ADVANCES IN FOREST FIRE RESEARCH

2022

Edited by
DOMINGOS XAVIER VIEGAS
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A long-term satellite-based burned area database for the Northern Boreal Region (1982-2020)

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Keywords

Burned Area Mapping; Time Series Analysis; Boreal Forest; LTDR.

Abstract

Burned Area (BA) is an essential variable for studying the Earth's climate evolution. The boreal forest is one of the largest biomes in the world, spanning North America and Eurasia. For North America, two record fire occurrence databases since the 1950s are available: Alaska Fire Service (AFS) database and the Canadian National Fire Database (CNFDB). However, there are currently no reliable burned area data for the boreal region of Eurasia, mainly Siberia, for the 1980s and 1990s. In this work, a Bayesian network algorithm was applied to the Long-Term Data Record (Version 5) to generate a burned area product at a resolution of 0.05 degrees for the entire boreal region above 60°N from 1982 to 2020. An assessment of burnt area estimates was carried out using high-resolution satellite images, official reference data and the MCD64A1 MODIS global burned area product (when were available). The results showed a high correlation with all the reference burned area datasets (95% with AFS-CNFDB, 93% and 95% with MCD64A1 in North America and Eurasia, respectively). The derived database constitutes unique long-term burned area information for studies of fire and carbon dynamics in the Northern Boreal Region, as well as their effects on the climate system.

1. Introduction

Forest fires contribute to greenhouse gas emissions and are responsible for changes in carbon dynamics and their implications for global climate change (Chuvieco *et al.* 2019). One of the regions of the planet where this global change is expected to have the highest impact is the northern boreal region. Boreal forests represent one of the largest sources of carbon storage on our planet (Schuur *et al.* 2015; Young *et al.* 2017).

Images derived from sensors aboard quasi-polar orbiting satellites have in recent years allowed the construction of time series of burned area (BA), providing the scientific community with essential information that could be correlated with other variables involved in global change. Among the main BA products developed are MCD64A1 (Giglio *et al.* 2018) and Fire_CCI (Chuvieco *et al.* 2018), both derived from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor. However, these products have only been available since 2000, so they do not allow the construction of time series of more than two decades, limiting their application in medium- and long-term fire trend studies.

In this paper, we present and validate a unique database containing annual BA estimates for the northern boreal forest from 1982 to 2020 with a spatial resolution of 0.05°. It is derived from a new BA product, generated by applying a Bayesian network-based classification algorithm to the LTDR (Land Long Term Data Record) v5 dataset (Pedelty *et al.* 2007).

2. Materials and Methods

2.1. Study area

The study area covers all northern boreal regions bounded by 60ºN and 72.5ºN parallels. It was divided into two sub-regions: North America (Alaska and boreal Canada), limited by the 168.5ºW and 43.5ºW meridians and Eurasia (from Scandinavia to the Pacific coast of Siberia), bounded by the 5ºE and 180ºE meridians. The North

American sub-region contains one-third of the boreal ecosystem and the Eurasian sub-region the other two thirds.

2.2. LTDR data set. Pre-processing

The Long-Term Data Record (LTDR) from NASA is a consistent long-term dataset at a spatial resolution of 0.05° (~5 km) based on daily data from the Advanced Very High-Resolution Radiometer (AVHRR) on-board the National Oceanic and Atmospheric Administration (NOAA) satellites and daily data acquired by MODIS on-board NASA's Terra and Aqua satellites (Pedelty *et al.* 2007). Daily global LTDR version 5, download from NASA server (https://ltdr.nascom.nasa.gov/cgi-bin/ltdr/ltdrPage.cgi), was used in this study. The original daily images in HDF (Hierarchical Data Format) format were transformed to BSQ (Band Sequential) format and cropped to the boundaries of the study region. Then, 10-day composites were constructed with the maximum brightness temperature criterion to eliminate atmospheric effects. Simultaneously, vegetation indices derived from the original radiometric bands were calculated for burned area discrimination: NDVI (Normalized Difference Vegetation Index) (Rouse et al. 1973), GEMI (Global Environmental Monitoring Index) (Pinty and Verstraete, 1992) and BBFI (Burned Boreal Forest Index) (Moreno-Ruiz *et al.* 2012).

2.3. Burned area detection

The BA-LTDR classifier initially developed for the NE Siberia region (García-Lázaro *et al.* 2018) was used to generate the corresponding annual BA maps. This classifier is based on the Bayes-Net algorithm of the WEKA (Waikato Environment for Knowledge Analysis) software package (Frank *et al.* 2016).

To assess the accuracy of the BA-LTDR time series for the Northern boreal region, we considered splitting the time series for both sub-regions (Eurasia and North America) into two parts: pre- and post-2000. Since 2000, accuracy assessments for the Eurasian sub-region have been evaluated using only MCD64A1 C6 burned area product with 500 m spatial resolution, according to CEOS validation protocol (Morisette *et al.* 2006). MCD64A1 Collection 6 is currently the product with the highest reliability compared to the other BA products (Padilla *et al.* 2015), and it has the lowest commission and omission errors in the boreal forest region (Boschetti *et al.* 2019). Before 2000, accuracy assessments could not be evaluated in this way because other BA products with a higher spatial resolution for this study sub-region were not available. For the North America boreal sub-region, the BA-LTDR burned area maps obtained (and also BA maps of the MCD64A1 C6 product) were compared with reference data from the Alaska Fire Service (AFS) database (https://afsmaps.blm.gov/imf/imf.jsp?site=firehistory) and Canadian National Fire Database (CNFDB) (http://cwfis.cfs.nrcan.gc.ca/ha/nfdb) (García-Lázaro *et al.* 2018).

