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Spatio-temporal variations of burned areas and carbon emissions from vegetation fires in Myanmar and Southeast Asia derived from GFED data

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Abstract: Fire is an important disturbance factor in terrestrial ecosystems of the world including Southeast Asia (SEA). Fires contribute emissions of carbon and other trace gases impacting air quality and human health. In this study, the temporal variations in vegetation fires based on burned areas and related carbon emissions in SEA were studied with a particular focus on Myanmar based on data retrieved from the Global Fire Emission Database (GFED) over the period 2000-2015. The potential influence of climatic conditions on vegetation fires, in particular El Nino and La Nina years were also investigated. It was found that burned areas and carbon emissions relate to crop land, savanna, peat and forest, and vary significantly among SEA countries. The fire season spreads mostly from January to May each year with a peak usually observed in March and April. The largest emissions of carbon in SEA are from Indonesia due to its extensive peat land cover and burning, particularly during El Nino years. However, excluding peat land related carbon emissions, Myanmar was found to be the largest contributor to carbon emissions mostly from forest and savanna fires. In Myanmar, although some correlation was observed between normal precipitation and monthly variations in BAs, there was no evidence of a strong correlation between yearly variations in burned areas and climate conditions related to El Nino and La Nina years. Although further investigations should be performed in regard of the above investigations, these initial results may highlight the potential influence of anthropogenic activities on vegetation fires.

Keywords: Global Fire Emission Database, burned areas, carbon emissions, Oceanic Niño Index, Southeast Asia.

1. Introduction

Fire is one of the most important disturbance agents in terrestrial ecosystems on a global scale. It significantly contributes to the global growth rate of several trace gases and aerosols. It is widely applied by humans to transform land for many purposes, especially in tropical ecosystems. In addition, climate and natural factors contribute also to drive the dynamics of fires all over the world. To know how fires and the Earth system interact with each other, quantitative information about vegetation fires and related emissions are required due to the increase in the rate of deforestation, peatland fires, agricultural burning and fires from different forest ecosystems which result in carbon emissions and contribute to global warming and climate change issues [1]. Hence, it is necessary to develop long-term records enabling to assess the relation between fires and carbon emissions based on information derived from satellites as well as local data so as to be able to explain their impacts on the global atmosphere in a systematic way. In this regard, the Global Fire Emissions Database (GFED) has been developed in order to show how fires influence the carbon cycle, air quality, and climate at a global scale and vice versa [2]. The first version of GFED was released in 2004 and has now been updated to the fourth generation GFED4 [3]. In tropical Asia, Chang and Song [4] showed that Indonesia is the most significant contributor to air pollutant emissions, followed by India, Myanmar and Cambodia. The reasons for the differences in burned areas and fire emissions in SEA need to be investigated. The objective of this study is to analyze the temporal variation in vegetation fires (as burned areas) and carbon emissions in SEA (2010-2015) with a particular focus on Myanmar (2000-2015) using data retrieved from GFED. The potential influence of climate conditions, including normal precipitation, and El Nino and La Nina years, as well as human factors were considered and discussed.

2. Methodology

In this study, monthly and annual data related to burned areas (BAs) and carbon emissions in Myanmar and other SEA countries were downloaded from GFED4s (which includes small fires) using the analysis tool option of GFED. The influence of climate conditions on vegetation fires was investigated. In this regard, the influence of El Nino and La Nina years was investigated based on the Oceanic Niño Index (ONI) retrieved from the National Oceanic and Atmospheric Administration (NOAA) [5]. For Myanmar more particularly, the investigations included also the influence of normal precipitation (average monthly rainfall) based on data covering the period 1981-2010 collected from the Myanmar climate report (2017) prepared by Department of Meteorology and Hydrology, Ministry of Transport and Communications, Myanmar [6]. In the last part of this paper, the process by which carbon emissions from active fires are estimated using GFED was also investigated to identify its various components and mechanisms.

