Forest Ecology and Management 317 (2014) 20–25

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Wildland fire emissions, carbon, and climate: Wildland fire detection and burned area in the United States

Wei Min Hao [a,*], Narasimhan K. Larkin [b]

[a] US Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT, USA
[b] US Forest Service, Pacific Northwest Research Station, Pacific Wildland Fire Sciences Laboratory, Seattle, WA, USA

ARTICLE INFO

Article history:
Available online 7 November 2013

Keywords:
Biomass burning
Burned area
MODIS
MTBS

ABSTRACT

Biomass burning is a major source of greenhouse gases, aerosols, black carbon, and atmospheric pollutants that affects regional and global climate and air quality. The spatial and temporal extent of fires and the size of burned areas are critical parameters in the estimation of fire emissions. Tremendous efforts have been made in the past 12 years to characterize the variability of fire locations and burned areas using high frequency satellite observations (e.g., MODIS, GOES) and improved ground-based reports. We describe and compare the major global and regional (e.g., western United States) burned area products and summarize their major findings. The various ground-based reporting systems and the data quality on fire characteristics and burned areas are examined, and we summarize the major knowledge gaps and recommend further improvements in our understanding of fire activity and burned areas.

Published by Elsevier B.V.

1. Introduction

Wildland fires can be an important source of greenhouse gases as well as black carbon emissions that have been shown to play an important role in the climate system (IPCC, 2007). Additionally, wildland fire emissions can have substantial impacts on air quality. For these reasons, obtaining accurate and detailed inventories of fire occurrence is important. Information on the spatial and temporal distribution of burned areas and fire emissions is also essential for modeling atmospheric photochemistry and the formation of tropospheric ozone, which is also a greenhouse gas (GHG). Because fire emissions are highly variable in time and space and depend on a variety of vegetation and atmospheric conditions, assessing the relative magnitude of climate response to fire emissions compared to other emission sources of GHG, aerosols, and black carbon to the atmosphere is difficult (e.g., van der Werf et al., 2010). The information on fire locations occurring for a period of time (fire activity) and the area of biomass impacted by that fire activity (burned area) are imperative pathways to quantify regional and global emissions of GHG, aerosols, and black carbon from biomass burning.

Seiler and Crutzen (1980) published the first estimation of total burned areas and the amount of biomass burned according to diverse sources in tropical, temperate, and boreal regions. About 80% of the area burned globally occurs in the tropics, where fires are widely used for the purposes of (1) deforestation to clear the land for agriculture and ranching, (2) shifting cultivation for sustaining subsistence agriculture, (3) growing fresh grass for ranching in the savannas, (4) energy consumption for heating and cooking and (5) clearing agricultural residues after harvest. Wildfires and prescribed burning dominate in temperate and boreal ecosystems in the United States, Canada, northern Mexico, Russia, and Australia. Since the global population will continue to grow and the major growth will take place in tropical countries, we anticipate increased fire activity, burned areas, and emissions of greenhouse gases, aerosols, and black carbon in the future. Hence, the impact and the contribution of fires to regional, global climate change are expected to intensify in the coming decades.

In order to understand the geographical impact of fire emissions on regional and global climate and air quality in comparison to other sources (e.g., industry, transportation, agriculture, forest), it is essential to characterize the spatial and temporal distribution of fire activity and burned area for estimation of emissions of GHG, aerosols, and black carbon. We must also overcome the challenges inherent with the transient nature of wildland fires, which tend to be of shorter duration and greater variability than other types of emissions sources. Wildland fire occurrence and emissions will vary on hourly, daily, monthly, and yearly timescales depending on diurnal, weather, seasonal, and climate patterns, as well as human activity and vegetation conditions. Hao and Liu (1994) published the first geospatially gridded monthly biomass burning inventory taking account of different land uses in the tropics at a $5^\circ \times 5^\circ$ resolution based on statistics of the United Nations Food and Agriculture Organization and published literature. By deriving the burned area and the aboveground biomass density in different ecosystems, Hao and Liu (1994) estimated the amount of biomass

* Corresponding author. Tel.: +1 406 329 4838; fax: +1 406 329 4877.
E-mail address: whao@fs.fed.us (W.M. Hao).

0378-1127/$ - see front matter Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.foreco.2013.09.029

burned in tropical Africa is about twice of that in tropical America because of the dominance of savanna fires in Africa. Our ability to provide such information has been greatly enhanced by the expanding availability of satellite based observations of fire activity and burned areas since the late 1990s, as well as efforts to better report and aggregate fire information gathered by ground personnel, helicopters, and aircraft. Here we review the current satellite-derived active fire detection and burned area products as well as modern ground based fire incident reporting systems.

2. Satellite derived burned areas based on active fire detections

Significant progress has been made in the past 12 years in estimating burned areas spatially and temporally, using NASA's MODIS (MODerate Resolution Imaging Spectroradiometer) instruments on the Terra and Aqua satellites and NOAA's Imager instrument on a series of GOES satellites. The Terra satellite was launched on December 18, 1999, and the Aqua satellite was launched on May 4, 2002. Both satellites provide consistent, spatially gridded coverage globally for the same locations four times daily during a period from early 2000 to present. Data from these satellites allow detection of fire locations and mapping of burned areas in near real-time, thus making essential improvements in understanding the spatial and temporal extent of fire activities and emissions from biomass burning globally.