The temporal accuracy of the BA-LTDR product in each sub-region was assessed considering the total calculated annual BA. A timing distribution of BA-LTDR product was represented on a chart together with the time series of reference BA and a correlation analysis was carried out. The relative percentages of the annual BA of the BA-LTDR product were calculated concerning the reference data for the common years when available.

3. Results

3.1. Annual burned area maps

The BA-LTDR database contains annually burned area maps for the Northern boreal forest (above 60°N) for the 1982-2020 period in 0.05° (~5 km) resolution Climate Modelling Grid (CMG) cells. Figure 1 presents a decade-by-decade grouping of the annually BA maps for both sub-regions. Burned pixels have been plotted in a dark colour on the green land.

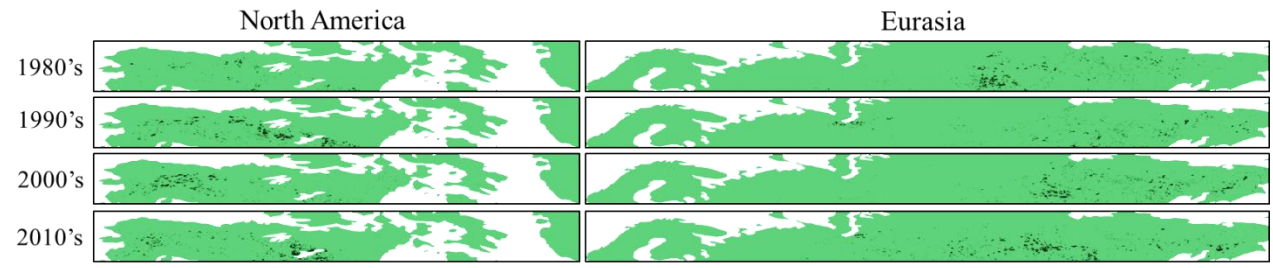

Figure 1- Maps of area burned by decades for the sub-regions of North America and Eurasia. Black: burned area, white: water, green: unburned.

3.1. Temporal Accuracy

Figure 2 shows the annual distribution of the total BA estimated for 1982-2020 in the North America sub-region. BA-LTDR detected 61% of the reference burned area, underestimating the BA in all years of the time series. There was a strong correlation (0.95) between the LTDR-BA data and the reference AFS-CNFDB data. If we divide the time series into two parts (pre-MODIS: 1982-1999, MODIS: 2000-2020), the BA-LTDR algorithm shows a practically homogeneous behaviour both in percentage of burnt area estimation (64% vs 59%) and correlation coefficient (0.98 vs 0.95), concerning the reference data. Making an intercomparison of BA-LTDR with the MCD64A1 C6 product in the common period (2000-2020) in North America, LTDR-BA detected approximately 86% of the area burned, with a correlation coefficient of 0.93.

In the Eurasia sub-region, the assessment of the temporal accuracy of the BA-LTDR burnt area was calculated using the MCD64A1 C6 product as a reference. MCD64A1 C6 estimated an annual BA of around 47.10 millions ha for the period 2000-2020. While BA-LTDR estimated around 66%. BA-LTDR underestimates the BA in all common years except for 2000, but its temporal pattern matches the reference, with a correlation coefficient of 0.95.

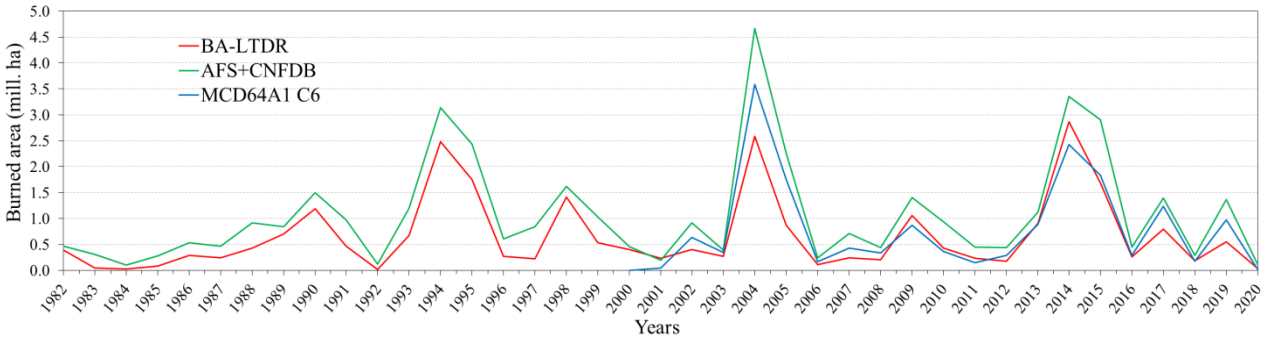

Figure 2- Annual distribution of the burned area estimate (mill. ha) in the North America boreal sub-region from the Alaska Fire Service/Canadian National Fire Database (AFS + CNFDB), BA-LTDR and MCD64A1 C6.

4. Conclusion

A comprehensive burned area database (1982–2020) for the Northern boreal region using a Bayesian network algorithm from the LTDR v5 dataset at 0.05° spatial resolution has been built. This time series is the longest developed for this region at this spatial resolution. It constitutes a unique data source for studies of fire and carbon dynamics in the Northern Boreal Region, as well as their effects on the climate system.

5. Acknowledgments

This research was funded by the Spanish Ministry of Science, Innovation and Universities (MCIU), the State Research Agency (AEI) and the European Regional Development Fund (ERDF) through the project RTI2018-099171-B-I00. The University of Almeria and the Andalusia ERDF Operational Program partially funded this work through projects 2019/006 and UAL18-TIC-A023-B1. The authors would like to thank the LTDR project and its team for the processing and free distribution of the data used in this work.

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