3. Results and Discussions

3.1 Vegetation fires in Myanmar

In GFED4s, the Moderate Resolution Imaging Spectroradiometer (MODIS) burn scar product MCD64A1 is used in order to calculate global burned areas and carbon emissions released from vegetation fires. These datasets were downloaded from the University of Maryland by ba1 FTP server (ftp://ba1.geog.umd.edu). The land cover map of Myanmar for the year 2015 as shown in Figure 1 was obtained from the global land cover map MCD12Q1 with classifications based on the University of Maryland (http://doi.org/10.5067/MODIS/MCD12Q1.006).

Detailed information about the annual area of vegetation burned in Myanmar over the period 2000-2015 is shown in Table 1. The data shows that about 93% of the total area of vegetation burned occurs during January-May each year. This period corresponds to the fire season as also identified by Biswas et al. [7]. In most years, the largest area of vegetation burned is observed in March with an average value of 18,615 km^2, followed by April and February. For illustrative purposes, the spatial distribution of these vegetation fires based on burn scars by state and regions (within the district administration boundary) are shown in Figure 2. These are provided for two selected years over the last 15 years of collected data, i.e. (a) 2002 which corresponds to the year with the lowest area of vegetation burned and (b) 2007 which corresponds to the year with the highest area of vegetation burned. Gridded BAs with a medium 500-m spatial resolution were constructed based on longitude-latitude coordinates as given by the processed burn scars product. In both cases, vegetation fires are observed to occur in similar areas in the country.

