Second, because CanadaFire2023 contains three datasets from different satellite-mounted sensors, fusing the three datasets could enable near real-time and cloud-free updates about wildfires, which are crucial for building a comprehensive wildfire intelligence platform for tracking fires in forests and directing resources to suppress ongoing fires. Last but not least, the resulting burn scar maps could serve as a foundation for historical and future climate impact assessments, including those related to the carbon cycle, permafrost thawing, and land use and land cover change. For example, the final burned area map shown in Fig. A1 in the Supplementary Material is produced by merging the burned pixels identified by trained multiscale ResNets on Landsat and Sentinel data. The total identified burned area is 15.1 million hectares, with the most severely impacted areas in Quebec province in eastern Canada and the intersection region of British Columbia, Alberta, and the Northwest Territories in western Canada. Then, we can use the identified burned area, the remotely sensed data (Landsat-8, Landsat-9, and Sentinel-2), their derivatives (NBR, NDWI), field samples, among others, to make an accurate estimation of carbon emissions across Canada.

4 Conclusions

In this paper, we introduce our burned area mapping datasets, CanadaFire2023, for three different satellite remote sensing platforms to facilitate the development and research in wildfire monitoring, disaster management, and carbon emission estimation. In addition, we trained four baseline semantic segmentation models on three CanadaFire2023 datasets and evaluated them using the metrics of precision, recall, and F1-score. More importantly, these results can serve as benchmarks for other machine learning and deep learning models. To tackle the task of burned area mapping, we advocate for more algorithms that consider the special characteristics of satellite imagery and burned area detection to be designed and compared with the baseline models on CanadaFire2023. Considering the record-breaking burned area generated by the 2023 wildfires in Canada, and the consequential air pollution, human evacuation, and forest degradation, we hope this new dataset can help the scientific community better understand regional and national climate impacts and provide a data source that could potentially be used to prevent or suppress such natural disasters from happening again.

References

[1] Itziar Alonso-Canas and Emilio Chuvieco. Global burned area mapping from envisat-meris and modis active fire data. *Remote Sensing of Environment*, 163:140–152, 2015.

[2] Sebastian Gerard, Yu Zhao, and Josephine Sullivan. Wildfirespreadts: A dataset of multi-modal time series for wildfire spread prediction. *Advances in Neural Information Processing Systems*, 36:74515–74529, 2023.

[3] Todd J Hawbaker, Melanie K Vanderhoof, Yen-Ju Beal, Joshua D Takacs, Gail L Schmidt, Jeff T Falgout, Brad Williams, Nicole M Fairaux, Megan K Caldwell, Joshua J Picotte, et al. Mapping burned areas using dense time-series of landsat data. *Remote Sensing of Environment*, 198:504–522, 2017.

[4] Kaiming He, Xiangyu Zhang, Shaoqing Ren, and Jian Sun. Deep residual learning for image recognition. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pages 770–778, 2016.

[5] Piyush Jain, Quinn E Barber, Stephen W Taylor, Ellen Whitman, Dante Castellanos Acuna, Yan Boulanger, Raphaël D Chavardès, Jack Chen, Peter Englefield, Mike Flannigan, et al. Drivers and impacts of the record-breaking 2023 wildfire season in canada. *Nature Communications*, 15(1):6764, 2024.

[6] Spyridon Kondylatos, Ioannis Prapas, Gustau Camps-Valls, and Ioannis Papoutsis. Mesogeos: A multi-purpose dataset for data-driven wildfire modeling in the mediterranean. *Advances in Neural Information Processing Systems*, 36, 2024.

[7] Jonathan Long, Evan Shelhamer, and Trevor Darrell. Fully convolutional networks for semantic sedevelopmentgmentation. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pages 3431–3440, 2015.

[8] Kaiwei Luo, Xianli Wang, Mark de Jong, and Mike Flannigan. Drought triggers and sustains overnight fires in north america. *Nature*, 627(8003):321–327, 2024.

[9] Carly A Phillips, Brendan M Rogers, Molly Elder, Sol Cooperdock, Michael Moubarak, James T Randerson, and Peter C Frumhoff. Escalating carbon emissions from north american boreal forest wildfires and the climate mitigation potential of fire management. *Science advances*, 8(17):eabl7161, 2022.

[10] Yudhi Prabowo, Anjar Dimara Sakti, Kuncoro Adi Pradono, Qonita Amriyah, Fadillah Halim Rasyidy, Irwan Bengkulah, Kurnia Ulfa, Danang Surya Candra, Muhammad Thufaili Imdad, and Shadiq Ali. Deep learning dataset for estimating burned areas: Case study, indonesia. *Data*, 7(6):78, 2022.