While the official MODIS active fire product (MOD14A1) offering global daily active fire detections at a 1 km resolution became readily available shortly after the satellite launches, developing the MODIS-derived burned areas at a 500 m resolution has proved to be much more challenging. Active fire detections characterize thermal anomalies relative to the adjacent pixels during the 10-min satellite overpass time. Burned areas characterize the propagation of fires between the satellite overpass intervals. Giglio et al. (2013) developed a method of estimating monthly burned areas at a 1° × 1° resolution globally from 2001 to 2004 derived from active fire detections. The methodology was based on the MODIS-detected active fires, the relationships between the burned areas and active fire observations over selected MODIS scenes, and regression tree analysis over 14 regions worldwide. During this four-year period, on average about 3.4×10^6 km^2 were burned annually globally (Table 1). Approximately two-thirds of the burned areas globally occurred in Africa, 15.5% in Australia, 5.9% in Central Asia, 4.9% in South America, 3.4% in Southeast Asia, 2.6% in boreal Asia, and only 1.1% in boreal and temperate North America. The active fire-derived burned area product served as a preliminary burned area product prior to the development of more accurate burned area products.

3. Satellite detections of burned areas

Satellite-based data on burned areas at a high spatial and temporal resolution globally and regionally have become available only in the last several years because of the difficulty of minimizing false identification of burned scars. The scales of the resolution for the burned area products depend on their applications (Urbanski et al., 2011). For modeling regional air quality, the requirements for the spatial and temporal scales would be less than 25 km and 1 day. For modeling global climate and atmospheric chemistry, the scales would be 0.5°–3° and weeks. The burned area products are being improved continuously by validation with ground observations or high-resolution satellite images (e.g., Landsat images at a 30 m resolution). We will discuss two MODIS-based global burned area products (Roy et al., 2008; Giglio et al., 2010) and a regional burned area product for the western United States (Urbanski et al., 2009, 2011) in the following sections. Additionally, we will discuss other satellite-derived systems such as the Monitoring Trends in Burn Severity product and NOAA's Hazard Mapping System, and provide an overview of the available ground-based reporting systems for wildfires and prescribed fires. The development and improvement of burned area products is an ongoing process, and they should be considered intermediate but not the final burned area products.

3.1. Official NASA MODIS burned area product

Roy et al. (2008) described the official global monthly MODIS 500 m resolution burned area product (MCD45A1) detected by NASA's Terra and Aqua satellites. The mapping of burned areas is based on changes in surface reflectance as a result of fires. The spectral characteristics of burned scars with charcoal and ash are quite different from that of vegetation before being burned. The MCD45A1 burned area product was compared with the MODIS ac-

Table 1
Comparisons of burned areas over 14 regions worldwide in 2001, 2002, 2003, and 2004.

	Burned area (10^4 km^2 yr^{-1})							
	2001		2002		2003		2004	
	Active fire obs[a]	MCD 64A1[b]	Active fire obs[a]	MCD 64A1[b]	Active fire obs[a]	MCD 64A1[b]	Active fire obs[a]	MCD 64A1[b]
Boreal North America	0.4	0.3	2.6	3.2	2.3	2.0	4.0	5.0
Temperate North America	1.4	1.2	1.7	1.4	1.5	1.3	1.2	0.7
Central America	1.8	1.0	2.2	1.0	2.9	1.7	1.8	0.8
NH South America	4.4	2.0	3.6	1.1	4.8	3.3	3.8	3.2
SH South America	12.4	19.4	12.7	21.3	10.8	16.1	13.4	18.7
Europe	2.9	1.1	1.6	0.4	2.6	0.9	1.9	0.5
Middle East	0.6	1.2	0.5	1.0	0.4	0.9	0.4	0.8
NH Africa	153.2	114.4	135.2	126.1	125.5	128.0	129.8	116.4
SH Africa	84.0	117.3	82.4	113.9	79.6	126.6	75.3	127.1
Boreal Asia	6.3	5.8	9.3	8.1	14.5	15.9	4.9	1.6
Central Asia	16.5	15.0	26.7	25.0	17.1	12.8	18.9	15.6
Southeast Asia	10.8	4.5	10.2	7.7	8.4	6.3	16.1	10.7
Equatorial Asia	0.8	0.7	3.4	2.4	1.4	0.8	2.9	1.2
Australia	78.7	88.3	58.9	73.1	24.8	29.0	44.9	60.4
Total	374.2	372.2	351.0	385.7	296.6	345.6	319.3	362.7

[a] Burned areas derived from MODIS detected active fire observations, regional regression trees, and the relationship between burned areas and active fire detections (Giglio et al., 2013).
[b] GFED3 burned areas derived from MODIS detected active fires, change in vegetation analysis, and regional regression trees (Giglio et al., 2010).