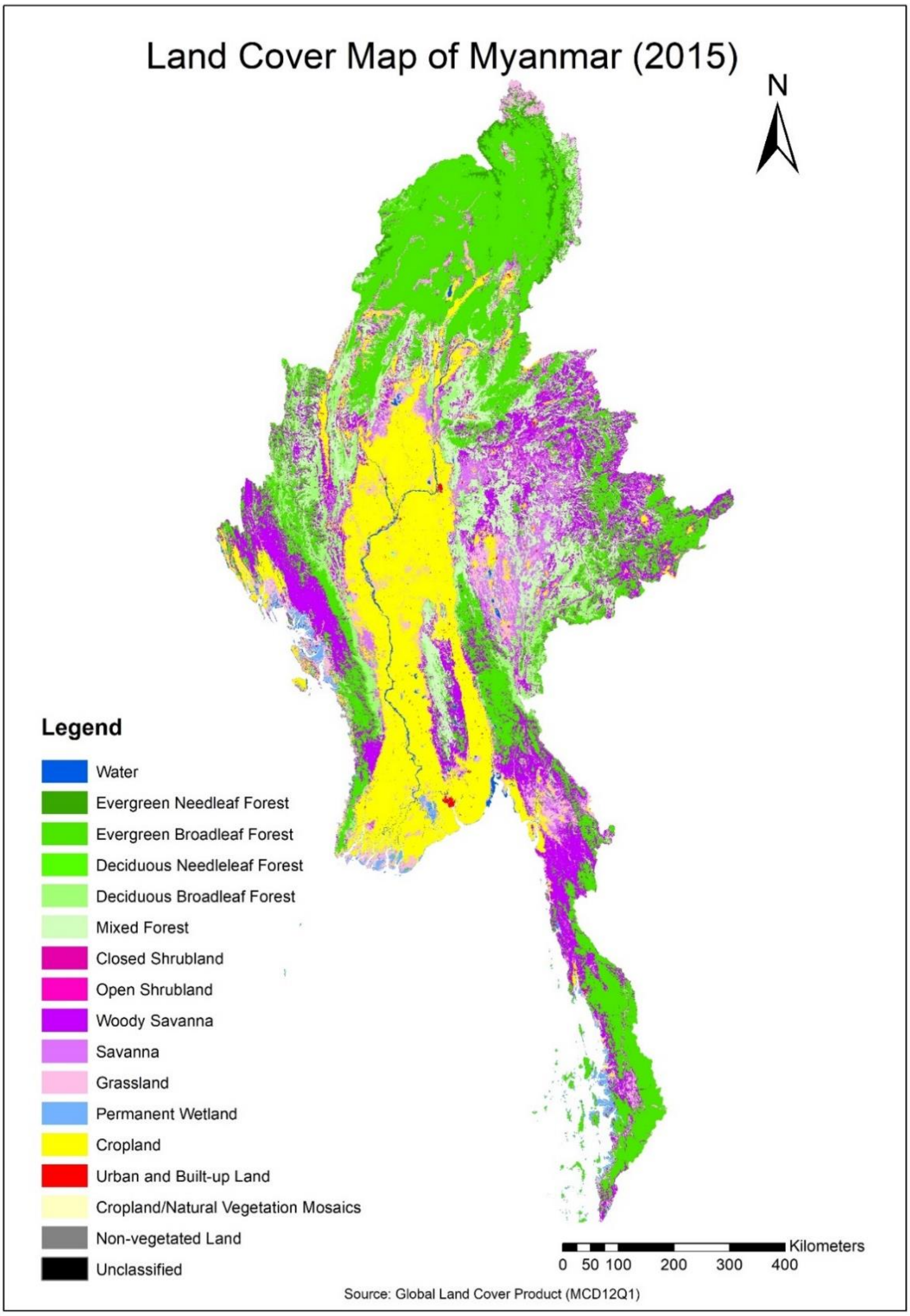


Figure 1. National Land Cover Map (2015) of Myanmar derived from the Global Land Cover Product (MCD12Q1).

Table 1. Burned Area in Myanmar on a Monthly Basis during the Fire Season (2000-2015).

Year	Burned area (km^2)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
2000	2,007	6,609	8,333	11,420	331	10	6	0	0	0	24	6	28,746
2001	2,793	7,320	7,500	5,458	156	1	1	2	21	9	35	95	23,391
2002	750	4,165	6,665	6,161	432	21	1	1	42	40	63	38	18,379
2003	402	2,610	16,484	9,704	311	10	5	6	8	25	81	297	29,943
2004	2,415	11,200	31,304	4,307	630	8	0	4	6	26	85	280	50,265
2005	1,566	13,826	11,507	7,830	529	65	9	6	19	34	45	52	35,488
2006	498	3,082	20,707	6,199	234	5	4	7	19	23	101	271	31,150
2007	1,504	8,012	31,354	9,213	499	23	5	15	11	14	49	137	50,836
2008	514	3,162	15,184	7,144	102	9	1	4	8	21	78	84	26,311
2009	1,034	16,380	18,971	6,683	313	20	5	7	53	46	125	340	43,977
2010	2,014	9,556	29,883	5,258	651	6	0	8	7	5	55	104	47,547
2011	359	4,224	13,832	4,356	172	6	5	5	27	17	59	261	23,323
2012	1,094	10,390	19,349	4,280	666	10	3	12	17	11	52	209	36,093
2013	795	5,664	14,713	8,736	181	34	3	6	10	17	20	78	30,257
2014	502	3,818	25,288	10,367	465	20	0	11	32	23	107	198	40,831
2015	1,074	5,097	26,771	2,759	430	22	6	12	34	27	195	280	36,707

Source: Based on data from GFED4s [9]

Table 2. Average Monthly Precipitation (mm) in Myanmar for the Periods 1981-2010.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981-2010	3.5	7.7	14.6	44.3	223.2	424.4	469.0	471.6	325.6	176.1	52.2	9.1

Source: Based on data from the Myanmar climate report [6]