[11] Tiago FR Ribeiro, Fernando Silva, José Moreira, and Rogério Luís de C Costa. Burned area semantic segmentation: A novel dataset and evaluation using convolutional networks. *ISPRS Journal of Photogrammetry and Remote Sensing*, 202:565–580, 2023.

[12] Olaf Ronneberger, Philipp Fischer, and Thomas Brox. U-net: Convolutional networks for biomedical image segmentation. In *Medical image computing and computer-assisted intervention–MICCAI 2015: 18th international conference, Munich, Germany, October 5-9, 2015, proceedings, part III 18*, pages 234–241. Springer, 2015.

[13] Xanthe J Walker, Jennifer L Baltzer, Steven G Cumming, Nicola J Day, Christopher Ebert, Scott Goetz, Jill F Johnstone, Stefano Potter, Brendan M Rogers, Edward AG Schuur, et al. Increasing wildfires threaten historic carbon sink of boreal forest soils. *Nature*, 572(7770):520–523, 2019.

[14] Enze Xie, Wenhai Wang, Zhiding Yu, Anima Anandkumar, Jose M Alvarez, and Ping Luo. Segformer: Simple and efficient design for semantic segmentation with transformers. *Advances in neural information processing systems*, 34:12077–12090, 2021.

[15] Massimo Zanetti, Sudipan Saha, Daniele Marinelli, Maria Lucia Magliozzi, Massimo Zavagli, Mario Costantini, Francesca Bovolo, and Lorenzo Bruzzone. A system for burned area detection on multispectral imagery. *IEEE Transactions on Geoscience and Remote Sensing*, 60:1–15, 2021.

Supplementary Material

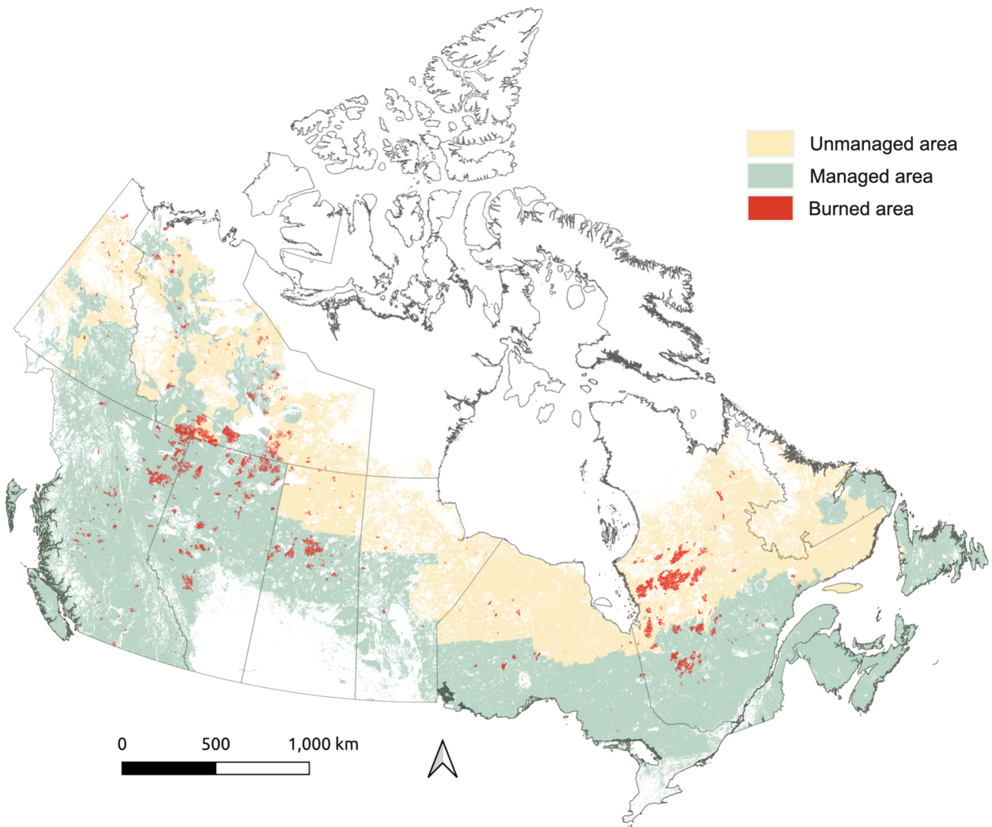


Figure A1: Burned area mapping results using multiscale residual networks. Yellow, Green, and Red represent unmanaged, managed, and detected burned areas, respectively. The total identified burned area is 15.1 million hectares for the record-breaking 2023 wildfires in Canada.

Acknowledgments

This research was funded by the Natural Sciences and Engineering Research Council of Canada (NSERC), Google Cloud Platform, Google Cloud Platform (GCP) Research Credits Program, and the Canada Research Chairs program (CRC2019-00139).