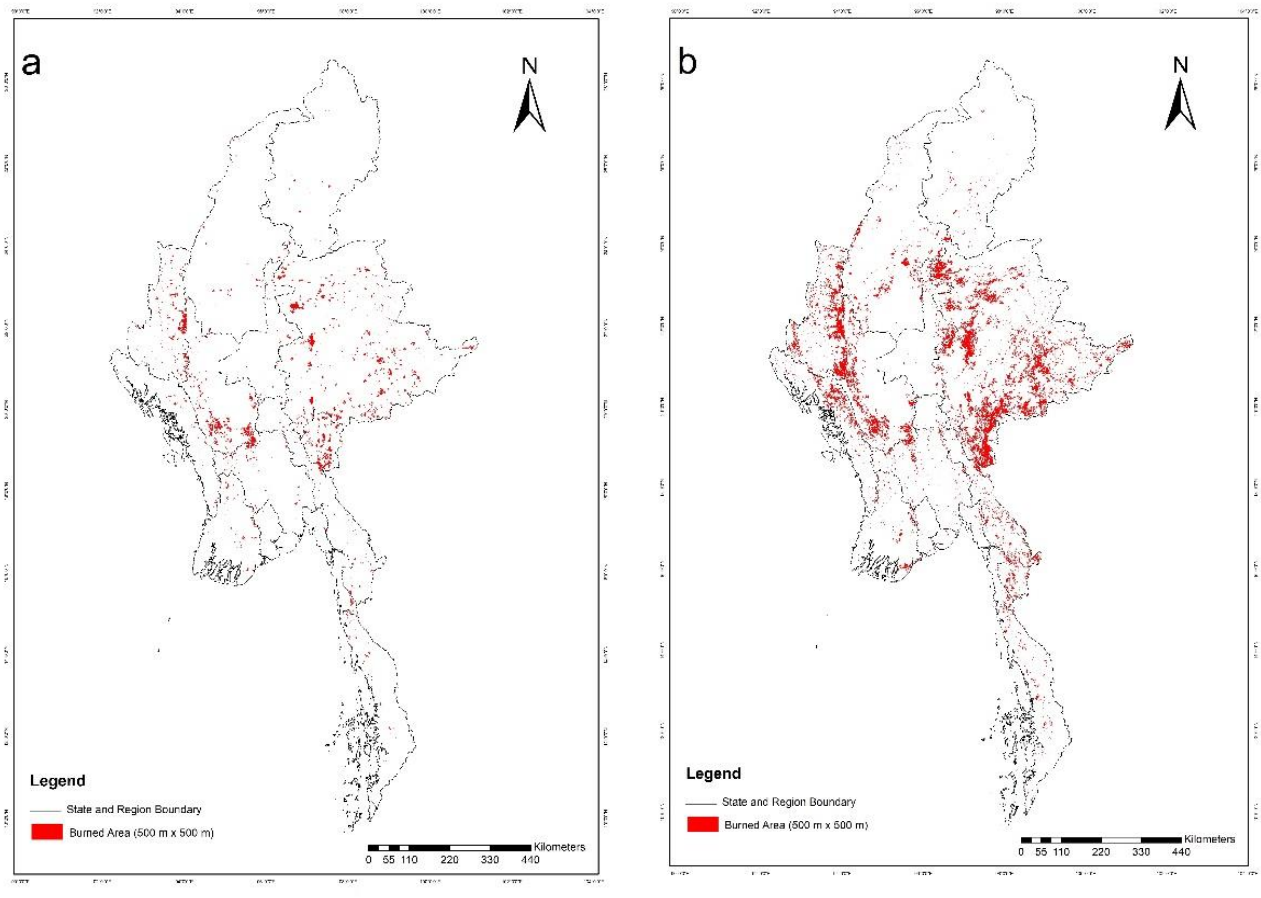


Figure 2. Spatial Distributions of Burned Areas (m^2yr^{-1}) from Vegetation Fires in Myanmar in (a) 2002 (lowest burned area), and (b) 2007 (highest burned area).

Data on normal precipitation (average monthly precipitation) in Myanmar over the period 1981-2010 are shown in Table 2. The data, which follows a normal distribution, shows that larger values are observed between May (223.2 mm) and October (176.1 mm) with peak values in July and August with 469 mm and 471.6 mm, respectively. Lower values are observed between November (52.2) and April (44.3 mm). The data in Table 1 shows that this is in line with the monthly variation in the area of vegetation burned in the country each year. Highest levels of BAs are reached over the period January-April (with peaks observed in March and April). It is worth noting that fire intensity potentially gains in strength during that period as a result of the contribution of tropical forest ecosystems to vegetation fires. Indeed, most of the tropical tree species shade their leaves during January-February providing therefore an extra pool of biomass available as fuel during that time [8].

Looking at average annual BAs (see Table 1), it is observed that the highest area of vegetation burned occurred in 2004 and 2007 with 50,264 km^2 and 50,839 km^2 whilst the lowest area of vegetation burned occurred in 2002 (18,379 km^2) and 2011 (23,316 km^2). According to long-term statistical records of annual BAs in Myanmar, these are in the range 20,000-50,000 km^2yr^{-1}. Prior to 2004, BAs were in the range 18,000 - 30,000 km^2. In 2004, the value peaked to 50,265 km^2 and in 2007 again to 50,836 km^2. Except for 2008 and 2011 when values were lower with 26,311 km^2 and 23,323 km^2, respectively, BAs have been averaging almost 40,000 km^2y^{-1} over the period 2009-2015, showing therefore an overall increase as compared to the situation prior to those years.

The Oceanic Nino Index (ONI) dataset was used to analyze the effects of seasonal temperature variations on BAs. As presented in Figure 3, based on data provided by the National Oceanic and Atmospheric Administration (NOAA) [5], the Oceanic Nino Index (ONI) from the Climate Prediction Center (CPC) shows that the La Nina years characterized by the strongest intensities occurred in 2007-2008 and 2010-2011 while the El Nino years characterized by the strongest intensities occurred in 2015-2016. A correlation between BA and such climatic factor is observed for the years 2008 and 2011 (La Nina years) and 2015 (El Nino year). However, BAs in 2004 and 2007 reached their highest levels (above 50,000 km^2) despite being years characterized by normal weather conditions. Overall therefore, it is observed that these particular climate events do not quite correlate with the peak of vegetation fires observed in Myanmar over the period 2000-2015 (reported in the form of burned areas). An explanation for this discrepancy may be due to the interference of anthropogenic factors, including man-made fires for land clearing, especially during the dry seasons (shifting cultivation and slash-and-burn practices) as well as potential control measures to prevent vegetation fires, especially forest fires, Myanmar having ratified the ASEAN Agreement on Transboundary Haze Pollution that targets zero burning.

Carbon emissions related to vegetation fires in Myanmar are shown in Figure 4. These results show that Myanmar emits on average about 35Tg of carbon per year. About 19TgC are contributed by savanna (53%) and over 15TgC (45%) by forest. They are therefore the largest contributors to carbon emissions in Myanmar.

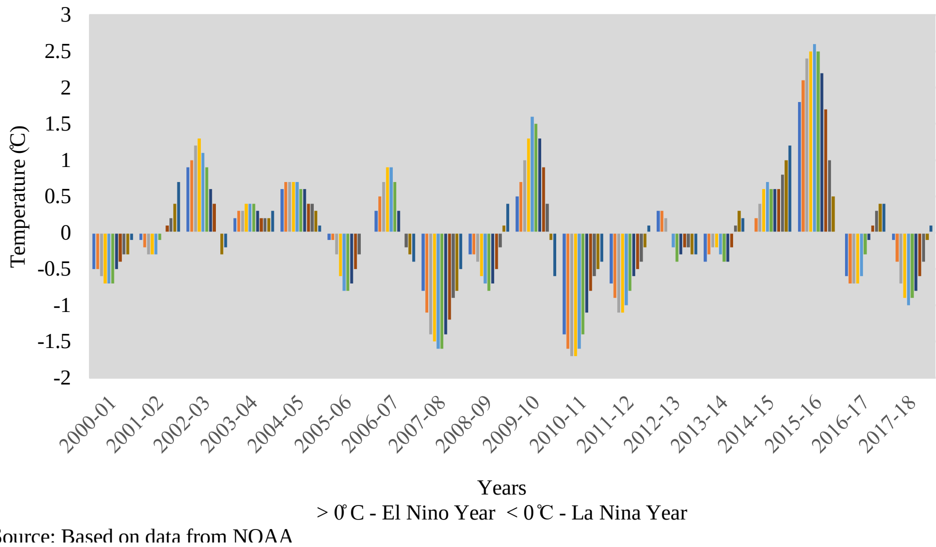
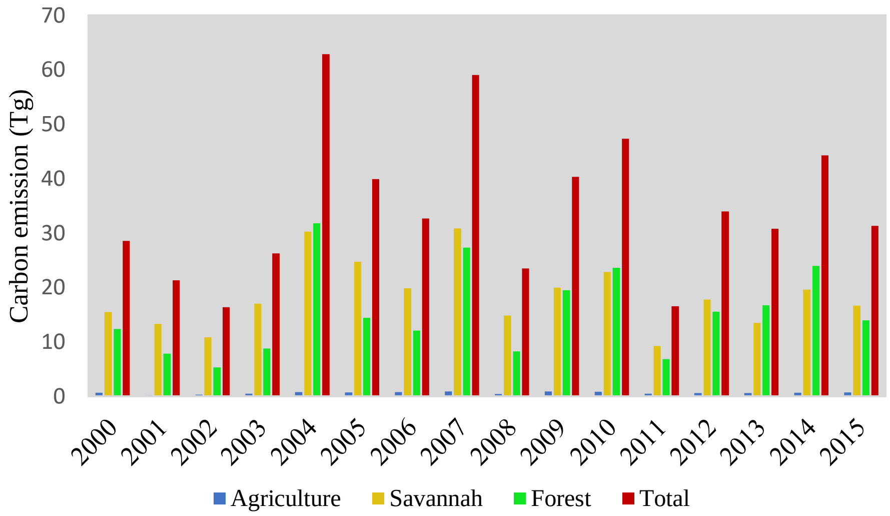


Figure 3. El Nino and La Nina Years and Intensities based on ONI Dataset [5].



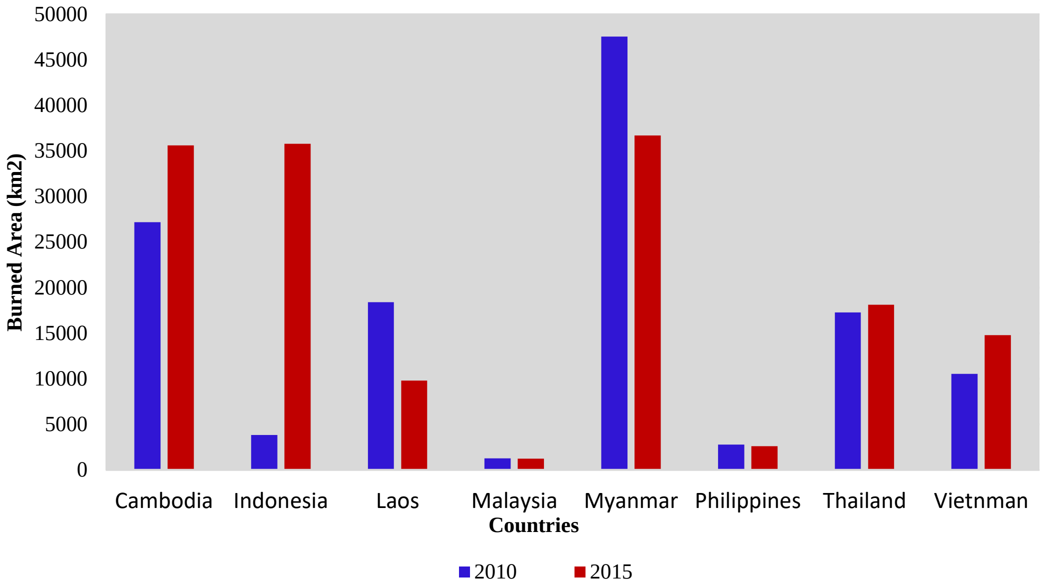
Source: Based on data from GFED4s [9]

Figure 4. Annual Carbon Emissions from Vegetation Fires in Myanmar (2000-2015).

3.2 Vegetation fires in South East Asia

The data related to burned areas and carbon emissions from SEA countries are shown in Figure 5 and Table 3. These 2 years were selected as they correspond to the strongest La Nina and El Nino periods. In terms of burned area, in 2010, it is observed that Myanmar was the country with the largest area of vegetation burned, followed by Cambodia, Indonesia and Thailand. In 2015, Myanmar was still the country with the largest area of land burned although it had decreased by 23% as compared to 2010. It is closely followed by Cambodia and Indonesia for which an outstanding 10 fold increase is observed as compared to 2010 because of peatland fires.

In terms of carbon emissions in SEA, the data in Table 3 shows that Myanmar, Laos, Thailand, Vietnam, and Indonesia in 2010 were major contributors with 40%, 25%, 10%, 9% and 5% respectively. However, in 2015, because of the substantial peatland fires that took place under the strong El Nino conditions of that year, Indonesia was found to contribute the largest share of carbon emissions with about 76% (or 344 TgC). This is followed by Cambodia and Myanmar with about 7% each. Although the area of vegetation subject to open burning was found to be the largest in Myanmar (36,707 km^2), carbon emissions from vegetation fires in Indonesia (burned area is 35,789 km^2) were observed to dominate the overall carbon emissions from SEA countries as peatland fires dominate the emissions. Under El Nino conditions in that year, Indonesia was therefore the largest contributor to air pollutant emissions as a result of peat fires. As about 80% of peatland areas in SEA are found in Indonesia, emissions from peat fires are largely contributed by this country [4].



Source: Based on data from GFED4s [9]

Figure 5. Burned Areas in SEA Countries (2010-2015).
Note: For Brunei [55.3 km^2 (2010), 31.3 km^2 (2015)]; For Singapore [0 km^2 (2010), 0 km^2 (2015)]

Table 3. Carbon Emissions (Gg C) in SEA Countries for 2010 and 2015.

Countries	Year	Agriculture	Savanna	Peat	Forest	Total
Brunei	2010	3	46	47	125	220
	2015	2	45		32	79
Cambodia	2010	172	5,325		334	5,831
	2015	1,037	13,739		16,843	31,619
Indonesia	2010	712	3,375	570	1,374	6,031
	2015	2,248	20,645	190,730	130,800	344,422
Laos	2010	679	14,330		15,449	30,458
	2015	231	8,243		5,459	13,932
Malaysia	2010	278	1,235	357	2,038	3,908
	2015	225	1,269	199	1,699	3,392
Myanmar	2010	855	22,855		23,603	47,313
	2015	721	16,634		13,961	31,317
Philippines	2010	615	1,819		498	2,932
	2015	685	1,871		108	2,665
Thailand	2010	2,181	7,049		2,534	11,764
	2015	2,317	6,767		1,844	10,927
Vietnam	2010	1,430	6,200		2,973	10,602
	2015	3,565	5,553		2,360	11,478

Source: Based on data from GFED4s [9]

3.3 Review of the global fire emission database

The Global Fire Emission Database (GFED4s in this study) based on which the above carbon emissions from active fire were determined, is constructed based on three main datasets that include (1) vegetation characteristics, (2) meteorological datasets, and (3) fire parameters.

In all GFED versions, vegetation characteristics datasets have been structured based on the Carnegie Ames Stanford Approach (CASA) model which was developed in the early 1990s to evaluate carbon fluxes which correspond to the difference between net primary production (NPP) and heterotrophic respiration (R_h) rates taking the benefits of satellite products. The fraction of Absorbed Photosynthetically Active Radiation (*f*APAR) dataset is applied to compute NPP over various live biomass "pools" categorized by global fractional tree cover and land cover maps. *f*APAR is obtained based on the Normalized Difference Vegetation Index (NDVI) of Global Inventory Modeling and Mapping Studies (GIMMS) applying Advanced Very High-Resolution Radiometer (AVHRR) sensors. The fractional tree cover dataset is obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) MOD 44 B vegetation continuous field product.

Meteorological datasets (temperature, solar radiations, and soil moisture) are collected from the European Center for medium-range weather forecasts (ECMWF). The soil moisture dataset is a modified key input dataset to determine R_h rates and combustion completeness instead of old rainfall and temperature datasets as used in GFEDv3. The soil moisture datasets are classified into four soil layers depending on soil depths; 0-7 cm, 8-28 cm, 29-100 cm, and 101-255 cm, respectively. Different values for each parameter are defined in accordance with the soil layer values, in which 0-7 cm is for combustion completeness as the first top soil layer; the average value of the first two soil layers {(0-7cm + 8-28 cm)/2} for NPP in herbaceous vegetations and for R_h rates; the average value of all soil layers {(0-7cm + 8-28cm+ 29-100 cm+101-255 cm)/4} for NPP in woody vegetation, and allocation for carbon assimilation to above and belowground pools, respectively.

Global burned areas including small fires are provided by the coupling of the 500-m MCD64A1 burned area product and 1-km active fires from Terra and Aqua MODIS product. Before going to the final classifications stage for different vegetation fire types, GFED4s partitions herbaceous and woody vegetation types based on 500 m burned area information distributed over tree cover ranges that are determined from the global fractional tree cover map. GFED then categorizes emission sources based on fire persistence, tree mortality rates and climate parameters. Metrics of fire-induced tree mortality and combustion completeness are calculated based on the global fractional tree cover map and the land cover dataset from the MODIS MCD12C1 land cover type product (University of Maryland classifications).

GFED4s assembles 15 original MCD12C1 land cover classes into six major groups; forest (evergreen needleleaf, evergreen broadleaf, deciduous needleleaf, deciduous broadleaf, and mixed forests), shrubland (closed and open shrublands), savanna (woody savannas and savannas), grassland, cropland, and others (permanent wetland, urban and built-up lands, non-vegetated land, and water). Global land cover is also useful in setting up the regrowth rates for stems and leaves to adjust each biome level in order to be consistent with aboveground biomass. GFEDv4s provides six main broad emissions sources on a global scale that are: (1) savanna (savanna, grassland, and shrubland), (2) boreal forest, (3) temperate forest, (4) tropical forest, (5) peat, and (6) agriculture. In GFED4s, emission factors (EFs) reported by Akagi et al. [10] are assigned for the conversion of dry matter burned to various species for different regional biomes. GFED4s provides all global emissions data with Hierarchical Data Format (hdf5) files consisting of data for four main groups; (i) burned area, (ii) emissions, (iii) biosphere fluxes, and (iv) ancillary data of six types of emissions sources. It is from such a complex framework that emissions from active fire in SEA were derived as analyzed in the previous section.

4. Conclusion

Fire is an important disturbance agent contributing emissions of air pollutants on a global scale. Based on vegetation fires and related emission data collected from GFED4s, this study shows that most fires occurred during the dry season with March and April as the peak fire months. The annual area of vegetation burned in Myanmar was found to be in the range 20,000-50,000 km^2 over the period 2000-2015. The largest emissions of carbon in SEA were found to be from Indonesia due to its extensive peatland cover and fire events, particularly under El Nino conditions. However, excluding peatland, Myanmar was found to be the country with the largest area of vegetation subject to open burning and the largest contributor to carbon emissions, which are mostly contributed by forest (45%) and savanna fires (53%). A correlation between normal precipitation and monthly variations in BAs was observed in Myanmar with highest BA values noticed during January-April when precipitations are lowest. However, no strong evidence of correlation was observed between yearly variations in BAs in Myanmar and climate conditions associated to El Nino and La Nina years.

Although further investigations and analyses should be performed in this regard, these results also highlight that more specific investigations on anthropogenic activities related to fires should be carried out and that policy measures may play an influential role with regard to fires and natural resource management.

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